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Biomass Integrated Gasification Combined Cycles (BIGCC)

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BIOMASS INTEGRATED GASIFICATION COMBINED CYCLES (BIGCC)

A Thesis

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NOMENCLATURE

ASU	Air Separator Unit
BIGCC	Biomass Integrated Gasification Combined Cycle
CC	Combined Cycle
CO	Carbon Monoxide
CO_2	Carbon Dioxide
GCU	Gas Clean Up Unit
GT	Gas Turbine
H_2	Hydrogen
H_2O	Water
HGCU	Hot Gas Clean-up Unit
HHV	Specific Higher Heating Value (MJ/kg, Btu/lbm)
HP	High Pressure
HRSG	Heat Recovery Steam Generator
ICE	Internal Combustion Engine
IGV	Inlet Guide Vane
IP	Intermediate Pressure
J	Energy (Joule)
kg	Mass (kg, lbm)
LGCU	Low Temperature Gas Clean-up Unit
LHV	Specific Lower Heating Value (MJ/kg, Btu/lbm)
LP	Low Pressure
m	Mass flow rate (kg/s)
MWe	Mega Watts Electric
Nm^3	Normalized Volume
NG	Natural Gas

NOx	Nitrous Oxides
η	Thermal Efficiency
O_2	Oxygen
p	Pressure (bar, Pa, psi)
RAM	Reliability, Availability and Maintainability
RH	Relative Humidity (%)
ST	Steam Turbine
T	Temperature (K, °C, °F)
TET	Turbine Exit Temperature (K, °C, °F)
TIT	Turbine Inlet Temperature (K, °C, °F)
We	Electrical Generated Energy (Watts electric)
Wt %	Weight (Percent)
x	steam quality

ABSTRACT

Conversion of biomass to energy does not contribute to the net increase of carbon dioxide in the environment, therefore the use of biomass waste as a clean and renewable fuel source is an attractive alternative to the use of fossil fuels. Biomass can be converted to energy via direct combustion or via thermo-chemical conversion to liquid or gas fuels. This study focuses on employing gasification technology to convert biomass waste to producer gas, which is then cleaned and fed as gaseous fuel into the gas turbine. Since the producer gases are usually low caloric values, the power plants performance under various operating conditions has not yet been proven. In this study, system performance calculations are conducted for a 5MWe and a 20MWe power plants using commercial software ThermoFlow. The power plants considered including simple gas turbine systems, steam turbine systems, combined cycle systems, and steam injection gas turbine systems (STIG) using the producer gas with low caloric values at approximately 30% and 15% of the natural gas heating value. The low caloric value fuels are shown to impose high back compressor pressure and increased power output due to increased fuel flow.

Power augmentations under four different weather conditions are also calculated by employing gas turbine inlet fog cooling. Different capacity options for the heat recovery steam generator (HRSG) that provides the steam for STIG are analyzed.

CHAPTER 1

INTRODUCTION

Ever since the discovery of fire by mankind, biomass has been used as a fuel and energy source even until today. Approximately 14 % of the world population still uses biomass as a source of energy [Bedi, 2001], and for developing countries, biomass accounts for 35% of the fuel needs [Bedi, 2001]. In the U.S. itself there are more than 350 biomass power plants producing about 7500 Mega Watts (MWe) of electrical Power, which is enough to power several million homes [Swanikemp, 2001]. Utilizing proper management and advanced scientific methods of energy production, the modern society has made biomass, a sustainable and indigenous energy source.

Biomass is an attractive alternative fuel because it is renewable, sustainable and indigenous. Biomass power plants using the conventional method of power production are subject to high exhaust emissions and low efficiencies. New technologies that are being developed will significantly reduce emissions and increase the energy-conversion efficiency. The technical challenges in the new technologies will need to be overcome to reduce costs, enhance efficiency and improve system reliability, availability and maintainability (RAM).

1.1 CONVENTIONAL STEAM-BOILER PLANTS

A common practice in agricultural, forest, and paper industries is the direct firing of biomass upon a boiler to create processed steam or for power generation purposes via

steam turbines. This conventional method is subject to low efficiency and high emissions of NO_X, CO and other pollutants. Typical small steam-boiler power systems have an electric energy conversion efficiency ranging from 20% to 30%. The low efficiency of such a system is caused by the inability of the steam system to effectively use the combustion energy at temperature levels higher than approximately 1700 °C / 3200 °F. The steam entering the steam turbine is restricted by metallurgical limitations (590 °C / 1100 °F) imposed by the material used to fabricate the heat exchangers. The temperature difference between the combustion flame temperature and the acceptable steam temperature limits the steam cycle from obtaining higher efficiencies. Another limitation is the high manufacturing cost, which limits the thick and bulky pipes to contain high-pressure / high-temperature steam, which has the nature of achieving very high pressure at relatively low temperatures.

1.2 COMBINED CYCLE

A method to resolve the aforementioned challenges is to install a gas turbine between the combustion flame and the steam turbine. The gas temperature entering a gas turbine is also restricted by metallurgical limitations, but without the corrosive nature of steam as in a steam turbine. A modern gas turbine can withstand inlet gas temperatures at approximately 1430 °C / 2600 °F. Exhaust exiting from the gas turbine can be utilized to boil and superheat steam via a Heat Recovery Steam Generator (HRSG). Combining the gas turbine and steam turbine systems forms the combined cycle system, which is popularly used by many of the new natural gas fired power plants. A modern combined cycle efficiency ranges from 55 % to 58 %. A higher than 60 % efficiency can be achieved by using an Advanced Turbine System [Layne, 2001].

1.3 GASIFICATION

Having a combined cycle system provides higher efficiency, although care should be taken for fuel cleanliness to prolong the life of a gas turbine. Since direct firing of biomass fuel is unclean, gasification becomes necessary to provide gaseous fuel to be used for combustion in a gas turbine. Gasification is a partial combustion process, producing a composition of synthetic gas (syngas) / producer gas. The dominant composition in the syngas is hydrogen (H_2) and carbon monoxide (CO). The heating value of syngas is low, typically around 5.5 – 7.5 MJ/Nm^3, approximately 15 % - 20 % heating value of natural gas. (Note: The N represents normalized volume). The syngas needs to be cleaned in order to remove impurities like particles, tars and other trace chemical elements before entering the gas turbine. In contrast with conventional steam-boiler turbine system, which the exhaust gases are cleaned after the boiler or no cleaning performed at all, in gasification system the fuel is cleaned before entering the gas turbine system. This in turn results in a reduction in emissions, cost and maintenance.

1.4 BIOMASS INTEGRATED COMBINED CYCLE (BIGCC)

The combined cycle, flue-gas cleaning and gasification are currently existing technologies. The main challenge is integrating these 3 technologies together to produce an affordable, highly efficient, environmentally friendly and reliable system. New technology for using biomass in an integrated gasification combined cycle (BIGCC) is in development and is subject to continuous improvement. Some of the technical challenges require in-depth understanding of the fundamental mechanisms involved in the process in order to overcome

them. Other challenges require development efforts in pulling together existing technologies to make it work. The ultimate challenge is to build a demonstration plant, accumulate operating experience, and continuously improve the performance.

Brief Description of BIGCC

The BIGCC consists of four major subsystems; fuel handling and feeding system, the gasifier, the gas clean-up unit (GCU), and the combined power system. The GT and ST combined and integrated together gives the combined cycle. This chapter aims to briefly introduce these four subsystems with a focus on the gasifier and the combined cycle power system for BIGCC in sizes of 5.5 MWe and 20 MWe.

Handling and Stock Feed System

The handling and stock feeding system is the front line where raw biomass waste is received, pre-processed, stored, measured and later fed into the gasifier. The gasifier converts the biomass waste into fuel gas to be cleaned and then fed into the gas turbine. Figure 1.1 is the layout of a typical BIGCC plant.

Biomass waste including wood waste, sugar cane bagasse, rice hull, corn cob, and cotton are in general are kept in a storage silo. A pre-drying process is needed before the biomass waste is stored. The bagasse originates from the pulp of squeezed sugar cane stalks. The wood waste could be from chips, bark, sawdust, wood pellet and scraps. Waste heat from the exhaust of an HRSG is utilized to dry the biomass material in the rotary dryer and hence, not wasted by exhausting into the air.

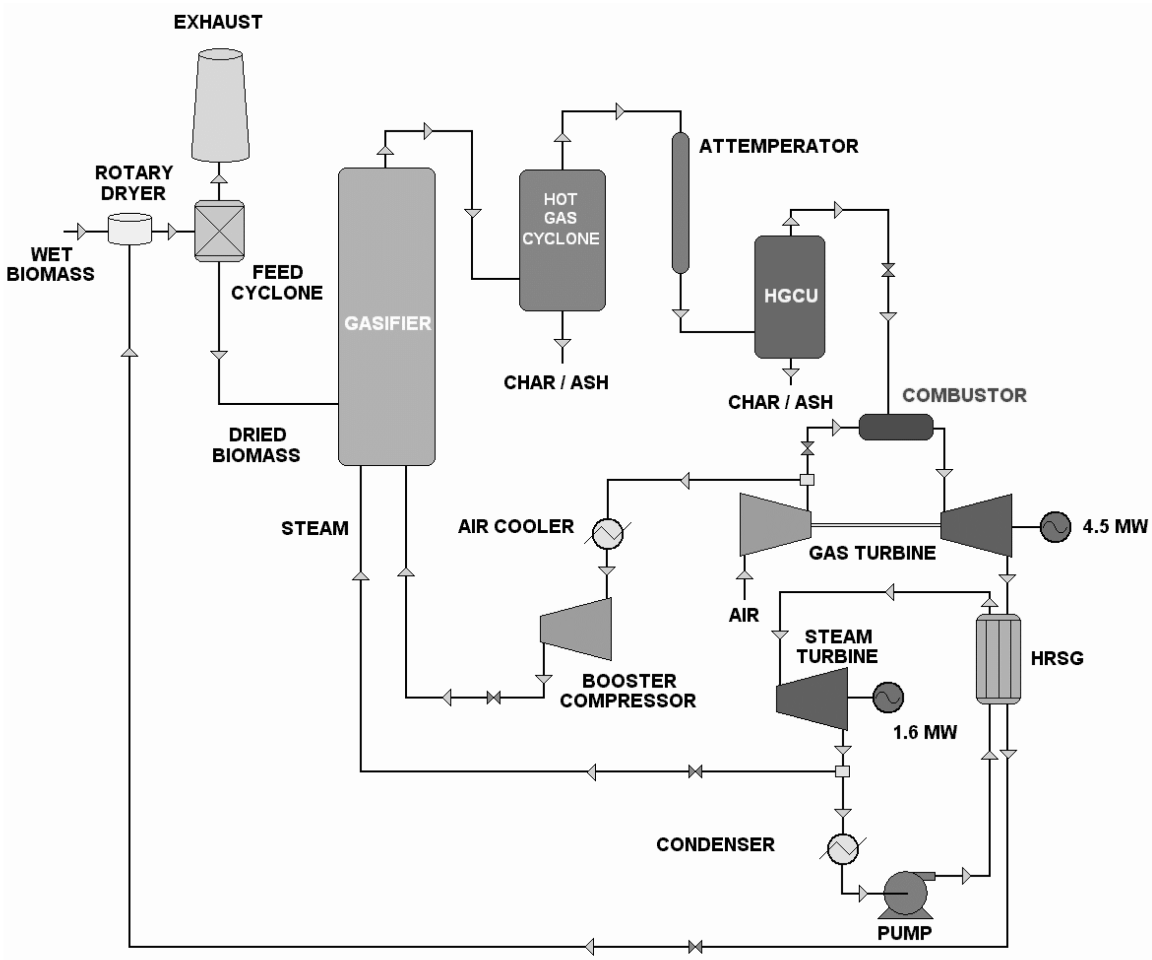

Figure 1.1: Overall BIGCC Power Plant Layout

The dry feed stock is fed into a lock hopper, which measures and feeds the biomass from the storage silo at a fixed rate depending on the demand of the gasifier and plant in general. No specialized equipment is necessary for pressurization because the gasifier considered in this study operates at atmospheric pressure. Figure 1.2 shows a typical biomass gasification system from the day silo until the hot gas clean-up unit (HGCU) connection.

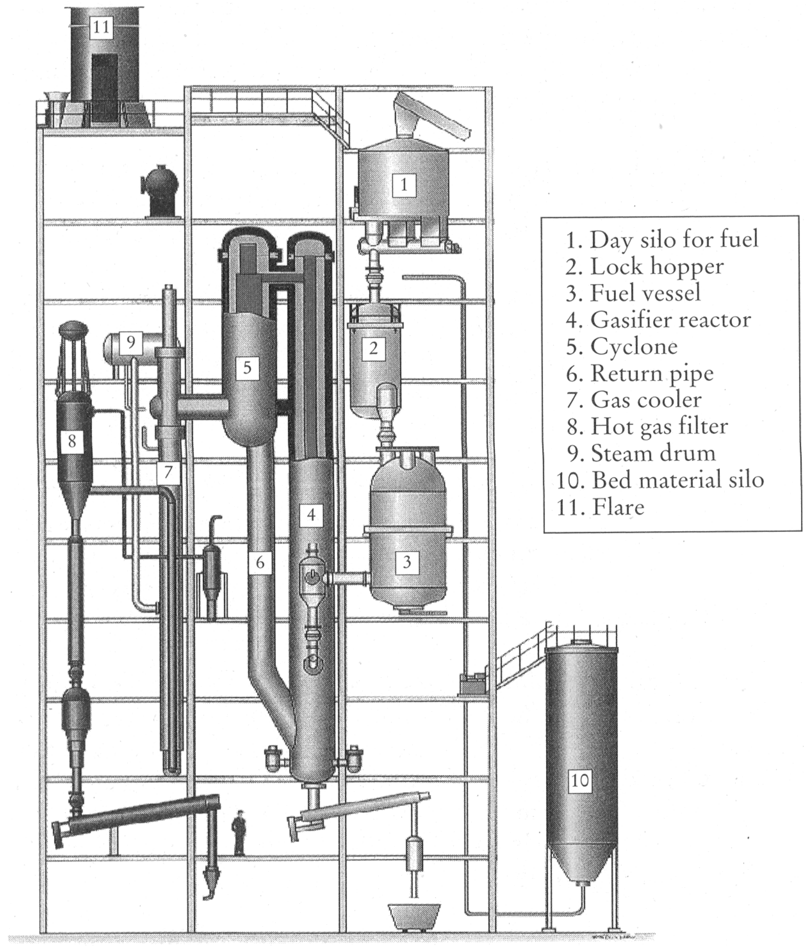

Figure 1.2: Stock Feed / Day Silo and Gasifier

(Biomass feedstock handling and feeding system courtesy of Värnamo Sydkraft Biomass Demonstration BIGCC Plant, 2001)

1.5 GASIFIER

Gasifier and the Biomass Gasification Technology

Gasification of biomass and coal is not a new technology. Biomass gasification was first developed around 1800. The peak gasifying of biomass and coal to obtain synthetic gas (syngas) was during the World War II (WWII) [Reed & Gaur, 2001], where petroleum and its distillates were used for military purposes while the rest of the civilian sector were limited to the use of

producer gases derived from coal or biomass. The producer gasses derived from biomass were primarily for transportation purposes, while direct burning of biomass were used for space heating. Ever since WWII, many countries have relied on fossil fuels and have since abandoned much use of biomass as a major fuel source.

Before biomass fuels can be put into a gasifier, a significant amount of drying upon the biomass waste material is necessary. The ignition temperature of the biomass waste is higher than the charring temperature. In a gasifier, there are 2 major processes, which occur sequentially: pyrolysis and gasification. Pyrolysis is the endothermic degradation of biomass in a gasifier transforming biomass into char and volatile vapors without oxygen. Pyrolysis occurs below 600 °C and in the absence of oxygen. The resulting char and volatile vapors from pyrolysis react with oxygen and burnt in the gas phase via flaming combustion, which provides the heat in the gasifier for further fuel drying and pyrolysis of present and incoming biomass waste into the gasifier. Gasification is a partial combustion process, which results in synthetic gas from pyrolysis. Table 1.1 shows five major global chemical reactions, which take place during the gasification process. Figure 1.3 illustrates various temperature stages and products during pyrolysis and gasification process.

Solid Fuel	
$C + \frac{1}{2}O_2 \rightarrow CO$,	-110.5 kJ/kmol (Incomplete Combustion)
$C + CO_2 \rightarrow 2CO$,	+172 kJ/kmol (Gasification, Boudouar reaction)
$C + H_2O \rightarrow CO + H_2$,	+131.4 kJ/kmol (Gasification)
Gas Phase	
$CO + 0.5O_2 \rightarrow CO_2$,	-283.1 kJ/kmol (Complete Combustion)
$CO + H_2O \rightarrow CO_2 + H_2$,	-41.0 kJ/kmol (Watershift)
Notes: At standard conditions (25°C, 1atm)	
"+" Endothermic (heat is absorbed), "-" exothermic (heat is released)	

Table 1.1: Five Major Global Chemical Reaction During Pyrolysis and Gasification Processes

The produced gas or synthetic gas (syngas) consists largely of H_2 and CO, is fed into the gas turbine as a gas fuel source after the necessary cleaning procedures of the syngas is performed. The heating value for the syngas is approximately 5.5 – 7.5MJ/Nm^3 (the N represents "normal").

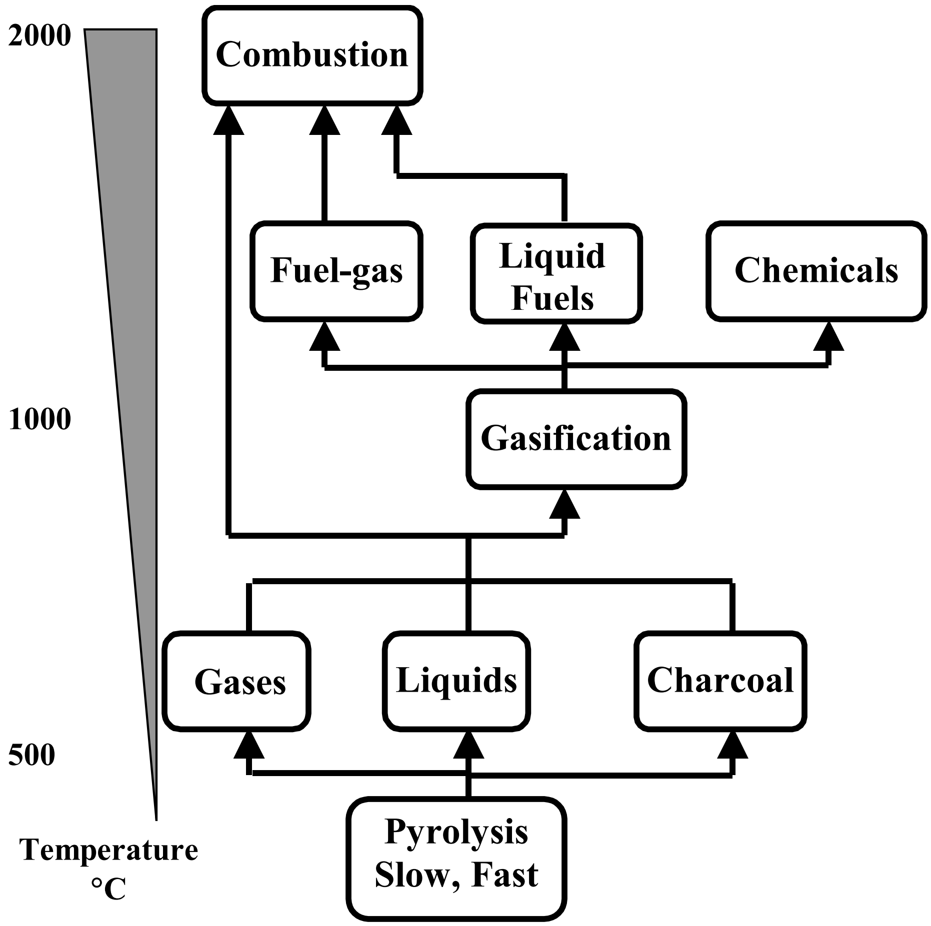

Figure 1.3: Pyrolysis and Gasification Temperatures (Reed, 2001)

There are numerous types of gasifiers. Basically, the gasifiers can be classified by its fuel flow direction as:

- updraft
- downdraft
- crossdraft

or by flow speeds as:

- fluidized bed
- moving bed

- entrained bed

Updraft Gasifier

The updraft gasifier (Fig. 1.4) is the simplest and oldest gasifier normally used for coal gasification [Reed & Gaur, 2001]. In an updraft gasifier, the fuel is fed from the top via feedstock (dried biomass with 20 % moisture content or less), and this is fed from the bottom. The feedstock from the top is met by hot gasses produced further down, which helps dry the biomass fuel source further while cooling down the synthetic gasses produced (H_2 & CO). This demonstrates a good use of heat recovery. Next, the very dry biomass being pyrolized by the up-flow of hot gasses, gives up the volatile combustible gas / vapors and becomes charcoal. These hot charcoals are a good reducing agent as it comes into contact with the rising hot CO_2 and H_2O to yield CO and H_2. In the last stage, the charcoal is combusted with the air / O_2 at very high temperatures. The resulting ashes are collected and disposed off. The advantages of this gasifier is the ability of slagging gasification where metals and minerals are melted due to the high temperature at the bottom of the gasifier and the ability of handling very wet fuels. On the other hand, the produced gas has high tars, which is detrimental to gas turbines or boilers. The tar must be removed before being fed into the gas turbine. The updraft gasifier requires a good temperature control and monitoring to avoid melting of grate at the bottom of the gasifier.

Downdraft Gasifier

Downdraft gasifiers have both the air / steam flowing with the fuel source from top to bottom, helping to burn 99.9 % of tars. The downdraft gasifier is good for biomass with high volatiles [Reed & Gaur, 2001]. Flaming pyrolysis occurs intensely at the top to produce 5-15 %

charcoal, and also produces CO_2 and H_2O. The next stage, the hot charcoal reacts with the combustion gasses with the absence of oxygen to produce CO and H_2. The char ash at the end of the process is disposed. There is minimal tar cleanup necessity as roughly 99 % or more tar is combusted. Downdraft gasifiers were used reliably in WWII vehicles and are easily manufactured. The temperature of the produced gas is roughly at 700 °C (973.15 K), which can be used to dry the raw biomass or preheat water or air before entering the cold clean-up process. Caution must be exercised with this type of gasifier as the fuel intake must have less than 20 % moisture content.

Crossdraft Gasifier

The crossdraft gasifier is the lightest and simplest gasifier design. The container houses the fuel for storage and gasification. Figure 1.6 illustrates the basic design of the crossdraft gasifier. The air blasts at high velocities enter the bottom of the cylinder to create a significant circulation across the bed of fuel and char. The syngas exits at the opposite end from the air blast entrance. A possible advantage of a crossdraft gasifier is the fact that the ash and fuel insulates the inner wall of the gasifier, and hence permitting the gasifier to be fabricated from mild steel; however, caution should be taken for the grate and nozzles materials, which should be resistant to the high temperatures.

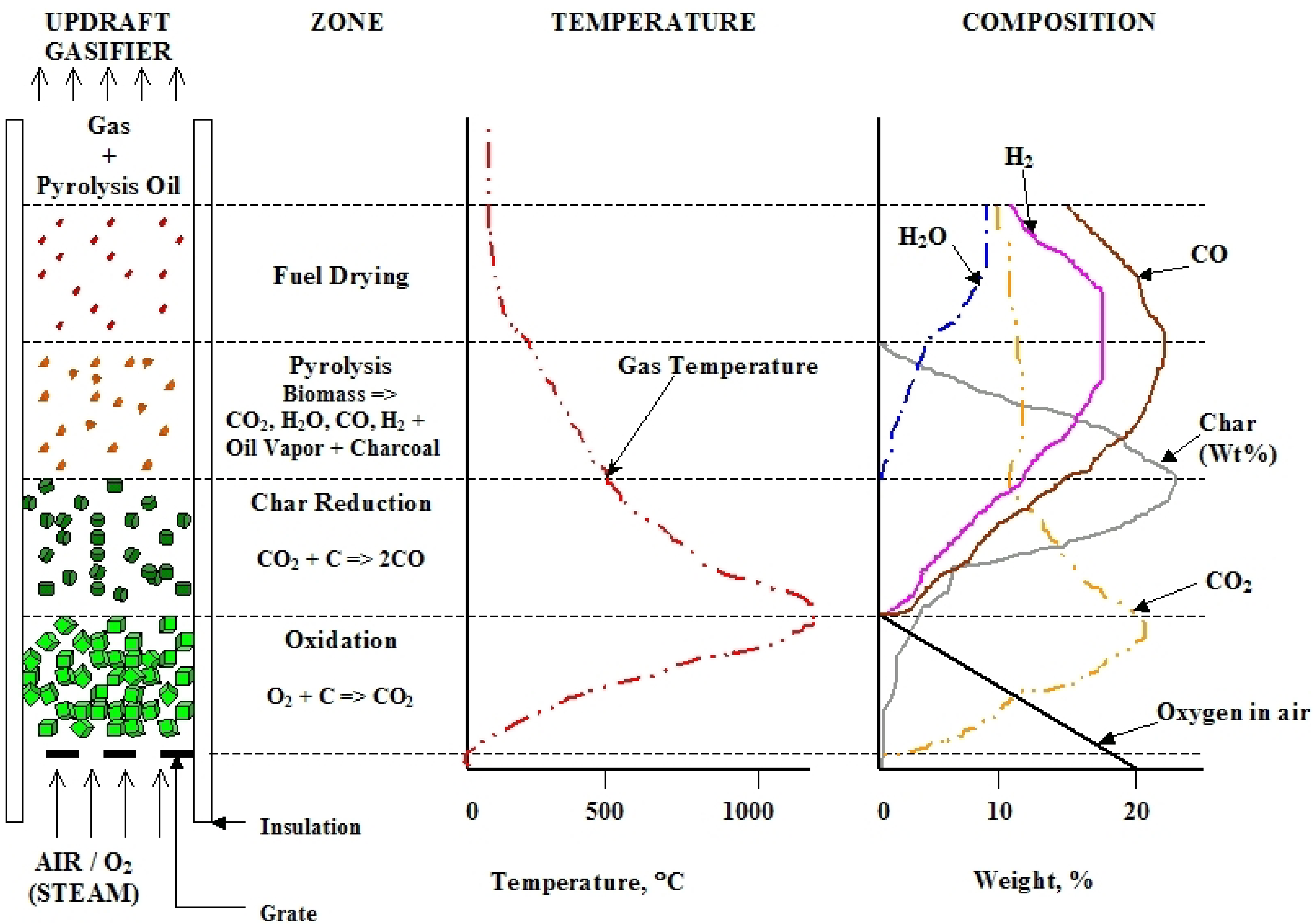

Figure 1.4: Updraft Gasifier (Reed, 2001)

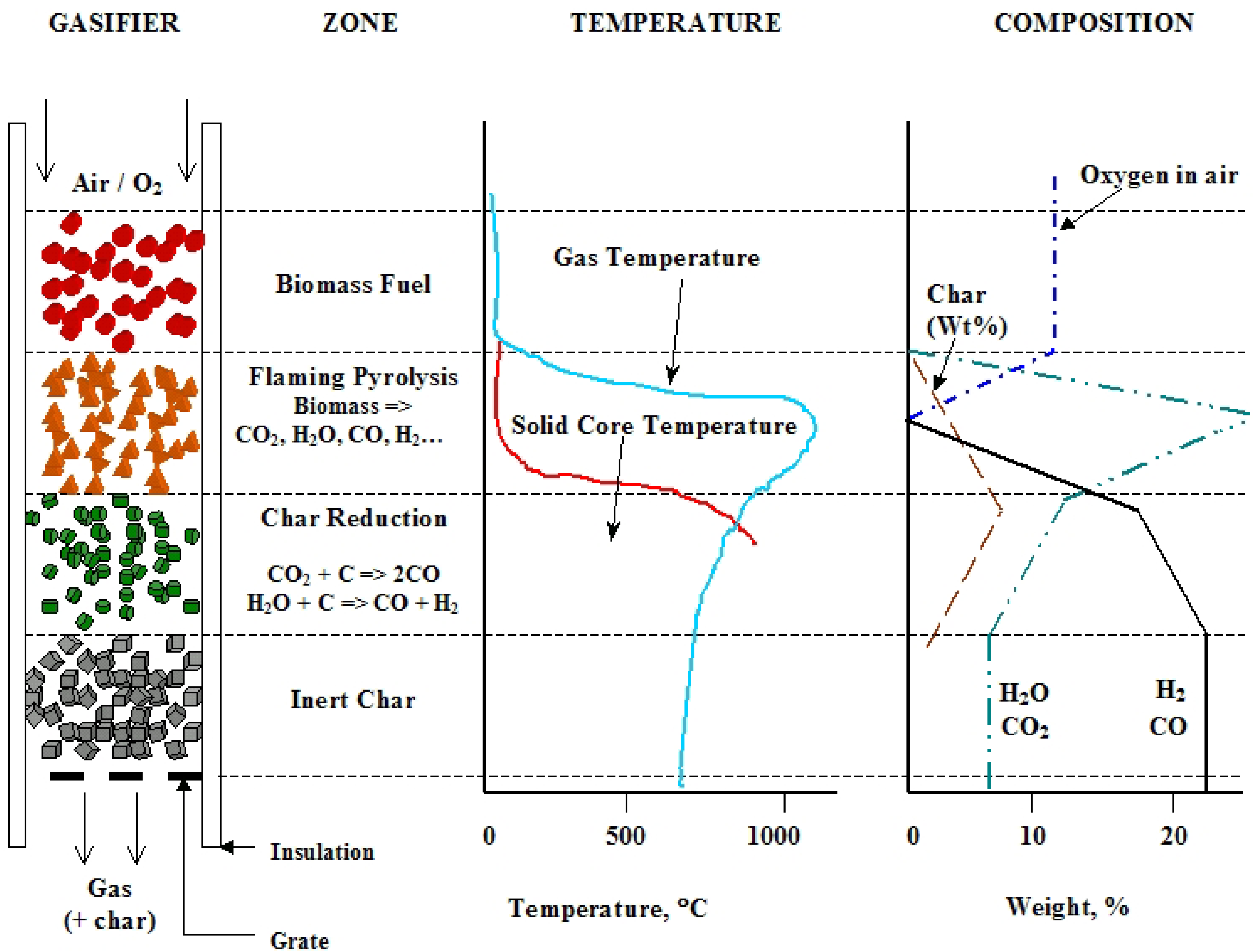

Figure 1.5: Downdraft Gasifier (Reed, 2001)

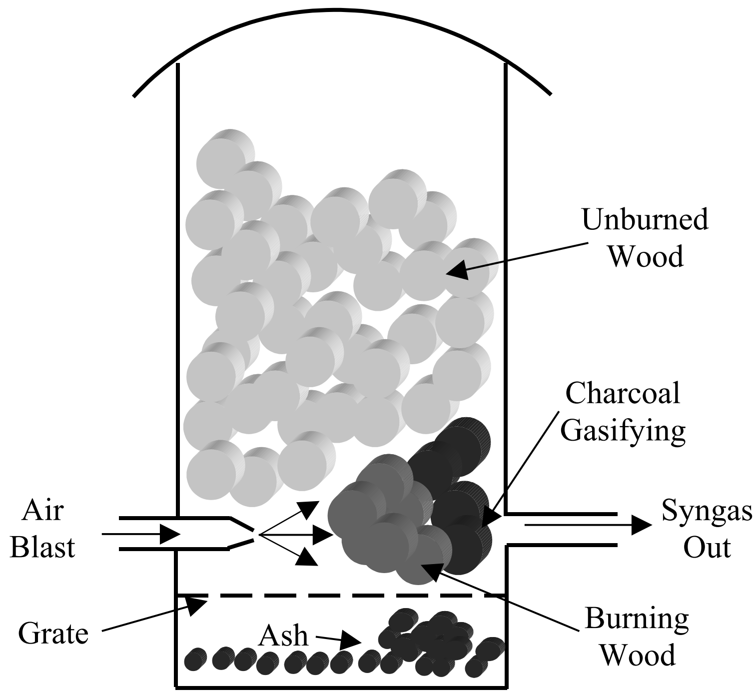

Figure 1.6: Crossdraft Gasifer (Reed, 2001)

Fluidized Bed Gasifier

Fluidized bed gasifiers are called because the bed material (biomass in this case) moves like a fluid) due to the levitation of biomass by the airflow. The fluidization occurs when the pressure drop across the gasification bed multiplied with the area of the bed is equal to or larger than the weight of the bed. The origins of this gasifier was to gasify coal, and currently the petrochemical industry utilizes this type of gasifier for cracking heavy hydrocarbons, catalysis etc. According to Reed and Gaur (pg. 1-17, 2001) there are 50 or more fluidized bed combustors successfully operating in California in the 10 – 50 MWe power range.

Entrained Flow and Moving Bed Gasifier

The entrained flow gasifiers on the other hand are fed with high-speed air flow such that all raw biomass is levitated and entrained in the airflow. A moving bed gasifier's behavior is somewhere between a fluidized and entrained flow gasifier with a flow moving over the bed, but the bed materials stay in the bed.

Types of Oxygen Sources

A gasifier can be operated with air or oxygen as the source of oxidizing agent. An oxygen-blown gasifier requires expensive and energy-intensive air separator unit (ASU). The heating value of an oxygen-blown gasifier is about 50 % of the natural gas' value. An air-blown gasifier is relatively easier to operate than the oxygen-blown gasifier; however the heating value of the producer gas is about 20 ~ 30 % of the heating value of the natural gas' heating value.

Selection of the Gasifier

Based on the literature survey conducted upon the different types of gasifiers, the preferred gasifier in this study for both proposed power plant configurations of 5.5 and 20 MWe is the air-blown downdraft gasifier, operating at atmospheric pressure condition. The following are the factors for choice of the downdraft gasifier:

- ease of construction and operation
    - a cylindrical steel design, not designed as a pressure vessel
- types of primary fuel being used for simulation
    - high cellulose and wet bagasse and bark with possible high tar content.
- Oxygen supply method: air-blown

The primary proposed biomass feed would be dry bagasse (20 % or less moisture content) wood chips, bark and pellets. The gas produced from the gasifier is then passed into a

gas cyclone to remove the initial fly ash. An attemperator connected after the gas cyclone is used to cool the gas down slightly. A good utilization of waste heat from the attemperator would be to preheat water for the steam cycle or for fuel drying. After attemperation, the syngas is cleaned using the gas clean-up unit (GCU), pressurized and fed into the combustion chamber of the gas turbine to be combusted.

1.6 GAS CLEAN-UP UNIT (GCU)

The gas clean-up unit (GCU) is important to ensure that clean syngas is passed into the combustion chamber of the GT. The combustion chamber and turbine of the GT is sensitive to the cleanliness of syngas due to the possibility of fouling and corrosion of component surfaces from burning unclean syngas. The GCU can be operated with hot gas or cool gas. The hot gas clean-up unit (HGCU) uses ceramic as the filtering material, is less reliable due to the cracking of the ceramic, leading to interrupted plant operation and reduced reliability. To achieve reliable operation, a low-temperature GCU (LGCU) is selected. The LGCU replaces the ceramic filter with a metallic filter material. LGCU requires the gas to be cooled down to below 800 K before being fed into the unit. This will reduce the plant thermal efficiency.

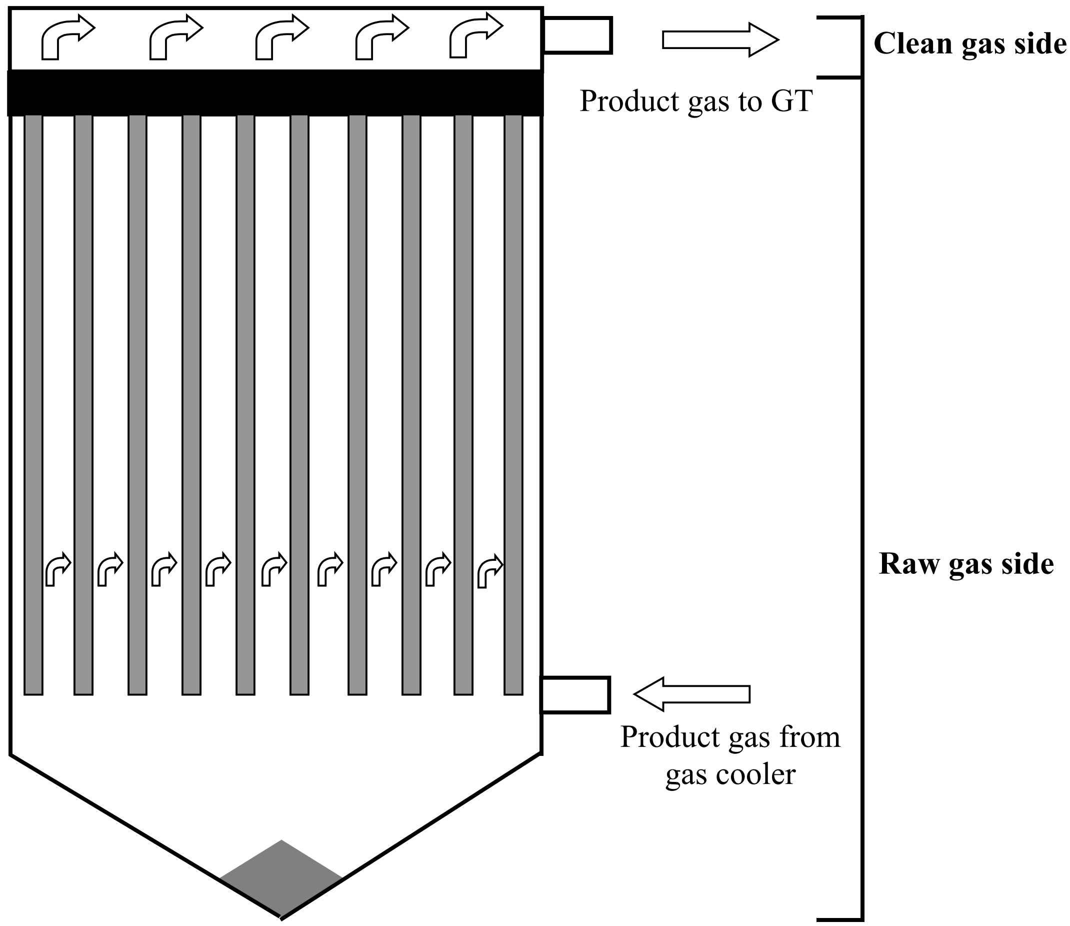

Figure 1.7: GCU

The attemperated syngas with ash, alkali vapor, tar vapor and other miscellaneous contaminants enter the GCU from the bottom and pass through a ceramic mesh. The mesh collects and precipitates the contaminants to the base of the unit, which will be emptied periodically. The end result is a cleaned syngas ready to be piped and / or combusted in the GT.

1.7 GAS TURBINES

A gas turbine (GT) burns fuel and compressed air to produce mechanical / shaft work. The major components of a gas turbine are the compressor, combustion chamber and the turbine. The compressor intakes and compresses the air from ambient conditions to high pressure, and then fed into the combustion chamber. In the combustion chamber, fuel is injected / introduced

and burnt with the hot compressed air, which is then fed into the turbine for expansion to generate shaft work. The shaft work is connected to a generator to produce electrical power, or connected directly to a machinery, to provide mechanical work. The advantages of using a gas turbine over an internal combustion engine (ICE) is that it is a once-through flow of mass and has a higher power per mass ratio especially for the power production range above 5 MWe.

The GT in a BIGCC design dictates a great majority of the power production. Factors for choice of GT is availability cost, efficiency and suitability of application for a BIGCC environment and operating configuration. In this study, the Rolls Royce 501 KH5 (Allison KH-5) GT is selected for the 5.5MWe power plant and the Siemens GT 10 (ABB GT 10) is selected for the 20 MWe power plant.

1.8 WASTE HEAT USAGE

One of the critical design considerations is the exergical efficiency of the overall plant where proper uses of energy grades are considered [Sonntag, 1998]. For example the syngas is combusted in the GT, a high efficiency energy producer, while the exhaust, a lower grade energy is not wasted and used to superheat steam for the steam power cycle. The exhaust from the HRSG is used to dry the raw biomass before storage.

During attemperation, depending on the thermal energy available to be harvested, heat can also be recovered either through a heat exchanger to pre-heat water before entering the steam power cycle, or possibly used to pre-dry the wet biomass. District water heating may also be utilized to cool the water / steam from the steam cycle if a local body of water is not present as a heat sink [Cengel, 1997].

1.9 MOTIVATION FOR STUDY

The main motivation for this study of the BIGCC system is the current problems related to the design, operation ability, and reliability of a BIGCC system. Also there is a concern of the gar turbine performance under the influence of various low-heating values of syngas and climate conditions.

1.10 OBJECTIVES

In response to the above concerns, the objective of this research is to study a small and medium sized BIGCC system integrate the change of system performance under the influence of carious fuel heating values, different climate conditions, and implementation of various power augmentation methods.

The following specific goals are identified to achieve the objectives:

- Design of a baseline BIGCC system
- Incorporate the design into two commercial gas turbine design software
- Investigate the performance of a BIGCC system on fuel with various heating values
- Study the effects of ambient temperature and humidity upon the overall system performance
- Study the different HRSG sizing upon the performance of the overall system
- Implement gas turbine compressor inlet air cooling to augment power [Nicholson, 2004]
- Investigate the potential of power augmentation by injecting steam into combustion chamber [Bathie, 1996]

CHAPTER 2

SIMULATION SCENARIOS

The simulations are conducted under controlled condition using the ISO condition as the baseline case for both 5.5 MWe and 20 MWe plants. Natural gas fired gas turbine are used as the reference case. Producer gases of various caloric values are fed into the GTs designed for natural gas. The simulations are conducted first by feeding the producer gases without modifying the GTs, but fixing the turbine inlet temperature (TIT) at the maximum allowable temperature. Then modifications are made by increasing TIT (Case 2b) or opening up the first stage nominal nozzle area (Case 2c) in the turbine to reduce the compression backpressure, and both TIT and nozzle area increase manipulation (Case 2d). Comparisons are then made among different cases. Typical producer gases consist of hydrogen (H_2), carbon monoxide (CO), hydrocarbons, carbon dioxide (CO_2), nitrogen (N_2), water (H_2O) tar, alkali, and other volatiles. For this study, three representative producer gases derived from biomass are used as shown in Table 2.1.

	Methane (CH_4) MJ/kg	5.015 MJ/kg	8.032 MJ/kg	11 MJ/kg
H_2	0.00 %	7.30 %	11.62 %	39.7 %
H_2O	0.00 %	23.00 %	36.62 %	0.00 %
N_2	0.00 %	37.20 %	0.00 %	0.00 %
CO	0.00 %	10.60 %	16.80 %	40.7 %
CO_2	0.00 %	14.60 %	23.24 %	18.6 %
C_xH_y	100.00 %	7.33 %	11.68 %	0.00 %

Table 2.1: Percent Volume Component of Methane and Various Low Caloric Gases

The first two low caloric fuels are obtained from the Biomass Gasifier-Based Electric Power Stations in Hawaii. The lowest heating value 5.015 MJ/kg includes nitrogen while the heating value of 8.032 MJ/kg does not include nitrogen. The third producer gas with a heating value of 11.00 MJ/kg, simulates a preheated dry producer gas derived from an oxygen blown gasifier. The lower heating value of natural gas is 51.624 MJ/kg. All of the fuels are at 986 ºF (803.15 K) with the sensible heat already accounted for in the lower heating value.

A summary of all the cases simulated is shown in Tables 2.2 and 2.3.

Case	Cycle	Fuel	LHV, MJ/kg	Power Level, MWe	Ambient Temperature, K	Rel. Hum., %	Notes
1	Simple	Nat. Gas	51.62	5	288.71	60	ISO GT NG
2a	Simple	Syngas	5.02	5	288.71	60	ISO GT Syngas 1
2b	Simple	Syngas	5.02	5	288.71	60	TIT Manipulation
2c	Simple	Syngas	5.02	5	288.71	60	Nozzle Manipulation
2d	Simple	Syngas	5.02	5	288.71	60	TIT and Nozzle Manipulation
3	Simple	Syngas	8.23	5	288.71	60	ISO GT Syngas 2
4	Simple	Syngas	11.16	5	288.71	60	ISO GT Syngas 3
5	Steam	Nat. Gas	51.62	5	288.71	60	ST ISO NG
6	Steam	Syngas	5.02	5	288.71	60	ISO ST Syngas 1
7	Steam	Syngas	8.23	5	288.71	60	ISO ST Syngas 2
8	Steam	Syngas	11.16	5	288.71	60	ISO ST Syngas 3
9	Combined	Nat. Gas	51.62	5	288.71	60	ISO GT and ST NG
10	Combined	Syngas	5.02	5	288.71	60	ISO GT and ST Syngas 1
11	Combined	Syngas	8.23	5	288.71	60	ISO GT and ST Syngas 2
12	Combined	Syngas	11.16	5	288.71	60	ISO GT and ST Syngas 3
13	Combined	Syngas	5.02	5	298.15	30	Ambient
14	Combined	Syngas	5.02	5	298.15	90	Ambient
15	Combined	Syngas	5.02	5	305.35	30	Ambient
16	Combined	Syngas	5.02	5	305.35	90	Ambient
17	Combined	Syngas	5.02	5	298.15	30	Mist Cool Case 13 287.55K 100%rh
18	Combined	Syngas	5.02	5	298.15	90	Mist Cool Case 14 295.93K 100%rh
19	Combined	Syngas	5.02	5	305.35	30	Mist Cool Case 15 293.15K 100%rh
20	Combined	Syngas	5.02	5	305.35	90	Mist Cool Case 16 303.15K 100%rh
21	Combined / STIG	Syngas	5.02	5	298.15	90	Max Steam Case 14
22	Combined / STIG	Syngas	5.02	5	298.15	90	Similar Fogger Mass Flow Rate for Steam Mass Flow Rates
23	Combined / STIG	Syngas	5.02	5	305.35	30	Max Steam Case 16
24	Combined / STIG	Syngas	5.02	5	305.35	30	Similar Fogger Mass Flow Rates for Steam Mass Flow Rates

Table 2.2: 5 MWe Cases

Case	Cycle	Fuel	LHV MJ/kg	Power Level MWe	Ambient Temperature K	Rel. Hum. %	Notes
20-1	Simple	Nat. Gas	51.62	20	288.71	60	ISO GT NG
20-2a	Simple	Syngas	5.02	20	288.71	60	ISO GT Syngas 1
20-2b	Simple	Syngas	5.02	20	288.71	60	TIT Manipulation
20-2c	Simple	Syngas	5.02	20	288.71	60	Nozzle Manipulation
20-2d	Simple	Syngas	5.02	20	288.71	60	TIT and Nozzle Manipulation
20-5	Steam	Nat. Gas	51.62	20	288.71	60	ISO ST NG
20-6	Steam	Syngas	5.02	20	288.71	60	ST ISO Syngas 1
20-9	Combined	Nat. Gas	51.62	20	288.71	60	ISO GT and ST NG
20-10	Combined	Syngas	5.02	20	288.71	60	ISO GT and ST Syngas 1
20-13	Combined	Syngas	5.02	20	298.15	30	Ambient
20-16	Combined	Syngas	5.02	20	305.35	90	Ambient
20-17	Combined	Syngas	5.02	20	298.15	30	Mist Cool Case 13 287.55K 100%rh
20-20	Combined	Syngas	5.02	20	305.35	90	Mist Cool Case 16 303.15K 100%rh
20-23	Combined / STIG	Syngas	5.02	20	298.15	30	Max Steam Case 16
20-24	Combined / STIG	Syngas	5.02	20	298.15	30	Similar Fogger Mass Flow Rates for Steam Mass Flow Rates

Table 2.3: 20 MWe Selected Cases

2.1 VARIOUS FUEL HEATING VALUES

Case 1 – 12

The ISO condition is 59 °F (15.5 °C) ambient air temperature at 60 % relative humidity. Under the ISO condition, 12 cases are simulated including: the simple cycle (gas turbine only), Rankine cycle (stem turbine only), BIGCC (combined cycle with both gas and steam turbines). The three cycles are first simulated using natural gas fuel source followed by feeding and different low caloric fuel sources derived from biomass. The purpose of these simulations is to investigate the effects of different LHV fuels on the gas turbine and cycle performances.

Case 13 - 16

The performance of a combined cycle using producer gas at various ambient conditions are simulated in case 13 -16. Four representative ambient conditions are employed to examine how low caloric fuels respond to ambient weather changes:

- Medium temperature and low humidity (77 °F and 30 % relative humidity)
- Medium temperature and high humidity (77 °F and 90 % relative humidity)
- High temperature and low humidity (90 °F and 30 % relative humidity)
- High temperature and high humidity (90 °F and 90 % relative humidity)

Case	Case	Cycle	Fuel	TIT (20MWe)	TIT (5MWe)	LHV, MJ/kg	Ambient Temp, K	Rel. Hum., %
20-13	13	Combined	Syngas	1280	1398	5.015	298.15	30
n/a	14	Combined	Syngas	n/a	1397	5.015	298.15	90
n/a	15	Combined	Syngas	n/a	1407	5.015	305.35	30
20-16	16	Combined	Syngas	1308	1404	5.015	305.35	90

Table 2.4: Four Representative Psychometric Cases 13 – 16

2.2 POWER AUGMENTATION

In order to boost power production and efficiency, two power augmentation methods are considered:

- GT fog inlet cooling
- Steam injected (STIG) GT

GT Fog Inlet Cooling (Cases 17 –20)

GT fog inlet cooling has been considered as an economic and effective means to augment GT power output on hot or dry days. Mist or fog inlet can increase gas turbine output by cooling down the inlet air and increasing the total mass flow rate by evaporation of the fine water particles. With increased fuel mass flow rate for using low-BTU producer gases, it is important to examine how the compressor is going to perform to allow more mass flow rate passing through the combustor and the turbine.

The previous four cases (13 – 15), under different weather and humidity conditions, are simulated with GT inlet fog cooling (cases 17 - 20).

Case	Case	Cycle	Fuel	LHV, MJ/kg	TIT (20MWe)	TIT (5MWe)	Ambient Fogged Temp, K	Rel. Hum., %
20-17	17	Combined	Syngas	5.015	1248	1390	287.55	100
n/a	18	Combined	Syngas	5.015	n/a	1395	295.93	100
n/a	19	Combined	Syngas	5.015	n/a	1390	293.15	100
20-20	20	Combined	Syngas	5.015	1301	1402	303.15	100

Table 2.5: Inlet Fog Cooling Cases 17 – 20

STIG (Cases 21 – 24)

Stem injection in the combustor has been employed conventionally to augment power and reduce NOx production. The performance of steam injection cycle also depends on how the steam is produced through the heat recovery steam generator (HRSG).

Case	Case	Cycle	Fuel	LHV, MJ/kg	TIT (20MWe)	TIT (5MWe)	Ambient Temp, K	Rel. Hum., %
n/a	21	STIG	Syngas	5.015	n/a	1218	298.15	90
n/a	22	STIG	Syngas	5.015	n/a	1398	298.15	90
20-23	23	STIG	Syngas	5.015	1184	1235	305.35	60
20-24	24	STIG	Syngas	5.015	1302	1403	305.35	60

Table 2.6: Power Augmentation Steam Injection into Gas Turbine Combustor (STIG) Case 21 – 24

Four cases are simulated in STIG study with three considerations: varying ambient temperatures, maximum potential of steam injection and steam mass flow rate similar to the fogger water mass flow rate used. Cases 21 and 22 are at medium temperature (77 °F) and 90 % humidity. Cases 23 and 24 are at high (90 °F) temperature at 60% humidity. Case 21 and 23 is at a lower TIT where the firing temperature is kept low while maximizing the steam recovery and hence increasing the amount of steam being injected. The lowered TIT is roughly at 84 % to 85 % of the designed maximum TIT of 1450 K (2150 °F / 946 °C). Cases 22 and 24 are simulated at a higher TIT with less steam recovered, and the steam injected mass flow rate is matched with similar mass flow rate of the fogger. Under the same ambient conditions, Cases 21 and 22 are compared to Case 14 while Cases 23 and 24 are compared to an independent case, to match the ambient conditions and fogger mass flow rate for the steam mass flow rate injection.

2.3 SOFTWARES UTILIZED

GateCycle and Thermoflow are the two commercial softwares being used to design and simulate the power plants and calculate the thermal efficiency of the overall system of the BIGCC in the study

G.E. Enter GateCycle Software

The secondary software used for the investigation and design of the BIGCC is the Enter GateCycle software by General Electric Company (G.E.). The software is employed through a graphical user interface (GUI) where icons are chosen, placed on the drawing area, and connected with the appropriate inputs and outputs for the components. Figure 2.1 shows a screen image of the software's GUI.

The software allows a user to quickly design and simulate from a simple stand-alone gas turbine or steam turbine to a full power plant with all associated components and connections. Input specifications are either user defined or else a default value is assigned. The software uses its proprietary algorithm to run iterations with the given inputs along with component data, and gives detailed outputs of each component and the overall power plant performance. The software calculates the performance of the entire power plant or individual hardware, predicting effects of parameter changes, calculates power augmentation, and allows building of innovative new power plants. The software includes a database of commercially available gas turbine models. A step-by-step screen shot example of GateCycle software is in Appendix B.

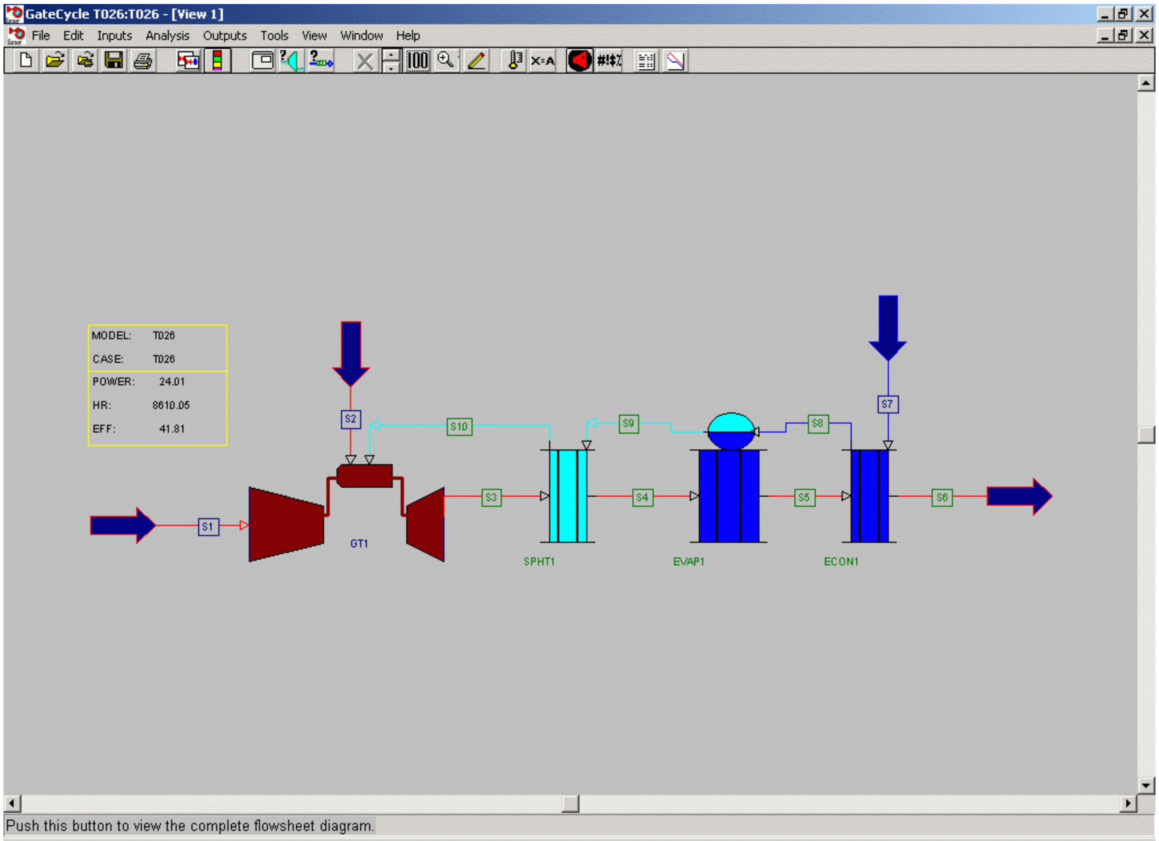

Fig. 2.1: GateCycle's GUI Environment

ThermoFlow Version 13 GT PRO, GTPRO and Steam PRO Software

ThermoFlow is one of the power industry's standard power plant design software, which utilizes a GUI environment for fast and easy design of a full power plant. The GTPRO and STEAMPRO software also features PEACE, which calculates the capital costs and financial aspects of building, maintenance and operating costs of the power plant. PEACE also includes information of regional costs, which accounts for local inflation, wages and taxes, etc. Figure 2.2 gives one example of the GUI screens in GT PRO. An example of step-by-step screenshot of building a BIGCC plant using the GT PRO is included in Appendix A.

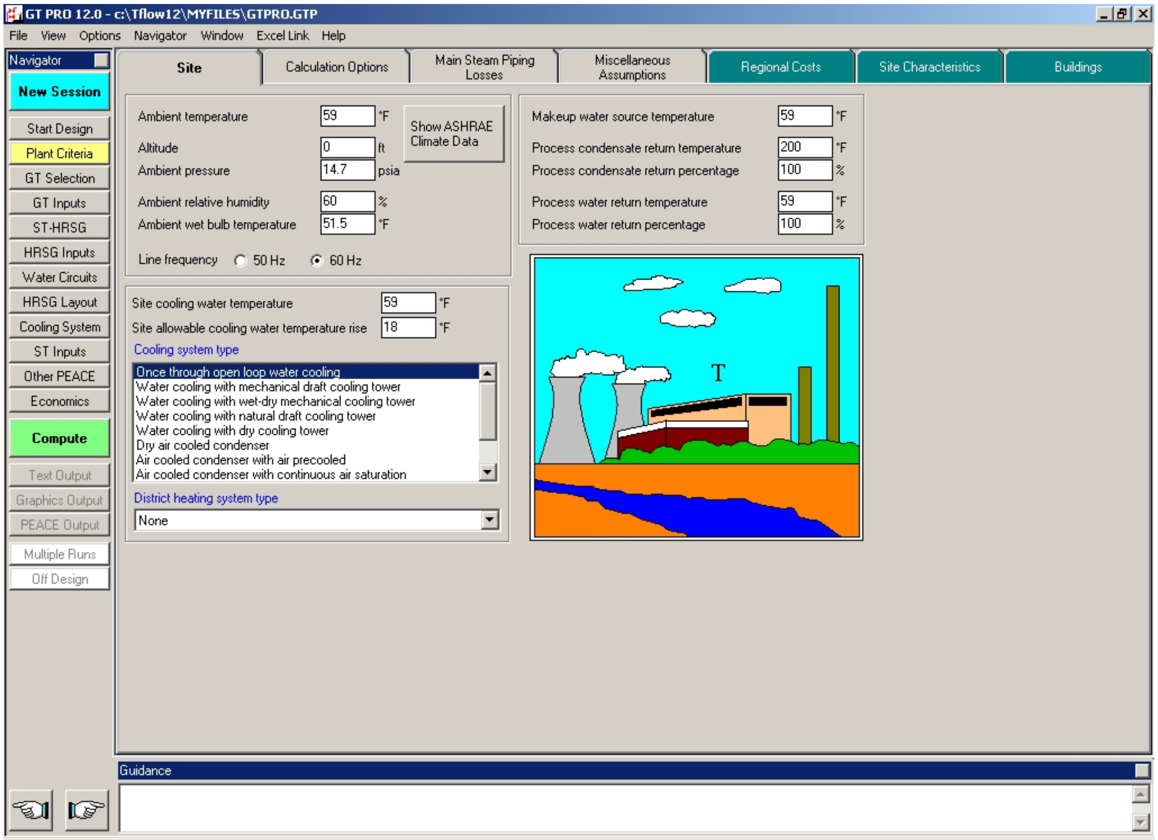

Figure 2.2: Plant Criteria for ThermoFlow's GUI

CHAPTER 3

RESULTS AND DISCUSSIONS

ThermoFlow software is used to simulate a proposed power plant system by first taking the inputs of: GT model, ambient conditions, general power plant requirements and GT setup (inlet cooling, stem injection, water injection, etc), fuel type, optional combined cycle with related components, and economic criteria. Using the fuel composition specification, the fuel is continuously added until the exhaust temperature reaches the pre-determined value for which the GT is designed in a natural gas fired system. The software performs the iteration by first calculating the combustion process using the given air mass flow rate and producing the result of the exhaust temperature. From the exhaust temperature and the combustion reaction, the compressor performance margin is checked with the existing GT model to ensure that the compressor can perform the required duty. If the compressor is not able to compress the needed amount of air, the iteration of the combustion is undertaken again with reduced fuel mass flow rate, and hence, lowering the turbine inlet temperature (TIT) and the pressure ratio (for low caloric value gas cases). The iteration follows the same method as described earlier until there is a convergence, which would suggest a possible actual performance of the GT with the given inputs. The default approach described above will use the GT exhaust temperature as a guideline. Users can also specify TIT as the operating criterion. Rolls Royce 501KH5 GT is selected for the 5 MWe plant simulations, and the Siemens GT 10 is selected for the 20 MWe power plant.

3.1 5 MWe POWER PLANT

3.1.1 Cases 1, 2a, 2b, 2c 2d, 3 and 4

Case 1 --- Natural Gas, ISO, LHV=51.624 MJ/kg, HHV=57.282 MJ/kg

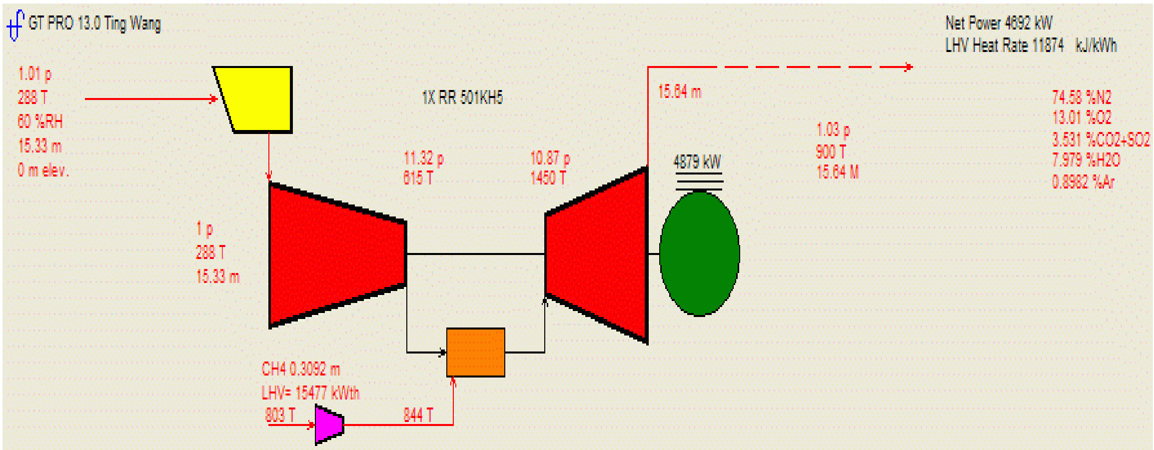

Figure 3.1: ThermoFlow GT Graphical Output of Case 1

Case 1 is the baseline case burning natural gas. In this case, natural gas is preheated to 986 °F (803.15 K). The LHV is 51,623.58 kJ/kg and HHV is 57,281.9 kJ/kg. One of the advantages of having a pre-heated fuel would be recovering the low-grade waste heat, which would be exhausted otherwise, to increase the overall thermal efficiency. Figure 3.1 shows the graphical output from the ThermoFlow. The states of each point is given with “p” representing pressure in units of bar, “T” for temperature in Kelvin, and “m” representing mass flow rate in kg/s.

The pressure ratio of the GT is at 11.3:1 and the TIT is 2150 °F (1450 K). The net output power is 4.692 MWe and an efficiency of 30.56 %. This case is used as the benchmark reference with which the other cases are compared.

Simple Cycle GT	ISO	ISO GT Manipulation				ISO	ISO
Case Number	1*	2a	2b	2c	2d	3	4
Ambient Temp, K (59F)	288.71	288.71	288.71	288.71	288.71	288.71	288.71
Rel. hum.	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Pressure Ratio	11.3	13.4	14.0	11.3	11.0	12.7	12.0
TIT, K	1450	1383	1452	1421	1433	1451	1451
Air kg/s	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Fuel LHV, MJ/kg	51.624	5.015	5.015	5.015	5.015	8.215	11.156
Fuel HHV, MJ/kg	57.282	5.919	5.919	5.919	5.919	9.689	12.079
Fuel kg/s	0.309	3.644	4.093	4.117	4.242	2.268	1.524
Fuel Compressor Power, MWe	0.080	0.605	0.680	0.684	0.705	0.400	0.324
GT Power, Mwe	4.879	6.050	6.848	7.006	7.171	5.913	5.291
Net Power, MWe	4.692	5.322	6.039	6.192	6.335	5.394	4.854
LHV Heat Rate, kJ / kW-hr	11874	10639	10529	10329	10403	11203	11651
LHV Thermal Efficiency, %	30.56	33.10	33.36	33.90	33.37	31.73	31.12
Net Power Increase, %	0.000	13.427	28.708	31.969	35.017	14.962	3.453
Efficiency Increase, %	0.000	8.312	9.162	10.929	9.195	3.829	1.832
Heat Rate Increase, %	0.000	-10.401	-11.327	-13.012	-12.388	-5.651	-1.878
* Case 1 is the reference case for comparison with other cases.							

Table 3.1: GT Summary of Case 1, 2a, 2b, 2c, 2d, 3, and 4

Case 2a --- Low Caloric Value Producer Gas, ISO, LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg, Design GT Operating Condition

This is the first case using producer gas as the fuel. The firing of producer gas in the GT combustion chamber results in a higher mass flow rate and higher pressure within the combustion chamber. The pressure ratio at the compressor is 13.4:1, and the TIT is lowered by 120.6 °F (67 K) to 2029.73 °F (1383 K). The increased pressure ratio may result in the need for a modified compressor or adding additional stages to handle an 18.6 % increase of compression.

The net power production is 5.322 MWe, which is 0.63 MWe (13.43 %) greater than a natural gas fired GT under similar ambient conditions. The additional 13.43 % of power is acceptable for the GT shaft and the generator as long as the increase is equal to or less than 25%. The producer gas is made up of different chemical compositions compared to natural gas. The producer gas is composed primarily of CO and H_2. Combustion of these chemicals results in higher flame temperature, which may lead to more NOx emission and may require higher combustion liner cooling. Since the fuel is of lower caloric value, a higher mass flow rate of producer gas is needed to reach the designed TIT value. The thermal efficiency for this system is 33.1 %, about 2.54 percentage point (or 8.3%) higher than Case 1. The heat rate is correspondingly reduced by 8.9 % from Case 1.

The increased output power is contributed by increased gas flow rate and increased pressure ratio. The fuel pump power is increased from 80 kW to 605 kW, which is consumed for compressing the producer gas to higher combustor pressure at higher fuel mass flow rate (3.644 kg/s producer gas compared to 0.309 kg/s of natural gas).

Case 2b --- Producer Gas, ISO, LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg, maximum TIT

Case 2a's TIT is 120.6 °F (67 K) lower than the designed value. It is interesting to know what the thermal efficiency would be if the TIT for producer gas fueled GT also reaches the designed value, 2150 °F (1450 K). Therefore, in the software, the TIT value is specified as 2150 °F. The results give a net power of 6.039 MWe with a compression ratio of 14.0:1 and thermal efficiency of 33.36 %. The pressure ratio is increased, and the net power output is 28.7 % higher than the natural gas fired Case 1. Replacement of a stronger GT shaft and a modified

compressor unit may be necessary. There is a 2.8 percentage point (or 9.16%) increase in the efficiency while the heat rate decreases by 11.32 %.

Case 2c --- Producer Gas, ISO, LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg, enlarged first-stage turbine nozzle open area

Due to increased backpressure when the first-stage nozzle openings are choked by the increased gas mass flow rate, in both Cases 2a and 2b, the pressure ratios are higher than the designed value (11.53). With higher than the designed pressure ratio, the compressor is operated under a thin margin to become unstable due to stall or rolling stall. The partial load performance can be questionable in Cases 2a and 2b, although the partial cases are not investigated in this study. To avoid the potential problems of operating the compressor too far away from the design point, in this case, the first stage nozzles openings are enlarged by 23 % to match the designed pressure ratio (11.3) as in Case 1. In addition, with the opening of the nozzle openings, the pressure ratio successfully reduces to 11.3, and the TIT is reduced to 2098.13 °F (1421 K) while the net power increases from 32% to 6.192 MWe from Case 1 There is a need to replace the compressor, generator, and shaft due to the increased gross power. The thermal efficiency is rated at 33.9 %, which is 3.3 percentage points (or 10.9 %) higher than the natural gas fired Case 1.

Case 2d ---Producer Gas 1, ISO, LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg, max TIT and an enlarged first-stage turbine nozzle open area

In this case, the maximum allowable TIT is assigned, and the first stage nozzle openings are enlarged; so the GT is operated at the designed TIT and the same pressure ratio as in Case 1. After opening the first stage turbine nozzles by 27.9% and increasing the TIT to 1433 K, the pressure ratio of 11.0 is maintained, and the net power output is 6.335 MWe with a thermal efficiency of 33.37%. Both the generator set and the turbine shaft may need to be replaced to accommodate the additional power produced.

Among the four Case 2's, enlarging the first stage turbine inlet guide vane without raising TIT (Case 2c) gives the highest thermal efficiency (33.9 %). However, opening the nozzle and raising the TIT to maximum capacity (Case 2d) gives the highest output power (6.335 MWe), but the thermal efficiency drops 1.73 percentage point from Case 2c.

Case 3 --- Producer Gas 2, ISO, LHV = 8.215 MJ/kg, HHV = 9.689 MJ/kg

The effects upon a GT with medium caloric syngas as a fuel source are studied in this case. The syngas is rated as 8215.2 kJ/kg (LHV) and 9689 kJ/kg (HHV) and fed at 986 °F (803 K). There are no adjustments to the TIT and the fist stage nozzle openings. The results give the pressure ratio of 12.7:1 (12.4 % higher than Case 1) with a TIT of 2152.13 °F (1451 K). The net power production is 5.394 MWe, which is 15 % higher than Case 1. Due to the higher fuel caloric value than in Case 2, the increased pressure ratio and net work output are acceptable to the selected GT. No specific modifications are needed. The thermal efficiency for this case is 31.73, which is only 0.56 percentage point (or 3.8 %) higher than Case 1 and 1.39 percentage (or 9.6 %) less than Case 2a. The fuel compressor power is 400 kW, which is lower than the fuel compressor consumption in Case 2a. In general, the increase in thermal efficiency would be observed when a low caloric value gas is used as a fuel in the GT.

Case 4 --- Producer Gas 3, ISO, LHV = 11.156 MJ/kg, HHV = 12.079 MJ/kg

Producer gas 3 has the highest caloric value (11.156 kJ/kg LHV and 12.079 kJ/kg HHV) among the three producer gases selected in this study. The net power produced is 4.845 MWe, which is within the shaft power limits. This producer gas is actually a clean syngas with the composition purely of CO and H_2. The operating pressure ratio is 12:1, and the TIT is 2152.13 °F (1451K), both of which closely match the operating condition for natural gas fueled Case 1. The thermal efficiency for this simulation is 31.12% and is marginally higher (1.8%) than Case 1.

In summary, the results in Table 1 show that fueling lower caloric producer gas to a simple gas turbine will require compressing more fuel mass flow to the combustor. The increased flue gas mass flow rate induces higher back pressure and produces more output power. Even though the auxiliary power is required to compress a large amount of low caloric fuel to higher pressure, the overall net output power and net plant efficiency increase. The percentage of increased power and efficiency increases as the caloric value of the fuel reduces (see the increasing trend from Case 4, to Case 3 and to Case 2). More output power and higher plant efficiency can be further harnessed if the first stage nozzles openings are widened 23 - 28% wider to match the pressure ratio to the designed value. Typically, higher pressure ratio and higher TIT increase the Brayton cycle efficiency. In the cases studied here, lower pressure ratio and lower TIT can achieve similar or slightest better performance (see Cases 2c and 2d vs. Cases 2a and 2b) because the higher pressure, induced by the low caloric fuel, deviates from the designed operating condition and adversely affects the compressor performance and does not improve the GT overall performance.

3.1.2 Steam Turbine Only Plant --- Cases 5, 6, 7, and 8

Case 5 --- Natural Gas, Steam Turbine, ISO, LHV = 51.624 MJ/kg, HHV = 57.282 MJ/kg

Cases 6, 7, and 8 --- Natural Gas, Steam Turbine, ISO, Steam Turbine Only, Various Low Caloric Value Producer Gases,

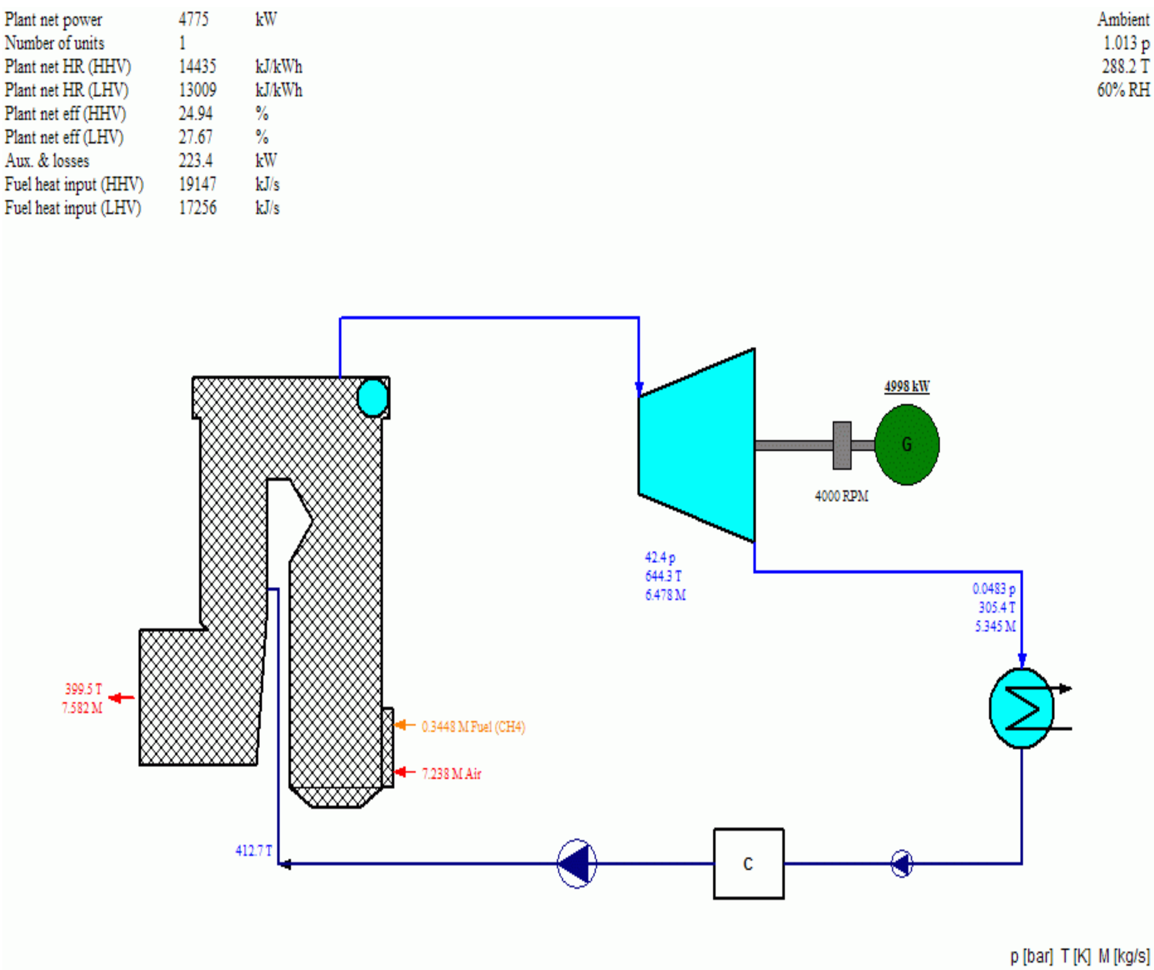

Figure 3.2: ThermoFlow ST Graphical Output for Case 5

Using the ISO condition, a steam cycle is simulated with a boiler fired with natural gas. Figure 3.2 shows the graphical output from ThermoFlow's Steam Pro. Starting from the left going clockwise is the boiler, the steam turbine with the generator set attached, a condenser, a feedwater heater, and the circulation pump (the c-box). The steam turbine cycle is designed to produce roughly 5 MWe. The purpose of this case is to compare the performance differences

between the standalone GT and the steam turbine (ST) with various fuels. The adiabatic flame temperature of natural gas combustion is greater than 2000 °F (1366.5 K) in the boiler with a 93.14 % thermal efficiency. The net power produced in Case 5 is 4.775 MWe with a steam cycle efficiency of 27.67 %, which is about 2.89 percentage points (9.5 %) lower than the GT performance in Case 1. The operating information of Case 5 is shown in Tables below.

Case	Fuel Caloric Value LHV (HHV) MJ/kg	Inlet / Outlet	P, Bar	T, °F (K)	Steam m, kg/s	x, quality
5	51.624 (57.282)	Inlet (HPT)	55.000	752.1 (673.2)	6.834	>1.000
		Outlet (LPT)	0.048	90.1 (305.4)	4.689	0.875
6	5.015 (5.919)	Inlet (HPT)	42.402	700.1 (644.3)	6.478	>1.000
		Outlet (LPT)	0.048	90.1 (305.4)	5.267	0.867
7	8.215 (9.689)	Inlet (HPT)	42.402	700.1 (644.3)	6.478	>1.000
		Outlet (LPT)	0.048	90.1 (305.4)	5.267	0.867
8	11.156 (12.079)	Inlet (HPT)	42.402	700.1 (644.3)	6.478	>1.000
		Outlet (LPT)	0.048	90.1 (305.4)	5.267	0.867

Table 3.2: Inlet and Exit Conditions of the Stem Turbine for Cases 5, 6,7 and 8

Case	Net Power MWe	Fuel Mass Flow Rate kg/s	% Power Difference	% Fuel Flow Rate Difference
5	4.775	0.340	1.8	10
6	4.782	3.63	10.1	0.9
7	4.778	2.17	11.4	4.3
8	4.784	1.60	1.4	3.7

Table 3.3: Results and Comparisons of Net Electric Power and Fuel Mass Flow Rate with corresponding Cases 1, 2a, 3, and 4, respectively.

Case	η, steam cycle %	η, boiler %	% Difference Cycle Efficiency
5	27.67	93.15	-9.5
6	30.54	91.12	-7.7
7	29.68	92.77	-6.5
8	29.29	93.81	-5.9

Table 3.4: Results and Comparisons of Steam Plant with corresponding Gas Turbine Plant in Cases 1, 2a, 3, and 4, respectively.

The same low caloric value producer gases used in Cases 2, 3 and 4, are used in Cases 5, 6, and 7, respectively in a steam power plant. In general, a sugarcane or wood mill needs steam for drying or for other manufacturing processes, so most produce steam in house by burning sugar cane bagasse or wood wastes in the boiler. In these simulation cases, no process steam is tapped, and all the steam is used for power generation. The inlet and exit condition of the steam turbine values are assigned as a standard design value regardless of the type of fuel used, and hence, the fuel is fed and fired until the designated superheated pressure (42.4 bar) and temperature (700 °F) are reached.

Tables 3.4 and 3.5 summarize the results of stand-alone steam turbine performance for Cases 5, 6, 7, and 8 and their comparisons with the corresponding GT Cases 1, 2a, 3, and 4, respectively.

In the GT plant, the parasitic power for compressing fuels is considered, but in the steam turbine plant, the fuel transport power is small and not considered because the furnace is operated at less than 2 atmospheric pressure. For the steam cycle cases, the effect of caloric value on the steam cycle performance is not as pronounced as in the single GT simple cycle cases. Producer gases of all three heating values render almost identical thermal efficiency at 30.54 %, 29.68 %, and 29.29 %, respectively, from lower heating value (5.015 MJ/kg) to higher heating value (11.156 MJ/kg). These efficiencies are all higher than the natural gas fired boiler in Case 5.

3.1.3 Combined Cycles with Various fuels --- Cases 9, 10, 11, and 12

Case 9 --- Natural Gas, Combined Cycle, ISO, LHV = 51.624 MJ/kg, HHV = 57.282 MJ/kg

Case 10, 11, and 12 --- Combined Cycle, ISO, Various Caloric Value Producer Gases

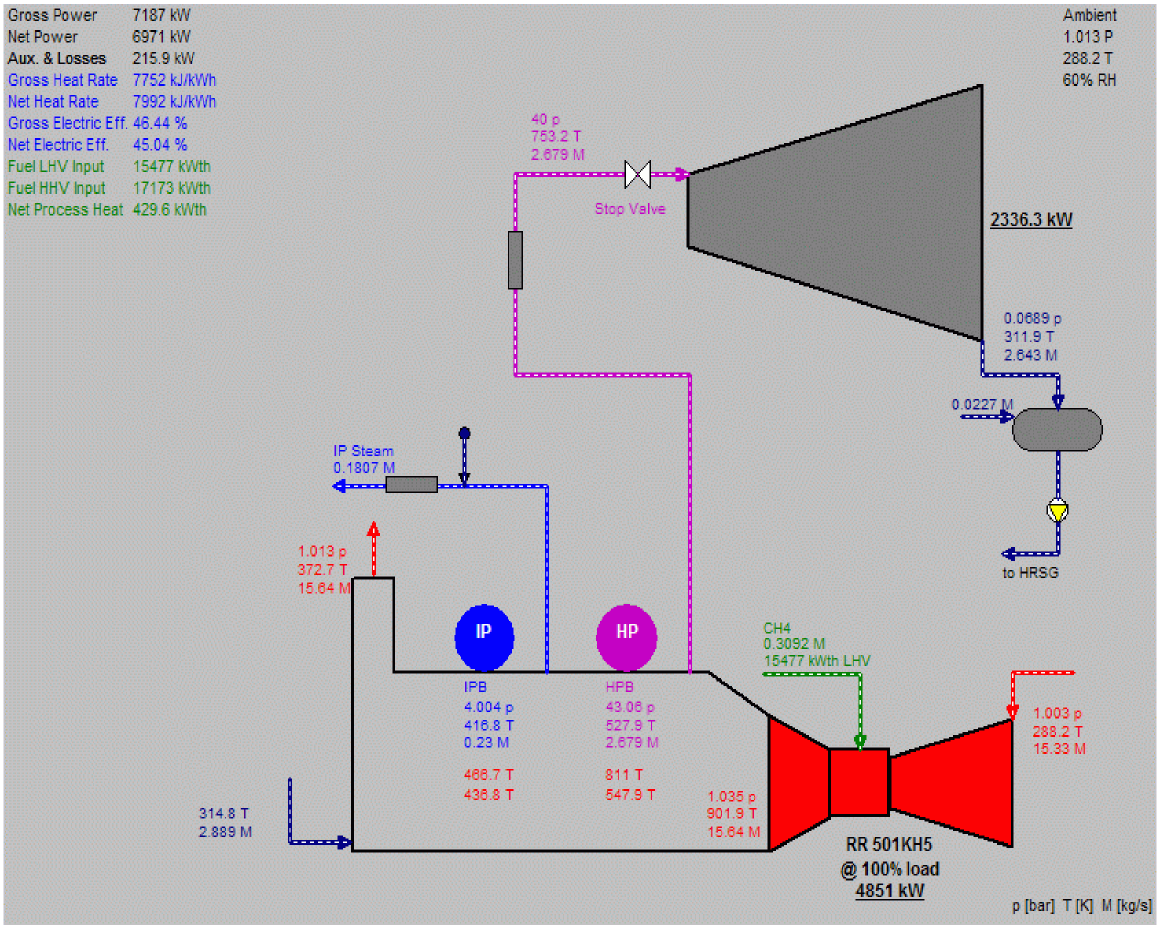

Figure 3.3: ThermoFlow GT Case 9 Graphical Output

Case 9 simulated a combined cycle with the configuration of a GT, a heat recovery steam generator (HRSG), and a condensing non-reheat ST. Figures 3.3 and 3.4 show the graphical and schematic output of Case 9, where each important state is shown next to the associated line of flow. Since this is a combined cycle, there are additional components like the HRSG unit, steam turbine, condenser, de-aerator, and valves for high pressure (HP) and low pressure (LP) steam.

Natural gas is fired in the same GT at ISO conditions in Case 9, which provides a benchmark reference for the combined cycle systems.

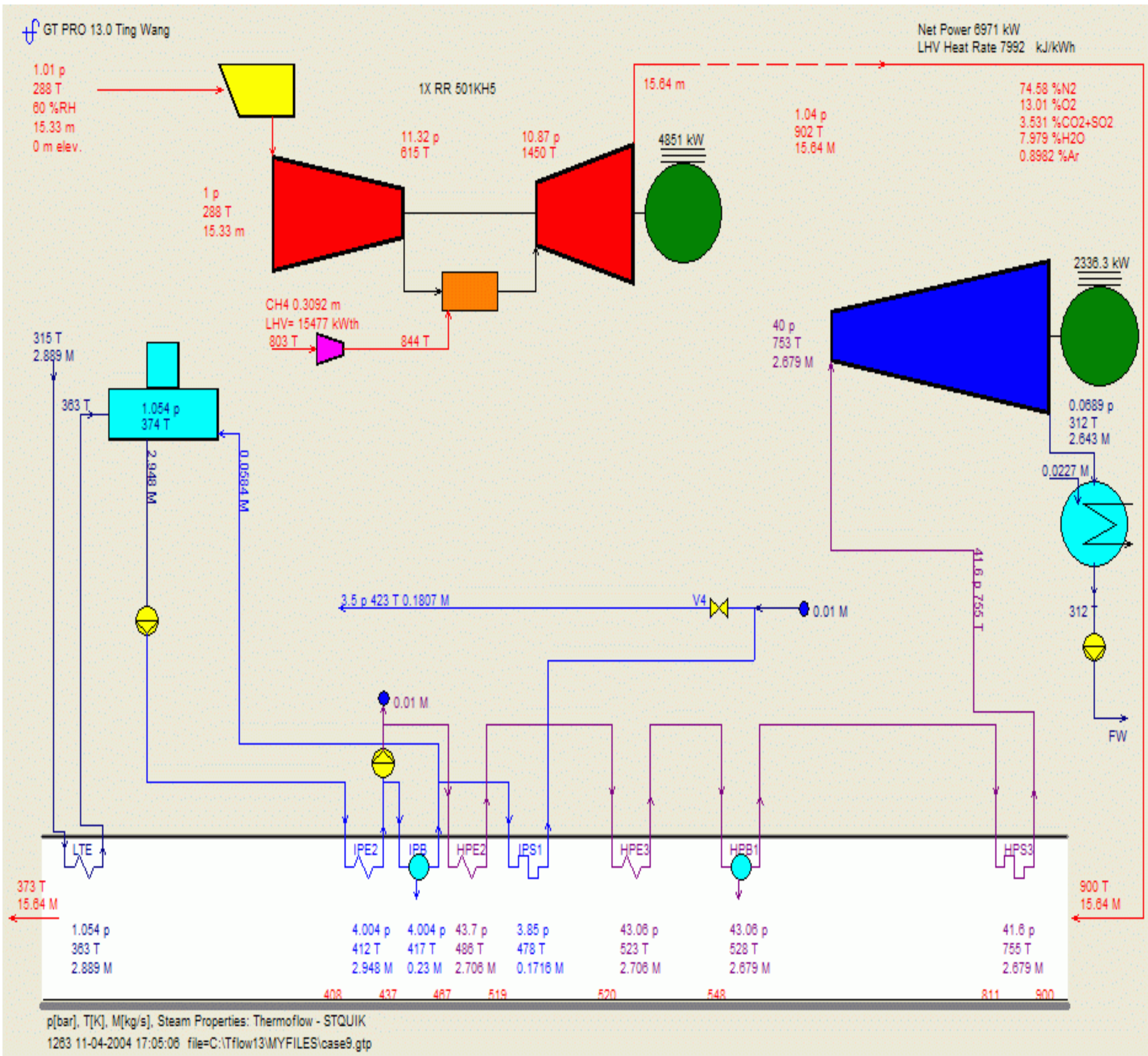

Figure 3.4: ThermoFlow GT Case 9 Schematic Output

In Case 1, with the GT alone, thermal efficiency achieves 30.56 %. With the given combined cycle, heat is recovered via the HRSG. The superheated steam is fed into the ST to produce more power; hence the output power and the thermal efficiency are both significantly increased. The natural gas flows at 0.31 kg/s into the combustion chamber. In the combined

cycle, the GT performance is identical to the cases where the GT is used as a simple cycle. The GT provides approximately 69.6 % of the total power output, while the ST provides the rest of the power. Compared with the simple GT cycle of Case 1, the net output power of the combined cycle increases to 22.7%, and the plant efficiency increases to 14.66 percentage points (or 47.38%).

Case Number	9*	10	11	12
Ambient Temp, K (59 F)	288.15	288.15	288.15	288.15
Rel. hum.	0.6	0.6	0.6	0.6
Pressure Ratio	11.3	13.4	12.4	11.9
TIT, K	1450	1385	1408	1431
Air, kg/s	15.3	15.3	15.3	15.3
Fuel LHV, MJ/kg	51.624	5.015	8.215	11.156
Fuel HHV, MJ/kg	57.282	5.919	9.689	12.079
Fuel kg/s	0.309	3.659	2.123	1.483
Fuel Compressor Power, MWe	0.080	0.608	0.375	0.315
GT Power, MWe	4.851	6.067	5.508	5.133
ST Power, Mwe	2.336	2.555	2.526	2.422
Net Total Power, MWe	6.971	7.870	7.518	7.102
LHV GT Heat Rate, kJ / kW-hr	11486	9371	10278	10728
Total LHV Heat Rate, kJ / kW-hr	7992	7224	7530	7754
GT Thermal Efficiency, %	30.38	33.05	31.55	31.01
Total LHV Thermal Efficiency, %	45.04	49.48	47.81	46.43
GT Power Increase, %	0.000	25.067	13.544	5.813
Total Power Increase, %	0.000	12.896	7.847	1.879
GT Efficiency Increase, %	0.000	8.789	3.851	2.074
Total LHV Efficiency Increase, %	0.000	9.858	6.150	3.086

Table 3.5: Combined Cycle performance for Cases 9, 10, 11, and 12 at ISO Condition

Case	Fuel Caloric Value LHV (HHV) MJ/kg	Inlet / Outlet	P, Bar	T, °F (K)	Steam kg/s	x, quality
9	51.624 (57.282)	Inlet (HPT)	40.000	896.1 (753.2)	2.679	>1.000
		Outlet (LPT)	0.069	101.8 (311.9)	2.643	0.957
10	5.015 (5.919)	Inlet (HPT)	40.00	896.1 (753.2)	2.900	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.860	0.954
11	8.215 (9.689)	Inlet (HPT)	40.00	896.1 (753.2)	2.767	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.729	0.954
12	11.156 (12.079)	Inlet (HPT)	40.00	896.1 (753.2)	2.767	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.729	0.956

Table 3.6: Steam Cycle Operation Condition for Cases 9, 10, 11, and 12

As expected, the steam mass flow rate is lower in the combined cycle Case 9 than in the steam turbine Case 5 because the waste heat is recovered to produce superheated steam. The quality, x, of the exit steam is higher than in Case 5 suggesting the ST blades are less likely subject to water droplet erosion.

There is no change in the output from the steam turbine and HRSG. Due to the limited amount of waste heat being available in Cases 10, 11, and 12, the amount of superheated steam created is less than in Cases 6, 7,and 8. Therefore, the steam mass flow rate and power output of the steam turbine are reduced. If the waste heat from the exhaust is not recovered, it will be exhausted into the environment, and the available waste energy bleeds into the air. Alternatives to waste heat usage includes district hot water heating and possibly biomass fuel drying.

The effects of low calorific value fuels to the combined cycle are similar to those on the simple GT system (efficiency increases 2 ~ 8 % and output power increases 2~13 %) because GT produces about 70% of the total plant power, and the effect of low calorific value fuels to the steam turbine is limited as shown in previous steam turbine Cases 6, 7, and 8. The percentage of increased power and efficiency increases as the caloric value of the fuel decreases (see the increasing trend from Case12, to Case 11 and to Case 10 in Table 3.5).

3.1.4 Combined Cycles Under Different Ambient Conditions

Cases 13, 14, 15, and 16 --- Low Caloric Value Producer Gas, Combined Cycle, Various Ambient Conditions, LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

Cases 9 ~ 12 are simulated at ISO condition (59 °F and 60% relative humidity) while cases 13, 14, 15, and 16 are simulated with four different ambient conditions as shown in Table 3.7. The fuel source is the producer gas 1 with 5.015 MJ/kg LHV and preheated to a temperature of 985.73 °F (803 K).

Combined Cycle	**ISO**	**Ambient**			
Case Number	10*	13	14	15	16
Ambient Temp, K (F)	288.15 (59)	298.15 (77)	298.15 (77)	305.35 (90)	305.35 (90)
Rel. hum.	0.6	0.3	0.9	0.3	0.9
Pressure Ratio	13.4	12.9	12.8	12.5	12.5
TIT, K	1385	1398	1397	1407	1404
Air, kg/s	15.3	14.6	14.5	14.2	14.0
Fuel LHV, MJ/kg	5.015	5.015	5.015	5.015	5.015
Fuel HHV, MJ/kg	5.919	5.919	5.919	5.919	5.919
Fuel kg/s	3.659	3.535	3.551	3.452	3.475
Fuel Compressor Power, MWe	0.608	0.587	0.590	0.573	0.577
GT Power, MWe	6.067	5.859	5.881	5.718	5.749
ST Power, Mwe	2.555	2.534	2.553	2.521	2.548
Net Total Power, MWe	7.870	7.664	7.701	7.524	7.577
LHV GT Heat Rate, kJ / kW-hr	9371	9372	9381	9377	9391
Total LHV Heat Rate, kJ / kW-hr	7224	7165	7163	7127	7125
GT Thermal Efficiency, %	33.05	33.05	33.020	33.030	32.980
Total LHV Thermal Efficiency, %	49.48	50.25	50.26	50.51	50.53
GT Power Increase, %		-3.428	-3.066	-5.752	-5.241
Total Power Increase, %		-2.618	-2.147	-4.396	-3.723
GT Efficiency Increase, %		0.000	-0.091	-0.061	-0.212
Total LHV Efficiency Increase, %		1.556	1.576	2.082	2.122
Total LHV Heat Rate Increase, %		-0.817	-0.844	-1.343	-1.370

* Case 10 is the reference for comparisons with other cases

Table 3.7: Results of Different Ambient Conditions for Cases 13, 14, 15, and 16

Comparing the results of Cases 13, 14, 15, and 16 with ISO Case 10, the output power of GT decreases by a range of 3.1 % to 5.7 %, while the plant total power is reduced by 2.1 % to

4.3 %. The combined cycle efficiency increases by 1.6 % to 2.1 %. There is a drop of 4.5 % to 6.7 % in compressor pressure ratio while the TIT increases by 0.9 % to 7.8 %. Although the steam turbine performance depends on the turbine exhaust temperature (TET) and the effectiveness of the HRSG, the effect of ambient condition is primarily manifested in the GT performance.

Case	Fuel Caloric Value LHV (HHV) MJ/kg	Inlet / Outlet	P, Bar	T, °F (K)	Steam m, kg/s	x, quality
13	5.015 (5.919)	Inlet (HPT)	40.00	896.1 (753.2)	2.880	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.840	0.954
14	5.015 (5.919)	Inlet (HPT)	40.00	896.1 (753.2)	2.898	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.858	0.954
15	5.015 (5.919)	Inlet (HPT)	40.00	896.1 (753.2)	2.867	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.827	0.954
16	5.015 (5.919)	Inlet (HPT)	40.00	896.1 (753.2)	2.894	>1.000
		Outlet (LPT)	0.07	101.8 (311.9)	2.854	0.954

Table 3.8: Summary of ST Performance For Cases 13, 14, 15, and 16

3.1.5 Combined Cycles with Inlet Fog Cooling

Cases 17, 18, 19, and 20 --- Combined Cycle with GT Compressor Inlet Fog Cooling at Four Different Ambient Conditions, Low Caloric Value Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

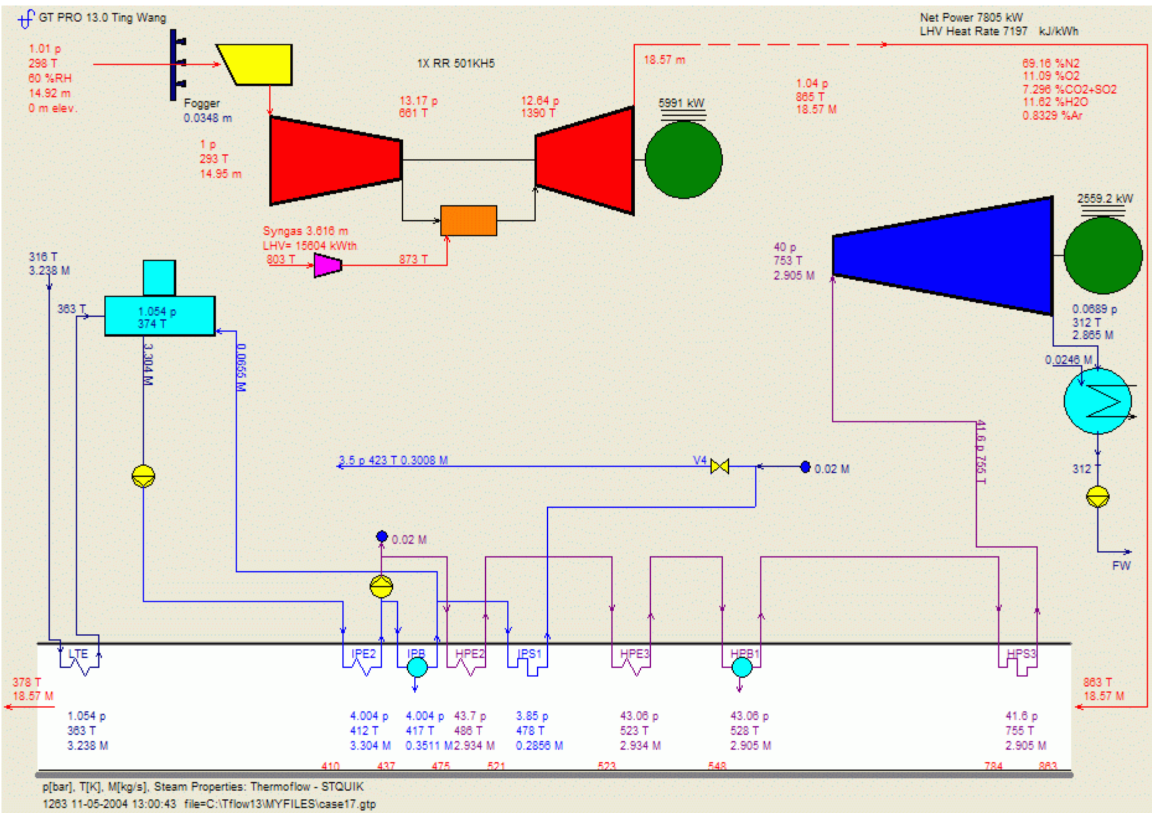

Figure 3.5: ThermoFlow GT Schematic Output for Case 17 with Inlet Fog Cooling

GT inlet fog cooling is considered the most economic and simple method for power augmentation. Cases 17, 18, 19, and 20 have the same ambient conditions corresponding to each individual Case of 13, 14, 15, and 16, respectively. Figure 3.5 shows a representative row of foggers in front of the compressor in the diagram. The relative humidity for each Case of 17 ~ 20

is raised from 30% till 100% by assuming all the fine mist droplets are completely evaporated before entering the compressor. The water droplets are injected at 5 to 10 microns in diameter. The projected air temperature after fog cooling, but before entering the compressor, is assumed to reaching the wet bulb temperature. For example, for Case 17 after saturation fogging, the compressor inlet temperature is assumed to have reached 57.92 °F (287.55 K).

Case Number	10*	17	18	19	20
Ambient Temp, K (F)	288.15 (59)	298.15 (77)	298.15 (77)	305.35(90)	305.35 (90)
Ambient RH	0.6	0.3	0.9	0.3	0.9
GT Inlet Temp after FogCooling , K (F)	288.15 (59)	287.55 (57.92)	295.93 (73)	293.15 (68)	303.15 (86)
RH after Fog Cooling	0.6	1.00	1.00	1.00	1.00
Pressure Ratio	13.4	13.1	12.9	13.1	12.5
TIT, K	1385	1390	1395	1390	1402
Air, kg/s	15.3	15.0	14.6	14.9	14.1
Fuel LHV, MJ/kg	5.015	5.015	5.015	5.015	5.015
Fuel HHV, MJ/kg	5.919	5.919	5.919	5.919	5.919
Fuel kg/s	3.659	3.616	3.569	3.615	3.496
Fuel Compressor Power, MWe	0.608	0.601	0.593	0.600	0.581
GT Power, MWe	6.067	5.991	5.911	5.990	5.783
ST Power, Mwe	2.555	2.559	2.557	2.559	2.554
Net Total Power, MWe	7.870	7.805	7.731	7.803	7.614
LHV GT Heat Rate, kJ / kW-hr	9371	9377	9380	9377	9390
Total LHV Heat Rate, kJ / kW-hr	7224	7197	7171	7197	7133
GT Thermal Efficiency, %	33.05	33.030	33.020	33.030	32.990
Total LHV Thermal Efficiency, %	49.48	50.02	50.20	50.02	50.47
GT Power Increase, %		-1.253	-2.571	-1.269	-4.681
Total Power Increase, %		-0.826	-1.766	-0.851	-3.253
GT Efficiency Increase, %		-0.061	-0.091	-0.061	-0.182
Total LHV Efficiency Increase, %		1.091	1.455	1.091	2.001
Total LHV Heat Rate Increase, %		-0.374	-0.734	-0.374	-1.260

* Case 10 is the ISO reference case for comparisons with other cases

Table 3.9: Combined Cycle Inlet Cooling Cases 17 - 20

Table 3.9 shows the comparison of the inlet fog cooling results with the ISO condition of Case 10. The results show fog inlet cooling will slightly increase the plant efficiency (1~2%) but not increase in the total output power when compared with the ISO condition. This is expected

because ISO condition is at relative low ambient temperature, and at best, fog cooling can only reach to the wet bulb temperature. However, the main purpose of employing the fog inlet cooling is not for improving ISO condition; rather, it is for augmenting power for the hot or dry ambient conditions. Therefore, the interest is focused on comparing the Cases between 13 ~ 16 with 17 ~ 20 as shown in Table 3.10. Recall that Cases 13 ~ 16, where no inlet fogging is employed, and GTs are run with the given ambient temperatures and humidity.

Combined Cycle	**Mist Cooling WRT Ambient Cases**			
Case Number	13 -> 17	14 -> 18	15 -> 19	16 -> 20
Temperature & humidity	298.15K, 30%--> 287.55K, 100%	298.15K, 90%--> 295.93K, 100%	305.35K, 30%--> 293.15K, 100%	305.35K, 90%--> 303.15K, 100%
GT Power Increase, %	2.253	0.510	4.757	0.591
Total Power Increase, %	1.840	0.390	3.708	0.488
GT Efficiency Increase, %	-0.061	0.000	0.000	0.030
Total Efficiency Increase, %	-0.458	-0.119	-0.970	-0.119
Total Heat Rate Increase, %	0.447	0.112	0.982	0.112

Table 3.10: Power Augmentation by Employing Inlet Fogging on Cases 13 ~ 16. The Results are Summarized as Cases 17~ 20

Table 3.10 shows that inlet fog cooling consistently provides power augmentation (0.4 ~ 3.7%) at dry or hot environment; however, the efficiency of each case slightly decreases (-0.11 ~ -0.97%). The power augmentation is more pronounced in the dry environment (30% RH for Cases 17 and 19) than in a hot environment (Case 20). Of course, the dry and hot environment harvests the most power augmentation out of fog cooling (Case 19) but with the worst degrading of efficiency. The result of the increased power output that accompanies the increased heat rate indicates more fuel is needed to heat up the saturated air for generating additional power at a less efficient way than the dry air.

Overall, power augmentation for a small gas turbine (5MWe) is not as good as a larger gas turbine. The use of low caloric fuel further impedes the performance of fog cooling because the compressor is already heavily loaded by the increased back pressure due to excessive fuel mass flow rate. An additional increase of mass flow rate from the water vapor does not augment as much power (in percentage) as the natural gas fired GT system.

3.1.6 Combined Cycles with Combustor Steam Injection (STIG)

Case 21, 22, 23, and 24 --- Combined Cycle with Combustor Steam Injection, Ambient Temperature, Low Caloric Value Producer Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

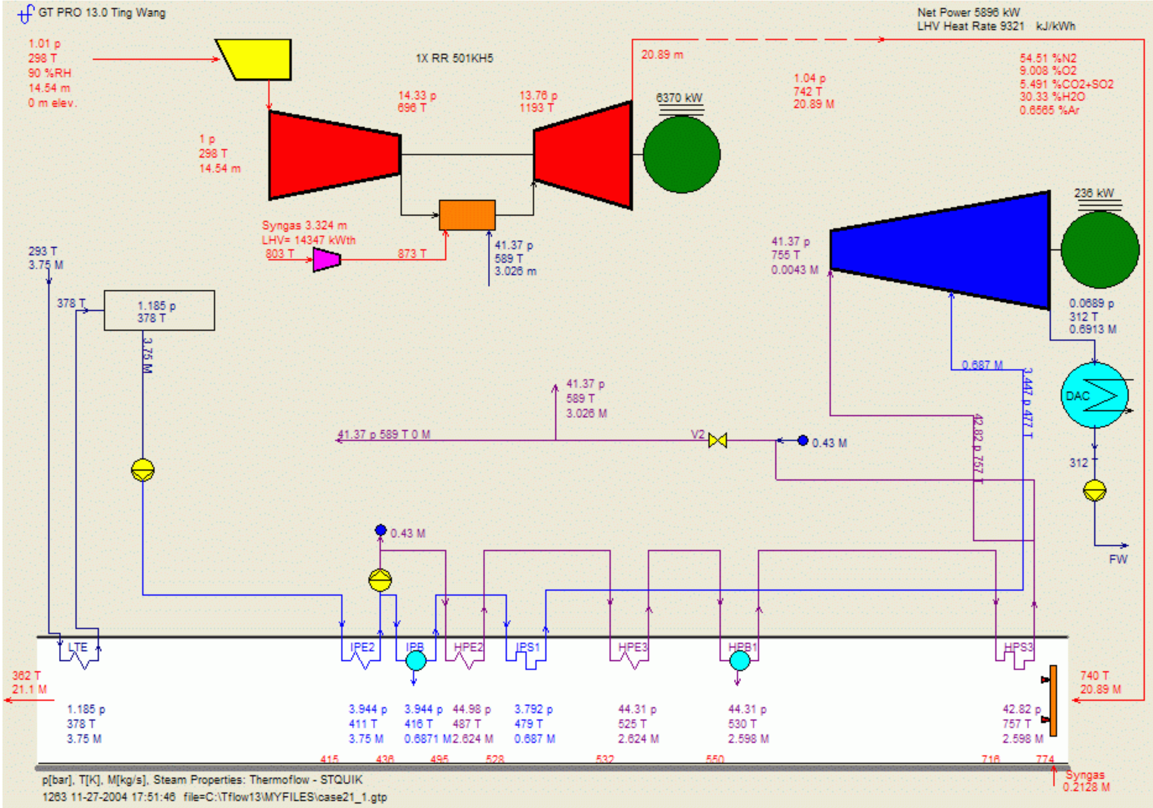

Figure 3.6: ThermoFlow GT Schematic Output for Combustor Steam Injection in Case 21

Steam injected into a combustor has been commercially used to reduce NO_X emissions and for augmenting output power as well. Steam injection was used in the 1940's to boost the power output of military airplane engines [Cohen, et. al. , 1996]. In the 1970's, steam injection was employed to lower the combustion flame temperature and reduce NO_X formation. Figure 3.6 shows the GT schematic with the HRSG, which supplies steam for injection into the combustion chamber via the HP sub-stream.

The similar ambient condition in Case 14 (77 °F, 90 % relative humidity) is now simulated with steam injection (Cases 21 and 22) into the combustion chamber to augment power under the condition of using low caloric value fuel. Case 21 investigates the cycle performance by maximizing the steam injection mass flow via the same HRSG. In Case 22, the amount of steam injection matches the same amount of water used for fog cooling in Case 18, which compares the effect of power augmentation between steam injection and fog inlet cooling. Cases 23 and 24 repeat the same simulation method as Case 21 (maximum steam injection mass flow) and 22 (matching water mass flow rate in Case 19) with the similar ambient condition of Case 15 (90 °F, 30 % relative humidity).

Table 3.11 summarizes the performance of steam injection Cases 21 ~ 24 and their comparisons with ISO Case 10. Both Cases 21 and 23 inject the maximum steam mass flow that can be generated by the HRSG at the pressure comparable to (or a bit higher than) the combustor pressure. When the steam is diverted into the combustor, the steam turbine operates at inefficient partial load. The results of Cases 21 and 23 show that the GT power increases 4~5%, and GT efficiency increases 15%. However, the steam turbine output drops 91%, and the total plant performance suffers a 25% reduction in net output power and 19 ~ 21% loss in efficiency.

Basically, the increased performance in GT is not sufficient enough to make up the poor performance in the steam turbine, and subsequently, a loss to the entire plant occurs.

Steam injection does not help Cases 22 and 24 enough to augment power in comparison with the ISO condition; however, the thermal efficiency for Cases 22 and 24 is raised by 1.7 %. The slightly increased thermal efficiency of Cases 22 and 24 may be due to the use of the HRSG to recover waste heat to produce superheated steam.

Case Number	10*	21	22	23	24
Ambient Temp, K (F)	288.15 (59)	298.15 (77)	298.15 (77)	305.35 (90)	305.35 (90)
Rel. hum.	0.6	0.9	0.9	0.3	0.3
Pressure Ratio	13.4	14.3	12.8	14.0	12.6
TIT, K	1385	1193	1396	1211	1404
Air, kg/s	15.3	14.5	14.5	14.2	14.2
Steam Injection (kg/s)	0	3.03	0.01	2.92	0.08
Fuel LHV, MJ/kg	5.015	5.015	5.015	5.015	5.015
Fuel HHV, MJ/kg	5.919	5.919	5.919	5.919	5.919
Fuel kg/s	3.659	3.324	3.553	3.302	3.470
Fuel Compressor Power, MWe	0.608	0.552	0.590	0.548	0.576
GT Power, MWe	6.067	6.370	5.886	6.314	5.774
ST Power, Mwe	2.555	0.236	2.565	0.230	2.484
Net Total Power, MWe	7.870	5.896	7.717	5.873	7.583
LHV GT Heat Rate, kJ / kW-hr	9371	8108	9376	8125	9337
Total LHV Heat Rate, kJ / kW-hr	7224	9321	7152	9077	7152
GT Thermal Efficiency, %	33.05	38.200	33.030	38.120	33.170
Total LHV Thermal Efficiency, %	49.48	38.62	50.34	39.66	50.34
GT Power Increase, %		4.994	-2.983	4.071	-4.829
Total Power Increase, %		-25.083	-1.944	-25.375	-3.647
GT Efficiency Increase, %		15.582	-0.061	15.340	0.363
Total LHV Efficiency Increase, %		-21.948	1.738	-19.846	1.738
Total LHV Heat Rate Increase, %		29.028	-0.997	25.651	-0.997

*Case 10 is the ISO reference case for comparisons with no steam injection.

Table 3.11 Summary of Steam Injection Performance for Cases 21 –24.

Similar to the motivation of using fog inlet cooling, the purpose of using steam injection is not to augment power at the ISO condition; rather, it is for power augmentation under non-ISO conditions. The performance of Case 21 and 23 are equally not as good when compared with Cases 14 and 16, respectively. This indicates that maximize steam injection is not a good

practice for a combined cycle designed with optimized load shares between the duties of GT and ST.

Comparison of the inlet fog cooling and steam injection using the same amount of water mass flow (Cases 22 vs. 18 and Cases 24 Vs. 19) indicates that steam injection provides a minor edge over fog inlet cooling in augmenting power under both dry and humid ambient conditions. Fog inlet cooling, however, shows a better efficiency than steam injection (Cases 19 vs. 24) under the dry ambient condition (30% RH). When relative humidity is high, fog cooling understandably underperforms the steam injection cases. In summary, steam performs better when expanded in the steam turbine than being injected to the gas turbine combustor for a combined cycle system. This is especially valid for the system burning low caloric fuel because the compressor is already burdened with increased fuel mass flow rate and higher back pressure.

Combined Cycle	**Steam Injection WRT Ambient Cases**			
Case Number	21 vs.14	22 vs.18	23 vs.16	24 vs.19
Ambient Temp, K	298.15	298.15	305.35	305.35
Rel. hum.	0.9	0.9	0.3	0.3
GT Power Increase, %	8.722	0.085	10.423	0.979
Total Power Increase, %	-23.439	0.208	-21.943	0.784
GT Efficiency Increase, %	15.687	0.030	15.410	0.424
Total Efficiency Increase, %	-23.160	0.159	-21.481	-0.337
Total Heat Rate Increase, %	30.127	-0.154	27.361	0.351

Table 3.12: Comparison of Steam Injection performance for Cases 21 – 24 vs. Cases 14, 18, 16, and 19.

3.2 LARGER 20 MWe POWER PLANTS

Larger power plants are usually more efficient and less expensive in regard to capital, operating, and maintenance costs. Therefore, investigating the performance of larger plants using low caloric value producer gases (5.015 MJ/kg) will be interesting. The case numbers of the 20

MWe power plants are assigned with a prefix "20-" followed by the case number corresponding to the 5MWe cases with the same operating conditions.

3.2.1 20MWe Simple Gas Turbine Systems

Cases 20-1, 20-2a, 20-2b, 20-2c, and 20-2d --- Simple GT Cycle, ISO, Natural Gas LHV = 51.624 MJ/kg, HHV = 57.282 MJ/kg, Low Caloric Value Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

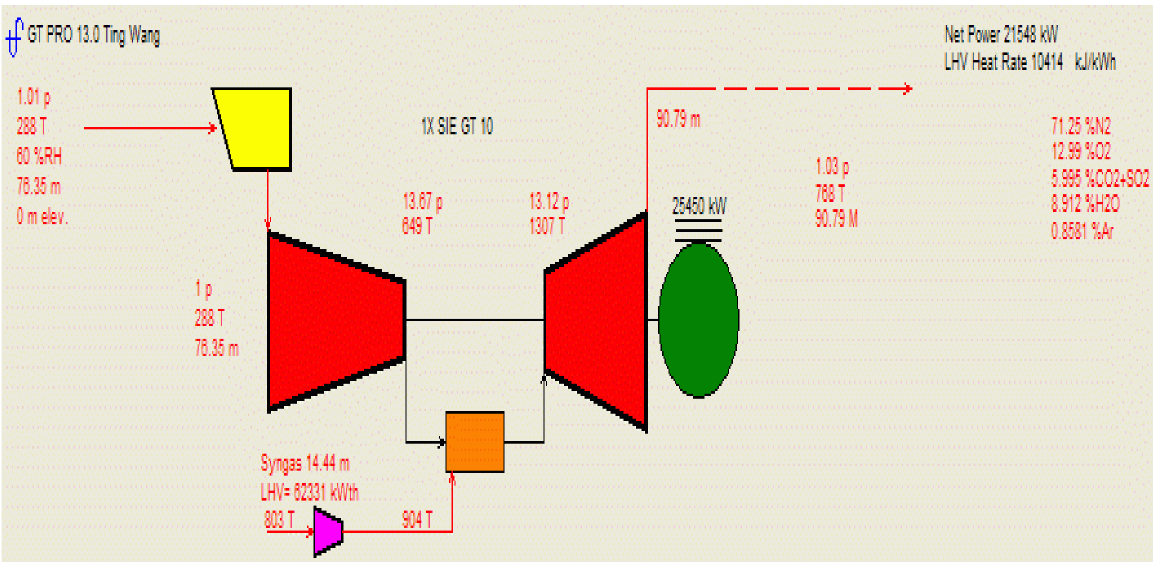

Figure 3.7: ThermoFlow GT Schematic Output for Case 20-1

A larger GT engine, Siemens GT10 capable of 20MWe power generation, is selected for the larger plant simulation. Case 20-1 is simulated under ISO conditions with natural gas, and Cases 20-2a to 20-2d are simulated with low caloric value producer gas.

Case Number	20-1*	20-2a	20-2b	20-2c	20-2d
Ambient Temp, K (59 F)	288.15	288.15	288.15	288.15	288.15
Rel. hum.	0.6	0.6	0.6	0.6	0.6
Pressure Ratio	13.6	14.8	14.8	13.6	13.6
TIT, K	1392	1249	1249	1307	1307
Air kg/s	76.0	76.0	76.0	76.0	76.0
Fuel LHV, MJ/kg	51.624	5.015	5.015	5.015	5.015
Fuel LHV, MJ/kg	57.282	5.919	5.919	5.919	5.919
Fuel kg/s	1.265	12.323	12.322	14.443	14.443
Fuel Compressor Power, MWe	0.471	2.964	2.964	3.474	3.474
GT Power, Mwe	21.144	21.076	21.076	25.450	25.450
Net Power, MWe	20.310	17.716	17.716	21.548	21.548
LHV Heat Rate, kJ / kW-hr	11211	10806	10806	10414	10414
LHV Thermal Efficiency, %	32.380	34.1	34.1	35.13	35.13
Net Power Increase, %	0.000	-12.772	-12.772	6.096	6.096
Efficiency Increase, %	0.000	5.312	5.312	8.493	8.493
Heat Rate Increase, %	0.000	-3.613	-3.613	-7.109	-7.109

* Case 20-1 is the natural gas fired reference case for comparisons with other cases.

Table 3.13: Summary of Comparisons of 20MWe Plant Performance Between Burning Natural Gas and Producer Gas 1

Generally Cases 20-1 to 20-2d are simulated similarly to those of the corresponding 5MWe Cases 1 to 2d. Case 20-1 serves as a reference with which other cases (Cases 20-2a to 20-2d) burning producer gas are compared.

Upon firing the low caloric value fuel in the GT, Case 20-2a (see Table 3.13) exhibits a result similar to the smaller 5MWe system with an increase in pressure compressor ratio due to back pressure and an increase in TIT. Differences between the 20MWe system and the 5MWe system (Case 20-1 vs. Case 1) are found. The smaller system exhibits increases in both net power output (13 %) and plant efficiency (1.8 %) while the larger system has a power reduction of 12.7 % but an increase of thermal efficiency by 1.72 percentage points (or 5.3%).

Case 20-2b is meant to raise the TIT to the maximum allowable value at 2045.93 °F (1392 K). The TIT adjustable range allows for an addition or reduction of 180 °F (100 K) when

the operating TIT is lower than the designed maximum value. In this case when TIT is raised, an automatic note is generated stating that the surge margin may be violated and any TIT adjustments made will not be put into effect. The desired TIT is not allowed to be achieved, and hence the highest allowable TIT 1788.5 °F (1249 K), similar to Case 20-2a, is implemented. Case 20-2b is therefore identical to Case 20-2a.

For Case 20-2c, the nominal first stage nozzle openings are widened 14 % more from the designed value to allow a reduction of back pressure until the desired design pressure ratio13.6 is achieved. In Case 20-2d, the highest allowable TIT and nominal nozzle openings adjustments are made; however, in Case 20-2d changes to the TIT are prohibited due to the possibility of surge margin violation. Case 20-2d is therefore identical to Case 20-2c. Similar to Case 2c in the 5MWe plant, Case 20-2c shows both output power and efficiency improvements due to widened nozzle openings and relatively higher TIT values (in comparison with Case 20-2a). This may suggest, due to the higher fuel mass flow rate, the increase in nominal nozzle opening area may be the main factor contributing to increasing the power production and efficiency in the GT.. Comparing the larger GT results with those of the 5 MWe systems, the 20 MWe power plants exhibit less power and efficiency increases (Case 20-2c vs. 2c).

3.2.2 20MWe Steam Turbine Only Plants

Case 20-5 and 20-6 ---- Steam Turbine Only, ISO, Natural Gas LHV = 51.624 MJ/kg, HHV = 57.282 MJ/kg, versus Low Caloric Value Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

Figure 3.8 and 3.9 show the schematic output of the steam cycle Case 20-6. There are three feed water heaters for a three-step preheating of water before the water enters the boiler

unit. The net output power of 20 MWe was specified in the software Steam Pro to match a standalone GT for the purpose of comparison.

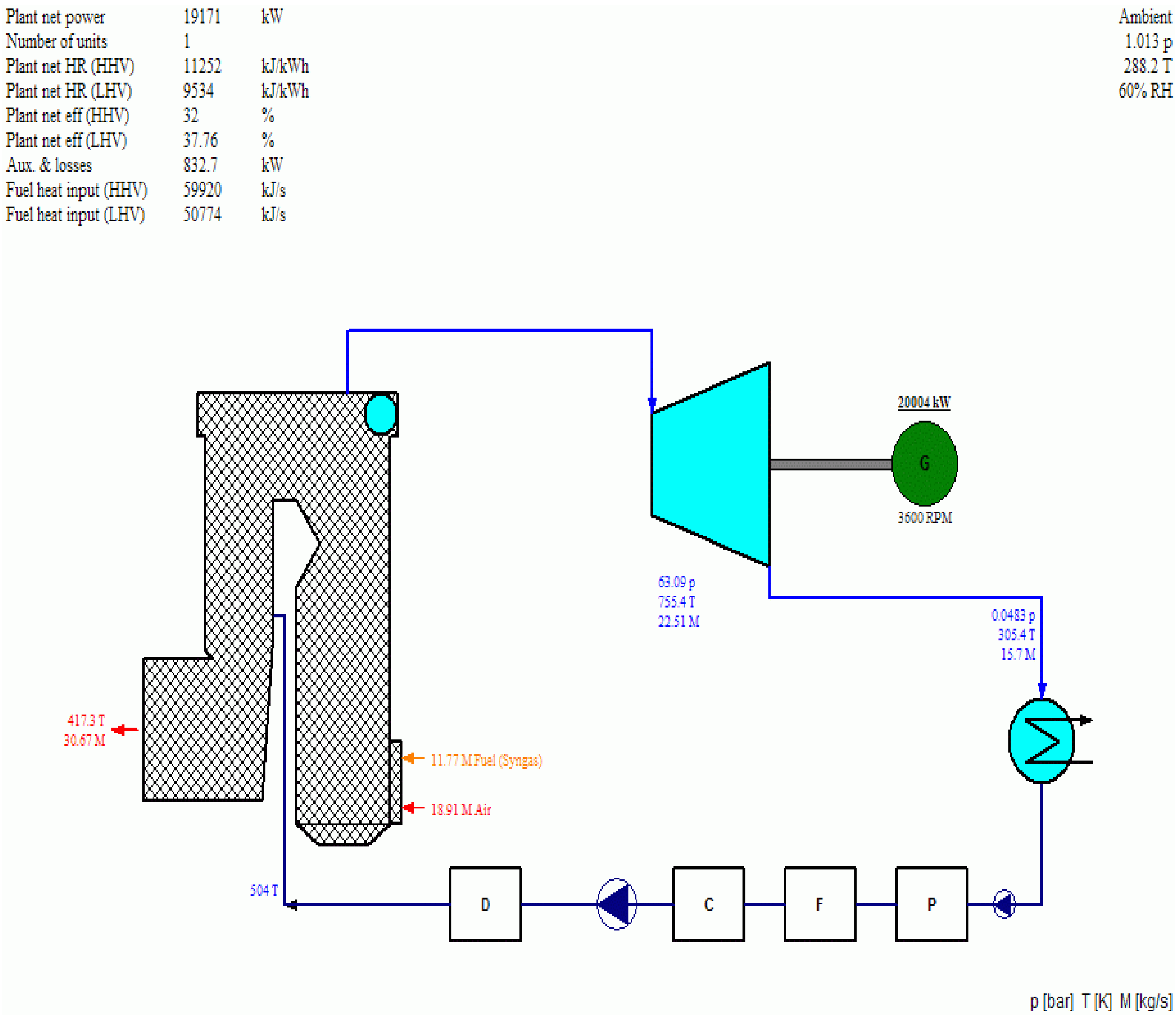

Figure 3.8: ThermoFlow ST Schematic Output for Steam Turbine Case 20-6

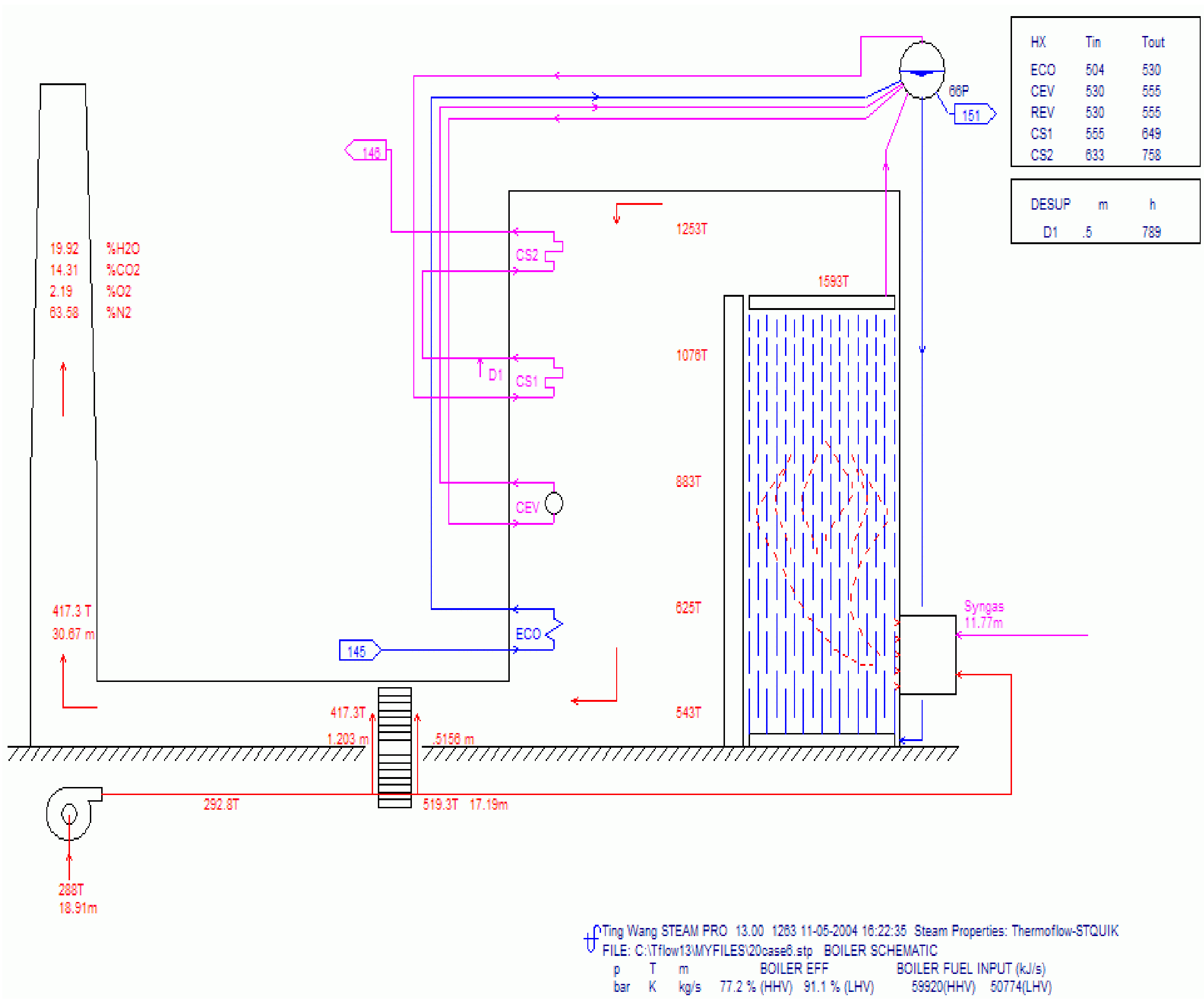

Figure 3.9: ThermoFlow Boiler Schematic Output for Steam Turbine Case 20-6

Under the similar output power, Table 3.14 shows using low caloric value fuel has a negligible effect on the steam turbine performance. When the steam cycle is compared with the GT cycle, Case 20-5 shows a significant, 4.82 percentage points (or 13%), increase from GT Case 20-1 (Table 3.13).

Case Number	20-5*	20-6
Ambient Temp, K (59 F)	288.15	288.15
Rel. hum.	0.6	0.6
Fuel LHV, MJ/kg	51.624	5.015
Fuel LHV, MJ/kg	57.282	5.919
Fuel, kg/s	1.12	11.77
Boiler Efficiency, %	93.15	91.13
Inlet Steam Pressure, bar	63.086	63.086
Inlet Steam Temperature, K	755.4	755.4
Inlet Steam Mass Flow Rate, kg/s	22.505	22.506
Inlet Quality	> 1.0	> 1.0
Exit Steam Pressure, bar	0.048	0.048
Exit Steam Temperature, K	305.4	305.4
Exit Steam Mass Flow Rate, kg/s	15.667	15.667
Exit Quality	0.870	0.870
ST Net Power, MWe	19.146	19.171
Heat Rate, kJ / kW-hr	10524.0	9534.0
ST Thermal Efficiency, %	37.20	37.20
Power Increase, %		0.131
Efficiency Increase, %		0.000
Heat Rate Increase, %		-9.407

Table 3.14: 20MWe Steam Turbine Performance Comparison between Burning Natural Gas and the Low Caloric Producer Gas 1.

3.2.3 20MWe Combined Cycle (CC) at Different Ambient Conditions

Case 20-9, 20-10, 20-13 and 20-16 --- Combined Cycle, ISO and Various Ambient Conditions using Natural Gas LHV = 51.624 MJ/kg, HHV = 57.282 MJ/kg and Low Caloric Value Producer Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

This group includes the reference case Case 20-9burning natural gas and five other cases fueled with the producer gas at various ambient conditions. Figures 3.10 and 3-11 show the Thermoflow graphic output for Case 2-16. There are two pressure ports (HP and IP) from the HRSG, which are tapped and expanded in the ST in two stages.

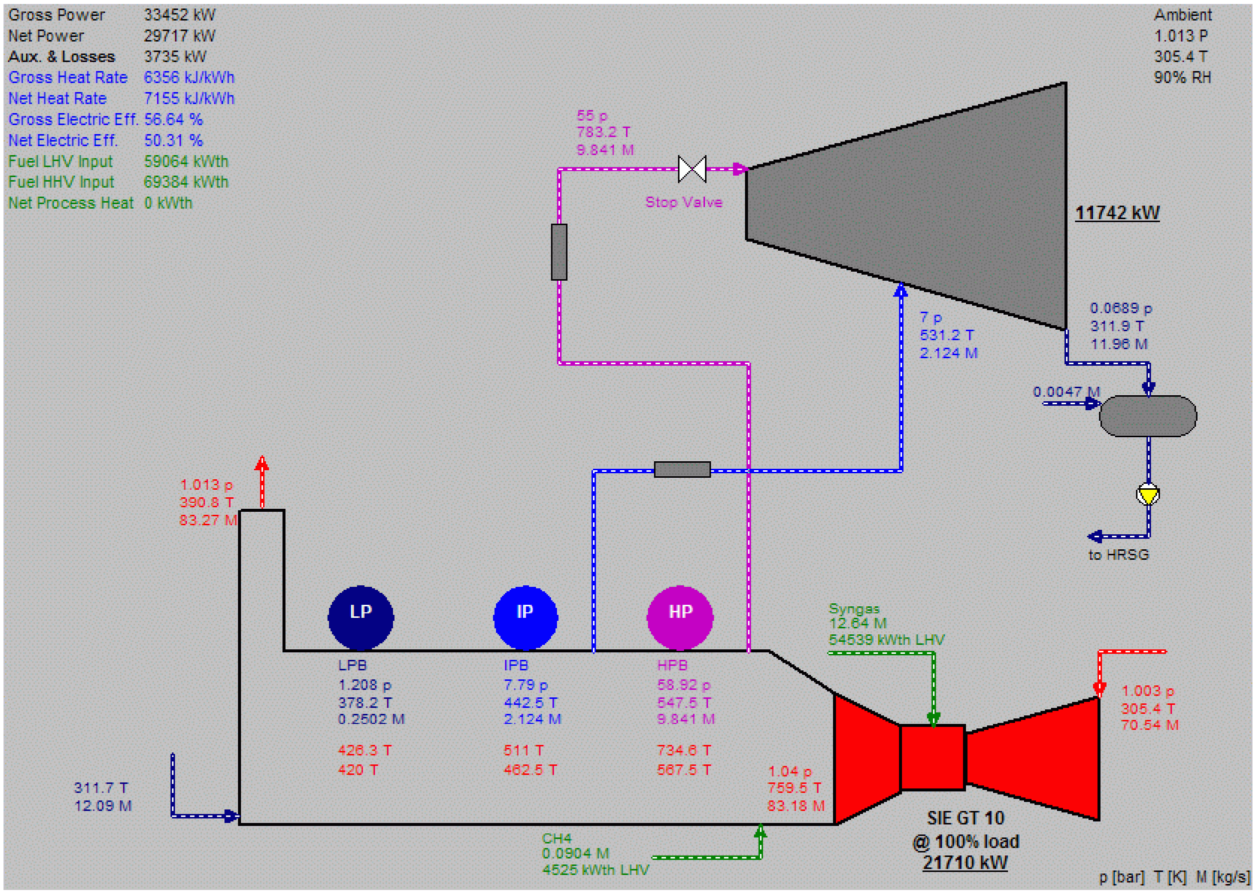

Figure 3.10: ThermoFlow Combined Cycle Graphical Output for Case 20-16

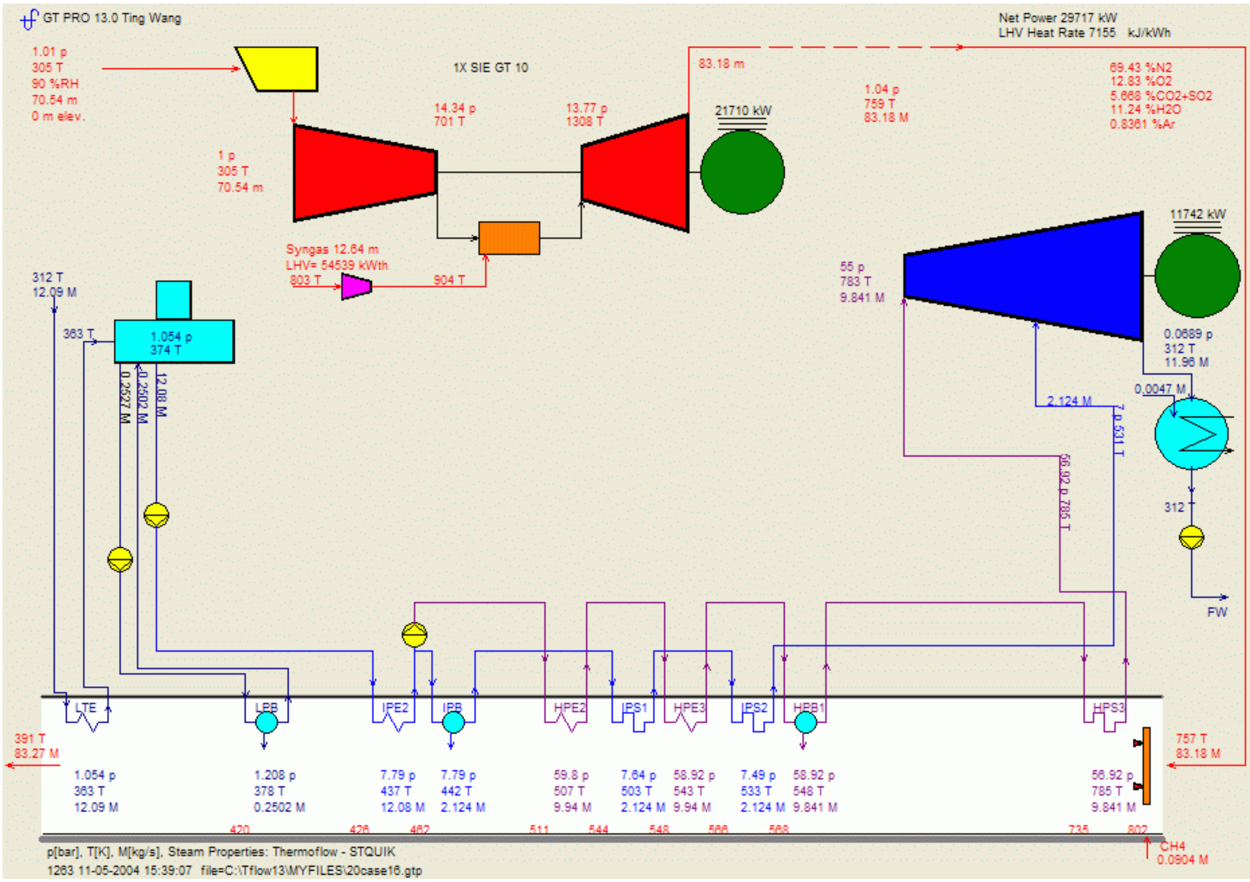

Figure 3.11: ThermoFlow Combined Cycle Schematic Output for Case 20-16

Table 3.15 displays the results of Case 20-9, 20-10, 20-13, and 20-16. Case 20-10 shows the typical GT reaction upon firing low caloric value producer gas. Where the TIT is reduced, the compression ratio increases and fuel mass flow rate increases approximately ten times. Case 20-10 has an increase of 0.6 % in GT power production, but the combined cycle suffers a 2.1% reduction in power production. This is different from the smaller 5MWe Case 10, which significantly increases in both power (12.89%) and efficiency (9.85%).

Combined Cycle	ISO		Different Ambient Conditions	
Case Number	20-9*	20-10	20-13	20-16
Ambient Temp, K (F)	288.15 (59)	288.15 (59)	298.15 (77)	305.35 (90)
Rel. hum.	0.6	0.6	0.3	0.9
Pressure Ratio	13.6	14.8	14.5	14.3
TIT, K	1392	1249	1280	1308
Air, kg/s	76.0	76.0	73.0	71.0
Fuel LHV, MJ/kg	51.624	5.015	5.015	5.015
Fuel HHV, MJ/kg	57.282	5.919	5.919	5.919
Fuel kg/s	1.265	12.323	12.359	12.638
Fuel Compressor Power, MWe	0.471	2.964	2.973	3.040
GT Power, MWe	20.936	21.066	21.285	21.710
ST Power, Mwe	10.576	12.355	11924.000	11.742
Net Total Power, MWe	30.387	29.748	29.539	29.717
LHV GT Heat Rate, kJ / kW-hr	10889	9088	9021	9044
Total LHV Heat Rate, kJ / kW-hr	7557	7540	7324	7155
GT Thermal Efficiency, %	32.05	34.08	34.34	34.25
Total LHV Thermal Efficiency, %	47.64	47.75	49.15	50.31
GT Power Increase, %		0.621	1.040	3.057
Total Power Increase, %		-2.103	-0.703	-0.104
GT Efficiency Increase, %		6.334	0.763	0.499
Total LHV Efficiency Increase, %		0.231	2.932	5.361
Total LHV Heat Rate Increase, %		-0.225	-2.865	-5.106

*Case 20-10 is compared with the Case 20-9. Both Cases 20-13 and 20-16 are compared with Case 20-10.

Table 3.15: Summary of Cases 20-9, 20-10, 20-13, and 20-16

Case 20-13 is simulated under a representative ambient condition with medium temperature (77F, 298K) and low relative humidity (30%); Case 20-16 considers an ambient condition with high temperature (90F, 305K) and high relative humidity (90%). In comparison with the ISO Case 20-10 burning low caloric fuel, Case 20-13 and 20-16 show an increase in GT power production ranging from 1 % to 3 %; however, the overall total combined cycle output power suffers approximately 0.1 % to 0.7 %. Comparing these Cases 20-13 and 20-16 with the smaller GT engine counterparts (Cases 13 and 16), the larger power plants have less GT and combine cycle power losses. In the 20MWe plants, both GT and combine cycle efficiencies increase at ambient temperatures higher than the ISO condition; but in the 5MWe plants, both efficiencies are reduced. In typical natural gas fired gas turbine systems or the combined cycle systems, higher ambient temperature renders reductions of both output power and plant

efficiency. The deviation of low caloric fuel fired systems from the behavior of the typical natural gas fired systems could not be clearly explained by the information provided by the simulation. One plausible explanation could be Cases 20-13 and 20-16 have higher TIT than 20-10. The TIT for the natural gas fired system could be fixed at the maximum allowable value; however, the low caloric value fuel fired system does not allow a fixed maximum TIT because the fuel mass flow rate is regulated by the compressor performance. Consequently, more fuel could not be added if the back pressure will trigger the compressor surge. With the fuel limited by the compressor performance curve, the TIT will be limited too.

3.2.4 20MWe Combined Cycle with Inlet Fog Cooling

Cases 20-17 and Case 20-20 --- Combined Cycle with Inlet Fog Cooling, Low Caloric Value Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

Inlet mist cooling is projected to cool down the high ambient temperature and thus raises the relative humidity to 100 %. Two cases are considered: Case 20-17 provides inlet fog cooling to Case 13's condition at 77^{o}F(298K) and 30% RH, and Case 20-20 provides inlet cooling to Case 20-16's condition at 90^{o}F(305K) and 90%RH.

In comparison with the ISO case 20-10, the results in Table 3.16 show that inlet fog cooling performs better in high ambient temperature and high RH condition (Case 20-20) than in the medium temperature and low RH condition (Case 20-17). In Case 20-17 inlet fog cooling has a negligible effect on power augmentation for both GT and the combined cycle systems. In Case 20-20, the GT power is augmented 2.85%, and the GT efficiency unexpectedly increases about 6.78%. The above comparisons are made with respect to the ISO condition (Case 20-10). Since

both Cases of 20-13 and 20-16 have higher total combined cycle efficiency than ISO Case 20-10, the true effect of inlet fog cooling is manifested in Table 3.17which summarizes the comparisons of 20-13 vs. 20-17 and 20-16 vs. 20-20. The results are not encouraging. The inlet fog cooling only provides 0.95% increase of output power for Case 20-13.

Combined Cycle	ISO	Mist Cooling	
Case Number	20-10*	20-17	20-20
Ambient Temp K (F)	288.15 (59)	298.15 (77)	305.35 (90)
Inlet Temp after Fog Cooling K(F)	N/A	287.55 (56)	303.15 (86)
Ambient RH	0.6	0.3	0.9
RH after Fog Inlet Cooling	N/A	1.00	1.00
Pressure Ratio	14.8	14.8	14.4
TIT, K	1249	1248	1301
Air, kg/s	76.0	76.0	71.0
Fuel LHV, MJ/kg	5.015	5.015	5.015
Fuel HHV, MJ/kg	5.919	5.919	5.919
Fuel kg/s	12.323	12.362	12.624
Fuel Compressor Power, MWe	2.964	2.973	3.036
GT Power, MWe	21.066	21.111	21.666
ST Power, Mwe	12.355	12.392	11.827
Net Total Power, MWe	29.748	29.820	29.759
LHV GT Heat Rate, kJ / kW-hr	9088	9097	9053
Total LHV Heat Rate, kJ / kW-hr	7540	7546	7119
GT Thermal Efficiency, %	32.05	34.05	34.220
Total LHV Thermal Efficiency, %	47.75	47.71	50.01
GT Power Increase, %		0.214	2.848
Total Power Increase, %		0.242	0.037
GT Efficiency Increase, %		6.240	6.771
Total LHV Efficiency Increase, %		-0.084	4.733

* Case 20-10 is the reference ISO case with which other cases are compared.

Table 3.16: 20 MWe Combined Cycle with Inlet Fog Cooling for Cases 20-17 and 20-20

Combining the results in the 5MWe systems (Table 3.10) with the results of 20MWe cases (Table 3.17), it can be concluded that inlet fog cooling only provides negligible power augmentation for the larger system and negative power augmentation for smaller systems if low caloric value fuels are used.

Combined Cycle	Mist Cooling WRT Ambient Cases	
Case Number	20-13 --> 20-17	20-16 --> 20-20
Temperature & humidity	298.15K, 30%--> 287.55K, 100%	305.35.15K, 90%--> 303.15K, 100%
GT Power Increase, %	-0.817	-0.203
Total Power Increase, %	0.951	0.141
GT Efficiency Increase, %	-0.844	-0.088
Total Efficiency Increase, %	-2.930	-0.596
Total Heat Rate Increase, %	3.031	-0.503

Table 3.17: Summary of Inlet Fog Cooling Effect on 20MWe Combined Cycle Under Two Ambient Conditions.

3.2.5 20MWe Combined Cycle with Steam Injection (STIG)

Cases 20-23 and Case 20-24 --- Combined Cycle with Combustor Steam Injection using Low Caloric Value Gas LHV = 5.015 MJ/kg, HHV = 5.919 MJ/kg

The stem injection is also investigated for the larger 20MWe power plant system. Two cases are simulated: Case 20-23 uses the maximum steam available through the HRSG in Case 20-13 with comparable pressure to (or a bit higher than) the combustor pressure, and Case 20-24 matches the amount of water used for fogging in Case 20-17. The steam injection results are summarized in Table 3.18 and 3.19.

In comparison with the ISO Case 20-10, Table 3.18 shows the overall performance of Case 20-23 and 20-24 results in losses of both efficiency and output power in the GT system and total combined cycle system. When compared with Cases 20-13 and 20-17, respectively, in Table 3-19, both Cases 20-23 and 20-24 show significant losses in both total power and plant efficiency. The performance of Case 20-23 is the worst of hese two cases. This indicates that maximize steam injection is not a good practice for a combined cycle that is usually designed with optimized load shares between the duties of GT and ST.

Comparison between inlet fog cooling and steam injection using the same amount of water mass flow (Cases 20- 24 Vs. 20-13) indicates steam injection is doing worse than inlet fog cooling in augmenting power. The results from combining the 5MWe systems (Table 3.13) and 20MWe systems (Table 3.19) indicate that steam performs better when expanded in the steam turbine rather than being injected into the gas turbine combustor for a combined cycle system. This is especially valid for a system burning low caloric fuels because the compressor is already burdened with increased fuel mass flow rate and higher back pressure.

Combined Cycle	**ISO**	**Steam Injection**	
Case Number	20-10	20-23	20-24
Ambient Temp, K (F)	288.15 (59)	298.15 (77)	298.15 (77)
Rel. hum.	0.6	0.3	0.3
Pressure Ratio	14.8	15.8	14.6
TIT, K	1249	1163	1275
Air, kg/s	76.0	81.0	74.0
Fuel LHV, MJ/kg	5.015	5.015	5.015
Fuel HHV, MJ/kg	5.919	5.919	5.919
Fuel kg/s	12.323	11.274	12.318
Fuel Compressor Power, MWe	2.964	2.711	2.962
GT Power, MWe	21.066	18.36	20.975
ST Power, Mwe	12.355	7.202	9.442
Net Total Power, MWe	29.748	22.395	27.020
LHV GT Heat Rate, kJ / kW-hr	9088	9540	9124
Total LHV Heat Rate, kJ / kW-hr	7540	9719	7622
GT Thermal Efficiency, %	32.05	32.470	33.950
Total LHV Thermal Efficiency, %	47.75	37.04	47.23
GT Power Increase, %		-12.845	-0.432
Total Power Increase, %		-24.718	-9.170
GT Efficiency Increase, %		1.310	5.928
Total LHV Efficiency Increase, %		-22.429	-1.089
Total LHV Heat Rate Increase, %		28.899	1.088

Table 3:18: Summary of Steam Injection Cases 20-23 and 20-24

Combined Cycle	Steam Injection WRT ISO Cases	
Case Number	20-23 vs. 20-13	20-24 vs.20-17
Ambient Temp, K (77 F)	298.15	298.15
Rel. hum.	0.3	0.3
GT Power Increase, %	-13.742	-1.456
Total Power Increase, %	-24.185	-8.528
GT Efficiency Increase, %	-5.446	-1.136
Total Efficiency Increase, %	-24.639	-3.906
Total Heat Rate Increase, %	32.701	4.069

Table 3.19: Comparisons of Steam Injection Cases 20-23 and 20-24 with Case 20-17.

CHAPTER 4

CONCLUSIONS

This study conducts performance analyses of small and medium power plants fueled with low caloric value gases derived from biomass gasification process. The analyses are performed using the proven commercial code ThermoFlow (release 13).

Three biomass derived producer gases with low heating values (LHV) of 5.02MJ/kg, 8.23MJ/kg, and 11.16 MJ/kg respectively, are used. To achieve the rated power, the low caloric value fuels must be supplied at a flow rate approximately 4.6 to 10 times more than a natural gas fired gas turbine. These increased mass flow rates result in higher back pressures and increased loads on the compressor blades. To accommodate the back pressure problem, the first stage nozzle openings are widened to achieve the design compression ratio of the gas turbine engine. Analysis is conducted to compare the gas turbine system performance with higher pressure ratios to those cases with the designed pressure ratio. When compared with the natural gas fueled system, the results show that typically the producer gas fueled system result in higher net output power and increased plant efficiency for 5 MWe plants; but the results of the 20 MWe plants are not consistent (some cases have increased power and efficiency while other cases have reduced output power). The best performance occurs when the designed pressure ratio with widened nozzle openings are achieved, even though the TIT are relatively low (Cases 2c, 2d, and 20-2c). The increased power and efficiency are attributed to increased total gas mass flow rate. Without widening the nozzle openings, the pressure ratio will be higher than the designed value, and the increase of output power and the efficiency (Cases 2a and 20-a) are less than the cases with

widened nozzles, irrespective of the increased TIT value without widened nozzle openings (Case 2b). The increased output power and efficiency in 20MWe cases are not as high as in the 5MWe cases because the parasite power, required to compress the fuel to higher pressure level, increases as the plant size increases.

When the heating value increases from 5 MJ/kg to 8.23 MJ/kg and 11.16 MJ/kg, the GT net output power and efficiency are all higher than the natural gas fueled system in a subsequently reduced amount -- increased GT power (25% ~6%) and increased efficiency (8.8% ~ 2%). The similar trend repeats in the combined cycle cases with less percentage increase -- CC power increases (12.8% ~ 2%) and efficiency increases (9.8% ~ 3%).

The ambient temperature and relative humidity plays a significant role in the performance of a gas turbine system. The result of 5MWe inlet fog cooling increases GT output power from 4.75 % to 0.59% (Cases 17, 18, 19, and 20) with negligible GT efficiency changes. Inlet cooling provides lower power augmentation for the combined cycle, raging from 3.7% ~ 0.39%, and adversely affects the CC efficiency ranging from –-0.1% ~ -1%. For larger 20MWe cases, inlet fog cooling adversely affects the simple GT output power, but the total combined cycle system outputs increase with a negligible amount (0.14% ~ 0.95%). Both the GT and the combined cycle efficiencies reduce with inlet fog cooling. The unexpected negative effect on the GT power output for 20MWe systems could be explained by the heavy loaded compressor condition, attributed to using the low caloric fuel. An additional burden from the fog cooling with the increased mass flow rate results in an undesirable compressor performance and reduced TIT, both factors contribute to reduced GT power and total plant efficiency.

Combining the 5MWe system results with the 20MWe system results, it can be concluded that the inlet fog cooling provides negligible power augmentation for the larger

system and negative power augmentation for smaller systems if low caloric value fuels are used. Efficiencies for GT and CC systems are all negatively affected by the inlet fog cooling.

Comparison between inlet fog cooling and steam injection using the same amount of water mass flow indicates that steam injection is doing worse than inlet fog cooling in augmenting power output when low caloric fuels are used. By combining the results from the 5MWe system and 20MWe system, the following conclusion can be reached: the steam performs better when the steam is to be expanded in the steam turbine than being injected into the gas turbine combustor for a combined cycle system. This is especially valid for the system burned with low caloric fuels because the compressor is already burdened with increased fuel mass flow rate. Maximizing steam injection, at the expense of supplying the steam to the steam turbine, significantly reduces both the efficiency and the output power of the combined cycle. Therefore, maximizing steam injection is not a good practice for a combined cycle because the combined cycle is usually designed with optimized load shares between the duties of GT and ST.

This study indicates that the performance of GT and CC systems fueled by the low caloric value fuels could be very different from the familiar behavior of natural gas fired systems. Care must be taken if on-shelf GTs are used to burn low caloric value fuels.

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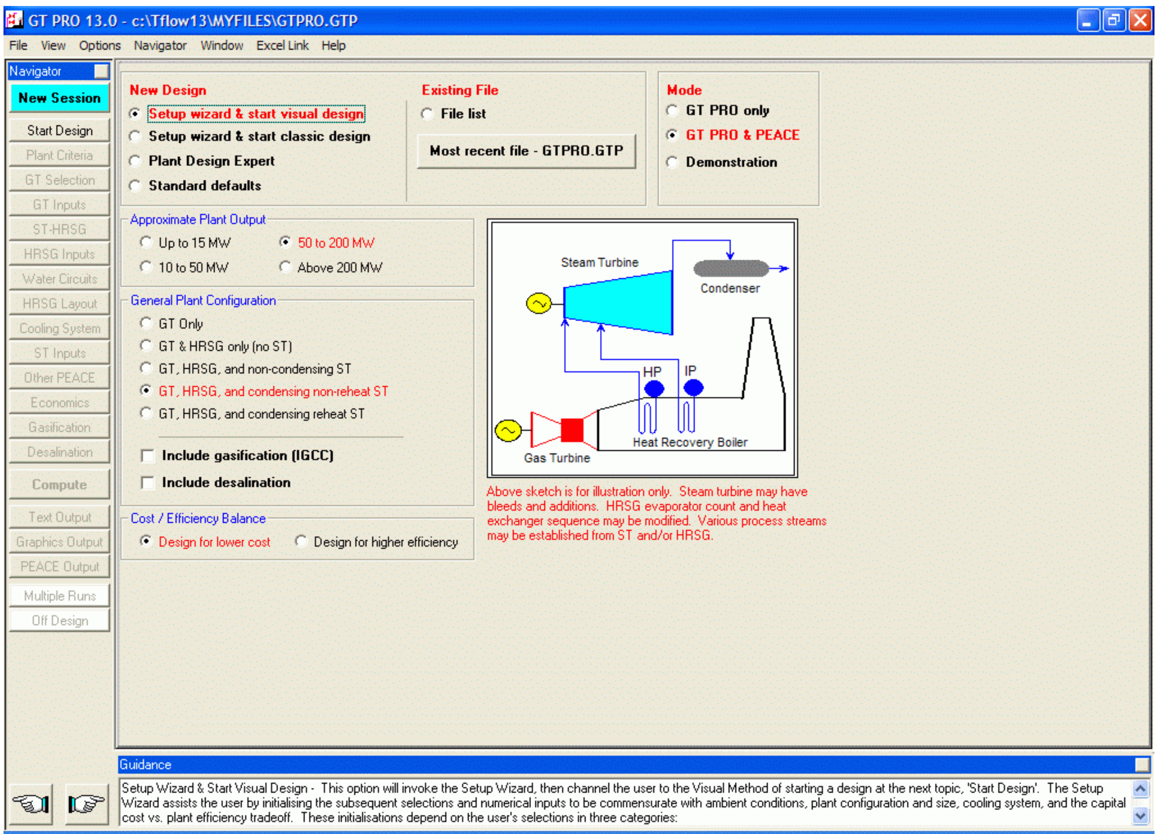
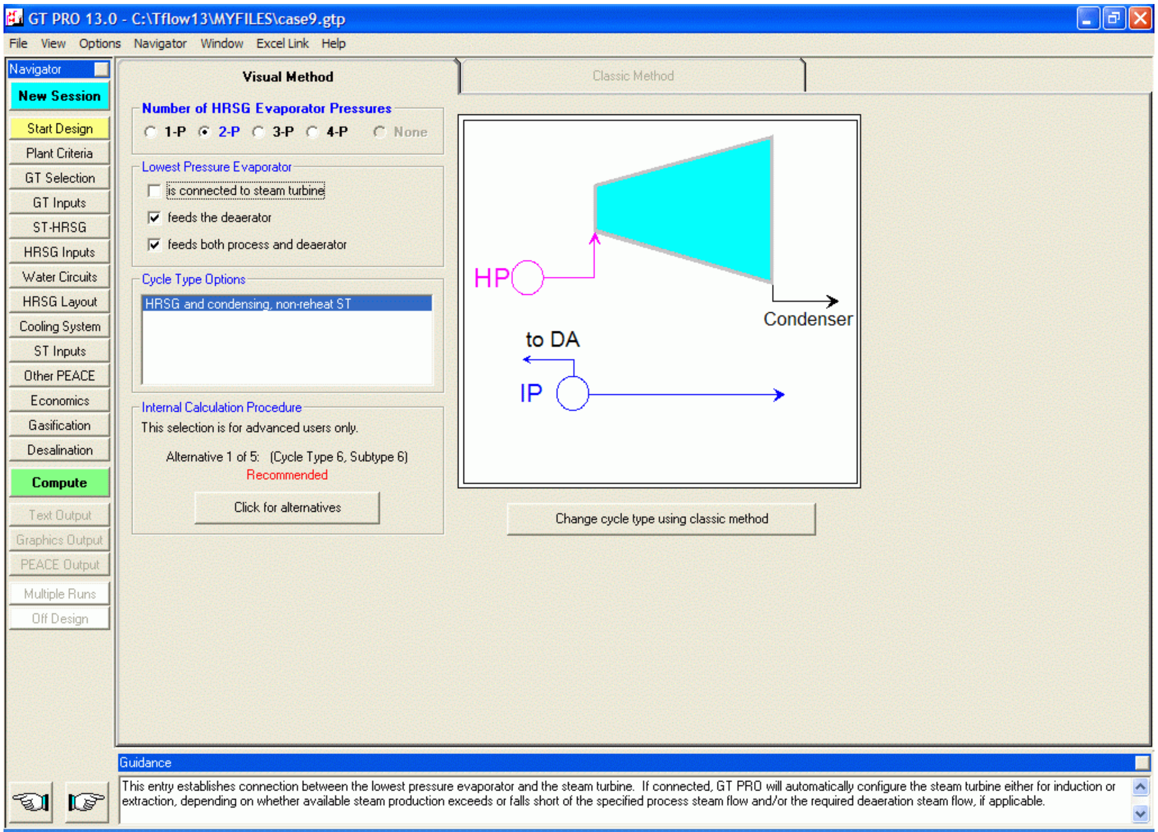
APPENDIX A

THERMOFLOW GAS TURBINE SIMULATION EXAMPLES

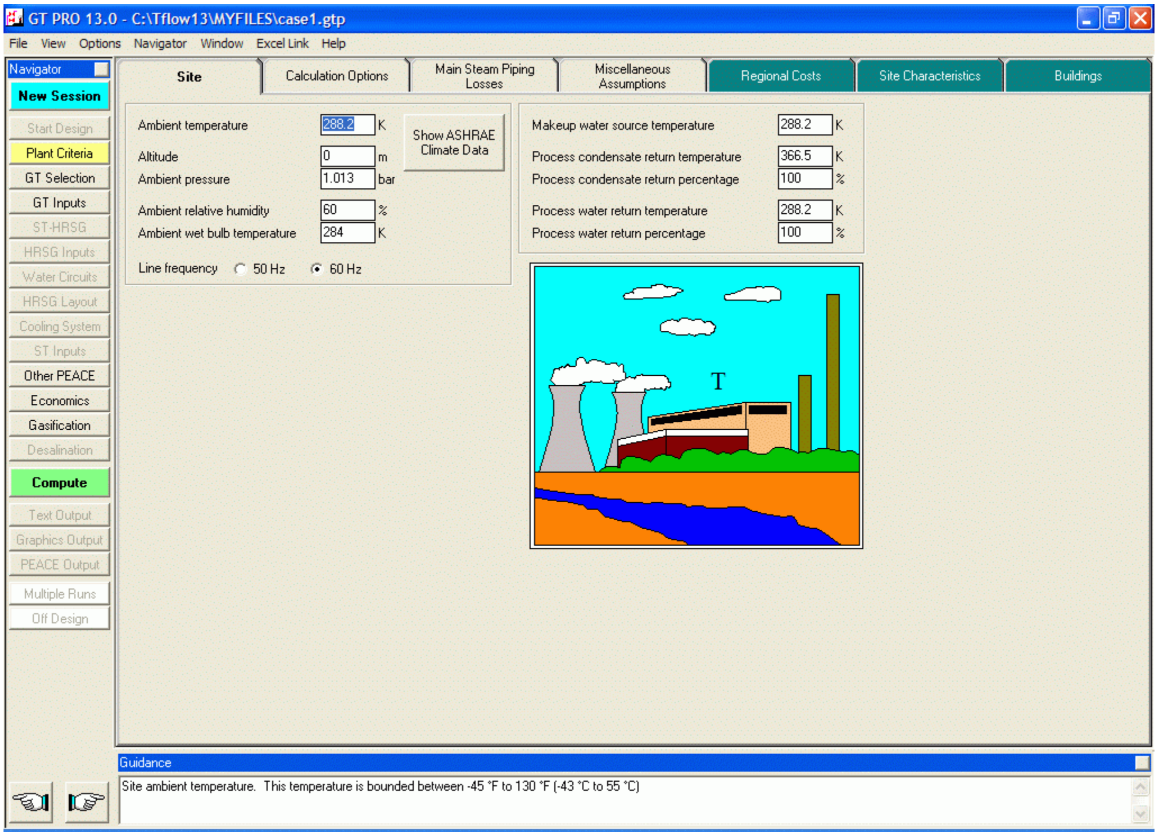
The example of several cases is shown below. Boot the PC into the Windows environment. Click the “Start” button, select the “Programs”, and expand the “ThermoFlow” group and select “GT Pro XX Site ID #YYYY”. The “X” and “Y” represents the version number and site license number respectively. The first screen seen in the software GUI, which looks like the following:



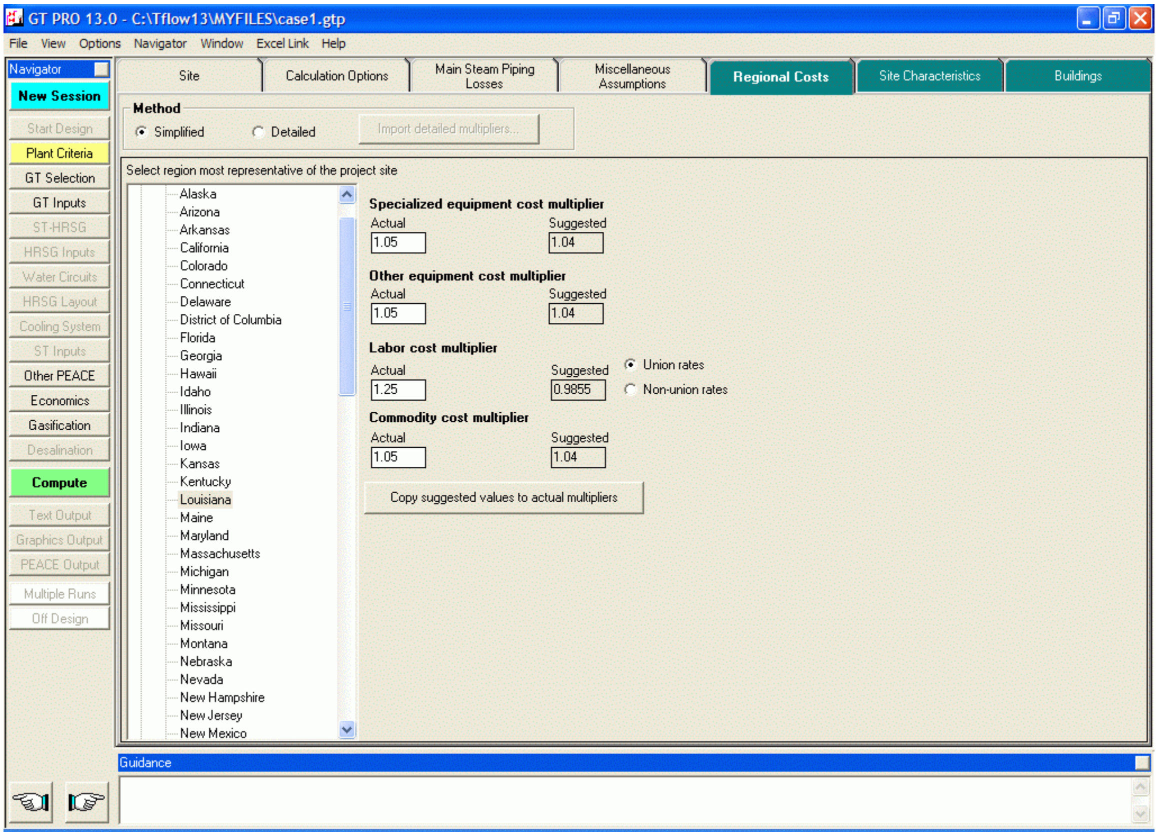
The user selects the desired mode under the New Design area, specify the estimated power generation and whether the plant will be a simple cycle (GT only) and its variations, or a combined cycle with differing types of steam turbines. Version 13 has the gasifier and the desalination option. To go to the next process of Start Design, the user can either press that button or the icon which looks like a right hand located at the left hand bottom side of the screen.



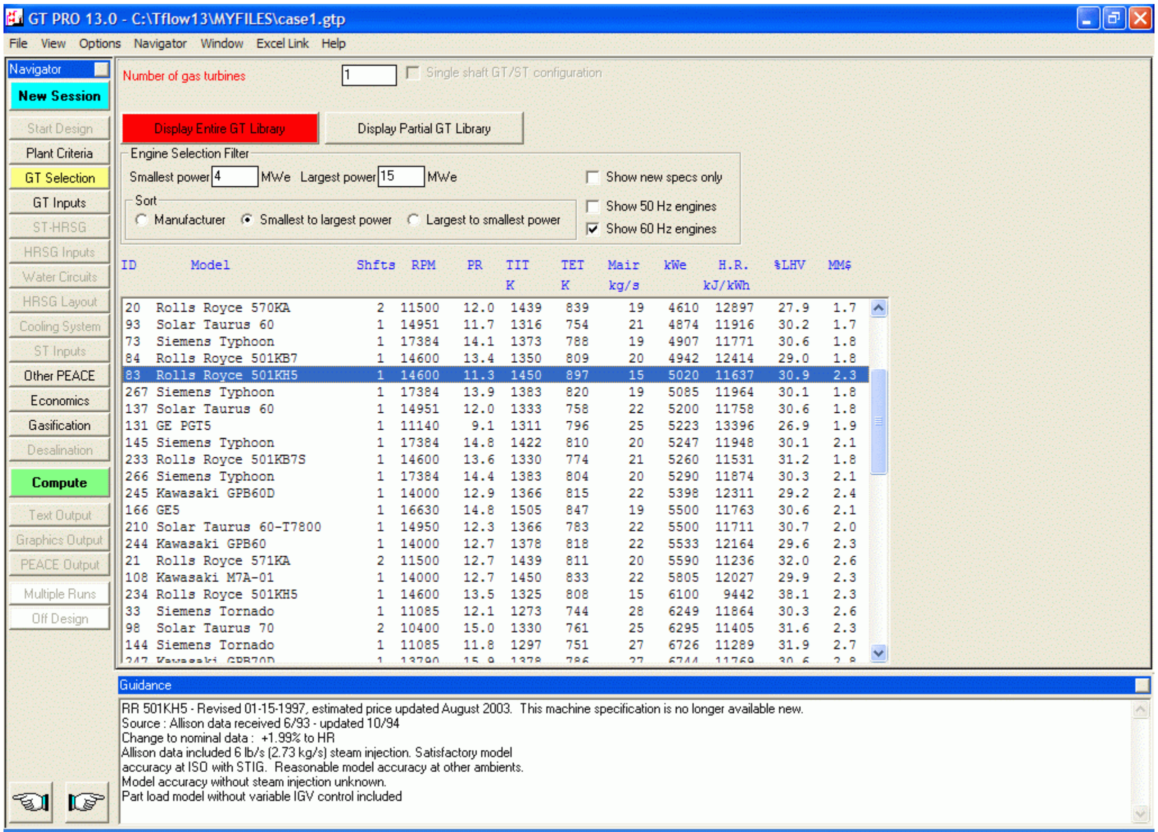
As soon as the initial design is decided, the GUI goes to the Heat Recovery Steam Generator (HRSG), as shown below. A choice of number of HRSG Evaporator Pressure points are presented and three methods of selecting the exit pressure points for different purposes (primarily ST, deaerator or process) are presented.



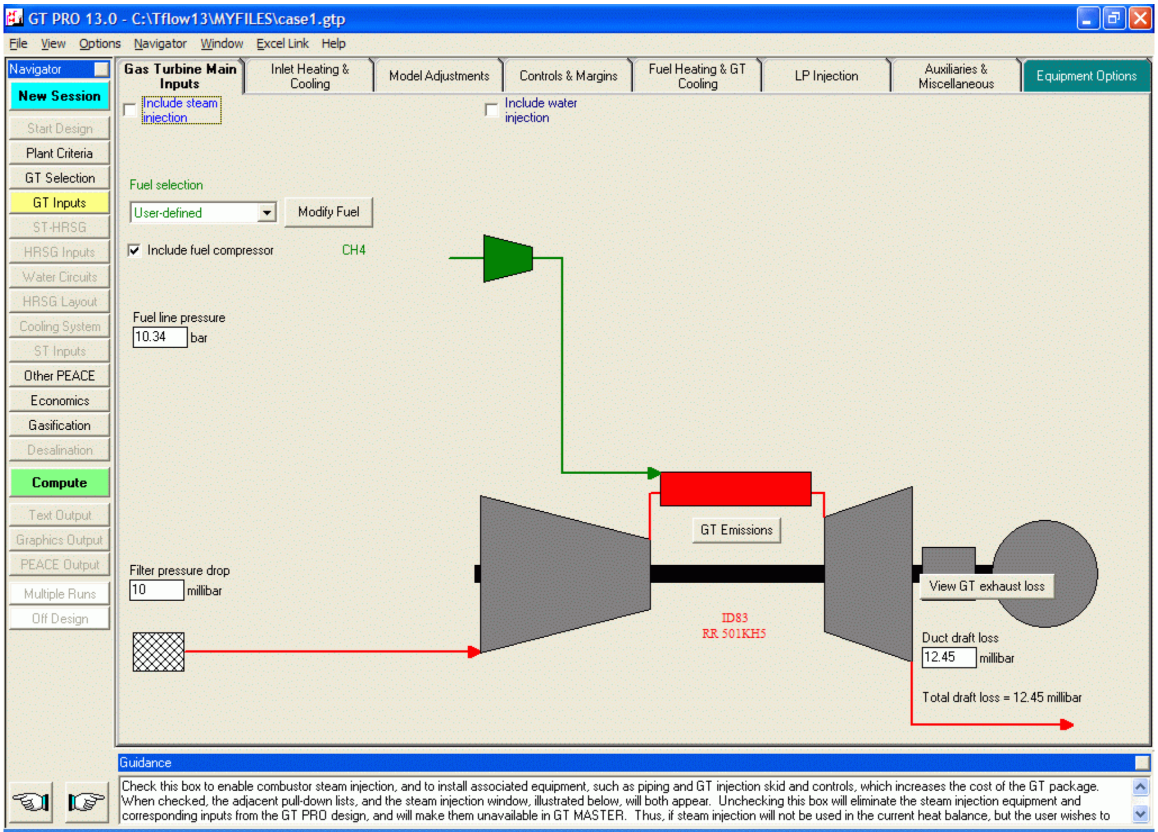
Upon completing the Start Design, the next step is to specify Plant Criteria. Ambient conditions can be specified with the default as the ISO condition of 59 °F and 60% relative humidity. Plant elevation can also be specified, and the ambient wet bulb temperature is automatically calculated with the given ambient temperature and relative humidity. There is an accompanying ASHRAE button, which enables access to all regional weather, temperature and humidity.



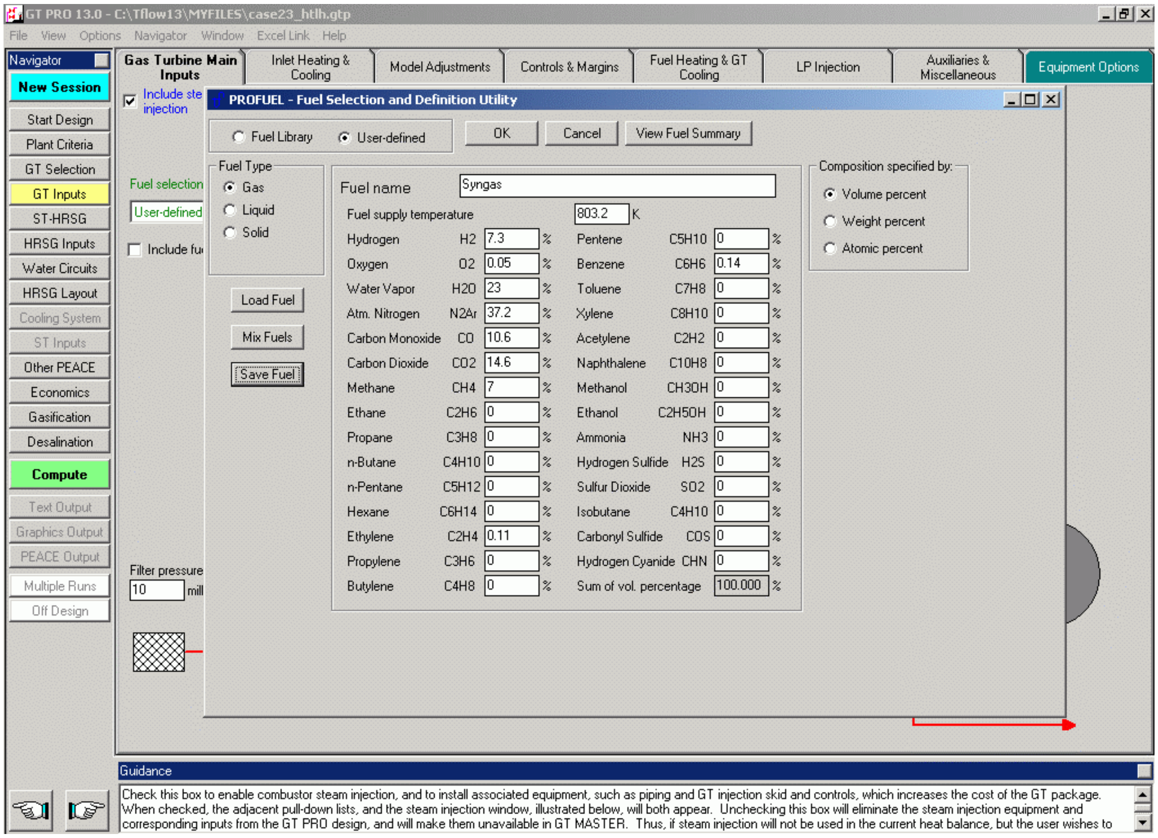
The green tabs are related to the PEACE option, in which the default regional costs were set to Delaware. By default, currently estimated labor costs and other multiplier costs are loaded in the module, which can be adjusted accordingly at the time of plant design to closely reflect the current and possible future actual cost.



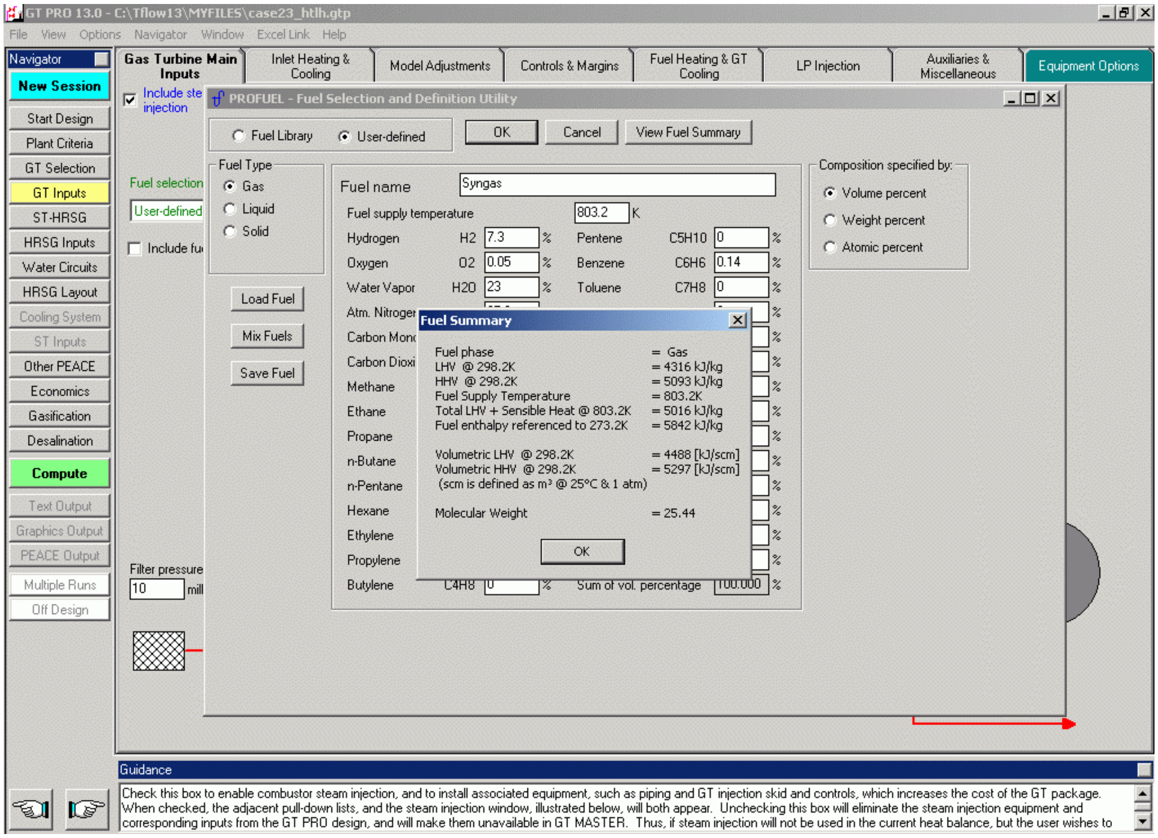
The next step is the GT selection. ThermoFlow continuously updates their software with known and updated GT hardware performance and specs to make sure that the design will reflect accurately the power and performance of the preliminary design till the implementation and actual operation of the power plant. The GT selection enables sorting the list by manufacturer, ascending or descending engine power and a specification of a power range of engine desired. The list of GT available has detailed ISO operation information such as TIT, pressure ratio, cost, heat rate, and upon highlighting an engine, the bottom white box has additional information like year of specs, previous company manufacturer, tests, errors, and various operating range information from the manufacturer's data. IN this panel, Rolls Royce 501 KH5 is slelcted.



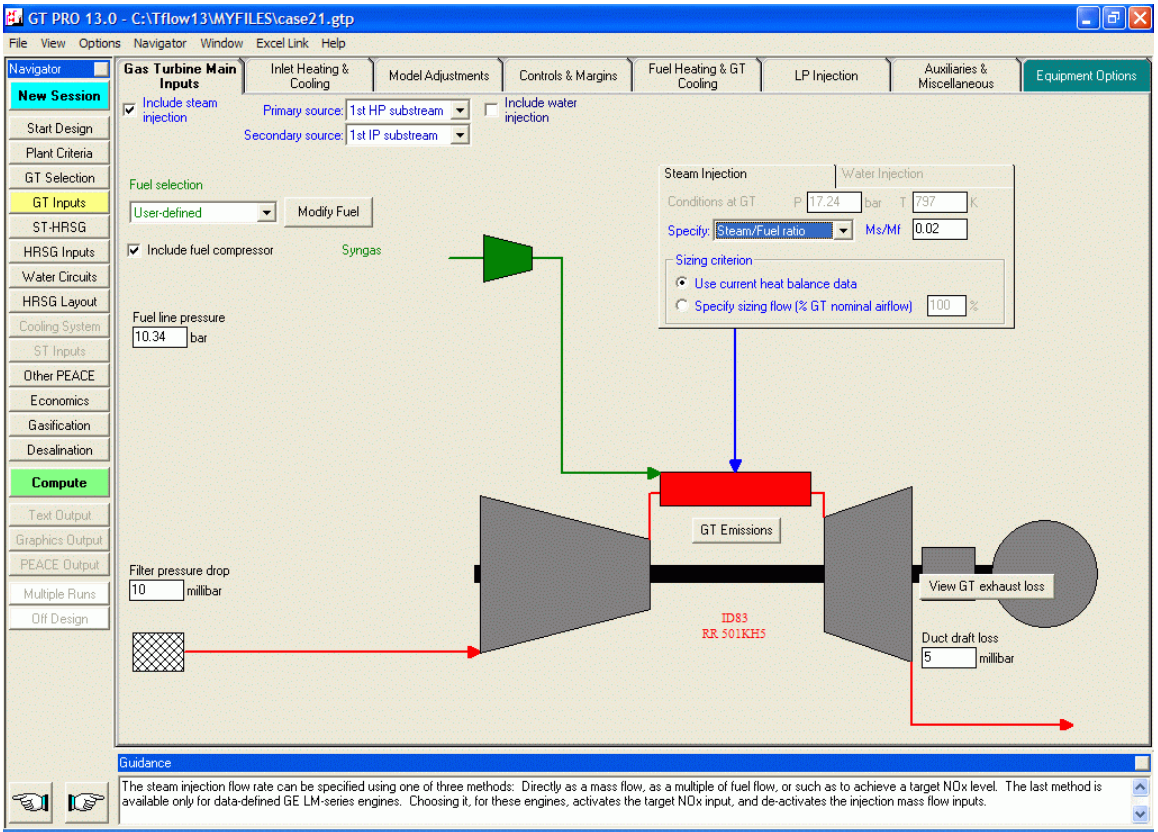
Upon successful selection of a GT, the GT inputs gives the designer an array of options to define the fuel (else the default is natural gas at 77 °F), enable or disable a fuel pump and its associated fuel line pressure, air filter and duct draft pressure drop, view GT exhaust losses and GT emissions, and to select power augmentation / NOx reduction options of water and steam injection into the combustion chamber.



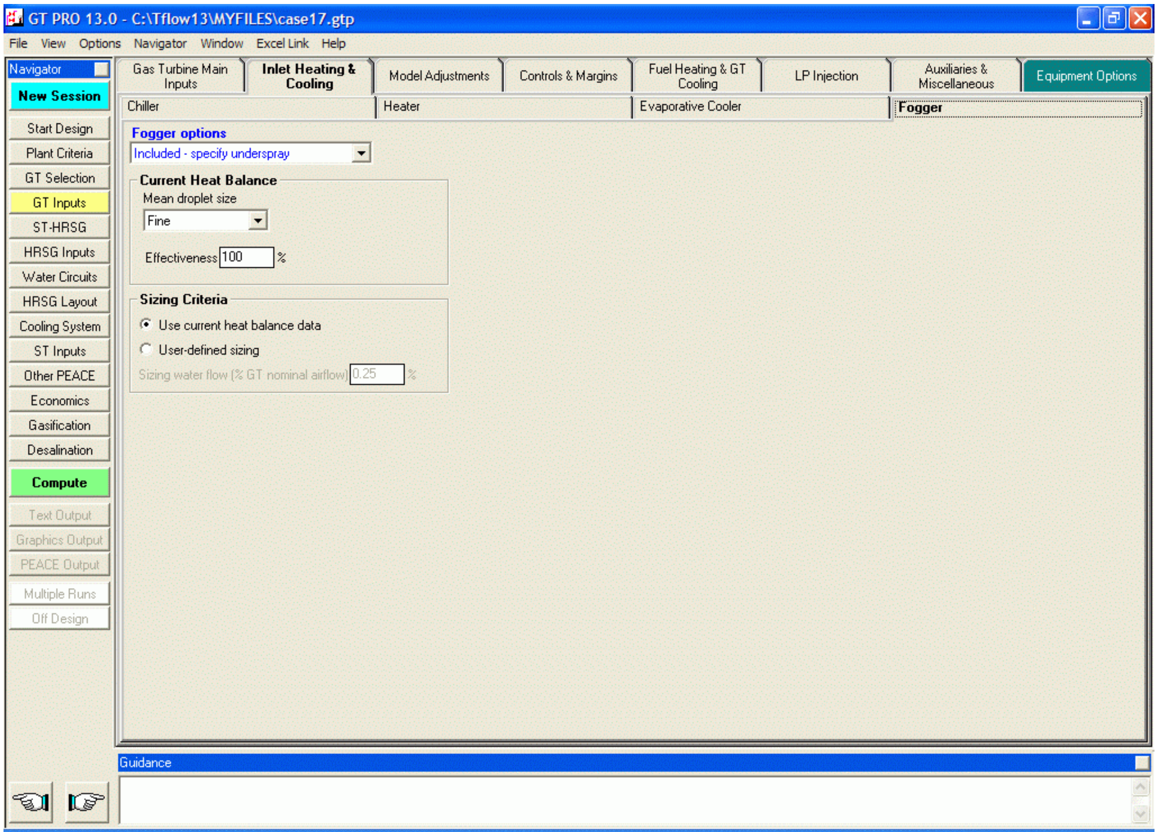
A new screen appears on top of the current design software for the customization of fuel source composition. This is especially useful for defining either by weight, volume or atomic percent for a specific fuel type intended to be used. The composition of producer gas 1 is provided in this panel.



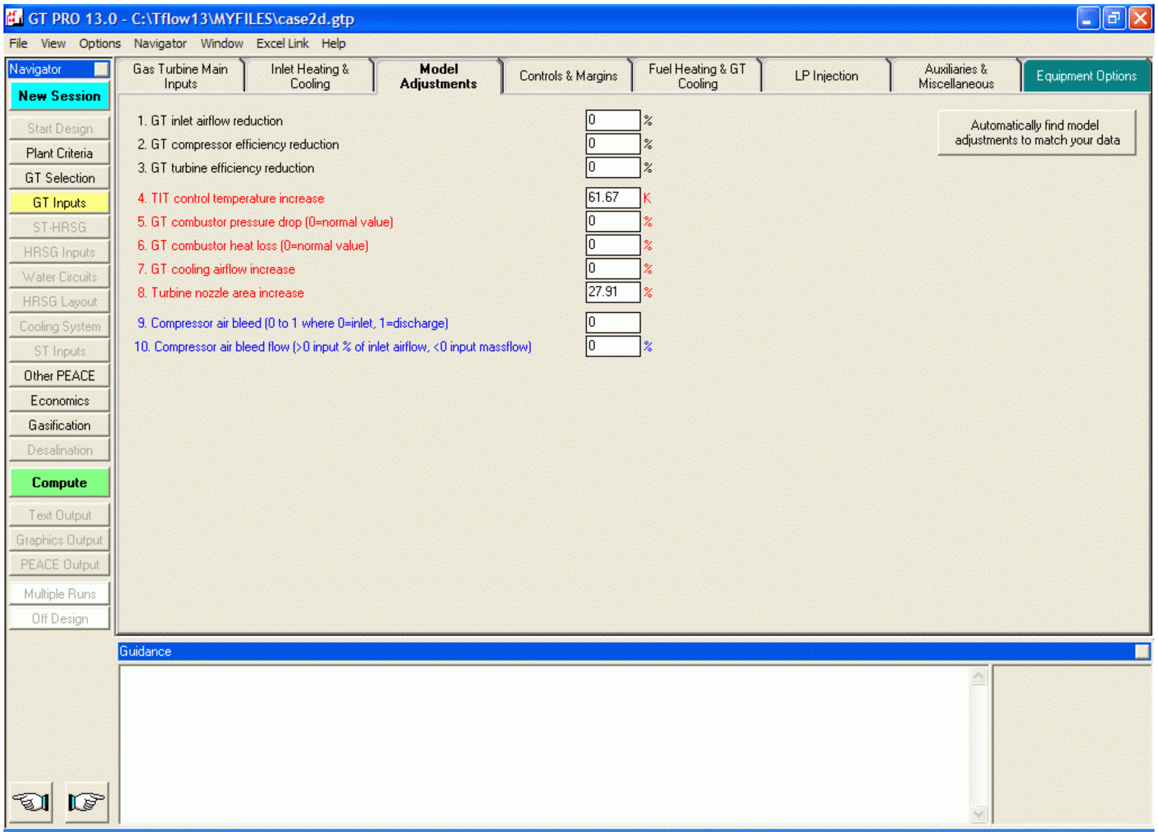
Upon accepting the values for the customized fuel, a brief summary of the calculated heating value of the user defined fuel will be shown and will then disappear upon clicking the OK button and return back to the GT Inputs page.



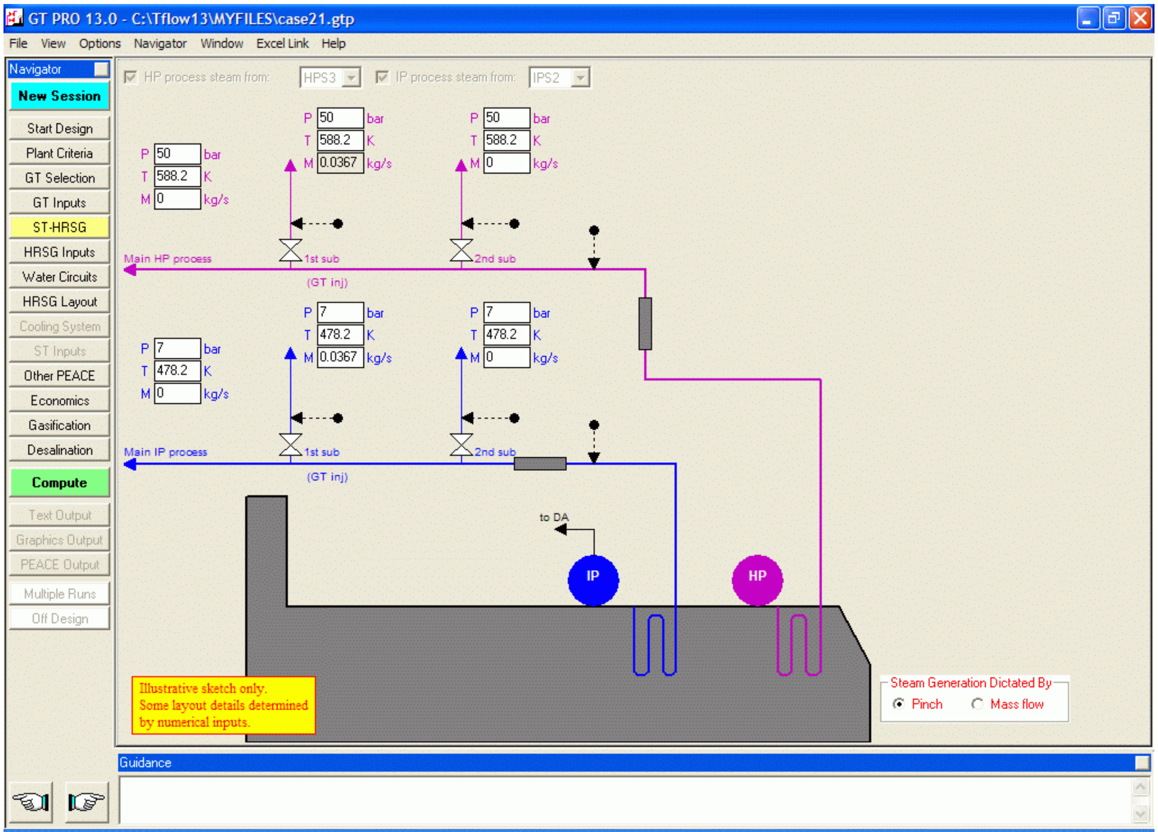
As soon as the steam injection box is checked, a steam injection GUI box appears. If an HRSG is selected during the Start Design phase, the steam injection source may originate from the high pressure (HP) and / or intermediate pressure (IP) source and its associated sub stream. The steam in the GUI is then specified as a mass flow rate or as a ratio of steam to fuel mass flow rate. In this panel, the steam / fuel ratio of 0.02 is specified for Case 21.



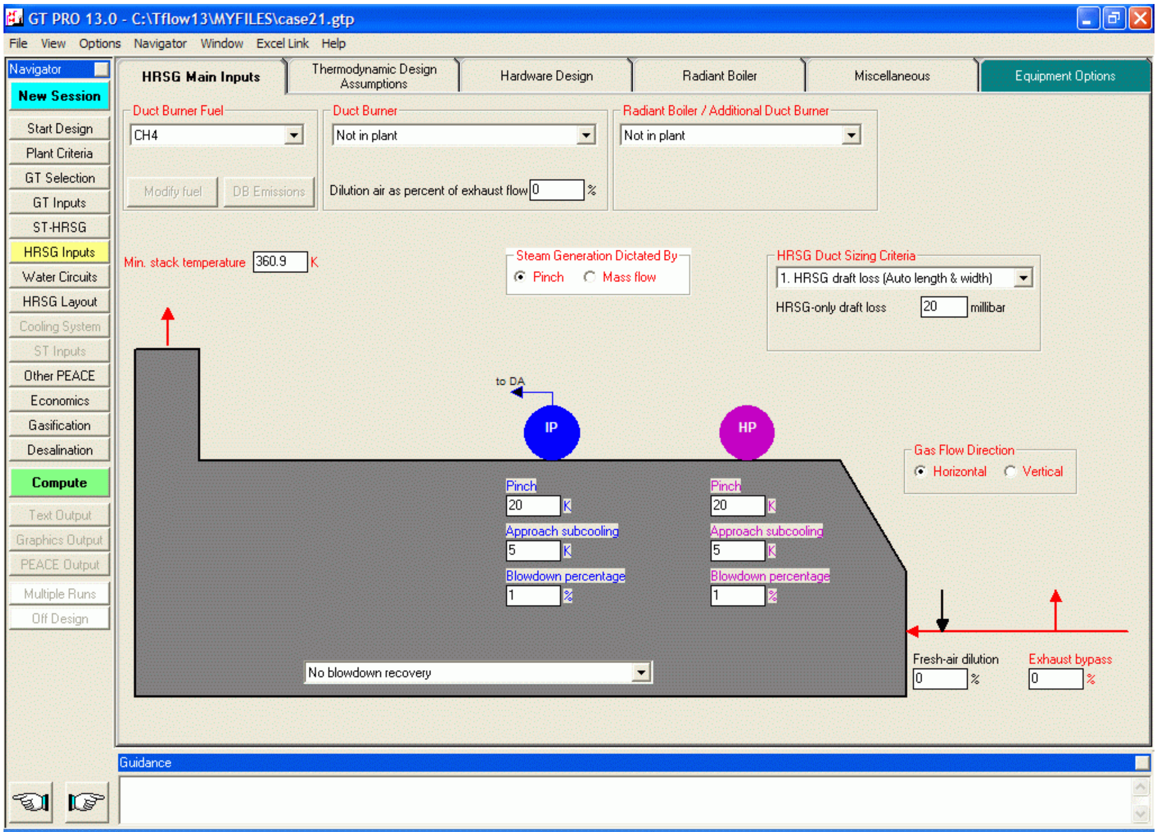
The inlet heating and cooling, and model adjustments are available for further customization for power augmentation (mist / fog inlet cooling) and conditioning of compressor inlet air. The optional units available are the Chiller, Heater, Evaporative Cooler and Fogger. The fogger enables a choice of particle sizing, effectiveness and either under spray or overspray of the ambient air before it enters the compressor. A 100 % saturation status is selected for fog cooling in Case 17.



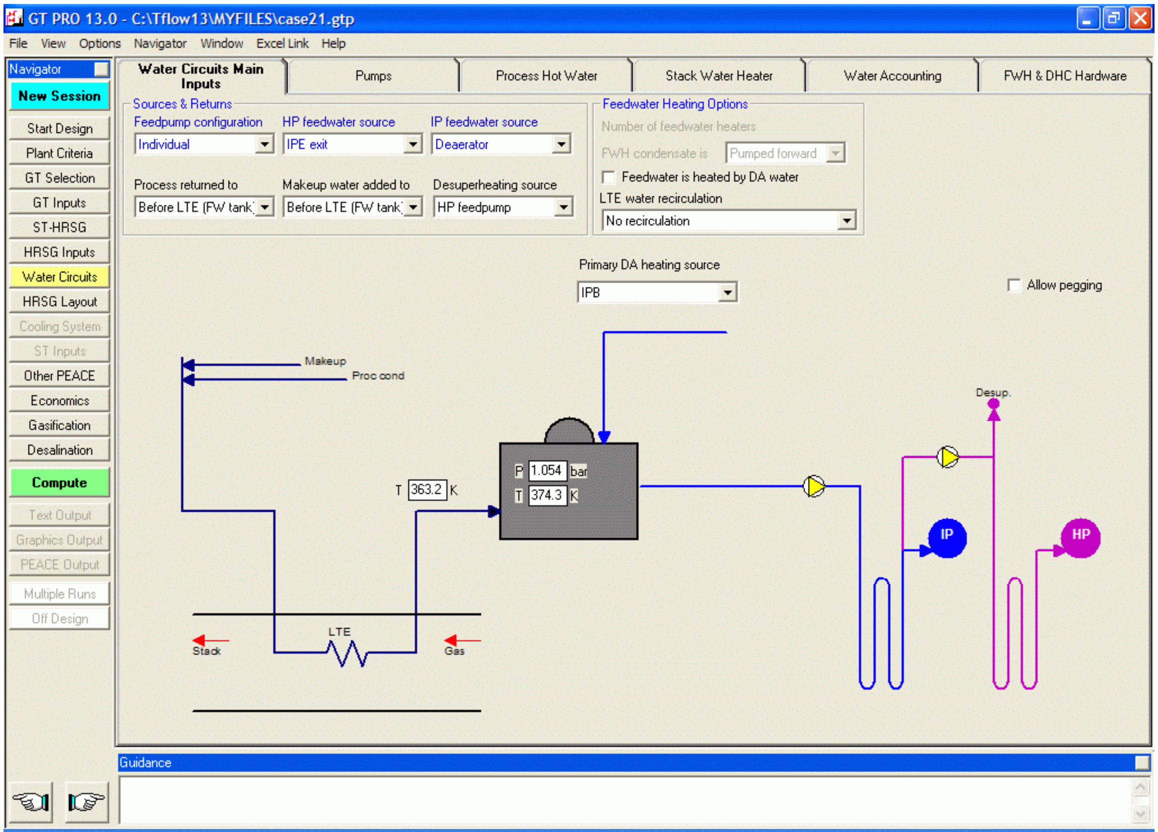
In order to simulate a currently running power plant, the Model Adjustment tab allows the simulation to accurately reflect operation of system, and helps designers plan and predict overall system functionality due to an addition of a component or change and replacement of an old part within the operating power plant. The Model Adjustment is also useful for simulating and studying the effects upon the overall system performance due to TIT and Nominal Turbine Nozzle Area Increase. These two variables are especially useful to model the GT when the low caloric value fuels are used. In this panel, the turbine nozzle area is increased 27.91 % and TIT is increased 61.67 K for Case 2d.



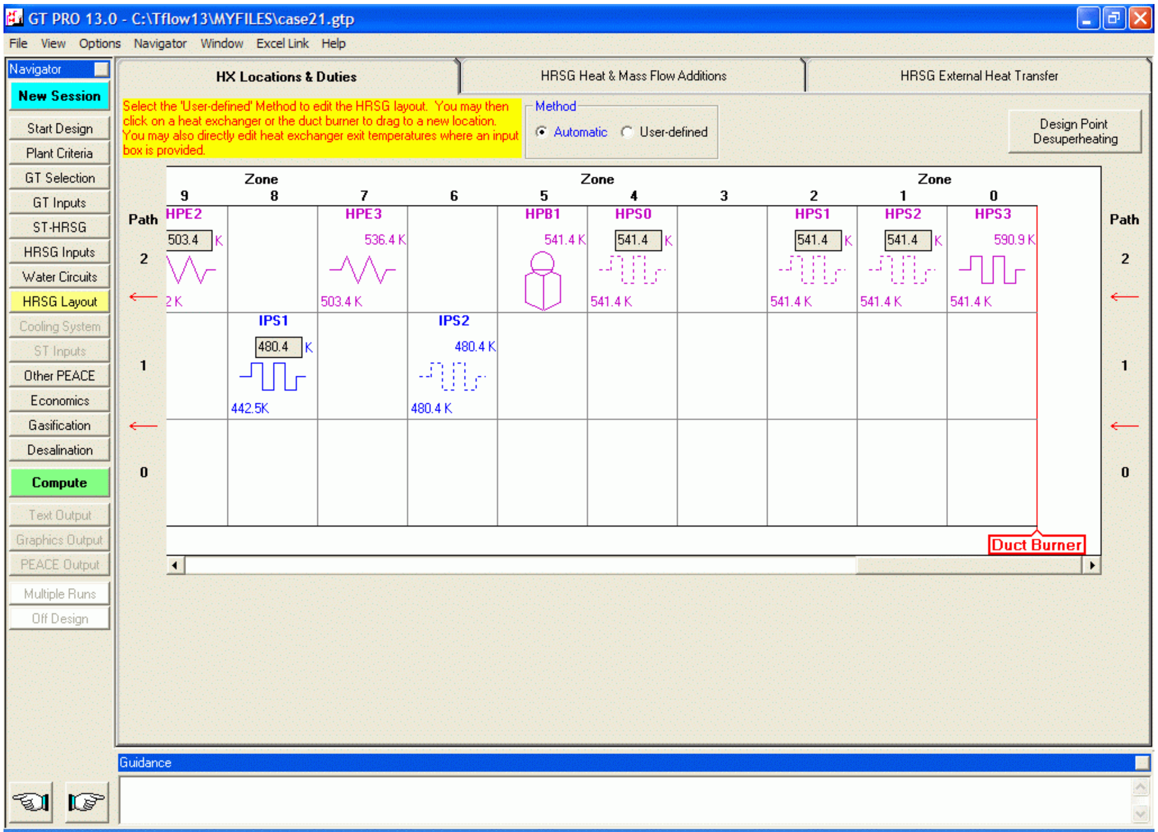
The ST-HRSG step shows the major outlets originating from the HRSG, which can be dictated either by Pinch or Mass Flow rate. Each evaporator pressure points have 3 outlets consisting of the Main Process, first and second sub stream. The Pressure, temperature and mass flow rate can be adjusted as needed, with the final lowest pressure typically being fed into the deaerator.



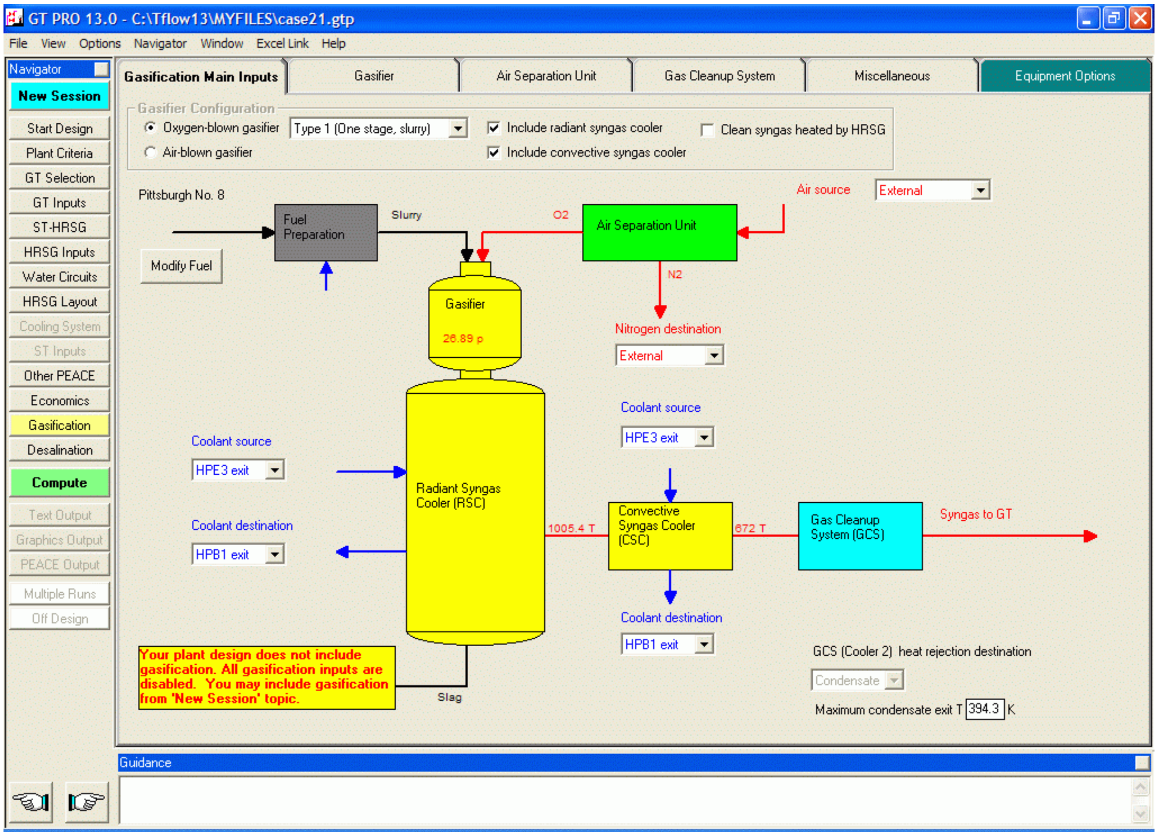
The HRSG inputs provide a further customization via pinch point of evaporator pressure vessel, steam generation dictation (pinch or mass flow), turbine exhaust flow direction which becomes the entrance direction of the HRSG and possible duct firing for reheat purposes. The fuel for the duct burner can be defined by the user also.



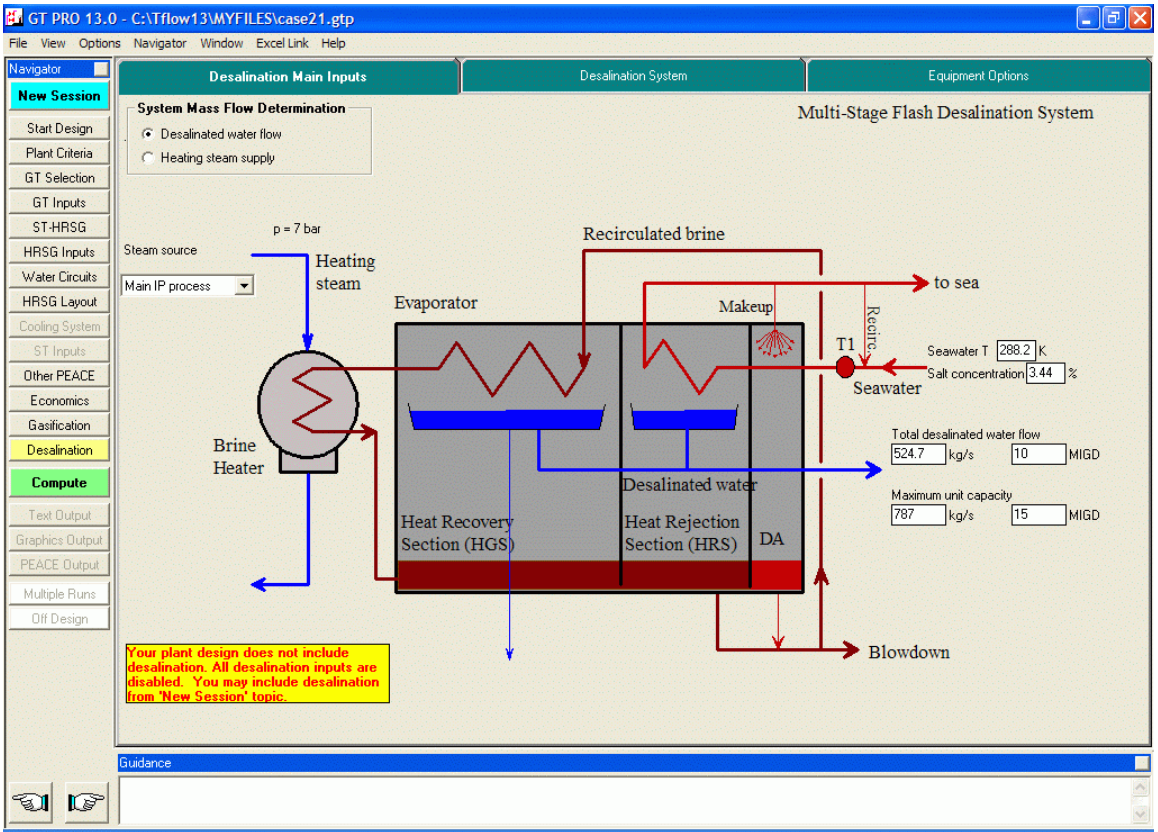
Beyond the HRSG, the water circuits, pumps, process hot water, stack water heater, feed water heater and DHC hardware, and water accounting are automatically loaded with default variables.



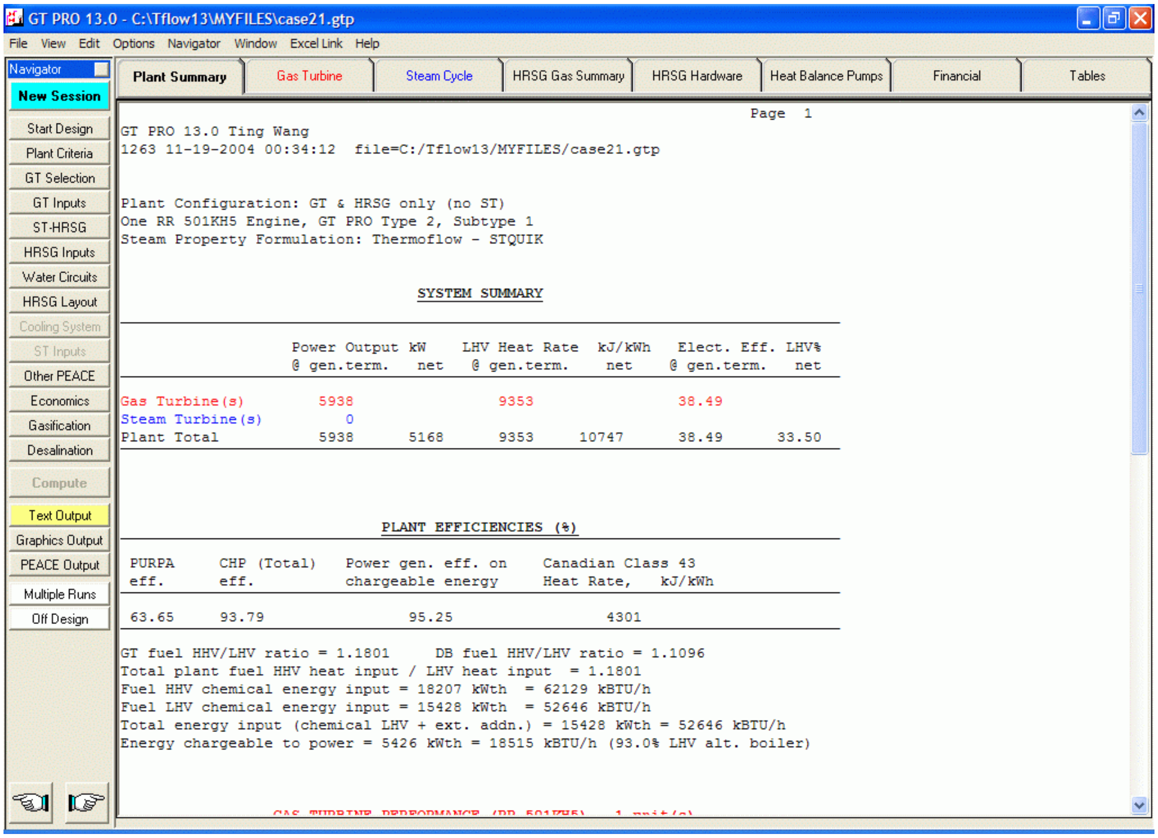
The final portion of design layout would be if there were no consideration for a gasification stage. The HRSG Layout has an automatic or user defined method, which can be used for placement of heat exchangers (HX) location and duties. The flow is from right to left starting at the duct burner, which also stands for the HRSG entry point. Two more tabs allow specification of additional HRSG heat and mass flow to be added, and the HRSG external heat transfers.



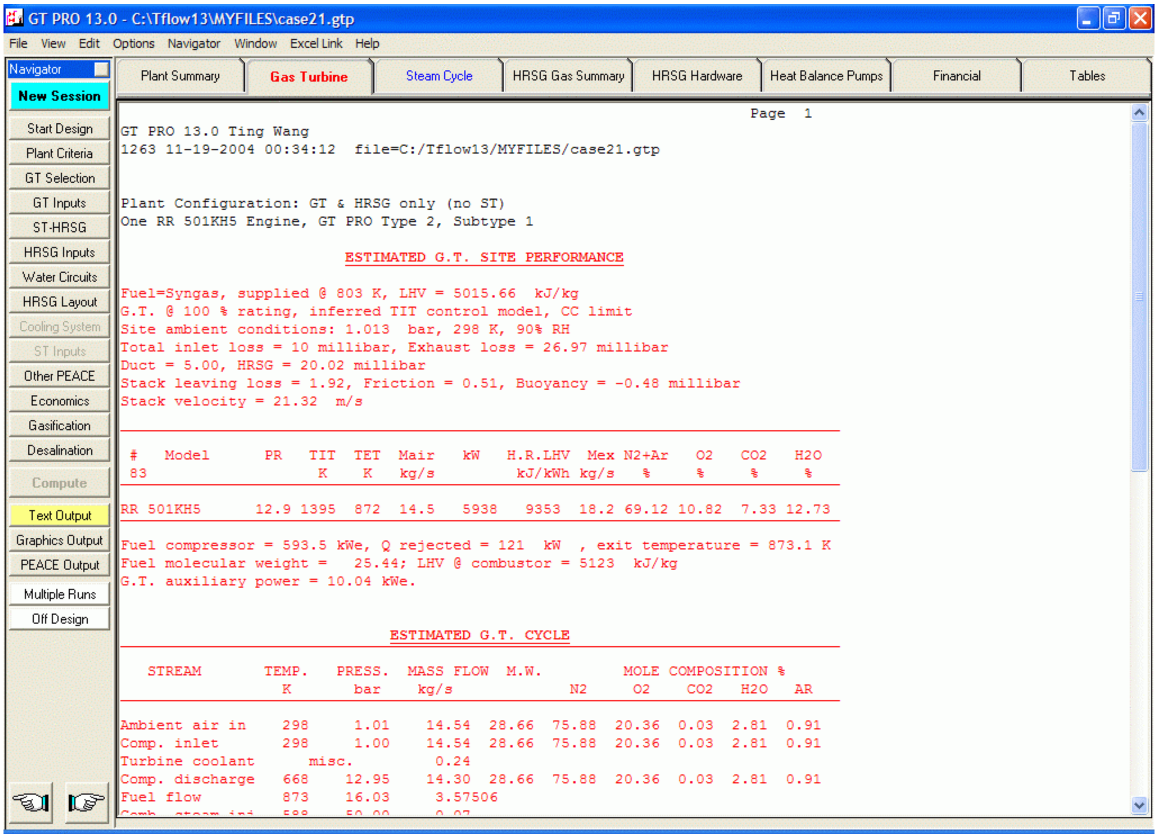
Just above the Gasification step, there are additional options for other Economics and PEACE consideration with regards to planning the related cost of building a power plant. The gasification option must be selected during the initial step in New Session. By default the gasifier is a pressurized and oxygen-blown gasifier, however an air-blown option may be selected. Modify Fuel is used to customize the raw fuel feed which may be derived from coke, coal, biomass, biomass wastes, etc. Under the gasifier tab, heat transfer parameters, fuel feed moisture, estimated power plant production and gasifier control are customizable. The Air Separation unit tab will be used provided that the gasifier is an oxygen-blown gasifier. The raw fuel gas exiting the gasifier is called the producer gas, contains tars, volatiles and alkali, which needs to be further cleaned to produce synthetic gas (syngas) via Gas Clean Up System, with a choice for hot or cold type gas clean up method.



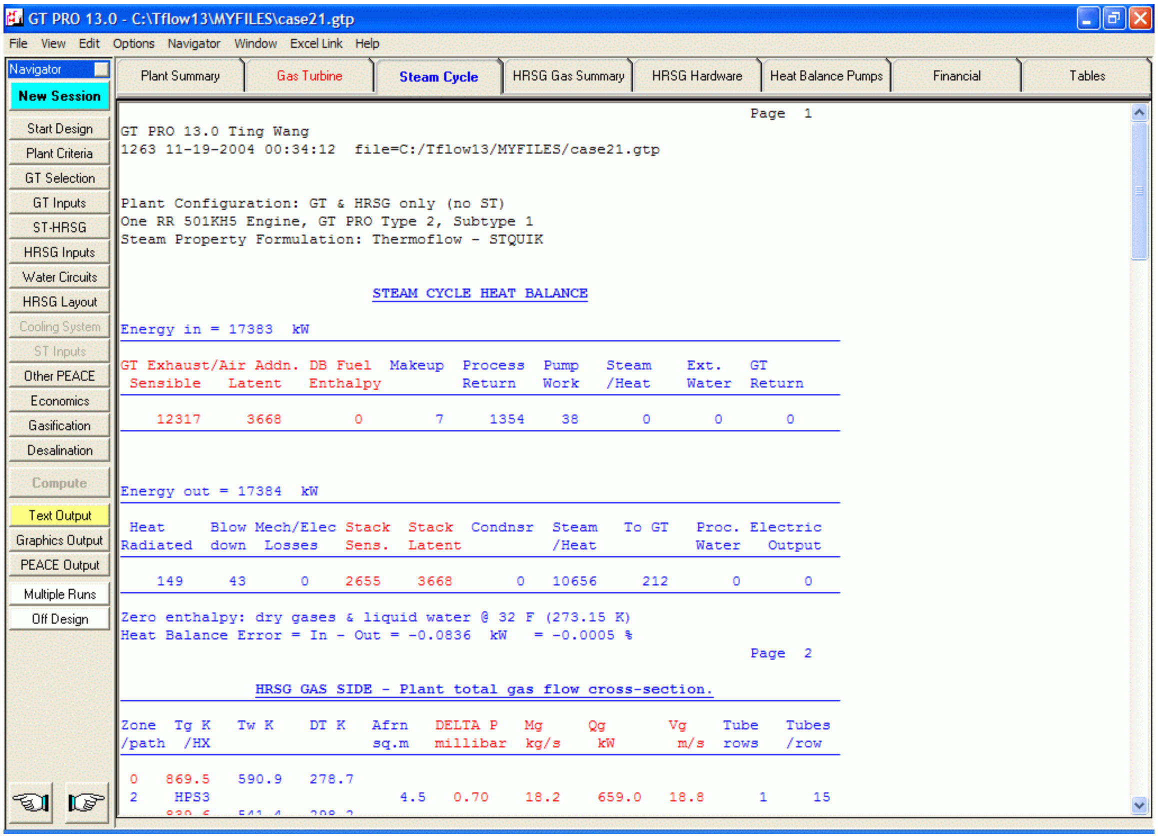
For power plants located near the sea, a desalination unit is employed to remove the impurities founding seawater. This is a new feature found in the ThermoFlow program version 13. Under the first tab, Desalination Main Inputs, the heating steam source and total desalinated water flow inputs are selected and specified. This is the Desalination System tab where more information is given for customization of the desalination unit, like the Top brine temperature, blow down and T1 temperature. This featured is not studied in this project.



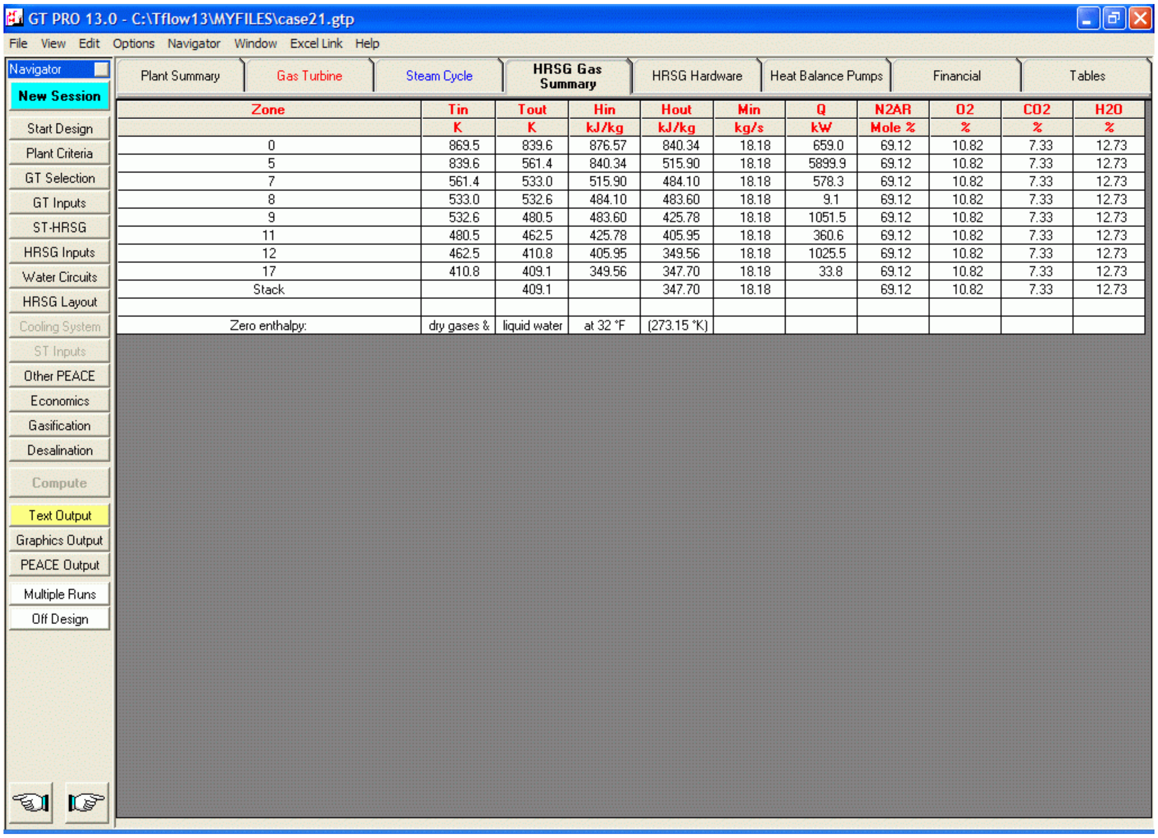
A text based MS-DOS window will appear, showing the iterations in progress as soon as the Compute button is pressed. The results in the Text Output are presented in the tabbed form consisting of Plant Summary, Gas Turbine, Steam Turbine, HRSG Gas Summary, HRSG Hardware, Heat Balance Pumps, Financial and Tables. The Plant Summary gives a good overview of the overall performance and quick glance of the system, as well as the ST performance along with estimated plant auxiliaries. The Steam Turbine and two HRSG report only appears if the HRSG and the ST are chosen during initial design setup for such components.



The results of the GT gives more detailed information such as the simulated values of the TIT, gross power output, pressure ratio, stream information (temperature, pressure and mass flow rate), compressor and turbine work, plant auxiliaries associated with the GT, losses and efficiency, exhaust gas composition, and a heat balance table.



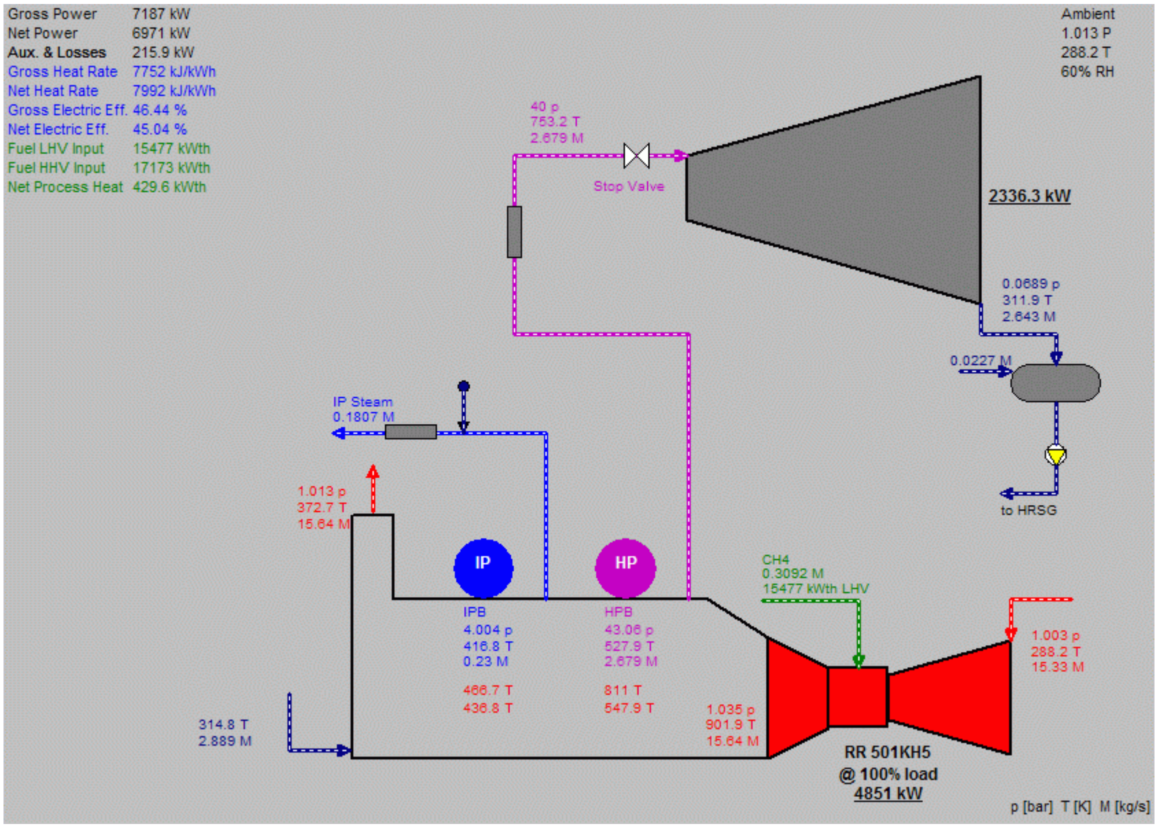
If the combined cycle was chosen, then there will be a result sheet for the ST. The initial information presented is the heat balance, followed by a gas side and steam / water side HRSG stream data in a tabulated form. The stream information is represented as pressure, temperature, mass flow rate, enthalpy, quality, etc. Losses and design pinch points are also included in the ST report along with the design details of the HRSG, mainly the Q, A and UA of the economizer, evaporator and superheater which makes up the HRSG unit.

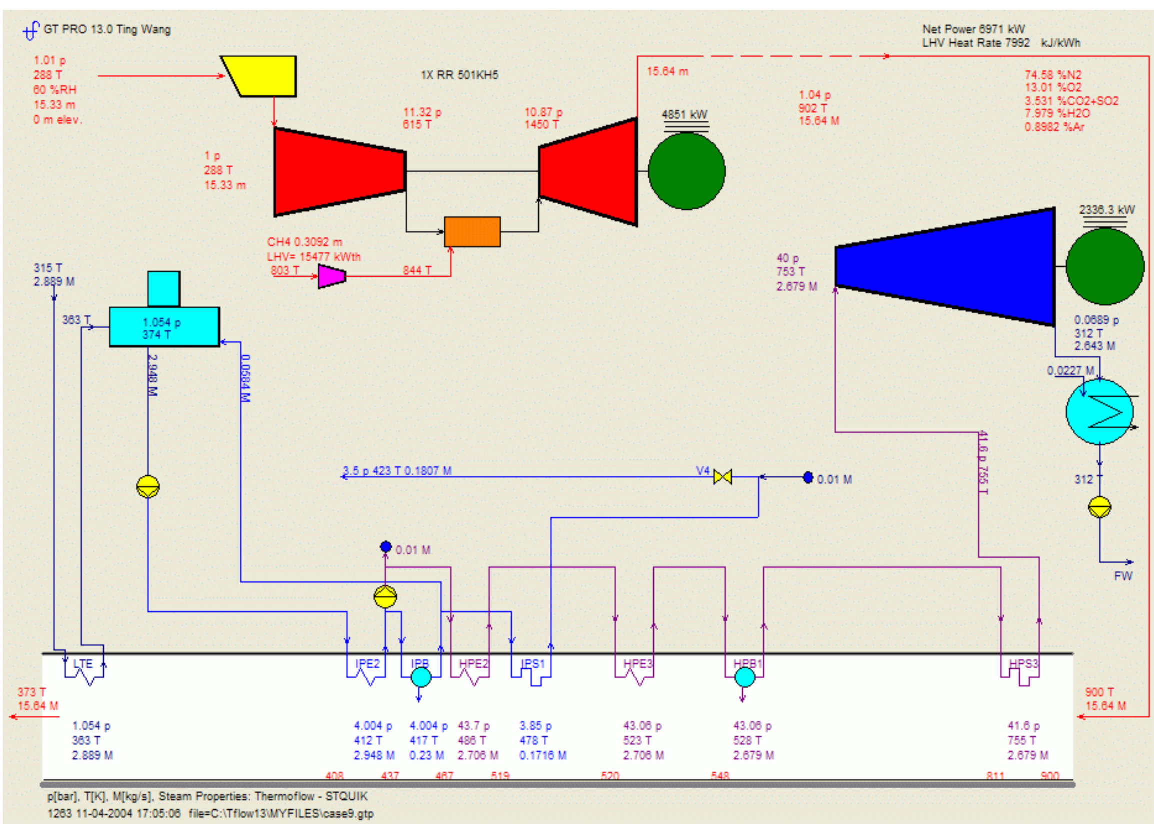


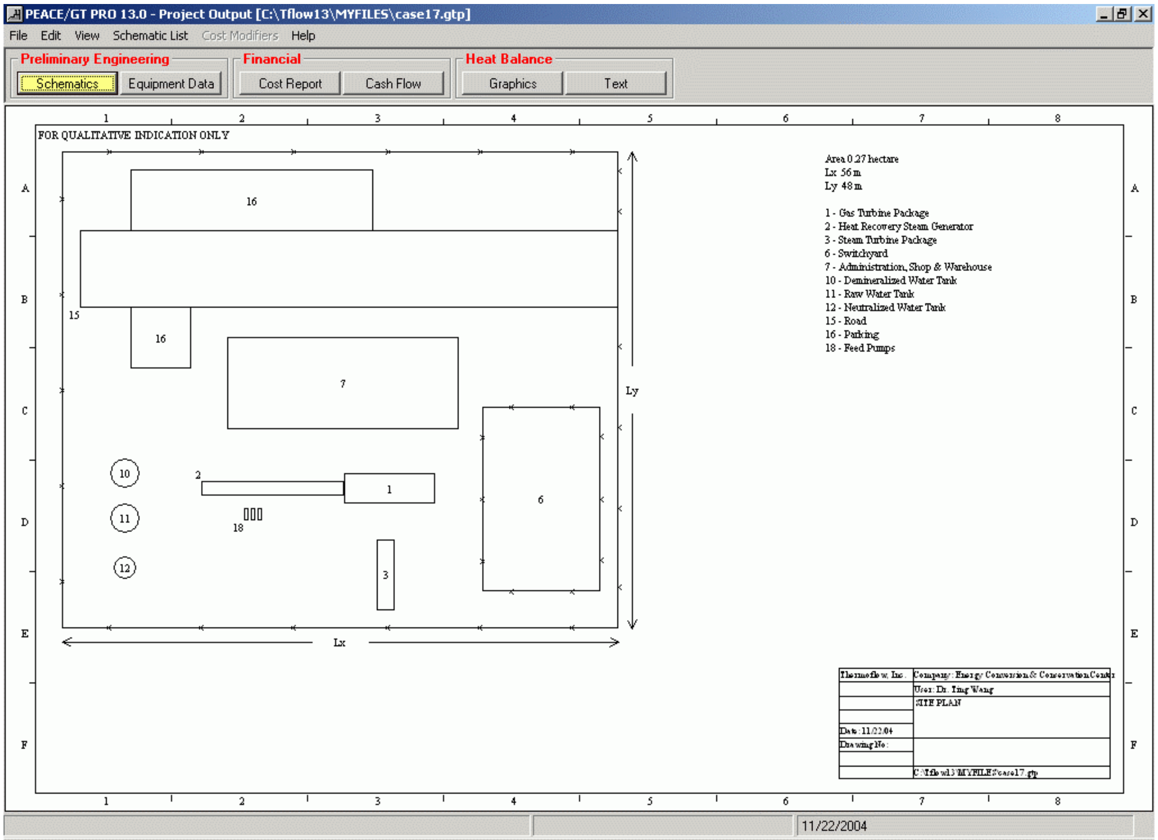
Zone	Tin	Tout	Hin	Hout	Min	Q	N2AR	O2	CO2	H2O
	K	K	kJ/kg	kJ/kg	kg/s	kW	Mole %	%	%	%
0	869.5	839.6	876.57	840.34	18.18	659.0	69.12	10.82	7.33	12.73
5	839.6	561.4	840.34	515.90	18.18	5899.9	69.12	10.82	7.33	12.73
7	561.4	533.0	515.90	484.10	18.18	578.3	69.12	10.82	7.33	12.73
8	533.0	532.6	484.10	483.60	18.18	9.1	69.12	10.82	7.33	12.73
9	532.6	480.5	483.60	425.78	18.18	1051.5	69.12	10.82	7.33	12.73
11	480.5	462.5	425.78	405.95	18.18	360.6	69.12	10.82	7.33	12.73
12	462.5	410.8	405.95	349.56	18.18	1025.5	69.12	10.82	7.33	12.73
17	410.8	409.1	349.56	347.70	18.18	33.8	69.12	10.82	7.33	12.73
Stack		409.1		347.70	18.18		69.12	10.82	7.33	12.73
Zero enthalpy:	dry gases &	liquid water	at 32 °F	(273.15 °K)						

The final Text Output tab illustrated here would be the HRSG Gas Summary, which shows from Zone 0 (the entrance of the HRSG, hottest exhaust gas from the GT) to stack where the remainder flue gas is exhausted into the environment.

The next two pictures represent the graphical and schematic representation of the simulated combined cycle power plant with each stream point labeled with pressure, temperature and mass flow rate.


Gross Power 7187 kW
Net Power 6971 kW
Aux. & Losses 215.9 kW
Gross Heat Rate 7752 kJ/kWh
Net Heat Rate 7992 kJ/kWh
Gross Electric Eff. 46.44 %
Net Electric Eff. 45.04 %
Fuel LHV Input 15477 kWth
Fuel HHV Input 17173 kWth
Net Process Heat 429.6 kWth
Ambient
1.013 P
288.2 T
60% RH
40 p
753.2 T
2.679 M
Stop Valve
2336.3 kW
0.0689 p
311.9 T
2.643 M
0.0227 M
IP Steam
0.1807 M
to HRSG
1.013 p
372.7 T
15.64 M
IP
HP
CH4
0.3092 M
15477 kWth LHV
IPB
4.004 p
416.8 T
0.23 M
HPB
43.06 p
527.9 T
2.679 M
466.7 T
436.8 T
811 T
547.9 T
1.003 p
288.2 T
15.33 M
314.8 T
2.889 M
1.035 p
901.9 T
15.64 M
RR 501KH5
@ 100% load
4851 kW
p [bar] T [K] M [kg/s]

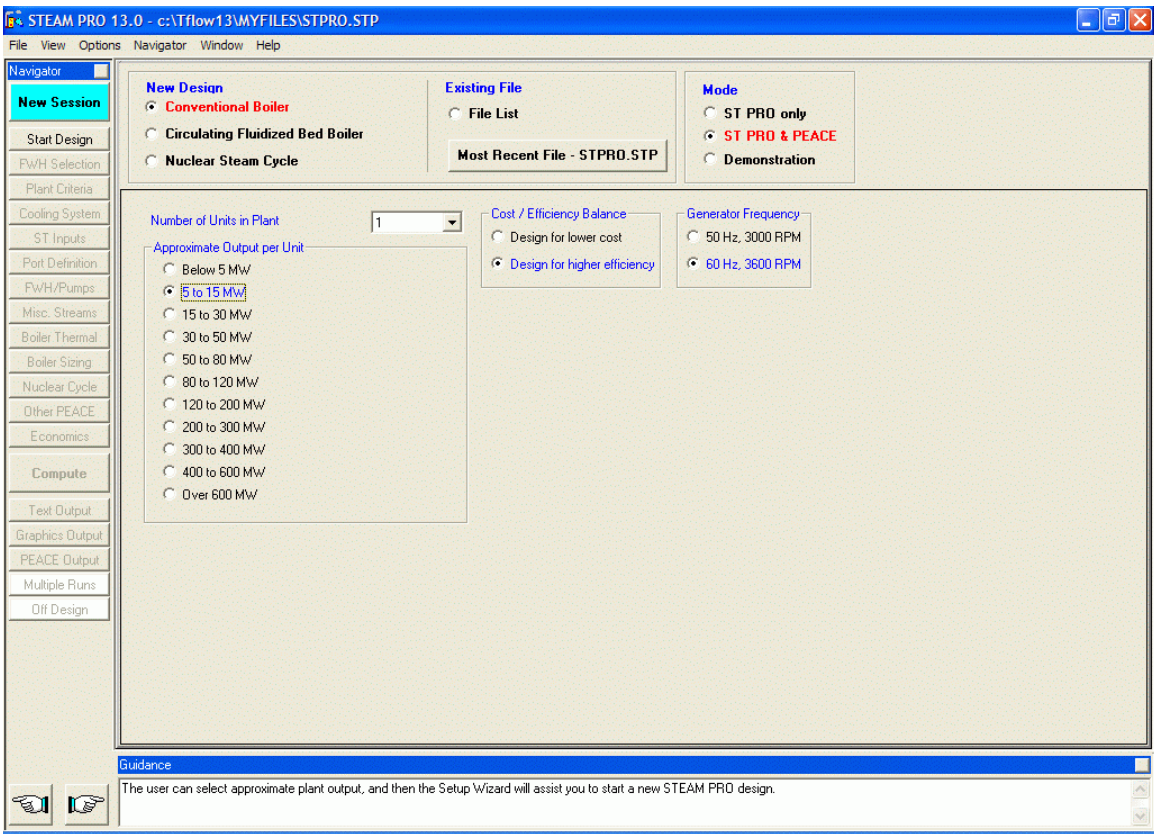

GT PRO 13.0 Ting Wang
Net Power 6971 kW
LHV Heat Rate 7992 kJ/kWh
1.01 p
288 T
60 %RH
15.33 m
0 m elev.
1X RR 501KH5
15.64 m
11.32 p
615 T
10.87 p
1450 T
4851 kW
1.04 p
902 T
15.64 M
74.58 %N2
13.01 %O2
3.531 %CO2+SO2
7.979 %H2O
0.8982 %Ar
1 p
288 T
15.33 m
CH4 0.3092 m
LHV= 15477 kWth
803 T
844 T
2336.3 kW
40 p
753 T
2.679 M
315 T
2.889 M
363 T
1.054 p
374 T
2.948 M
0.0684 M
0.0689 p
312 T
2.643 M
0.0227 M
41.6 p 755 T
3.5 p 423 T 0.1807 M
V4
0.01 M
312 T
0.01 M
FW
LTE
IPE2
IPB
HPE2
IPS1
HPE3
HPB1
HPS3
373 T
15.64 M
1.054 p
363 T
2.889 M
4.004 p
412 T
2.948 M
4.004 p
417 T
0.23 M
43.7 p
486 T
2.706 M
3.85 p
478 T
0.1716 M
43.06 p
523 T
2.706 M
43.06 p
528 T
2.679 M
41.6 p
755 T
2.679 M
900 T
15.64 M
408
437
467
519
520
548
811
900
p[bar], T[K], M[kg/s], Steam Properties: Thermoflow - STQUIK
1263 11-04-2004 17:05:06 file=C:\Tflow13\MYFILES\case9.gtp



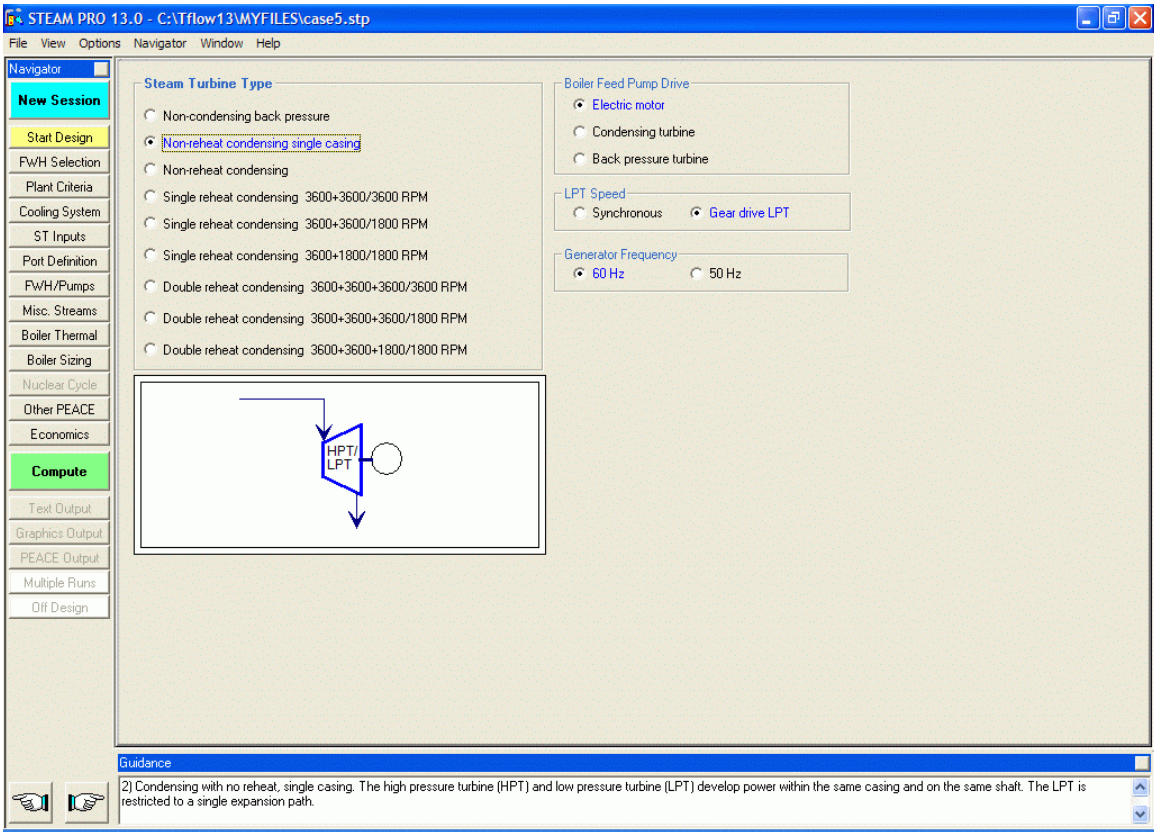
This is the graphical schematic drawing generated from the PEACE output which plans the layout of each component of the power plant.

Steam Pro Steam Turbine Simulation

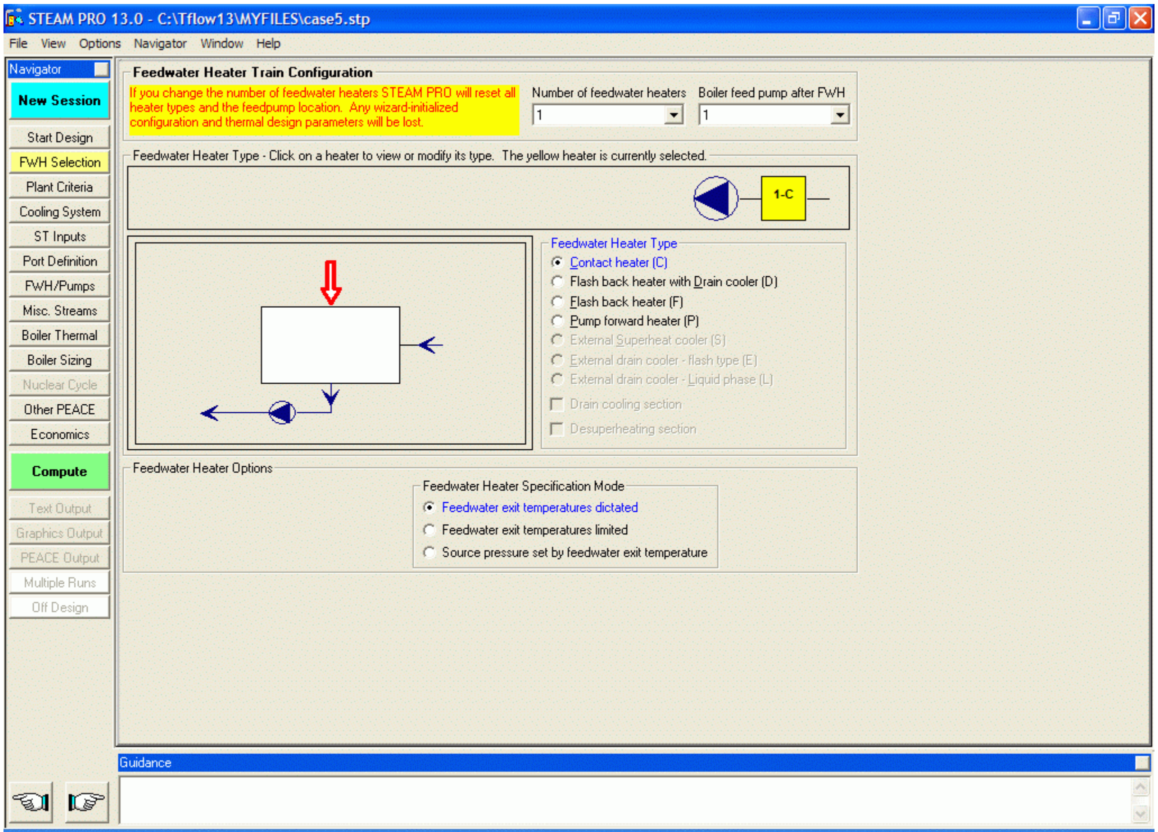
Boot the PC into the Windows environment. Click the “Start” button, select the “Programs”, and expand the “ThermoFlow” group and select “Steam Pro XX Site ID #YYYY”. The “X” and “Y” represents the version number and site license number respectively. The first screen seen in the software GUI, which looks like the following:



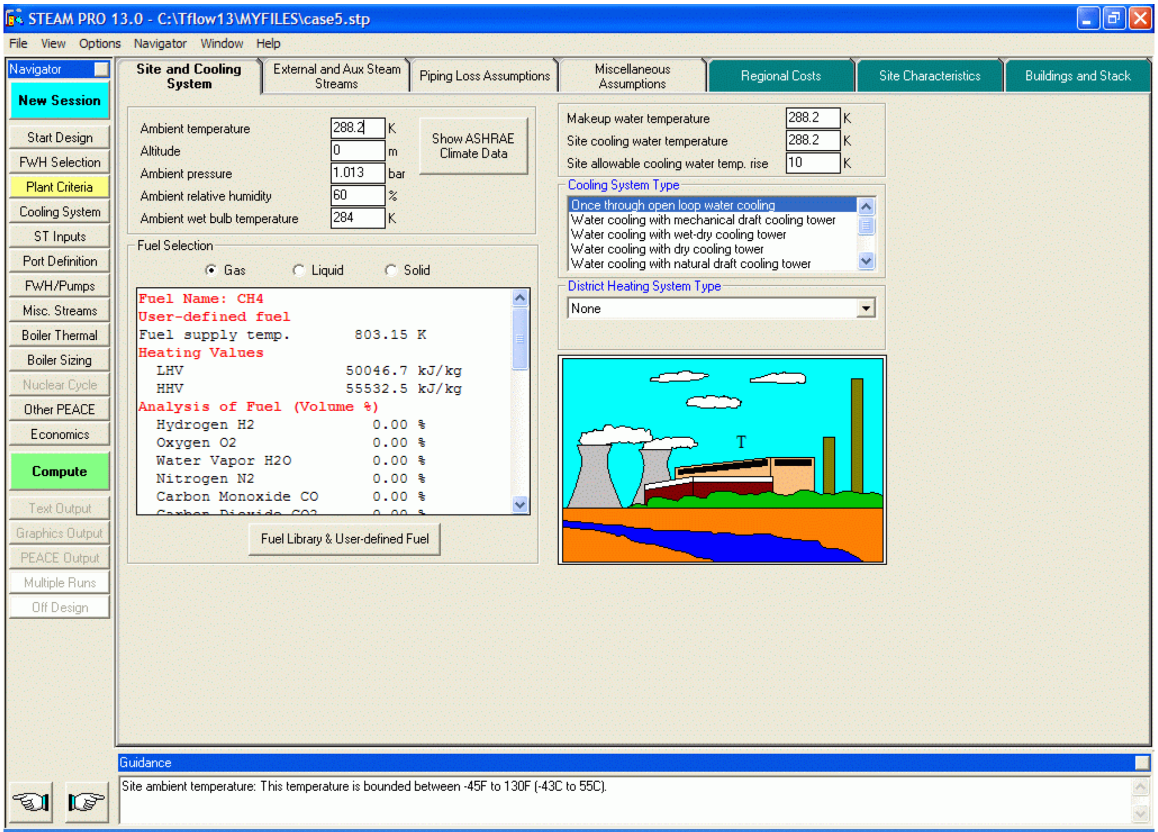
The desired power output range is selected along with the type of boiler desired and the option for cost estimation vie PEACE. The number of ST can be selected, and by default it is one unit. The desired design for higher efficiency or lower cost is among the available options. The generator efficiency is also taken into consideration with regards to the RPM and the frequency of the electricity generated.



The Start Design offers various Steam Turbine Types to choose from, including a boiler feed pump drive, and low-pressure turbine (LPT) speed selector.

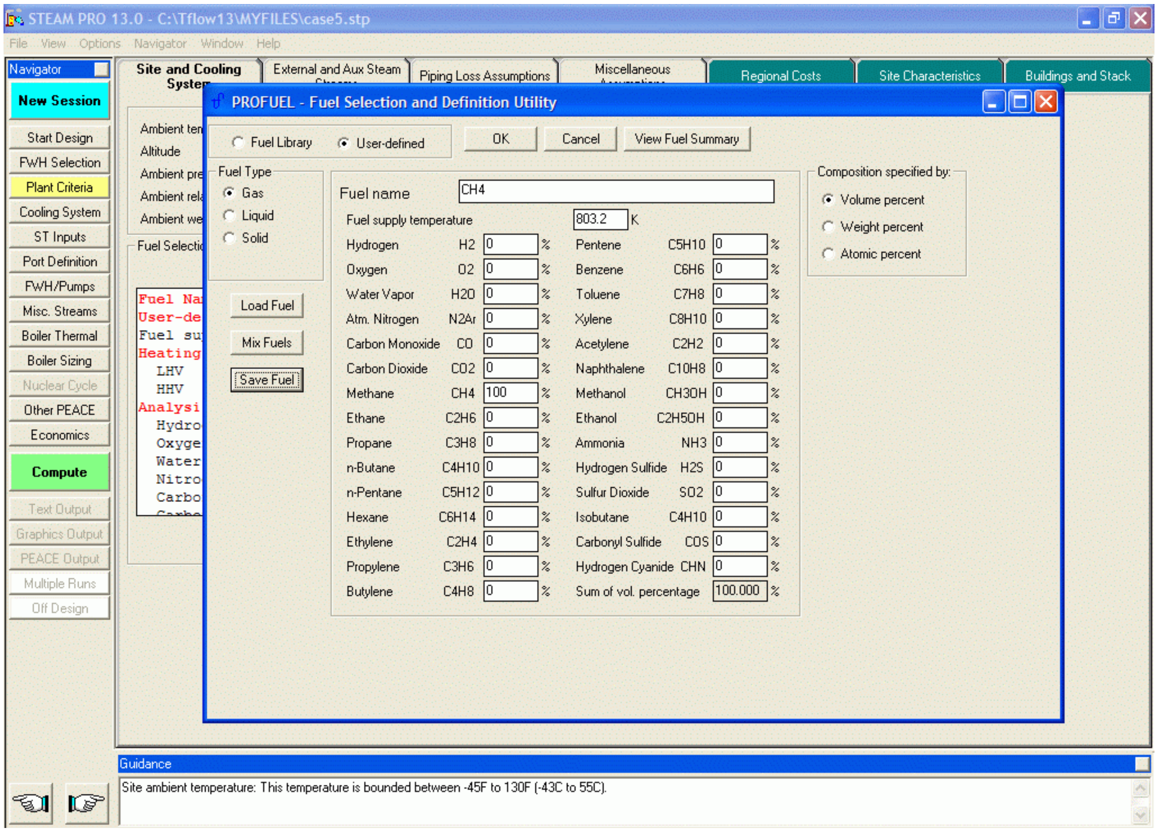


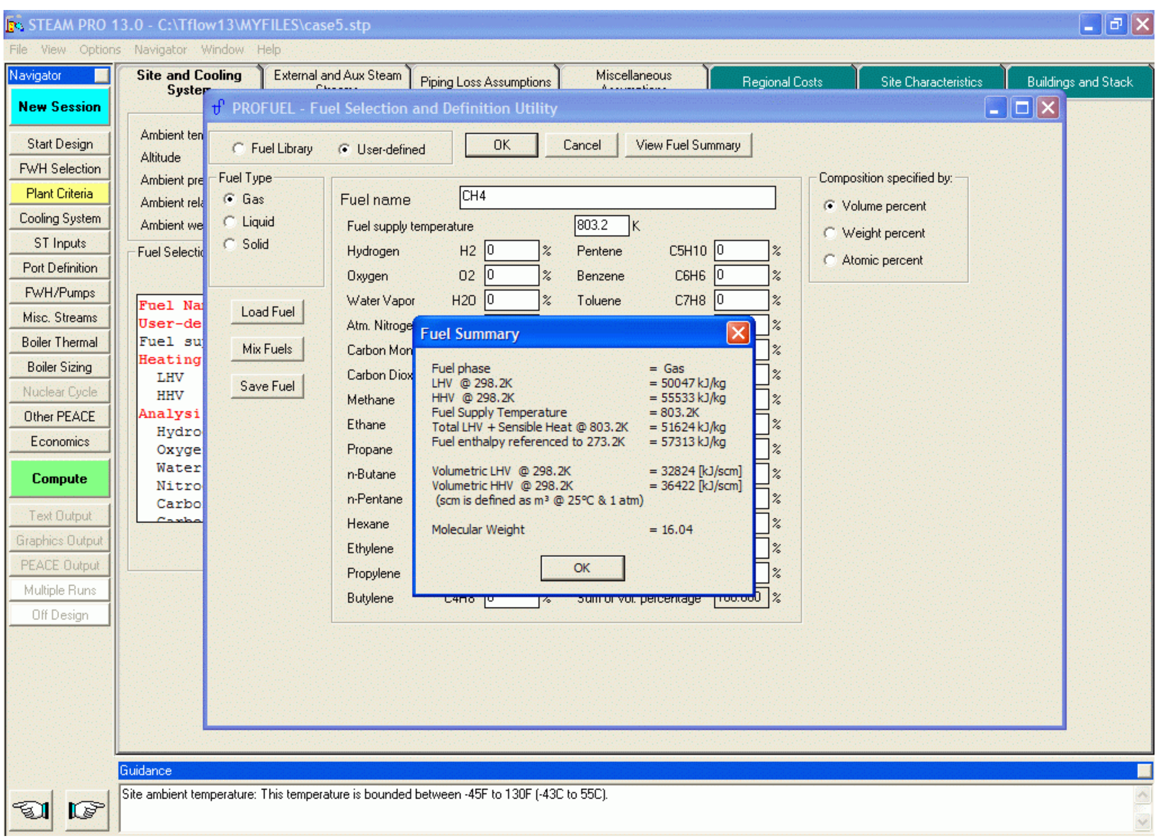
The FWH Selection presents the number of feed water heaters and boiler feed pumps after the FWH needed, along with the type of FWH, options associated with the chosen FWH. A contact heater is selected in this panel.



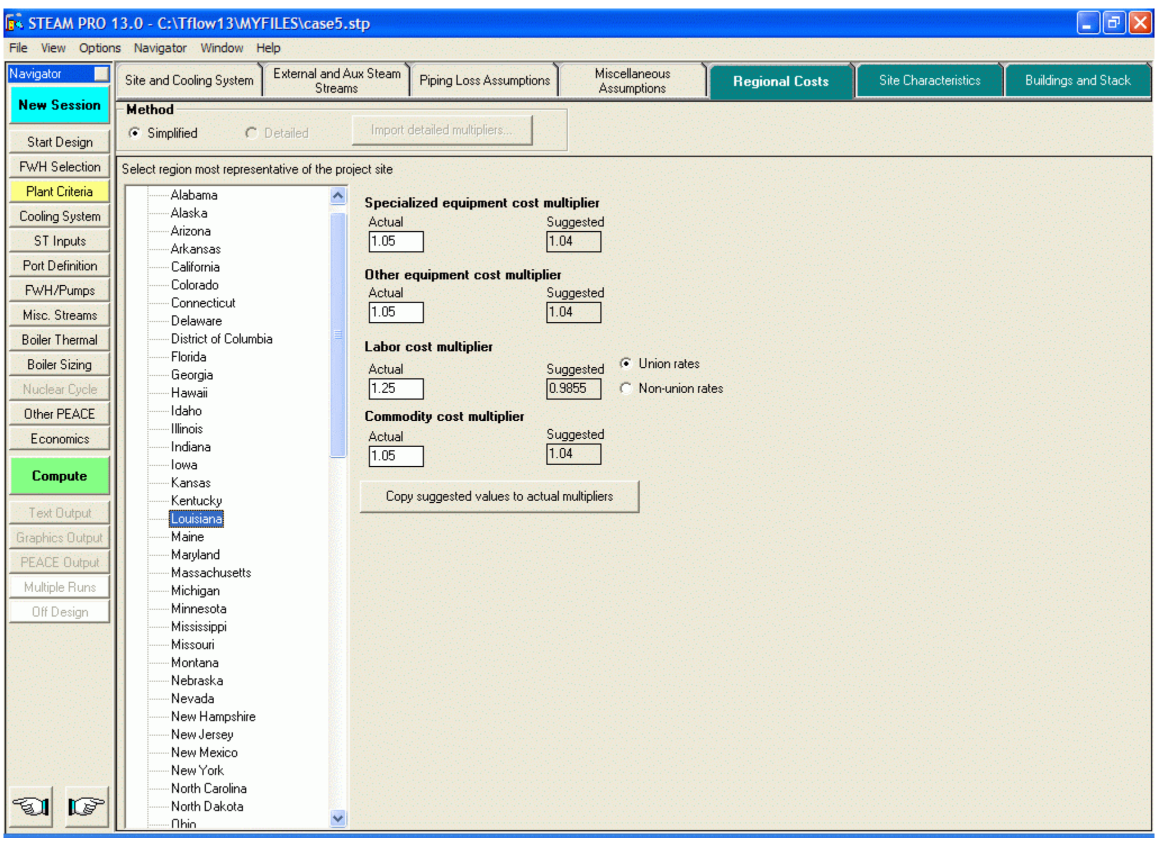
The Plant Criteria functions the same as the GT's Plant Criteria in which the site ambient condition is specified, along with the fuel selection.

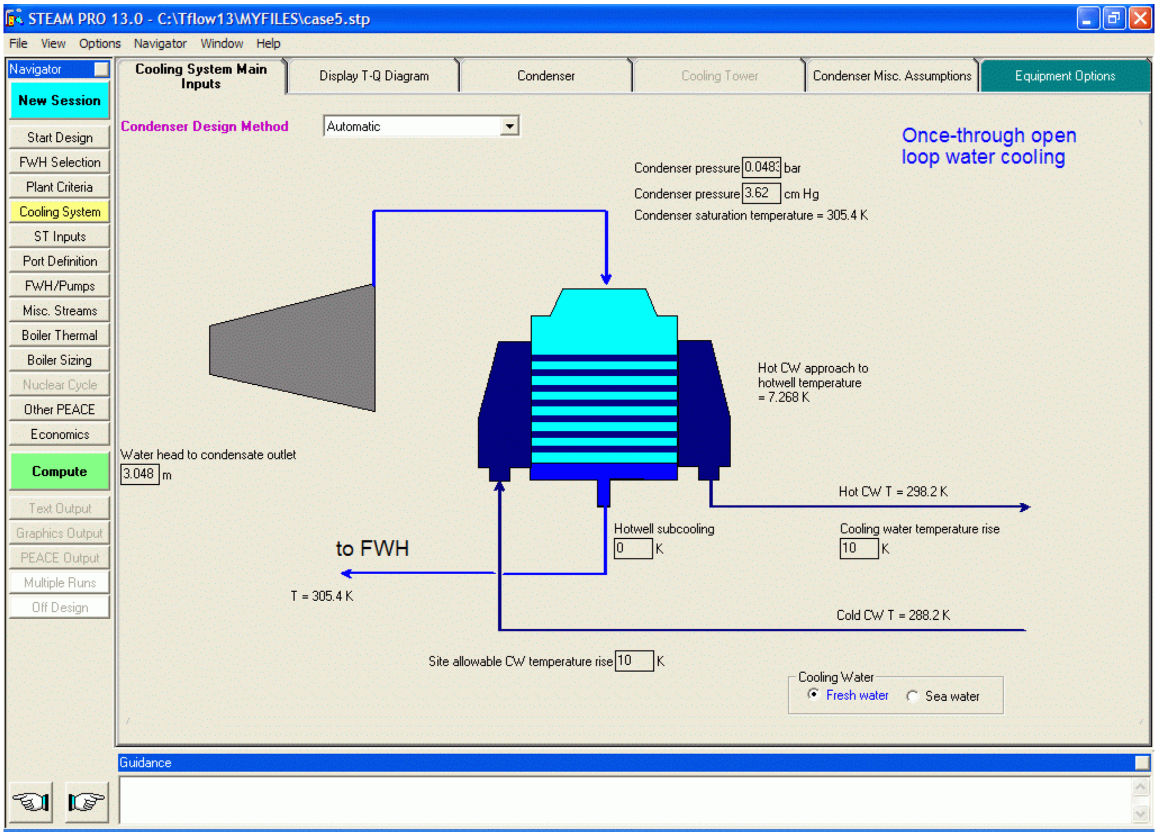
The next two figures show the fuel customization should a proposed low caloric value gas is employed.


STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
File View Options Navigator Window Help
Navigator
New Session
Start Design
FWH Selection
Plant Criteria
Cooling System
ST Inputs
Port Definition
FWH/Pumps
Misc. Streams
Boiler Thermal
Boiler Sizing
Nuclear Cycle
Other PEACE
Economics
Compute
Text Output
Graphics Output
PEACE Output
Multiple Runs
Off Design
Site and Cooling System
External and Aux Steam
Piping Loss Assumptions
Miscellaneous
Regional Costs
Site Characteristics
Buildings and Stack
PROFUEL - Fuel Selection and Definition Utility
Fuel Library
User-defined
OK
Cancel
View Fuel Summary
Fuel Type
Gas
Liquid
Solid
Load Fuel
Mix Fuels
Save Fuel
Fuel name CH4
Fuel supply temperature 803.2 K
Hydrogen H2 0 %
Oxygen O2 0 %
Water Vapor H2O 0 %
Atm. Nitrogen N2Ar 0 %
Carbon Monoxide CO 0 %
Carbon Dioxide CO2 0 %
Methane CH4 100 %
Ethane C2H6 0 %
Propane C3H8 0 %
n-Butane C4H10 0 %
n-Pentane C5H12 0 %
Hexane C6H14 0 %
Ethylene C2H4 0 %
Propylene C3H6 0 %
Butylene C4H8 0 %
Pentene C5H10 0 %
Benzene C6H6 0 %
Toluene C7H8 0 %
Xylene C8H10 0 %
Acetylene C2H2 0 %
Naphthalene C10H8 0 %
Methanol CH3OH 0 %
Ethanol C2H5OH 0 %
Ammonia NH3 0 %
Hydrogen Sulfide H2S 0 %
Sulfur Dioxide SO2 0 %
Isobutane C4H10 0 %
Carbonyl Sulfide COS 0 %
Hydrogen Cyanide CHN 0 %
Sum of vol. percentage 100.000 %
Composition specified by:
Volume percent
Weight percent
Atomic percent
Guidance
Site ambient temperature: This temperature is bounded between -45F to 130F (-43C to 55C).

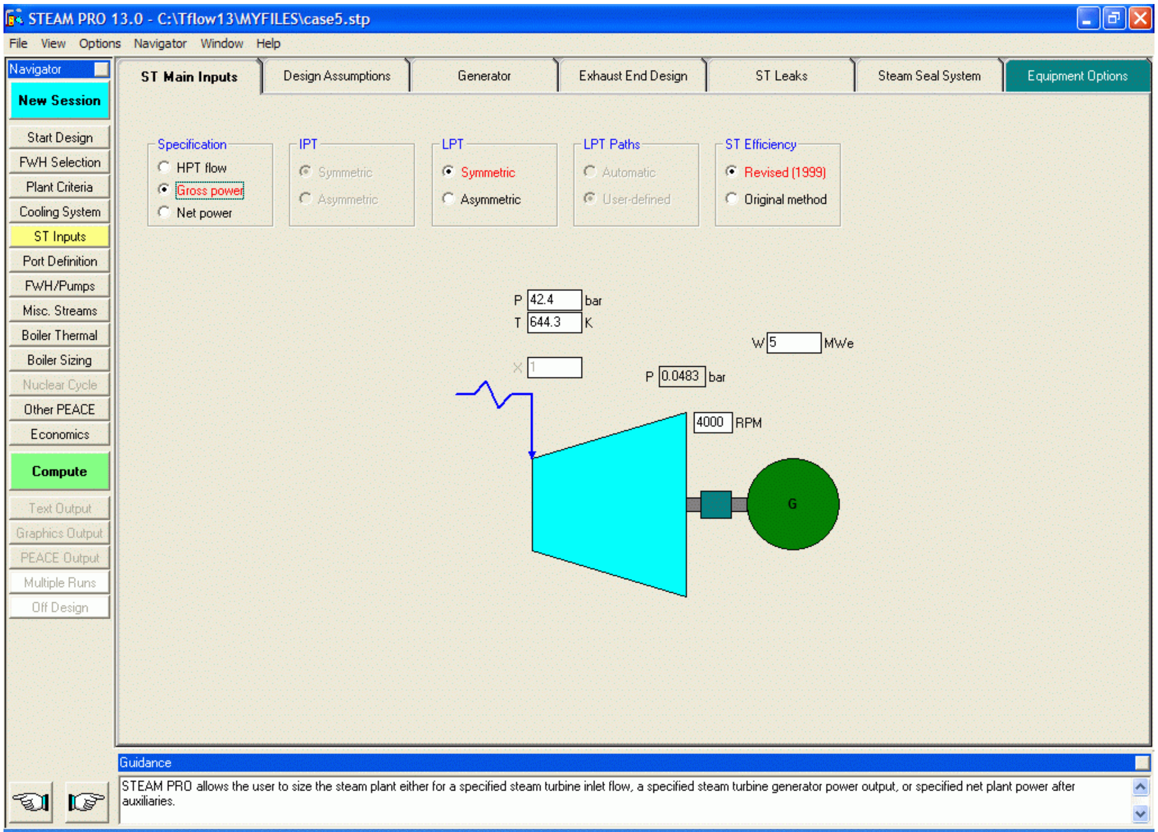

STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
PROFUEL - Fuel Selection and Definition Utility
Fuel Summary
Fuel phase = Gas
LHV @ 298.2K = 50047 kJ/kg
HHV @ 298.2K = 55533 kJ/kg
Fuel Supply Temperature = 803.2K
Total LHV + Sensible Heat @ 803.2K = 51624 kJ/kg
Fuel enthalpy referenced to 273.2K = 57313 kJ/kg
Volumetric LHV @ 298.2K = 32824 [kJ/scm]
Volumetric HHV @ 298.2K = 36422 [kJ/scm]
(scm is defined as m³ @ 25°C & 1 atm)
Molecular Weight = 16.04
OK
Guidance
Site ambient temperature: This temperature is bounded between -45F to 130F (-43C to 55C).

Under the PEACE information, the Regional Cost can be set to the desired location in which the plant will be built. Current cost multipliers and user defined cost multipliers may be used to fine-tune the design cost for current projects and future cost multipliers.



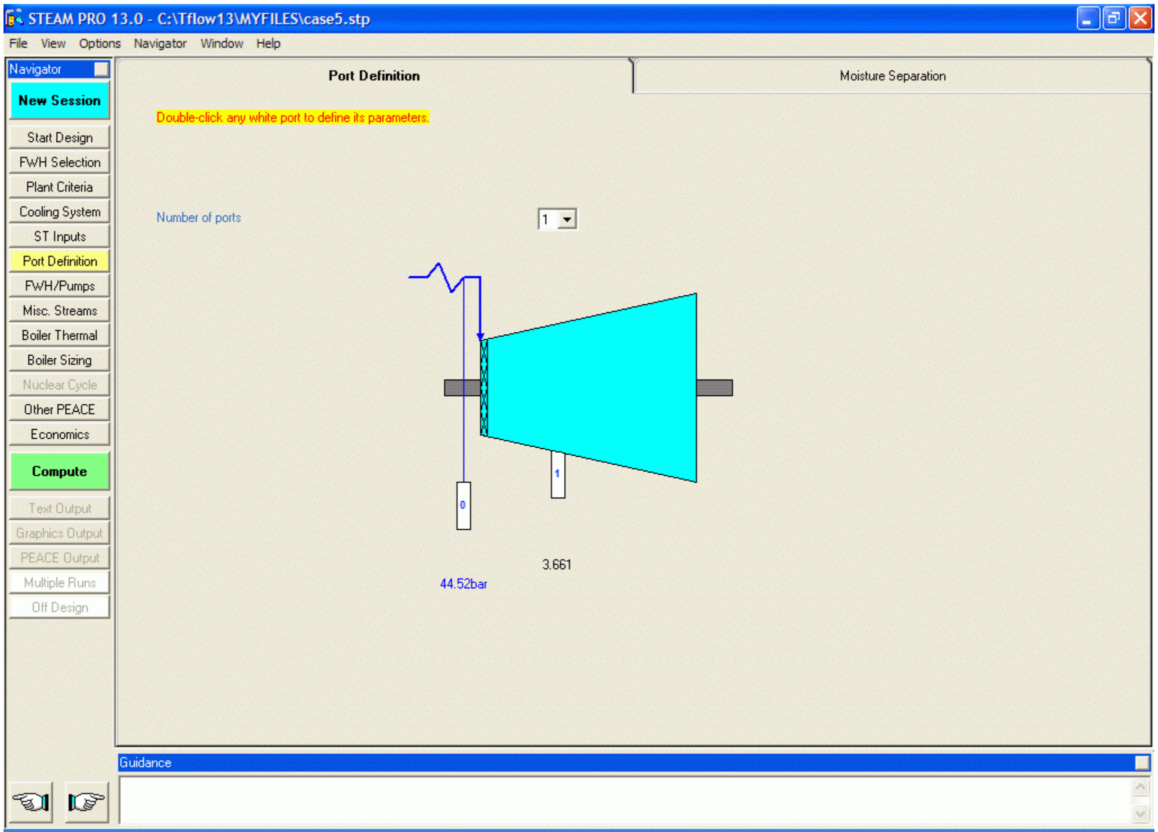


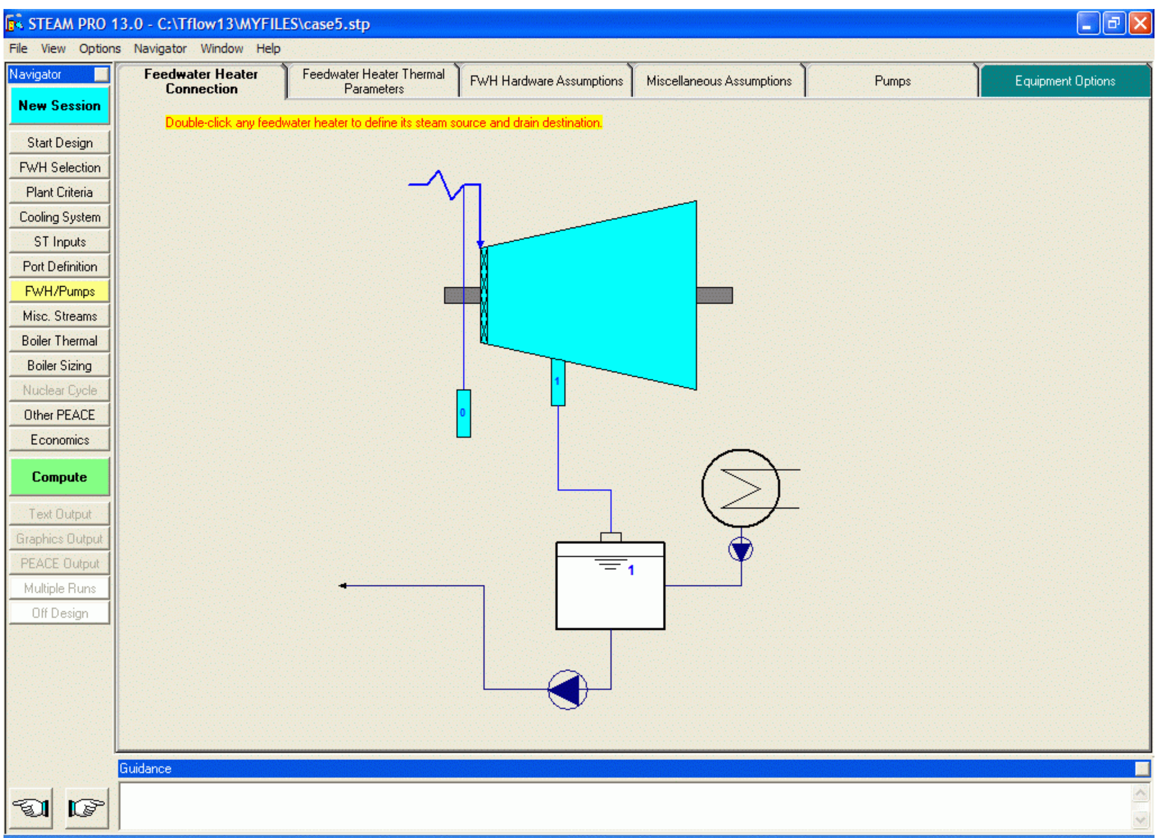
The default cooling system is a once-through open loop water-cooling system, with two options: either a user defined pressure only or with all parameters fully defined by the user. With all user-defined parameters, the water head, hot and cold CW may be entered into the boxes. The next tab "Display T-Q Diagram" shows the T-Q graph of the cooling system.

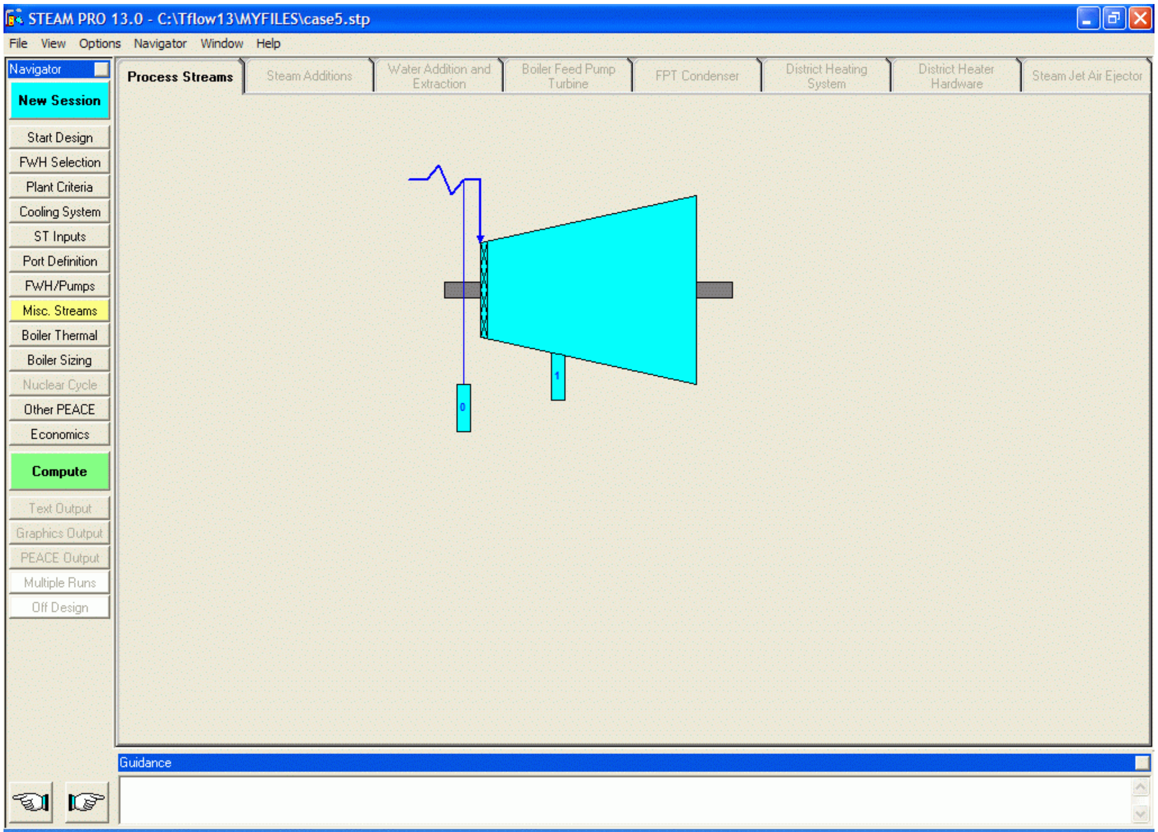


The ST Inputs enables the customization of the generic ST in terms of specification, efficiencies and inlet condition (pressure and temperature) of the superheated steam. The user defined power (W) will enable the overall simulation software to determine how much steam will be needed in order to achieve the specified power output. Other additional detail design details may be changed in this stage of the design.

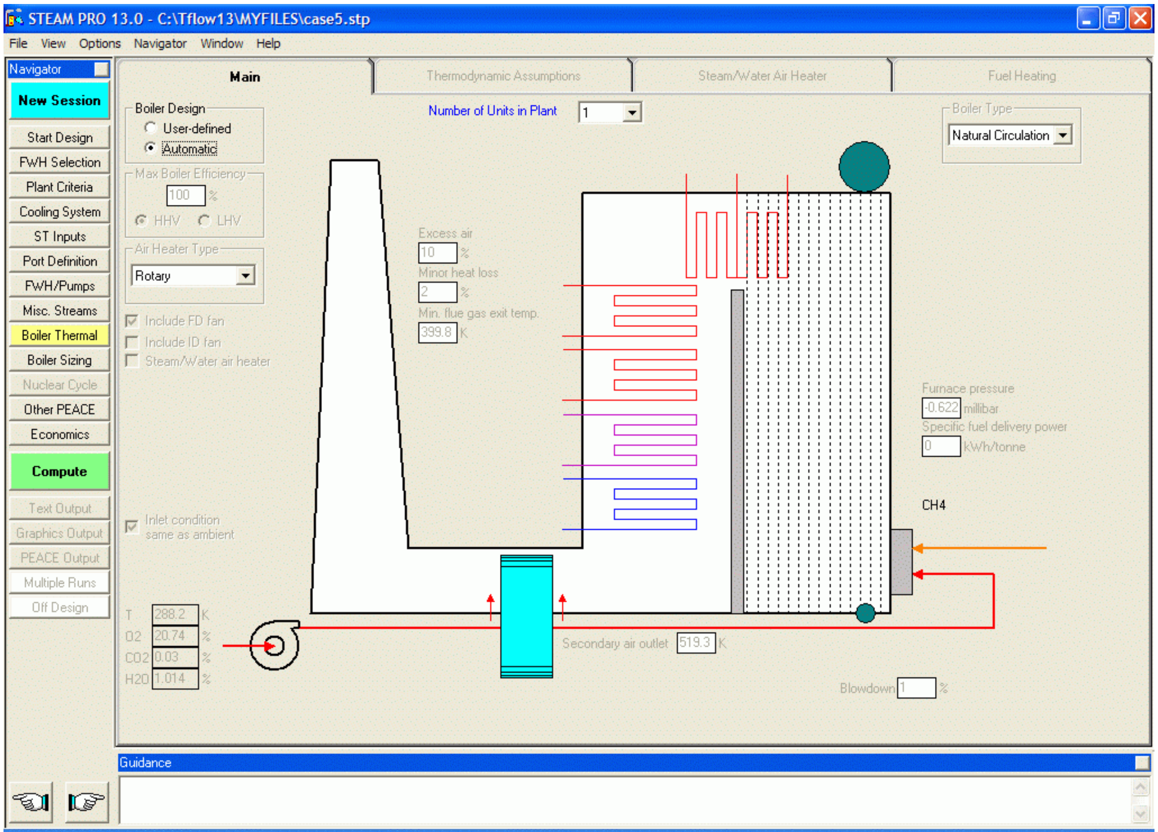
The next 3 pictures show the Port Definition, FWH / Pumps and Miscellaneous Streams.

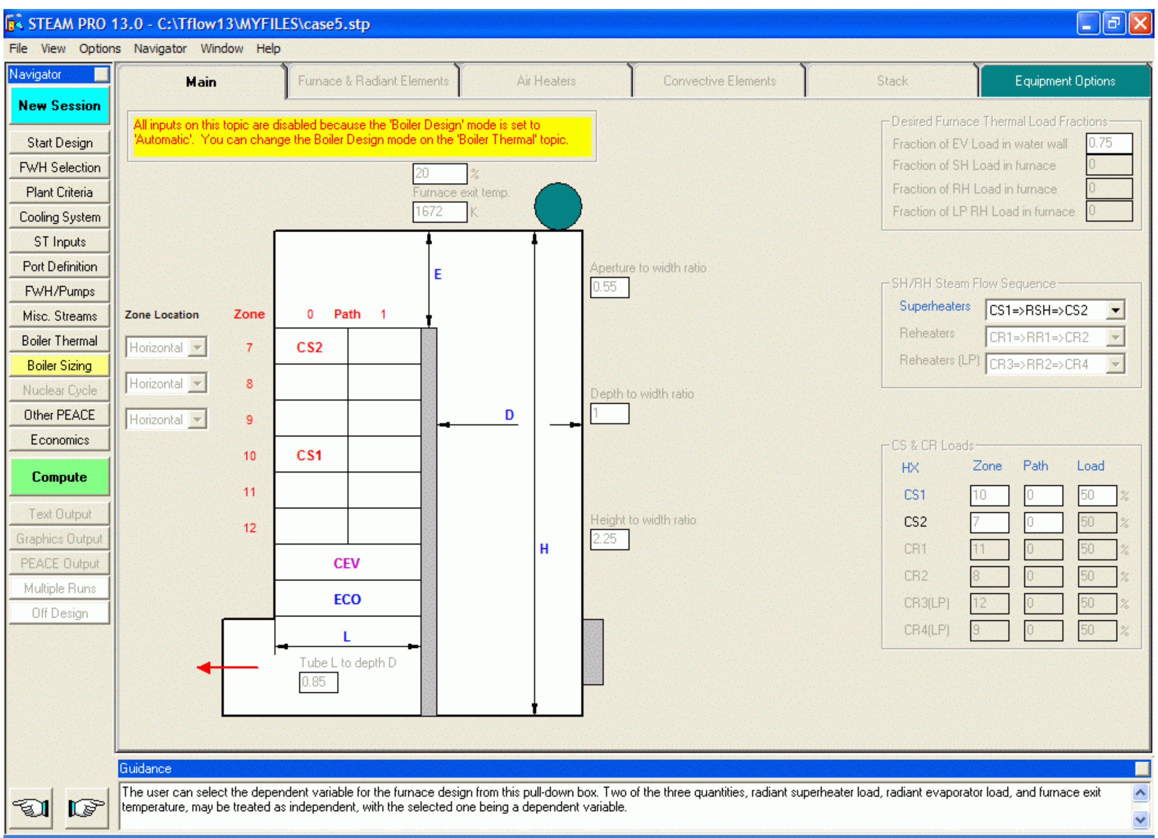

STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
File View Options Navigator Window Help
Navigator
New Session
Start Design
FWH Selection
Plant Criteria
Cooling System
ST Inputs
Port Definition
FWH/Pumps
Misc. Streams
Boiler Thermal
Boiler Sizing
Nuclear Cycle
Other PEACE
Economics
Compute
Text Output
Graphics Output
PEACE Output
Multiple Runs
Off Design
Port Definition
Moisture Separation
Double-click any white port to define its parameters.
Number of ports
1
0
1
3.661
44.52bar
Guidance

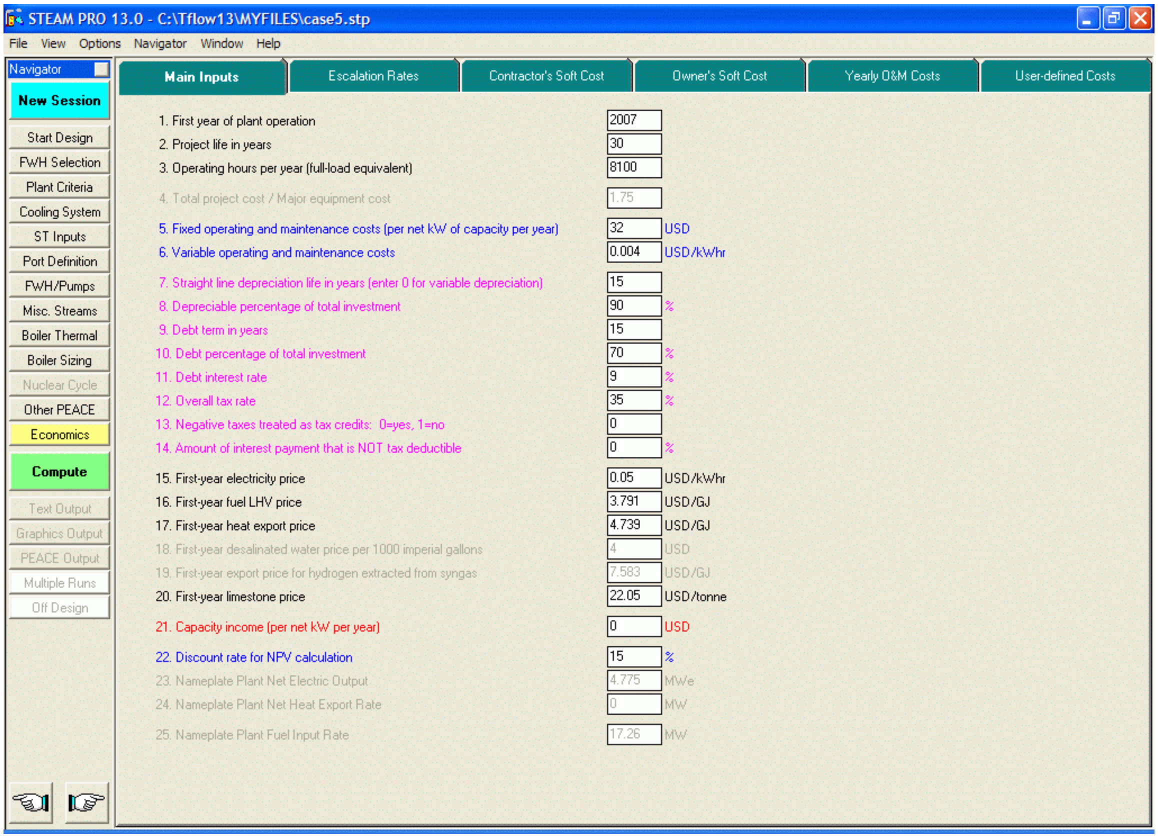

STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
File View Options Navigator Window Help
Navigator
New Session
Start Design
FWH Selection
Plant Criteria
Cooling System
ST Inputs
Port Definition
FWH/Pumps
Misc. Streams
Boiler Thermal
Boiler Sizing
Nuclear Cycle
Other PEACE
Economics
Compute
Text Output
Graphics Output
PEACE Output
Multiple Runs
Off Design
Feedwater Heater Connection
Feedwater Heater Thermal Parameters
FWH Hardware Assumptions
Miscellaneous Assumptions
Pumps
Equipment Options
Double-click any feedwater heater to define its steam source and drain destination.
1
0
1
Guidance



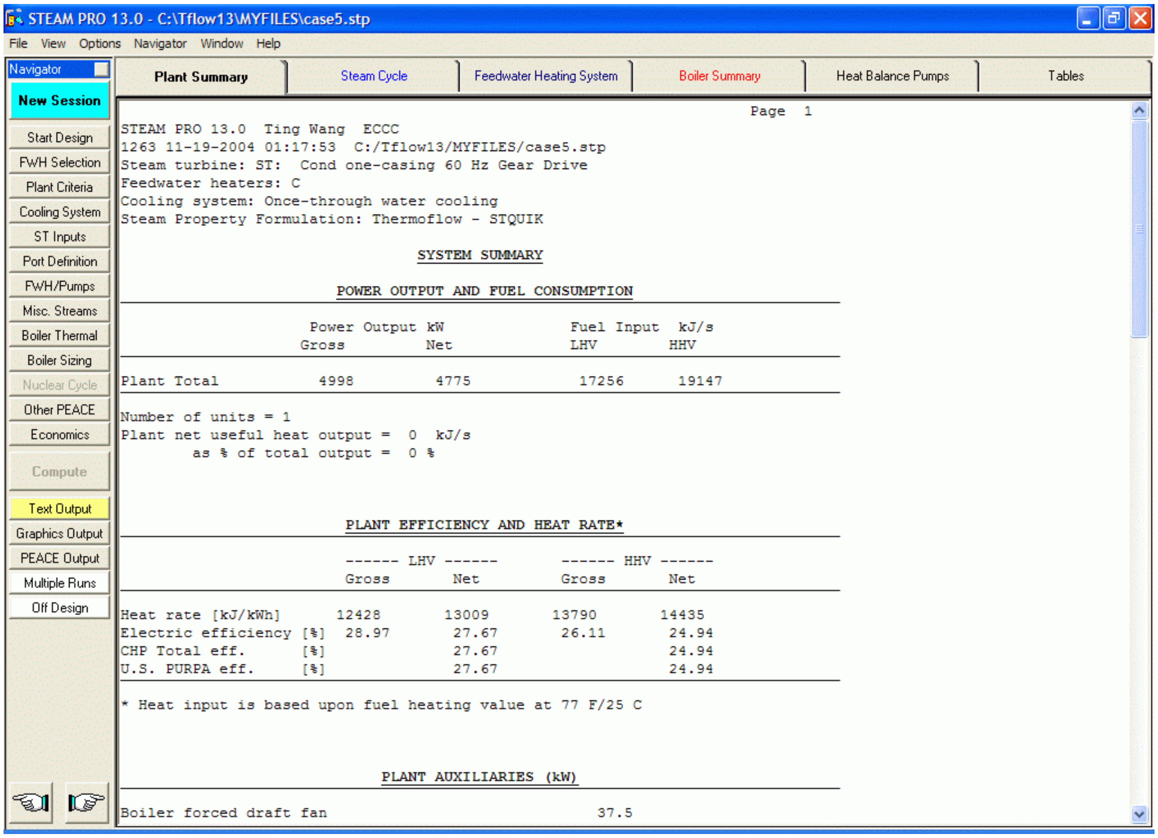
The Boiler Thermal and Boiler Sizing in the next two pictures were left as the default values however, customization is available should the user decide to do so.


STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
Main
Thermodynamic Assumptions
Steam/Water Air Heater
Fuel Heating
Boiler Design
User-defined
Automatic
Number of Units in Plant
Boiler Type
Natural Circulation
Max Boiler Efficiency
Air Heater Type
Rotary
Include FD fan
Include ID fan
Steam/Water air heater
Excess air
Minor heat loss
Min. flue gas exit temp.
Furnace pressure
Specific fuel delivery power
CH4
Inlet condition same as ambient
Secondary air outlet
Blowdown
Guidance

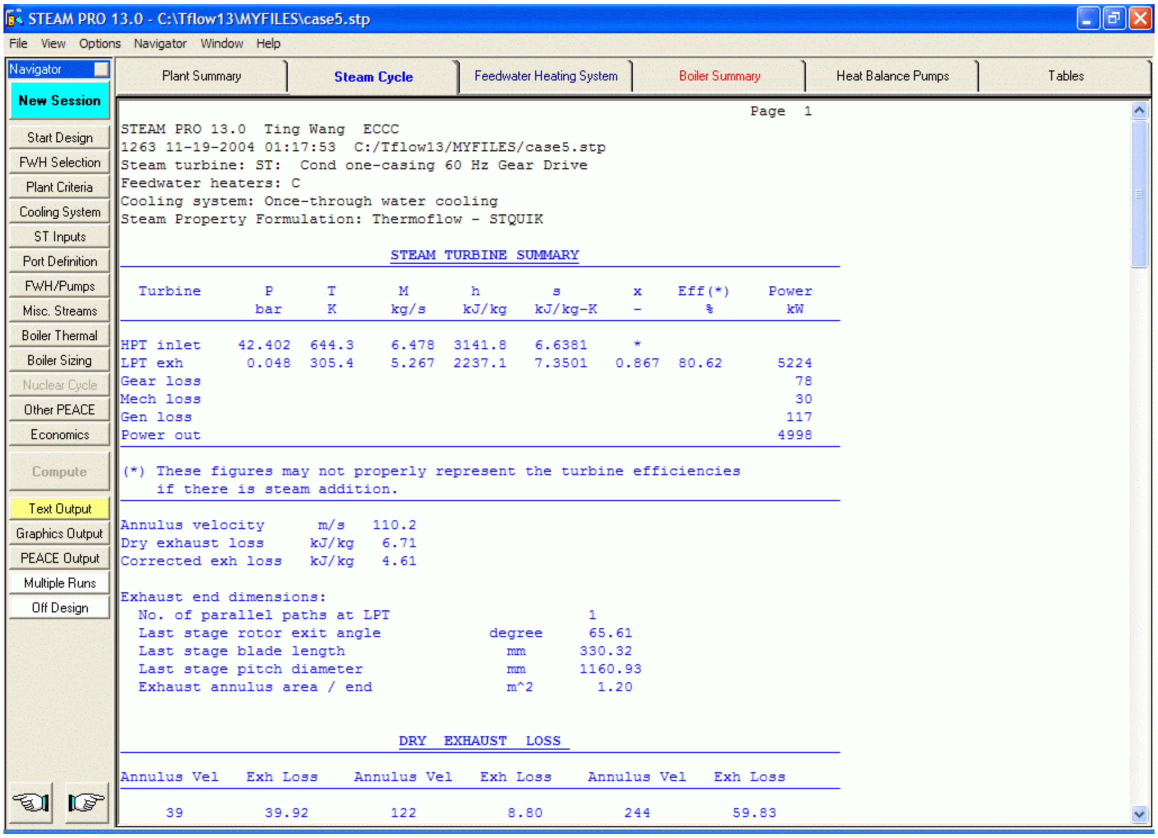

STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
Main
Furnace & Radiant Elements
Air Heaters
Convective Elements
Stack
Equipment Options
All inputs on this topic are disabled because the 'Boiler Design' mode is set to 'Automatic'. You can change the Boiler Design mode on the 'Boiler Thermal' topic.
Furnace exit temp.
Desired Furnace Thermal Load Fractions
Fraction of EV Load in water wall
Fraction of SH Load in furnace
Fraction of RH Load in furnace
Fraction of LP RH Load in furnace
Aperture to width ratio
SH/RH Steam Flow Sequence
Superheaters
Reheaters
Reheaters (LP)
Depth to width ratio
Height to width ratio
CS & CR Loads
Zone Location
Zone
Path
CS2
CS1
CEV
ECO
Tube L to depth D
Guidance
The user can select the dependent variable for the furnace design from this pull-down box. Two of the three quantities, radiant superheater load, radiant evaporator load, and furnace exit temperature, may be treated as independent, with the selected one being a dependent variable.



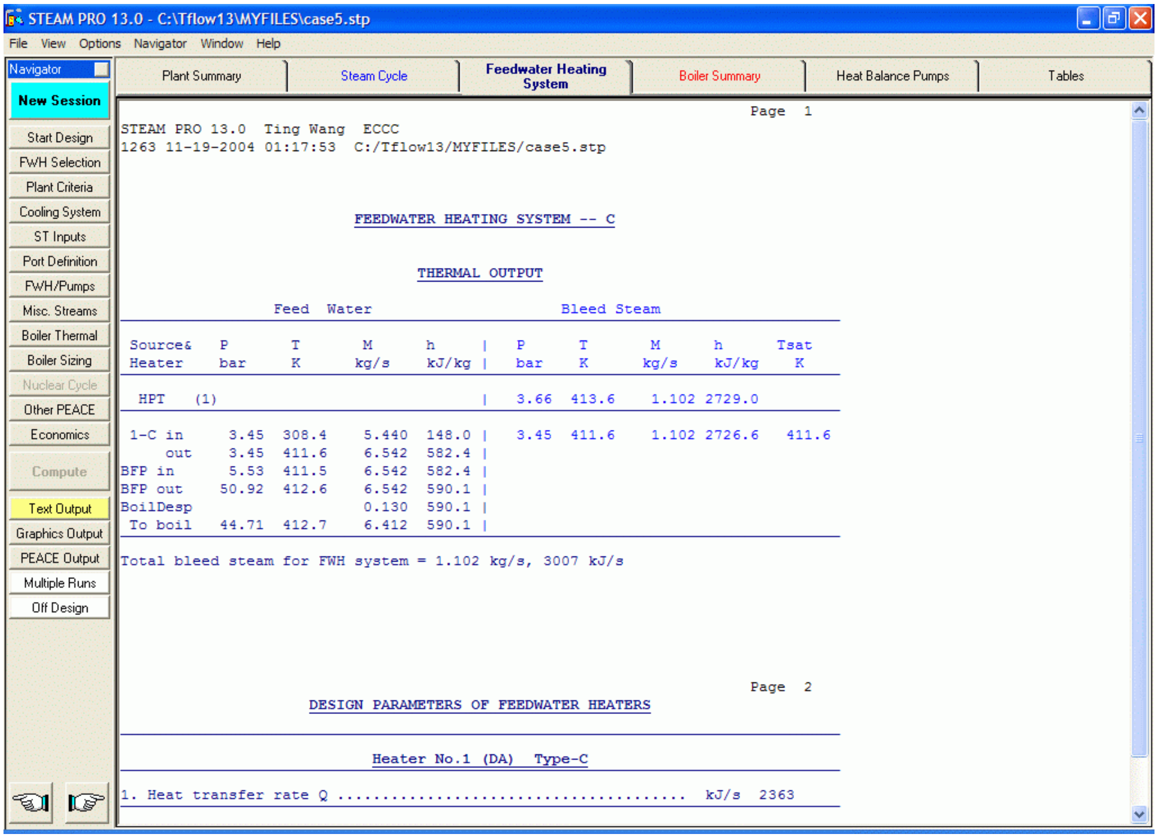
Under Economics, various costs per unit is shown as one of the last steps before the computation starts.



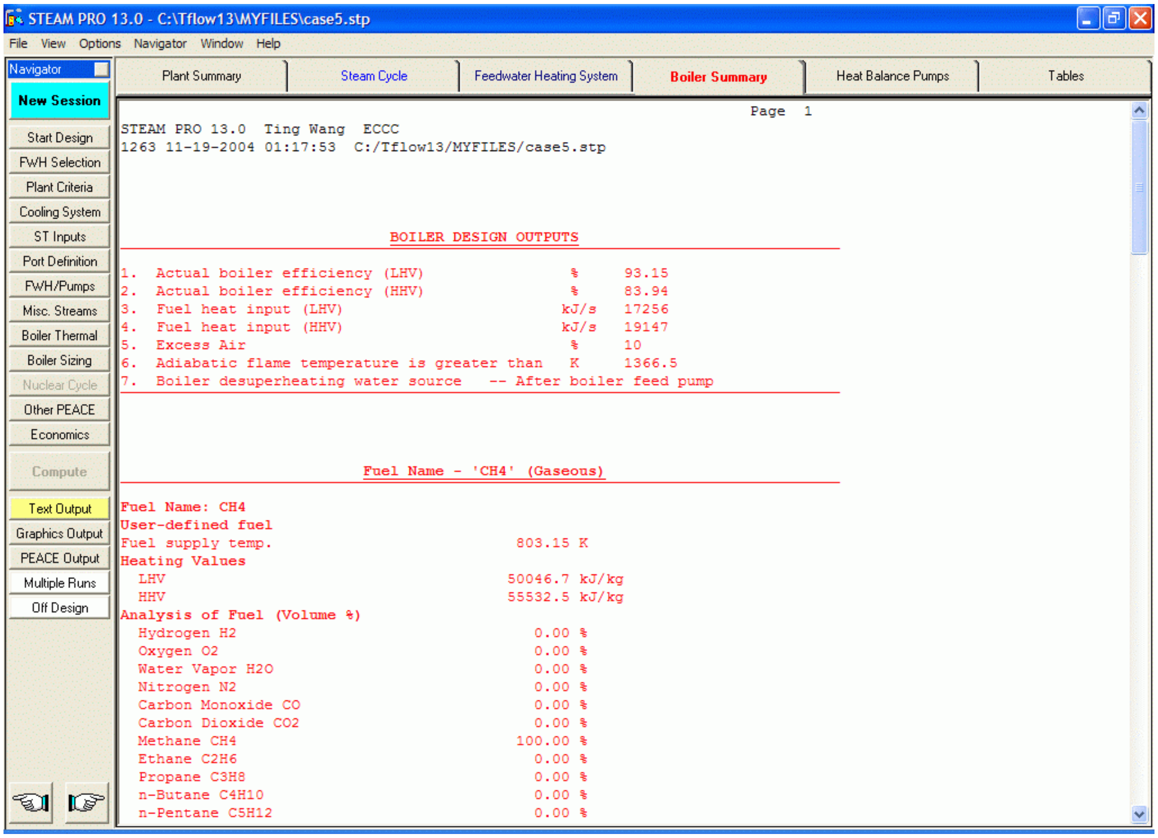
Similar to the GT ThermoFlow, a MS-DOS window will appear briefly, showing the iteration in progress, and the results will be presented in the Text Output shown above after all the iteration is complete. The overall output, fuel consumption, efficiency, heat rate and plant auxiliaries are shown.



The Steam Cycle summarizes in detail the turbine summary, dry exhaust loss, efficiencies, losses, design parameters, and condenser information.

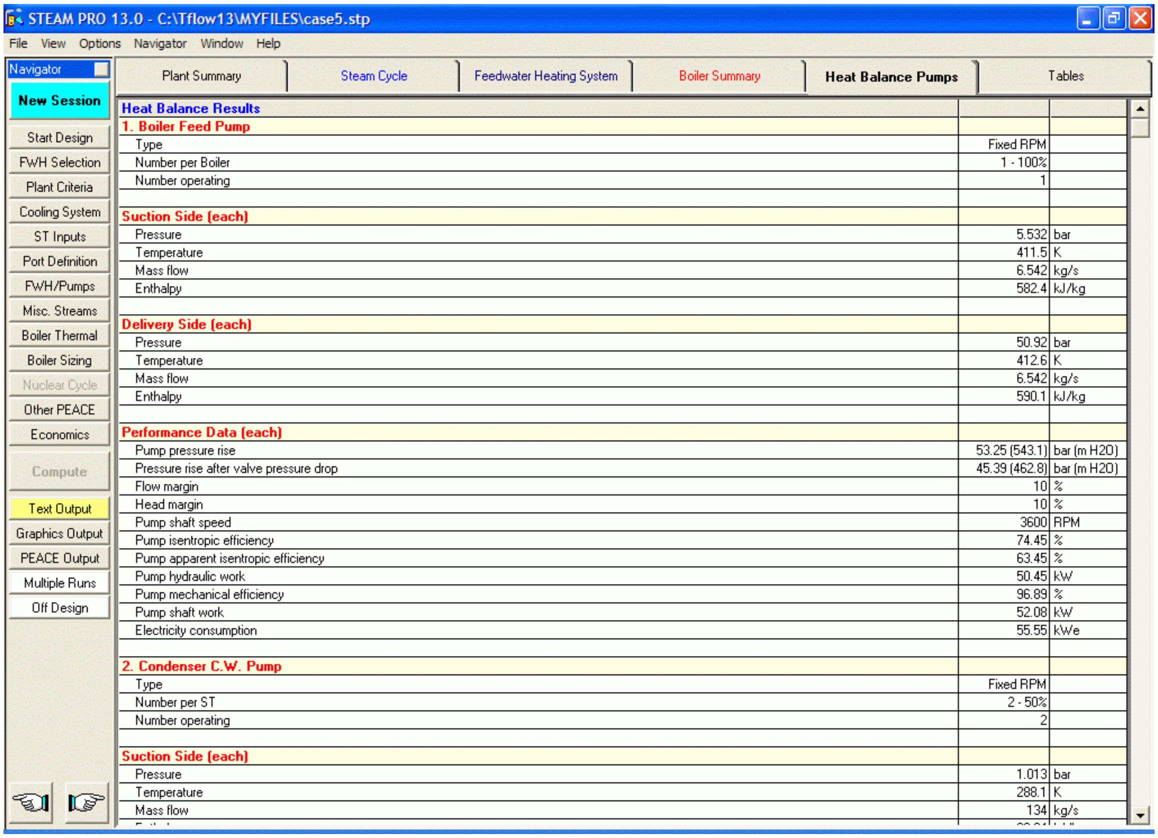


The FWH system summarizes the thermal output, and FWH design parameters.

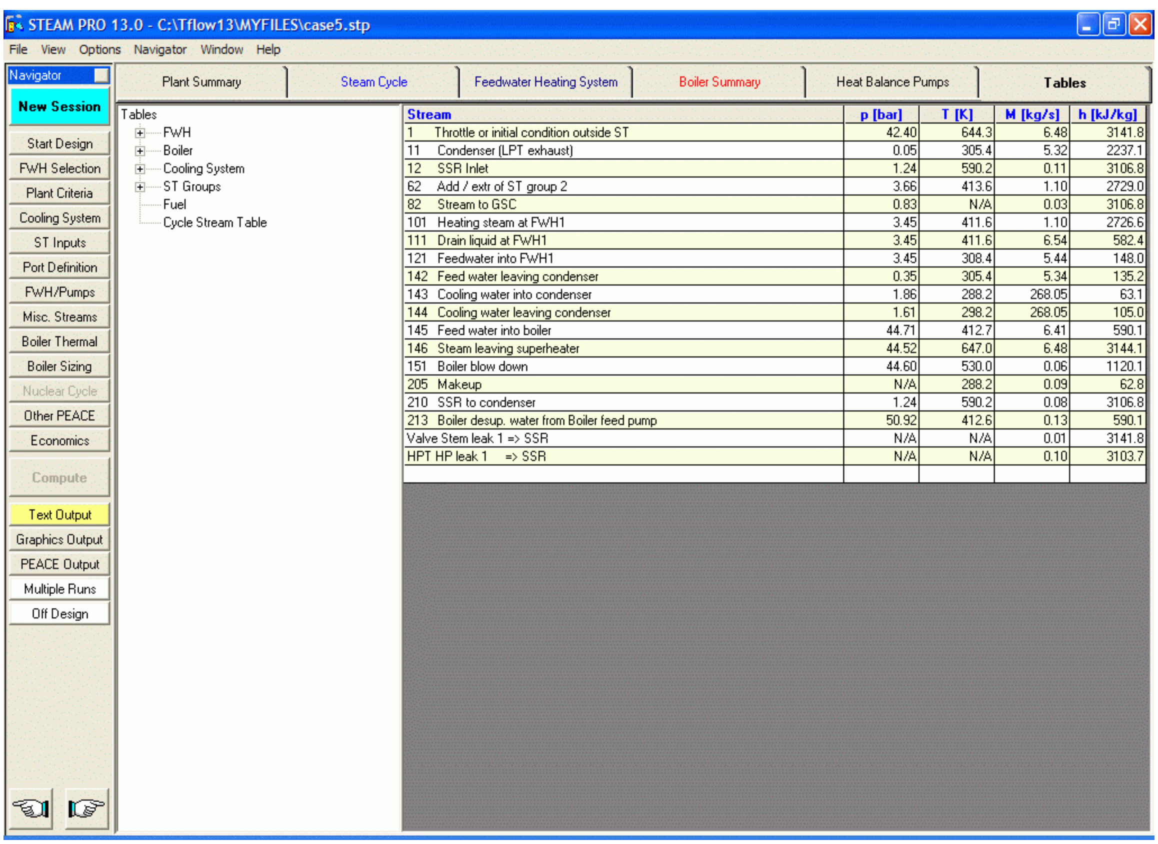


The boiler summary documents the fuel composition, boiler design output, steam summary and the boiler (economizer, evaporator and super heater) heat transfer information.

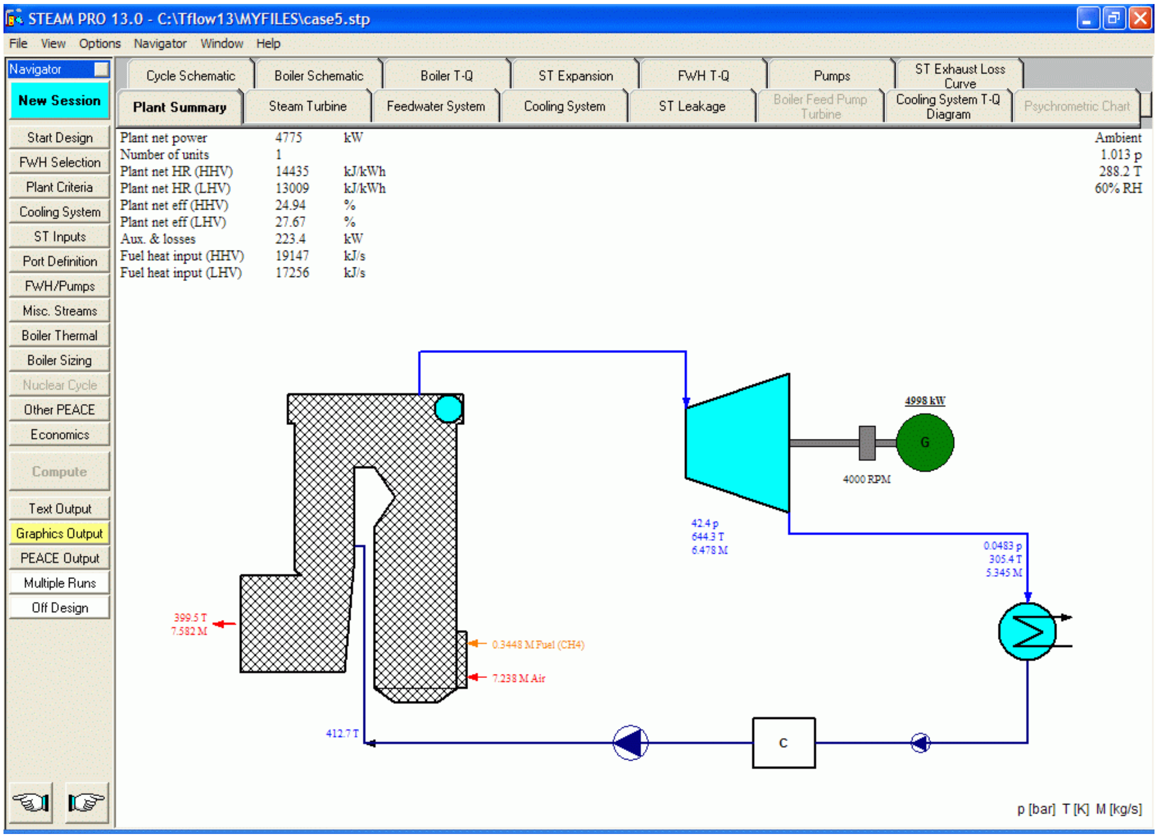
The next two pictures show the heat balance pumps and summary tables.

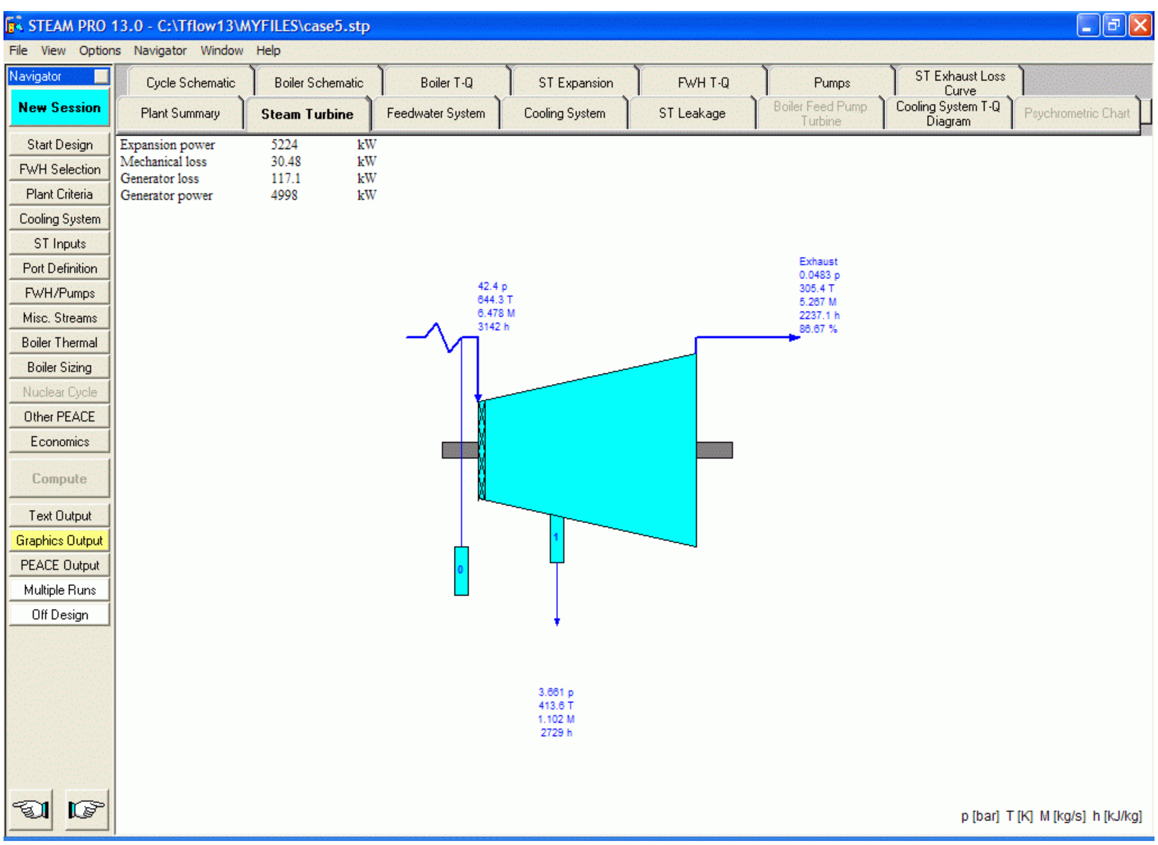


Heat Balance Results		
1. Boiler Feed Pump		
Type	Fixed RPM	
Number per Boiler	1 - 100%	
Number operating	1	
Suction Side (each)		
Pressure	5.532	bar
Temperature	411.5	K
Mass flow	6.542	kg/s
Enthalpy	582.4	kJ/kg
Delivery Side (each)		
Pressure	50.92	bar
Temperature	412.6	K
Mass flow	6.542	kg/s
Enthalpy	590.1	kJ/kg
Performance Data (each)		
Pump pressure rise	53.25 (543.1)	bar (m H2O)
Pressure rise after valve pressure drop	45.39 (462.8)	bar (m H2O)
Flow margin	10	%
Head margin	10	%
Pump shaft speed	3600	RPM
Pump isentropic efficiency	74.45	%
Pump apparent isentropic efficiency	63.45	%
Pump hydraulic work	50.45	kW
Pump mechanical efficiency	96.89	%
Pump shaft work	52.08	kW
Electricity consumption	55.55	kWe
2. Condenser C.W. Pump		
Type	Fixed RPM	
Number per ST	2 - 50%	
Number operating	2	
Suction Side (each)		
Pressure	1.013	bar
Temperature	288.1	K
Mass flow	134	kg/s



Stream	p [bar]	T [K]	M [kg/s]	h [kJ/kg]
1 Throttle or initial condition outside ST	42.40	644.3	6.48	3141.8
11 Condenser (LPT exhaust)	0.05	305.4	5.32	2237.1
12 SSR Inlet	1.24	590.2	0.11	3106.8
62 Add / extr of ST group 2	3.66	413.6	1.10	2729.0
82 Stream to GSC	0.83	N/A	0.03	3106.8
101 Heating steam at FWH1	3.45	411.6	1.10	2726.6
111 Drain liquid at FWH1	3.45	411.6	6.54	582.4
121 Feedwater into FWH1	3.45	308.4	5.44	148.0
142 Feed water leaving condenser	0.35	305.4	5.34	135.2
143 Cooling water into condenser	1.86	288.2	268.05	63.1
144 Cooling water leaving condenser	1.61	298.2	268.05	105.0
145 Feed water into boiler	44.71	412.7	6.41	590.1
146 Steam leaving superheater	44.52	647.0	6.48	3144.1
151 Boiler blow down	44.60	530.0	0.06	1120.1
205 Makeup	N/A	288.2	0.09	62.8
210 SSR to condenser	1.24	590.2	0.08	3106.8
213 Boiler desup. water from Boiler feed pump	50.92	412.6	0.13	590.1
Valve Stem leak 1 => SSR	N/A	N/A	0.01	3141.8
HPT HP leak 1 => SSR	N/A	N/A	0.10	3103.7


STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
File View Options Navigator Window Help
Navigator
New Session
Start Design
FWH Selection
Plant Criteria
Cooling System
ST Inputs
Port Definition
FWH/Pumps
Misc. Streams
Boiler Thermal
Boiler Sizing
Nuclear Cycle
Other PEACE
Economics
Compute
Text Output
Graphics Output
PEACE Output
Multiple Runs
Off Design
Cycle Schematic
Boiler Schematic
Boiler T-Q
ST Expansion
FWH T-Q
Pumps
ST Exhaust Loss Curve
Plant Summary
Steam Turbine
Feedwater System
Cooling System
ST Leakage
Boiler Feed Pump Turbine
Cooling System T-Q Diagram
Psychrometric Chart
Plant net power 4775 kW
Number of units 1
Plant net HR (HHV) 14435 kJ/kWh
Plant net HR (LHV) 13009 kJ/kWh
Plant net eff (HHV) 24.94 %
Plant net eff (LHV) 27.67 %
Aux. & losses 223.4 kW
Fuel heat input (HHV) 19147 kJ/s
Fuel heat input (LHV) 17256 kJ/s
Ambient
1.013 p
288.2 T
60% RH
4998 kW
G
4000 RPM
42.4 p
644.3 T
6.478 M
0.0483 p
305.4 T
5.345 M
399.5 T
7.582 M
0.3448 M Fuel (CH4)
7.238 M Air
412.7 T
C
p [bar] T [K] M [kg/s]


STEAM PRO 13.0 - C:\Tflow13\MYFILES\case5.stp
File View Options Navigator Window Help
Navigator
New Session
Start Design
FWH Selection
Plant Criteria
Cooling System
ST Inputs
Port Definition
FWH/Pumps
Misc. Streams
Boiler Thermal
Boiler Sizing
Nuclear Cycle
Other PEACE
Economics
Compute
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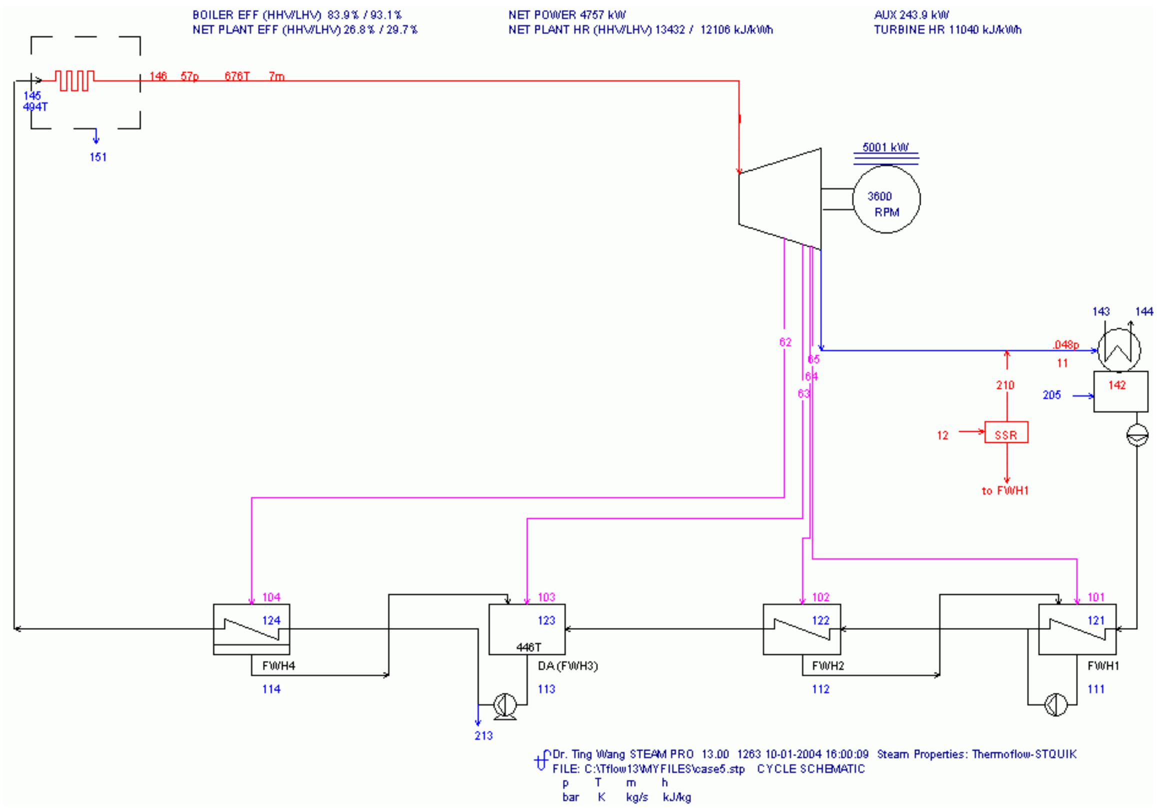
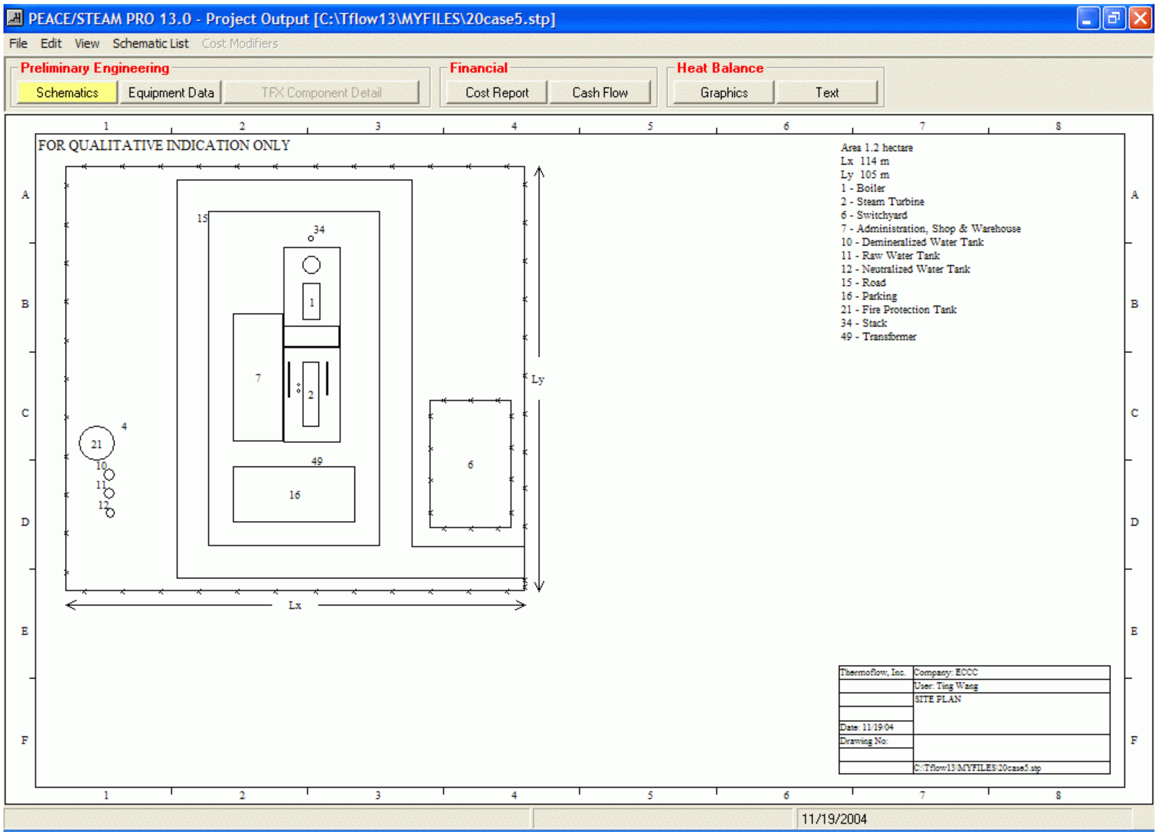
Graphics Output
PEACE Output
Multiple Runs
Off Design
Cycle Schematic
Boiler Schematic
Boiler T-Q
ST Expansion
FWH T-Q
Pumps
ST Exhaust Loss Curve
Plant Summary
Steam Turbine
Feedwater System
Cooling System
ST Leakage
Boiler Feed Pump Turbine
Cooling System T-Q Diagram
Psychrometric Chart
Expansion power 5224 kW
Mechanical loss 30.48 kW
Generator loss 117.1 kW
Generator power 4998 kW
42.4 p
644.3 T
6.478 M
3142 h
Exhaust
0.0483 p
305.4 T
5.267 M
2237.1 h
86.67 %
0
1
3.661 p
413.6 T
1.102 M
2729 h
p [bar] T [K] M [kg/s] h [kJ/kg]

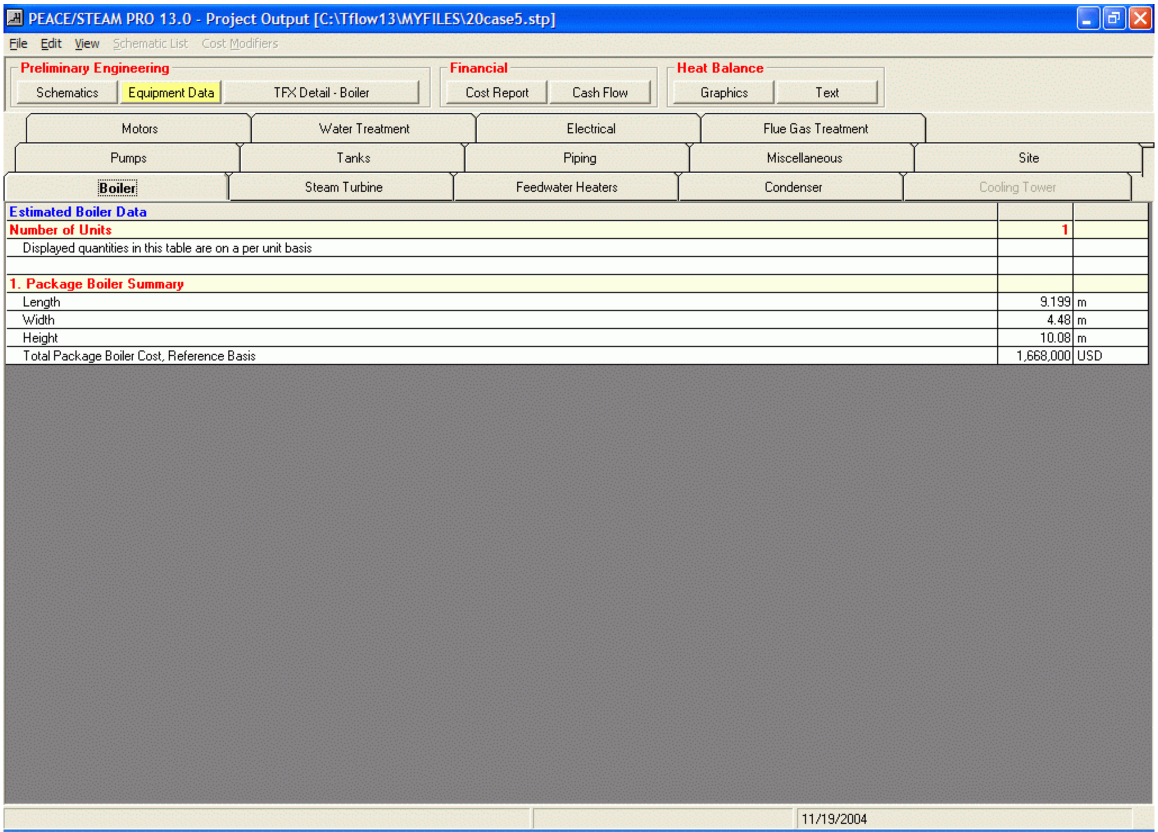
The Graphics Output shows the plant summary schematic diagram and steam turbine. Cycle schematic is useful for technical business proposals, schematic reference purposes etc.



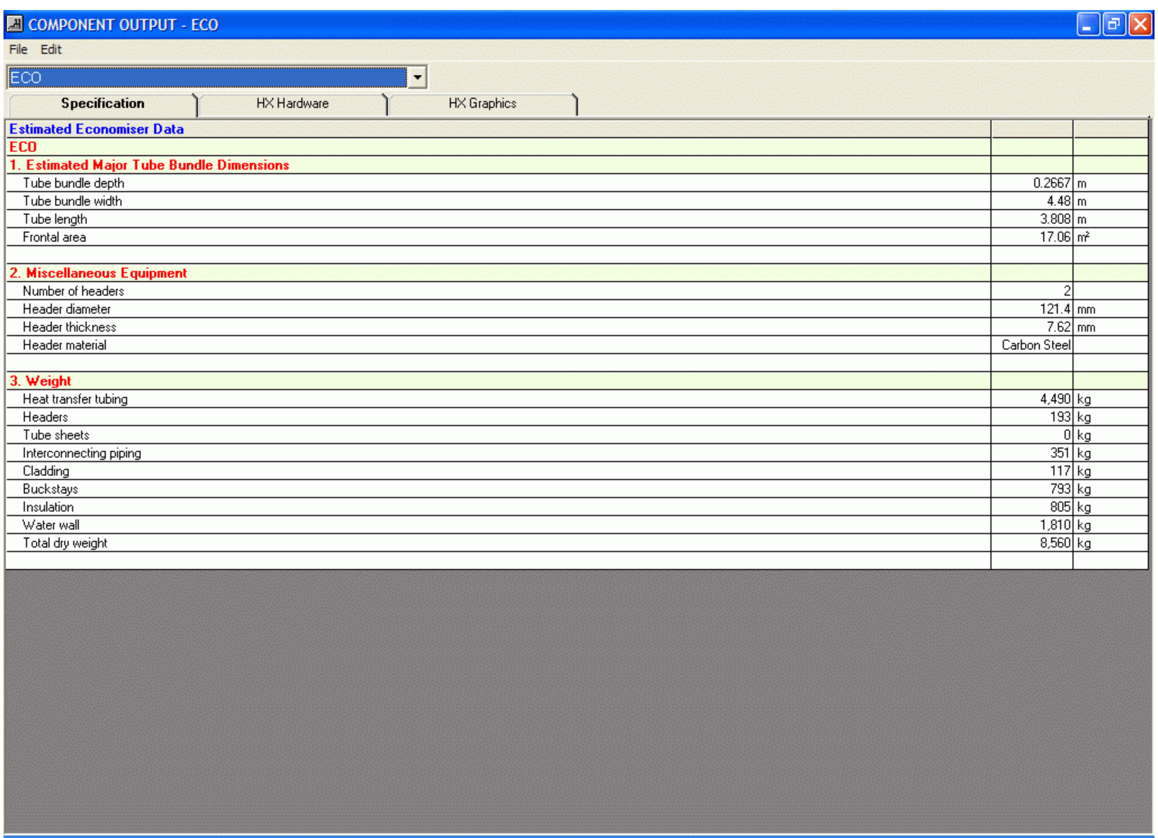


PEACE Project Output gives a professional engineering schematic of the steam power plant layout as shown above. This will give a good idea for an initially proposed layout of the plant and its components.

The next two pictures show the Equipment Data and an economizer Component Output from the TFX Detail Boiler.

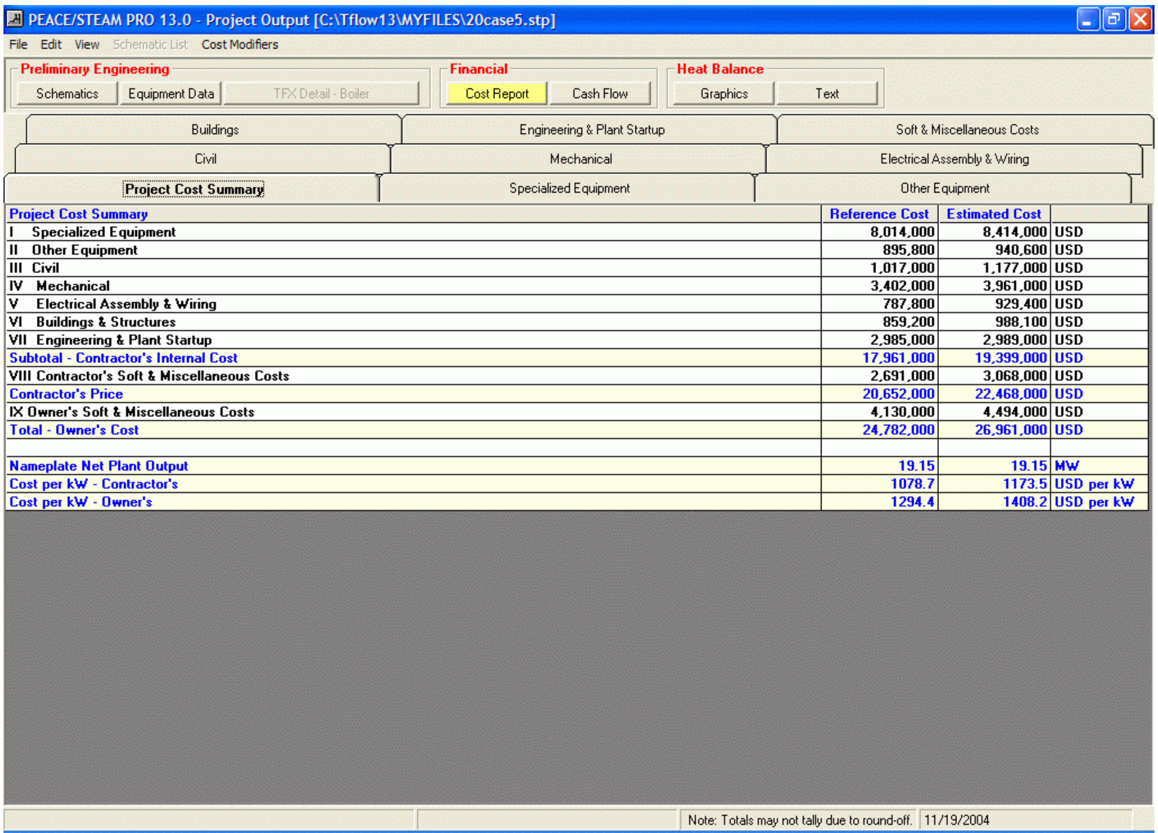


Estimated Boiler Data		
Number of Units	1	
Displayed quantities in this table are on a per unit basis		
1. Package Boiler Summary		
Length	9.199	m
Width	4.48	m
Height	10.08	m
Total Package Boiler Cost, Reference Basis	1,668,000	USD

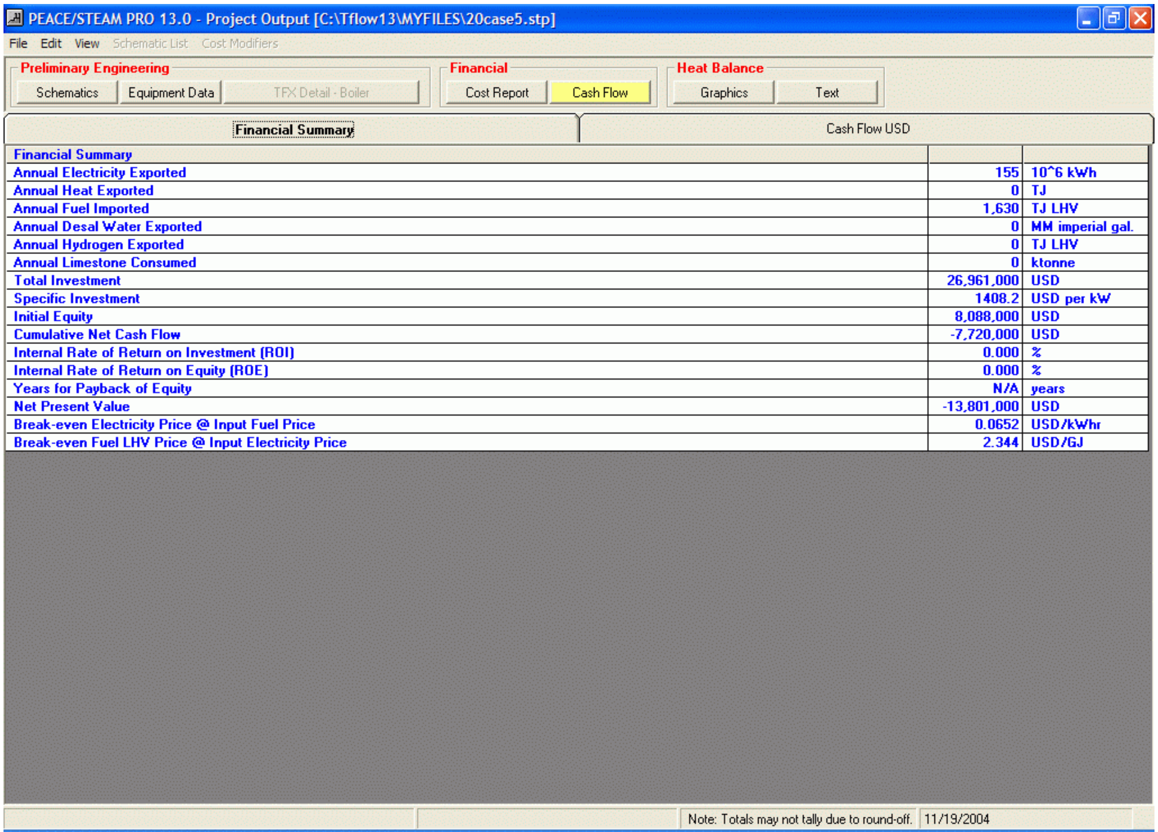


Estimated Economiser Data		
ECO		
1. Estimated Major Tube Bundle Dimensions		
Tube bundle depth	0.2667	m
Tube bundle width	4.48	m
Tube length	3.808	m
Frontal area	17.06	m²
2. Miscellaneous Equipment		
Number of headers	2	
Header diameter	121.4	mm
Header thickness	7.62	mm
Header material	Carbon Steel	
3. Weight		
Heat transfer tubing	4,490	kg
Headers	193	kg
Tube sheets	0	kg
Interconnecting piping	351	kg
Cladding	117	kg
Buckstays	793	kg
Insulation	805	kg
Water wall	1,810	kg
Total dry weight	8,560	kg

The next 3 pictures are the last portions of the results for the Steam Pro PEACE for startup Cost Report and Cash Flow.



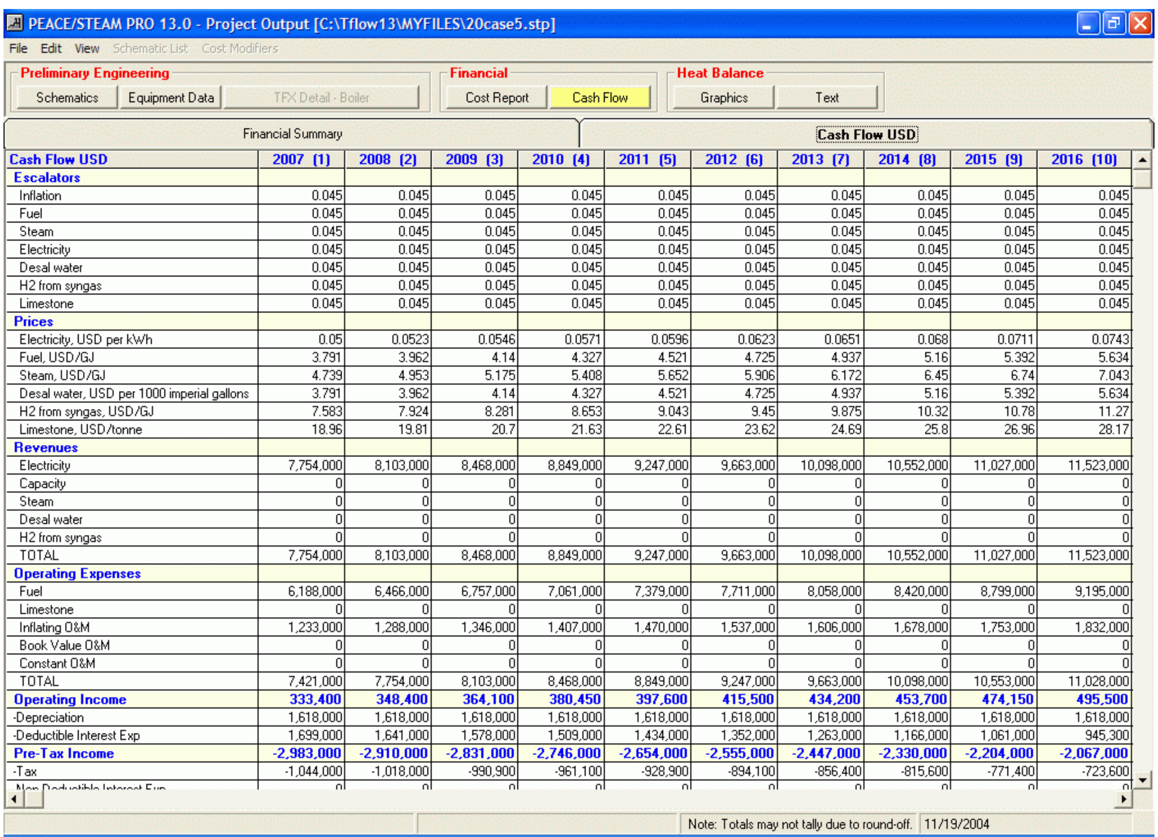
Project Cost Summary	Reference Cost	Estimated Cost	
I Specialized Equipment	8,014,000	8,414,000	USD
II Other Equipment	895,800	940,600	USD
III Civil	1,017,000	1,177,000	USD
IV Mechanical	3,402,000	3,961,000	USD
V Electrical Assembly & Wiring	787,800	929,400	USD
VI Buildings & Structures	859,200	988,100	USD
VII Engineering & Plant Startup	2,985,000	2,989,000	USD
Subtotal - Contractor's Internal Cost	17,961,000	19,399,000	USD
VIII Contractor's Soft & Miscellaneous Costs	2,691,000	3,068,000	USD
Contractor's Price	20,652,000	22,468,000	USD
IX Owner's Soft & Miscellaneous Costs	4,130,000	4,494,000	USD
Total - Owner's Cost	24,782,000	26,961,000	USD
Nameplate Net Plant Output	19.15	19.15	MW
Cost per kW - Contractor's	1078.7	1173.5	USD per kW
Cost per kW - Owner's	1294.4	1408.2	USD per kW



PEACE/STEAM PRO 13.0 - Project Output [C:\Tflow13\MYFILES\20case5.stp]

Financial Summary		
Annual Electricity Exported	155	10^6 kWh
Annual Heat Exported	0	TJ
Annual Fuel Imported	1,630	TJ LHV
Annual Desal Water Exported	0	MM imperial gal.
Annual Hydrogen Exported	0	TJ LHV
Annual Limestone Consumed	0	ktonne
Total Investment	26,961,000	USD
Specific Investment	1408.2	USD per kW
Initial Equity	8,088,000	USD
Cumulative Net Cash Flow	-7,720,000	USD
Internal Rate of Return on Investment (ROI)	0.000	%
Internal Rate of Return on Equity (ROE)	0.000	%
Years for Payback of Equity	N/A	years
Net Present Value	-13,801,000	USD
Break-even Electricity Price @ Input Fuel Price	0.0652	USD/kWhr
Break-even Fuel LHV Price @ Input Electricity Price	2.344	USD/GJ

Note: Totals may not tally due to round-off. 11/19/2004



PEACE/STEAM PRO 13.0 - Project Output [C:\Tflow13\MYFILES\20case5.stp]

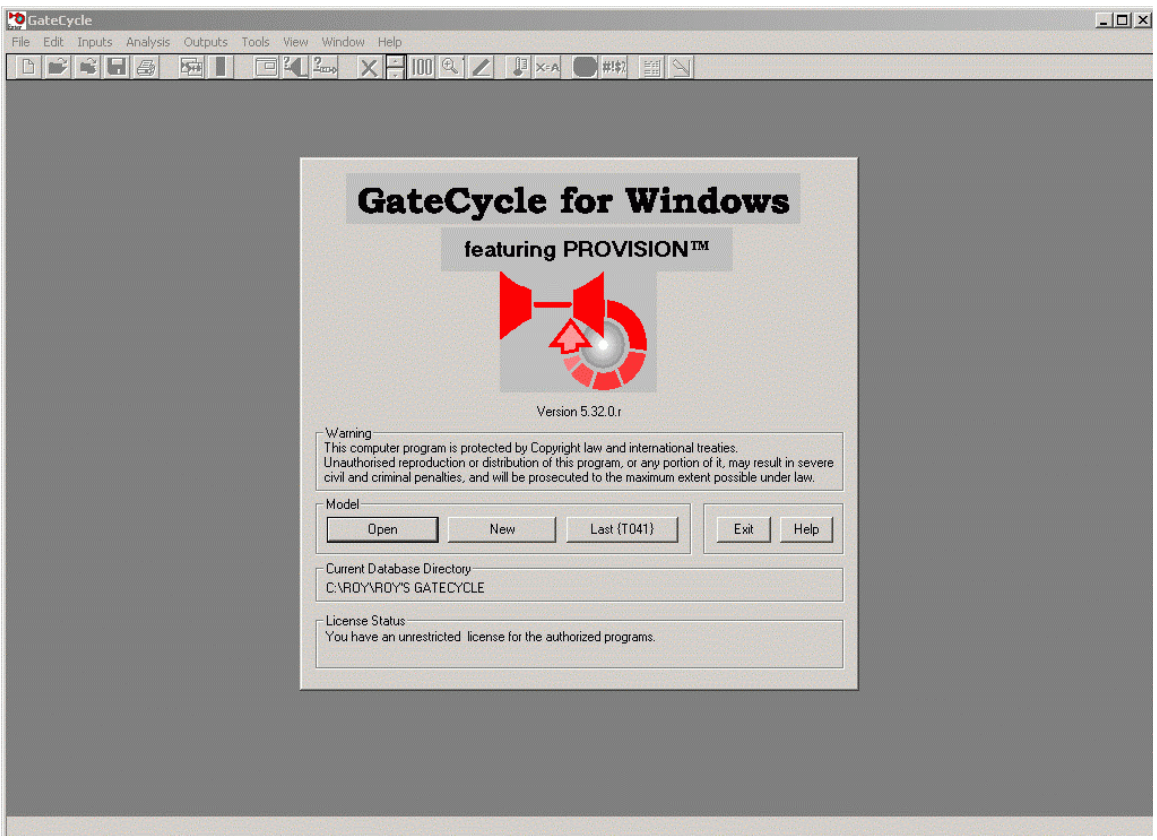
Cash Flow USD	2007 (1)	2008 (2)	2009 (3)	2010 (4)	2011 (5)	2012 (6)	2013 (7)	2014 (8)	2015 (9)	2016 (10)
Escalators										
Inflation	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Fuel	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Steam	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Electricity	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Desal water	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
H2 from syngas	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Limestone	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Prices										
Electricity, USD per kWh	0.05	0.0523	0.0546	0.0571	0.0596	0.0623	0.0651	0.068	0.0711	0.0743
Fuel, USD/GJ	3.791	3.962	4.14	4.327	4.521	4.725	4.937	5.16	5.392	5.634
Steam, USD/GJ	4.739	4.953	5.175	5.408	5.652	5.906	6.172	6.45	6.74	7.043
Desal water, USD per 1000 imperial gallons	3.791	3.962	4.14	4.327	4.521	4.725	4.937	5.16	5.392	5.634
H2 from syngas, USD/GJ	7.583	7.924	8.281	8.653	9.043	9.45	9.875	10.32	10.78	11.27
Limestone, USD/tonne	18.96	19.81	20.7	21.63	22.61	23.62	24.69	25.8	26.96	28.17
Revenues										
Electricity	7,754,000	8,103,000	8,468,000	8,849,000	9,247,000	9,663,000	10,098,000	10,552,000	11,027,000	11,523,000
Capacity	0	0	0	0	0	0	0	0	0	0
Steam	0	0	0	0	0	0	0	0	0	0
Desal water	0	0	0	0	0	0	0	0	0	0
H2 from syngas	0	0	0	0	0	0	0	0	0	0
TOTAL	7,754,000	8,103,000	8,468,000	8,849,000	9,247,000	9,663,000	10,098,000	10,552,000	11,027,000	11,523,000
Operating Expenses										
Fuel	6,188,000	6,466,000	6,757,000	7,061,000	7,379,000	7,711,000	8,058,000	8,420,000	8,799,000	9,195,000
Limestone	0	0	0	0	0	0	0	0	0	0
Inflating O&M	1,233,000	1,288,000	1,346,000	1,407,000	1,470,000	1,537,000	1,606,000	1,678,000	1,753,000	1,832,000
Book Value O&M	0	0	0	0	0	0	0	0	0	0
Constant O&M	0	0	0	0	0	0	0	0	0	0
TOTAL	7,421,000	7,754,000	8,103,000	8,468,000	8,849,000	9,247,000	9,663,000	10,098,000	10,553,000	11,028,000
Operating Income	333,400	348,400	364,100	380,450	397,600	415,500	434,200	453,700	474,150	495,500
-Depreciation	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000	1,618,000
-Deductible Interest Exp	1,699,000	1,641,000	1,578,000	1,509,000	1,434,000	1,352,000	1,263,000	1,166,000	1,061,000	945,300
Pre-Tax Income	-2,983,000	-2,910,000	-2,831,000	-2,746,000	-2,654,000	-2,555,000	-2,447,000	-2,330,000	-2,204,000	-2,067,000
-Tax	-1,044,000	-1,018,000	-990,900	-961,100	-928,900	-894,100	-856,400	-815,600	-771,400	-723,600

Note: Totals may not tally due to round-off. 11/19/2004

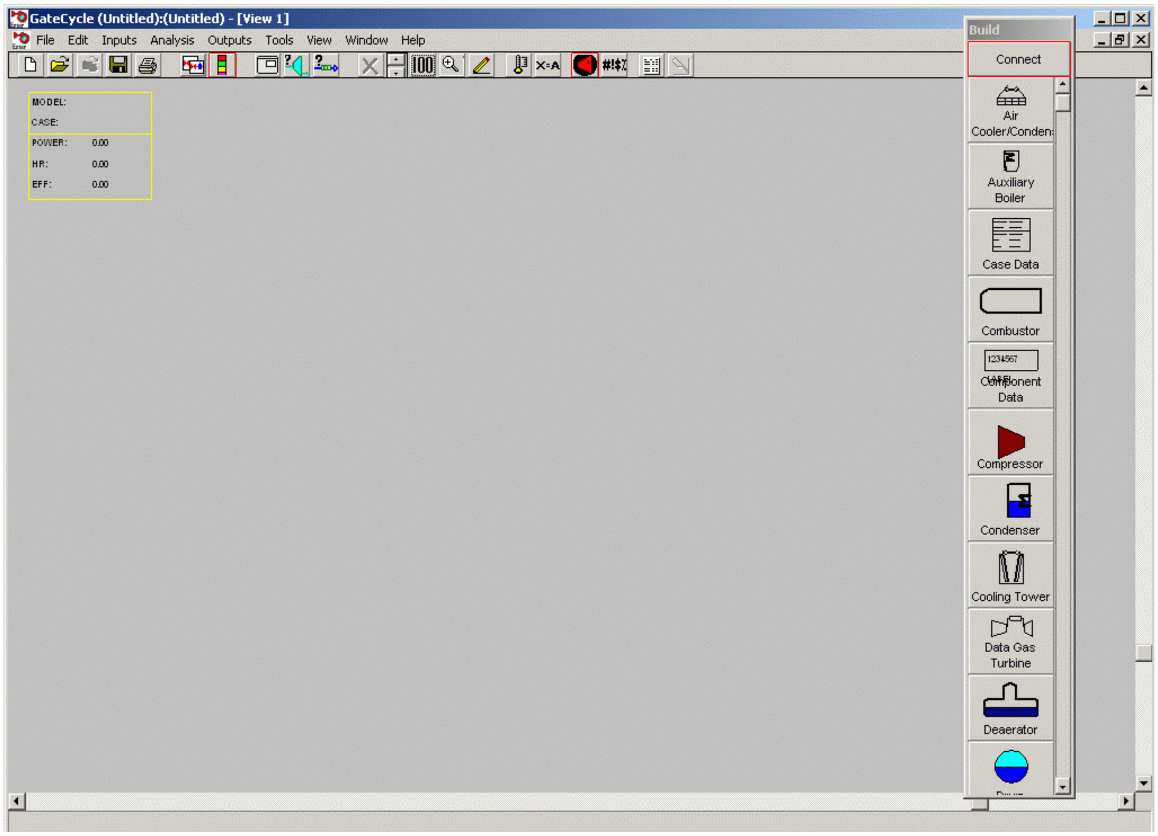
APPENDIX B

G.E. Enter GateCycle Simulation

The General Electric's Enter GateCycle software can be accessed from the Windows desktop icon or else by clicking the Star button, select and expand the Programs and look for the GateCycle group of programs. Expand the group and select the GateCycle software. The initial Graphical User Interface (GUI) image should look like the screen capture image shown below:

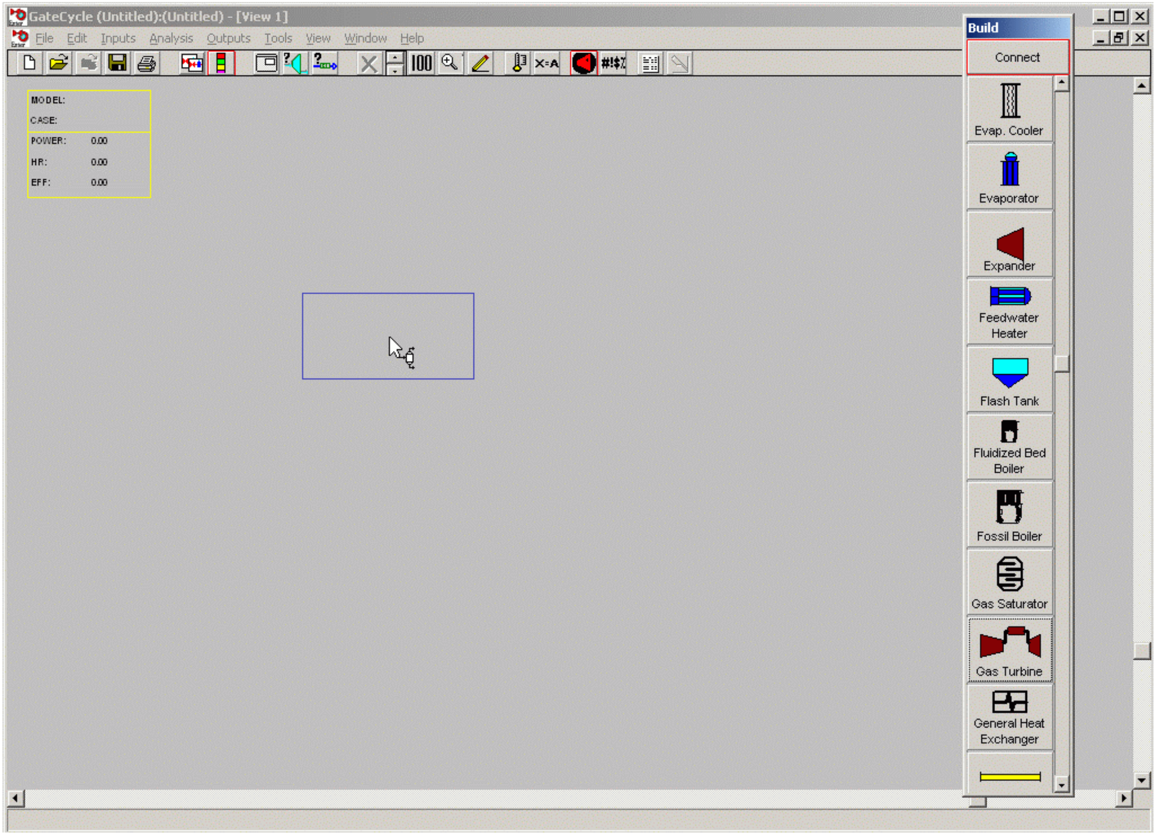


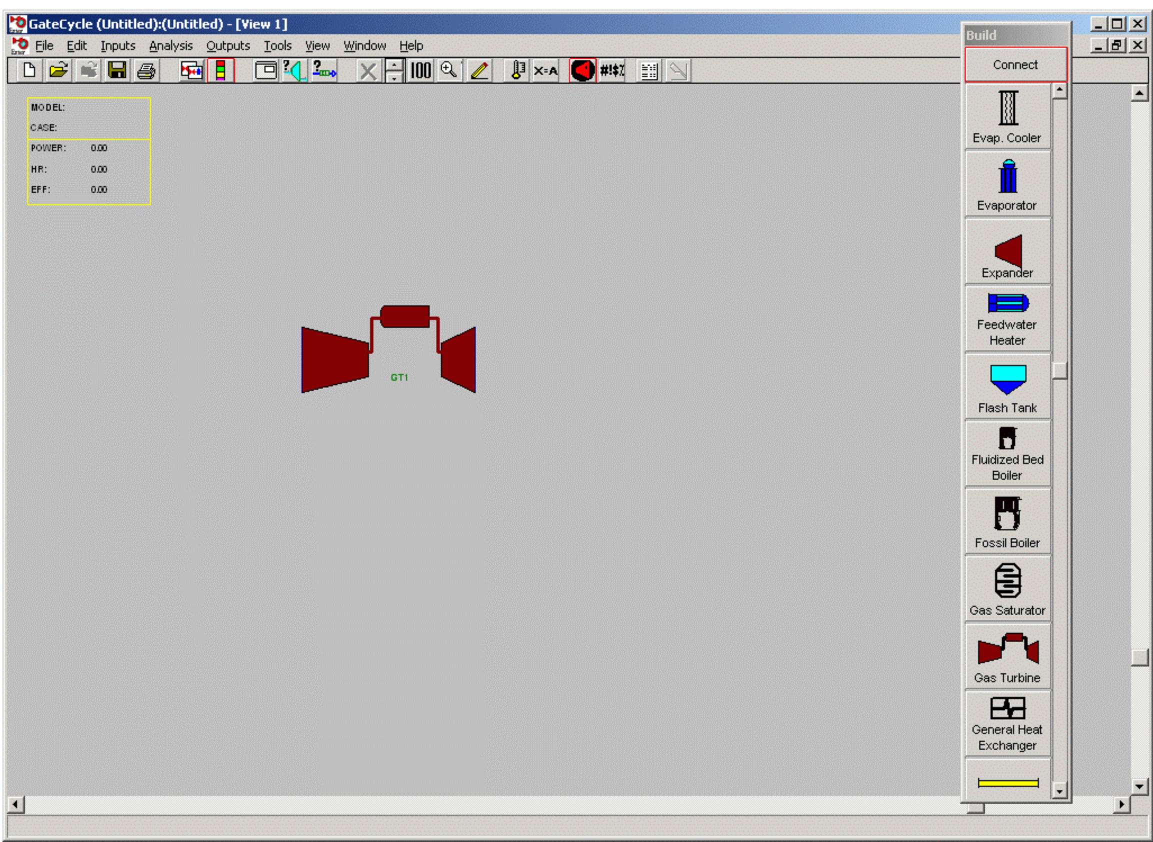
The new button is pressed in order to start a new GateCycle model, Open is used to open an existing file and the Last button is for the convenience of opening the most recently opened model in a previous session. This process is assumed that the license for the software is properly installed. The New button is clicked for a new session leading to the next step.



The GateCycle is similar to a drawing board where an empty space is given to the designer to insert the needed components to make either a complete power plant, or just a component. This means that the user may very well build their own gas turbine (GT) from scratch, consisting of the compressor, combustor and the expansion turbine. If the long Build tool bar is not visible as shown above, click the 7th icon from the left, which looks like a long and tall bar.

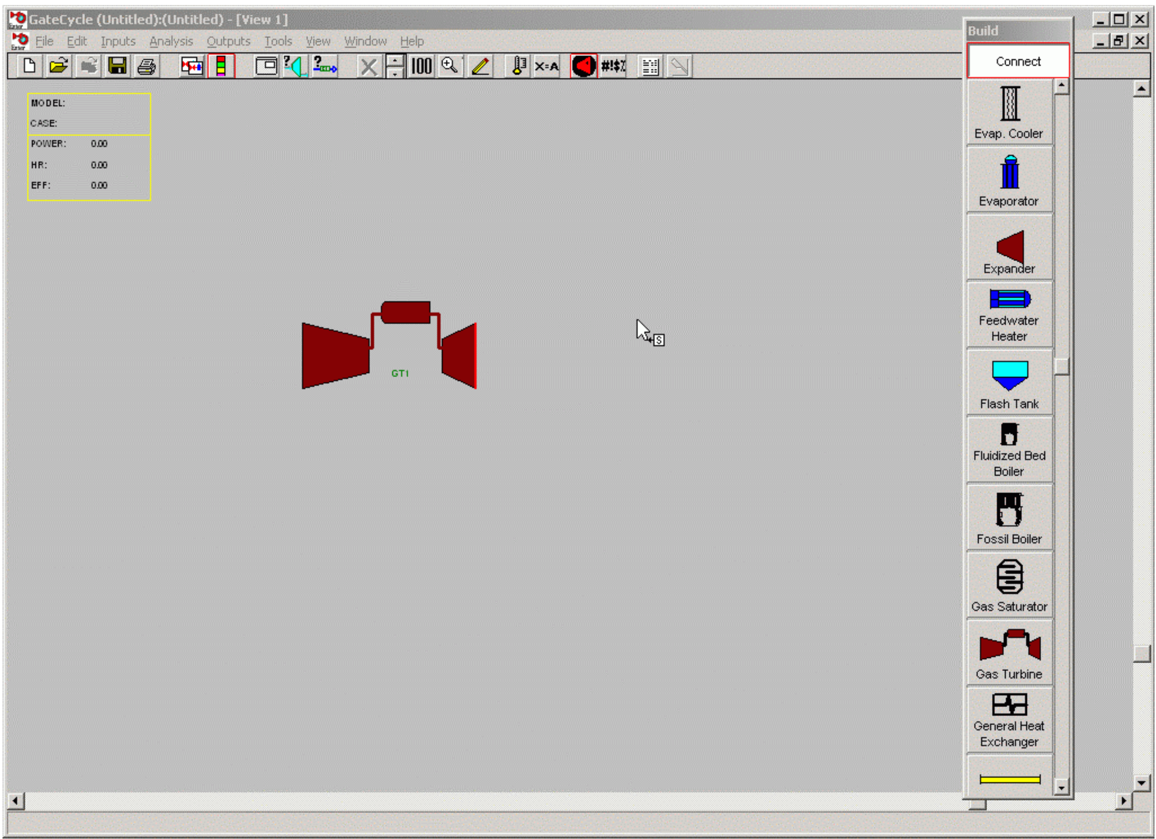
Click an icon to select the component that you want to drop onto the drawing board. Note that a summary box on the top left hand corner contains Model and Case name, Power, Heat Rate (HR) and Efficiency (EFF), which will be filled with values upon successful convergence of the simulation. The next two screen shot shows the selection and placing of a GT onto the drawing design space.


GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger

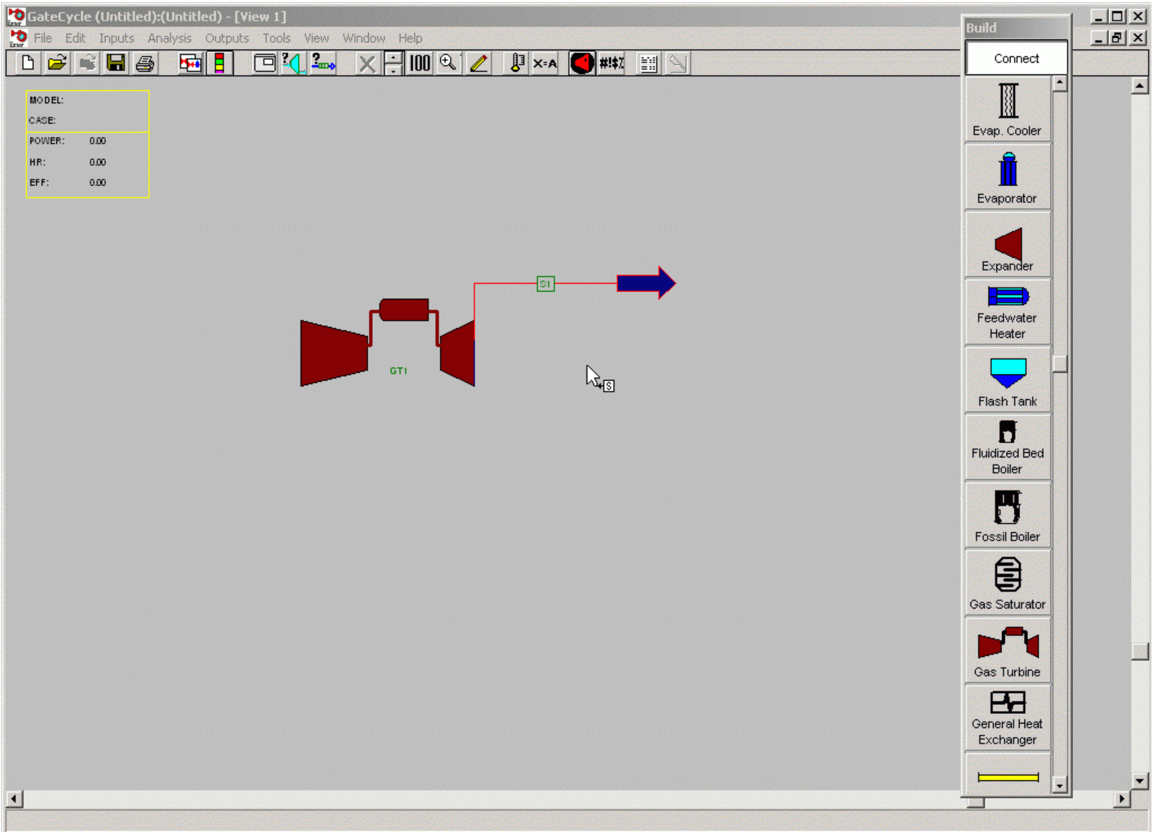

GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
GT1
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger

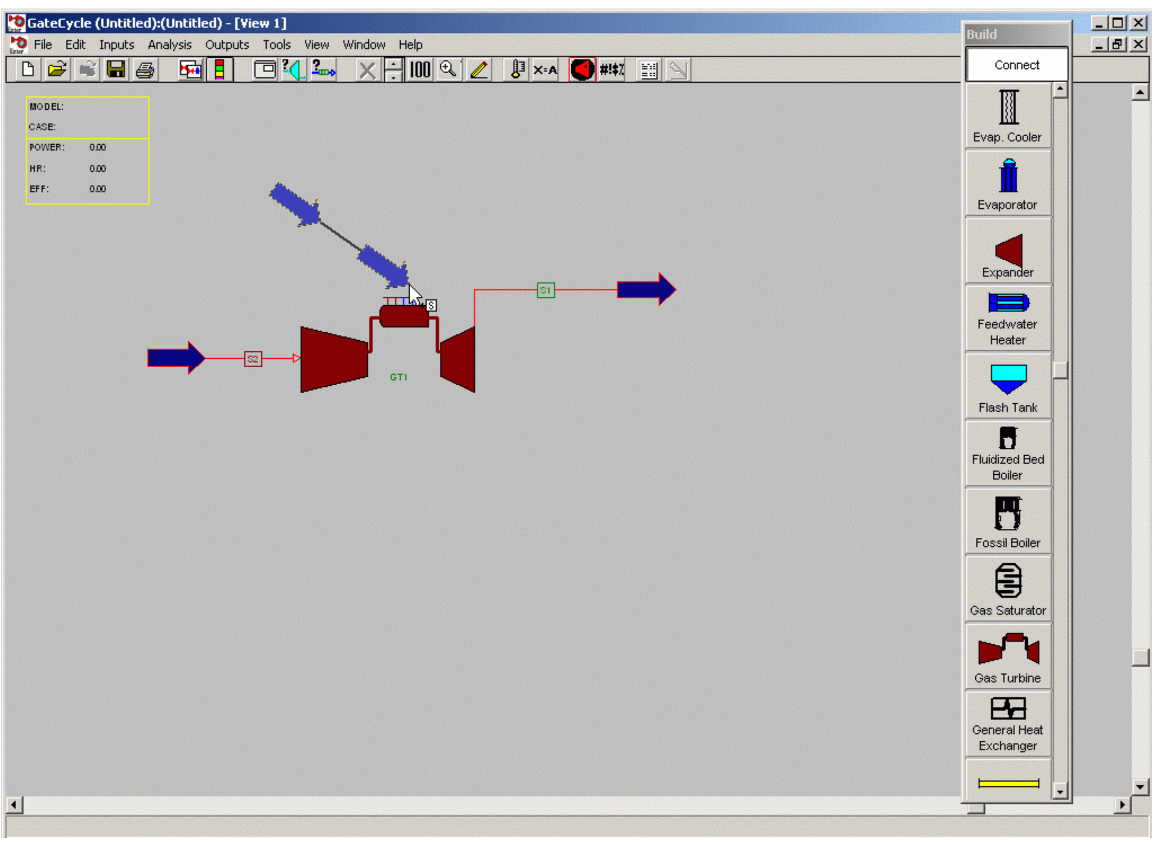
More components may be selected and dropped onto the drawing design space like a heat recovery steam generator (HRSG), which is made up of a superheater, evaporator and economizer, and a steam turbine. With these components, a combined cycle can be designed and simulated.

When all the needed components are placed on the drawing design space, clicking the Connect button located at the top of the Build toolbar links the components. The mouse pointer will change its look and the components with an exit port will turn red.

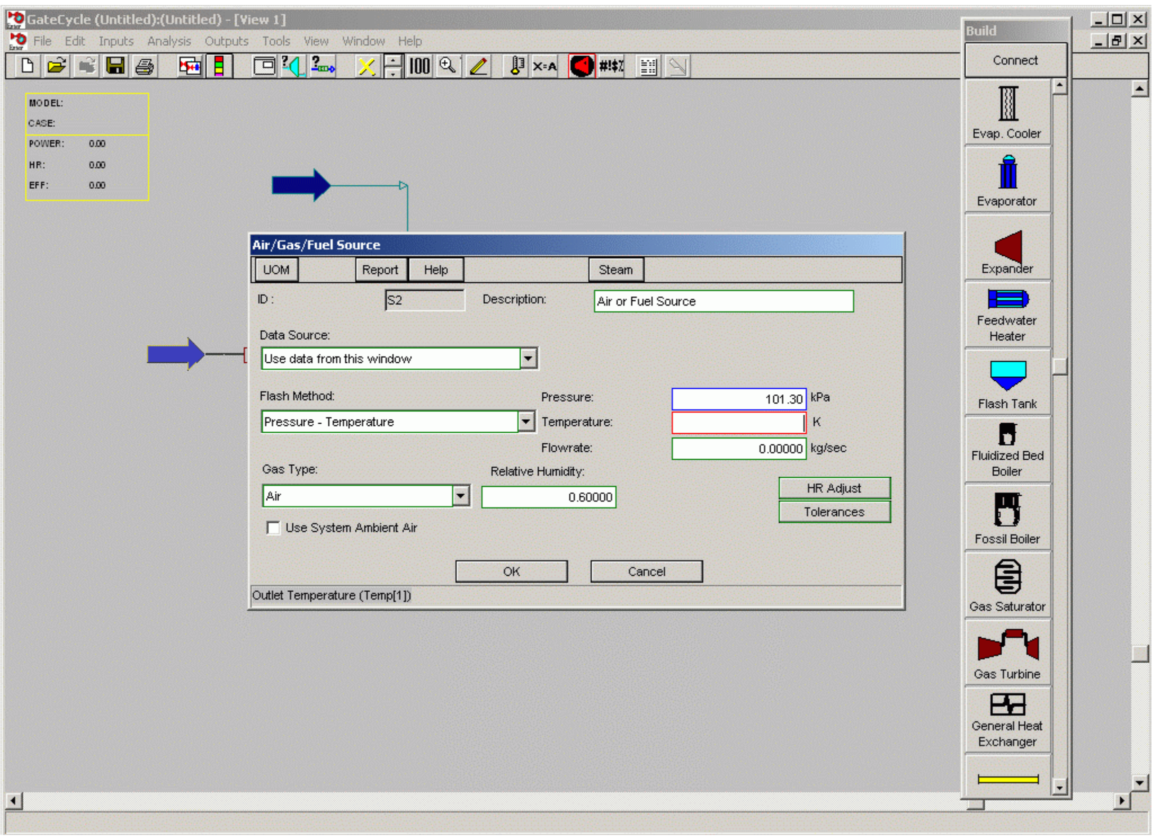


Click on the exit port and drag the mouse pointer to draw an exit stream. The streams are labeled sequentially from the first to the last stream connection made. The next two screen shots show the process of drawing an inlet and exit streams.

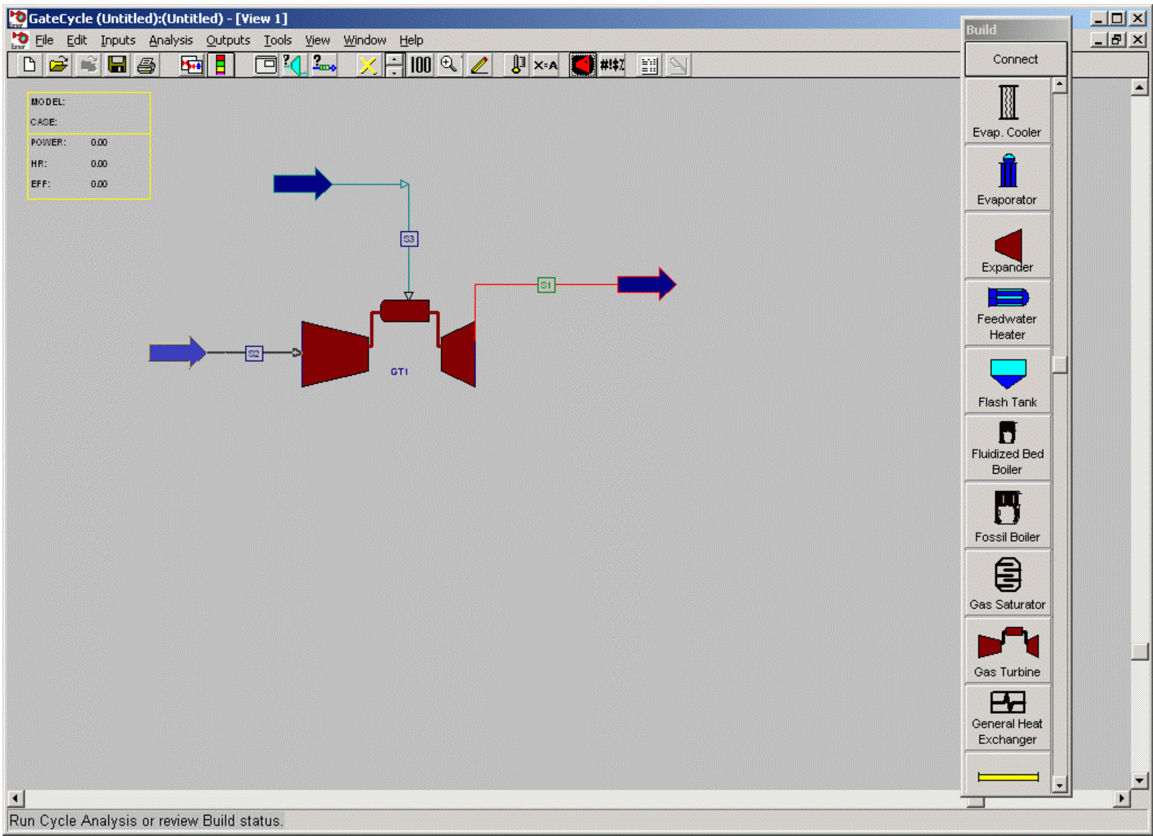

GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
GT1
S1
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger

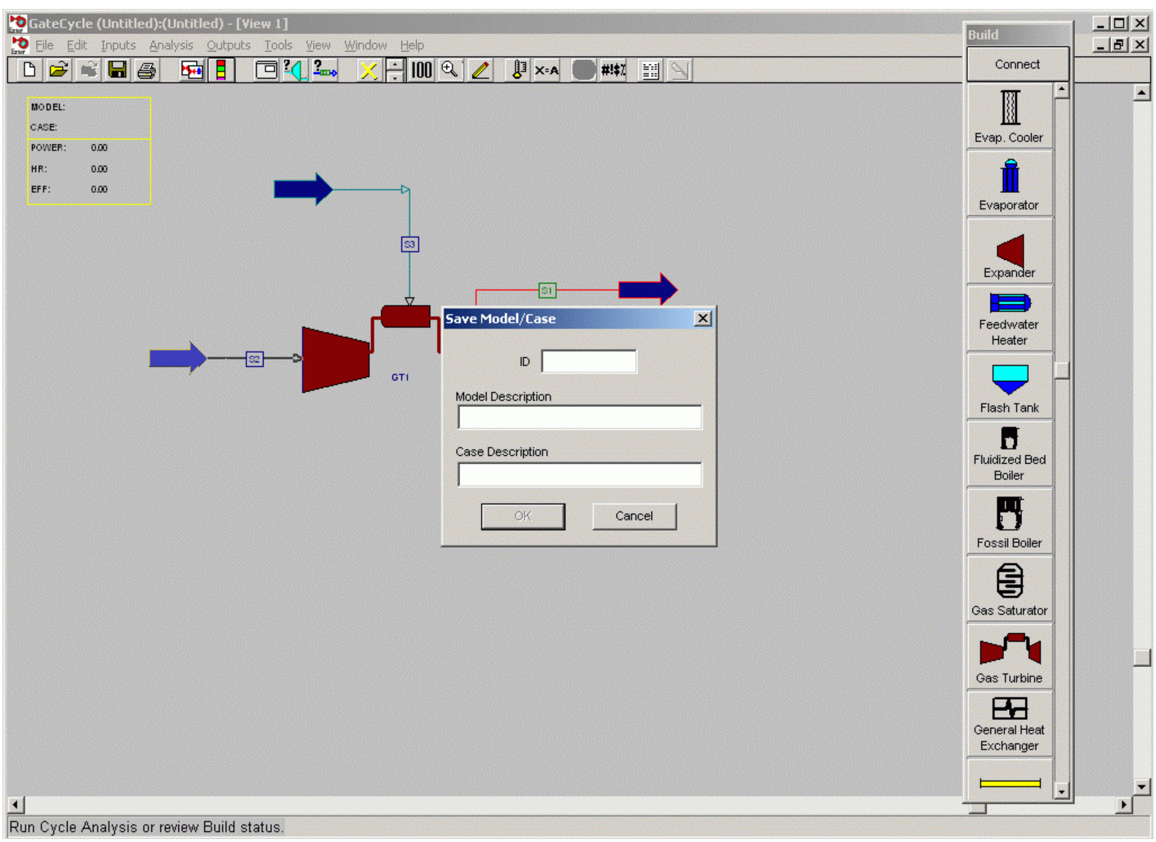

GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
GT1
S1
S2
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger

The simulation button is 4th from the right A red outline signals that the stream and component information are insufficient to initiate the simulation. Upon clicking the simulation button, a window will appear with the undefined stream and component information, if there is not enough information specified. The user needs to double click the red streams and components, and inserts the necessary parameters. The red boxes will turn blue as the user defines it. The green boxes contain system default values.

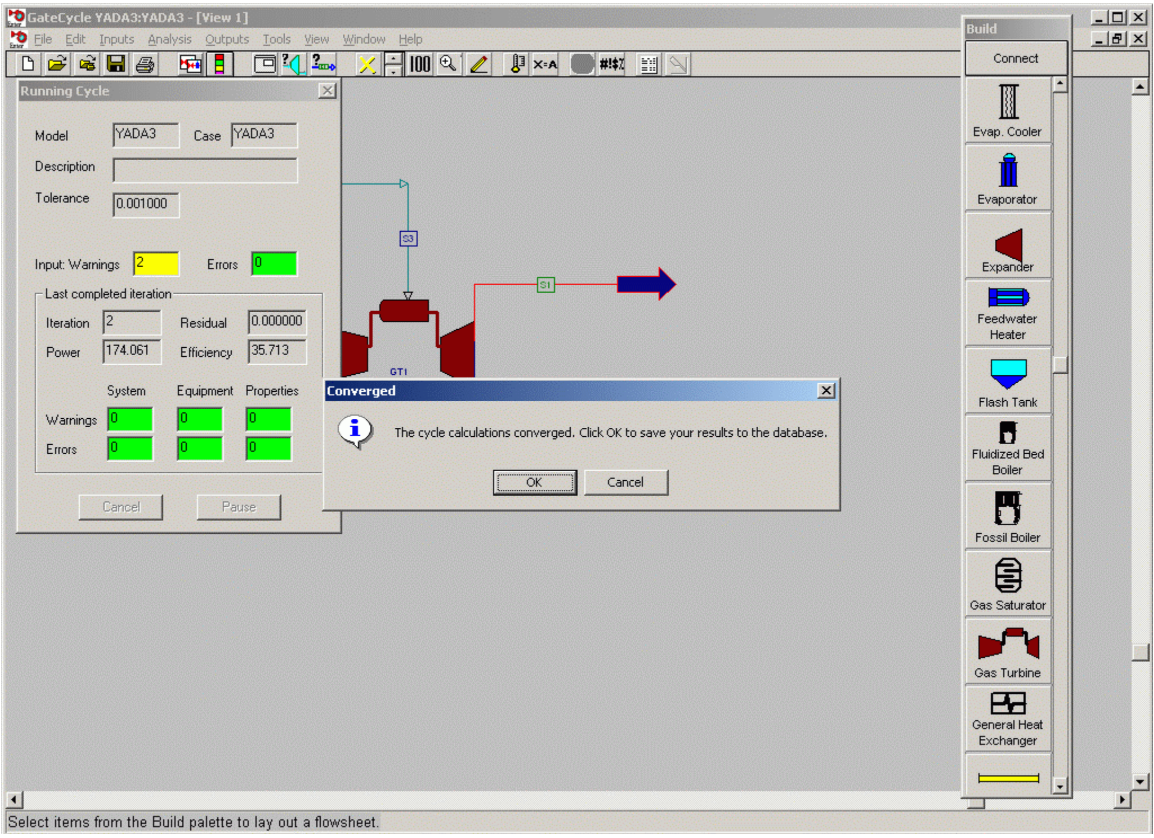


The next two screen shots show a model ready to be simulated (the red box surrounding the simulation button is removed) and a Save Model / Case appears if the Model or Case has not been saved prior to the start of the design.

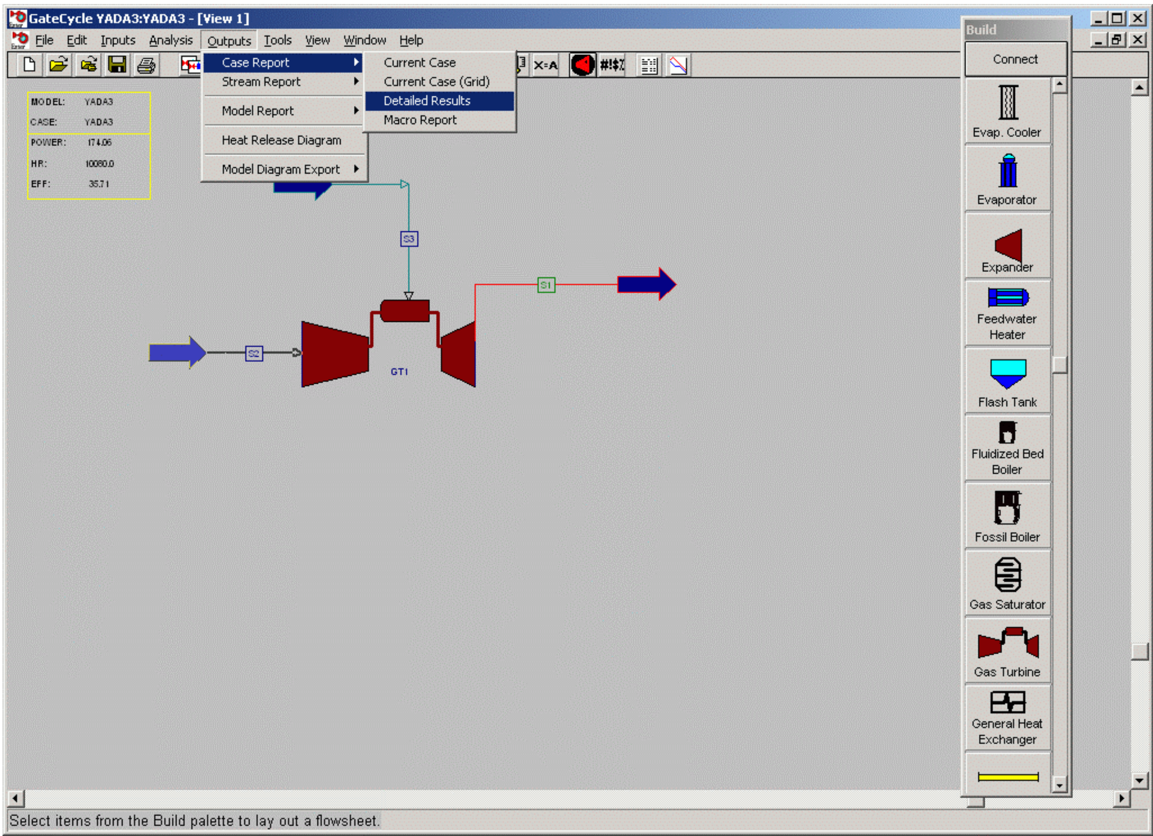

GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
S3
S1
S2
GT1
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger
Run Cycle Analysis or review Build status.

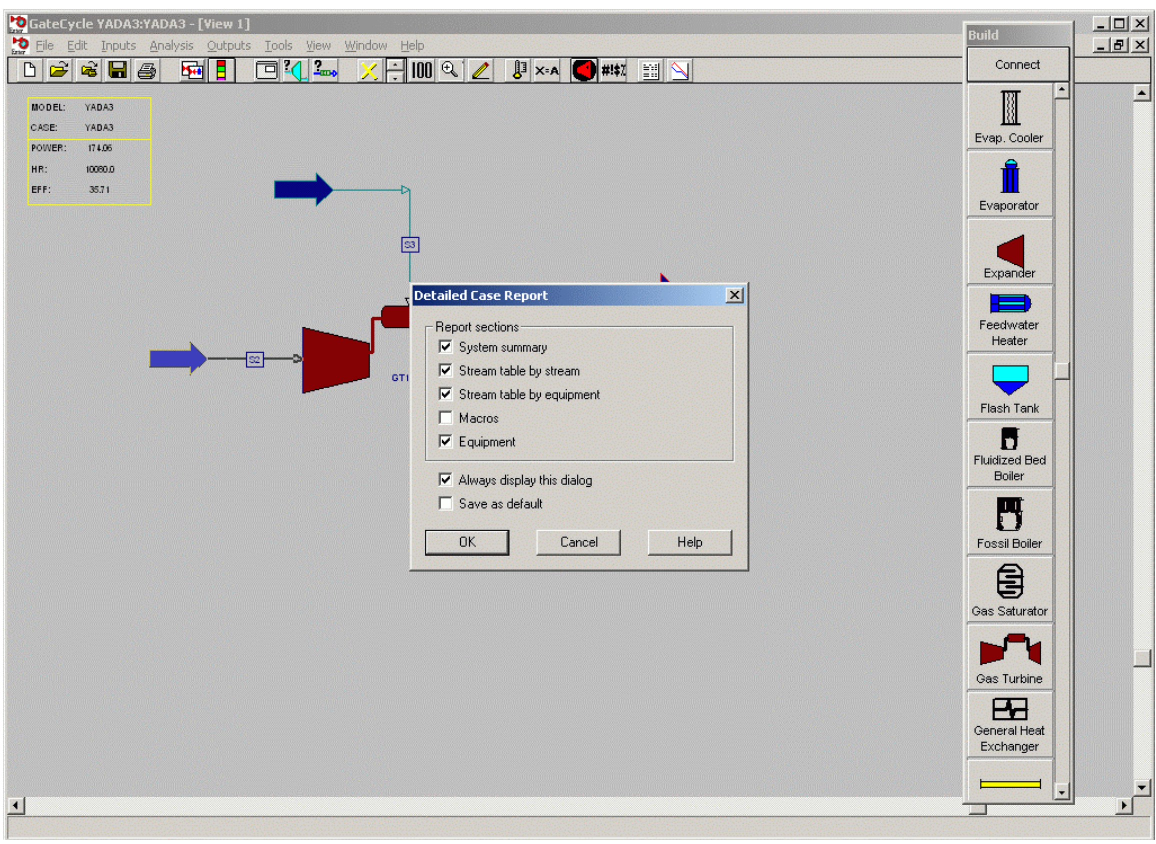

GateCycle (Untitled):(Untitled) - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL:
CASE:
POWER: 0.00
HR: 0.00
EFF: 0.00
S3
S1
S2
GT1
Save Model/Case
ID
Model Description
Case Description
OK
Cancel
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger
Run Cycle Analysis or review Build status.

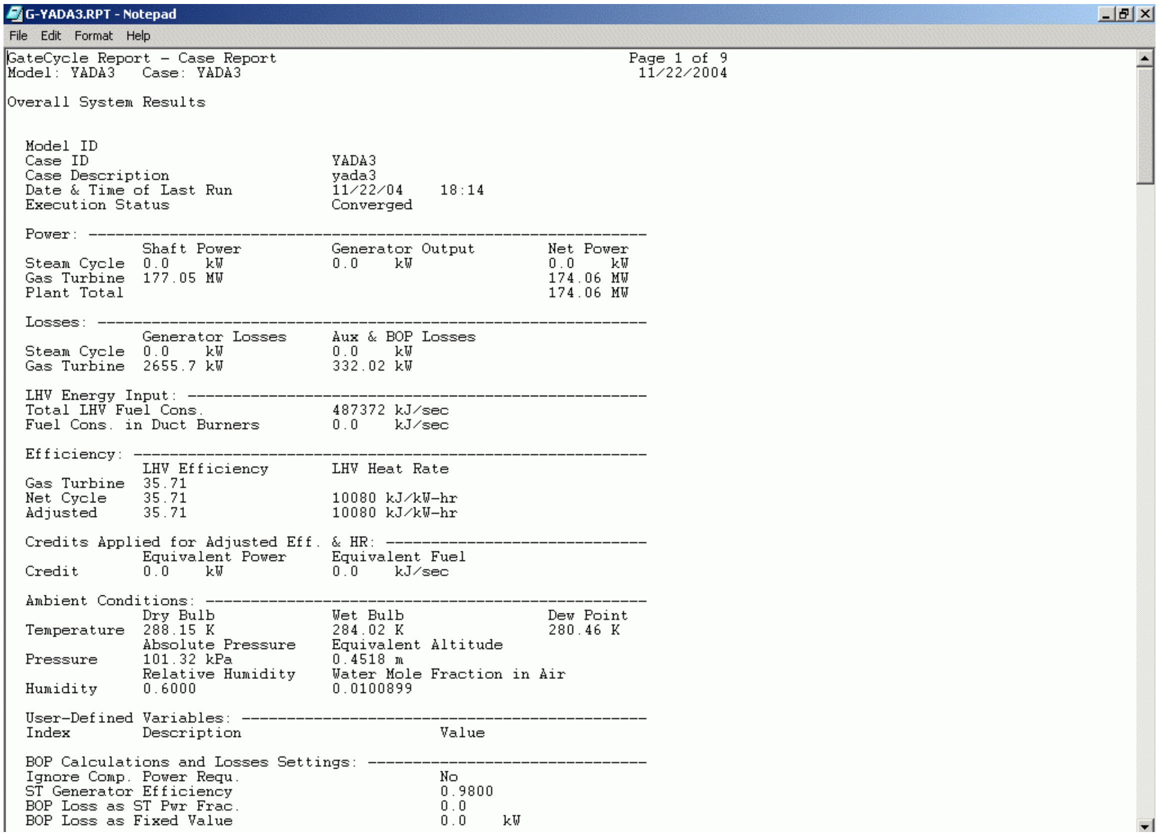
The simulation is running as soon as the Running Cycle window opens. Upon successfully reaching convergence, the “Converged” information window opens and asks to click ok to save the results to the model’s or case’s database.



The method of viewing the results is shown in the next two screen shots via output complete text with various choices.

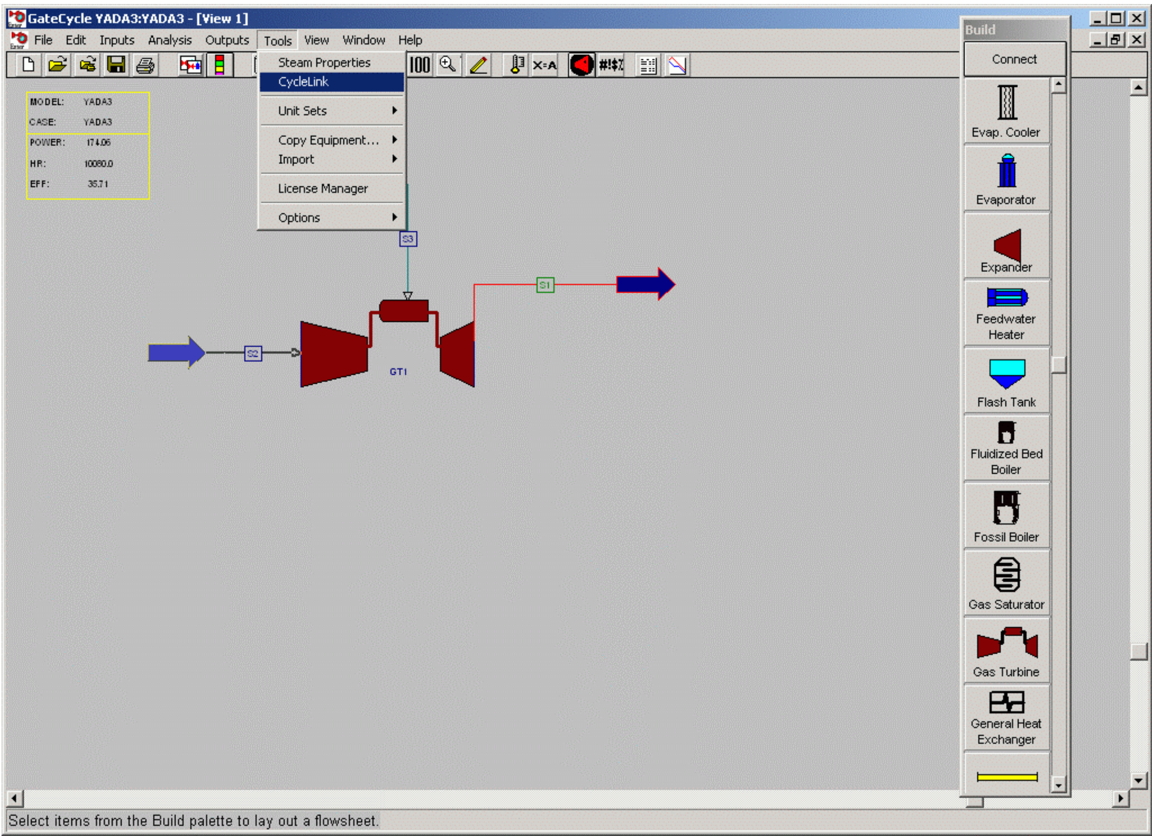

GateCycle YADA3:YADA3 - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
Case Report
Stream Report
Model Report
Heat Release Diagram
Model Diagram Export
Current Case
Current Case (Grid)
Detailed Results
Macro Report
MODEL: YADA3
CASE: YADA3
POWER: 174.06
HR: 10080.0
EFF: 35.71
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger
Select items from the Build palette to lay out a flowsheet.


GateCycle YADA3:YADA3 - [View 1]
File Edit Inputs Analysis Outputs Tools View Window Help
MODEL: YADA3
CASE: YADA3
POWER: 174.06
HR: 10080.0
EFF: 35.71
Detailed Case Report
Report sections
System summary
Stream table by stream
Stream table by equipment
Macros
Equipment
Always display this dialog
Save as default
OK
Cancel
Help
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger



```
G-YADA3.RPT - Notepad
File  Edit  Format  Help
GateCycle Report - Case Report                                      Page 1 of 9
Model: YADA3   Case: YADA3                                           11/22/2004

Overall System Results


  Model ID
  Case ID                          YADA3
  Case Description                 yada3
  Date & Time of Last Run          11/22/04     18:14
  Execution Status                 Converged

  Power: ---------------------------------------------------------------
              Shaft Power          Generator Output        Net Power
  Steam Cycle  0.0    kW           0.0    kW               0.0    kW
  Gas Turbine  177.05 MW                                   174.06 MW
  Plant Total                                              174.06 MW

  Losses: --------------------------------------------------------------
              Generator Losses     Aux & BOP Losses
  Steam Cycle  0.0    kW           0.0    kW
  Gas Turbine  2655.7 kW           332.02 kW

  LHV Energy Input: ----------------------------------------------------
  Total LHV Fuel Cons.             487372 kJ/sec
  Fuel Cons. in Duct Burners       0.0    kJ/sec

  Efficiency: ----------------------------------------------------------
              LHV Efficiency       LHV Heat Rate
  Gas Turbine  35.71
  Net Cycle    35.71               10080 kJ/kW-hr
  Adjusted     35.71               10080 kJ/kW-hr

  Credits Applied for Adjusted Eff. & HR: -----------------------------
              Equivalent Power     Equivalent Fuel
  Credit       0.0    kW           0.0    kJ/sec

  Ambient Conditions: --------------------------------------------------
              Dry Bulb             Wet Bulb                Dew Point
  Temperature  288.15 K            284.02 K                280.46 K
              Absolute Pressure    Equivalent Altitude
  Pressure     101.32 kPa          0.4518 m
              Relative Humidity    Water Mole Fraction in Air
  Humidity     0.6000              0.0100899

  User-Defined Variables: ----------------------------------------------
  Index       Description                 Value

  BOP Calculations and Losses Settings: --------------------------------
  Ignore Comp. Power Requ.                    No
  ST Generator Efficiency                     0.9800
  BOP Loss as ST Pwr Frac.                    0.0
  BOP Loss as Fixed Value                     0.0    kW
```

The text output would look like the above screen shot. Another advantageous output from the GateCycle is the Cyclelink, which enables exportation of the simulated data and automatic building of Visual Basic macros of the entire plant into the Microsoft Excel spreadsheet. The Cyclelink enables the exported data to be run in Excel even without the GateCycle present and is useful for sharing a design and re-simulation of the plant based on different input parameters. Unfortunately, the design and the macros cannot be edited in the exported format.


GateCycle YADA3:YADA3 - [View 1]
File
Edit
Inputs
Analysis
Outputs
Tools
View
Window
Help
Steam Properties
CycleLink
Unit Sets
Copy Equipment...
Import
License Manager
Options
MODEL: YADA3
CASE: YADA3
Build
Connect
Evap. Cooler
Evaporator
Expander
Feedwater Heater
Flash Tank
Fluidized Bed Boiler
Fossil Boiler
Gas Saturator
Gas Turbine
General Heat Exchanger
Select items from the Build palette to lay out a flowsheet.

APPENDIX C: COMPLETE THERMOFLOW SIMULATION OUTPUTS

GT PRO 13.0 Ting Wang

1263 11-03-2004 17:43:57 file=C:/Tflow13/MYFILES/case1.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	4879		11419		31.53	
Steam Turbine(s)	0					
Plant Total	4879	4692	11419	11874	31.53	30.32

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
30.32	30.32	30.32	12670

GT fuel HHV/LHV ratio = 1.1096 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1096
Fuel HHV chemical energy input = 17173 kWth = 58600 kBTU/h
Fuel LHV chemical energy input = 15477 kWth = 52811 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15477 kWth = 52811 kBTU/h
Energy chargeable to power = 15477 kWth = 52811 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	4879	31.53	11419	16	900
Total	4879			16	

Fuel chemical HHV per gas turbine = 17173 kWth = 58600 kBTU/h
Fuel chemical LHV per gas turbine = 15477 kWth = 52811 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 10610 kWth = 36203 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
80	0	0	10	0	0	0	0

HVAC = 2.5 kW, Lights = 3.25 kW
Additional auxiliaries from PEACE running motor/load list = 64.25 kW
Miscellaneous plant auxiliaries = 2.44 kW
Program estimated overall plant auxiliaries = 162.5 kW
Actual (user input) overall plant auxiliaries = 162.5 kW
Transformer losses = 24.4 kW, Total aux. & transformer losses = 186.9 kW

ESTIMATED G.T. SITE PERFORMANCE

Fuel=CH4, supplied @ 803 K, LHV = 51623.58 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

# 83 Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	11.3	1450	900	15.3	4879	11419	15.6	75.48	13.01	3.53	7.98

Fuel compressor = 80.06 kWe, Q rejected = 16.6 kW , exit temperature = 843.6 K
Fuel molecular weight = 16.04; LHV @ combustor = 51790 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	616	11.32	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	844	16.03	0.30924						
Turbine inlet	1450	10.87	15.39	28.40	74.54	12.88	3.59	8.09	0.90
Turbine coolant			0.25						
Turbine exhaust	900	1.03	15.64	28.41	74.58	13.01	3.53	7.98	0.90

(MOLE COMPOSITION %: N2, O2, CO2, H2O, AR)

Compressor = 5167 Turbine = 10429 kW
Turbine coolant = 1.634% compr in
Mech loss = 109.1 kW Gear box loss = 80.22 kW Generator loss = 193.7 kW
Mech eff. = 97.93% Gear box eff. = 98.44% Generator eff. = 96.18%
GT specific power @ gen term = 318.3 kW per kg/s
GT efficiency @ gen term = 28.413% HHV = 31.53% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.545% HHV = 30.56% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 18250 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	17775

Energy out = 18258 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
160	109	80	194	0	10856	1979	4879	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -7.921 kW = -0.0434 %

GT PRO 13.0 Ting Wang
1263 11-03-2004 18:18:22 file=C:/Tflow13/MYFILES/case2a.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	6050		9359		38.47	
Steam Turbine(s)	0					
Plant Total	6050	5322	9359	10639	38.47	33.84

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
33.84	33.84	33.84	11044

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18561 kWth = 63335 kBTU/h
Fuel LHV chemical energy input = 15728 kWth = 53668 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15728 kWth = 53668 kBTU/h
Energy chargeable to power = 15728 kWth = 53668 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	6050	38.47	9359	19	858
Total	6050			19	

Fuel chemical HHV per gas turbine = 18561 kWth = 63335 kBTU/h
Fuel chemical LHV per gas turbine = 15728 kWth = 53668 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 12084 kWth = 41233 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
605	0	0	10	0	0	0	0

HVAC = 3 kW, Lights = 3.75 kW
Additional auxiliaries from PEACE running motor/load list = 72.75 kW
Miscellaneous plant auxiliaries = 3.025 kW
Program estimated overall plant auxiliaries = 697.8 kW
Actual (user input) overall plant auxiliaries = 697.8 kW
Transformer losses = 30.25 kW, Total aux. & transformer losses = 728 kW

GT PRO 13.0 Ting Wang
1263 11-03-2004 18:18:22 file=C:/Tflow13/MYFILES/case2a.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.43 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

# Model 83	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	13.4	1383	858	15.3	6050	9359	19.0	70.84	11.39	7.22	10.54

Fuel compressor = 605.2 kWe, Q rejected = 123.3 kW , exit temperature = 873 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	657	13.39	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	873	16.03	3.64446						
Turbine inlet	1383	12.86	18.72	28.67	69.90	11.27	7.32	10.67	0.84
Turbine coolant			0.25						
Turbine exhaust	858	1.03	18.97	28.67	70.00	11.39	7.22	10.54	0.84

Compressor = 5849 Turbine = 12302 kW
Turbine coolant = 1.634% compr in
Mech loss = 110.6 kW Gear box loss = 81.31 kW Generator loss = 210.7 kW
Mech eff. = 98.29% Gear box eff. = 98.72% Generator eff. = 96.63%
GT specific power @ gen term = 394.7 kW per kg/s
GT efficiency @ gen term = 32.6% HHV = 38.47% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.047% HHV = 33.1% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22158 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	21683

Energy out = 22167 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
187	111	81	211	0	12384	3143	6050	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)

Heat Balance Error = In - Out = -9.202 kW = -0.0415 %

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:30:17 file=C:/Tflow13/MYFILES/case2b.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	6848		9286		38.77	
Steam Turbine(s)	0					
Plant Total	6848	6039	9286	10529	38.77	34.19

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
34.19	34.19	34.19	10959

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 20845 kWth = 71131 kBTU/h
Fuel LHV chemical energy input = 17664 kWth = 60274 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 17664 kWth = 60274 kBTU/h
Energy chargeable to power = 17664 kWth = 60274 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	6848	38.77	9286	19	906
Total	6848			19	

Fuel chemical HHV per gas turbine = 20845 kWth = 71131 kBTU/h
Fuel chemical LHV per gas turbine = 17664 kWth = 60274 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 13553 kWth = 46247 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
680	0	0	10	0	0	0	0

HVAC = 3.25 kW, Lights = 4 kW
Additional auxiliaries from PEACE running motor/load list = 73.75 kW
Miscellaneous plant auxiliaries = 3.424 kW
Program estimated overall plant auxiliaries = 774.3 kW
Actual (user input) overall plant auxiliaries = 774.3 kW
Transformer losses = 34.24 kW, Total aux. & transformer losses = 808.5 kW

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:30:17 file=C:/Tflow13/MYFILES/case2b.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Maximum firing temperature excess over base load = 62 K

# 83 Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	14.0	1452	906	15.3	6848	9286	19.4	70.13	10.49	7.92	11.46

Fuel compressor = 679.8 kWe, Q rejected = 138.5 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	671	14.06	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	873	16.03	4.09302						
Turbine inlet	1452	13.50	19.17	28.65	69.19	10.36	8.02	11.60	0.83
Turbine coolant			0.25						
Turbine exhaust	906	1.03	19.42	28.65	69.30	10.49	7.92	11.46	0.83

Compressor = 6070 Turbine = 13336 kW
Turbine coolant = 1.634% compr in
Mech loss = 111.6 kW Gear box loss = 82.05 kW Generator loss = 224.3 kW
Mech eff. = 98.46% Gear box eff. = 98.85% Generator eff. = 96.83%
GT specific power @ gen term = 446.7 kW per kg/s
GT efficiency @ gen term = 32.85% HHV = 38.77% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.265% HHV = 33.36% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 24828 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	24352

Energy out = 24838 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
210	112	82	224	0	13862	3501	6848	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -10.35 kW = -0.0417 %

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:42:59 file=C:/Tflow13/MYFILES/case2c.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	7006		9130		39.43	
Steam Turbine(s)	0					
Plant Total	7006	6192	9130	10329	39.43	34.85

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
34.85	34.85	34.85	10775

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 20968 kWth = 71549 kBTU/h
Fuel LHV chemical energy input = 17768 kWth = 60629 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 17768 kWth = 60629 kBTU/h
Energy chargeable to power = 17768 kWth = 60629 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	7006	39.43	9130	19	903
Total	7006			19	

Fuel chemical HHV per gas turbine = 20968 kWth = 71549 kBTU/h
Fuel chemical LHV per gas turbine = 17768 kWth = 60629 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 13512 kWth = 46108 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
684	0	0	10	0	0	0	0

HVAC = 3.25 kW, Lights = 4 kW
Additional auxiliaries from PEACE running motor/load list = 73.75 kW
Miscellaneous plant auxiliaries = 3.503 kW
Program estimated overall plant auxiliaries = 778.3 kW
Actual (user input) overall plant auxiliaries = 778.3 kW
Transformer losses = 35.03 kW, Total aux. & transformer losses = 813.3 kW

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:42:59 file=C:/Tflow13/MYFILES/case2c.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.43 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar

Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Turbine nozzle area % increase = 23

# Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
83											
RR 501KH5	11.3	1421	903	15.3	7006	9130	19.4	70.10	10.44	7.96	11.51

Fuel compressor = 683.7 kWe, Q rejected = 139.3 kW , exit temperature = 873 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	615	11.32	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	873	16.03	4.11712						
Turbine inlet	1421	10.87	19.20	28.65	69.16	10.31	8.06	11.64	0.83
Turbine coolant			0.25						
Turbine exhaust	903	1.03	19.45	28.65	69.26	10.44	7.96	11.51	0.83

Compressor = 5165 Turbine = 12592 kW
Turbine coolant = 1.634% compr in
Mech loss = 111.8 kW Gear box loss = 82.2 kW Generator loss = 227.2 kW
Mech eff. = 98.49% Gear box eff. = 98.88% Generator eff. = 96.86%
GT specific power @ gen term = 457 kW per kg/s
GT efficiency @ gen term = 33.41% HHV = 39.43% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.748% HHV = 33.93% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 24970 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	24495

Energy out = 24979 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
211	112	82	227	0	13822	3520	7006	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.324 kW = -0.0373 %

GT PRO 13.0 Ting Wang
1263 11-19-2004 03:50:44 file=C:/Tflow13/MYFILES/case2d.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	7171		9191		39.17	
Steam Turbine(s)	0					
Plant Total	7171	6335	9191	10403	39.17	34.60

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
34.60	34.60	34.60	10847

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 21605 kWth = 73724 kBTU/h
Fuel LHV chemical energy input = 18308 kWth = 62471 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 18308 kWth = 62471 kBTU/h
Energy chargeable to power = 18308 kWth = 62471 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	7171	39.17	9191	20	918
Total	7171			20	

Fuel chemical HHV per gas turbine = 21605 kWth = 73724 kBTU/h
Fuel chemical LHV per gas turbine = 18308 kWth = 62471 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 13980 kWth = 47705 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
704	0	0	10	0	0	0	0

HVAC = 3.5 kW, Lights = 4.25 kW
Additional auxiliaries from PEACE running motor/load list = 73.75 kW
Miscellaneous plant auxiliaries = 3.585 kW
Program estimated overall plant auxiliaries = 799.6 kW
Actual (user input) overall plant auxiliaries = 799.6 kW
Transformer losses = 35.85 kW, Total aux. & transformer losses = 835.5 kW

GT PRO 13.0 Ting Wang
1263 11-19-2004 03:50:44 file=C:/Tflow13/MYFILES/case2d.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.43 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, Power limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Maximum firing temperature excess over base load = 61.67 K
Turbine nozzle area % increase = 27.906

# 83 Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	11.0	1433	918	15.3	7171	9191	19.6	69.90	10.20	8.14	11.76

Fuel compressor = 704.5 kWe, Q rejected = 143.6 kW , exit temperature = 873 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	609	11.01	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	873	16.03	4.24223						
Turbine inlet	1433	10.57	19.32	28.64	68.97	10.06	8.25	11.89	0.83
Turbine coolant			0.25						
Turbine exhaust	918	1.03	19.57	28.65	69.07	10.20	8.14	11.76	0.83

Compressor = 5064 Turbine = 12659 kW
Turbine coolant = 1.634% compr in
Mech loss = 112 kW Gear box loss = 82.35 kW Generator loss = 230.3 kW
Mech eff. = 98.53% Gear box eff. = 98.9% Generator eff. = 96.89%
GT specific power @ gen term = 467.8 kW per kg/s
GT efficiency @ gen term = 33.19% HHV = 39.17% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.558% HHV = 33.7% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 25714 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	25239

Energy out = 25724 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
217	112	82	230	0	14292	3619	7171	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.781 kW = -0.038 %

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:52:44 file=C:/Tflow13/MYFILES/case3.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5913		10220		35.22	
Steam Turbine(s)	0					
Plant Total	5913	5394	10220	11203	35.22	32.13

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
32.13	32.13	32.13	12054

GT fuel HHV/LHV ratio = 1.1794 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1794
Fuel HHV chemical energy input = 19798 kWth = 67556 kBTU/h
Fuel LHV chemical energy input = 16786 kWth = 57278 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 16786 kWth = 57278 kBTU/h
Energy chargeable to power = 16786 kWth = 57278 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5913	35.22	10220	18	911
Total	5913			18	

Fuel chemical HHV per gas turbine = 19798 kWth = 67556 kBTU/h
Fuel chemical LHV per gas turbine = 16786 kWth = 57278 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 12429 kWth = 42412 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
400	0	0	10	0	0	0	0

HVAC = 3 kW, Lights = 3.75 kW
Additional auxiliaries from PEACE running motor/load list = 69.25 kW
Miscellaneous plant auxiliaries = 2.956 kW
Program estimated overall plant auxiliaries = 489 kW
Actual (user input) overall plant auxiliaries = 489 kW
Transformer losses = 29.56 kW, Total aux. & transformer losses = 518.6 kW

GT PRO 13.0 Ting Wang
1263 11-03-2004 19:52:44 file=C:/Tflow13/MYFILES/case3.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 8215.20 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar

Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Maximum firing temperature excess over base load = 38.5 K

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	RR 501KH5	12.7	1451	911	15.3	5913	10220	17.6	67.78	11.91	8.27	12.04

Fuel compressor = 400 kWe, Q rejected = 81.9 kW , exit temperature = 864.8 K
Fuel molecular weight = 23.84; LHV @ combustor = 8329 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant		misc.	0.25						
Comp. discharge	643	12.71	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	865	16.03	2.26817						
Turbine inlet	1451	12.20	17.35	28.70	66.83	11.78	8.39	12.20	0.80
Turbine coolant			0.25						
Turbine exhaust	911	1.03	17.60	28.70	66.97	11.91	8.27	12.04	0.81

Compressor = 5622 Turbine = 11934 kW
Turbine coolant = 1.634% compr in
Mech loss = 110.4 kW Gear box loss = 81.18 kW Generator loss = 208.5 kW
Mech eff. = 98.25% Gear box eff. = 98.69% Generator eff. = 96.59%
GT specific power @ gen term = 385.7 kW per kg/s
GT efficiency @ gen term = 29.865% HHV = 35.22% LHV
GT eff. @ gen term adjusted for fuel temp. = 26.903% HHV = 31.73% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22529 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	22054

Energy out = 22537 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
189	110	81	209	0	12709	3327	5913	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.813 kW = -0.0391 %

GT PRO 13.0 Ting Wang
1263 11-03-2004 20:07:26 file=C:/Tflow13/MYFILES/case4.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5291		10690		33.68	
Steam Turbine(s)	0					
Plant Total	5291	4854	10690	11651	33.68	30.90

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
30.90	30.90	30.90	11573

GT fuel HHV/LHV ratio = 1.0827 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.0827
Fuel HHV chemical energy input = 17008 kWth = 58036 kBTU/h
Fuel LHV chemical energy input = 15709 kWth = 53606 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15709 kWth = 53606 kBTU/h
Energy chargeable to power = 15709 kWth = 53606 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5291	33.68	10690	17	905
Total	5291			17	

Fuel chemical HHV per gas turbine = 17008 kWth = 58036 kBTU/h
Fuel chemical LHV per gas turbine = 15709 kWth = 53606 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11381 kWth = 38836 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
323	0	0	10	0	0	0	0

HVAC = 2.75 kW, Lights = 3.5 kW
Additional auxiliaries from PEACE running motor/load list = 67.75 kW
Miscellaneous plant auxiliaries = 2.645 kW
Program estimated overall plant auxiliaries = 410.2 kW
Actual (user input) overall plant auxiliaries = 410.2 kW
Transformer losses = 26.45 kW, Total aux. & transformer losses = 436.6 kW

GT PRO 13.0 Ting Wang
1263 11-03-2004 20:07:26 file=C:/Tflow13/MYFILES/case4.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One RR 501KH5 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas 3, supplied @ 830 K, LHV = 11156.23 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar

Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Maximum firing temperature excess over base load = 17.5 K

# Model 83	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	12.0	1451	905	15.3	5291	10690	16.9	72.25	13.96	7.72	6.07

Fuel compressor = 323.5 kWe, Q rejected = 65.65 kW , exit temperature = 909.7 K
Fuel molecular weight = 20.65; LHV @ combustor = 11294 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	630	12.03	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	910	16.03	1.52365						
Turbine inlet	1451	11.55	16.60	29.31	71.30	13.86	7.84	6.14	0.86
Turbine coolant			0.25						
Turbine exhaust	905	1.03	16.85	29.30	71.39	13.96	7.72	6.07	0.86

Compressor = 5399 Turbine = 11079 kW
Turbine coolant = 1.634% compr in
Mech loss = 109.6 kW Gear box loss = 80.6 kW Generator loss = 199.3 kW
Mech eff. = 98.07% Gear box eff. = 98.55% Generator eff. = 96.37%
GT specific power @ gen term = 345.2 kW per kg/s
GT efficiency @ gen term = 31.11% HHV = 33.68% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.748% HHV = 31.12% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 19056 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	18581

Energy out = 19065 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
172	110	81	199	0	11640	1572	5291	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.174 kW = -0.0429 %

STEAM PRO 13.0 Ting Wang ECCC
1263 11-04-2004 15:01:49 C:/Tflow13/MYFILES/case5.stp
Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW Gross	Power Output kW Net	Fuel Input kJ/s LHV	Fuel Input kJ/s HHV
Plant Total	4998	4775	17256	19147

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	LHV Gross	LHV Net	HHV Gross	HHV Net
Heat rate [kJ/kWh]	12428	13009	13790	14435
Electric efficiency [%]	28.97	27.67	26.11	24.94
CHP Total eff. [%]		27.67		24.94
U.S. PURPA eff. [%]		27.67		24.94

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	37.5
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0
Ash handling	0.0

Condenser C.W. pump	29.9
Condensate pump	4.8
Boiler feed pump	55.5
Boiler feed booster pump	0.0
FW heater drain pump(s)	0.0
Additional auxiliaries from PEACE	70.7
Misc. plant aux.	25.0
Calculated total auxiliaries	223.4

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	16579.3
Addition steam	0.0
Addition water	0.0
Makeup water	6.0
Process return	0.0
Feedwater enthalpy increase in pumps	54.6
TOTAL ENERGY IN	16639.8
ST / generator output	4998.4
Gear box loss	78.4
ST / generator mechanical losses	30.5
Generator losses	117.1
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	71.1
Steam pipe heat loss	15.1
FWH system pipe heat loss	2.6
Condenser heat rejected	11228.8
Sealing steam discharged	97.9
TOTAL ENERGY OUT	16639.8

Error (in - out) = 0.0001 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	19760.9
Inlet air sensible	144.2
Inlet air latent	114.6
TOTAL ENERGY IN	20019.7
Heat added to water, steam & blowdown	16579.3
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	1057.0
Exhaust gas latent	2051.8
Boiler minor losses	331.6
TOTAL ENERGY OUT	20019.7

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	12820	13419
Electric efficiency [%]	28.08	26.83
CHP Total efficiency [%]		26.83
U.S. PURPA efficiency [%]		26.83

Turbine heat rate [kJ/kWh]	11906
Steam cycle heat rate [kJ/kWh]	11941
Steam cycle efficiency [%]	30.15
Boiler efficiency (LHVadj) [%]	93.15

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C

and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 17799 kJ/s
Fuel input to boiler (LHVadj) = 17799 kJ/s

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x -	Eff(*) %	Power kW
HPT inlet	42.402	644.3	6.478	3141.8	6.6381	*		
LPT exh	0.048	305.4	5.267	2237.1	7.3501	0.867	80.62	5224
Gear loss							78	
Mech loss							30	
Gen loss							117	
Power out							4998	

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity m/s 110.2
Dry exhaust loss kJ/kg 6.71
Corrected exh loss kJ/kg 4.61

Exhaust end dimensions:
No. of parallel paths at LPT 1
Last stage rotor exit angle degree 65.61
Last stage blade length mm 330.32
Last stage pitch diameter mm 1160.93
Exhaust annulus area / end m^2 1.20

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss
39	39.92	122	8.80	244	59.83
46	30.95	137	13.49	274	76.41
53	23.14	152	19.64	305	90.65
61	17.33	168	26.21	335	100.76
76	9.98	183	32.46	366	104.94
91	6.64	198	38.47	396	101.40
107	6.38	213	44.99	427	88.32

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	5224	80.62

Air COOLED GENERATOR 60 Hz

Turbine Shaft Speed 4000 RPM

Gear loss	kW	78.4
Mech loss	kW	30.5
Gen loss	kW	117.1
Power	kW	4998.4

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			44.522	647.0	6.478	3144.1		
pipe inlet			44.522	647.0	6.478	3144.1		
pipe outlet			42.402	644.3	6.478	3141.8		
ST inlet			42.402	644.3	6.478	3141.8	6.6381	*
-Valve Stem leak 1					-0.009	3141.8		
1	HPT	Inlet	40.706	642.8	6.469	3141.8	6.6556	*
		Exit	32.617	619.7	6.469	3103.7	6.6897	*
-HPT HP leak 1					-0.100	3103.7		
2	HPT	Inlet	32.617	619.7	6.369	3103.7	6.6897	*
		Exit	3.661	413.6	6.369	2729.0	6.9124	0.998
(1)		add/extr	3.661	413.6	-1.102	2729.0	6.9124	0.998
3	LPT1	Inlet	3.661	413.6	5.267	2729.0	6.9124	0.998
		Exit	0.048	305.4	5.267	2232.5	7.3350	0.865
Exhaust to condenser			0.048	305.4	5.267	2237.1	7.3501	0.867
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	SSR	0.3	0.009	3141.8
4	HPT HP leak 1	SSR	3.9	0.100	3103.7

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.002	1	65.05	55.18
2	0.002	8	77.02	80.27
3	0.009	6	82.73	78.63

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 1			0.009	3141.8
HPT HP leak 1			0.100	3103.7
Steam at SSR inlet	1.241	590.2	0.109	3106.8
LPT SS to condenser			0.050	3106.8
LPT SS packing exhaust discharged			0.031	3106.8
SS to GSC from SSR			0.027	3106.8

	P	T	M	h
Steam at GSC inlet	0.827	589.8	0.027	3106.8
GSC drain to Cond.			0.027	395.6

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	5.267	2237.1
LPT SS to condenser			0.050	3106.8
Drain from GSC	0.827	367.6	0.027	395.6
Condenser in	0.048	305.4	5.345	2236.1
Condensate well	0.347	305.4	5.345	135.2
Cooling water in	1.857	288.2	268.054	63.1
Cooling water out	1.611	298.2	268.054	105.0

Condenser C.W. pump power 29.86 kW
Condenser heat rejection 11229 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	5.345	135.2
Makeup water		288.2	0.095	62.8
Condensate pump suction	0.347	305.1	5.440	133.9
Condensate pump exit	5.685	305.2	5.440	134.7
To SJAE, GSC & rcvry HXs	5.685	305.2	5.440	134.7
Feedwater to 1st FWHT	5.685	308.4	5.440	148.0

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FEEDWATER HEATING SYSTEM -- C

THERMAL OUTPUT

	Feed Water				Bleed Steam				
Source& Heater	P bar	T K	M kg/s	h kJ/kg	P bar	T K	M kg/s	h kJ/kg	Tsat K
HPT (1)					3.66	413.6	1.102	2729.0	
1-C in	3.45	308.4	5.440	148.0	3.45	411.6	1.102	2726.6	411.6
out	3.45	411.6	6.542	582.4					
BFP in	5.53	411.5	6.542	582.4					
BFP out	50.92	412.6	6.542	590.1					
BoilDesp			0.130	590.1					
To boil	44.71	412.7	6.412	590.1					

Total bleed steam for FWH system = 1.102 kg/s, 3007 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 2363

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV)   %   93.15
2. Actual boiler efficiency (HHV)   %   83.94
3. Fuel heat input (LHV)   kJ/s   17256
4. Fuel heat input (HHV)   kJ/s   19147
5. Excess Air   %   10
6. Adiabatic flame temperature is greater than   K   1366.5
7. Boiler desuperheating water source   -- After boiler feed pump

Fuel Name - 'CH4' (Gaseous)

Fuel Name: CH4
User-defined fuel
Fuel supply temp.   803.15 K
Heating Values
LHV   50046.7 kJ/kg
HHV   55532.5 kJ/kg
Analysis of Fuel (Volume %)

Hydrogen H2	0.00 %
Oxygen O2	0.00 %
Water Vapor H2O	0.00 %
Nitrogen N2	0.00 %
Carbon Monoxide CO	0.00 %
Carbon Dioxide CO2	0.00 %
Methane CH4	100.00 %
Ethane C2H6	0.00 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.00 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.00 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %
Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight   16.04
Mole flow   0.02 kg-mol/s
Mass flow (ash-free)   0.34 kg/s
Mass flow   0.34 kg/s
LHV (ash-free) @ 298 K   50047.00 kJ/kg
LHV (adj)* @ 803 K   51624.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K   57313.00 kJ/kg
Atomic percentage

C	20.00 %
H	80.00 %
O	0.00 %
N	0.00 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	44.71	412.7	6.412	590.1
ECO exit	44.60	505.0	6.412	999.9
CEV exit	44.60	530.0	1.587	2797.8
REV exit	44.60	530.0	4.761	2797.8
Blow down	44.60	530.0	0.063	1120.1

CS1 inlet	44.60	530.0	6.349	2797.8
CS1 exit	44.56	590.9	6.349	2997.0
DESUP water			0.130	590.1
CS2 inlet	44.56	574.1	6.478	2948.9
CS2 exit	44.52	647.0	6.478	3144.1
HP steam	44.52	647.0	6.478	3144.1

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	N2+Ar	O2	CO2	H2O
	288.2			7.238	28.86	78.22	20.74	0.03	1.01
1 FDF		50.4	34						
	292.8			7.238	28.86	78.22	20.74	0.03	1.01
Cold end leakage				-0.4606					
	292.8			6.777	28.86	78.22	20.74	0.03	1.01
3 AHA		6.3	1570						
	519.3			6.777	28.86	78.22	20.74	0.03	1.01
Hot end leakage				-0.1974					
	519.3			6.58	28.86	78.22	20.74	0.03	1.01
4 BRN		12.5	17799						
	Ad Flame			6.924	27.75	71.48	1.72	8.64	18.15
	Ad Flame								
5,6 FRN		0.0	8932						
	1916.9			6.924	27.75	71.48	1.72	8.64	18.15
	1493.9								
7 CS2		0.3	1193						
	1370.4			6.924	27.75	71.48	1.72	8.64	18.15
	1370.4								
10 CS1		0.1	1290						
	1234.4			6.924	27.75	71.48	1.72	8.64	18.15
	1234.4								
13 CEV		0.4	2913						
	915.3			6.924	27.75	71.48	1.72	8.64	18.15
	915.3								
14 ECO		0.2	2680						
	600.0			6.924	27.75	71.48	1.72	8.64	18.15
Hot end leakage				0.1974					
	598.0								
16 AHG		8.4	-1570						
	405.7			7.122	27.78	71.66	2.23	8.41	17.70
Cold end leakage				0.4606					
	399.5								
25 STK		2.3	0						

399.5	7.582	27.84	72.05	3.31	7.92	16.72

Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

Zone /path	Tg K /HX	Tw K	DT K	Delta P millibar	Qg kJ/s	Afrn m^2	Mg kg/s	Vg m/s	Tube rows
5	1916.9	530.0	1386.9						
	REV			0.0	8738		6.9	5.1	
	1916.9	530.0	1386.9						
7	1493.9	647.0	846.9						
0	CS2			0.3	1290	4.2	6.9	21.6	2.0
	1370.4	574.1	796.3						
10	1370.4	590.9	779.6						
0	CS1			0.1	1290	6.4	6.9	11.9	2.0
	1234.4	530.0	704.4						
13	1234.4	530.0	704.4						
0	CEV			0.4	2913	6.4	6.9	13.0	6.0
	915.3	530.0	385.3						
14	915.3	505.0	410.2						
0	ECO			0.2	2680	6.4	6.9	5.4	4.0
	600.0	412.7	187.2						
Totals				1.1	16911				14.0

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2627.8	ECO	2627.8
Evaporators	11421.6	REV	8566.2
		CEV	2855.4
Superheaters	2529.8		
		CS1	1264.9
		CS2	1264.9
TOTAL	16579.2		

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW		Fuel Input kJ/s	
	Gross	Net	LHV	HHV
Plant Total	4998	4782	15654	18474

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	------ LHV ------		------ HHV ------	
	Gross	Net	Gross	Net
Heat rate [kJ/kWh]	11275	11786	13306	13909
Electric efficiency [%]	31.93	30.54	27.06	25.88
CHP Total eff. [%]		30.54		25.88
U.S. PURPA eff. [%]		30.54		25.88

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	29.7
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0
Ash handling	0.0
Condenser C.W. pump	29.9
Condensate pump	4.8
Boiler feed pump	55.5
Boiler feed booster pump	0.0
FW heater drain pump(s)	0.0
Additional auxiliaries from PEACE	71.9
Misc. plant aux.	25.0
Calculated total auxiliaries	216.8

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	16579.3
Addition steam	0.0
Addition water	0.0
Makeup water	6.0
Process return	0.0
Feedwater enthalpy increase in pumps	54.6
TOTAL ENERGY IN	16639.8
ST / generator output	4998.4
Gear box loss	78.4
ST / generator mechanical losses	30.5
Generator losses	117.1
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	71.1
Steam pipe heat loss	15.1
FWH system pipe heat loss	2.6
Condenser heat rejected	11228.8
Sealing steam discharged	97.9
TOTAL ENERGY OUT	16639.8

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	21193.2
Inlet air sensible	115.6
Inlet air latent	92.3
TOTAL ENERGY IN	21401.1

Heat added to water, steam & blowdown	16579.3
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	1509.8
Exhaust gas latent	2980.3
Boiler minor losses	331.6
TOTAL ENERGY OUT	21401.0

Error (in - out) = 0.0008 % = 0.2

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	13104	13698
Electric efficiency [%]	27.47	26.28
CHP Total efficiency [%]		26.28
U.S. PURPA efficiency [%]		26.28

Turbine heat rate [kJ/kWh]	11906
Steam cycle heat rate [kJ/kWh]	11941
Steam cycle efficiency [%]	30.15
Boiler efficiency (LHVadj) [%]	91.12

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C

and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 18194 kJ/s
Fuel input to boiler (LHVadj) = 18194 kJ/s

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P	T	M	h	s	x	Eff(*)	Power
	bar	K	kg/s	kJ/kg	kJ/kg-K	-	%	kW
HPT inlet	42.402	644.3	6.478	3141.8	6.6381		*	
LPT exh	0.048	305.4	5.267	2237.1	7.3501	0.867	80.62	5224
Gear loss							78	
Mech loss							30	
Gen loss							117	
Power out							4998	

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity	m/s	110.2
Dry exhaust loss	kJ/kg	6.71
Corrected exh loss	kJ/kg	4.61

Exhaust end dimensions:

No. of parallel paths at LPT		1
Last stage rotor exit angle	degree	65.61
Last stage blade length	mm	330.32
Last stage pitch diameter	mm	1160.93
Exhaust annulus area / end	m^2	1.20

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss

39	39.92	122	8.80	244	59.83
46	30.95	137	13.49	274	76.41
53	23.14	152	19.64	305	90.65
61	17.33	168	26.21	335	100.76
76	9.98	183	32.46	366	104.94
91	6.64	198	38.47	396	101.40
107	6.38	213	44.99	427	88.32

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	5224	80.62

Air COOLED GENERATOR 60 Hz

Turbine Shaft Speed 4000 RPM

Gear loss	kW	78.4
Mech loss	kW	30.5
Gen loss	kW	117.1
Power	kW	4998.4

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			44.522	647.0	6.478	3144.1		
pipe inlet			44.522	647.0	6.478	3144.1		
pipe outlet			42.402	644.3	6.478	3141.8		
ST inlet			42.402	644.3	6.478	3141.8	6.6381	*
-Valve Stem leak 1					-0.009	3141.8		
1	HPT	Inlet	40.706	642.8	6.469	3141.8	6.6556	*
		Exit	32.617	619.7	6.469	3103.7	6.6897	*
-HPT HP leak 1					-0.100	3103.7		
2	HPT	Inlet	32.617	619.7	6.369	3103.7	6.6897	*
		Exit	3.661	413.6	6.369	2729.0	6.9124	0.998
(1)		add/extr	3.661	413.6	-1.102	2729.0	6.9124	0.998
3	LPT1	Inlet	3.661	413.6	5.267	2729.0	6.9124	0.998
		Exit	0.048	305.4	5.267	2232.5	7.3350	0.865
Exhaust to condenser			0.048	305.4	5.267	2237.1	7.3501	0.867
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	SSR	0.3	0.009	3141.8
4	HPT HP leak 1	SSR	3.9	0.100	3103.7

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.002	1	65.05	55.18
2	0.002	8	77.02	80.27
3	0.009	6	82.73	78.63

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 1			0.009	3141.8
HPT HP leak 1			0.100	3103.7
Steam at SSR inlet	1.241	590.2	0.109	3106.8
LPT SS to condenser			0.050	3106.8
LPT SS packing exhaust discharged			0.031	3106.8
SS to GSC from SSR			0.027	3106.8
Steam at GSC inlet	0.827	589.8	0.027	3106.8
GSC drain to Cond.			0.027	395.6

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	5.267	2237.1
LPT SS to condenser			0.050	3106.8
Drain from GSC	0.827	367.6	0.027	395.6
Condenser in	0.048	305.4	5.345	2236.1
Condensate well	0.347	305.4	5.345	135.2
Cooling water in	1.857	288.2	268.054	63.1
Cooling water out	1.611	298.2	268.054	105.0

Condenser C.W. pump power 29.86 kW
Condenser heat rejection 11229 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	5.345	135.2
Makeup water		288.2	0.095	62.8
Condensate pump suction	0.347	305.1	5.440	133.9
Condensate pump exit	5.685	305.2	5.440	134.7
To SJAE, GSC & rcvry HXs	5.685	305.2	5.440	134.7
Feedwater to 1st FWHT	5.685	308.4	5.440	148.0

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FEEDWATER HEATING SYSTEM -- C

THERMAL OUTPUT

Source& Heater	Feed Water P bar	T K	M kg/s	h kJ/kg	Bleed Steam P bar	T K	M kg/s	h kJ/kg	Tsat K
HPT (1)					3.66	413.6	1.102	2729.0	
1-C in	3.45	308.4	5.440	148.0	3.45	411.6	1.102	2726.6	411.6
out	3.45	411.6	6.542	582.4					
BFP in	5.53	411.5	6.542	582.4					
BFP out	50.91	412.6	6.542	590.1					
BoilDesp			0.130	590.1					
To boil	44.70	412.7	6.412	590.1					

Total bleed steam for FWH system = 1.102 kg/s, 3007 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 2363

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV)   %   91.12
2. Actual boiler efficiency (HHV)   %   77.22
3. Fuel heat input (LHV)   kJ/s   15654
4. Fuel heat input (HHV)   kJ/s   18474
5. Excess Air   %   10
6. Adiabatic flame temperature is greater than   K   1366.5
7. Boiler desuperheating water source   -- After boiler feed pump

Fuel Name - 'Syngas' (Gaseous)

Fuel Name: Syngas
User-defined fuel
Fuel supply temp.   803.15 K
Heating Values
  LHV   4315.5 kJ/kg
  HHV   5092.8 kJ/kg
Analysis of Fuel (Volume %)

Hydrogen H2	7.30 %
Oxygen O2	0.05 %
Water Vapor H2O	23.00 %
Nitrogen N2	37.20 %
Carbon Monoxide CO	10.60 %
Carbon Dioxide CO2	14.60 %
Methane CH4	7.00 %
Ethane C2H6	0.00 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.11 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.14 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %

Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight	25.44
Mole flow	0.14 kg-mol/s
Mass flow (ash-free)	3.63 kg/s
Mass flow	3.63 kg/s
LHV (ash-free) @ 298 K	4316.00 kJ/kg
LHV (adj)* @ 803 K	5016.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K	5842.00 kJ/kg
Atomic percentage	
C	12.77 %
H	34.51 %
O	24.15 %
N	28.57 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	44.70	412.7	6.412	590.1
ECO exit	44.62	505.0	6.412	1000.0
CEV exit	44.62	530.0	1.587	2797.8
REV exit	44.62	530.0	4.761	2797.8
Blow down	44.62	530.0	0.063	1120.2
CS1 inlet	44.62	530.0	6.349	2797.8
CS1 exit	44.59	590.9	6.349	2997.0
DESUP water			0.130	590.1
CS2 inlet	44.59	574.1	6.478	2948.9
CS2 exit	44.52	647.0	6.478	3144.1
HP steam	44.52	647.0	6.478	3144.1

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	Mole compositions [%] N2+Ar	O2	CO2	H2O
	288.2			5.829	28.86	78.22	20.74	0.03	1.01
1 FDF		49.5	27						
	292.7			5.829	28.86	78.22	20.74	0.03	1.01

Cold end leakage -0.371

	292.7		5.458	28.86	78.22	20.74	0.03	1.01
3 AHA		3.7	1265					
	519.3		5.458	28.86	78.22	20.74	0.03	1.01

Hot end leakage -0.159

	519.3		5.299	28.86	78.22	20.74	0.03	1.01
4 BRN		12.5	18194					
	Ad Flame		8.927	28.47	62.73	1.10	15.14	21.03
	Ad Flame							
5,6 FRN		0.0	8931					
	1589.3		8.927	28.47	62.73	1.10	15.14	21.03
	1245.1							
7 CS2		0.1	1193					
	1147.9		8.927	28.47	62.73	1.10	15.14	21.03
	1147.9							
10 CS1		0.1	1290					
	1040.9		8.927	28.47	62.73	1.10	15.14	21.03
	1040.9							
13 CEV		0.2	2912					
	789.8		8.927	28.47	62.73	1.10	15.14	21.03
	789.8							
14 ECO		0.1	2681					
	543.0		8.927	28.47	62.73	1.10	15.14	21.03

Hot end leakage 0.159

	542.7							
16 AHG		10.7	-1265					
	421.8		9.086	28.47	62.99	1.44	14.88	20.68

Cold end leakage 0.371

	417.3							
25 STK		2.1	0					
	417.3		9.457	28.49	63.58	2.19	14.31	19.92

Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

Zone /path	Tg K /HX	Tw K	DT K	Delta P millibar	Qg kJ/s	Afrn m^2	Mg kg/s	Vg m/s	Tube rows
5	1589.3	530.0	1059.3						
	REV			0.0	8737		8.9	3.6	
	1589.3	530.0	1059.3						
7	1245.1	647.0	598.0						
0	CS2			0.1	1290	6.1	8.9	11.5	3.0
	1147.9	574.1	573.8						
10	1147.9	590.9	557.0						
0	CS1			0.1	1290	9.5	8.9	6.4	1.0
	1040.9	530.0	510.8						
13	1040.9	530.0	510.8						
0	CEV			0.2	2912	9.5	8.9	7.0	2.0
	789.8	530.0	259.7						
14	789.8	505.0	284.7						
0	ECO			0.1	2681	9.5	8.9	4.0	4.0
	543.0	412.7	130.3						
Totals				0.5	16911			10.0	

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2628.4	ECO	2628.4
Evaporators	11421.0	REV	8565.7
		CEV	2855.2
Superheaters	2529.9		
		CS1	1264.9
		CS2	1264.9
TOTAL	16579.3		

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW		Fuel Input kJ/s	
	Gross	Net	LHV	HHV
Plant Total	4998	4778	16099	18988

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	------ LHV ------		------ HHV ------	
	Gross	Net	Gross	Net
Heat rate [kJ/kWh]	11595	12129	13676	14305
Electric efficiency [%]	31.05	29.68	26.32	25.17
CHP Total eff. [%]		29.68		25.17
U.S. PURPA eff. [%]		29.68		25.17

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	33.1
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0

Ash handling	0.0
Condenser C.W. pump	29.9
Condensate pump	4.8
Boiler feed pump	55.6
Boiler feed booster pump	0.0
FW heater drain pump(s)	0.0
Additional auxiliaries from PEACE	71.7
Misc. plant aux.	25.0
Calculated total auxiliaries	220.0

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	16579.2
Addition steam	0.0
Addition water	0.0
Makeup water	6.0
Process return	0.0
Feedwater enthalpy increase in pumps	54.6
TOTAL ENERGY IN	16639.8
ST / generator output	4998.4
Gear box loss	78.4
ST / generator mechanical losses	30.5
Generator losses	117.1
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	71.1
Steam pipe heat loss	15.1
FWH system pipe heat loss	2.6
Condenser heat rejected	11228.8
Sealing steam discharged	97.9
TOTAL ENERGY OUT	16639.8

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	20903.8
Inlet air sensible	121.0
Inlet air latent	94.8
TOTAL ENERGY IN	21119.6
Heat added to water, steam & blowdown	16579.2
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	1155.3
Exhaust gas latent	3053.5
Boiler minor losses	331.6
TOTAL ENERGY OUT	21119.6

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	12872	13464
Electric efficiency [%]	27.97	26.74
CHP Total efficiency [%]		26.74
U.S. PURPA efficiency [%]		26.74

Turbine heat rate [kJ/kWh]	11906
Steam cycle heat rate [kJ/kWh]	11941
Steam cycle efficiency [%]	30.15
Boiler efficiency (LHVadj) [%]	92.77

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C

and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 17872 kJ/s
Fuel input to boiler (LHVadj) = 17872 kJ/s

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x -	Eff(*) %	Power kW
HPT inlet	42.402	644.3	6.478	3141.8	6.6381	*		
LPT exh	0.048	305.4	5.267	2237.1	7.3501	0.867	80.62	5224
Gear loss						78		
Mech loss						30		
Gen loss						117		
Power out						4998		

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity m/s 110.2
Dry exhaust loss kJ/kg 6.71
Corrected exh loss kJ/kg 4.61

Exhaust end dimensions:
No. of parallel paths at LPT 1
Last stage rotor exit angle degree 65.61
Last stage blade length mm 330.32
Last stage pitch diameter mm 1160.93
Exhaust annulus area / end m^2 1.20

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss
39	39.92	122	8.80	244	59.83
46	30.95	137	13.49	274	76.41
53	23.14	152	19.64	305	90.65
61	17.33	168	26.21	335	100.76
76	9.98	183	32.46	366	104.94
91	6.64	198	38.47	396	101.40
107	6.38	213	44.99	427	88.32

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	5224	80.62

Air COOLED GENERATOR 60 Hz

Turbine Shaft Speed 4000 RPM

Gear loss	kW	78.4
Mech loss	kW	30.5
Gen loss	kW	117.1
Power	kW	4998.4

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			44.522	647.0	6.478	3144.1		
pipe inlet			44.522	647.0	6.478	3144.1		
pipe outlet			42.402	644.3	6.478	3141.8		
ST inlet			42.402	644.3	6.478	3141.8	6.6381	*
-Valve Stem leak 1					-0.009	3141.8		
1	HPT	Inlet	40.706	642.8	6.469	3141.8	6.6556	*
		Exit	32.617	619.7	6.469	3103.7	6.6897	*
-HPT HP leak 1					-0.100	3103.7		
2	HPT	Inlet	32.617	619.7	6.369	3103.7	6.6897	*
		Exit	3.661	413.6	6.369	2729.0	6.9124	0.998
(1)		add/extr	3.661	413.6	-1.102	2729.0	6.9124	0.998
3	LPT1	Inlet	3.661	413.6	5.267	2729.0	6.9124	0.998
		Exit	0.048	305.4	5.267	2232.5	7.3350	0.865
Exhaust to condenser			0.048	305.4	5.267	2237.1	7.3501	0.867
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	SSR	0.3	0.009	3141.8
4	HPT HP leak 1	SSR	3.9	0.100	3103.7

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.002	1	65.05	55.18
2	0.002	8	77.02	80.27
3	0.009	6	82.73	78.63

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 1			0.009	3141.8
HPT HP leak 1			0.100	3103.7
Steam at SSR inlet	1.241	590.2	0.109	3106.8
LPT SS to condenser			0.050	3106.8
LPT SS packing exhaust discharged			0.031	3106.8

SS to GSC from SSR			0.027	3106.8
Steam at GSC inlet	0.827	589.8	0.027	3106.8
GSC drain to Cond.			0.027	395.6

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	5.267	2237.1
LPT SS to condenser			0.050	3106.8
Drain from GSC	0.827	367.6	0.027	395.6
Condenser in	0.048	305.4	5.345	2236.1
Condensate well	0.347	305.4	5.345	135.2
Cooling water in	1.857	288.2	268.054	63.1
Cooling water out	1.611	298.2	268.054	105.0

Condenser C.W. pump power 29.86 kW
Condenser heat rejection 11229 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	5.345	135.2
Makeup water		288.2	0.095	62.8
Condensate pump suction	0.347	305.1	5.440	133.9
Condensate pump exit	5.685	305.2	5.440	134.7
To SJAE, GSC & rcvry HXs	5.685	305.2	5.440	134.7
Feedwater to 1st FWHT	5.685	308.4	5.440	148.0

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FEEDWATER HEATING SYSTEM -- C

THERMAL OUTPUT

	Feed Water				Bleed Steam				
Source& Heater	P bar	T K	M kg/s	h kJ/kg	P bar	T K	M kg/s	h kJ/kg	Tsat K
HPT (1)					3.66	413.6	1.102	2729.0	
1-C in	3.45	308.4	5.440	148.0	3.45	411.6	1.102	2726.6	411.6
out	3.45	411.6	6.542	582.4					
BFP in	5.53	411.5	6.542	582.4					
BFP out	50.94	412.6	6.542	590.1					
BoilDesp			0.130	590.1					
To boil	44.74	412.7	6.412	590.1					

Total bleed steam for FWH system = 1.102 kg/s, 3007 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 2363

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

STEAM PRO 13.0 Ting Wang ECCC

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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV) % 92.77
2. Actual boiler efficiency (HHV) % 78.66
3. Fuel heat input (LHV) kJ/s 16099
4. Fuel heat input (HHV) kJ/s 18988
5. Excess Air % 10
6. Adiabatic flame temperature is greater than K 1366.5
7. Boiler desuperheating water source -- After boiler feed pump

Fuel Name - 'Syngas' (Gaseous)

Fuel Name: Syngas
User-defined fuel

Fuel supply temp.	803.15 K
Heating Values	
LHV	7405.9 kJ/kg
HHV	8734.8 kJ/kg
Analysis of Fuel (Volume %)	
Hydrogen H2	11.62 %
Oxygen O2	0.08 %
Water Vapor H2O	36.62 %
Nitrogen N2	0.00 %
Carbon Monoxide CO	16.80 %
Carbon Dioxide CO2	23.20 %
Methane CH4	11.15 %
Ethane C2H6	0.13 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.18 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.22 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %
Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight	23.82
Mole flow	0.09 kg-mol/s
Mass flow (ash-free)	2.17 kg/s
Mass flow	2.17 kg/s
LHV (ash-free) @ 298 K	7406.00 kJ/kg
LHV (adj)* @ 803 K	8221.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K	9616.00 kJ/kg
Atomic percentage	
C	17.88 %
H	48.46 %
O	33.67 %
N	0.00 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	44.74	412.7	6.412	590.1
ECO exit	44.64	505.1	6.412	1000.1
CEV exit	44.64	530.1	1.587	2797.8
REV exit	44.64	530.1	4.761	2797.8
Blow down	44.64	530.1	0.063	1120.3
CS1 inlet	44.64	530.1	6.349	2797.8
CS1 exit	44.60	590.9	6.349	2997.0

DESUP water			0.130	590.1
CS2 inlet	44.60	574.1	6.478	2948.9
CS2 exit	44.52	647.0	6.478	3144.1
HP steam	44.52	647.0	6.478	3144.1

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	Mole compositions [%] N2+Ar	O2	CO2	H2O
	288.2			6.003	28.86	78.22	20.74	0.03	1.01
1 FDF		53.6	30						
	293.0			6.003	28.86	78.22	20.74	0.03	1.01
Cold end leakage			-0.382						
	293.0			5.621	28.86	78.22	20.74	0.03	1.01
3 AHA		6.0	1301						
	519.3			5.621	28.86	78.22	20.74	0.03	1.01
Hot end leakage			-0.1637						
	519.3			5.457	28.86	78.22	20.74	0.03	1.01
4 BRN		12.5	17872						
	Ad Flame			7.631	28.52	55.29	1.33	18.13	25.25
	Ad Flame								
5,6 FRN		0.0	8931						
	1723.8			7.631	28.52	55.29	1.33	18.13	25.25
	1340.4								
7 CS2		0.1	1193						
	1231.3			7.631	28.52	55.29	1.33	18.13	25.25
	1231.3								
10 CS1		0.1	1290						
	1111.0			7.631	28.52	55.29	1.33	18.13	25.25
	1111.0								
13 CEV		0.1	2912						
	827.9			7.631	28.52	55.29	1.33	18.13	25.25
	827.9								
14 ECO		0.2	2682						
	547.2			7.631	28.52	55.29	1.33	18.13	25.25
Hot end leakage			0.1637						
	546.7								
16 AHG		12.2	-1301						
	404.1			7.795	28.53	55.77	1.74	17.75	24.75
Cold end leakage			0.382						
	399.5								
25 STK		2.4	0						
	399.5			8.177	28.54	56.80	2.61	16.93	23.65

Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

Zone /path	Tg K /HX	Tw K	DT K	Delta P millibar	Qg kJ/s	Afrn m^2	Mg kg/s	Vg m/s	Tube rows
5	1723.8	530.1	1193.7						
	REV			0.0	8736		7.6	4.4	
	1723.8	530.1	1193.7						
7	1340.4	647.0	693.4						
0	CS2			0.1	1290	4.7	7.6	13.9	3.0
	1231.3	574.1	657.1						
10	1231.3	590.9	640.3						
0	CS1			0.1	1290	7.2	7.6	11.0	2.0
	1111.0	530.1	580.9						
13	1111.0	530.1	580.9						
0	CEV			0.1	2912	7.2	7.6	7.9	3.0
	827.9	530.1	297.8						
14	827.9	505.1	322.8						
0	ECO			0.2	2682	7.2	7.6	4.9	4.0
	547.2	412.7	134.5						
Totals				0.6	16911				12.0

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2629.2	ECO	2629.2
Evaporators	11420.1	REV	8565.1
		CEV	2855.0
Superheaters	2529.9		
		CS1	1265.0
		CS2	1265.0
TOTAL	16579.2		

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW		Fuel Input kJ/s	
	Gross	Net	LHV	HHV
Plant Total	4998	4784	16333	17683

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	------ LHV ------		------ HHV ------	
	Gross	Net	Gross	Net
Heat rate [kJ/kWh]	11763	12291	12735	13307
Electric efficiency [%]	30.60	29.29	28.27	27.05
CHP Total eff. [%]		29.29		27.05
U.S. PURPA eff. [%]		29.29		27.05

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	28.5
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0
Ash handling	0.0
Condenser C.W. pump	29.9
Condensate pump	4.8
Boiler feed pump	55.6
Boiler feed booster pump	0.0
FW heater drain pump(s)	0.0
Additional auxiliaries from PEACE	70.7
Misc. plant aux.	25.0
Calculated total auxiliaries	214.5

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	16579.2
Addition steam	0.0
Addition water	0.0
Makeup water	6.0
Process return	0.0
Feedwater enthalpy increase in pumps	54.7
TOTAL ENERGY IN	16639.8
ST / generator output	4998.4
Gear box loss	78.4
ST / generator mechanical losses	30.5
Generator losses	117.1
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	71.1
Steam pipe heat loss	15.1
FWH system pipe heat loss	2.6
Condenser heat rejected	11228.8
Sealing steam discharged	97.9
TOTAL ENERGY OUT	16639.8

Error (in - out) = 0.0001 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	19101.2
Inlet air sensible	105.2
Inlet air latent	82.6
TOTAL ENERGY IN	19289.0

Heat added to water, steam & blowdown	16579.2
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	913.0
Exhaust gas latent	1465.3
Boiler minor losses	331.6
TOTAL ENERGY OUT	19289.0

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	12729	13299
Electric efficiency [%]	28.28	27.07
CHP Total efficiency [%]		27.07
U.S. PURPA efficiency [%]		27.07

Turbine heat rate [kJ/kWh]	11906
Steam cycle heat rate [kJ/kWh]	11941
Steam cycle efficiency [%]	30.15
Boiler efficiency (LHVadj) [%]	93.81

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C

and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 17673 kJ/s
Fuel input to boiler (LHVadj) = 17673 kJ/s

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: ST: Cond one-casing 60 Hz Gear Drive
Feedwater heaters: C
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x -	Eff(*) %	Power kW
HPT inlet	42.402	644.3	6.478	3141.8	6.6381	*		
LPT exh	0.048	305.4	5.267	2237.1	7.3501	0.867	80.62	5224
Gear loss						78		
Mech loss						30		
Gen loss						117		
Power out						4998		

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity	m/s	110.2
Dry exhaust loss	kJ/kg	6.71
Corrected exh loss	kJ/kg	4.61

Exhaust end dimensions:

No. of parallel paths at LPT		1
Last stage rotor exit angle	degree	65.61
Last stage blade length	mm	330.32
Last stage pitch diameter	mm	1160.93
Exhaust annulus area / end	m^2	1.20

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss

39	39.92	122	8.80	244	59.83
46	30.95	137	13.49	274	76.41
53	23.14	152	19.64	305	90.65
61	17.33	168	26.21	335	100.76
76	9.98	183	32.46	366	104.94
91	6.64	198	38.47	396	101.40
107	6.38	213	44.99	427	88.32

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	5224	80.62

Air COOLED GENERATOR 60 Hz

Turbine Shaft Speed 4000 RPM

Gear loss	kW	78.4
Mech loss	kW	30.5
Gen loss	kW	117.1
Power	kW	4998.4

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			44.522	647.0	6.478	3144.1		
pipe inlet			44.522	647.0	6.478	3144.1		
pipe outlet			42.402	644.3	6.478	3141.8		
ST inlet			42.402	644.3	6.478	3141.8	6.6381	*
-Valve Stem leak 1					-0.009	3141.8		
1	HPT	Inlet	40.706	642.8	6.469	3141.8	6.6556	*
		Exit	32.617	619.7	6.469	3103.7	6.6897	*
-HPT HP leak 1					-0.100	3103.7		
2	HPT	Inlet	32.617	619.7	6.369	3103.7	6.6897	*
		Exit	3.661	413.6	6.369	2729.0	6.9124	0.998
(1)		add/extr	3.661	413.6	-1.102	2729.0	6.9124	0.998
3	LPT1	Inlet	3.661	413.6	5.267	2729.0	6.9124	0.998
		Exit	0.048	305.4	5.267	2232.5	7.3350	0.865
Exhaust to condenser			0.048	305.4	5.267	2237.1	7.3501	0.867
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	SSR	0.3	0.009	3141.8
4	HPT HP leak 1	SSR	3.9	0.100	3103.7

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.002	1	65.05	55.18
2	0.002	8	77.02	80.27
3	0.009	6	82.73	78.63

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 1			0.009	3141.8
HPT HP leak 1			0.100	3103.7
Steam at SSR inlet	1.241	590.2	0.109	3106.8
LPT SS to condenser			0.050	3106.8
LPT SS packing exhaust discharged			0.031	3106.8
SS to GSC from SSR			0.027	3106.8
Steam at GSC inlet	0.827	589.8	0.027	3106.8
GSC drain to Cond.			0.027	395.6

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	5.267	2237.1
LPT SS to condenser			0.050	3106.8
Drain from GSC	0.827	367.6	0.027	395.6
Condenser in	0.048	305.4	5.345	2236.1
Condensate well	0.347	305.4	5.345	135.2
Cooling water in	1.857	288.2	268.054	63.1
Cooling water out	1.611	298.2	268.054	105.0

Condenser C.W. pump power 29.86 kW
Condenser heat rejection 11229 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	5.345	135.2
Makeup water		288.2	0.095	62.8
Condensate pump suction	0.347	305.1	5.440	133.9
Condensate pump exit	5.685	305.2	5.440	134.7
To SJAE, GSC & rcvry HXs	5.685	305.2	5.440	134.7
Feedwater to 1st FWHT	5.685	308.4	5.440	148.0

STEAM PRO 13.0 Ting Wang ECCC
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FEEDWATER HEATING SYSTEM -- C

THERMAL OUTPUT

Source& Heater	Feed Water P bar	T K	M kg/s	h kJ/kg	Bleed Steam P bar	T K	M kg/s	h kJ/kg	Tsat K
HPT (1)					3.66	413.6	1.102	2729.0	
1-C in	3.45	308.4	5.440	148.0	3.45	411.6	1.102	2726.6	411.6
out	3.45	411.6	6.542	582.4					
BFP in	5.53	411.5	6.542	582.4					
BFP out	51.00	412.6	6.542	590.1					
BoilDesp			0.130	590.1					
To boil	44.80	412.7	6.412	590.1					

Total bleed steam for FWH system = 1.102 kg/s, 3007 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 2363

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

STEAM PRO 13.0 Ting Wang ECCC

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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV) % 93.81
2. Actual boiler efficiency (HHV) % 86.65
3. Fuel heat input (LHV) kJ/s 16333
4. Fuel heat input (HHV) kJ/s 17683
5. Excess Air % 10
6. Adiabatic flame temperature is greater than K 1366.5
7. Boiler desuperheating water source -- After boiler feed pump

Fuel Name - 'Syngas 3' (Gaseous)

Fuel Name: Syngas 3	
User-defined fuel	
Fuel supply temp.	830.15 K
Heating Values	
LHV	10310.3 kJ/kg
HHV	11162.5 kJ/kg
Analysis of Fuel (Volume %)	
Hydrogen H2	40.00 %
Oxygen O2	0.00 %
Water Vapor H2O	0.00 %
Nitrogen N2	0.00 %
Carbon Monoxide CO	41.00 %
Carbon Dioxide CO2	19.00 %
Methane CH4	0.00 %
Ethane C2H6	0.00 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.00 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.00 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %

Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight	20.65
Mole flow	0.08 kg-mol/s
Mass flow (ash-free)	1.58 kg/s
Mass flow	1.58 kg/s
LHV (ash-free) @ 298 K	10310.00 kJ/kg
LHV (adj)* @ 830 K	11156.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K	12058.00 kJ/kg
Atomic percentage	
C	27.40 %
H	36.53 %
O	36.07 %
N	0.00 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	44.80	412.7	6.412	590.1
ECO exit	44.61	505.0	6.412	1000.0
CEV exit	44.61	530.0	1.587	2797.8
REV exit	44.61	530.0	4.761	2797.8
Blow down	44.61	530.0	0.063	1120.1
CS1 inlet	44.61	530.0	6.349	2797.8
CS1 exit	44.56	590.9	6.349	2997.0
DESUP water			0.130	590.1
CS2 inlet	44.56	574.1	6.478	2948.9
CS2 exit	44.52	647.0	6.478	3144.1
HP steam	44.52	647.0	6.478	3144.1

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	Mole compositions [%] N2+Ar	O2	CO2	H2O
	288.2			5.23	28.86	78.22	20.74	0.03	1.01
1 FDF		53.1	26						
	293.0			5.23	28.86	78.22	20.74	0.03	1.01

```
 Cold end leakage           -0.3328
     293.0                4.897  28.86  78.22  20.74   0.03   1.01
3 AHA        6.1    1134
     519.3                4.897  28.86  78.22  20.74   0.03   1.01
 Hot end leakage           -0.1426
```

```
     519.3                4.755  28.86  78.22  20.74   0.03   1.01
4 BRN       12.5    17673
    Ad Flame                6.339  30.13  61.26   1.48  21.90  15.37
```

```
    Ad Flame
5,6 FRN      0.0    8932
    2011.1                6.339  30.13  61.26   1.48  21.90  15.37
```

```
    1551.1
7  CS2       0.3    1193
    1415.5                6.339  30.13  61.26   1.48  21.90  15.37
```

```
    1415.5
10  CS1      0.1    1290
    1266.0                6.339  30.13  61.26   1.48  21.90  15.37
```

```
    1266.0
13  CEV      0.3    2912
     914.3                6.339  30.13  61.26   1.48  21.90  15.37
```

```
     914.3
14  ECO      0.2    2680
     562.9                6.339  30.13  61.26   1.48  21.90  15.37
```

```
  Hot end leakage           0.1426
     562.0
16  AHG     11.0   -1134
     404.7                6.482  30.10  61.65   1.92  21.39  15.04
  Cold end leakage          0.3328
```

```
     399.6
25 STK       2.7       0
     399.6                6.814  30.03  62.49   2.88  20.31  14.33
```


Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

```
 Zone  Tg K   Tw K   DT K   Delta P    Qg     Afrn     Mg     Vg    Tube
/path  /HX                  millibar   kJ/s   m^2     kg/s    m/s  rows
```

```
 5  2011.1   530.0  1481.1
      REV                    0.0   8737            6.3    5.1
   2011.1   530.0  1481.1
```

```
 7  1551.1   647.0   904.1
 0    CS2                    0.3   1290    3.7    6.3   21.5    2.0
   1415.5   574.1   841.4
```

```
10  1415.5   590.9   824.6
 0    CS1                    0.1   1290    5.7    6.3   11.8    2.0
   1266.0   530.0   735.9
```

```
13  1266.0   530.0   735.9
 0    CEV                    0.3   2912    5.7    6.3   10.1    8.0
    914.3   530.0   384.2
```

```
14   914.3   505.0   409.2
 0    ECO                    0.2   2680    5.7    6.3    4.7    6.0
    562.9   412.7   150.2
```

```
Totals                       0.9  16911                 18.0
```

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2627.9	ECO	2627.9
Evaporators	11421.4	REV	8566.0
		CEV	2855.3
Superheaters	2529.8		
		CS1	1264.9
		CS2	1264.9
TOTAL	16579.2		

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	4851		11486		31.34	
Steam Turbine(s)	2336					
Plant Total	7187	6971	7752	7992	46.44	45.04

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
46.43	47.82	46.43	8117

GT fuel HHV/LHV ratio = 1.1096 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1096
Fuel HHV chemical energy input = 17173 kWth = 58600 kBTU/h
Fuel LHV chemical energy input = 15477 kWth = 52811 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15477 kWth = 52811 kBTU/h
Energy chargeable to power = 15015 kWth = 51235 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	4851	31.34	11486	16	902
Total	4851			16	

Fuel chemical HHV per gas turbine = 17173 kWth = 58600 kBTU/h
Fuel chemical LHV per gas turbine = 15477 kWth = 52811 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
85.71	2336	25.62	21.96	430	1466

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 10639 kWth = 36302 kBTU/h
Net process heat output = 5.805% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
80	0	0	10	27	18	0	5

HVAC = 3.5 kW, Lights = 4.75 kW
Additional auxiliaries from PEACE running motor/load list = 64.25 kW
Miscellaneous plant auxiliaries = 3.594 kW
Program estimated overall plant auxiliaries = 215.8 kW
Actual (user input) overall plant auxiliaries = 215.8 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 215.8 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=CH4, supplied @ 803 K, LHV = 51623.58 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.83 millibar

Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.76, Friction = 0.51, Buoyancy = -0.44 millibar
Stack velocity = 19.45 m/s

# 83	Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
	RR 501KH5	11.3	1450	902	15.3	4851	11486	15.6	75.48	13.01	3.53	7.98

Fuel compressor = 80.06 kWe, Q rejected = 16.6 kW , exit temperature = 843.6 K
Fuel molecular weight = 16.04; LHV @ combustor = 51790 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	616	11.32	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	844	16.03	0.30924						
Turbine inlet	1450	10.87	15.39	28.40	74.54	12.88	3.59	8.09	0.90
Turbine coolant			0.25						
Turbine exhaust	902	1.04	15.64	28.41	74.58	13.01	3.53	7.98	0.90

Compressor = 5167 Turbine = 10400 kW
Turbine coolant = 1.634% compr in
Mech loss = 109.1 kW Gear box loss = 80.19 kW Generator loss = 193.4 kW
Mech eff. = 97.92% Gear box eff. = 98.44% Generator eff. = 96.17%
GT specific power @ gen term = 316.5 kW per kg/s
GT efficiency @ gen term = 28.246% HHV = 31.34% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.383% HHV = 30.38% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 18250 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	17775

Energy out = 18258 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
160	109	80	193	0	10885	1979	4851	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -7.896 kW = -0.0433 %

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:05:06 file=C:/Tflow13/MYFILES/case9.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 12959 kW

GT Exhaust Sensible	/Air Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
10885	1979	0	3	68	23	0	0	0

Energy out = 12959 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
135	79	122	1639	1979	6170	498	0	0	2336

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1999 kW = -0.0015 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	899.9	755.1	144.9							
2	HPS3			4.4	1.76	15.6	1632.4	16.2	4	15
	811.0	527.9	283.2							
5	811.0	527.9	283.2							
2	HPB1			4.4	6.15	15.6	4638.0	14.2	14	14
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			4.4	1.53	15.6	475.0	9.9	6	17
	520.0	485.9	34.1							
9	520.0	478.2	41.8							
1	IPS1			4.4	0.17	15.6	23.2	9.6	1	14
	518.6	416.8	101.8							
10	518.6	485.9	32.8							
2	HPE2			4.4	1.79	15.6	876.2	9.1	8	17

	466.7	412.9	53.8					
11	466.7	416.8	49.9					
1	IPB		4.4	1.48	15.6	500.5	9.6	5	14
	436.8	416.8	20.0					
12	436.8	411.8	25.0					
1	IPE2		4.4	1.18	15.6	473.4	7.7	7	17
	408.4	374.4	34.0					
17	408.4	363.2	45.2					
1	LTE		4.4	0.93	15.6	590.8	7.1	6	17
	372.7	314.8	57.9					
Totals				15.00		9209.5	51.0	

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.526 kg/m²-s
Exhaust loss = 21.83 millibar:
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.76, Friction = 0.51, Buoyancy = -0.44 millibar
Stack velocity = 19.45 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=74.58% O_2=13.01% CO_2=3.531% H_2O=7.979% AR=0.8982%
Flue gas dew point = 315 K   M.W.= 28.41

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2391	5088	1639	9118
UA kW/K	65	62	8	135
A sq.m	1195	1268	227	2689

Tube length = 3.563 m, HRSG width = 1.245 m, Aspect ratio = 2.863

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
-----------							
from FW Pump	54.13	412.7	590.8	2.715			
HPFW	44.35	412.9	590.8	2.715			
To desup	44.35	412.9	590.8	0.009			
HPE1				2.706	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.706	20.65	868	367
7	43.70	485.9	911.3	0.000			
HPE3				2.706	16.20	470	283
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.027			
HPB1				2.679	46.71	4592	919
9	43.06	527.9	2798.7	0.000			
HPS0				2.679	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.679	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.679	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.679	7.91	1616	205
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.679			
Aft HP pipe	40.00	753.2	3399.4	2.679			
To HPT	40.00	753.2	3399.4	2.679			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
-----------							
from FW Pump	6.01	374.3	424.5	2.948			

IPFW 4.12 374.4 424.5 2.948
IPE1 2.948 0.00 0 0
19 4.12 374.4 424.5 0.000
IPE2 2.948 16.17 469 289
1 4.00 411.8 583.5 0.000
to HP pump 4.00 411.8 583.5 2.715
IP blowdown 4.00 416.8 605.0 0.002
IPB 0.230 15.31 496 349
2 4.00 416.8 2737.6 0.000
Steam to DA 4.00 416.8 2737.6 0.058
IPS1 0.172 0.34 23 22
3 3.85 478.2 2871.5 0.000
IPS2 0.172 0.00 0 0
4 3.85 478.2 2871.5 0.172

Feedwater:

Cond return	0.43	311.9	162.2	2.665
After pump	1.09	312.0	162.7	2.665
Proc stm ret	3.45	363.2	377.2	0.181
Makeup	3.45	288.1	63.3	0.043
FW to LTE	1.09	314.8	174.6	2.889

LTE 2.889 11.51 585 256
13 1.05 363.2 377.0 0.000
LTE to D/A 1.05 363.2 377.0 2.889

Deaerator:

IPB to D/A	4.00	416.8	2737.6	0.058
FW to IP/HP	1.05	374.3	423.8	2.948

Boiler feedpumps = 25.05 kWe: HP = 22.45 kWe IP = 2.594 kWe
Condensate pump(s) = 1.483 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.009			
From source	3.85	425.7	2756.7	0.181	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.181	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.679	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.679	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.034					
HPT inlet	39.00	752.6	3399.4	2.643	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.643	7.0427	230.6			73.52*
OUT	3.61	513.3	2945.9	2.643	7.3910	100.2		1198	73.52**
	3.61	513.3	2945.9	2.643	7.3910	100.2			
HP/IP/LP Casing: Group LPTL									
IN	3.61	513.3	2945.9	2.643	7.3910	100.2			73.13*
OUT	0.069	311.9	2450.6	2.643	7.8930		0.950		75.98**
After LL	0.07	311.9	2469.2	2.643	7.9526		0.957	1260	
To condenser	0.069	311.9	2469.2	2.643	7.9526		0.957		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	68.20	73.52	73.52	Sup.	1198.3
HP/IP/LP Casing	LPTL	6	73.51	75.98	73.13	0.950	1259.7

Number of physical casings = 1
Gross power = 2458 kW
ST mech. loss = 8.603 kW. gear box loss= 36.87 kW.
Gen. elec. loss= 70.43 kW. Gen. mech. loss= 5.735 kW.
ST/Generator mech. x elect. efficiency = 95.05 %
Generator output = 2336.3 kWe. ST auxiliaries = 4.673 kWe
Annulus velocity = 205.7 m/s, RPM = 14785
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.59 kJ/kg
Exhaust volume flow per path = 52.26 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.254 sq.m
Last stage bucket length = 165.8 mm, pitch dia. = 487.7 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2469.22	2.64
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.67
Cooling water in		288.20		147.37
Cooling water out		298.20		147.37

Number of passes = 2 UA = 337.4 kW/K Surface area = 100.9 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 337
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3386 condenser + 0.5982 piping)
CW pump(s) = 18.46 kWe Condensate pump(s) = 1.483 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:26:41 file=C:/Tflow13/MYFILES/case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	6067		9371		38.42	
Steam Turbine(s)	2555					
Plant Total	8621	7870	6594	7224	54.59	49.84

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.24	54.64	52.55	7153

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18637 kWth = 63595 kBTU/h
Fuel LHV chemical energy input = 15792 kWth = 53889 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15792 kWth = 53889 kBTU/h
Energy chargeable to power = 14977 kWth = 51108 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	6067	38.42	9371	19	860
Total	6067			19	

Fuel chemical HHV per gas turbine = 18637 kWth = 63595 kBTU/h
Fuel chemical LHV per gas turbine = 15792 kWth = 53889 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
83.69	2555	25.14	21.04	758	2586

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 12144 kWth = 41438 kBTU/h
Net process heat output = 8.784% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
608	0	0	10	29	20	0	5

HVAC = 4 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66 kW
Miscellaneous plant auxiliaries = 4.311 kW
Program estimated overall plant auxiliaries = 750.9 kW
Actual (user input) overall plant auxiliaries = 750.9 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 750.9 kW

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:26:41 file=C:/Tflow13/MYFILES/case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.76 millibar

Duct = 5.00, HRSG = 14.99 millibar
Stack leaving loss = 1.77, Friction = 0.45, Buoyancy = -0.45 millibar
Stack velocity = 19.61 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5	13.4	1385	860	15.3	6067	9371	19.0	70.82	11.36	7.25	10.57

Fuel compressor = 607.8 kWe, Q rejected = 123.9 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	658	13.42	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	873	16.03	3.65941						
Turbine inlet	1385	12.88	18.74	28.67	69.88	11.24	7.34	10.70	0.84
Turbine coolant			0.25						
Turbine exhaust	860	1.04	18.99	28.67	69.98	11.36	7.25	10.57	0.84

Compressor = 5857 Turbine = 12327 kW
Turbine coolant = 1.634% compr in
Mech loss = 110.6 kW Gear box loss = 81.32 kW Generator loss = 211 kW
Mech eff. = 98.29% Gear box eff. = 98.72% Generator eff. = 96.64%
GT specific power @ gen term = 395.8 kW per kg/s
GT efficiency @ gen term = 32.55% HHV = 38.42% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.008% HHV = 33.05% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22248 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	21773

Energy out = 22257 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
187	111	81	211	0	12444	3155	6067	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.227 kW = -0.0415 %

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:26:41 file=C:/Tflow13/MYFILES/case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15748 kW

GT Exhaust/Air Addn. Sensible	Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12444	3155	0	3	120	25	0	0	0

Energy out = 15748 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT	Proc. Water	Electric Output
155	87	130	2134	3155	6654	878	0	0	2555

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1086 kW = -0.0007 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	858.1	755.1	103.0							
2	HPS3			5.3	2.17	19.0	1766.9	16.3	4	16
	779.6	527.9	251.7							
5	779.6	527.9	251.7							
2	HPB1			5.3	6.06	19.0	5020.2	14.2	13	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.3	1.34	19.0	514.1	10.1	5	19
	523.4	485.9	37.5							
9	523.4	478.2	45.2							
1	IPS1			5.3	0.21	19.0	40.9	10.0	1	15
	521.4	416.8	104.6							
10	521.4	485.9	35.5							
2	HPE2			5.3	1.50	19.0	948.4	9.4	6	19
	475.8	412.9	62.9							
11	475.8	416.8	59.0							
1	IPB			5.3	1.80	19.0	801.9	9.7	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.3	1.10	19.0	532.8	7.9	6	19
	410.7	374.4	36.4							
17	410.7	363.2	47.6							
1	LTE			5.3	0.81	19.0	639.8	7.3	5	19
	379.3	316.7	62.6							
Totals					14.99		10265.1		46.0	

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.582 kg/m²-s
Exhaust loss = 21.76 millibar:
Duct = 5.00, HRSG = 14.99 millibar
Stack leaving loss = 1.77, Friction = 0.45, Buoyancy = -0.45 millibar
Stack velocity = 19.61 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=69.98% O_2=11.36% CO_2=7.248% H_2O=10.57%
AR=0.8428%
Flue gas dew point = 320 K   M.W.= 28.67

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2609	5765	1790	10163
UA kW/K	66	77	11	154
A sq.m	1231	1581	346	3158

Tube length = 3.975 m, HRSG width = 1.334 m, Aspect ratio = 2.981

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.945			
HPFW	44.35	412.9	590.8	2.945			
To desup	44.35	412.9	590.8	0.016			
HPE1				2.929	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.929	19.79	939	359
7	43.70	485.9	911.3	0.000			
HPE3				2.929	16.68	509	292
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.900	54.87	4971	1086
9	43.06	527.9	2798.7	0.000			
HPS0				2.900	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.900	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.900	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.900	10.62	1749	310
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.900			
Aft HP pipe	40.00	753.2	3399.4	2.900			
To HPT	40.00	753.2	3399.4	2.900			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.318			
IPFW	4.12	374.4	424.5	3.318			
IPE1				3.318	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.318	17.57	527	320
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.945			
IP blowdown	4.00	416.8	605.0	0.004			
IPB				0.369	22.25	794	495
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.066			
IPS1				0.303	0.58	41	36
3	3.85	478.2	2871.5	0.000			
IPS2				0.303	0.00	0	0
4	3.85	478.2	2871.5	0.303			
Feedwater:							
Cond return	0.43	311.9	162.2	2.885			
After pump	1.09	312.0	162.7	2.885			
Proc stm ret	3.45	363.2	377.2	0.319			
Makeup	3.45	288.1	63.3	0.048			
FW to LTE	1.09	316.7	182.2	3.252			
LTE				3.252	11.69	633	260
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.252			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.066			
FW to IP/HP	1.05	374.3	423.8	3.318			

Boiler feedpumps = 27.21 kWe: HP = 24.3 kWe IP = 2.906 kWe
Condensate pump(s) = 1.601 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.016			
From source	3.85	425.7	2756.7	0.319	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.319	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.900	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.900	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.860	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.860	7.0427	230.6			74.38*
OUT	3.61	510.7	2940.6	2.860	7.3807	97.7		1312	74.38**
	3.61	510.7	2940.6	2.860	7.3807	97.7			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.7	2940.6	2.860	7.3807	97.7			73.86*
OUT	0.069	311.9	2442.2	2.860	7.8661		0.946		76.70**
After LL	0.07	311.9	2460.7	2.860	7.9253		0.954	1373	
To condenser	0.069	311.9	2460.7	2.860	7.9253		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.16	74.38	74.38	Sup.	1312.3
HP/IP/LP Casing	LPTL	6	74.36	76.70	73.86	0.946	1372.6

Number of physical casings = 1
Gross power = 2684.9 kW
ST mech. loss = 9.397 kW. gear box loss= 40.27 kW.
Gen. elec. loss= 74.26 kW. Gen. mech. loss= 6.265 kW.

ST/Generator mech. x elect. efficiency = 95.15 %
Generator output = 2554.7 kWe.   ST auxiliaries = 5.109 kWe
Annulus velocity = 205.7 m/s,   RPM = 14237
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.36 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2739 sq.m
Last stage bucket length = 172.2 mm, pitch dia. = 506.4 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.71	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.88
Cooling water in		288.20		158.94
Cooling water out		298.20		158.94

Number of passes = 2   UA = 363.8 kW/K   Surface area = 108.8 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.918 m   Number = 364
CW vel. = 2.134 m/s DP = 0.9364 bar (0.3382 condenser + 0.5982 piping)
CW pump(s) = 19.86 kWe   Condensate pump(s) = 1.601 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:25:49 file=C:/Tflow13/MYFILES/case11.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5508		10278		35.03	
Steam Turbine(s)	2526					
Plant Total	8034	7518	7046	7530	51.09	47.81

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
49.66	51.52	49.80	7747

GT fuel HHV/LHV ratio = 1.1794   DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1794
Fuel HHV chemical energy input = 18547 kWth = 63287 kBTU/h
Fuel LHV chemical energy input = 15725 kWth = 53658 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15725 kWth = 53658 kBTU/h
Energy chargeable to power = 15097 kWth = 51515 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5508	35.03	10278	17	882
Total	5508			17	

Fuel chemical HHV per gas turbine = 18547 kWth = 63287 kBTU/h
Fuel chemical LHV per gas turbine = 15725 kWth = 53658 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
84.90	2526	25.52	21.67	584	1993

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11656 kWth = 39775 kBTU/h
Net process heat output = 7.21% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
375	0	0	10	28	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 65.5 kW
Miscellaneous plant auxiliaries = 4.017 kW
Program estimated overall plant auxiliaries   = 516.3 kW
Actual (user input) overall plant auxiliaries = 516.3 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 516.3 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 8221.16 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.76 millibar

Duct = 5.00, HRSG = 14.97 millibar
Stack leaving loss = 1.75, Friction = 0.47, Buoyancy = -0.43 millibar
Stack velocity = 19.39 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	RR 501KH5	12.4	1408	882	15.3	5508	10278	17.5	68.36	12.39	7.81	11.43

Fuel compressor = 374.8 kWe, Q rejected = 76.74 kW , exit temperature = 865 K
Fuel molecular weight = 23.82; LHV @ combustor = 8335 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	637	12.41	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	865	16.03	2.12328						
Turbine inlet	1408	11.91	17.20	28.71	67.41	12.27	7.92	11.58	0.81
Turbine coolant			0.25						
Turbine exhaust	882	1.03	17.45	28.71	67.55	12.39	7.81	11.43	0.81

Compressor = 5524 Turbine = 11425 kW
Turbine coolant = 1.634% compr in
Mech loss = 109.9 kW Gear box loss = 80.8 kW Generator loss = 202.4 kW
Mech eff. = 98.14% Gear box eff. = 98.6% Generator eff. = 96.46%
GT specific power @ gen term = 359.3 kW per kg/s
GT efficiency @ gen term = 29.698% HHV = 35.03% LHV
GT eff. @ gen term adjusted for fuel temp. = 26.753% HHV = 31.55% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 21135 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	20660

Energy out = 21143 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
177	110	81	202	0	11933	3132	5508	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.411 kW = -0.0398 %

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:25:49 file=C:/Tflow13/MYFILES/case11.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15185 kW

GT Exhaust Sensible	GT Exhaust Latent	Air Addn. Enthalpy	DB Fuel	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
11933	3132	0	3	93	25	0	0	0	

Energy out = 15186 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc. Water	Electric Output
149	85	129	1896	3132	6592	677	0	0	2526

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0841 kW = -0.0006 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	879.7	755.1	124.6							
2	HPS3			4.9	1.93	17.5	1749.4	16.2	4	15
	796.0	527.9	268.1							
5	796.0	527.9	268.1							
2	HPB1			4.9	6.11	17.5	4970.5	14.1	14	14
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			4.9	1.41	17.5	509.1	9.8	6	18
	521.6	485.9	35.7							
9	521.6	478.2	43.4							
1	IPS1			4.9	0.19	17.5	31.6	9.8	1	14
	519.9	416.8	103.1							
10	519.9	485.9	34.1							
2	HPE2			4.9	1.67	17.5	939.0	9.3	7	18
	470.9	412.9	58.0							
11	470.9	416.8	54.1							
1	IPB			4.9	1.59	17.5	646.3	9.4	6	14
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			4.9	1.21	17.5	515.9	8.0	6	18
	409.4	374.4	35.0							
17	409.4	363.2	46.3							
1	LTE			4.9	0.86	17.5	633.3	7.1	6	18
	375.6	315.6	59.9							
Totals					14.97		9995.0	49.9		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.572 kg/m²-s
Exhaust loss = 21.76 millibar:
Duct = 5.00, HRSG = 14.97 millibar
Stack leaving loss = 1.75, Friction = 0.47, Buoyancy = -0.43 millibar
Stack velocity = 19.39 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=67.55% O_2=12.39% CO_2=7.811% H_2O=11.43%
AR=0.8135%
Flue gas dew point = 322 K   M.W.= 28.71

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2572	5561	1763	9896
UA kW/K	67	71	10	148
A sq.m	1241	1420	279	2940

Tube length = 3.886 m, HRSG width = 1.257 m, Aspect ratio = 3.091

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.913			
HPFW	44.35	412.9	590.8	2.913			
To desup	44.35	412.9	590.8	0.012			
HPE1				2.900	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.900	20.88	930	375
7	43.70	485.9	911.3	0.000			
HPE3				2.900	16.95	504	283
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.872	52.01	4921	1009
9	43.06	527.9	2798.7	0.000			
HPS0				2.872	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.872	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.872	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.872	9.34	1732	251
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.872			
Aft HP pipe	40.00	753.2	3399.4	2.872			
To HPT	40.00	753.2	3399.4	2.872			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.213			
IPFW	4.12	374.4	424.5	3.213			
IPE1				3.213	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.213	17.35	511	327
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.913			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.297	18.86	640	411
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.064			
IPS1				0.233	0.46	31	29
3	3.85	478.2	2871.5	0.000			
IPS2				0.233	0.00	0	0
4	3.85	478.2	2871.5	0.233			
Feedwater:							
Cond return	0.43	311.9	162.2	2.856			
After pump	1.09	312.0	162.7	2.856			
Proc stm ret	3.45	363.2	377.2	0.246			
Makeup	3.45	288.1	63.3	0.047			
FW to LTE	1.09	315.6	177.9	3.149			
LTE				3.149	11.99	627	256
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.149			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.064			
FW to IP/HP	1.05	374.3	423.8	3.213			

Boiler feedpumps = 26.86 kWe: HP = 24.04 kWe IP = 2.817 kWe
Condensate pump(s) = 1.585 kWe

PROCESS STEAM FLOWS - Plant Totals

	P	T	h	M	s	Superheat	Quality
	bar	K	kJ/kg	kg/s	kJ/kg-K	K	

Main IP Process:

	P	T	h	M	s	Superheat	Quality
main desup.		412.9	590.8	0.012			
From source	3.85	425.7	2756.7	0.246	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.246	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P	T	h	M	s	Super-heat K	x	Work	Eff
	bar	K	kJ/kg	kg/s	kJ/kg-K			kW	%
From boiler	40.00	753.2	3399.4	2.872	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.872	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.036					
HPT inlet	39.00	752.6	3399.4	2.832	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.832	7.0427	230.6			74.27*
OUT	3.61	511.1	2941.3	2.832	7.3820	98.0		1297	74.27**
	3.61	511.1	2941.3	2.832	7.3820	98.0			
HP/IP/LP Casing: Group LPTL									
IN	3.61	511.1	2941.3	2.832	7.3820	98.0			73.75*
OUT	0.069	311.9	2443.4	2.832	7.8698		0.947		76.60**
After LL	0.07	311.9	2461.9	2.832	7.9291		0.954	1358	
To condenser	0.069	311.9	2461.9	2.832	7.9291		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.03	74.27	74.27	Sup.	1297.3
HP/IP/LP Casing	LPTL	6	74.23	76.60	73.75	0.947	1357.6

Number of physical casings = 1
Gross power = 2654.9 kW
ST mech. loss = 9.292 kW. gear box loss= 39.82 kW.
Gen. elec. loss= 73.75 kW. Gen. mech. loss= 6.195 kW.

ST/Generator mech. x elect. efficiency = 95.14 %
Generator output = 2525.8 kWe.   ST auxiliaries = 5.052 kWe
Annulus velocity = 205.7 m/s,   RPM = 14304
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.5 kJ/kg
Exhaust volume flow per path = 55.83 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2714 sq.m
Last stage bucket length = 171.4 mm, pitch dia. = 504 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in   m/s, exhaust loss in   kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2461.89	2.83
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.86
Cooling water in		288.20		157.44
Cooling water out		298.20		157.44

Number of passes = 2   UA = 360.4 kW/K   Surface area = 107.8 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.924 m   Number = 360
CW vel. = 2.134 m/s DP = 0.9368 bar (0.3386 condenser + 0.5982 piping)
CW pump(s) = 19.68 kWe   Condensate pump(s) = 1.585 kWe

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:27:47 file=C:/Tflow13/MYFILES/case12.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5133		10728		33.56	
Steam Turbine(s)	2422					
Plant Total	7555	7102	7288	7754	49.39	46.43

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
48.05	49.68	48.11	7404

GT fuel HHV/LHV ratio = 1.0827 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.0827
Fuel HHV chemical energy input = 16559 kWth = 56506 kBTU/h
Fuel LHV chemical energy input = 15295 kWth = 52192 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15295 kWth = 52192 kBTU/h
Energy chargeable to power = 14761 kWth = 50368 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5133	33.56	10728	17	892
Total	5133			17	

Fuel chemical HHV per gas turbine = 16559 kWth = 56506 kBTU/h
Fuel chemical LHV per gas turbine = 15295 kWth = 52192 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
85.38	2422	25.58	21.84	497	1696

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11092 kWth = 37850 kBTU/h
Net process heat output = 6.54% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
315	0	0	10	27	19	0	5

HVAC = 3.5 kW, Lights = 4.75 kW
Additional auxiliaries from PEACE running motor/load list = 65 kW
Miscellaneous plant auxiliaries = 3.777 kW
Program estimated overall plant auxiliaries = 453.3 kW
Actual (user input) overall plant auxiliaries = 453.3 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 453.3 kW

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:27:47 file=C:/Tflow13/MYFILES/case12.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas 3, supplied @ 830 K, LHV = 11156.48 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.77 millibar

Duct = 5.00, HRSG = 14.99 millibar
Stack leaving loss = 1.71, Friction = 0.47, Buoyancy = -0.40 millibar
Stack velocity = 18.92 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5	11.9	1431	892	15.3	5133	10728	16.8	72.40	14.12	7.54	5.94

Fuel compressor = 315 kWe, Q rejected = 63.93 kW , exit temperature = 909.9 K
Fuel molecular weight = 20.65; LHV @ combustor = 11294 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	15.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		0.25						
Comp. discharge	628	11.92	15.08	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	910	16.03	1.48346						
Turbine inlet	1431	11.45	16.56	29.30	71.45	14.02	7.65	6.02	0.86
Turbine coolant			0.25						
Turbine exhaust	892	1.04	16.81	29.29	71.54	14.12	7.54	5.94	0.86

Compressor = 5363 Turbine = 10883 kW
Turbine coolant = 1.634% compr in
Mech loss = 109.4 kW Gear box loss = 80.45 kW Generator loss = 197.1 kW
Mech eff. = 98.02% Gear box eff. = 98.51% Generator eff. = 96.3%
GT specific power @ gen term = 334.8 kW per kg/s
GT efficiency @ gen term = 30.99% HHV = 33.56% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.644% HHV = 31.01% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 18567 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
233	242	0	0	18092

Energy out = 18575 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
168	109	80	197	0	11351	1537	5133	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.051 kW = -0.0434 %

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:27:47 file=C:/Tflow13/MYFILES/case12.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 12993 kW

GT Exhaust/Air Sensible	Latent	Addn. DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
11351	1537	0	3	79	24	0	0	0

Energy out = 12993 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT	Proc. Water	Electric Output
142	82	125	1746	1537	6363	576	0	0	2422

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1333 kW = -0.001 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	890.2	755.1	135.1							
2	HPS3			4.7	1.85	16.8	1685.9	16.1	4	15
	803.8	527.9	275.9							
5	803.8	527.9	275.9							
2	HPB1			4.7	6.16	16.8	4790.0	14.1	14	14
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			4.7	1.48	16.8	490.6	9.8	6	18
	520.7	485.9	34.9							
9	520.7	478.2	42.6							
1	IPS1			4.7	0.18	16.8	26.8	9.6	1	14
	519.2	416.8	102.4							
10	519.2	485.9	33.4							
2	HPE2			4.7	1.70	16.8	904.9	9.0	8	18
	468.7	412.9	55.8							
11	468.7	416.8	51.8							
1	IPB			4.7	1.48	16.8	564.3	9.2	6	14
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			4.7	1.25	16.8	492.6	7.9	6	18
	408.8	374.4	34.5							
17	408.8	363.2	45.7							
1	LTE			4.7	0.90	16.8	610.2	7.1	6	18
	374.0	315.2	58.8							
Totals					14.99		9565.3	51.0		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.612 kg/m²-s
Exhaust loss = 21.77 millibar:
Duct = 5.00, HRSG = 14.99 millibar
Stack leaving loss = 1.71, Friction = 0.47, Buoyancy = -0.40 millibar
Stack velocity = 18.92 m/s
DB fuel = 0 kg/s; Fuel=CH4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N2=71.54% O2=14.12% CO2=7.537% H2O=5.942%
AR=0.8615%
Flue gas dew point = 309 K   M.W.= 29.29

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2474	5301	1696	9471
UA kW/K	66	66	9	141
A sq.m	1217	1323	250	2790

Tube length = 3.702 m, HRSG width = 1.257 m, Aspect ratio = 2.945

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.805			
HPFW	44.35	412.9	590.8	2.805			
To desup	44.35	412.9	590.8	0.011			
HPE1				2.795	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.795	20.75	896	359
7	43.70	485.9	911.3	0.000			
HPE3				2.795	16.54	486	283
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.028			
HPB1				2.767	49.13	4743	960
9	43.06	527.9	2798.7	0.000			
HPS0				2.767	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.767	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.767	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.767	8.55	1669	225
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.767			
Aft HP pipe	40.00	753.2	3399.4	2.767			
To HPT	40.00	753.2	3399.4	2.767			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.067			
IPFW	4.12	374.4	424.5	3.067			
IPE1				3.067	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.067	16.71	488	319
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.805			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.259	16.88	559	363
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.061			
IPS1				0.199	0.39	27	25
3	3.85	478.2	2871.5	0.000			
IPS2				0.199	0.00	0	0
4	3.85	478.2	2871.5	0.199			
Feedwater:							
Cond return	0.43	311.9	162.2	2.753			
After pump	1.09	312.0	162.7	2.753			
Proc stm ret	3.45	363.2	377.2	0.209			
Makeup	3.45	288.1	63.3	0.045			
FW to LTE	1.09	315.2	176.1	3.007			
LTE				3.007	11.74	604	256
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.007			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.061			
FW to IP/HP	1.05	374.3	423.8	3.067			

Boiler feedpumps = 25.87 kWe: HP = 23.18 kWe IP = 2.695 kWe
Condensate pump(s) = 1.53 kWe

PROCESS STEAM FLOWS - Plant Totals

	P	T	h	M	s	Superheat	Quality
	bar	K	kJ/kg	kg/s	kJ/kg-K	K	
Main IP Process:							
main desup.		412.9	590.8	0.011			
From source	3.85	425.7	2756.7	0.209	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.209	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P	T	h	M	s	Super-heat	x	Work	Eff
	bar	K	kJ/kg	kg/s	kJ/kg-K	K		kW	%
From boiler	40.00	753.2	3399.4	2.767	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.767	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.035					
HPT inlet	39.00	752.6	3399.4	2.729	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.729	7.0427	230.6			73.86*
OUT	3.61	512.3	2943.8	2.729	7.3869	99.2		1243	73.86**
	3.61	512.3	2943.8	2.729	7.3869	99.2			
HP/IP/LP Casing: Group LPTL									
IN	3.61	512.3	2943.8	2.729	7.3869	99.2			73.39*
OUT	0.069	311.9	2447.4	2.729	7.8828		0.948		76.24**
After LL	0.07	311.9	2466.0	2.729	7.9423		0.956	1304	
To condenser	0.069	311.9	2466.0	2.729	7.9423		0.956		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	68.58	73.86	73.86	Sup.	1243.3
HP/IP/LP Casing	LPTL	6	73.79	76.24	73.39	0.948	1304.0

Number of physical casings = 1
Gross power = 2547.3 kW
ST mech. loss = 8.916 kW. gear box loss= 38.21 kW.
Gen. elec. loss= 71.94 kW. Gen. mech. loss= 5.944 kW.
ST/Generator mech. x elect. efficiency = 95.09 %

Generator output = 2422.3 kWe.   ST auxiliaries = 4.845 kWe
Annulus velocity = 205.7 m/s,   RPM = 14558
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.55 kJ/kg
Exhaust volume flow per path = 53.9 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.262 sq.m
Last stage bucket length = 168.4 mm, pitch dia. = 495.2 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2465.99	2.73
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.75
Cooling water in		288.20		152.00
Cooling water out		298.20		152.00

Number of passes = 2   UA = 347.9 kW/K   Surface area = 104 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.919 m   Number = 348
CW vel. = 2.134 m/s DP = 0.9364 bar (0.3382 condenser + 0.5982 piping)
CW pump(s) = 19.02 kWe   Condensate pump(s) = 1.53 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5859		9372		38.41	
Steam Turbine(s)	2534					
Plant Total	8394	7664	6542	7165	55.03	50.25

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.43	54.61	52.72	7153

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18001 kWth = 61426 kBTU/h
Fuel LHV chemical energy input = 15254 kWth = 52051 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15254 kWth = 52051 kBTU/h
Energy chargeable to power = 14538 kWth = 49608 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5859	38.41	9372	18	871
Total	5859			18	

Fuel chemical HHV per gas turbine = 18001 kWth = 61426 kBTU/h
Fuel chemical LHV per gas turbine = 15254 kWth = 52051 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
85.69	2534	25.33	21.70	666	2271

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11676 kWth = 39843 kBTU/h
Net process heat output = 7.991% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries: Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Steam Cycle Auxiliaries: Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
587	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66 kW
Miscellaneous plant auxiliaries = 4.197 kW
Program estimated overall plant auxiliaries = 729.4 kW
Actual (user input) overall plant auxiliaries = 729.4 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 729.4 kW

GT PRO 13.0 Ting Wang
1263 11-04-2004 17:38:10 file=C:/Tflow13/MYFILES/case13.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 298 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.86 millibar

Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.76, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.51 m/s

# Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
83											
RR 501KH5	12.9	1398	871	14.6	5859	9372	18.2	70.80	11.29	7.31	10.60

Fuel compressor = 587.1 kWe, Q rejected = 119.6 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	14.64	28.86	77.35	20.75	0.03	0.94	0.93
Comp. inlet	298	1.00	14.64	28.86	77.35	20.75	0.03	0.94	0.93
Turbine coolant	misc.		0.24						
Comp. discharge	668	12.90	14.40	28.86	77.35	20.75	0.03	0.94	0.93
Fuel flow	873	16.03	3.53460						
Turbine inlet	1398	12.39	17.94	28.67	69.86	11.16	7.41	10.73	0.84
Turbine coolant			0.24						
Turbine exhaust	871	1.04	18.18	28.68	69.96	11.29	7.31	10.60	0.84

Compressor = 5611 Turbine = 11869 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.4 kW Gear box loss = 81.13 kW Generator loss = 207.7 kW
Mech eff. = 98.24% Gear box eff. = 98.68% Generator eff. = 96.58%
GT specific power @ gen term = 400.2 kW per kg/s
GT efficiency @ gen term = 32.55% HHV = 38.41% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.006% HHV = 33.05% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 21615 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
371	214	0	0	21030

Energy out = 21624 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
181	110	81	208	0	12156	3028	5859	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.887 kW = -0.0411 %

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15318 kW

GT Exhaust/Air Sensible	Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12156	3028	0	3	106	25	0	0	0

Energy out = 15318 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT	Proc. Water	Electric Output
152	86	129	2007	3028	6610	771	0	0	2534

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1086 kW = -0.0007 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	869.1	755.1	114.1							
2	HPS3			5.1	2.05	18.2	1754.5	16.2	4	16
	787.9	527.9	260.1							
5	787.9	527.9	260.1							
2	HPB1			5.1	6.19	18.2	4985.1	14.3	13	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.1	1.33	18.2	510.5	9.7	6	19
	522.5	485.9	36.6							
9	522.5	478.2	44.3							
1	IPS1			5.1	0.20	18.2	36.0	9.9	1	15
	520.7	416.8	103.8							
10	520.7	485.9	34.8							
2	HPE2			5.1	1.53	18.2	941.7	9.2	7	19
	473.3	412.9	60.4							
11	473.3	416.8	56.5							
1	IPB			5.1	1.69	18.2	719.1	9.6	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.1	1.15	18.2	523.0	7.9	6	19
	410.1	374.4	35.7							
17	410.1	363.2	46.9							
1	LTE			5.1	0.87	18.2	635.2	7.4	5	19
	377.4	316.1	61.3							
Totals					15.01		10105.2	48.1		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.576 kg/m²-s
Exhaust loss = 21.86 millibar:
Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.76, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.51 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=69.96% O_2=11.29% CO_2=7.314% H_2O=10.6%
AR=0.8425%
Flue gas dew point = 320 K   M.W.= 28.68

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2585	5648	1773	10005
UA kW/K	66	74	10	150
A sq.m	1221	1510	312	3044

Tube length = 3.812 m, HRSG width = 1.334 m, Aspect ratio = 2.859

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.923			
HPFW	44.35	412.9	590.8	2.923			
To desup	44.35	412.9	590.8	0.014			
HPE1				2.909	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.909	20.28	932	352
7	43.70	485.9	911.3	0.000			
HPE3				2.909	16.78	505	274
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.880	53.27	4936	1059
9	43.06	527.9	2798.7	0.000			
HPS0				2.880	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.880	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.880	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.880	9.90	1737	279
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.880			
Aft HP pipe	40.00	753.2	3399.4	2.880			
To HPT	40.00	753.2	3399.4	2.880			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.257			
IPFW	4.12	374.4	424.5	3.257			
IPE1				3.257	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.257	17.41	518	323
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.923			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.330	20.46	712	452
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.065			
IPS1				0.266	0.51	36	33
3	3.85	478.2	2871.5	0.000			
IPS2				0.266	0.00	0	0
4	3.85	478.2	2871.5	0.266			
Feedwater:							
Cond return	0.43	311.9	162.2	2.865			
After pump	1.09	312.0	162.7	2.865			
Proc stm ret	3.45	363.2	377.2	0.280			
Makeup	3.45	288.1	63.3	0.047			
FW to LTE	1.09	316.1	180.0	3.192			
LTE				3.192	11.81	629	272
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.192			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.065			
FW to IP/HP	1.05	374.3	423.8	3.257			

Boiler feedpumps = 26.97 kWe: HP = 24.12 kWe IP = 2.854 kWe
Condensate pump(s) = 1.59 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.014			
From source	3.85	425.7	2756.7	0.280	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.280	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.880	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.880	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.036					
HPT inlet	39.00	752.6	3399.4	2.840	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.840	7.0427	230.6			74.30*
OUT	3.61	511.0	2941.1	2.840	7.3817	97.9		1302	74.30**
	3.61	511.0	2941.1	2.840	7.3817	97.9			
HP/IP/LP Casing: Group LPTL									
IN	3.61	511.0	2941.1	2.840	7.3817	97.9			73.78*
OUT	0.069	311.9	2443.1	2.840	7.8687		0.946		76.63**
After LL	0.07	311.9	2461.5	2.840	7.9280		0.954	1362	
To condenser	0.069	311.9	2461.5	2.840	7.9280		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.07	74.30	74.30	Sup.	1301.7
HP/IP/LP Casing	LPTL	6	74.27	76.63	73.78	0.946	1362.0

Number of physical casings = 1
Gross power = 2663.7 kW
ST mech. loss = 9.323 kW. gear box loss= 39.96 kW.
Gen. elec. loss= 73.9 kW. Gen. mech. loss= 6.215 kW.
ST/Generator mech. x elect. efficiency = 95.14 %

Generator output = 2534.3 kWe.   ST auxiliaries = 5.069 kWe
Annulus velocity = 205.7 m/s,   RPM = 14284
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.49 kJ/kg
Exhaust volume flow per path = 55.99 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2721 sq.m
Last stage bucket length = 171.6 mm, pitch dia. = 504.7 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2461.54	2.84
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.86
Cooling water in		288.20		157.88
Cooling water out		298.20		157.88

Number of passes = 2   UA = 361.4 kW/K   Surface area = 108.1 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.924 m   Number = 361
CW vel. = 2.134 m/s DP = 0.9368 bar (0.3386 condenser + 0.5982 piping)
CW pump(s) = 19.74 kWe   Condensate pump(s) = 1.59 kWe

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:50:23 file=C:/Tflow13/MYFILES/case14.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5881		9381		38.38	
Steam Turbine(s)	2553					
Plant Total	8433	7701	6541	7163	55.04	50.26

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.42	54.59	52.71	7156

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18083 kWth = 61706 kBTU/h
Fuel LHV chemical energy input = 15323 kWth = 52287 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15323 kWth = 52287 kBTU/h
Energy chargeable to power = 14610 kWth = 49852 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5881	38.38	9381	18	872
Total	5881			18	

Fuel chemical HHV per gas turbine = 18083 kWth = 61706 kBTU/h
Fuel chemical LHV per gas turbine = 15323 kWth = 52287 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
85.74	2553	25.37	21.75	664	2264

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11736 kWth = 40047 kBTU/h
Net process heat output = 7.934% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
590	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66 kW
Miscellaneous plant auxiliaries = 4.217 kW
Program estimated overall plant auxiliaries = 732.5 kW
Actual (user input) overall plant auxiliaries = 732.5 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 732.5 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:50:23 file=C:/Tflow13/MYFILES/case14.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 298 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.88 millibar

Duct = 5.00, HRSG = 15.02 millibar
Stack leaving loss = 1.77, Friction = 0.47, Buoyancy = -0.37 millibar
Stack velocity = 19.61 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5		12.8	1397	872	14.5	5881	9381	18.1	69.59	10.94	7.34	12.13

Fuel compressor = 589.8 kWe, Q rejected = 120.2 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Comp. inlet	298	1.00	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Turbine coolant		misc.	0.24						
Comp. discharge	666	12.87	14.30	28.66	75.88	20.36	0.03	2.81	0.91
Fuel flow	873	16.03	3.55068						
Turbine inlet	1397	12.36	17.85	28.51	68.66	10.81	7.44	12.26	0.83
Turbine coolant			0.24						
Turbine exhaust	872	1.04	18.09	28.51	68.76	10.94	7.34	12.13	0.83

Compressor = 5592 Turbine = 11872 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.4 kW Gear box loss = 81.15 kW Generator loss = 208 kW
Mech eff. = 98.24% Gear box eff. = 98.68% Generator eff. = 96.58%
GT specific power @ gen term = 404.5 kW per kg/s
GT efficiency @ gen term = 32.52% HHV = 38.38% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.98% HHV = 33.02% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22140 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
372	643	0	0	21126

Energy out = 22149 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
182	110	81	208	0	12218	3470	5881	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.883 kW = -0.0401 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:50:23 file=C:/Tflow13/MYFILES/case14.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15821 kW

GT Exhaust/Air Addn. Sensible	GT Exhaust/Air Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12218	3470	0	3	105	25	0	0	0

Energy out = 15821 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT	Proc. Water	Electric Output
152	86	130	2011	3470	6650	769	0	0	2553

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0942 kW = -0.0006 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	869.9	755.1	114.8							
2	HPS3			5.1	2.07	18.1	1765.6	16.4	4	16
	788.5	527.9	260.6							
5	788.5	527.9	260.6							
2	HPB1			5.1	6.06	18.1	5016.6	14.1	14	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.1	1.35	18.1	513.8	9.8	6	19
	522.4	485.9	36.5							
9	522.4	478.2	44.2							
1	IPS1			5.1	0.20	18.1	35.8	10.0	1	15
	520.6	416.8	103.8							
10	520.6	485.9	34.7							
2	HPE2			5.1	1.56	18.1	947.7	9.2	7	19
	473.1	412.9	60.2							
11	473.1	416.8	56.3							
1	IPB			5.1	1.71	18.1	718.1	9.6	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.1	1.17	18.1	525.9	8.0	6	19
	410.0	374.4	35.7							
17	410.0	363.2	46.9							
1	LTE			5.1	0.89	18.1	639.2	7.4	5	19
	377.3	316.1	61.2							
Totals					15.02		10162.8	49.1		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.576 kg/m²-s
Exhaust loss = 21.88 millibar:
Duct = 5.00, HRSG = 15.02 millibar
Stack leaving loss = 1.77, Friction = 0.47, Buoyancy = -0.37 millibar
Stack velocity = 19.61 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=68.76% O_2=10.94% CO_2=7.34% H_2O=12.13%
AR=0.8281%
Flue gas dew point = 323 K   M.W.= 28.51

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2601	5678	1784	10062
UA kW/K	67	74	10	151
A sq.m	1233	1487	312	3032

Tube length = 3.793 m, HRSG width = 1.334 m, Aspect ratio = 2.845

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.941			
HPFW	44.35	412.9	590.8	2.941			
To desup	44.35	412.9	590.8	0.014			
HPE1				2.927	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.927	20.46	938	356
7	43.70	485.9	911.3	0.000			
HPE3				2.927	16.90	509	276
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.898	53.53	4967	1035
9	43.06	527.9	2798.7	0.000			
HPS0				2.898	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.898	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.898	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.898	9.93	1748	279
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.898			
Aft HP pipe	40.00	753.2	3399.4	2.898			
To HPT	40.00	753.2	3399.4	2.898			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.275			
IPFW	4.12	374.4	424.5	3.275			
IPE1				3.275	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.275	17.52	521	326
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.941			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.330	20.47	711	451
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.065			
IPS1				0.265	0.51	35	33
3	3.85	478.2	2871.5	0.000			
IPS2				0.265	0.00	0	0
4	3.85	478.2	2871.5	0.265			
Feedwater:							
Cond return	0.43	311.9	162.2	2.883			
After pump	1.09	312.0	162.7	2.883			
Proc stm ret	3.45	363.2	377.2	0.279			
Makeup	3.45	288.1	63.3	0.048			
FW to LTE	1.09	316.1	179.9	3.210			
LTE				3.210	11.90	633	275
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.210			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.065			
FW to IP/HP	1.05	374.3	423.8	3.275			

Boiler feedpumps = 27.14 kWe: HP = 24.27 kWe IP = 2.869 kWe
Condensate pump(s) = 1.6 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.014			
From source	3.85	425.7	2756.7	0.279	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.279	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.898	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.898	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.858	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.858	7.0427	230.6			74.37*
OUT	3.61	510.8	2940.6	2.858	7.3808	97.7		1311	74.37**
	3.61	510.8	2940.6	2.858	7.3808	97.7			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.8	2940.6	2.858	7.3808	97.7			73.85*
OUT	0.069	311.9	2442.3	2.858	7.8664		0.946		76.69**
After LL	0.07	311.9	2460.8	2.858	7.9256		0.954	1372	
To condenser	0.069	311.9	2460.8	2.858	7.9256		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.15	74.37	74.37	Sup.	1311.2
HP/IP/LP Casing	LPTL	6	74.35	76.69	73.85	0.946	1371.5

Number of physical casings = 1
Gross power = 2682.7 kW
ST mech. loss = 9.389 kW. gear box loss= 40.24 kW.
Gen. elec. loss= 74.22 kW. Gen. mech. loss= 6.26 kW.
ST/Generator mech. x elect. efficiency = 95.15 %

Generator output = 2552.6 kWe.   ST auxiliaries = 5.105 kWe
Annulus velocity = 205.7 m/s,   RPM = 14242
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.32 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2738 sq.m
Last stage bucket length = 172.1 mm, pitch dia. = 506.2 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in   m/s, exhaust loss in   kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.79	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.88
Cooling water in		288.20		158.83
Cooling water out		298.20		158.83

Number of passes = 2   UA = 363.6 kW/K   Surface area = 108.7 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.926 m   Number = 363
CW vel. = 2.134 m/s DP = 0.9369 bar (0.3387 condenser + 0.5982 piping)
CW pump(s) = 19.85 kWe   Condensate pump(s) = 1.6 kWe

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:52:12 file=C:/Tflow13/MYFILES/case15.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5718		9377		38.39	
Steam Turbine(s)	2521					
Plant Total	8240	7524	6508	7127	55.32	50.51

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.55	54.58	52.82	7155

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 17578 kWth = 59982 kBTU/h
Fuel LHV chemical energy input = 14895 kWth = 50827 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 14895 kWth = 50827 kBTU/h
Energy chargeable to power = 14245 kWth = 48607 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5718	38.39	9377	18	879
Total	5718			18	

Fuel chemical HHV per gas turbine = 17578 kWth = 59982 kBTU/h
Fuel chemical LHV per gas turbine = 14895 kWth = 50827 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
87.11	2521	25.46	22.18	605	2065

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11367 kWth = 38788 kBTU/h
Net process heat output = 7.444% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
573	0	0	10	28	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66 kW
Miscellaneous plant auxiliaries = 4.12 kW
Program estimated overall plant auxiliaries = 715.3 kW
Actual (user input) overall plant auxiliaries = 715.3 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 715.3 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:52:12 file=C:/Tflow13/MYFILES/case15.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 305 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.90 millibar

Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.76, Friction = 0.47, Buoyancy = -0.33 millibar
Stack velocity = 19.47 m/s

# Model 83	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
RR 501KH5	12.5	1407	879	14.2	5718	9377	17.6	70.44	11.14	7.36	11.05

Fuel compressor = 573.3 kWe, Q rejected = 116.8 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Comp. inlet	305	1.00	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Turbine coolant	misc.		0.23						
Comp. discharge	675	12.54	13.92	28.81	76.97	20.65	0.03	1.42	0.93
Fuel flow	873	16.03	3.45152						
Turbine inlet	1407	12.04	17.37	28.63	69.51	11.01	7.46	11.18	0.84
Turbine coolant			0.23						
Turbine exhaust	879	1.04	17.60	28.63	69.60	11.14	7.36	11.05	0.84

Compressor = 5440 Turbine = 11555 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.2 kW Gear box loss = 81 kW Generator loss = 205.5 kW
Mech eff. = 98.2% Gear box eff. = 98.65% Generator eff. = 96.53%
GT specific power @ gen term = 404.1 kW per kg/s
GT efficiency @ gen term = 32.53% HHV = 38.39% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.99% HHV = 33.03% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 21314 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
463	315	0	0	20536

Energy out = 21322 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
177	110	81	206	0	11967	3063	5718	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.514 kW = -0.0399 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:52:12 file=C:/Tflow13/MYFILES/case15.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15154 kW

GT Exhaust Sensible	GT Exhaust Latent	Air Addn. Enthalpy	DB Fuel	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
11967	3063	0	3	96	25	0	0	0	

Energy out = 15154 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
149	85	129	1924	3063	6581	701	0	0	2521

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1015 kW = -0.0007 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	876.9	755.1	121.8							
2	HPS3			4.9	1.98	17.6	1746.5	16.2	4	16
	793.8	527.9	265.9							
5	793.8	527.9	265.9							
2	HPB1			4.9	6.07	17.6	4962.3	14.1	14	14
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			4.9	1.39	17.6	508.2	9.8	6	19
	521.8	485.9	35.9							
9	521.8	478.2	43.7							
1	IPS1			4.9	0.19	17.6	32.7	9.8	1	14
	520.1	416.8	103.3							
10	520.1	485.9	34.3							
2	HPE2			4.9	1.63	17.6	937.4	9.3	7	19
	471.6	412.9	58.7							
11	471.6	416.8	54.8							
1	IPB			4.9	1.62	17.6	664.8	9.5	6	14
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			4.9	1.20	17.6	516.6	8.0	6	19
	409.6	374.4	35.2							
17	409.6	363.2	46.5							
1	LTE			4.9	0.92	17.6	632.3	7.4	5	19
	376.1	315.8	60.4							
Totals					15.01		10000.7	49.1		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.57 kg/m²-s
Exhaust loss = 21.90 millibar:
Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.76, Friction = 0.47, Buoyancy = -0.33 millibar
Stack velocity = 19.47 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=69.6% O_2=11.14% CO_2=7.364% H_2O=11.05% AR=0.8383%
Flue gas dew point = 321 K   M.W.= 28.63

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2569	5571	1762	9902
UA kW/K	67	71	10	148
A sq.m	1255	1433	290	2979

Tube length = 3.733 m, HRSG width = 1.321 m, Aspect ratio = 2.826

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.908			
HPFW	44.35	412.9	590.8	2.908			
To desup	44.35	412.9	590.8	0.013			
HPE1				2.895	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.895	20.65	928	368
7	43.70	485.9	911.3	0.000			
HPE3				2.895	16.86	503	280
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.867	52.21	4913	1013
9	43.06	527.9	2798.7	0.000			
HPS0				2.867	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.867	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.867	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.867	9.46	1729	261
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.867			
Aft HP pipe	40.00	753.2	3399.4	2.867			
To HPT	40.00	753.2	3399.4	2.867			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.217			
IPFW	4.12	374.4	424.5	3.217			
IPE1				3.217	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.217	17.32	511	326
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.908			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.306	19.26	658	421
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.064			
IPS1				0.242	0.47	32	29
3	3.85	478.2	2871.5	0.000			
IPS2				0.242	0.00	0	0
4	3.85	478.2	2871.5	0.242			
Feedwater:							
Cond return	0.43	311.9	162.2	2.852			
After pump	1.09	312.0	162.7	2.852			
Proc stm ret	3.45	363.2	377.2	0.255			
Makeup	3.45	288.1	63.3	0.047			
FW to LTE	1.09	315.8	178.5	3.153			
LTE				3.153	11.90	626	281
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.153			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.064			
FW to IP/HP	1.05	374.3	423.8	3.217			

Boiler feedpumps = 26.82 kWe: HP = 24 kWe IP = 2.821 kWe
Condensate pump(s) = 1.583 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.013			
From source	3.85	425.7	2756.7	0.255	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.255	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.867	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.867	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.036					
HPT inlet	39.00	752.6	3399.4	2.827	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.827	7.0427	230.6			74.25*
OUT	3.61	511.1	2941.4	2.827	7.3823	98.1		1295	74.25**
	3.61	511.1	2941.4	2.827	7.3823	98.1			
HP/IP/LP Casing: Group LPTL									
IN	3.61	511.1	2941.4	2.827	7.3823	98.1			73.73*
OUT	0.069	311.9	2443.6	2.827	7.8704		0.947		76.58**
After LL	0.07	311.9	2462.1	2.827	7.9298		0.954	1355	
To condenser	0.069	311.9	2462.1	2.827	7.9298		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.01	74.25	74.25	Sup.	1294.8
HP/IP/LP Casing	LPTL	6	74.21	76.58	73.73	0.947	1355.1

Number of physical casings = 1
Gross power = 2650 kW
ST mech. loss = 9.275 kW. gear box loss= 39.75 kW.
Gen. elec. loss= 73.67 kW. Gen. mech. loss= 6.183 kW.
ST/Generator mech. x elect. efficiency = 95.14 %

Generator output = 2521.1 kWe.   ST auxiliaries = 5.042 kWe
Annulus velocity = 205.7 m/s,   RPM = 14316
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.5 kJ/kg
Exhaust volume flow per path = 55.74 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2709 sq.m
Last stage bucket length = 171.2 mm, pitch dia. = 503.6 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2462.08	2.83
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.85
Cooling water in		288.20		157.20
Cooling water out		298.20		157.20

Number of passes = 2   UA = 359.8 kW/K   Surface area = 107.6 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.918 m   Number = 360
CW vel. = 2.134 m/s DP = 0.9364 bar (0.3382 condenser + 0.5982 piping)
CW pump(s) = 19.65 kWe   Condensate pump(s) = 1.583 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:59:44 file=C:/Tflow13/MYFILES/case16.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5749		9391		38.34	
Steam Turbine(s)	2548					
Plant Total	8297	7577	6507	7125	55.33	50.53

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.53	54.54	52.81	7159

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 17698 kWth = 60391 kBTU/h
Fuel LHV chemical energy input = 14997 kWth = 51173 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 14997 kWth = 51173 kBTU/h
Energy chargeable to power = 14349 kWth = 48964 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5749	38.34	9391	17	880
Total	5749			17	

Fuel chemical HHV per gas turbine = 17698 kWth = 60391 kBTU/h
Fuel chemical LHV per gas turbine = 14997 kWth = 51173 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
87.18	2548	25.52	22.25	602	2054

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11455 kWth = 39087 kBTU/h
Net process heat output = 7.36% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
577	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66 kW
Miscellaneous plant auxiliaries = 4.149 kW
Program estimated overall plant auxiliaries = 719.7 kW
Actual (user input) overall plant auxiliaries = 719.7 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 719.7 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:59:44 file=C:/Tflow13/MYFILES/case16.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 305 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.93 millibar

Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.77, Friction = 0.48, Buoyancy = -0.32 millibar
Stack velocity = 19.63 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5	12.5	1404	880	14.0	5749	9391	17.5	68.61	10.61	7.40	13.38

Fuel compressor = 577.2 kWe, Q rejected = 117.6 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	14.00	28.50	74.75	20.05	0.03	4.27	0.90
Comp. inlet	305	1.00	14.00	28.50	74.75	20.05	0.03	4.27	0.90
Turbine coolant	misc.		0.23						
Comp. discharge	672	12.49	13.77	28.50	74.75	20.05	0.03	4.27	0.90
Fuel flow	873	16.03	3.47502						
Turbine inlet	1404	11.99	17.25	28.38	67.70	10.49	7.50	13.50	0.82
Turbine coolant			0.23						
Turbine exhaust	880	1.04	17.47	28.38	67.79	10.61	7.40	13.38	0.82

Compressor = 5413 Turbine = 11559 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.2 kW Gear box loss = 81.03 kW Generator loss = 206 kW
Mech eff. = 98.21% Gear box eff. = 98.66% Generator eff. = 96.54%
GT specific power @ gen term = 410.7 kW per kg/s
GT efficiency @ gen term = 32.48% HHV = 38.34% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.95% HHV = 32.98% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22086 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
465	945	0	0	20676

Energy out = 22094 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
178	110	81	206	0	12058	3712	5749	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.654 kW = -0.0392 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 12:59:44 file=C:/Tflow13/MYFILES/case16.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15893 kW

GT Exhaust/Air Sensible	Latent	Addn. DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12058	3712	0	3	96	25	0	0	0

Energy out = 15894 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
150	86	130	1929	3712	6640	698	0	0	2548

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0823 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	/HX	Tg K	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0		878.0	755.1	122.9							
2	HPS3				4.9	1.97	17.5	1762.9	16.3	4	16
		794.6	527.9	266.7							
5		794.6	527.9	266.7							
2	HPB1				4.9	6.07	17.5	5009.0	14.1	14	14
		547.9	527.9	20.0							
7		547.9	522.9	25.0							
2	HPE3				4.9	1.40	17.5	513.0	9.8	6	19
		521.7	485.9	35.9							
9		521.7	478.2	43.6							
1	IPS1				4.9	0.19	17.5	32.5	9.8	1	14
		520.0	416.8	103.2							
10		520.0	485.9	34.2							
2	HPE2				4.9	1.65	17.5	946.3	9.3	7	19
		471.3	412.9	58.4							
11		471.3	416.8	54.5							
1	IPB				4.9	1.61	17.5	663.1	9.5	6	14
		436.8	416.8	20.0							
12		436.8	411.8	25.0							
1	IPE2				4.9	1.20	17.5	520.8	8.0	6	19
		409.5	374.4	35.2							
17		409.5	363.2	46.4							
1	LTE				4.9	0.93	17.5	638.2	7.5	5	19
		375.9	315.7	60.2							
Totals						15.01		10085.9	49.1		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.541 kg/m²-s
Exhaust loss = 21.93 millibar:
Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.77, Friction = 0.48, Buoyancy = -0.32 millibar
Stack velocity = 19.63 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=67.79% O_2=10.61% CO_2=7.403% H_2O=13.38%
AR=0.8164%
Flue gas dew point = 325 K   M.W.= 28.38

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2592	5616	1778	9986
UA kW/K	67	72	10	149
A sq.m	1275	1441	289	3005

Tube length = 3.736 m, HRSG width = 1.321 m, Aspect ratio = 2.828

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.935			
HPFW	44.35	412.9	590.8	2.935			
To desup	44.35	412.9	590.8	0.013			
HPE1				2.923	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.923	20.92	937	375
7	43.70	485.9	911.3	0.000			
HPE3				2.923	17.04	508	284
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.894	52.59	4959	1020
9	43.06	527.9	2798.7	0.000			
HPS0				2.894	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.894	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.894	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.894	9.50	1745	260
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.894			
Aft HP pipe	40.00	753.2	3399.4	2.894			
To HPT	40.00	753.2	3399.4	2.894			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.243			
IPFW	4.12	374.4	424.5	3.243			
IPE1				3.243	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.243	17.48	516	330
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.935			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.305	19.27	657	421
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.064			
IPS1				0.241	0.47	32	29
3	3.85	478.2	2871.5	0.000			
IPS2				0.241	0.00	0	0
4	3.85	478.2	2871.5	0.241			
Feedwater:							
Cond return	0.43	311.9	162.2	2.878			
After pump	1.09	312.0	162.7	2.878			
Proc stm ret	3.45	363.2	377.2	0.253			
Makeup	3.45	288.1	63.3	0.047			
FW to LTE	1.09	315.7	178.3	3.179			
LTE				3.179	12.04	632	286
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.179			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.064			
FW to IP/HP	1.05	374.3	423.8	3.243			

Boiler feedpumps = 27.06 kWe: HP = 24.22 kWe IP = 2.843 kWe
Condensate pump(s) = 1.597 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.013			
From source	3.85	425.7	2756.7	0.253	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.253	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.894	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.894	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.854	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.854	7.0427	230.6			74.35*
OUT	3.61	510.8	2940.7	2.854	7.3810	97.7		1309	74.35**
	3.61	510.8	2940.7	2.854	7.3810	97.7			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.8	2940.7	2.854	7.3810	97.7			73.83*
OUT	0.069	311.9	2442.5	2.854	7.8669		0.946		76.68**
After LL	0.07	311.9	2461.0	2.854	7.9262		0.954	1369	
To condenser	0.069	311.9	2461.0	2.854	7.9262		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.13	74.35	74.35	Sup.	1308.9
HP/IP/LP Casing	LPTL	6	74.33	76.68	73.83	0.946	1369.2

Number of physical casings = 1
Gross power = 2678.1 kW
ST mech. loss = 9.373 kW. gear box loss= 40.17 kW.
Gen. elec. loss= 74.14 kW. Gen. mech. loss= 6.249 kW.
ST/Generator mech. x elect. efficiency = 95.15 %
Generator output = 2548.2 kWe. ST auxiliaries = 5.096 kWe

Annulus velocity = 205.7 m/s, RPM = 14252
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.24 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2734 sq.m
Last stage bucket length = 172 mm, pitch dia. = 505.9 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.97	2.85
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.88
Cooling water in		288.20		158.60
Cooling water out		298.20		158.60

Number of passes = 2 UA = 363.1 kW/K Surface area = 108.6 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.921 m Number = 363
CW vel. = 2.134 m/s DP = 0.9365 bar (0.3383 condenser + 0.5982 piping)
CW pump(s) = 19.82 kWe Condensate pump(s) = 1.597 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:00:43 file=C:/Tflow13/MYFILES/case17.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5991		9377		38.39	
Steam Turbine(s)	2559					
Plant Total	8550	7805	6570	7197	54.79	50.02

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.31	54.60	52.61	7155

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18414 kWth = 62835 kBTU/h
Fuel LHV chemical energy input = 15604 kWth = 53245 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15604 kWth = 53245 kBTU/h
Energy chargeable to power = 14835 kWth = 50621 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5991	38.39	9377	19	865
Total	5991			19	

Fuel chemical HHV per gas turbine = 18414 kWth = 62835 kBTU/h
Fuel chemical LHV per gas turbine = 15604 kWth = 53245 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
85.40	2559	25.25	21.56	715	2440

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11868 kWth = 40496 kBTU/h
Net process heat output = 8.391% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries: Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Steam Cycle Auxiliaries: Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
601	0	0	10	29	20	0	5

HVAC = 4 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 67 kW
Miscellaneous plant auxiliaries = 4.275 kW
Program estimated overall plant auxiliaries = 744.7 kW
Actual (user input) overall plant auxiliaries = 744.7 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 744.7 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:00:43 file=C:/Tflow13/MYFILES/case17.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 298 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.85 millibar

Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.63 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5		13.1	1390	866	15.0	5991	9377	18.6	69.99	11.09	7.30	11.62

Fuel compressor = 600.6 kWe, Q rejected = 122.4 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	14.92	28.76	76.62	20.56	0.03	1.87	0.92
Fogger inlet	298	1.01	14.92	28.76	76.62	20.56	0.03	1.87	0.92
Fogger H2O evap			0.03						
Comp. inlet	293	1.00	14.95	28.72	76.33	20.48	0.03	2.24	0.92
Turbine coolant		misc.	0.24						
Comp. discharge	661	13.17	14.71	28.72	76.33	20.48	0.03	2.24	0.92
Fuel flow	873	16.03	3.61569						
Turbine inlet	1390	12.64	18.32	28.56	69.07	10.97	7.39	11.74	0.83
Turbine coolant			0.24						
Turbine exhaust	866	1.04	18.57	28.56	69.16	11.09	7.30	11.62	0.83

Fogging water = 0.0348 kg/s Fogger exit RH = 100 %
Compressor = 5734 Turbine = 12127 kW
Turbine coolant = 1.634% compr in
Mech loss = 110.5 kW Gear box loss = 81.25 kW Generator loss = 209.7 kW
Mech eff. = 98.27% Gear box eff. = 98.71% Generator eff. = 96.62%
GT specific power @ gen term = 400.7 kW per kg/s
GT efficiency @ gen term = 32.53% HHV = 38.39% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.992% HHV = 33.03% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22333 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
295	525	0	0	21512

Energy out = 22342 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
185	111	81	210	0	12361	3403	5991	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.075 kW = -0.0406 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:00:43 file=C:/Tflow13/MYFILES/case17.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15906 kW

GT Exhaust/Air Sensible	Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12361	3403	0	3	113	25	0	0	0

Energy out = 15906 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
154	87	130	2080	3403	6664	828	0	0	2559

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1026 kW = -0.0006 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	863.5	755.1	108.4							
2	HPS3			5.2	2.10	18.6	1769.6	16.3	4	16
	783.7	527.9	255.8							
5	783.7	527.9	255.8							
2	HPB1			5.2	6.12	18.6	5028.0	14.3	13	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.2	1.39	18.6	514.9	10.2	5	19
	522.9	485.9	37.1							
9	522.9	478.2	44.8							
1	IPS1			5.2	0.21	18.6	38.6	9.9	1	15
	521.0	416.8	104.2							
10	521.0	485.9	35.2							
2	HPE2			5.2	1.46	18.6	949.9	9.1	7	19
	474.6	412.9	61.7							
11	474.6	416.8	57.7							
1	IPB			5.2	1.75	18.6	763.9	9.7	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.2	1.13	18.6	530.5	7.9	6	19
	410.4	374.4	36.0							
17	410.4	363.2	47.3							
1	LTE			5.2	0.84	18.6	640.8	7.3	5	19
	378.4	316.4	61.9							
Totals					15.00		10236.2		47.0	

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.568 kg/m²-s
Exhaust loss = 21.85 millibar:
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.63 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=69.16% O_2=11.09% CO_2=7.296% H_2O=11.62% AR=0.8329%
Flue gas dew point = 322 K   M.W.= 28.56

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2610	5735	1790	10135
UA kW/K	66	76	11	153
A sq.m	1232	1554	330	3115

Tube length = 3.902 m, HRSG width = 1.334 m, Aspect ratio = 2.926

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.949			
HPFW	44.35	412.9	590.8	2.949			
To desup	44.35	412.9	590.8	0.015			
HPE1				2.934	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.934	20.13	940	343
7	43.70	485.9	911.3	0.000			
HPE3				2.934	16.81	510	298
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.905	54.34	4978	1078
9	43.06	527.9	2798.7	0.000			
HPS0				2.905	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.905	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.905	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.905	10.31	1752	295
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.905			
Aft HP pipe	40.00	753.2	3399.4	2.905			
To HPT	40.00	753.2	3399.4	2.905			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.304			
IPFW	4.12	374.4	424.5	3.304			
IPE1				3.304	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.304	17.58	525	323
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.949			
IP blowdown	4.00	416.8	605.0	0.004			
IPB				0.351	21.46	756	476
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.065			
IPS1				0.286	0.55	38	35
3	3.85	478.2	2871.5	0.000			
IPS2				0.286	0.00	0	0
4	3.85	478.2	2871.5	0.286			
Feedwater:							
Cond return	0.43	311.9	162.2	2.889			
After pump	1.09	312.0	162.7	2.889			
Proc stm ret	3.45	363.2	377.2	0.301			
Makeup	3.45	288.1	63.3	0.048			
FW to LTE	1.09	316.4	181.1	3.238			
LTE				3.238	11.81	634	267
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.238			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.065			
FW to IP/HP	1.05	374.3	423.8	3.304			

Boiler feedpumps = 27.22 kWe: HP = 24.33 kWe IP = 2.894 kWe
Condensate pump(s) = 1.603 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							

main desup.		412.9	590.8	0.015		
From source	3.85	425.7	2756.7	0.301	6.9565	10.3
Main stream	3.50	423.2	2754.2	0.301	6.9925	11.1

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.905	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.905	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.865	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.865	7.0427	230.6			74.40*
OUT	3.61	510.7	2940.5	2.865	7.3805	97.6		1315	74.40**
	3.61	510.7	2940.5	2.865	7.3805	97.6			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.7	2940.5	2.865	7.3805	97.6			73.87*
OUT	0.069	311.9	2442.0	2.865	7.8655		0.946		76.72**
After LL	0.07	311.9	2460.5	2.865	7.9247		0.954	1375	
To condenser	0.069	311.9	2460.5	2.865	7.9247		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.18	74.40	74.40	Sup.	1314.6
HP/IP/LP Casing	LPTL	6	74.38	76.72	73.87	0.946	1374.9

Number of physical casings = 1
Gross power = 2689.5 kW
ST mech. loss = 9.413 kW. gear box loss= 40.34 kW.
Gen. elec. loss= 74.34 kW. Gen. mech. loss= 6.276 kW.
ST/Generator mech. x elect. efficiency = 95.15 %

Generator output = 2559.2 kWe. ST auxiliaries = 5.118 kWe
Annulus velocity = 205.7 m/s, RPM = 14226
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.44 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2743 sq.m
Last stage bucket length = 172.3 mm, pitch dia. = 506.8 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.52	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.89
Cooling water in		288.20		159.17
Cooling water out		298.20		159.17

Number of passes = 2 UA = 364.4 kW/K Surface area = 109 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 364
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 19.89 kWe Condensate pump(s) = 1.603 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:02:17 file=C:/Tflow13/MYFILES/case18.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5911		9380		38.38	
Steam Turbine(s)	2557					
Plant Total	8467	7731	6548	7171	54.98	50.20

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.39	54.59	52.68	7156

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18175 kWth = 62020 kBTU/h
Fuel LHV chemical energy input = 15401 kWth = 52553 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15401 kWth = 52553 kBTU/h
Energy chargeable to power = 14675 kWth = 50074 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5911	38.38	9380	18	870
Total	5911			18	

Fuel chemical HHV per gas turbine = 18175 kWth = 62020 kBTU/h
Fuel chemical LHV per gas turbine = 15401 kWth = 52553 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
85.66	2557	25.34	21.71	676	2306

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11776 kWth = 40184 kBTU/h
Net process heat output = 8.038% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
593	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66.5 kW
Miscellaneous plant auxiliaries = 4.234 kW
Program estimated overall plant auxiliaries = 736.1 kW
Actual (user input) overall plant auxiliaries = 736.1 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 736.1 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:02:17 file=C:/Tflow13/MYFILES/case18.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 298 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.87 millibar

Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.63 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	RR 501KH5	12.9	1395	870	14.6	5911	9380	18.2	69.54	10.93	7.33	12.20

Fuel compressor = 592.8 kWe, Q rejected = 120.8 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	14.62	28.66	75.88	20.36	0.03	2.81	0.91
Fogger inlet	298	1.01	14.62	28.66	75.88	20.36	0.03	2.81	0.91
Fogger H2O evap			0.01						
Comp. inlet	297	1.00	14.63	28.65	75.81	20.34	0.03	2.90	0.91
Turbine coolant	misc.		0.24						
Comp. discharge	664	12.94	14.39	28.65	75.81	20.34	0.03	2.90	0.91
Fuel flow	873	16.03	3.56875						
Turbine inlet	1395	12.42	17.96	28.50	68.62	10.81	7.43	12.32	0.83
Turbine coolant			0.24						
Turbine exhaust	870	1.04	18.19	28.50	68.71	10.93	7.33	12.20	0.83

Fogging water = 0.0085 kg/s Fogger exit RH = 100 %
Compressor = 5625 Turbine = 11935 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.4 kW Gear box loss = 81.18 kW Generator loss = 208.5 kW
Mech eff. = 98.25% Gear box eff. = 98.69% Generator eff. = 96.59%
GT specific power @ gen term = 404.1 kW per kg/s
GT efficiency @ gen term = 32.52% HHV = 38.38% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.98% HHV = 33.02% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22254 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy

353	668	0	0	21233

Energy out = 22263 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
183	110	81	208	0	12261	3509	5911	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.924 kW = -0.0401 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:02:17 file=C:/Tflow13/MYFILES/case18.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15905 kW

GT Exhaust/Air Sensible	Latent	Addn.	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12261	3509	0	3	107	25	0	0	0	

Energy out = 15905 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
153	87	130	2028	3509	6658	783	0	0	2557

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0937 kW = -0.0006 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	868.4	755.1	113.3							
2	HPS3			5.1	2.09	18.2	1768.1	16.4	4	16
	787.4	527.9	259.5							
5	787.4	527.9	259.5							
2	HPB1			5.1	6.06	18.2	5023.7	14.1	14	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.1	1.34	18.2	514.5	9.8	6	19
	522.5	485.9	36.6							
9	522.5	478.2	44.4							
1	IPS1			5.1	0.21	18.2	36.5	10.0	1	15
	520.7	416.8	103.9							
10	520.7	485.9	34.8							
2	HPE2			5.1	1.54	18.2	949.0	9.2	7	19
	473.5	412.9	60.6							
11	473.5	416.8	56.6							
1	IPB			5.1	1.73	18.2	729.1	9.7	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.1	1.17	18.2	527.4	8.0	6	19
	410.1	374.4	35.7							
17	410.1	363.2	47.0							
1	LTE			5.1	0.88	18.2	640.2	7.4	5	19
	377.5	316.2	61.4							
Totals					15.01		10188.5	49.1		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.579 kg/m²-s
Exhaust loss = 21.87 millibar:
Duct = 5.00, HRSG = 15.01 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.38 millibar
Stack velocity = 19.63 m/s
DB fuel = 0 kg/s; Fuel=CH4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N2=68.71% O2=10.93% CO2=7.333% H2O=12.2%
AR=0.8275%
Flue gas dew point = 323 K   M.W.= 28.5

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2605	5696	1787	10088
UA kW/K	67	74	11	152
A sq.m	1228	1496	317	3041

Tube length = 3.813 m, HRSG width = 1.334 m, Aspect ratio = 2.859

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.946			
HPFW	44.35	412.9	590.8	2.946			
To desup	44.35	412.9	590.8	0.014			
HPE1				2.931	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.931	20.40	940	354
7	43.70	485.9	911.3	0.000			
HPE3				2.931	16.89	509	275
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.902	53.76	4974	1039
9	43.06	527.9	2798.7	0.000			
HPS0				2.902	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.902	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.902	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.902	10.02	1751	283
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.902			
Aft HP pipe	40.00	753.2	3399.4	2.902			
To HPT	40.00	753.2	3399.4	2.902			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.284			
IPFW	4.12	374.4	424.5	3.284			
IPE1				3.284	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.284	17.55	522	325
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.946			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.335	20.71	722	457
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.065			
IPS1				0.270	0.52	36	34
3	3.85	478.2	2871.5	0.000			
IPS2				0.270	0.00	0	0
4	3.85	478.2	2871.5	0.270			
Feedwater:							
Cond return	0.43	311.9	162.2	2.887			
After pump	1.09	312.0	162.7	2.887			
Proc stm ret	3.45	363.2	377.2	0.284			
Makeup	3.45	288.1	63.3	0.048			
FW to LTE	1.09	316.2	180.1	3.219			
LTE				3.219	11.89	634	274
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.219			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.065			
FW to IP/HP	1.05	374.3	423.8	3.284			

Boiler feedpumps = 27.18 kWe: HP = 24.3 kWe IP = 2.877 kWe
Condensate pump(s) = 1.602 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.014			
From source	3.85	425.7	2756.7	0.284	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.284	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.902	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.902	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.862	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.862	7.0427	230.6			74.39*
OUT	3.61	510.7	2940.5	2.862	7.3806	97.6		1313	74.39**
	3.61	510.7	2940.5	2.862	7.3806	97.6			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.7	2940.5	2.862	7.3806	97.6			73.86*
OUT	0.069	311.9	2442.1	2.862	7.8658		0.946		76.71**
After LL	0.07	311.9	2460.6	2.862	7.9251		0.954	1374	
To condenser	0.069	311.9	2460.6	2.862	7.9251		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.17	74.39	74.39	Sup.	1313.3
HP/IP/LP Casing	LPTL	6	74.37	76.71	73.86	0.946	1373.6

Number of physical casings = 1
Gross power = 2687 kW
ST mech. loss = 9.404 kW. gear box loss= 40.3 kW.
Gen. elec. loss= 74.29 kW. Gen. mech. loss= 6.27 kW.
ST/Generator mech. x elect. efficiency = 95.15 %

Generator output = 2556.7 kWe.   ST auxiliaries = 5.113 kWe
Annulus velocity = 205.7 m/s,   RPM = 14232
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.4 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2741 sq.m
Last stage bucket length = 172.2 mm, pitch dia. = 506.6 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.62	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.89
Cooling water in		288.20		159.04
Cooling water out		298.20		159.04

Number of passes = 2   UA = 364.1 kW/K   Surface area = 108.9 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.921 m   Number = 364
CW vel. = 2.134 m/s DP = 0.9365 bar (0.3383 condenser + 0.5982 piping)
CW pump(s) = 19.88 kWe   Condensate pump(s) = 1.602 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:03:08 file=C:/Tflow13/MYFILES/case19.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5990		9377		38.39	
Steam Turbine(s)	2559					
Plant Total	8549	7803	6570	7197	54.80	50.02

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.31	54.60	52.61	7155

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18411 kWth = 62823 kBTU/h
Fuel LHV chemical energy input = 15601 kWth = 53235 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15601 kWth = 53235 kBTU/h
Energy chargeable to power = 14833 kWth = 50614 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5990	38.39	9377	19	866
Total	5990			19	

Fuel chemical HHV per gas turbine = 18411 kWth = 62823 kBTU/h
Fuel chemical LHV per gas turbine = 15601 kWth = 53235 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
86.44	2559	25.25	21.83	714	2437

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11725 kWth = 40008 kBTU/h
Net process heat output = 8.386% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
600	0	0	10	29	20	0	5

HVAC = 4 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 67.75 kW
Miscellaneous plant auxiliaries = 4.274 kW
Program estimated overall plant auxiliaries = 745.3 kW
Actual (user input) overall plant auxiliaries = 745.3 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 745.3 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:03:08 file=C:/Tflow13/MYFILES/case19.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 305 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.89 millibar
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.34 millibar
Stack velocity = 19.63 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

RR 501KH5	13.1	1390	866	14.9	5990	9377	18.6	69.99	11.09	7.30	11.62

Fuel compressor = 600.4 kWe, Q rejected = 122.4 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	305	1.01	14.87	28.81	76.97	20.65	0.03	1.42	0.93
Fogger inlet	305	1.01	14.87	28.81	76.97	20.65	0.03	1.42	0.93
Fogger H2O evap			0.08						
Comp. inlet	293	1.00	14.95	28.72	76.33	20.48	0.03	2.24	0.92
Turbine coolant	misc.		0.24						
Comp. discharge	661	13.16	14.70	28.72	76.33	20.48	0.03	2.24	0.92
Fuel flow	873	16.03	3.61500						
Turbine inlet	1390	12.64	18.32	28.56	69.06	10.97	7.39	11.75	0.83
Turbine coolant			0.24						
Turbine exhaust	866	1.04	18.56	28.56	69.16	11.09	7.30	11.62	0.83

Fogging water = 0.0784 kg/s Fogger exit RH = 100 %
Compressor = 5733 Turbine = 12124 kW
Turbine coolant = 1.634% compr in
Mech loss = 110.5 kW Gear box loss = 81.25 kW Generator loss = 209.7 kW
Mech eff. = 98.27% Gear box eff. = 98.71% Generator eff. = 96.62%
GT specific power @ gen term = 400.7 kW per kg/s
GT efficiency @ gen term = 32.53% HHV = 38.39% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.991% HHV = 33.03% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22330 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
296	525	0	0	21508

Energy out = 22339 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant

185	111	81	210	0	12359	3404	5990	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.071 kW = -0.0406 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:03:08 file=C:/Tflow13/MYFILES/case19.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15904 kW

GT Exhaust Sensible	GT Exhaust Latent	Air Addn. Enthalpy	DB Fuel	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12359	3404	0	3	113	25	0	0	0	

Energy out = 15904 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT	Proc. Water	Electric Output
154	87	130	2079	3404	6664	828	0	0	2559

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.1006 kW = -0.0006 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	863.6	755.1	108.5							
2	HPS3			5.2	2.10	18.6	1769.6	16.3	4	16
	783.7	527.9	255.9							
5	783.7	527.9	255.9							
2	HPB1			5.2	6.12	18.6	5028.0	14.3	13	15
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.2	1.39	18.6	514.9	10.2	5	19
	522.9	485.9	37.0							
9	522.9	478.2	44.8							
1	IPS1			5.2	0.21	18.6	38.6	9.9	1	15
	521.0	416.8	104.2							
10	521.0	485.9	35.2							
2	HPE2			5.2	1.46	18.6	949.9	9.1	7	19
	474.5	412.9	61.7							
11	474.5	416.8	57.7							
1	IPB			5.2	1.75	18.6	763.4	9.7	6	15
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.2	1.13	18.6	530.5	7.9	6	19
	410.4	374.4	36.0							
17	410.4	363.2	47.3							
1	LTE			5.2	0.84	18.6	640.8	7.3	5	19
	378.3	316.4	61.9							
Totals					15.00		10235.6	47.0		

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.568 kg/m²-s
Exhaust loss = 21.89 millibar:
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.46, Buoyancy = -0.34 millibar
Stack velocity = 19.63 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=69.16% O_2=11.09% CO_2=7.297% H_2O=11.62%
AR=0.8329%
Flue gas dew point = 322 K   M.W.= 28.56

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2610	5734	1790	10134
UA kW/K	66	76	11	153
A sq.m	1232	1553	330	3115

Tube length = 3.902 m, HRSG width = 1.334 m, Aspect ratio = 2.926

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.949			
HPFW	44.35	412.9	590.8	2.949			
To desup	44.35	412.9	590.8	0.015			
HPE1				2.934	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.934	20.13	940	344
7	43.70	485.9	911.3	0.000			
HPE3				2.934	16.81	510	298
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.905	54.34	4978	1078
9	43.06	527.9	2798.7	0.000			
HPS0				2.905	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.905	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.905	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.905	10.30	1752	295
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.905			
Aft HP pipe	40.00	753.2	3399.4	2.905			
To HPT	40.00	753.2	3399.4	2.905			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.303			
IPFW	4.12	374.4	424.5	3.303			
IPE1				3.303	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.303	17.58	525	323
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.949			
IP blowdown	4.00	416.8	605.0	0.004			
IPB				0.351	21.45	756	476
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.065			
IPS1				0.285	0.55	38	35
3	3.85	478.2	2871.5	0.000			
IPS2				0.285	0.00	0	0
4	3.85	478.2	2871.5	0.285			
Feedwater:							
Cond return	0.43	311.9	162.2	2.889			
After pump	1.09	312.0	162.7	2.889			
Proc stm ret	3.45	363.2	377.2	0.301			
Makeup	3.45	288.1	63.3	0.048			
FW to LTE	1.09	316.4	181.1	3.238			
LTE				3.238	11.81	634	268
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.238			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.065			
FW to IP/HP	1.05	374.3	423.8	3.303			

Boiler feedpumps = 27.22 kWe: HP = 24.33 kWe IP = 2.894 kWe
Condensate pump(s) = 1.603 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							
main desup.		412.9	590.8	0.015			
From source	3.85	425.7	2756.7	0.301	6.9565	10.3	
Main stream	3.50	423.2	2754.2	0.301	6.9925	11.1	

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.905	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.905	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.865	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.865	7.0427	230.6			74.40*
OUT	3.61	510.7	2940.5	2.865	7.3805	97.6		1315	74.40**
	3.61	510.7	2940.5	2.865	7.3805	97.6			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.7	2940.5	2.865	7.3805	97.6			73.87*
OUT	0.069	311.9	2442.0	2.865	7.8655		0.946		76.72**
After LL	0.07	311.9	2460.5	2.865	7.9247		0.954	1375	
To condenser	0.069	311.9	2460.5	2.865	7.9247		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)

**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.18	74.40	74.40	Sup.	1314.6
HP/IP/LP Casing	LPTL	6	74.38	76.72	73.87	0.946	1374.9

Number of physical casings = 1
Gross power = 2689.5 kW
ST mech. loss = 9.413 kW. gear box loss= 40.34 kW.
Gen. elec. loss= 74.34 kW. Gen. mech. loss= 6.276 kW.
ST/Generator mech. x elect. efficiency = 95.15 %
Generator output = 2559.2 kWe. ST auxiliaries = 5.118 kWe
Annulus velocity = 205.7 m/s, RPM = 14226
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.44 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2743 sq.m
Last stage bucket length = 172.3 mm, pitch dia. = 506.8 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.52	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.89
Cooling water in		288.20		159.17
Cooling water out		298.20		159.17

Number of passes = 2 UA = 364.4 kW/K Surface area = 109 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 364
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 19.89 kWe Condensate pump(s) = 1.603 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:14:51 file=C:/Tflow13/MYFILES/case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	5783		9390		38.34	
Steam Turbine(s)	2554					
Plant Total	8337	7614	6514	7133	55.27	50.47

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.51	54.55	52.78	7159

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 17802 kWth = 60747 kBTU/h
Fuel LHV chemical energy input = 15085 kWth = 51475 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15085 kWth = 51475 kBTU/h
Energy chargeable to power = 14424 kWth = 49219 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5783	38.34	9390	18	878
Total	5783			18	

Fuel chemical HHV per gas turbine = 17802 kWth = 60747 kBTU/h
Fuel chemical LHV per gas turbine = 15085 kWth = 51475 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	kWth	Net process heat output kBTU/h
87.10	2554	25.49	22.20	615	2098

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11500 kWth = 39242 kBTU/h
Net process heat output = 7.473% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
581	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 66.25 kW
Miscellaneous plant auxiliaries = 4.169 kW
Program estimated overall plant auxiliaries = 723.5 kW
Actual (user input) overall plant auxiliaries = 723.5 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 723.5 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:14:51 file=C:/Tflow13/MYFILES/case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 305 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.93 millibar
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.47, Buoyancy = -0.33 millibar
Stack velocity = 19.65 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

RR 501KH5	12.5	1402	878	14.1	5783	9390	17.6	68.55	10.61	7.40	13.45

Fuel compressor = 580.6 kWe, Q rejected = 118.3 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	14.08	28.50	74.75	20.05	0.03	4.27	0.90
Fogger inlet	305	1.01	14.08	28.50	74.75	20.05	0.03	4.27	0.90
Fogger H2O evap			0.01						
Comp. inlet	304	1.00	14.09	28.49	74.67	20.03	0.03	4.37	0.90
Turbine coolant	misc.		0.23						
Comp. discharge	670	12.57	13.86	28.49	74.67	20.03	0.03	4.37	0.90
Fuel flow	873	16.03	3.49555						
Turbine inlet	1402	12.07	17.36	28.37	67.64	10.48	7.49	13.57	0.81
Turbine coolant			0.23						
Turbine exhaust	878	1.04	17.59	28.37	67.73	10.61	7.40	13.45	0.82

Fogging water = 0.0095 kg/s Fogger exit RH = 100 %
Compressor = 5448 Turbine = 11629 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.3 kW Gear box loss = 81.06 kW Generator loss = 206.5 kW
Mech eff. = 98.22% Gear box eff. = 98.66% Generator eff. = 96.55%
GT specific power @ gen term = 410.3 kW per kg/s
GT efficiency @ gen term = 32.49% HHV = 38.34% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.952% HHV = 32.99% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22217 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
445	975	0	0	20798

Energy out = 22226 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
179	110	81	207	0	12108	3758	5783	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.708 kW = -0.0392 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 13:14:51 file=C:/Tflow13/MYFILES/case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15991 kW

GT Exhaust Sensible	/Air Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
12108	3758	0	3	98	25	0	0	0

Energy out = 15991 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
151	86	130	1948	3758	6652	712	0	0	2554

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0828 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	876.3	755.1	121.2							
2	HPS3			5.0	1.98	17.6	1766.2	16.3	4	16
	793.4	527.9	265.5							
5	793.4	527.9	265.5							
2	HPB1			5.0	6.07	17.6	5018.4	14.1	14	14
	547.9	527.9	20.0							
7	547.9	522.9	25.0							
2	HPE3			5.0	1.39	17.6	514.0	9.8	6	19
	521.8	485.9	36.0							
9	521.8	478.2	43.7							
1	IPS1			5.0	0.19	17.6	33.2	9.9	1	14
	520.2	416.8	103.3							
10	520.2	485.9	34.3							
2	HPE2			5.0	1.63	17.6	948.0	9.3	7	19
	471.7	412.9	58.8							
11	471.7	416.8	54.9							
1	IPB			5.0	1.63	17.6	674.8	9.5	6	14
	436.8	416.8	20.0							
12	436.8	411.8	25.0							
1	IPE2			5.0	1.20	17.6	522.6	8.0	6	19
	409.6	374.4	35.3							
17	409.6	363.2	46.5							
1	LTE			5.0	0.92	17.6	639.4	7.5	5	19
	376.2	315.8	60.4							
Totals					15.00		10116.7		49.0	

HP pinch = 20.0 K IP pinch = 20.0 K
HRSG gas-side mass flux = 3.545 kg/m²-s
Exhaust loss = 21.93 millibar:
Duct = 5.00, HRSG = 15.00 millibar
Stack leaving loss = 1.77, Friction = 0.47, Buoyancy = -0.33 millibar
Stack velocity = 19.65 m/s
DB fuel = 0 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=67.73% O_2=10.61% CO_2=7.395% H_2O=13.45%
AR=0.8157%
Flue gas dew point = 325 K M.W.= 28.37

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2598	5637	1782	10017
UA kW/K	67	72	10	150
A sq.m	1269	1451	294	3014

Tube length = 3.757 m, HRSG width = 1.321 m, Aspect ratio = 2.844

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	54.13	412.7	590.8	2.941			
HPFW	44.35	412.9	590.8	2.941			
To desup	44.35	412.9	590.8	0.013			
HPE1				2.928	0.00	0	0
6	44.35	412.9	590.8	0.000			
HPE2				2.928	20.86	939	372
7	43.70	485.9	911.3	0.000			
HPE3				2.928	17.04	509	283
8	43.06	522.9	1085.1	0.000			
HP blowdown	43.06	527.9	1109.6	0.029			
HPB1				2.899	52.86	4969	1024
9	43.06	527.9	2798.7	0.000			
HPS0				2.899	0.00	0	0
22	43.06	527.9	2798.7	0.000			
HPS1				2.899	0.00	0	0
10	43.06	527.9	2798.7	0.000			
HPS2				2.899	0.00	0	0
18	43.06	527.9	2798.7	0.000			
HPS3				2.899	9.60	1749	264
11	41.60	755.1	3401.9	0.000			
HP steam	41.60	755.1	3401.9	2.899			
Aft HP pipe	40.00	753.2	3399.4	2.899			
To HPT	40.00	753.2	3399.4	2.899			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	6.01	374.3	424.5	3.254			
IPFW	4.12	374.4	424.5	3.254			
IPE1				3.254	0.00	0	0
19	4.12	374.4	424.5	0.000			
IPE2				3.254	17.52	517	330
1	4.00	411.8	583.5	0.000			
to HP pump	4.00	411.8	583.5	2.941			
IP blowdown	4.00	416.8	605.0	0.003			
IPB				0.310	19.54	668	427
2	4.00	416.8	2737.6	0.000			
Steam to DA	4.00	416.8	2737.6	0.064			
IPS1				0.246	0.48	33	30
3	3.85	478.2	2871.5	0.000			
IPS2				0.246	0.00	0	0
4	3.85	478.2	2871.5	0.246			
Feedwater:							
Cond return	0.43	311.9	162.2	2.884			
After pump	1.09	312.0	162.7	2.884			
Proc stm ret	3.45	363.2	377.2	0.259			
Makeup	3.45	288.1	63.3	0.047			
FW to LTE	1.09	315.8	178.6	3.190			
LTE				3.190	12.03	633	284
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	3.190			
Deaerator:							
IPB to D/A	4.00	416.8	2737.6	0.064			
FW to IP/HP	1.05	374.3	423.8	3.254			

Boiler feedpumps = 27.12 kWe: HP = 24.27 kWe IP = 2.853 kWe
Condensate pump(s) = 1.6 kWe

PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main IP Process:							

	P	T	h	M	s	Super-heat K	x	Work kW	Eff %
main desup.		412.9	590.8	0.013					
From source	3.85	425.7	2756.7	0.259	6.9565	10.3			
Main stream	3.50	423.2	2754.2	0.259	6.9925	11.1			

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	40.00	753.2	3399.4	2.899	7.0315	229.7			
Aft stop vlv	39.00	752.6	3399.4	2.899	7.0427	230.6			
-VS leak 1			3399.4	0.003					
-HP inlet leak 1			3399.4	0.037					
HPT inlet	39.00	752.6	3399.4	2.859	7.0427	230.6			
HP/IP/LP Casing: Group HPTL									
IN	39.00	752.6	3399.4	2.859	7.0427	230.6			74.37*
OUT	3.61	510.7	2940.6	2.859	7.3808	97.7		1312	74.37**
	3.61	510.7	2940.6	2.859	7.3808	97.7			
HP/IP/LP Casing: Group LPTL									
IN	3.61	510.7	2940.6	2.859	7.3808	97.7			73.85*
OUT	0.069	311.9	2442.3	2.859	7.8662		0.946		76.70**
After LL	0.07	311.9	2460.8	2.859	7.9255		0.954	1372	
To condenser	0.069	311.9	2460.8	2.859	7.9255		0.954		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

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STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	69.15	74.37	74.37	Sup.	1311.7
HP/IP/LP Casing	LPTL	6	74.36	76.70	73.85	0.946	1372.0

Number of physical casings = 1
Gross power = 2683.7 kW
ST mech. loss = 9.393 kW. gear box loss= 40.26 kW.
Gen. elec. loss= 74.24 kW. Gen. mech. loss= 6.262 kW.
ST/Generator mech. x elect. efficiency = 95.15 %
Generator output = 2553.6 kWe. ST auxiliaries = 5.107 kWe
Annulus velocity = 205.7 m/s, RPM = 14239
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.48 kJ/kg
Exhaust volume flow per path = 56.34 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2738 sq.m
Last stage bucket length = 172.2 mm, pitch dia. = 506.3 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2460.75	2.86
Saturation	0.0689	311.90		
SSR steam		731.60	3399.35	0.02
Condensate out	0.4279	311.90	162.21	2.88
Cooling water in		288.20		158.88
Cooling water out		298.20		158.88

Number of passes = 2 UA = 363.7 kW/K Surface area = 108.8 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.928 m Number = 363
CW vel. = 2.134 m/s DP = 0.9369 bar (0.3388 condenser + 0.5982 piping)
CW pump(s) = 19.86 kWe Condensate pump(s) = 1.6 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.60
IP process pipe	0.35

* Non-heat balance pipes are shown in PEACE output

Page 1

GT PRO 13.0 Ting Wang
1263 11-27-2004 17:51:46 file=C:/Tflow13/MYFILES/case21_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	6370		8108		44.40	
Steam Turbine(s)	236					
Plant Total	6606	5896	8318	9321	43.28	38.62

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
38.62	38.62	38.62	9817

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18015 kWth = 61472 kBTU/h
Fuel LHV chemical energy input = 15265 kWth = 52089 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15265 kWth = 52089 kBTU/h
Energy chargeable to power = 15265 kWth = 52089 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	6370	44.40	8108	21	742
Total	6370			21	

Fuel chemical HHV per gas turbine = 16931 kWth = 57774 kBTU/h
Fuel chemical LHV per gas turbine = 14347 kWth = 48956 kBTU/h

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STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
87.12	236	2.19	1.91	0	0

Fuel chemical HHV to duct burners = 1083.7 kWth = 3698 kBTU/h
Fuel chemical LHV to duct burners = 918.3 kWth = 3134 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 12372 kWth = 42217 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
552	0	0	10	30	5	0	0

HVAC = 3.25 kW, Lights = 4.75 kW
Additional auxiliaries from PEACE running motor/load list = 69 kW
Miscellaneous plant auxiliaries = 3.303 kW
Program estimated overall plant auxiliaries = 677.4 kW
Actual (user input) overall plant auxiliaries = 677.4 kW
Transformer losses = 33.03 kW, Total aux. & transformer losses = 710.4 kW

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GT PRO 13.0 Ting Wang
1263 11-27-2004 17:51:46 file=C:/Tflow13/MYFILES/case21_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST

One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 298 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.80 millibar
Duct = 4.98, HRSG = 14.96 millibar
Stack leaving loss = 1.84, Friction = 0.44, Buoyancy = -0.43 millibar
Stack velocity = 20.37 m/s

#	Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
83	RR 501KH5	14.3	1193	743	14.5	6370	8108	20.9	55.17	9.01	5.49	30.33

Fuel compressor = 551.9 kWe, Q rejected = 112.5 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Comp. inlet	298	1.00	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Turbine coolant		misc.	0.24						
Comp. discharge	696	14.33	14.30	28.66	75.88	20.36	0.03	2.81	0.91
Fuel flow	873	16.03	3.32442						
Comb. steam inj	589	41.37	3.03						
Turbine inlet	1193	13.76	20.65	26.27	54.28	8.89	5.55	30.62	0.65
Turbine coolant			0.24						
Turbine exhaust	743	1.04	20.89	26.30	54.51	9.01	5.49	30.33	0.66

Steam Injection / Fuel Flow = 0.9102
Compressor = 6070 Turbine = 12849 kW
Turbine coolant = 1.633% compr in
Mech loss = 111 kW Gear box loss = 81.61 kW Generator loss = 216 kW
Mech eff. = 98.36% Gear box eff. = 98.78% Generator eff. = 96.72%
GT specific power @ gen term = 438.2 kW per kg/s

GT efficiency @ gen term = 37.63% HHV = 44.4% LHV
GT eff. @ gen term adjusted for fuel temp. = 32.37% HHV = 38.2% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 29874 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
372	643	0	9080	19779

Energy out = 29884 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
170	111	82	216	0	12076	10859	6370	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.953 kW = -0.0333 %

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GT PRO 13.0 Ting Wang
1263 11-27-2004 17:51:46 file=C:/Tflow13/MYFILES/case21_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 24398 kW

GT Exhaust Sensible	GT Exhaust Latent	Air Addn. Enthalpy	DB Fuel	Makeup Return	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return

12076	10859	1243	194	0	26	0	0	0

Energy out = 24398 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc. Output	Electric
177	33	39	2203	11029	1600	0	9080	0	236

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0271 kW = -0.0001 %

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HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	774.2	757.2	17.0							
2	HPS3			6.3	3.27	21.1	1593.3	14.8	8	17
	716.5	529.6	186.9							
5	716.5	529.6	186.9							
2	HPB1			6.3	5.09	21.1	4473.3	13.8	12	16
	549.6	529.6	**20.0**							
7	549.6	524.6	25.0							
2	HPE3			6.3	0.90	21.1	471.2	10.1	4	21
	531.6	486.8	44.8							
9	531.6	479.1	52.5							
1	IPS1			6.3	0.37	21.1	95.0	11.4	1	16
	528.0	416.3	111.7							
10	528.0	486.8	41.1							
2	HPE2			6.3	0.92	21.1	867.2	9.8	4	21
	494.6	412.4	82.2							
11	494.6	416.3	78.3							
1	IPB			6.3	2.28	21.1	1496.1	10.1	8	16
	436.3	416.3	**20.0**							
12	436.3	411.3	25.0							
1	IPE2			6.3	0.90	21.1	540.2	8.1	5	21
	415.0	377.7	37.3							
17	415.0	377.6	37.4							
1	LTE			6.3	1.24	21.1	1349.5	7.4	8	21
	361.7	292.6	69.1							
Totals					14.96		10885.7		49.9	

HP pinch = 20.0 K IP pinch = 20.0 K
HRSG gas-side mass flux = 3.373 kg/m²-s
Exhaust loss = 21.80 millibar:
Duct = 4.98, HRSG = 14.96 millibar
Stack leaving loss = 1.84, Friction = 0.44, Buoyancy = -0.43 millibar
Stack velocity = 20.37 m/s
DB fuel = 0.2128 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66 kJ/kg; MW = 25.439
Gas mole composition: N2=54.37% O2=8.669% CO2=5.785% H2O=30.52% AR=0.6549%
Flue gas dew point = 343 K M.W.= 26.31

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	3196	5910	1672	10778
UA kW/K	72	95	24	191
A sq.m	1315	1928	721	3964

Tube length = 4.265 m, HRSG width = 1.467 m, Aspect ratio = 2.908

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HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m

HP Circuit:

	P	T	h	M	UA	Q	A
from FW Pump	55.75	412.2	588.7	3.056			
HPFW	45.64	412.4	588.7	3.056			
To desup	45.64	412.4	588.7	0.432			
HPE1				2.624	0.00	0	0
6	45.64	412.4	588.7	0.000			
HPE2				2.624	14.62	859	262
7	44.98	486.8	915.9	0.000			
HPE3				2.624	13.89	466	230
8	44.31	524.6	1093.6	0.000			
HP blowdown	44.31	529.6	1118.1	0.026			
HPB1				2.598	59.91	4429	1171
9	44.31	529.6	2797.9	0.000			
HPS0				2.598	0.00	0	0
22	44.31	529.6	2797.9	0.000			
HPS1				2.598	0.00	0	0
10	44.31	529.6	2797.9	0.000			
HPS2				2.598	0.00	0	0
18	44.31	529.6	2797.9	0.000			
HPS3				2.598	22.49	1578	633
11	42.82	757.2	3405.1	2.594			
HP steam	42.82	757.2	3405.1	0.004			
Aft HP pipe	41.37	755.4	3402.8	0.004			
To HPT	41.37	755.4	3402.8	0.004			

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HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m

IP Circuit:

	P	T	h	M	UA	Q	A
from FW Pump	5.83	377.7	438.6	3.750			
IPFW	4.06	377.7	438.6	3.750			
IPE1				3.750	0.00	0	0
19	4.06	377.7	438.6	0.000			
IPE2				3.750	17.57	535	319
1	3.94	411.3	581.2	0.000			
to HP pump	3.94	411.3	581.2	3.056			
IP blowdown	3.94	416.3	602.6	0.007			
IPB				0.687	35.03	1481	757
2	3.94	416.3	2737.0	0.000			
IPS1				0.687	1.21	94	88
3	3.79	479.1	2873.8	0.000			
IPS2				0.687	0.00	0	0
4	3.79	479.1	2873.8	0.000			
IP steam	3.79	479.1	2873.8	0.687			
Aft IP pipe	3.45	477.2	2871.5	0.687			

Feedwater:

	P	T	h	M	UA	Q	A
Cond return	0.43	311.9	162.2	0.691			
After pump	1.22	312.0	162.8	0.691			
Makeup	3.45	288.1	63.3	3.059			
FW to LTE	1.22	292.6	81.6	3.750			
LTE				3.750	26.12	1336	504
13	1.18	377.6	437.9	0.000			
LTE exit	1.18	377.6	437.9	3.750			

LTE Exit:

	P	T	h	M
FW to IP/HP	1.18	377.6	437.9	3.750

Boiler feedpumps = 29.08 kWe: HP = 26 kWe IP = 3.079 kWe
Condensate pump(s) = 0.5264 kWe

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PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality
Main HP Process:							
main desup.		412.4	588.7	0.432			
From source	42.82	591.1	3003.0	3.026	6.4076	63.6	
HP Process Substreams:							
1st substrm	41.37	588.7	3000.7	3.026	6.4184	63.2	

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STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	41.37	755.4	3402.8	0.004	7.0211	229.9			
Aft stop vlv	40.33	754.8	3402.8	0.004	7.0323	230.8			
-VS leak 1			3402.8	0.000					
-VS leak 2			3402.8	0.000					
-HP inlet leak 1			3402.8	0.000					
HPT inlet	40.33	754.8	3402.8	0.004	7.0323	230.8			
HP/IP/LP Casing: Group HPTL									
IN	40.33	754.8	3402.8	0.004	7.0323	230.8			63.53*
OUT	3.45	539.2	3000.1	0.004	7.5131	127.7		2	63.53**
IP induction	3.45	477.2	2871.5	0.687	7.2620	65.7			
+VS leak 1			3402.8	0.000					
+HP inlet leak 1			3402.8	0.000					
	3.45	477.6	2872.3	0.691	7.2637	66.1			
HP/IP/LP Casing: Group LPTL									
IN	3.45	477.6	2872.3	0.691	7.2637	66.1			64.05*
OUT	0.069	311.9	2457.8	0.691	7.9161		0.953		67.07**
After LL	0.07	311.9	2476.5	0.691	7.9761		0.960	274	
To condenser	0.069	311.9	2476.5	0.691	7.9761		0.960		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

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STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	9	57.43	63.53	63.53	Sup.	1.7
HP/IP/LP Casing	LPTL	6	64.60	67.07	64.05	0.953	273.6

Number of physical casings = 1

Gross power = 275.3 kW
ST mech. loss = 0.9636 kW. gear box loss= 4.13 kW.
Gen. elec. loss= 33.58 kW. Gen. mech. loss= 0.6424 kW.
ST/Generator mech. x elect. efficiency = 85.72 %
Generator output = 236 kWe. ST auxiliaries = 0.472 kWe
Annulus velocity = 205.7 m/s, RPM = 28860
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.69 kJ/kg
Exhaust volume flow per path = 13.72 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.0667 sq.m
Last stage bucket length = 84.94 mm, pitch dia. = 249.8 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2476.53	0.69
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	0.69
Cooling water in		288.20		38.22
Cooling water out		298.20		38.22

Number of passes = 2 UA = 87.48 kW/K Surface area = 26.16 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1

h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.942 m Number = 87
CW vel. = 2.134 m/s DP = 0.9378 bar (0.3397 condenser + 0.5982 piping)
CW pump(s) = 5.019 kWe Condensate pump(s) = 0.5264 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
IPB to LPT induction pipe	0.34

* Non-heat balance pipes are shown in PEACE output

Page 1
GT PRO 13.0 Ting Wang
1263 11-27-2004 12:39:59
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	5886		9376		38.39	
Steam Turbine(s)	2565					
Plant Total	8452	7717	6530	7152	55.13	50.34

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
53.06	55.78	53.46	7014

GT fuel HHV/LHV ratio = 1.1801   DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 18093 kWth = 61739 kBTU/h
Fuel LHV chemical energy input = 15331 kWth = 52315 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 15331 kWth = 52315 kBTU/h
Energy chargeable to power = 14434 kWth = 49254 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5886	38.39	9376	18	872
Total	5886			18	

Fuel chemical HHV per gas turbine = 18093 kWth = 61739 kBTU/h
Fuel chemical LHV per gas turbine = 15331 kWth = 52315 kBTU/h

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STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
86.96	2565	25.12	21.85	834	2847

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11743 kWth = 40072 kBTU/h
Net process heat output = 9.756% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
590	0	0	10	29	20	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 68 kW
Miscellaneous plant auxiliaries = 4.226 kW
Program estimated overall plant auxiliaries   = 734.6 kW
Actual (user input) overall plant auxiliaries = 734.6 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 734.6 kW

Page 3
GT PRO 13.0 Ting Wang
1263 11-27-2004 12:39:59
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 298 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.83 millibar
Duct = 4.98, HRSG = 15.01 millibar
Stack leaving loss = 1.73, Friction = 0.46, Buoyancy = -0.35 millibar
Stack velocity = 19.22 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5	12.8	1396	872	14.5	5886	9376	18.1	69.53	10.93	7.34	12.20

Fuel compressor = 589.8 kWe, Q rejected = 120.2 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	N2	O2	CO2	H2O	AR
	K	bar	kg/s						
Ambient air in	298	1.01	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Comp. inlet	298	1.00	14.54	28.66	75.88	20.36	0.03	2.81	0.91
Turbine coolant	misc.		0.24						
Comp. discharge	666	12.88	14.30	28.66	75.88	20.36	0.03	2.81	0.91
Fuel flow	873	16.03	3.55258						
Comb. steam inj	589	41.37	0.01						
Turbine inlet	1396	12.36	17.86	28.50	68.61	10.80	7.43	12.33	0.83
Turbine coolant			0.24						
Turbine exhaust	872	1.04	18.10	28.50	68.70	10.93	7.34	12.20	0.83

Steam Injection / Fuel Flow = 0.0024
Compressor = 5595 Turbine = 11881 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.4 kW Gear box loss = 81.16 kW Generator loss = 208.1 kW
Mech eff. = 98.24% Gear box eff. = 98.69% Generator eff. = 96.59%
GT specific power @ gen term = 404.9 kW per kg/s
GT efficiency @ gen term = 32.53% HHV = 38.39% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.993% HHV = 33.03% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 22177 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
372	643	0	26	21137

```
Energy out = 22186 kW
________________________________________________________________
______________________

  Misc  Mech  Gbox   Gen   Turb(Q1) Exhaust   Exhaust
Electric  Proc   Steam(Q2)
  Loss  Loss  Loss   Loss  Coolant  Sensible  Latent
Output    Air   Coolant
________________________________________________________________
______________________

   182   110    81    208       0     12225     3493
5886       0         0
________________________________________________________________
______________________

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.885 kW  = -0.0401 %


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GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat
ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6,
Subtype 6
Steam Property Formulation: Thermoflow - STQUIK
```

STEAM CYCLE HEAT BALANCE

```
Energy in = 15884  kW
________________________________________________________________
______________________

GT Exhaust/Air Addn. DB Fuel  Makeup  Process  Pump
Steam    Ext.   GT
 Sensible   Latent   Enthalpy         Return   Work
/Heat    Water  Return
________________________________________________________________
______________________

    12225     3493        0        3       138    25
0        0        0
________________________________________________________________
```



```
______________________


Energy out = 15884  kW
________________________________________________________________
______________________

 Heat      Blow Mech/Elec Stack  Stack  Condnsr  Steam   To
GT   Proc. Electric
Radiated  down  Losses   Sens.  Latent          /Heat
Water   Output
________________________________________________________________
______________________

   158     35    131    1863    3493    6641     973
26       0    2565
________________________________________________________________
______________________

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0942  kW   = -0.0006 %

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```

HRSG GAS SIDE - Plant total gas flow cross-section.

```
________________________________________________________________
______________________

Zone  Tg K   Tw K    DT K   Afrn   DELTA P   Mg     Qg
Vg    Tube   Tubes
/path  /HX                  sq.m   millibar  kg/s    kW
m/s  rows   /row
________________________________________________________________
______________________

 0   869.5   757.2   112.3
 2    HPS3                     5.1   2.04    18.1   1771.4
16.1      4     16
     787.9   529.6   258.3
________________________________________________________________
______________________

 5   787.9   529.6   258.3
 2    HPB1                     5.1   6.00    18.1   4973.4
14.1     13     15
     549.6   529.6    20.0
________________________________________________________________
______________________

 7   549.6   524.6    25.0
 2    HPE3                     5.1   1.33    18.1    523.8
```

9.7 6 19
523.7 486.8 36.8

9 523.7 479.1 44.6
1 IPS1 5.1 0.29 18.1 46.3
10.3 1 15
521.4 416.3 105.1

10 521.4 486.8 34.5
2 HPE2 5.1 1.53 18.1 964.1
9.1 7 19
473.1 412.4 60.8

11 473.1 416.3 56.9
1 IPB 5.1 1.66 18.1 729.3
9.5 6 15
436.3 416.3 **20.0**

12 436.3 411.3 25.0
1 IPE2 5.1 0.99 18.1 471.9
7.7 6 19
412.3 377.7 34.6

17 412.3 377.6 34.7
1 LTE 5.1 1.17 18.1 833.5
7.2 7 19
369.6 317.6 52.0

Totals 15.01 10313.7
50.1

HP pinch = 20.0 K IP pinch = 20.0 K
HRSG gas-side mass flux = 3.518 kg/m²-s
Exhaust loss = 21.83 millibar:
Duct = 4.98, HRSG = 15.01 millibar
Stack leaving loss = 1.73, Friction = 0.46, Buoyancy = -0.35 millibar

Stack velocity = 19.22 m/s
DB fuel = 0 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66 kJ/kg; MW = 25.439
Gas mole composition: N2=68.7% O2=10.93% CO2=7.338% H2O=12.2% AR=0.8274%
Flue gas dew point = 323 K M.W.= 28.5

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	2766	5646	1800	10212
UA kW/K	73	74	11	158
A sq.m	1313	1521	343	3177

Tube length = 3.858 m, HRSG width = 1.334 m, Aspect ratio = 2.893

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HRSG WATER SIDE - Plant total flow

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
HP Circuit:							
-----------							
from FW Pump	55.75	412.2	588.7	2.937			
HPFW	45.64	412.4	588.7	2.937			
To desup	45.64	412.4	588.7	0.020			
HPE1				2.918	0.00	0	0
6	45.64	412.4	588.7	0.000			
HPE2				2.918	20.77	955	366
7	44.98	486.8	915.9	0.000			
HPE3				2.918	17.16		

		P	T	h	M	UA
519	283					
8		44.31	524.6	1093.6	0.000	
HP blowdown		44.31	529.6	1118.1	0.029	
HPB1					2.889	53.40
4924	1062					
9		44.31	529.6	2797.9	0.000	
HPS0					2.889	0.00
0	0					
22		44.31	529.6	2797.9	0.000	
HPS1					2.889	0.00
0	0					
10		44.31	529.6	2797.9	0.000	
HPS2					2.889	0.00
0	0					
18		44.31	529.6	2797.9	0.000	
HPS3					2.889	10.11
1754	287					
11		42.82	757.2	3405.1	0.007	
HP steam		42.82	757.2	3405.1	2.881	
Aft HP pipe		41.37	755.4	3402.8	2.881	
To HPT		41.37	755.4	3402.8	2.881	

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HRSG WATER SIDE (contd.)

		P	T	h	M	UA
Q	A					
		bar	K	kJ/kg	kg/s	kW/K
kW	sq.m					

IP Circuit:

		P	T	h	M	UA
from FW Pump		5.83	377.7	438.6	3.276	
IPFW		4.06	377.7	438.6	3.276	
IPE1					3.276	0.00
0	0					
19		4.06	377.7	438.6	0.000	
IPE2					3.276	15.98
467	283					
1		3.94	411.3	581.2	0.000	
to HP pump		3.94	411.3	581.2	2.937	
IP blowdown		3.94	416.3	602.6	0.003	
IPB					0.335	20.68
722	459					
2		3.94	416.3	2737.0	0.000	
IPS1					0.335	0.66
46	55					
3		3.79	479.1	2873.8	0.000	
IPS2					0.335	0.00
0	0					
4		3.79	479.1	2873.8	0.335	

Feedwater:

		P	T	h	M	UA
Cond return		0.43	311.9	162.2	2.881	
After pump		1.22	312.0	162.5	2.881	
Proc stm ret		3.45	366.5	391.2	0.353	
Makeup		3.45	288.1	63.3	0.041	
FW to LTE		1.22	317.6	186.0	3.276	
LTE					3.276	19.49
825	381					
13		1.18	377.6	437.9	0.000	
LTE exit		1.18	377.6	437.9	3.276	

LTE Exit:

		P	T	h	M	UA
FW to IP/HP		1.18	377.6	437.9	3.276	

Boiler feedpumps = 27.72 kWe: HP = 25.02 kWe IP = 2.703 kWe
Condensate pump(s) = 1.117 kWe

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PROCESS STEAM FLOWS - Plant Totals

	P	T	h	M	s
Superheat	Quality				
	bar	K	kJ/kg	kg/s	kJ/kg-K
K					

```
Main HP Process:
----------------
main desup.             412.4   588.7     0.001
From source    42.82   591.1  3003.0     0.009     6.4076
63.6
Main stream    41.37   588.7  3000.7     0.009     6.4184
63.2
```

```
Main IP Process:
----------------
main desup.             412.4   588.7     0.018
From source     3.79   424.5  2754.5     0.353     6.9582
9.6
Main stream     3.45   422.0  2752.2     0.353     6.9946
10.5
```

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STEAM TURBINE FLOWS

```
               P        T       h         M       s
Super-    x    Work   Eff
               bar      K      kJ/kg      kg/s  kJ/kg-K
heat K         kW      %
```

```
From boiler    41.37   755.4  3402.8    2.881  7.0211
229.9
Aft stop vlv   40.33   754.8  3402.8    2.881  7.0323
230.8
-VS leak 1                    3402.8    0.003
-VS leak 2                    3402.8    0.000
-HP inlet leak 1              3402.8    0.038
```

```
HPT inlet      40.33   754.8  3402.8    2.840  7.0323
230.8
```

```
HP/IP/LP Casing: Group HPTL
IN                40.33   754.8  3402.8    2.840  7.0323
230.8                74.02*
OUT                3.55   509.4  2938.0    2.840  7.3825
96.8          1320 74.02**
----------------------------------------------------------
---------------------
```

```
+VS leak 1                       3402.8    0.003
+HP inlet leak 1                 3402.8    0.038
                   3.55   512.5  2944.5    2.881  7.3953
100.0
```

```
HP/IP/LP Casing: Group LPTL
IN                 3.55   512.5  2944.5    2.881  7.3953
100.0                73.56*
OUT                0.069  311.9  2448.4    2.881  7.8860
0.949         76.42**
After LL           0.07   311.9  2467.0    2.881  7.9455
0.956   1376
----------------------------------------------------------
---------------------
To condenser       0.069  311.9  2467.0    2.881  7.9455
0.956
```

```
* : Group overall efficiency (including control valve
and/or leaving losses)
**: Group blading efficiency
```

Page 11

STEAM TURBINE DESIGN

```
Casing              Group   No. of  Dry step  Blading
Overall  Exit        Work
                    name    stages  eff. %    eff. %    eff.
%   quality    kW
```

```
HP/IP/LP Casing   HPTL       9    68.68      74.02     74.02
Sup.     1320.2
HP/IP/LP Casing   LPTL       6    73.98      76.42     73.56
```

0.949   1375.8

Number of physical casings = 1
Gross power = 2696 kW
ST mech. loss = 9.436 kW. gear box loss= 40.44 kW.
Gen. elec. loss= 74.45 kW. Gen. mech. loss= 6.291 kW.
ST/Generator mech. x elect. efficiency = 95.16 %
Generator output = 2565.4 kWe.   ST auxiliaries = 5.131 kWe
Annulus velocity = 205.7 m/s,   RPM = 14166
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.56 kJ/kg
Exhaust volume flow per path = 56.92 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2767 sq.m
Last stage bucket length = 173 mm, pitch dia. = 508.9 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in   m/s, exhaust loss in   kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2466.99	2.88
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	2.88
Cooling water in		288.20		158.63
Cooling water out		298.20		158.63

Number of passes = 2   UA = 363.1 kW/K   Surface area = 108.6 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.921 m   Number = 363
CW vel. = 2.134 m/s DP = 0.9365 bar (0.3384 condenser + 0.5982 piping)
CW pump(s) = 19.83 kWe   Condensate pump(s) = 1.117 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
HP process pipe	1.45
IP process pipe	0.34

* Non-heat balance pipes are shown in PEACE output

Page 1
GT PRO 13.0 Ting Wang
1263 11-27-2004 17:53:08
file=C:/Tflow13/MYFILES/case23_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	6314		8125		44.31	
Steam Turbine(s)	230					
Plant Total	6544	5873	8146	9077	44.20	39.66

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
39.66	39.66	39.66	9613

GT fuel HHV/LHV ratio = 1.1801   DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 17475 kWth = 59628 kBTU/h
Fuel LHV chemical energy input = 14807 kWth = 50527 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 14807 kWth = 50527 kBTU/h
Energy chargeable to power = 14807 kWth = 50527 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	6314	44.31	8125	20	755
Total	6314			20	

Fuel chemical HHV per gas turbine = 16818 kWth = 57388 kBTU/h
Fuel chemical LHV per gas turbine = 14251 kWth = 48629 kBTU/h

Page 2

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
87.98	230	2.21	1.94	0	0

Fuel chemical HHV to duct burners = 656.4 kWth = 2240 kBTU/h
Fuel chemical LHV to duct burners = 556.2 kWth = 1898.1 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11837 kWth = 40392 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries: Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Steam Cycle Auxiliaries: Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
548	0	0	10	28	5	0	0

HVAC = 3.25 kW, Lights = 4.5 kW
Additional auxiliaries from PEACE running motor/load list = 68 kW
Miscellaneous plant auxiliaries = 3.272 kW
Program estimated overall plant auxiliaries   = 671.1 kW
Actual (user input) overall plant auxiliaries = 671.1 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 671.1 kW

Page 3
GT PRO 13.0 Ting Wang
1263 11-27-2004 17:53:08

file=C:/Tflow13/MYFILES/case23_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 305 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.85 millibar
Duct = 4.98, HRSG = 14.98 millibar
Stack leaving loss = 1.83, Friction = 0.44, Buoyancy = -0.39 millibar
Stack velocity = 20.29 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
RR 501KH5	14.0	1211	755	14.2	6314	8125	20.4	55.85	9.06	5.61	29.47

Fuel compressor = 548.2 kWe, Q rejected = 111.7 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Comp. inlet	305	1.00	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Turbine coolant	misc.		0.23						
Comp. discharge	708	14.06	13.92	28.81	76.97	20.65	0.03	1.42	0.93
Fuel flow	873	16.03	3.30226						
Comb. steam inj	589	41.37	2.92						
Turbine inlet	1211	13.49	20.14	26.38	54.96	8.94	5.67	29.77	0.66
Turbine coolant			0.23						
Turbine exhaust	755	1.04	20.37	26.41	55.18	9.06	5.61	29.47	0.66

Steam Injection / Fuel Flow = 0.8842
Compressor = 5932 Turbine = 12654 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.9 kW Gear box loss = 81.55 kW Generator loss = 215 kW
Mech eff. = 98.35% Gear box eff. = 98.77% Generator eff. = 96.71%
GT specific power @ gen term = 446.2 kW per kg/s
GT efficiency @ gen term = 37.54% HHV = 44.31% LHV
GT eff. @ gen term adjusted for fuel temp. = 32.3% HHV = 38.12% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 29188 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy

463 315 0 8762 19648

Energy out = 29198 kW

Misc Mech Gbox Gen Turb(Q1) Exhaust Exhaust
Electric Proc Steam(Q2)
Loss Loss Loss Loss Coolant Sensible Latent
Output Air Coolant

169 111 82 215 0 12058 10249
6314 0 0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -9.93 kW = -0.034 %

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GT PRO 13.0 Ting Wang
1263 11-27-2004 17:53:08
file=C:/Tflow13/MYFILES/case23_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 5
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 23271 kW

GT Exhaust/Air Addn. DB Fuel Makeup Process Pump
Steam Ext. GT
Sensible Latent Enthalpy Return Work
/Heat Water Return

12058 10249 753 187 0 25
0 0 0

Energy out = 23271 kW

Heat Blow Mech/Elec Stack Stack Condnsr Steam To
GT Proc. Electric
Radiated down Losses Sens. Latent /Heat
Water Output

172 32 39 2131 10351 1555 0
8762 0 230

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0299 kW = -0.0001 %

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HRSG GAS SIDE - Plant total gas flow cross-section.

Zone Tg K Tw K DT K Afrn DELTA P Mg Qg
Vg Tube Tubes
/path /HX sq.m millibar kg/s kW
m/s rows /row

0 774.2 757.2 17.0
2 HPS3 6.1 3.30 20.5 1539.6
14.8 8 17
716.5 529.6 186.9

5 716.5 529.6 186.9
2 HPB1 6.1 5.07 20.5 4322.6
13.8 12 16
549.6 529.6 **20.0**

```
 7   549.6   524.6    25.0
 2    HPE3                         6.1   0.89    20.5    455.3
10.1       4      20
     531.6   486.8    44.8

 9   531.6   479.1    52.5
 1    IPS1                         6.1   0.38    20.5     91.8
11.4       1      16
     528.0   416.3   111.7

10   528.0   486.8    41.1
 2    HPE2                         6.1   0.92    20.5    837.9
9.8       4      20
     494.6   412.4    82.2

11   494.6   416.3    78.3
 1    IPB                          6.1   2.27    20.5   1446.1
10.1       8      16
     436.3   416.3    20.0

12   436.3   411.3    25.0
 1    IPE2                         6.1   0.89    20.5    522.0
8.1       5      20
     415.0   377.7    37.3

17   415.0   377.6    37.4
 1    LTE                          6.1   1.23    20.5   1303.6
7.4       8      20
     361.7   292.6    69.1

Totals                                  14.98           10518.8
49.9
```

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.379 kg/m²-s
Exhaust loss = 21.85 millibar:

Duct = 4.98, HRSG = 14.98 millibar
Stack leaving loss = 1.83, Friction = 0.44, Buoyancy = -0.39 millibar
Stack velocity = 20.29 m/s
DB fuel = 0.1289 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66 kJ/kg; MW = 25.439
Gas mole composition: N2=55.1% O2=8.85% CO2=5.799% H2O=29.59% AR=0.6635%
Flue gas dew point = 342 K   M.W.= 26.42

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	3088	5712	1615	10415
UA kW/K	70	92	23	184
A sq.m	1269	1866	710	3844

Tube length = 4.266 m, HRSG width = 1.422 m, Aspect ratio = 2.999

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HRSG WATER SIDE - Plant total flow

```
                     P        T        h          M         UA
Q          A
                    bar       K      kJ/kg       kg/s      kW/K
kW      sq.m

HP Circuit:
-----------
from FW Pump   55.75   412.2   588.7     2.953
HPFW           45.64   412.4   588.7     2.953
To desup       45.64   412.4   588.7     0.417
HPE1                                     2.536      0.00
0         0
    6          45.64   412.4   588.7     0.000
HPE2                                     2.536     14.13
```

```
830        253
    7          44.98   486.8   915.9     0.000
HPE3                                     2.536     13.42
451        222
    8          44.31   524.6  1093.6     0.000
HP blowdown    44.31   529.6  1118.1     0.025
HPB1                                     2.511     57.89
4280       1133
    9          44.31   529.6  2797.9     0.000
HPS0                                     2.511      0.00
0          0
   22          44.31   529.6  2797.9     0.000
HPS1                                     2.511      0.00
0          0
   10          44.31   529.6  2797.9     0.000
HPS2                                     2.511      0.00
0          0
   18          44.31   529.6  2797.9     0.000
HPS3                                     2.511     21.73
1524        621
   11          42.82   757.2  3405.1     2.503
HP steam       42.82   757.2  3405.1     0.008
Aft HP pipe    41.37   755.4  3402.8     0.008
To HPT         41.37   755.4  3402.8     0.008
```

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HRSG WATER SIDE (contd.)

```
                P       T       h          M         UA
Q        A
               bar      K     kJ/kg       kg/s      kW/K
kW     sq.m
```

```
IP Circuit:
-----------
from FW Pump    5.83   377.7   438.6     3.623
IPFW            4.06   377.7   438.6     3.623
IPE1                                     3.623      0.00
0          0
   19           4.06   377.7   438.6     0.000
IPE2                                     3.623     16.97
517        308
    1           3.94   411.3   581.2     0.000
to HP pump      3.94   411.3   581.2     2.953
IP blowdown     3.94   416.3   602.6     0.007
IPB                                      0.664     33.85
1432        732
    2           3.94   416.3  2737.0     0.000
IPS1                                     0.664      1.17
91         89
    3           3.79   479.1  2873.8     0.000
IPS2                                     0.664      0.00
0          0
    4           3.79   479.1  2873.8     0.000
IP steam        3.79   479.1  2873.8     0.664
```

```
Aft IP pipe     3.45   477.2  2871.5     0.664
```

```
Feedwater:
----------
Cond return     0.43   311.9   162.2     0.672
After pump      1.22   312.0   162.5     0.672
Makeup          3.45   288.1    63.3     2.952
FW   to LTE     1.22   292.6    81.7     3.623
LTE                                      3.623     25.24
1291        486
   13           1.18   377.6   437.9     0.000
LTE exit        1.18   377.6   437.9     3.623
```

```
LTE Exit:
---------
FW to IP/HP     1.18   377.6   437.9     3.623
```

Boiler feedpumps = 28.12 kWe: HP = 25.15 kWe IP = 2.979 kWe
Condensate pump(s) = 0.3495 kWe

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PROCESS STEAM FLOWS - Plant Totals

```
                  P         T        h          M         s
Superheat  Quality
                 bar        K      kJ/kg       kg/s     kJ/kg-K
K
```

```
Main HP Process:
----------------
main desup.              412.4   588.7      0.417
From source    42.82     591.1  3003.0      2.920      6.4076
63.6
```

```
HP Process Substreams:
1st substrm    41.37     588.7  3000.7      2.920      6.4184
63.2
```

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STEAM TURBINE FLOWS

```
                  P         T        h          M       s
Super-    x    Work   Eff
                 bar        K      kJ/kg      kg/s   kJ/kg-K
heat K          kW      %
```

```
From boiler    41.37     755.4  3402.8     0.008   7.0211
229.9
Aft stop vlv   40.33     754.8  3402.8     0.008   7.0323
230.8
-VS leak 1                      3402.8     0.000
-VS leak 2                      3402.8     0.000
-HP inlet leak 1                3402.8     0.000
```

```
HPT inlet      40.33     754.8  3402.8     0.007   7.0323
230.8
```

```
HP/IP/LP Casing: Group HPTL
IN                40.33   754.8  3402.8     0.007  7.0323
230.8                 63.55*
OUT                3.45   539.2  3000.0     0.007  7.5130
127.7               3 63.55**
-------------------------------------------------------------
---------------------
```

```
IP induction     3.45   477.2  2871.5     0.664  7.2620
65.7
+VS leak 1                     3402.8     0.000
+HP inlet leak 1               3402.8     0.000
                 3.45   477.9  2873.0     0.672  7.2651
66.4
```

```
HP/IP/LP Casing: Group LPTL
IN               3.45   477.9  2873.0     0.672  7.2651
66.4               64.07*
OUT              0.069  311.9  2458.2     0.672  7.9174
0.953         67.09**
After LL         0.07   311.9  2476.9     0.672  7.9774
0.961    266
-------------------------------------------------------------
---------------------
To condenser     0.069  311.9  2476.9     0.672  7.9774
0.961
```

```
* : Group overall efficiency (including control valve
and/or leaving losses)
**: Group blading efficiency
```

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STEAM TURBINE DESIGN

```
Casing               Group   No. of  Dry step  Blading
Overall   Exit        Work
                     name    stages  eff. %    eff. %    eff.
%   quality    kW
```

```
HP/IP/LP Casing   HPTL       9    57.44     63.55    63.55
```

Sup.	3.0						
HP/IP/LP Casing	LPTL	6	64.61	67.09	64.07	0.953	266.0

Number of physical casings = 1
Gross power = 269 kW
ST mech. loss = 0.9416 kW. gear box loss= 4.035 kW.
Gen. elec. loss= 33.48 kW. Gen. mech. loss= 0.6277 kW.
ST/Generator mech. x elect. efficiency = 85.47 %
Generator output = 229.9 kWe.   ST auxiliaries = 0.4599 kWe
Annulus velocity = 205.7 m/s,   RPM = 29278
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.69 kJ/kg
Exhaust volume flow per path = 13.33 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.0648 sq.m
Last stage bucket length = 83.73 mm, pitch dia. = 246.3 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in   m/s, exhaust loss in   kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2476.94	0.67
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	0.67
Cooling water in		288.20		37.13
Cooling water out		298.20		37.13

Number of passes = 2   UA = 85.01 kW/K   Surface area = 25.42 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.92 m   Number = 85
CW vel. = 2.134 m/s DP = 0.9365 bar (0.3383 condenser + 0.5982 piping)
CW pump(s) = 4.871 kWe   Condensate pump(s) = 0.3495 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
IPB to LPT induction pipe	0.34

* Non-heat balance pipes are shown in PEACE output

Page 1
GT PRO 13.0 Ting Wang
1263 11-27-2004 12:44:17
file=C:/Tflow13/MYFILES/case24_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	5774		9337		38.56	
Steam Turbine(s)	2484					
Plant Total	8258	7538	6528	7152	55.15	50.34

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.96	55.58	53.35	7035

GT fuel HHV/LHV ratio = 1.1801   DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 17672 kWth = 60302 kBTU/h
Fuel LHV chemical energy input = 14975 kWth = 51098 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 14975 kWth = 51098 kBTU/h
Energy chargeable to power = 14130 kWth = 48217 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (RR 501KH5) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	5774	38.56	9337	18	877
Total	5774			18	

Fuel chemical HHV per gas turbine = 17672 kWth = 60302 kBTU/h
Fuel chemical LHV per gas turbine = 14975 kWth = 51098 kBTU/h

Page 2

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
88.38	2484	24.57	21.72	785	2680

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 11438 kWth = 39031 kBTU/h
Net process heat output = 9.435% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
576	0	0	10	29	19	0	5

HVAC = 3.75 kW, Lights = 5 kW
Additional auxiliaries from PEACE running motor/load list = 67.75 kW
Miscellaneous plant auxiliaries = 4.129 kW
Program estimated overall plant auxiliaries   = 719.7 kW
Actual (user input) overall plant auxiliaries = 719.7 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 719.7 kW

Page 3
GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 1.013 bar, 305 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.88 millibar
Duct = 4.98, HRSG = 15.02 millibar
Stack leaving loss = 1.72, Friction = 0.46, Buoyancy = -0.30 millibar
Stack velocity = 19.1 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
83			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	RR 501KH5	12.6	1404	877	14.2	5774	9337	17.7	69.92	11.02	7.34	11.72

Fuel compressor = 576.1 kWe, Q rejected = 117.4 kW , exit temperature = 873.1 K
Fuel molecular weight = 25.44; LHV @ combustor = 5123 kJ/kg
G.T. auxiliary power = 10.04 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Comp. inlet	305	1.00	14.15	28.81	76.97	20.65	0.03	1.42	0.93
Turbine coolant	misc.		0.23						
Comp. discharge	677	12.62	13.92	28.81	76.97	20.65	0.03	1.42	0.93
Fuel flow	873	16.03	3.46990						
Comb. steam inj	589	41.37	0.08						
Turbine inlet	1404	12.11	17.47	28.55	68.98	10.90	7.44	11.85	0.83
Turbine coolant			0.23						
Turbine exhaust	877	1.04	17.70	28.56	69.08	11.02	7.34	11.72	0.83

Steam Injection / Fuel Flow = 0.0226
Compressor = 5464 Turbine = 11635 kW
Turbine coolant = 1.633% compr in
Mech loss = 110.3 kW Gear box loss = 81.05 kW Generator loss = 206.4 kW
Mech eff. = 98.21% Gear box eff. = 98.66% Generator eff. = 96.55%
GT specific power @ gen term = 408 kW per kg/s
GT efficiency @ gen term = 32.67% HHV = 38.56% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.111% HHV = 33.17% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 21658 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
463	315	0	235	20645

Energy out = 21667 kW

Misc Mech Gbox Gen Turb(Q1) Exhaust Exhaust
Electric Proc Steam(Q2)
Loss Loss Loss Loss Coolant Sensible Latent
Output Air Coolant

178 110 81 206 0 12044 3274
5774 0 0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -8.718 kW = -0.0403 %

Page 5
GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One RR 501KH5 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 15480 kW

GT Exhaust/Air Addn. DB Fuel Makeup Process Pump
Steam Ext. GT
Sensible Latent Enthalpy Return Work
/Heat Water Return

12044 3274 0 7 130 25
0 0 0

Energy out = 15480 kW

Heat Blow Mech/Elec Stack Stack Condnsr Steam To
GT Proc. Electric
Radiated down Losses Sens. Latent /Heat
Water Output

156 35 127 1787 3274 6467 915
235 0 2484

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.0955 kW = -0.0006 %

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HRSG GAS SIDE - Plant total gas flow cross-section.

Zone Tg K Tw K DT K Afrn DELTA P Mg Qg
Vg Tube Tubes
/path /HX sq.m millibar kg/s kW
m/s rows /row

0 875.1 757.2 117.9
2 HPS3 5.0 1.96 17.7 1759.2
16.0 4 16
792.1 529.6 262.5

5 792.1 529.6 262.5
2 HPB1 5.0 6.00 17.7 4939.1
14.1 13 15
549.6 529.6 **20.0**

7 549.6 524.6 25.0

2 HPE3 5.0 1.36 17.7 520.2
9.7 6 19
523.2 486.8 36.4

9 523.2 479.1 44.1
1 IPS1 5.0 0.28 17.7 43.6
10.2 1 15
521.0 416.3 104.7

10 521.0 486.8 34.1
2 HPE2 5.0 1.59 17.7 957.5
9.1 7 19
471.8 412.4 59.5

11 471.8 416.3 55.6
1 IPB 5.0 1.59 17.7 686.5
9.4 6 15
436.3 416.3 **20.0**

12 436.3 411.3 25.0
1 IPE2 5.0 1.01 17.7 467.4
7.6 6 19
411.9 377.7 34.2

17 411.9 377.6 34.3
1 LTE 5.0 1.23 17.7 836.6
7.2 7 19
368.0 316.8 51.2

Totals 15.02 10210.0
50.1

HP pinch = 20.0 K IP pinch = 20.0 K
HRSG gas-side mass flux = 3.507 kg/m^2-s
Exhaust loss = 21.88 millibar:
Duct = 4.98, HRSG = 15.02 millibar
Stack leaving loss = 1.72, Friction = 0.46, Buoyancy = -

0.30 millibar
Stack velocity = 19.1 m/s
DB fuel = 0 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66
kJ/kg; MW = 25.439
Gas mole composition: N2=69.08% O2=11.02% CO2=7.343%
H2O=11.72% AR=0.832%
Flue gas dew point = 322 K M.W.= 28.56

TOTALS (per HRSG) Economisers Evaporators
Superheaters TOTAL

Q kW 2754 5570 1785
10109
UA kW/K 74 72 10
156
A sq.m 1347 1482 325
3154

Tube length = 3.785 m, HRSG width = 1.334 m, Aspect
ratio = 2.839

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HRSG WATER SIDE - Plant total flow

P T h M UA
Q A
bar K kJ/kg kg/s kW/K
kW sq.m

HP Circuit:
----
from FW Pump 55.75 412.2 588.7 2.926
HPFW 45.64 412.4 588.7 2.926
To desup 45.64 412.4 588.7 0.029
HPE1 2.897 0.00
0 0
6 45.64 412.4 588.7 0.000
HPE2 2.897 20.98
948 377
7 44.98 486.8 915.9 0.000

HPE3				2.897	17.16	515	287
8	44.31	524.6	1093.6	0.000			
HP blowdown	44.31	529.6	1118.1	0.029			
HPB1				2.869	52.44	4890	1046
9	44.31	529.6	2797.9	0.000			
HPS0				2.869	0.00	0	0
22	44.31	529.6	2797.9	0.000			
HPS1				2.869	0.00	0	0
10	44.31	529.6	2797.9	0.000			
HPS2				2.869	0.00	0	0
18	44.31	529.6	2797.9	0.000			
HPS3				2.869	9.74	1742	272
11	42.82	757.2	3405.1	0.067			
HP steam	42.82	757.2	3405.1	2.802			
Aft HP pipe	41.37	755.4	3402.8	2.802			
To HPT	41.37	755.4	3402.8	2.802			

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HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	5.83	377.7	438.6	3.244			
IPFW	4.06	377.7	438.6	3.244			
IPE1				3.244	0.00	0	0
19	4.06	377.7	438.6	0.000			
IPE2				3.244	15.92	463	286
1	3.94	411.3	581.2	0.000			
to HP pump	3.94	411.3	581.2	2.926			
IP blowdown	3.94	416.3	602.6	0.003			
IPB				0.315	19.72	680	436
2	3.94	416.3	2737.0	0.000			
IPS1				0.315	0.62	43	53
3	3.79	479.1	2873.8	0.000			
IPS2				0.315	0.00	0	0
4	3.79	479.1	2873.8	0.315			
Feedwater:							
Cond return	0.43	311.9	162.2	2.801			
After pump	1.22	312.0	162.5	2.801			
Proc stm ret	3.45	366.5	391.2	0.333			
Makeup	3.45	288.1	63.3	0.110			
FW to LTE	1.22	316.8	182.6	3.244			
LTE				3.244	19.83	828	397
13	1.18	377.6	437.9	0.000			
LTE exit	1.18	377.6	437.9	3.244			
LTE Exit:							
FW to IP/HP	1.18	377.6	437.9	3.244			

Boiler feedpumps = 27.6 kWe: HP = 24.92 kWe IP = 2.679 kWe
Condensate pump(s) = 1.087 kWe

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PROCESS STEAM FLOWS - Plant Totals

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Superheat K	Quality

```
Main HP Process:
----------------
main desup.            412.4   588.7      0.011
From source    42.82   591.1  3003.0      0.078     6.4076
63.6
Main stream    41.37   588.7  3000.7      0.078     6.4184
63.2
```

```
Main IP Process:
----------------
main desup.            412.4   588.7      0.017
From source     3.79   424.5  2754.5      0.333     6.9582
9.6
Main stream     3.45   422.0  2752.2      0.333     6.9946
10.5
```

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STEAM TURBINE FLOWS

```
                P        T        h         M       s
Super-    x    Work   Eff
               bar       K      kJ/kg      kg/s  kJ/kg-K
heat K          kW      %
```

```
From boiler    41.37   755.4  3402.8    2.802  7.0211
229.9
Aft stop vlv   40.33   754.8  3402.8    2.802  7.0323
230.8
-VS leak 1                    3402.8    0.003
-VS leak 2                    3402.8    0.000
-HP inlet leak 1              3402.8    0.037
```

```
HPT inlet      40.33   754.8  3402.8    2.762  7.0323
230.8
```

```
HP/IP/LP Casing: Group HPTL
IN              40.33   754.8  3402.8    2.762  7.0323
230.8               73.72*
OUT              3.55   510.3  2939.9    2.762  7.3862
97.8          1278 73.72**
---------------------------------------------------------------
---------------------
```

```
+VS leak 1                     3402.8    0.003
+HP inlet leak 1               3402.8    0.037
                 3.55   513.4  2946.4    2.801  7.3989
100.9
```

```
HP/IP/LP Casing: Group LPTL
IN               3.55   513.4  2946.4    2.801  7.3989
100.9               73.23*
OUT              0.069  311.9  2451.9    2.801  7.8970
0.950         76.09**
After LL         0.07   311.9  2470.5    2.801  7.9567
0.958   1333
---------------------------------------------------------------
---------------------
To condenser     0.069  311.9  2470.5    2.801  7.9567
0.958
```

```
* : Group overall efficiency (including control valve
and/or leaving losses)
**: Group blading efficiency
```

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STEAM TURBINE DESIGN

```
Casing             Group   No. of   Dry step   Blading
Overall  Exit       Work
                   name    stages   eff. %     eff. %    eff.
%   quality    kW
```

```
HP/IP/LP Casing   HPTL       9    68.35      73.72    73.72
Sup.     1278.4
```

HP/IP/LP Casing	LPTL	6	73.62	76.09	73.23	0.950	1333.1

Number of physical casings = 1
Gross power = 2611.5 kW
ST mech. loss = 9.14 kW. gear box loss= 39.17 kW.
Gen. elec. loss= 73.02 kW. Gen. mech. loss= 6.094 kW.
ST/Generator mech. x elect. efficiency = 95.12 %
Generator output = 2484.1 kWe. ST auxiliaries = 4.968 kWe
Annulus velocity = 205.7 m/s, RPM = 14356
Dry exhaust loss = 23.26 kJ/kg, corrected exhaust loss = 18.61 kJ/kg
Exhaust volume flow per path = 55.43 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 0.2694 sq.m
Last stage bucket length = 170.8 mm, pitch dia. = 502.2 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	149.87	122	37.69	244	36.25
46	145.47	137	29.46	274	51.60
53	139.85	152	24.15	305	67.90
61	120.98	168	21.27	335	83.16
76	89.45	183	20.58	366	98.39
91	66.33	198	21.89	396	115.55
107	49.60	213	25.08	427	133.99

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2470.48	2.80
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	2.80
Cooling water in		288.20		154.46
Cooling water out		298.20		154.46

Number of passes = 2 UA = 353.6 kW/K Surface area = 105.7 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.927 m Number = 353
CW vel. = 2.134 m/s DP = 0.9369 bar (0.3387 condenser + 0.5982 piping)
CW pump(s) = 19.32 kWe Condensate pump(s) = 1.087 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
HP process pipe	1.45
IP process pipe	0.34

* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 14:58:54 file=C:/Tflow13/MYFILES/20case1.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	21144		10779		33.40	
Steam Turbine(s)	0					
Plant Total	21144	20310	10779	11221	33.40	32.08

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
32.08	32.08	32.08	11960

GT fuel HHV/LHV ratio = 1.1096 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1096
Fuel HHV chemical energy input = 70245 kWth = 239696 kBTU/h
Fuel LHV chemical energy input = 63306 kWth = 216018 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 63306 kWth = 216018 kBTU/h
Energy chargeable to power = 63306 kWth = 216018 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21144	33.40	10779	78	797
Total	21144			78	

Fuel chemical HHV per gas turbine = 70245 kWth = 239696 kBTU/h
Fuel chemical LHV per gas turbine = 63306 kWth = 216018 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 42900 kWth = 146388 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
471	0	0	44	0	0	0	0

HVAC = 7.5 kW, Lights = 9.5 kW
Additional auxiliaries from PEACE running motor/load list = 186 kW
Miscellaneous plant auxiliaries = 10.57 kW
Program estimated overall plant auxiliaries = 727.7 kW
Actual (user input) overall plant auxiliaries = 727.7 kW
Transformer losses = 105.7 kW, Total aux. & transformer losses = 833.4 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 14:58:54 file=C:/Tflow13/MYFILES/20case1.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=CH4, supplied @ 803 K, LHV = 51623.58 kJ/kg
G.T. @ 100 % rating, direct TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

# 27	Model	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
	SIE GT 10	13.6	1392	797	76	21144	10779	78	75.95	14.35	2.92	6.77

Fuel compressor = 470.5 kWe, Q rejected = 96.56 kW , exit temperature = 861 K
Fuel molecular weight = 16.04; LHV @ combustor = 51863 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.33	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.33	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	649	13.63	70.24	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	861	19.29	1.26491						
Turbine inlet	1392	13.08	71.50	28.45	74.86	13.81	3.17	7.26	0.90
Turbine coolant			6.10						
Turbine exhaust	797	1.03	77.60	28.48	75.05	14.35	2.92	6.77	0.90

Compressor = 28276 Turbine = 50429 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.2 kW Gear box loss = 337.5 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.46% Generator eff. = 97.94%
GT specific power @ gen term = 277 kW per kg/s
GT efficiency @ gen term = 30.1% HHV = 33.4% LHV
GT eff. @ gen term adjusted for fuel temp. = 29.181% HHV = 32.38% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 75173 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1164	1209	0	0	72800

Energy out = 74950 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
361	227	338	445	0	44119	8316	21144	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)

Heat Balance Error = In - Out = 223.9 kW = 0.2979 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 14:59:45 file=C:/Tflow13/MYFILES/20case2a.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	21076		9084		39.63	
Steam Turbine(s)	0					
Plant Total	21076	17716	9084	10806	39.63	33.31

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
33.31	33.31	33.31	10720

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 62758 kWth = 214148 kBTU/h
Fuel LHV chemical energy input = 53179 kWth = 181462 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 53179 kWth = 181462 kBTU/h
Energy chargeable to power = 53179 kWth = 181462 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21076	39.63	9084	89	717
Total	21076			89	

Fuel chemical HHV per gas turbine = 62758 kWth = 214148 kBTU/h
Fuel chemical LHV per gas turbine = 53179 kWth = 181462 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 41213 kWth = 140631 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2964	0	0	44	0	0	0	0

HVAC = 7.5 kW, Lights = 9.5 kW
Additional auxiliaries from PEACE running motor/load list = 219.2 kW
Miscellaneous plant auxiliaries = 10.54 kW
Program estimated overall plant auxiliaries = 3254 kW
Actual (user input) overall plant auxiliaries = 3254 kW
Transformer losses = 105.4 kW, Total aux. & transformer losses = 3360 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 14:59:45 file=C:/Tflow13/MYFILES/20case2a.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

# Model 27	PR	TIT K	TET K	Mair kg/s	kW	H.R.LHV kJ/kWh	Mex kg/s	N2+Ar %	O2 %	CO2 %	H2O %
SIE GT 10	14.8	1249	718	76	21076	9084	89	72.87	13.96	5.24	7.92

Fuel compressor = 2963.9 kWe, Q rejected = 593.4 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	672	14.84	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	905	19.29	12.32256						
Turbine inlet	1249	14.25	82.57	28.71	71.62	13.47	5.63	8.43	0.86
Turbine coolant			6.10						
Turbine exhaust	718	1.03	88.67	28.72	72.01	13.96	5.24	7.92	0.87

Compressor = 30172 Turbine = 52257 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.1 kW Gear box loss = 337.4 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.46% Generator eff. = 97.93%
GT specific power @ gen term = 276 kW per kg/s
GT efficiency @ gen term = 33.58% HHV = 39.63% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.895% HHV = 34.1% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 76286 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	73920

Energy out = 76053 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
351	227	337	445	0	42601	11016	21076	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 233 kW = 0.3054 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:00:29 file=C:/Tflow13/MYFILES/20case2b.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	21076		9083		39.63	
Steam Turbine(s)	0					
Plant Total	21076	17716	9083	10806	39.63	33.32

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
33.32	33.32	33.32	10720

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 62756 kWth = 214142 kBTU/h
Fuel LHV chemical energy input = 53177 kWth = 181457 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 53177 kWth = 181457 kBTU/h
Energy chargeable to power = 53177 kWth = 181457 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21076	39.63	9083	89	717
Total	21076			89	

Fuel chemical HHV per gas turbine = 62756 kWth = 214142 kBTU/h
Fuel chemical LHV per gas turbine = 53177 kWth = 181457 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 41213 kWth = 140630 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2964	0	0	44	0	0	0	0

HVAC = 7.5 kW, Lights = 9.5 kW
Additional auxiliaries from PEACE running motor/load list = 219.2 kW
Miscellaneous plant auxiliaries = 10.54 kW
Program estimated overall plant auxiliaries = 3254 kW
Actual (user input) overall plant auxiliaries = 3254 kW
Transformer losses = 105.4 kW, Total aux. & transformer losses = 3360 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:00:29 file=C:/Tflow13/MYFILES/20case2b.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE

Maximum firing temperature excess over base load = 100 K

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10	14.8	1249	718	76	21076	9083	89	72.88	13.96	5.24	7.92

Fuel compressor = 2963.8 kWe, Q rejected = 593.3 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	672	14.84	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	905	19.29	12.32221						
Turbine inlet	1249	14.25	82.57	28.71	71.62	13.47	5.63	8.42	0.86
Turbine coolant			6.10						
Turbine exhaust	718	1.03	88.67	28.72	72.01	13.96	5.24	7.92	0.87

Compressor = 30172 Turbine = 52257 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.1 kW Gear box loss = 337.4 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.46% Generator eff. = 97.93%
GT specific power @ gen term = 276 kW per kg/s
GT efficiency @ gen term = 33.58% HHV = 39.63% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.895% HHV = 34.1% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 76284 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	73917

Energy out = 76052 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
351	227	337	445	0	42601	11016	21076	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)

Heat Balance Error = In - Out = 231.6 kW = 0.3036 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:01:11 file=C:/Tflow13/MYFILES/20case2c.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	net	LHV Heat Rate kJ/kWh @ gen.term.	net	Elect. Eff. LHV% @ gen.term.	net
Gas Turbine(s)	25450		8817		40.83	
Steam Turbine(s)	0					
Plant Total	25450	21548	8817	10414	40.83	34.57

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
34.57	34.57	34.57	10405

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 73559 kWth = 251006 kBTU/h
Fuel LHV chemical energy input = 62332 kWth = 212694 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 62332 kWth = 212694 kBTU/h
Energy chargeable to power = 62332 kWth = 212694 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	25450	40.83	8817	91	768
Total	25450			91	

Fuel chemical HHV per gas turbine = 73559 kWth = 251006 kBTU/h
Fuel chemical LHV per gas turbine = 62332 kWth = 212694 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 47752 kWth = 162945 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
3474	0	0	44	0	0	0	0

HVAC = 8.5 kW, Lights = 10 kW
Additional auxiliaries from PEACE running motor/load list = 226 kW
Miscellaneous plant auxiliaries = 12.73 kW
Program estimated overall plant auxiliaries = 3775 kW
Actual (user input) overall plant auxiliaries = 3775 kW
Transformer losses = 127.3 kW, Total aux. & transformer losses = 3902 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:01:11 file=C:/Tflow13/MYFILES/20case2c.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, RPM limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Turbine nozzle area % increase = 14

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	SIE GT 10	13.6	1307	768	76	25450	8817	91	72.11	12.99	5.99	8.91

Fuel compressor = 3474 kWe, Q rejected = 695.5 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	N2	O2	CO2	H2O	AR
					MOLE COMPOSITION %				
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	649	13.67	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	905	19.29	14.44345						
Turbine inlet	1307	13.12	84.69	28.69	70.81	12.43	6.42	9.48	0.85
Turbine coolant			6.10						
Turbine exhaust	768	1.03	90.79	28.70	71.25	12.99	5.99	8.91	0.86

Compressor = 28334 Turbine = 54804 kW
Turbine coolant = 7.987% compr in
Mech loss = 231 kW Gear box loss = 343.2 kW Generator loss = 444.9 kW
Mech eff. = 99.13% Gear box eff. = 98.69% Generator eff. = 98.28%
GT specific power @ gen term = 333.3 kW per kg/s
GT efficiency @ gen term = 34.6% HHV = 40.83% LHV
GT eff. @ gen term adjusted for fuel temp. = 29.769% HHV = 35.13% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 89008 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	86642

Energy out = 88764 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
411	231	343	445	0	49180	12704	25450	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 244 kW = 0.2741 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:06:50 file=C:/Tflow13/MYFILES/20case2d.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	25450		8817		40.83	
Steam Turbine(s)	0					
Plant Total	25450	21548	8817	10414	40.83	34.57

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
34.57	34.57	34.57	10405

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 0.0000
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 73559 kWth = 251005 kBTU/h
Fuel LHV chemical energy input = 62331 kWth = 212693 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 62331 kWth = 212693 kBTU/h
Energy chargeable to power = 62331 kWth = 212693 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	25450	40.83	8817	91	768
Total	25450			91	

Fuel chemical HHV per gas turbine = 73559 kWth = 251005 kBTU/h
Fuel chemical LHV per gas turbine = 62331 kWth = 212693 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
0.00	0	0.00	0.00	0	0

Fuel chemical HHV to duct burners = 0 kWth = 0 kBTU/h
Fuel chemical LHV to duct burners = 0 kWth = 0 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 47752 kWth = 162944 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
3474	0	0	44	0	0	0	0

HVAC = 8.5 kW, Lights = 10 kW
Additional auxiliaries from PEACE running motor/load list = 226 kW
Miscellaneous plant auxiliaries = 12.73 kW
Program estimated overall plant auxiliaries = 3775 kW
Actual (user input) overall plant auxiliaries = 3775 kW
Transformer losses = 127.3 kW, Total aux. & transformer losses = 3902 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:06:50 file=C:/Tflow13/MYFILES/20case2d.gtp

Plant Configuration: Simple Cycle Gas Turbine(s)
One SIE GT 10 Engine, GT PRO Type 0, Subtype 0

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, RPM limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 12.45 millibar
Duct = 12.45, HRSG = 0.00 millibar

G.T. DEVIATION FROM NOMINAL, CLEAN ENGINE
Maximum firing temperature excess over base load = 100 K
Turbine nozzle area % increase = 14

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O

27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
SIE GT 10		13.6	1307	768	76	25450	8817	91	72.11	12.99	5.99	8.91

Fuel compressor = 3474 kWe, Q rejected = 695.5 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	649	13.67	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	905	19.29	14.44337						
Turbine inlet	1307	13.12	84.69	28.69	70.81	12.43	6.42	9.48	0.85
Turbine coolant			6.10						
Turbine exhaust	768	1.03	90.79	28.70	71.25	12.99	5.99	8.91	0.86

Compressor = 28334 Turbine = 54804 kW
Turbine coolant = 7.987% compr in
Mech loss = 231 kW Gear box loss = 343.2 kW Generator loss = 444.9 kW
Mech eff. = 99.13% Gear box eff. = 98.69% Generator eff. = 98.28%
GT specific power @ gen term = 333.3 kW per kg/s
GT efficiency @ gen term = 34.6% HHV = 40.83% LHV
GT eff. @ gen term adjusted for fuel temp. = 29.769% HHV = 35.13% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 89008 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	86642

Energy out = 88764 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
411	231	343	445	0	49180	12704	25450	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 243.8 kW = 0.2739 %

STEAM PRO 13.0 Ting Wang ECCC
1263 11-05-2004 16:11:11 C:/Tflow13/MYFILES/20case5.stp
Steam turbine: Non-reheat condensing single casing turbine 3600
Feedwater heaters: DCFP
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW		Fuel Input kJ/s	
	Gross	Net	LHV	HHV
Plant Total	20004	19146	55966	62101

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	------ LHV ------		------ HHV ------	
	Gross	Net	Gross	Net
Heat rate [kJ/kWh]	10072	10524	11176	11677
Electric efficiency [%]	35.74	34.21	32.21	30.83
CHP Total eff. [%]		34.21		30.83
U.S. PURPA eff. [%]		34.21		30.83

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	125.1
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0
Ash handling	0.0
Condenser C.W. pump	102.8
Condensate pump	33.0
Boiler feed pump	273.3
Boiler feed booster pump	0.0
FW heater drain pump(s)	5.2
Additional auxiliaries from PEACE	219.0
Misc. plant aux.	100.0
Calculated total auxiliaries	858.4

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	53774.6
Addition steam	0.0
Addition water	0.0
Makeup water	15.1
Process return	0.0
Feedwater enthalpy increase in pumps	287.4
TOTAL ENERGY IN	54077.1
ST / generator output	20003.9
ST / generator mechanical losses	119.6
Generator losses	375.0
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	275.0
Steam pipe heat loss	52.3
FWH system pipe heat loss	13.8
Condenser heat rejected	33170.7
Sealing steam discharged	66.8
TOTAL ENERGY OUT	54077.1

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	64091.9
Inlet air sensible	469.5
Inlet air latent	370.6
TOTAL ENERGY IN	64932.0

Heat added to water, steam & blowdown	53774.6
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	3428.3
Exhaust gas latent	6653.7
Boiler minor losses	1075.5
TOTAL ENERGY OUT	64932.0

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	10389	10855
Electric efficiency [%]	34.65	33.16
CHP Total efficiency [%]		33.16
U.S. PURPA efficiency [%]		33.16

Turbine heat rate [kJ/kWh]	9658
Steam cycle heat rate [kJ/kWh]	9678
Steam cycle efficiency [%]	37.20
Boiler efficiency (LHVadj) [%]	93.15

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C
and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 57730 kJ/s
Fuel input to boiler (LHVadj) = 57730 kJ/s

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: Non-reheat condensing single casing turbine 3600
Feedwater heaters: DCFP
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x -	Eff(*) %	Power kW
HPT inlet	63.086	755.4	22.505	3376.2	6.8007	*		
LPT exh	0.048	305.4	15.667	2245.8	7.3786	0.870	86.49	20498
Mech loss						120		
Gen loss						375		
Power out						20004		

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity m/s 147.8

Dry exhaust loss kJ/kg 12.05
Corrected exh loss kJ/kg 8.30

Exhaust end dimensions:

No. of parallel paths at LPT		1
Last stage rotor exit angle	degree	65.13
Last stage blade length	mm	504.37
Last stage pitch diameter	mm	1691.11
Exhaust annulus area / end	m^2	2.68

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss
39	97.39	122	11.87	244	55.75
46	82.44	137	11.05	274	71.36
53	66.58	152	12.89	305	88.30
61	53.69	168	17.15	335	109.66
76	34.90	183	23.44	366	130.71
91	22.91	198	31.15	396	149.54
107	15.63	213	39.51	427	164.84

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	20498	86.49

Air COOLED GENERATOR 60 Hz

3600 RPM

Mech loss	kW	119.6
Gen loss	kW	375.0
Power	kW	20003.9

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			65.609	757.7	22.505	3378.5		
pipe inlet			65.609	757.7	22.505	3378.5		
pipe outlet			63.086	755.4	22.505	3376.2		
ST inlet			63.086	755.4	22.505	3376.2	6.8007	*
-Valve Stem leak 1					-0.067	3376.2		
-Valve Stem leak 2					-0.005	3376.2		
1	HPT	Inlet	60.563	754.0	22.434	3376.2	6.8185	*
		Exit	48.528	725.5	22.434	3324.8	6.8453	*
-HPT HP leak 1					-0.778	3324.8		
-HPT HP leak 2					-0.047	3324.8		
2	HPT	Inlet	48.528	725.5	21.608	3324.8	6.8453	*
		Exit	28.337	652.5	21.608	3188.7	6.8848	*
(1)		add/extr	28.337	652.5	-1.933	3188.7	6.8848	*
3	HPT	Inlet	28.337	652.5	19.675	3188.7	6.8848	*
		Exit	11.376	544.8	19.675	2986.3	6.9494	*
(2)		add/extr	11.376	544.8	-1.965	2986.3	6.9494	*
4	HPT	Inlet	11.376	544.8	17.710	2986.3	6.9494	*
		Exit	2.965	416.1	17.710	2743.4	7.0407	*
(3)		add/extr	2.965	416.1	-0.583	2743.4	7.0407	*
5	HPT	Inlet	2.965	416.1	17.128	2743.4	7.0407	*
		Exit	0.621	360.0	17.128	2520.7	7.1484	0.942
(4)		add/extr	0.621	360.0	-1.461	2520.7	7.1484	0.942
6	LPT1	Inlet	0.621	360.0	15.667	2520.7	7.1484	0.942
		Exit	0.048	305.4	15.667	2237.5	7.3514	0.867
Exhaust to condenser			0.048	305.4	15.667	2245.8	7.3786	0.870
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	FWH 2	1.6	0.067	3376.2
2	Valve Stem leak 2	SSR	2.4	0.005	3376.2
4	HPT HP leak 1	FWH 2	23.5	0.778	3324.8
5	HPT HP leak 2	SSR	23.5	0.047	3324.8

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.005	1	72.77	61.80
2	0.005	4	83.03	83.99
3	0.006	5	84.25	85.31
4	0.012	4	84.95	86.60
5	0.038	3	86.46	85.17
6	0.149	4	88.16	79.64

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 2			0.005	3376.2
HPT HP leak 2			0.047	3324.8
Steam at SSR inlet	1.241	698.2	0.052	3329.5
LPT SS to condenser			0.032	3329.5
LPT SS packing exhaust discharged			0.020	3329.5

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	15.667	2245.8
LPT SS to condenser			0.032	3329.5
Condenser in	0.048	305.4	15.699	2248.0
Condensate well	0.347	305.4	15.699	135.2
Cooling water in	2.021	288.2	792.144	63.2
Cooling water out	1.611	298.2	792.144	105.0

Condenser C.W. pump power 102.8 kW
Condenser heat rejection 33171 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	15.699	135.2
Makeup water		288.2	0.241	62.8
Condensate pump suction	0.347	305.1	15.940	134.1
Condensate pump exit	13.450	305.3	15.940	135.9
Feedwater to 1st FWHT	13.450	305.3	15.940	135.9

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FEEDWATER HEATING SYSTEM -- DCFP

THERMAL OUTPUT

	Feed Water					Bleed Steam					
Source& Heater	P bar	T K	M kg/s	h kJ/kg	|	P bar	T K	M kg/s	h kJ/kg	Tsat K	
HPT (4)					|	0.62	360.0	1.461	2520.7		
1-P in	13.45	305.3	15.940	135.9	|	0.59	358.5	1.461	2518.4	358.5	
F/B					|			1.428	551.4		
out	13.08	356.8	15.940	351.3	|	0.59	358.5	2.889	357.4		to HX2
HPT (3)					|	2.96	416.1	0.583	2743.4		
HX1 drain			2.889	359.0	|						
2-F in	13.08	357.1	18.828	352.5	|	2.80	414.3	0.583	2741.0	404.3	
LK(s)					|			0.845	3328.9		
out	12.93	402.6	18.828	545.0	|	2.80	404.3	1.428	551.4		to HX1
HPT (2)					|	11.38	544.8	1.965	2986.3		
3-C in	10.83	402.7	18.828	545.0	|	10.83	543.0	1.965	2984.0	456.5	
F/B					|			1.933	809.3		
out	10.83	456.5	22.726	778.3	|						
BFP in	12.81	456.5	22.726	778.3	|						
BFP out	75.24	458.3	22.726	789.5	|						

BoilDesp 0.450 789.5 |

HPT (1) | 28.34 652.5 1.933 3188.7

4-D in 75.24 458.3 22.276 789.5 | 26.99 650.3 1.933 3186.4 501.2
out 75.11 504.0 22.276 995.7 | 26.99 463.3 1.933 809.3 to HX3
To boil 66.15 504.0 22.276 995.7 |

Total bleed steam for FWH system = 5.941 kg/s, 17311 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 Type-P

1. Heat transfer rate Q .... kJ/s 3434
2. Overall h.t.c. in desuperheating section................. W/m^2-K 0
3. Overall h.t.c. in condensing section..................... W/m^2-K 2424
4. Overall h.t.c. in drain cooling section.................. W/m^2-K 0
5. Desuperheater heat transfer area .... m^2 0
6. Condensing section heat transfer area .... m^2 95
7. Drain cooler heat transfer area .... m^2 0
8. Total heat transfer area .... m^2 95
9. Water velocity .... m/s 1.31
10. Tube outer diameter .... mm 15.875
11. Tube wall thickness .... mm 1.245
12. Tube length per pass .... m 7.2
13. No. of passes 3
14. No. of tubes 264
15. Tube material .... S.S.

Heater No.2 Type-F

1. Heat transfer rate Q .... kJ/s 3624
2. Overall h.t.c. in desuperheating section................. W/m^2-K 0
3. Overall h.t.c. in condensing section..................... W/m^2-K 2697
4. Overall h.t.c. in drain cooling section.................. W/m^2-K 0
5. Desuperheater heat transfer area .... m^2 0
6. Condensing section heat transfer area .... m^2 99
7. Drain cooler heat transfer area .... m^2 0
8. Total heat transfer area .... m^2 99
9. Water velocity .... m/s 1.07
10. Tube outer diameter .... mm 15.875

11. Tube wall thickness .... mm 1.245
12. Tube length per pass .... m 7.5
13. No. of passes 2
14. No. of tubes 262
15. Tube material .... S.S.

Heater No.3 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 4394

Heater No.4 Type-D

1. Heat transfer rate Q .... kJ/s 4594
2. Overall h.t.c. in desuperheating section................. W/m^2-K 363
3. Overall h.t.c. in condensing section..................... W/m^2-K 2941
4. Overall h.t.c. in drain cooling section.................. W/m^2-K 762
5. Desuperheater heat transfer area .... m^2 26
6. Condensing section heat transfer area .... m^2 84
7. Drain cooler heat transfer area .... m^2 26
8. Total heat transfer area .... m^2 136
9. Water velocity .... m/s 1.07
10. Tube outer diameter .... mm 15.875
11. Tube wall thickness .... mm 1.245
12. Tube length per pass .... m 7.9
13. No. of passes 2
14. No. of tubes 344
15. Tube material .... S.S.

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV) % 93.15
2. Actual boiler efficiency (HHV) % 83.95
3. Fuel heat input (LHV) kJ/s 55967
4. Fuel heat input (HHV) kJ/s 62102
5. Excess Air % 10
6. Adiabatic flame temperature is greater than K 1366.5
7. Boiler desuperheating water source -- After boiler feed pump

Fuel Name - 'CH4' (Gaseous)

Fuel Name: CH4
Thermoflow library fuel
Fuel supply temp. 803.15 K
Heating Values
LHV 50046.7 kJ/kg
HHV 55532.5 kJ/kg
Analysis of Fuel (Volume %)

Hydrogen H2	0.00 %
Oxygen O2	0.00 %
Water Vapor H2O	0.00 %
Nitrogen N2	0.00 %
Carbon Monoxide CO	0.00 %
Carbon Dioxide CO2	0.00 %
Methane CH4	100.00 %
Ethane C2H6	0.00 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.00 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.00 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %
Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight 16.04
Mole flow 0.07 kg-mol/s
Mass flow (ash-free) 1.12 kg/s
Mass flow 1.12 kg/s
LHV (ash-free) @ 298 K 50047.00 kJ/kg
LHV (adj)* @ 803 K 51624.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K 57313.00 kJ/kg
Atomic percentage

C	20.00 %
H	80.00 %
O	0.00 %
N	0.00 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	66.15	504.0	22.276	995.7
ECO exit	65.93	529.9	22.276	1119.5
CEV exit	65.93	554.9	5.514	2778.3
REV exit	65.93	554.9	16.542	2778.3
Blow down	65.93	554.9	0.221	1247.0
CS1 inlet	65.93	554.9	22.055	2778.3
CS1 exit	65.73	649.4	22.055	3104.8
DESUP water			0.450	789.5
CS2 inlet	65.73	632.9	22.505	3058.5
CS2 exit	65.61	757.7	22.505	3378.5
HP steam	65.61	757.7	22.505	3378.5

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	N2+Ar	O2	CO2	H2O
	288.2			23.47	28.86	78.22	20.74	0.03	1.01
1 FDF		51.8	113						
	292.9			23.47	28.86	78.22	20.74	0.03	1.01
Cold end leakage				-1.494					
	292.9			21.98	28.86	78.22	20.74	0.03	1.01
3 AHA		6.3	5090						
	519.3			21.98	28.86	78.22	20.74	0.03	1.01
Hot end leakage				-0.6402					
	519.3			21.34	28.86	78.22	20.74	0.03	1.01
4 BRN		12.5	57730						
	Ad Flame			22.46	27.75	71.48	1.72	8.64	18.15
	Ad Flame								
5,6 FRN		0.0	28632						
	1921.9			22.46	27.75	71.48	1.72	8.64	18.15
	1504.4								
7 CS2		1.8	7034						
	1278.7			22.46	27.75	71.48	1.72	8.64	18.15
	1278.7								
10 CS1		0.3	7346						
	1034.3			22.46	27.75	71.48	1.72	8.64	18.15
	1034.3								
13 CEV		0.5	9336						
	704.8			22.46	27.75	71.48	1.72	8.64	18.15
	704.7								
14 ECO		0.2	2813						
	599.9			22.46	27.75	71.48	1.72	8.64	18.15

Hot end leakage 0.6402

	597.9								
16	AHG	8.4	-5090						
	405.7		23.1	27.78	71.66	2.23	8.41	17.69	
	Cold end leakage		1.494						
	399.5								
25	STK	1.9	0						
	399.5		24.59	27.84	72.05	3.32	7.92	16.72	

Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

Zone /path	Tg K /HX	Tw K	DT K	Delta P millibar	Qg kJ/s	Afrn m^2	Mg kg/s	Vg m/s	Tube rows
5	1921.9	554.9	1367.0						
	REV			0.0	28009		22.5	6.2	
	1921.9	554.9	1367.0						
7	1504.4	757.7	746.8						
0	CS2			1.8	7346	11.0	22.5	33.2	4.0
	1278.7	632.9	645.8						
10	1278.7	649.4	629.3						
0	CS1			0.3	7346	17.1	22.5	13.4	6.0
	1034.3	554.9	479.3						
13	1034.3	554.9	479.3						
0	CEV			0.5	9336	17.1	22.5	9.7	4.0
	704.8	554.9	149.8						
14	704.7	529.9	174.8						
0	ECO			0.2	2813	17.1	22.5	5.4	3.0
	599.9	504.0	95.9						
Totals				2.9	54850			17.0	

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2757.9	ECO	2757.9
Evaporators	36613.4	REV	27460.0
		CEV	9153.3
Superheaters	14403.3		

CS1	7201.6
CS2	7201.7

TOTAL	53774.6

STEAM PRO 13.0 Ting Wang ECCC
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Steam turbine: Non-reheat condensing single casing turbine 3600
Feedwater heaters: DCFP
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

POWER OUTPUT AND FUEL CONSUMPTION

	Power Output kW		Fuel Input kJ/s	
	Gross	Net	LHV	HHV
Plant Total	20004	19171	50774	59919

Number of units = 1
Plant net useful heat output = 0 kJ/s
as % of total output = 0 %

PLANT EFFICIENCY AND HEAT RATE*

	------ LHV ------		------ HHV ------	
	Gross	Net	Gross	Net
Heat rate [kJ/kWh]	9137	9534	10783	11252
Electric efficiency [%]	39.40	37.76	33.38	32.00
CHP Total eff. [%]		37.76		32.00
U.S. PURPA eff. [%]		37.76		32.00

* Heat input is based upon fuel heating value at 77 F/25 C

PLANT AUXILIARIES (kW)

Boiler forced draft fan	97.7
Boiler induced draft fan	0.0
Boiler fuel delivery	0.0
Boiler forced circulation pump	0.0

Ash handling	0.0
Condenser C.W. pump	102.8
Condensate pump	33.0
Boiler feed pump	273.0
Boiler feed booster pump	0.0
FW heater drain pump(s)	5.2
Additional auxiliaries from PEACE	221.0
Misc. plant aux.	100.0
Calculated total auxiliaries	832.7

STEAM CYCLE HEAT BALANCE (kJ/s)

Heat added in boiler	53774.8
Addition steam	0.0
Addition water	0.0
Makeup water	15.1
Process return	0.0
Feedwater enthalpy increase in pumps	287.1
TOTAL ENERGY IN	54077.0
ST / generator output	20004.0
ST / generator mechanical losses	119.6
Generator losses	375.0
Process steam	0.0
Extraction water	0.0
Steam drum blowdown	275.0
Steam pipe heat loss	52.3
FWH system pipe heat loss	13.8
Condenser heat rejected	33170.6
Sealing steam discharged	66.8
TOTAL ENERGY OUT	54077.0

Error (in - out) = 0.0000 % = 0.0

Reference: Dry gases & liquid water @ 32 F/0.0 C

BOILER HEAT BALANCE (kJ/s)

Total fuel enthalpy to boiler*	68738.3
Inlet air sensible	376.4
Inlet air latent	299.4
TOTAL ENERGY IN	69414.1
Heat added to water, steam & blowdown	53774.8
Bottom ash sensible	0.0
Fly ash sensible	0.0
Exhaust gas sensible (to boiler exit)	4897.0
Exhaust gas latent	9666.3
Boiler minor losses	1075.5
TOTAL ENERGY OUT	69413.6

Error (in - out) = 0.0008 % = 0.5

Reference: Dry gases & liquid water @ 32 F/0.0 C
* Fuel HHV corrected for fuel supply temperature

EFFICIENCY AND HEAT RATE (based on total boiler heat input*)

	Gross	Net
Heat rate [kJ/kWh]	10620	11081
Electric efficiency [%]	33.90	32.49
CHP Total efficiency [%]		32.49
U.S. PURPA efficiency [%]		32.49

Turbine heat rate [kJ/kWh]	9658
Steam cycle heat rate [kJ/kWh]	9678
Steam cycle efficiency [%]	37.20
Boiler efficiency (LHVadj) [%]	91.13

* Total heat input includes fuel sensible enthalpy above 77 F/ 25 C

and enthalpy of supply air (gas) in excess of ambient temperature
Total heat input (LHVadj) = 59012 kJ/s
Fuel input to boiler (LHVadj) = 59012 kJ/s

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Steam turbine: Non-reheat condensing single casing turbine 3600
Feedwater heaters: DCFP
Cooling system: Once-through water cooling
Steam Property Formulation: Thermoflow - STQUIK

STEAM TURBINE SUMMARY

Turbine	P	T	M	h	s	x	Eff(*)	Power
	bar	K	kg/s	kJ/kg	kJ/kg-K	-	%	kW
HPT inlet	63.086	755.4	22.506	3376.2	6.8007		*	
LPT exh	0.048	305.4	15.667	2245.8	7.3786	0.870	86.49	20498
Mech loss							120	
Gen loss							375	
Power out							20004	

(*) These figures may not properly represent the turbine efficiencies
if there is steam addition.

Annulus velocity m/s 147.8
Dry exhaust loss kJ/kg 12.05
Corrected exh loss kJ/kg 8.30

Exhaust end dimensions:

No. of parallel paths at LPT		1
Last stage rotor exit angle	degree	65.13
Last stage blade length	mm	504.37
Last stage pitch diameter	mm	1691.11
Exhaust annulus area / end	m^2	2.68

DRY EXHAUST LOSS

Annulus Vel	Exh Loss	Annulus Vel	Exh Loss	Annulus Vel	Exh Loss
39	97.39	122	11.87	244	55.75
46	82.44	137	11.05	274	71.36
53	66.58	152	12.89	305	88.30
61	53.69	168	17.15	335	109.66
76	34.90	183	23.44	366	130.71
91	22.91	198	31.15	396	149.54
107	15.63	213	39.51	427	164.84

Annulus velocity in m/s, exhaust loss in kJ/kg

STEAM TURBINE CASING WHEEL KW & EFFICIENCIES

CASING	Wheel Power (kW)	Efficiency (%)
HPT	20498	86.49

Air COOLED GENERATOR 60 Hz

3600 RPM

Mech loss	kW	119.6
Gen loss	kW	375.0
Power	kW	20004.0

STEAM TURBINE GROUP CONDITIONS

Group (Port)	Casing	Stream	P bar	T K	M kg/s	h kJ/kg	s kJ/kg-K	x
HP steam			65.609	757.7	22.506	3378.5		
pipe inlet			65.609	757.7	22.506	3378.5		
pipe outlet			63.086	755.4	22.506	3376.2		
ST inlet			63.086	755.4	22.506	3376.2	6.8007	*
-Valve Stem leak 1					-0.067	3376.2		
-Valve Stem leak 2					-0.005	3376.2		
1	HPT	Inlet	60.563	754.0	22.434	3376.2	6.8185	*
		Exit	48.528	725.5	22.434	3324.8	6.8453	*
-HPT HP leak 1					-0.778	3324.8		
-HPT HP leak 2					-0.047	3324.8		
2	HPT	Inlet	48.528	725.5	21.608	3324.8	6.8453	*
		Exit	28.337	652.5	21.608	3188.7	6.8848	*
(1)		add/extr	28.337	652.5	-1.933	3188.7	6.8848	*
3	HPT	Inlet	28.337	652.5	19.675	3188.7	6.8848	*
		Exit	11.376	544.8	19.675	2986.3	6.9494	*
(2)		add/extr	11.376	544.8	-1.965	2986.3	6.9494	*
4	HPT	Inlet	11.376	544.8	17.710	2986.3	6.9494	*
		Exit	2.965	416.1	17.710	2743.4	7.0407	*
(3)		add/extr	2.965	416.1	-0.583	2743.4	7.0407	*
5	HPT	Inlet	2.965	416.1	17.128	2743.4	7.0407	*
		Exit	0.621	360.0	17.128	2520.7	7.1484	0.942
(4)		add/extr	0.621	360.0	-1.461	2520.7	7.1484	0.942
6	LPT1	Inlet	0.621	360.0	15.667	2520.7	7.1484	0.942
		Exit	0.048	305.4	15.667	2237.5	7.3514	0.867
Exhaust to condenser			0.048	305.4	15.667	2245.8	7.3786	0.870
pipe inlet			34.356	255.4	0.000	0.0	0.0000	0.000
pipe outlet			0.000	255.4	0.000	0.0		

STEAM TURBINE LEAKAGES

No.	Leakage	Destination	C Factor m^2	M kg/s	h kJ/kg
1	Valve Stem leak 1	FWH 2	1.6	0.067	3376.2
2	Valve Stem leak 2	SSR	2.4	0.005	3376.2
4	HPT HP leak 1	FWH 2	23.5	0.778	3324.8
5	HPT HP leak 2	SSR	23.5	0.047	3324.8

TURBINE GROUP DESIGN PARAMETERS

Group	Adj Nozzle Area m^2	No. of Steps	Dry Step Eff. %	Group Eff. %
1	0.005	1	72.77	61.80
2	0.005	4	83.03	83.99
3	0.006	5	84.25	85.31
4	0.012	4	84.95	86.60
5	0.038	3	86.46	85.17
6	0.149	4	88.16	79.64

SEALING STEAM REGULATOR & GLAND SEAL CONDENSER (IF ANY)

Stream	P bar	T K	M kg/s	h kJ/kg
Valve Stem leak 2			0.005	3376.2
HPT HP leak 2			0.047	3324.8
Steam at SSR inlet	1.241	698.2	0.052	3329.5
LPT SS to condenser			0.032	3329.5
LPT SS packing exhaust discharged			0.020	3329.5

CONDENSER TYPE: Once-through water cooling

	P bar	T K	M kg/s	h kJ/kg
LPT exhaust	0.048	305.4	15.667	2245.8
LPT SS to condenser			0.032	3329.5
Condenser in	0.048	305.4	15.699	2248.0
Condensate well	0.347	305.4	15.699	135.2
Cooling water in	2.021	288.2	792.160	63.2
Cooling water out	1.611	298.2	792.160	105.0

Condenser C.W. pump power 102.8 kW
Condenser heat rejection 33171 kJ/s

CONDENSATE, MAKEUP WATER & FEEDWATER

	P bar	T K	M kg/s	h kJ/kg
Condenser condensate	0.347	305.4	15.699	135.2
Makeup water		288.2	0.241	62.8
Condensate pump suction	0.347	305.1	15.940	134.1
Condensate pump exit	13.450	305.3	15.940	135.9
Feedwater to 1st FWHT	13.450	305.3	15.940	135.9

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FEEDWATER HEATING SYSTEM -- DCFP

THERMAL OUTPUT

	Feed Water				Bleed Steam				
Source& Heater	P bar	T K	M kg/s	h kJ/kg	P bar	T K	M kg/s	h kJ/kg	Tsat K
HPT (4)					0.62	360.0	1.461	2520.7	
1-P in	13.45	305.3	15.940	135.9	0.59	358.5	1.461	2518.4	358.5
F/B							1.428	551.4	
out	13.08	356.8	15.940	351.3	0.59	358.5	2.889	357.4	to HX2
HPT (3)					2.96	416.1	0.583	2743.4	
HX1 drain			2.889	359.0					
2-F in	13.08	357.1	18.828	352.5	2.80	414.3	0.583	2741.0	404.3
LK(s)							0.845	3328.9	
out	12.93	402.6	18.828	545.0	2.80	404.3	1.428	551.4	to HX1
HPT (2)					11.38	544.8	1.965	2986.3	
3-C in	10.83	402.7	18.828	545.0	10.83	543.0	1.965	2984.0	456.5
F/B							1.933	809.3	
out	10.83	456.5	22.726	778.3					
BFP in	12.81	456.5	22.726	778.3					
BFP out	75.17	458.3	22.726	789.5					

BoilDesp 0.450 789.5 |

HPT (1) | 28.34 652.5 1.933 3188.7

4-D in 75.17 458.3 22.276 789.5 | 26.99 650.3 1.933 3186.4 501.2
out 75.04 504.0 22.276 995.7 | 26.99 463.3 1.933 809.3 to HX3
To boil 66.08 504.0 22.276 995.7 |

Total bleed steam for FWH system = 5.941 kg/s, 17311 kJ/s

DESIGN PARAMETERS OF FEEDWATER HEATERS

Heater No.1 Type-P

1. Heat transfer rate Q .... kJ/s 3434
2. Overall h.t.c. in desuperheating section................. W/m^2-K 0
3. Overall h.t.c. in condensing section..................... W/m^2-K 2424
4. Overall h.t.c. in drain cooling section.................. W/m^2-K 0
5. Desuperheater heat transfer area .... m^2 0
6. Condensing section heat transfer area .... m^2 95
7. Drain cooler heat transfer area .... m^2 0
8. Total heat transfer area .... m^2 95
9. Water velocity .... m/s 1.31
10. Tube outer diameter .... mm 15.875
11. Tube wall thickness .... mm 1.245
12. Tube length per pass .... m 7.2
13. No. of passes 3
14. No. of tubes 264
15. Tube material .... S.S.

Heater No.2 Type-F

1. Heat transfer rate Q .... kJ/s 3624
2. Overall h.t.c. in desuperheating section................. W/m^2-K 0
3. Overall h.t.c. in condensing section..................... W/m^2-K 2697
4. Overall h.t.c. in drain cooling section.................. W/m^2-K 0
5. Desuperheater heat transfer area .... m^2 0
6. Condensing section heat transfer area .... m^2 99
7. Drain cooler heat transfer area .... m^2 0
8. Total heat transfer area .... m^2 99
9. Water velocity .... m/s 1.07
10. Tube outer diameter .... mm 15.875

11. Tube wall thickness .... mm 1.245
12. Tube length per pass .... m 7.5
13. No. of passes 2
14. No. of tubes 262
15. Tube material .... S.S.

Heater No.3 (DA) Type-C

1. Heat transfer rate Q .... kJ/s 4394

Heater No.4 Type-D

1. Heat transfer rate Q	kJ/s	4594
2. Overall h.t.c. in desuperheating section.................	W/m^2-K	363
3. Overall h.t.c. in condensing section.....................	W/m^2-K	2941
4. Overall h.t.c. in drain cooling section..................	W/m^2-K	762
5. Desuperheater heat transfer area	m^2	26
6. Condensing section heat transfer area	m^2	84
7. Drain cooler heat transfer area	m^2	26
8. Total heat transfer area	m^2	136
9. Water velocity	m/s	1.07
10. Tube outer diameter	mm	15.875
11. Tube wall thickness	mm	1.245
12. Tube length per pass	m	7.9
13. No. of passes		2
14. No. of tubes		344
15. Tube material		S.S.

Note: S.S. = stainless steel, C.S. = carbon steel, U.D. = user-defined.

STEAM PRO 13.0 Ting Wang ECCC
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BOILER DESIGN OUTPUTS

1. Actual boiler efficiency (LHV)	%	91.13
2. Actual boiler efficiency (HHV)	%	77.22
3. Fuel heat input (LHV)	kJ/s	50774
4. Fuel heat input (HHV)	kJ/s	59920
5. Excess Air	%	10
6. Adiabatic flame temperature is greater than	K	1366.5
7. Boiler desuperheating water source		-- After boiler feed pump

Fuel Name - 'Syngas' (Gaseous)

Fuel Name: Syngas
User-defined fuel
Fuel supply temp. 803.15 K
Heating Values

LHV	4315.5 kJ/kg
HHV	5092.8 kJ/kg

Analysis of Fuel (Volume %)

Hydrogen H2	7.30 %
Oxygen O2	0.05 %
Water Vapor H2O	23.00 %
Nitrogen N2	37.20 %
Carbon Monoxide CO	10.60 %
Carbon Dioxide CO2	14.60 %
Methane CH4	7.00 %
Ethane C2H6	0.00 %
Propane C3H8	0.00 %
n-Butane C4H10	0.00 %
n-Pentane C5H12	0.00 %
Hexane C6H14	0.00 %
Ethylene C2H4	0.11 %
Propylene C3H6	0.00 %
Butylene C4H8	0.00 %
Pentene C5H10	0.00 %
Benzene C6H6	0.14 %
Toluene C7H8	0.00 %
Xylene C8H10	0.00 %
Acetylene C2H2	0.00 %
Naphthalene C10H8	0.00 %
Methanol CH3OH	0.00 %
Ethanol C2H5OH	0.00 %
Ammonia NH3	0.00 %
Hydrogen Sulfide H2	0.00 %
Sulfur Dioxide SO2	0.00 %
Isobutane C4H10	0.00 %
Carbonyl Sulfide CO	0.00 %
Hydrogen Cyanide CH	0.00 %
Total	100.00 %

Fuel molecular weight	25.44
Mole flow	0.46 kg-mol/s
Mass flow (ash-free)	11.77 kg/s
Mass flow	11.77 kg/s
LHV (ash-free) @ 298 K	4316.00 kJ/kg
LHV (adj)* @ 803 K	5016.00 kJ/kg
Enthalpy (ash-free) ref. to 273 K	5842.00 kJ/kg

Atomic percentage

C	12.77 %
H	34.51 %
O	24.15 %
N	28.57 %
S	0.00 %

* Adjusted heating values include fuel sensible enthalpy above 77 F/25 C and are on an ash-free basis

BOILER WATER/STEAM SUMMARY

Stream	P bar	T K	M kg/s	h kJ/kg
ECO inlet	66.08	504.0	22.276	995.7
ECO exit	65.86	529.9	22.276	1119.2
CEV exit	65.86	554.9	5.514	2778.4
REV exit	65.86	554.9	16.542	2778.4
Blow down	65.86	554.9	0.221	1246.6
CS1 inlet	65.86	554.9	22.055	2778.4
CS1 exit	65.79	649.5	22.055	3104.8
DESUP water			0.450	789.5
CS2 inlet	65.79	633.0	22.506	3058.5
CS2 exit	65.61	757.7	22.506	3378.5
HP steam	65.61	757.7	22.506	3378.5

BOILER AIR/GAS ZONE SUMMARY

Zone	Temp K	Dp millibar	Q kJ/s	Flow kg/s	Mw	Mole compositions [%] N2+Ar	O2	CO2	H2O
	288.2			18.91	28.86	78.22	20.74	0.03	1.01
1 FDF		50.2	88						
	292.8			18.91	28.86	78.22	20.74	0.03	1.01
Cold end leakage				-1.203					
	292.8			17.7	28.86	78.22	20.74	0.03	1.01
3 AHA		3.7	4102						
	519.3			17.7	28.86	78.22	20.74	0.03	1.01
Hot end leakage				-0.5156					
	519.3			17.19	28.86	78.22	20.74	0.03	1.01
4 BRN		12.5	59012						
	Ad Flame			28.95	28.47	62.73	1.10	15.14	21.03
	Ad Flame								
5,6 FRN		0.0	28640						
	1593.2			28.95	28.47	62.73	1.10	15.14	21.03
	1253.1								
7 CS2		0.6	7033						
	1075.5			28.95	28.47	62.73	1.10	15.14	21.03
	1075.5								
10 CS1		0.3	7345						
	883.2			28.95	28.47	62.73	1.10	15.14	21.03
	883.2								
13 CEV		0.4	9339						
	624.5			28.95	28.47	62.73	1.10	15.14	21.03
	624.5								
14 ECO		0.2	2805						
	543.0			28.95	28.47	62.73	1.10	15.14	21.03
Hot end leakage				0.5156					

	542.6								
16	AHG	10.7	-4102						
	421.8		29.47	28.47	62.99	1.44	14.88	20.68	
	Cold end leakage		1.203						
	417.3								
25	STK	1.8	0						
	417.3		30.67	28.49	63.58	2.19	14.31	19.92	

Miscellaneous & ducts air-side pressure drop = 12.45 millibar
Miscellaneous & ducts gas-side pressure drop = 7.472 millibar

BOILER HEAT EXCHANGER SUMMARY

Zone /path	Tg K /HX	Tw K	DT K	Delta P millibar	Qg kJ/s	Afrn m^2	Mg kg/s	Vg m/s	Tube rows
5	1593.2	554.9	1038.4						
	REV			0.0	28016		29.0	4.4	
	1593.2	554.9	1038.4						
7	1253.1	757.7	495.5						
0	CS2			0.6	7345	16.4	29.0	17.3	6.0
	1075.5	633.0	442.5						
10	1075.5	649.5	426.1						
0	CS1			0.3	7345	25.4	29.0	9.1	2.0
	883.2	554.9	328.3						
13	883.2	554.9	328.3						
0	CEV			0.4	9339	25.4	29.0	6.9	4.0
	624.5	554.9	69.7						
14	624.5	529.9	94.7						
0	ECO			0.2	2805	25.4	29.0	4.2	4.0
	543.0	504.0	39.0						

Totals	1.6	54850	16.0

BOILER HEAT TRANSFERS

Thermal Loads kJ/s		Individual Heat Exchangers	
Economiser	2750.3	ECO	2750.3
Evaporators	36622.8	REV	27467.1
		CEV	9155.7
Superheaters	14401.6		
		CS1	7200.8
		CS2	7200.8
TOTAL	53774.8		

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	20936		10889		33.06	
Steam Turbine(s)	10576					
Plant Total	31512	30387	7287	7557	49.40	47.64

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
47.64	47.64	47.64	8086

GT fuel HHV/LHV ratio = 1.1096 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1096
Fuel HHV chemical energy input = 70775 kWth = 241506 kBTU/h
Fuel LHV chemical energy input = 63784 kWth = 217649 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 63784 kWth = 217649 kBTU/h
Energy chargeable to power = 63784 kWth = 217649 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	20936	33.06	10889	78	799
Total	20936			78	

Fuel chemical HHV per gas turbine = 70263 kWth = 239758 kBTU/h
Fuel chemical LHV per gas turbine = 63322 kWth = 216073 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	Net process heat output kBTU/h
79.80	10576	30.41	24.26	0	0

Fuel chemical HHV to duct burners = 512.3 kWth = 1748.2 kBTU/h
Fuel chemical LHV to duct burners = 461.7 kWth = 1575.5 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 43588 kWth = 148736 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
471	0	0	44	123	69	0	21

HVAC = 17 kW, Lights = 27 kW
Additional auxiliaries from PEACE running motor/load list = 179.8 kW
Miscellaneous plant auxiliaries = 15.76 kW
Program estimated overall plant auxiliaries = 967.7 kW
Actual (user input) overall plant auxiliaries = 967.7 kW
Transformer losses = 157.6 kW, Total aux. & transformer losses = 1125.3 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=CH4, supplied @ 803 K, LHV = 51623.58 kJ/kg
G.T. @ 100 % rating, direct TIT control model, CC limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.49 millibar

Duct = 5.00, HRSG = 19.99 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.56 millibar
Stack velocity = 20.35 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
SIE GT 10	13.6	1392	799	76	20936	10889	78	75.96	14.35	2.92	6.77

Fuel compressor = 470.8 kWe, Q rejected = 96.61 kW , exit temperature = 861 K
Fuel molecular weight = 16.04; LHV @ combustor = 51863 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	649	13.63	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	861	19.29	1.26524						
Turbine inlet	1392	13.09	71.52	28.45	74.87	13.81	3.17	7.26	0.90
Turbine coolant			6.10						
Turbine exhaust	799	1.04	77.61	28.49	75.05	14.35	2.92	6.77	0.90

Compressor = 28281 Turbine = 50226 kW
Turbine coolant = 7.987% compr in
Mech loss = 227 kW Gear box loss = 337.3 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.45% Generator eff. = 97.92%
GT specific power @ gen term = 274.2 kW per kg/s
GT efficiency @ gen term = 29.796% HHV = 33.06% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.886% HHV = 32.05% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 75185 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	72819

Energy out = 74962 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
361	227	337	445	0	44342	8314	20936	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 223 kW = 0.2966 %

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 53289 kW

```
---------------------------------------------------------------------------
GT Exhaust/Air Addn. DB Fuel  Makeup  Process  Pump   Steam    Ext.   GT
 Sensible   Latent   Enthalpy        Return   Work   /Heat   Water  Return
---------------------------------------------------------------------------
   44342     8314      514       7       0   111      0       0      0
---------------------------------------------------------------------------
```

Energy out = 53289 kW

```
---------------------------------------------------------------------------
 Heat     Blow Mech/Elec Stack  Stack  Condnsr  Steam    To GT    Proc. Electric
Radiated  down  Losses   Sens.  Latent          /Heat           Water   Output
---------------------------------------------------------------------------
   466    132    275    9584   8366   23889      0       0      0  10576
---------------------------------------------------------------------------
```

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.3666 kW = -0.0007 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	802.1	785.1	17.0							
2	HPS3			20.5	4.29	77.6	5995.3	16.9	8	29
	734.5	547.5	187.0							
5	734.5	547.5	187.0							
2	HPB1			20.5	6.92	77.6	14400.4	16.0	11	24
	567.5	547.5	20.0							
6	567.5	533.1	34.4							
1	IPS2			20.5	0.19	77.6	129.4	11.9	1	24
	566.0	502.9	63.1							
7	566.0	542.5	23.5							
2	HPE3			20.5	1.25	77.6	1548.9	11.3	4	32
	547.6	507.5	40.1							
8	547.6	502.9	44.7							
1	IPS1			20.5	0.40	77.6	275.1	12.5	1	24
	544.4	442.5	101.9							
9	544.4	507.5	36.9							
2	HPE2			20.5	1.29	77.6	2789.2	10.9	4	32
	511.1	439.0	72.1							
11	511.1	442.5	68.6							
1	IPB			20.5	2.88	77.6	4039.0	12.1	6	24
	462.5	442.5	20.0							
12	462.5	437.5	25.0							
1	IPE2			20.5	1.63	77.6	2970.9	9.3	6	32
	426.4	374.5	51.9							
14	426.4	378.2	48.3							
0	LPB			20.5	0.37	77.6	516.5	10.0	1	24
	420.1	378.2	42.0							
17	420.1	363.2	57.0							
1	LTE			20.5	0.77	77.6	2378.3	8.1	4	32
	391.1	311.7	79.4							
Totals					19.99		35042.9		46.0	

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 42.0 K
HRSG gas-side mass flux = 3.782 kg/m²-s

Exhaust loss = 26.49 millibar:
Duct = 5.00, HRSG = 19.99 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.56 millibar
Stack velocity = 20.35 m/s
DB fuel = 0.0092 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=75.04% O_2=14.3% CO_2=2.944% H_2O=6.812%
AR=0.9037%
Flue gas dew point = 312 K M.W.= 28.48

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	9615	18815	6352	34782
UA kW/K	219	307	91	617
A sq.m	4620	7322	2553	14495

Tube length = 7.769 m, HRSG width = 2.642 m, Aspect ratio = 2.941

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	9.002			
HPFW	60.68	439.0	704.3	9.002			
HPE1				9.002	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				9.002	53.12	2768	1080
7	59.80	507.5	1011.9	0.000			
HPE3				9.002	49.87	1537	957
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.089			
HPB1				8.913	192.76	14293	4442
9	58.92	547.5	2786.0	0.000			
HPS0				8.913	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				8.913	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				8.913	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				8.913	84.57	5951	2208
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	8.913			
Aft HP pipe	55.00	783.2	3451.1	8.913			
To HPT	55.00	783.2	3451.1	8.913			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	10.956			
IPFW	8.02	374.5	425.4	10.956			
IPE1				10.956	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				10.956	80.67	2949	1700
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	9.002			
IP blowdown	7.79	442.5	716.4	0.019			
IPB				1.935	102.43	4009	2549
2	7.79	442.5	2766.3	0.000			
IPS1				1.935	3.96	273	260
3	7.64	502.9	2907.4	0.000			
IPS2				1.935	2.74	128	84
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	1.935			
Aft IP pipe	7.00	531.2	2971.3	1.935			
Feedwater:							
Cond return	0.43	311.9	162.2	10.845			
After pump	1.09	312.0	162.7	10.845			
Makeup	3.45	288.1	63.3	0.114			
FW to LTE	1.09	311.7	161.6	10.959			
LTE				10.959	35.20	2361	884
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	10.959			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.227			
FW to LP	1.05	374.3	423.8	0.229			
FW to IP/HP	1.05	374.3	423.8	10.956			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.229			
LPFW	1.21	374.3	423.9	0.229			
LP blowdown	1.21	378.2	440.2	0.002			
LPB				0.227	11.46	513	331
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.227			
Stm to D/A	1.21	378.2	2683.5	0.227			

Boiler feedpumps = 117.7 kWe: HP = 97.08 kWe IP = 20.32 kWe LP = 0.3054 kWe
Condensate pump(s) = 5.733 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	8.913	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	8.913	6.9686	241.0			
-VS leak 1			3451.1	0.030					
-VS leak 2			3451.1	0.007					
-HP inlet leak 1			3451.1	0.421					
HPT inlet	53.63	782.5	3451.1	8.454	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	8.454	6.9686	241.0			82.22*
OUT	7.00	537.5	2984.9	8.454	7.1638	99.4		3941	82.22**
IP induction	7.00	531.2	2971.3	1.935	7.1386	93.1			
+VS leak 1			3451.1	0.030					
+HP inlet leak 1			3451.1	0.421					
	7.00	545.5	3001.9	10.841	7.1948	107.4			
HP/IP/LP Casing: Group LPTL									
IN	7.00	545.5	3001.9	10.841	7.1948	107.4			82.89*
OUT	0.069	311.9	2358.5	10.841	7.5977		0.911		83.66**
After LL	0.07	311.9	2364.4	10.841	7.6167		0.914	6911	
To condenser	0.069	311.9	2364.4	10.841	7.6167		0.914		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	78.82	82.22	82.22	Sup.	3941.1
HP/IP/LP Casing	LPTL	7	82.75	83.66	82.89	0.911	6910.7

Number of physical casings = 1
Gross power = 10852 kW
ST mech. loss = 37.98 kW. No gear box
Gen. elec. loss= 212.1 kW. Gen. mech. loss= 25.32 kW.
ST/Generator mech. x elect. efficiency = 97.46 %
Generator output = 10576 kWe. ST auxiliaries = 21.15 kWe
Annulus velocity = 119.7 m/s, RPM = 3600
Dry exhaust loss = 7.919 kJ/kg, corrected exhaust loss = 5.917 kJ/kg

Exhaust volume flow per path = 205.8 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.718 sq.m
Last stage bucket length = 395.4 mm, pitch dia. = 1383.2 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	51.57	122	8.22	244	57.67
46	40.85	137	11.68	274	74.68
53	31.30	152	17.15	305	91.76
61	23.98	168	23.82	335	106.15
76	14.25	183	30.75	366	116.25
91	9.11	198	37.34	396	120.42
107	7.26	213	43.68	427	120.42

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2364.44	10.84
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	10.85
Cooling water in		288.20		570.60
Cooling water out		298.20		570.60

Number of passes = 2 UA = 1306.2 kW/K Surface area = 390.6 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 1305
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 69.27 kWe Condensate pump(s) = 5.733 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

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* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:16:34 file=C:/Tflow13/MYFILES/20case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	21066		9088		39.61	
Steam Turbine(s)	12355					
Plant Total	33421	29748	6711	7540	53.64	47.75

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
47.75	47.75	47.75	7851

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1698
Fuel HHV chemical energy input = 72882 kWth = 248696 kBTU/h
Fuel LHV chemical energy input = 62303 kWth = 212598 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 62303 kWth = 212598 kBTU/h
Energy chargeable to power = 62303 kWth = 212598 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21066	39.61	9088	89	718
Total	21066			89	

Fuel chemical HHV per gas turbine = 62758 kWth = 214148 kBTU/h
Fuel chemical LHV per gas turbine = 53179 kWth = 181462 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
79.94	12355	30.69	24.54	0	0

Fuel chemical HHV to duct burners = 10125 kWth = 34548 kBTU/h
Fuel chemical LHV to duct burners = 9124 kWth = 31135 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 50347 kWth = 171799 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2964	0	0	44	142	80	0	25

HVAC = 17 kW, Lights = 28 kW
Additional auxiliaries from PEACE running motor/load list = 189.2 kW
Miscellaneous plant auxiliaries = 16.71 kW
Program estimated overall plant auxiliaries = 3505 kW
Actual (user input) overall plant auxiliaries = 3505 kW
Transformer losses = 167.1 kW, Total aux. & transformer losses = 3672 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:16:34 file=C:/Tflow13/MYFILES/20case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 288 K, 60% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.45 millibar
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.59 millibar
Stack velocity = 20.2 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10	14.8	1249	718	76	21066	9088	89	72.87	13.96	5.24	7.92

Fuel compressor = 2963.9 kWe, Q rejected = 593.4 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Comp. inlet	288	1.00	76.35	28.86	77.29	20.74	0.03	1.01	0.93
Turbine coolant	misc.		6.10						
Comp. discharge	672	14.84	70.25	28.86	77.29	20.74	0.03	1.01	0.93
Fuel flow	905	19.29	12.32256						
Turbine inlet	1249	14.25	82.57	28.71	71.62	13.47	5.63	8.43	0.86
Turbine coolant			6.10						
Turbine exhaust	718	1.04	88.67	28.72	72.01	13.96	5.24	7.92	0.87

Compressor = 30172 Turbine = 52247 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.1 kW Gear box loss = 337.4 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.46% Generator eff. = 97.93%
GT specific power @ gen term = 275.9 kW per kg/s
GT efficiency @ gen term = 33.57% HHV = 39.61% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.882% HHV = 34.08% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 76286 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1161	1205	0	0	73920

Energy out = 76053 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
351	227	337	445	0	42611	11016	21066	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 233 kW = 0.3054 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:16:34 file=C:/Tflow13/MYFILES/20case10.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 63925 kW

GT Exhaust/Air Sensible	Addn. Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
42611	11016	10162	8	0	128	0	0	0

Energy out = 63925 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc. Output	Electric
535	152	317	10996	12040	27531	0	0	0	12355

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.3277 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	802.1	785.1	17.0							
2	HPS3			23.4	4.21	88.9	6942.6	16.8	8	31
	734.6	547.5	187.0							
5	734.6	547.5	187.0							
2	HPB1			23.4	6.99	88.9	16675.8	16.0	11	26
	567.5	547.5	20.0							
6	567.5	533.1	34.4							
1	IPS2			23.4	0.19	88.9	149.2	11.9	1	26
	566.0	502.9	63.1							
7	566.0	542.5	23.5							
2	HPE3			23.4	1.25	88.9	1793.6	11.3	4	34
	547.6	507.5	40.1							
8	547.6	502.9	44.7							
1	IPS1			23.4	0.37	88.9	317.1	12.3	1	26
	544.3	442.5	101.9							
9	544.3	507.5	36.8							
2	HPE2			23.4	1.30	88.9	3229.9	10.9	4	34
	511.0	439.0	72.0							
11	511.0	442.5	68.5							
1	IPB			23.4	2.90	88.9	4655.9	12.1	6	26
	462.5	442.5	20.0							
12	462.5	437.5	25.0							
1	IPE2			23.4	1.65	88.9	3437.6	9.3	6	34
	426.3	374.5	51.8							
14	426.3	378.2	48.2							
0	LPB			23.4	0.37	88.9	597.6	10.0	1	26
	420.0	378.2	41.9							
17	420.0	363.2	56.9							
1	LTE			23.4	0.77	88.9	2751.9	8.1	4	34
	390.9	311.7	79.1							
Totals					20.00		40551.2		46.0	

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 41.9 K
HRSG gas-side mass flux = 3.795 kg/m²-s

Exhaust loss = 26.45 millibar:
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.59 millibar
Stack velocity = 20.2 m/s
DB fuel = 0.1823 kg/s; Fuel=CH4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N2=71.74% O2=13.18% CO2=5.592% H2O=8.622%
AR=0.864%
Flue gas dew point = 316 K M.W.= 28.68

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	11130	21766	7354	40249
UA kW/K	254	355	106	714
A sq.m	5342	8438	2839	16620

Tube length = 8.342 m, HRSG width = 2.807 m, Aspect ratio = 2.972

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	10.425			
HPFW	60.68	439.0	704.3	10.425			
HPE1				10.425	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				10.425	61.56	3206	1247
7	59.80	507.5	1011.9	0.000			
HPE3				10.425	57.77	1780	1103
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.103			
HPB1				10.322	223.18	16552	5122
9	58.92	547.5	2786.0	0.000			
HPS0				10.322	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				10.322	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				10.322	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				10.322	97.91	6891	2477
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	10.322			
Aft HP pipe	55.00	783.2	3451.1	10.322			
To HPT	55.00	783.2	3451.1	10.322			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	12.677			
IPFW	8.02	374.5	425.4	12.677			
IPE1				12.677	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				12.677	93.45	3412	1965
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	10.425			
IP blowdown	7.79	442.5	716.4	0.022			
IPB				2.230	118.16	4621	2932
2	7.79	442.5	2766.3	0.000			
IPS1				2.230	4.57	315	270
3	7.64	502.9	2907.4	0.000			
IPS2				2.230	3.16	148	92
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	2.230			
Aft IP pipe	7.00	531.2	2971.3	2.230			
Feedwater:							
Cond return	0.43	311.9	162.2	12.549			
After pump	1.09	312.0	162.7	12.549			
Makeup	3.45	288.1	63.3	0.131			
FW to LTE	1.09	311.7	161.6	12.680			
LTE				12.680	40.84	2731	1028
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	12.680			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.262			
FW to LP	1.05	374.3	423.8	0.265			
FW to IP/HP	1.05	374.3	423.8	12.677			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.265			
LPFW	1.21	374.3	423.9	0.265			
LP blowdown	1.21	378.2	440.2	0.003			
LPB				0.262	13.30	593	384
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.262			
Stm to D/A	1.21	378.2	2683.5	0.262			

Boiler feedpumps = 135.9 kWe: HP = 112.2 kWe IP = 23.42 kWe LP = 0.3073 kWe
Condensate pump(s) = 6.603 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	10.322	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	10.322	6.9686	241.0			
-VS leak 1			3451.1	0.032					
-VS leak 2			3451.1	0.008					
-HP inlet leak 1			3451.1	0.453					
HPT inlet	53.63	782.5	3451.1	9.828	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	9.828	6.9686	241.0			83.48*
OUT	7.00	534.2	2977.7	9.828	7.1506	96.1		4652	83.48**
IP induction	7.00	531.2	2971.3	2.230	7.1386	93.1			
+VS leak 1			3451.1	0.032					
+HP inlet leak 1			3451.1	0.453					
	7.00	542.2	2994.9	12.544	7.1821	104.1			
HP/IP/LP Casing: Group LPTL									
IN	7.00	542.2	2994.9	12.544	7.1821	104.1			83.45*
OUT	0.069	311.9	2349.2	12.544	7.5677		0.908		84.30**
After LL	0.07	311.9	2355.6	12.544	7.5885		0.910	8019	
To condenser	0.069	311.9	2355.6	12.544	7.5885		0.910		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	80.20	83.48	83.48	Sup.	4651.9
HP/IP/LP Casing	LPTL	7	83.79	84.30	83.45	0.908	8019.4

Number of physical casings = 1
Gross power = 12671 kW
ST mech. loss = 44.35 kW. No gear box
Gen. elec. loss= 242.8 kW. Gen. mech. loss= 29.57 kW.
ST/Generator mech. x elect. efficiency = 97.5 %
Generator output = 12355 kWe. ST auxiliaries = 24.71 kWe
Annulus velocity = 125.8 m/s, RPM = 3600
Dry exhaust loss = 8.733 kJ/kg, corrected exhaust loss = 6.481 kJ/kg

Exhaust volume flow per path = 237.1 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.885 sq.m
Last stage bucket length = 415.3 mm, pitch dia. = 1445 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	59.99	122	8.31	244	57.05
46	48.10	137	10.92	274	73.15
53	37.34	152	15.76	305	91.60
61	28.98	168	22.20	335	108.14
76	17.59	183	29.36	366	121.25
91	11.19	198	36.45	396	129.39
107	8.31	213	43.14	427	131.05

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2355.65	12.54
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	12.55
Cooling water in		288.20		657.59
Cooling water out		298.20		657.59

Number of passes = 2 UA = 1505.3 kW/K Surface area = 450.1 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.923 m Number = 1504
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 79.63 kWe Condensate pump(s) = 6.603 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

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* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:17:38 file=C:/Tflow13/MYFILES/20case13.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	21285		9021		39.91	
Steam Turbine(s)	11924					
Plant Total	33209	29539	6514	7324	55.26	49.15

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
49.15	49.15	49.15	7636

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1722
Fuel HHV chemical energy input = 70443 kWth = 240373 kBTU/h
Fuel LHV chemical energy input = 60095 kWth = 205063 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 60095 kWth = 205063 kBTU/h
Energy chargeable to power = 60095 kWth = 205063 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21285	39.91	9021	86	738
Total	21285			86	

Fuel chemical HHV per gas turbine = 62944 kWth = 214785 kBTU/h
Fuel chemical LHV per gas turbine = 53337 kWth = 182002 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
81.44	11924	30.63	24.95	0	0

Fuel chemical HHV to duct burners = 7499 kWth = 25588 kBTU/h
Fuel chemical LHV to duct burners = 6758 kWth = 23060 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 47800 kWth = 163108 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2973	0	0	44	138	77	0	24

HVAC = 17 kW, Lights = 27 kW
Additional auxiliaries from PEACE running motor/load list = 188.2 kW
Miscellaneous plant auxiliaries = 16.6 kW
Program estimated overall plant auxiliaries = 3504 kW
Actual (user input) overall plant auxiliaries = 3504 kW
Transformer losses = 166 kW, Total aux. & transformer losses = 3670 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 298 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.53 millibar
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.51 millibar
Stack velocity = 20.19 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10	14.5	1280	738	73	21285	9021	86	72.73	13.73	5.44	8.11

Fuel compressor = 2972.7 kWe, Q rejected = 595.1 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	73.43	28.86	77.35	20.75	0.03	0.94	0.93
Comp. inlet	298	1.00	73.43	28.86	77.35	20.75	0.03	0.94	0.93
Turbine coolant	misc.		5.86						
Comp. discharge	689	14.55	67.57	28.86	77.35	20.75	0.03	0.94	0.93
Fuel flow	905	19.29	12.35924						
Turbine inlet	1280	13.96	79.93	28.71	71.46	13.21	5.83	8.63	0.86
Turbine coolant			5.86						
Turbine exhaust	738	1.04	85.79	28.72	71.86	13.73	5.44	8.11	0.87

Compressor = 29580 Turbine = 51875 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.3 kW Gear box loss = 337.7 kW Generator loss = 444.9 kW
Mech eff. = 98.98% Gear box eff. = 98.47% Generator eff. = 97.95%
GT specific power @ gen term = 289.9 kW per kg/s
GT efficiency @ gen term = 33.82% HHV = 39.91% LHV
GT eff. @ gen term adjusted for fuel temp. = 29.095% HHV = 34.34% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 77074 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1860	1075	0	0	74140

Energy out = 76843 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
352	227	338	445	0	43282	10915	21285	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 231.2 kW = 0.2999 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:17:38 file=C:/Tflow13/MYFILES/20case13.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 61855 kW

GT Exhaust/Air Addn. Sensible	Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
43282	10915	7526	8	0	124	0	0	0

Energy out = 61855 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
519	147	307	10632	11673	26653	0	0	0	11924

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.3231 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	802.1	785.1	17.0							
2	HPS3			22.7	4.24	85.9	6715.2	16.8	8	31
	734.6	547.5	187.0							
5	734.6	547.5	187.0							
2	HPB1			22.7	6.97	85.9	16129.6	16.0	11	25
	567.5	547.5	20.0							
6	567.5	533.1	34.4							
1	IPS2			22.7	0.19	85.9	144.3	11.9	1	25
	566.0	502.9	63.1							
7	566.0	542.5	23.5							
2	HPE3			22.7	1.25	85.9	1734.8	11.3	4	33
	547.6	507.5	40.1							
8	547.6	502.9	44.7							
1	IPS1			22.7	0.37	85.9	306.6	12.3	1	25
	544.3	442.5	101.9							
9	544.3	507.5	36.8							
2	HPE2			22.7	1.30	85.9	3124.2	10.9	4	33
	511.0	439.0	72.0							
11	511.0	442.5	68.5							
1	IPB			22.7	2.89	85.9	4502.7	12.1	6	25
	462.5	442.5	20.0							
12	462.5	437.5	25.0							
1	IPE2			22.7	1.65	85.9	3324.9	9.3	6	33
	426.3	374.5	51.8							
14	426.3	378.2	48.2							
0	LPB			22.7	0.37	85.9	578.0	10.0	1	25
	420.0	378.2	41.9							
17	420.0	363.2	56.9							
1	LTE			22.7	0.77	85.9	2661.7	8.1	4	33
	390.8	311.7	79.1							
Totals					20.00		39222.0		46.0	

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 41.9 K
HRSG gas-side mass flux = 3.792 kg/m²-s

Exhaust loss = 26.53 millibar:
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.51 millibar
Stack velocity = 20.19 m/s
DB fuel = 0.1350 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=71.66% O_2=13.13% CO_2=5.702% H_2O=8.648%
AR=0.863%
Flue gas dew point = 316 K M.W.= 28.69

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	10765	21052	7113	38930
UA kW/K	245	343	102	691
A sq.m	5172	8163	2776	16111

Tube length = 8.223 m, HRSG width = 2.756 m, Aspect ratio = 2.984

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	10.083			
HPFW	60.68	439.0	704.3	10.083			
HPE1				10.083	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				10.083	59.55	3101	1207
7	59.80	507.5	1011.9	0.000			
HPE3				10.083	55.88	1722	1068
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.100			
HPB1				9.983	215.86	16010	4955
9	58.92	547.5	2786.0	0.000			
HPS0				9.983	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				9.983	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				9.983	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				9.983	94.70	6665	2421
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	9.983			
Aft HP pipe	55.00	783.2	3451.1	9.983			
To HPT	55.00	783.2	3451.1	9.983			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	12.262			
IPFW	8.02	374.5	425.4	12.262			
IPE1				12.262	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				12.262	90.39	3300	1902
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	10.083			
IP blowdown	7.79	442.5	716.4	0.022			
IPB				2.157	114.27	4469	2836
2	7.79	442.5	2766.3	0.000			
IPS1				2.157	4.42	304	266
3	7.64	502.9	2907.4	0.000			
IPS2				2.157	3.05	143	89
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	2.157			
Aft IP pipe	7.00	531.2	2971.3	2.157			
Feedwater:							
Cond return	0.43	311.9	162.2	12.137			
After pump	1.09	312.0	162.7	12.137			
Makeup	3.45	288.1	63.3	0.127			
FW to LTE	1.09	311.7	161.6	12.264			
LTE				12.264	39.51	2642	996
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	12.264			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.254			
FW to LP	1.05	374.3	423.8	0.256			
FW to IP/HP	1.05	374.3	423.8	12.262			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.256			
LPFW	1.21	374.3	423.9	0.256			
LP blowdown	1.21	378.2	440.2	0.003			
LPB				0.254	12.86	574	372
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.254			
Stm to D/A	1.21	378.2	2683.5	0.254			

Boiler feedpumps = 131.5 kWe: HP = 108.5 kWe IP = 22.67 kWe LP = 0.3068 kWe
Condensate pump(s) = 6.394 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	9.983	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	9.983	6.9686	241.0			
-VS leak 1			3451.1	0.032					
-VS leak 2			3451.1	0.008					
-HP inlet leak 1			3451.1	0.446					
HPT inlet	53.63	782.5	3451.1	9.498	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	9.498	6.9686	241.0			83.21*
OUT	7.00	534.9	2979.3	9.498	7.1534	96.8		4481	83.21**
IP induction	7.00	531.2	2971.3	2.157	7.1386	93.1			
+VS leak 1			3451.1	0.032					
+HP inlet leak 1			3451.1	0.446					
	7.00	542.9	2996.5	12.133	7.1849	104.8			
HP/IP/LP Casing: Group LPTL									
IN	7.00	542.9	2996.5	12.133	7.1849	104.8			83.31*
OUT	0.069	311.9	2351.3	12.133	7.5747		0.908		84.14**
After LL	0.07	311.9	2357.7	12.133	7.5950		0.911	7750	
To condenser	0.069	311.9	2357.7	12.133	7.5950		0.911		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	79.90	83.21	83.21	Sup.	4481.1
HP/IP/LP Casing	LPTL	7	83.58	84.14	83.31	0.908	7750.1

Number of physical casings = 1
Gross power = 12231 kW
ST mech. loss = 42.81 kW. No gear box
Gen. elec. loss= 235.4 kW. Gen. mech. loss= 28.54 kW.
ST/Generator mech. x elect. efficiency = 97.49 %
Generator output = 11924 kWe. ST auxiliaries = 23.85 kWe
Annulus velocity = 124.4 m/s, RPM = 3600
Dry exhaust loss = 8.54 kJ/kg, corrected exhaust loss = 6.348 kJ/kg

Exhaust volume flow per path = 229.5 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.846 sq.m
Last stage bucket length = 410.7 mm, pitch dia. = 1430.7 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	57.98	122	8.26	244	57.26
46	46.36	137	11.06	274	73.56
53	35.88	152	16.07	305	91.72
61	27.76	168	22.58	335	107.80
76	16.77	183	29.71	366	120.26
91	10.67	198	36.70	396	127.54
107	8.03	213	43.28	427	128.09

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2357.68	12.13
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	12.14
Cooling water in		288.20		636.63
Cooling water out		298.20		636.63

Number of passes = 2 UA = 1457.3 kW/K Surface area = 435.8 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 1456
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 77.14 kWe Condensate pump(s) = 6.394 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

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* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	21710		9044		39.81	
Steam Turbine(s)	11742					
Plant Total	33452	29717	6356	7155	56.64	50.31

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
50.31	50.31	50.31	7467

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1747
Fuel HHV chemical energy input = 69384 kWth = 236758 kBTU/h
Fuel LHV chemical energy input = 59064 kWth = 201544 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 59064 kWth = 201544 kBTU/h
Energy chargeable to power = 59064 kWth = 201544 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21710	39.81	9044	83	759
Total	21710			83	

Fuel chemical HHV per gas turbine = 64362 kWth = 219623 kBTU/h
Fuel chemical LHV per gas turbine = 54539 kWth = 186102 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
82.59	11742	30.60	25.28	0	0

Fuel chemical HHV to duct burners = 5021 kWth = 17135 kBTU/h
Fuel chemical LHV to duct burners = 4525 kWth = 15442 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 46457 kWth = 158526 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
3040	0	0	44	136	76	0	23

HVAC = 17 kW, Lights = 27 kW
Additional auxiliaries from PEACE running motor/load list = 188.2 kW
Miscellaneous plant auxiliaries = 16.73 kW
Program estimated overall plant auxiliaries = 3568 kW
Actual (user input) overall plant auxiliaries = 3568 kW
Transformer losses = 167.3 kW, Total aux. & transformer losses = 3735 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 305 K, 90% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.64 millibar
Duct = 5.00, HRSG = 20.02 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.44 millibar
Stack velocity = 20.4 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10	14.3	1308	760	71	21710	9044	83	70.26	12.83	5.67	11.24

Fuel compressor = 3040 kWe, Q rejected = 608.5 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	305	1.01	70.54	28.50	74.75	20.05	0.03	4.27	0.90
Comp. inlet	305	1.00	70.54	28.50	74.75	20.05	0.03	4.27	0.90
Turbine coolant	misc.		5.63						
Comp. discharge	701	14.34	64.91	28.50	74.75	20.05	0.03	4.27	0.90
Fuel flow	905	19.29	12.63763						
Turbine inlet	1308	13.77	77.54	28.40	69.04	12.31	6.08	11.74	0.83
Turbine coolant			5.63						
Turbine exhaust	760	1.04	83.18	28.41	69.43	12.83	5.67	11.24	0.84

Compressor = 29360 Turbine = 52081 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.7 kW Gear box loss = 338.3 kW Generator loss = 444.9 kW
Mech eff. = 99% Gear box eff. = 98.5% Generator eff. = 97.99%
GT specific power @ gen term = 307.8 kW per kg/s
GT efficiency @ gen term = 33.73% HHV = 39.81% LHV
GT eff. @ gen term adjusted for fuel temp. = 29.022% HHV = 34.25% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 82915 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
2342	4764	0	0	75810

Energy out = 82683 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
359	228	338	445	0	44778	14825	21710	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 232.1 kW = 0.2799 %

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 64773 kW

GT Exhaust/Air Addn. Sensible	Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
44778	14825	5040	8	0	122	0	0	0

Energy out = 64773 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
513	145	303	10459	15333	26279	0	0	0	11742

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.2917 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	802.1	785.1	17.0							
2	HPS3			22.2	4.26	83.3	6619.6	16.9	8	31
	734.6	547.5	187.1							
5	734.6	547.5	187.1							
2	HPB1			22.2	6.96	83.3	15900.0	16.0	11	25
	567.5	547.5	20.0							
6	567.5	533.1	34.4							
1	IPS2			22.2	0.19	83.3	142.1	11.9	1	25
	566.0	502.9	63.1							
7	566.0	542.5	23.5							
2	HPE3			22.2	1.25	83.3	1710.2	11.3	4	33
	547.6	507.5	40.1							
8	547.6	502.9	44.7							
1	IPS1			22.2	0.38	83.3	301.9	12.4	1	25
	544.3	442.5	101.9							
9	544.3	507.5	36.8							
2	HPE2			22.2	1.30	83.3	3079.7	10.9	4	33
	511.0	439.0	72.0							
11	511.0	442.5	68.5							
1	IPB			22.2	2.89	83.3	4433.2	12.1	6	25
	462.5	442.5	20.0							
12	462.5	437.5	25.0							
1	IPE2			22.2	1.65	83.3	3276.9	9.3	6	33
	426.3	374.5	51.8							
14	426.3	378.2	48.1							
0	LPB			22.2	0.37	83.3	569.6	10.1	1	25
	420.0	378.2	41.8							
17	420.0	363.2	56.8							
1	LTE			22.2	0.77	83.3	2623.2	8.1	4	33
	390.8	311.7	79.0							
Totals					20.02		38656.4		46.0	

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 41.8 K
HRSG gas-side mass flux = 3.755 kg/m²-s

Exhaust loss = 26.64 millibar:
Duct = 5.00, HRSG = 20.02 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.44 millibar
Stack velocity = 20.4 m/s
DB fuel = 0.0904 kg/s; Fuel=CH4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N2=69.29% O2=12.43% CO2=5.849% H2O=11.6%
AR=0.8345%
Flue gas dew point = 322 K M.W.= 28.39

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	10610	20747	7011	38369
UA kW/K	242	338	101	681
A sq.m	5118	8046	2756	15920

Tube length = 8.048 m, HRSG width = 2.756 m, Aspect ratio = 2.92

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	9.940			
HPFW	60.68	439.0	704.3	9.940			
HPE1				9.940	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				9.940	58.72	3057	1193
7	59.80	507.5	1011.9	0.000			
HPE3				9.940	55.09	1697	1054
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.098			
HPB1				9.841	212.78	15782	4880
9	58.92	547.5	2786.0	0.000			
HPS0				9.841	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				9.841	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				9.841	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				9.841	93.35	6570	2399
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	9.841			
Aft HP pipe	55.00	783.2	3451.1	9.841			
To HPT	55.00	783.2	3451.1	9.841			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	12.085			
IPFW	8.02	374.5	425.4	12.085			
IPE1				12.085	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				12.085	89.11	3252	1883
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	9.940			
IP blowdown	7.79	442.5	716.4	0.021			
IPB				2.124	112.53	4400	2798
2	7.79	442.5	2766.3	0.000			
IPS1				2.124	4.35	300	268
3	7.64	502.9	2907.4	0.000			
IPS2				2.124	3.01	141	89
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	2.124			
Aft IP pipe	7.00	531.2	2971.3	2.124			
Feedwater:							
Cond return	0.43	311.9	162.2	11.962			
After pump	1.09	312.0	162.7	11.962			
Makeup	3.45	288.1	63.3	0.125			
FW to LTE	1.09	311.7	161.6	12.087			
LTE				12.087	38.96	2604	988
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	12.087			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.250			
FW to LP	1.05	374.3	423.8	0.253			
FW to IP/HP	1.05	374.3	423.8	12.085			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.253			
LPFW	1.21	374.3	423.9	0.253			
LP blowdown	1.21	378.2	440.2	0.003			
LPB				0.250	12.69	565	368
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.250			
Stm to D/A	1.21	378.2	2683.5	0.250			

Boiler feedpumps = 129.7 kWe: HP = 107 kWe IP = 22.35 kWe LP = 0.3066 kWe
Condensate pump(s) = 6.304 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	9.841	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	9.841	6.9686	241.0			
-VS leak 1			3451.1	0.032					
-VS leak 2			3451.1	0.008					
-HP inlet leak 1			3451.1	0.443					
HPT inlet	53.63	782.5	3451.1	9.359	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	9.359	6.9686	241.0			83.09*
OUT	7.00	535.2	2980.0	9.359	7.1547	97.1		4409	83.09**
IP induction	7.00	531.2	2971.3	2.124	7.1386	93.1			
+VS leak 1			3451.1	0.032					
+HP inlet leak 1			3451.1	0.443					
	7.00	543.2	2997.1	11.957	7.1861	105.1			
HP/IP/LP Casing: Group LPTL									
IN	7.00	543.2	2997.1	11.957	7.1861	105.1			83.25*
OUT	0.069	311.9	2352.3	11.957	7.5777		0.909		84.07**
After LL	0.07	311.9	2358.6	11.957	7.5979		0.911	7635	
To condenser	0.069	311.9	2358.6	11.957	7.5979		0.911		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	79.77	83.09	83.09	Sup.	4409.3
HP/IP/LP Casing	LPTL	7	83.48	84.07	83.25	0.909	7635.3

Number of physical casings = 1
Gross power = 12045 kW
ST mech. loss = 42.16 kW. No gear box
Gen. elec. loss= 232.3 kW. Gen. mech. loss= 28.1 kW.
ST/Generator mech. x elect. efficiency = 97.49 %
Generator output = 11742 kWe. ST auxiliaries = 23.48 kWe
Annulus velocity = 123.8 m/s, RPM = 3600
Dry exhaust loss = 8.457 kJ/kg, corrected exhaust loss = 6.291 kJ/kg

Exhaust volume flow per path = 226.3 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.829 sq.m
Last stage bucket length = 408.6 mm, pitch dia. = 1424.5 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	57.11	122	8.24	244	57.34
46	45.61	137	11.13	274	73.73
53	35.26	152	16.20	305	91.76
61	27.25	168	22.74	335	107.63
76	16.42	183	29.86	366	119.80
91	10.45	198	36.79	396	126.69
107	7.92	213	43.33	427	126.75

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2358.59	11.96
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	11.96
Cooling water in		288.20		627.69
Cooling water out		298.20		627.69

Number of passes = 2 UA = 1436.8 kW/K Surface area = 429.7 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.922 m Number = 1436
CW vel. = 2.134 m/s DP = 0.9366 bar (0.3384 condenser + 0.5982 piping)
CW pump(s) = 76.07 kWe Condensate pump(s) = 6.304 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

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* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	21111		9097		39.57	
Steam Turbine(s)	12392					
Plant Total	33503	29820	6716	7546	53.60	47.71

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
47.71	47.71	47.71	7856

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1698
Fuel HHV chemical energy input = 73116 kWth = 249494 kBTU/h
Fuel LHV chemical energy input = 62503 kWth = 213280 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 62503 kWth = 213280 kBTU/h
Energy chargeable to power = 62503 kWth = 213280 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21111	39.57	9097	89	718
Total	21111			89	

Fuel chemical HHV per gas turbine = 62957 kWth = 214828 kBTU/h
Fuel chemical LHV per gas turbine = 53348 kWth = 182038 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
79.86	12392	30.70	24.52	0	0

Fuel chemical HHV to duct burners = 10159 kWth = 34666 kBTU/h
Fuel chemical LHV to duct burners = 9156 kWth = 31241 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 50543 kWth = 172469 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2973	0	0	44	143	80	0	25

HVAC = 17 kW, Lights = 28 kW
Additional auxiliaries from PEACE running motor/load list = 189.2 kW
Miscellaneous plant auxiliaries = 16.75 kW
Program estimated overall plant auxiliaries = 3515 kW
Actual (user input) overall plant auxiliaries = 3515 kW
Transformer losses = 167.5 kW, Total aux. & transformer losses = 3683 kW

GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 288 K, 100% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.45 millibar
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.83, Friction = 0.22, Buoyancy = -0.59 millibar
Stack velocity = 20.24 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10	14.8	1248	718	76	21111	9097	89	72.45	13.84	5.25	8.45	

Fuel compressor = 2973.3 kWe, Q rejected = 595.2 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	288	1.01	76.29	28.79	76.81	20.61	0.03	1.62	0.93
Comp. inlet	288	1.00	76.29	28.79	76.81	20.61	0.03	1.62	0.93
Turbine coolant	misc.		6.09						
Comp. discharge	671	14.85	70.20	28.79	76.81	20.61	0.03	1.62	0.93
Fuel flow	905	19.29	12.36169						
Turbine inlet	1248	14.26	82.56	28.66	71.21	13.35	5.63	8.95	0.86
Turbine coolant			6.09						
Turbine exhaust	718	1.04	88.66	28.66	71.59	13.84	5.25	8.45	0.86

Compressor = 30197 Turbine = 52318 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.1 kW Gear box loss = 337.5 kW Generator loss = 444.9 kW
Mech eff. = 98.97% Gear box eff. = 98.46% Generator eff. = 97.94%
GT specific power @ gen term = 276.7 kW per kg/s
GT efficiency @ gen term = 33.53% HHV = 39.57% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.852% HHV = 34.05% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 77207 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
1117	1935	0	0	74154

Energy out = 76974 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
352	227	337	445	0	42724	11777	21111	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 233.3 kW = 0.3022 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 15:52:54 file=C:/Tflow13/MYFILES/20case17.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 64834 kW

GT Exhaust/Air Addn. Sensible	Latent	DB Fuel Enthalpy	Makeup	Process Return	Pump Work	Steam /Heat	Ext. Water	GT Return
42724	11777	10196	8	0	129	0	0	0

Energy out = 64835 kW

Heat Radiated	Blow down	Mech/Elec Losses	Stack Sens.	Stack Latent	Condnsr	Steam /Heat	To GT Water	Proc.	Electric Output
536	153	318	11024	12805	27607	0	0	0	12392

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.337 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

Zone /path	Tg K /HX	Tw K	DT K	Afrn sq.m	DELTA P millibar	Mg kg/s	Qg kW	Vg m/s	Tube rows	Tubes /row
0	802.1	785.1	17.0							
2	HPS3			23.4	4.21	88.8	6962.6	16.8	8	31
	734.6	547.5	187.1							
5	734.6	547.5	187.1							
2	HPB1			23.4	6.99	88.8	16723.9	16.0	11	26
	567.5	547.5	20.0							
6	567.5	533.1	34.4							
1	IPS2			23.4	0.19	88.8	149.6	11.9	1	26
	566.0	502.9	63.1							
7	566.0	542.5	23.5							
2	HPE3			23.4	1.25	88.8	1798.8	11.3	4	34
	547.6	507.5	40.1							
8	547.6	502.9	44.7							
1	IPS1			23.4	0.37	88.8	317.9	12.3	1	26
	544.3	442.5	101.9							
9	544.3	507.5	36.8							
2	HPE2			23.4	1.30	88.8	3239.3	10.9	4	34
	511.0	439.0	72.0							
11	511.0	442.5	68.5							
1	IPB			23.4	2.90	88.8	4668.5	12.1	6	26
	462.5	442.5	20.0							
12	462.5	437.5	25.0							
1	IPE2			23.4	1.65	88.8	3447.4	9.3	6	34
	426.3	374.5	51.8							
14	426.3	378.2	48.2							
0	LPB			23.4	0.37	88.8	599.3	10.0	1	26
	420.0	378.2	41.9							
17	420.0	363.2	56.9							
1	LTE			23.4	0.77	88.8	2759.7	8.1	4	34
	390.8	311.7	79.1							
Totals					20.00		40667.0		46.0	

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 41.9 K
HRSG gas-side mass flux = 3.789 kg/m²-s

Exhaust loss = 26.45 millibar:
Duct = 5.00, HRSG = 20.00 millibar
Stack leaving loss = 1.83, Friction = 0.22, Buoyancy = -0.59 millibar
Stack velocity = 20.24 m/s
DB fuel = 0.1829 kg/s; Fuel=CH_4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N_2=71.33% O_2=13.06% CO_2=5.599% H_2O=9.153%
AR=0.859%
Flue gas dew point = 318 K M.W.= 28.62

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	11161	21828	7375	40364
UA kW/K	254	356	106	716
A sq.m	5359	8461	2845	16665

Tube length = 8.354 m, HRSG width = 2.807 m, Aspect ratio = 2.976

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	10.455			
HPFW	60.68	439.0	704.3	10.455			
HPE1				10.455	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				10.455	61.74	3215	1250
7	59.80	507.5	1011.9	0.000			
HPE3				10.455	57.94	1785	1106
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.104			
HPB1				10.351	223.82	16599	5135
9	58.92	547.5	2786.0	0.000			
HPS0				10.351	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				10.351	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				10.351	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				10.351	98.19	6911	2482
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	10.351			
Aft HP pipe	55.00	783.2	3451.1	10.351			
To HPT	55.00	783.2	3451.1	10.351			

HRSG WATER SIDE (contd.)

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	12.714			
IPFW	8.02	374.5	425.4	12.714			
IPE1				12.714	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				12.714	93.72	3422	1971
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	10.455			
IP blowdown	7.79	442.5	716.4	0.022			
IPB				2.236	118.48	4634	2940
2	7.79	442.5	2766.3	0.000			
IPS1				2.236	4.58	316	271
3	7.64	502.9	2907.4	0.000			
IPS2				2.236	3.16	149	92
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	2.236			
Aft IP pipe	7.00	531.2	2971.3	2.236			
Feedwater:							
Cond return	0.43	311.9	162.2	12.585			
After pump	1.09	312.0	162.7	12.585			
Makeup	3.45	288.1	63.3	0.132			
FW to LTE	1.09	311.7	161.6	12.716			
LTE				12.716	40.97	2739	1032
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	12.716			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.263			
FW to LP	1.05	374.3	423.8	0.266			
FW to IP/HP	1.05	374.3	423.8	12.714			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.266			
LPFW	1.21	374.3	423.9	0.266			
LP blowdown	1.21	378.2	440.2	0.003			
LPB				0.263	13.34	595	385
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.263			
Stm to D/A	1.21	378.2	2683.5	0.263			

Boiler feedpumps = 136.3 kWe: HP = 112.5 kWe IP = 23.49 kWe LP = 0.3073 kWe
Condensate pump(s) = 6.622 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	10.351	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	10.351	6.9686	241.0			
-VS leak 1			3451.1	0.033					
-VS leak 2			3451.1	0.008					
-HP inlet leak 1			3451.1	0.454					
HPT inlet	53.63	782.5	3451.1	9.857	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	9.857	6.9686	241.0			83.50*
OUT	7.00	534.1	2977.6	9.857	7.1503	96.0		4667	83.50**
IP induction	7.00	531.2	2971.3	2.236	7.1386	93.1			
+VS leak 1			3451.1	0.033					
+HP inlet leak 1			3451.1	0.454					
	7.00	542.2	2994.8	12.580	7.1819	104.1			
HP/IP/LP Casing: Group LPTL									
IN	7.00	542.2	2994.8	12.580	7.1819	104.1			83.47*
OUT	0.069	311.9	2349.0	12.580	7.5671		0.907		84.31**
After LL	0.07	311.9	2355.5	12.580	7.5879		0.910	8043	
To condenser	0.069	311.9	2355.5	12.580	7.5879		0.910		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	80.23	83.50	83.50	Sup.	4666.9
HP/IP/LP Casing	LPTL	7	83.81	84.31	83.47	0.907	8042.8

Number of physical casings = 1
Gross power = 12710 kW
ST mech. loss = 44.48 kW. No gear box
Gen. elec. loss= 243.5 kW. Gen. mech. loss= 29.66 kW.
ST/Generator mech. x elect. efficiency = 97.5 %
Generator output = 12392 kWe. ST auxiliaries = 24.78 kWe
Annulus velocity = 125.9 m/s, RPM = 3600
Dry exhaust loss = 8.75 kJ/kg, corrected exhaust loss = 6.492 kJ/kg

Exhaust volume flow per path = 237.7 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.889 sq.m
Last stage bucket length = 415.7 mm, pitch dia. = 1446.2 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	60.17	122	8.32	244	57.03
46	48.25	137	10.90	274	73.12
53	37.47	152	15.73	305	91.59
61	29.08	168	22.16	335	108.17
76	17.66	183	29.33	366	121.33
91	11.23	198	36.43	396	129.55
107	8.33	213	43.13	427	131.29

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2355.47	12.58
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	12.58
Cooling water in		288.20		659.42
Cooling water out		298.20		659.42

Number of passes = 2 UA = 1509.5 kW/K Surface area = 451.4 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 1508
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 79.85 kWe Condensate pump(s) = 6.622 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

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* Non-heat balance pipes are shown in PEACE output

GT PRO 13.0 Ting Wang
1263 11-05-2004 16:00:15 file=C:/Tflow13/MYFILES/20case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	21666		9053		39.77	
Steam Turbine(s)	11827					
Plant Total	33493	29759	6396	7199	56.28	50.01

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
50.01	50.01	50.01	7510

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1096
Total plant fuel HHV heat input / LHV heat input = 1.1742
Fuel HHV chemical energy input = 69873 kWth = 238427 kBTU/h
Fuel LHV chemical energy input = 59509 kWth = 203061 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 59509 kWth = 203061 kBTU/h
Energy chargeable to power = 59509 kWth = 203061 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	21666	39.77	9053	84	755
Total	21666			84	

Fuel chemical HHV per gas turbine = 64294 kWth = 219390 kBTU/h
Fuel chemical LHV per gas turbine = 54481 kWth = 185904 kBTU/h

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
82.24	11827	30.62	25.18	0	0

Fuel chemical HHV to duct burners = 5579 kWth = 19037 kBTU/h
Fuel chemical LHV to duct burners = 5028 kWth = 17157 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 46970 kWth = 160274 kBTU/h
Net process heat output = 0% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
3036	0	0	44	137	77	0	24

HVAC = 17 kW, Lights = 27 kW
Additional auxiliaries from PEACE running motor/load list = 188.2 kW
Miscellaneous plant auxiliaries = 16.75 kW
Program estimated overall plant auxiliaries = 3566 kW
Actual (user input) overall plant auxiliaries = 3566 kW
Transformer losses = 167.5 kW, Total aux. & transformer losses = 3734 kW

GT PRO 13.0 Ting Wang
1263 11-05-2004 16:00:15 file=C:/Tflow13/MYFILES/20case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 303 K, 100% RH
Total inlet loss = 10 millibar, Exhaust loss = 26.62 millibar
Duct = 5.00, HRSG = 20.01 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.46 millibar
Stack velocity = 20.4 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%

SIE GT 10 14.4 1301 755 71 21666 9053 84 70.36 12.91 5.62 11.11

Fuel compressor = 3036 kWe, Q rejected = 607.9 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP. K	PRESS. bar	MASS FLOW kg/s	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
Ambient air in	303	1.01	71.15	28.51	74.81	20.07	0.03	4.19	0.90
Comp. inlet	303	1.00	71.15	28.51	74.81	20.07	0.03	4.19	0.90
Turbine coolant	misc.		5.68						
Comp. discharge	697	14.40	65.47	28.51	74.81	20.07	0.03	4.19	0.90
Fuel flow	905	19.29	12.62420						
Turbine inlet	1301	13.83	78.09	28.41	69.14	12.39	6.03	11.61	0.83
Turbine coolant			5.68						
Turbine exhaust	755	1.04	83.78	28.42	69.52	12.91	5.62	11.11	0.84

Compressor = 29474 Turbine = 52151 kW
Turbine coolant = 7.987% compr in
Mech loss = 227.6 kW Gear box loss = 338.2 kW Generator loss = 444.9 kW
Mech eff. = 99% Gear box eff. = 98.49% Generator eff. = 97.99%
GT specific power @ gen term = 304.5 kW per kg/s
GT efficiency @ gen term = 33.7% HHV = 39.77% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.994% HHV = 34.22% LHV

GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 82638 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy
2200	4709	0	0	75729

Energy out = 82406 kW

Misc Loss	Mech Loss	Gbox Loss	Gen Loss	Turb(Q1) Coolant	Exhaust Sensible	Exhaust Latent	Electric Output	Proc Air	Steam(Q2) Coolant
359	228	338	445	0	44611	14760	21666	0	0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 232.4 kW = 0.2812 %

GT PRO 13.0 Ting Wang
1263 11-05-2004 16:00:15 file=C:/Tflow13/MYFILES/20case20.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 1
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 65101 kW

```
-----------------------------------------------------------------------------
GT Exhaust/Air Addn. DB Fuel  Makeup  Process  Pump   Steam    Ext.   GT
 Sensible   Latent   Enthalpy        Return   Work   /Heat    Water  Return
-----------------------------------------------------------------------------
   44611    14760     5599       8       0   123      0       0      0
-----------------------------------------------------------------------------
```

Energy out = 65101 kW

```
-----------------------------------------------------------------------------
 Heat     Blow Mech/Elec Stack  Stack  Condnsr  Steam    To GT    Proc. Electric
Radiated  down  Losses   Sens.  Latent          /Heat    Water    Output
-----------------------------------------------------------------------------
   516    146    304   10531   15324   26452      0       0       0   11827
-----------------------------------------------------------------------------
```

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.2934 kW = -0.0005 %

HRSG GAS SIDE - Plant total gas flow cross-section.

```
-----------------------------------------------------------------------------
Zone  Tg K   Tw K    DT K   Afrn   DELTA P   Mg      Q        Vg    Tube   Tubes
/path  /HX                  sq.m   millibar  kg/s    kW       m/s   rows   /row
-----------------------------------------------------------------------------
 0   802.1   785.1   17.0
 2    HPS3                  22.3   4.25     83.9   6664.6    16.9    8     31
     734.6   547.5  187.1
-----------------------------------------------------------------------------
 5   734.6   547.5  187.1
 2    HPB1                  22.3   6.96     83.9  16007.9    16.0   11     25
     567.5   547.5   20.0
-----------------------------------------------------------------------------
 6   567.5   533.1   34.4
 1    IPS2                  22.3   0.19     83.9    143.1    11.9    1     25
     566.0   502.9   63.1
-----------------------------------------------------------------------------
 7   566.0   542.5   23.5
 2    HPE3                  22.3   1.25     83.9   1721.8    11.3    4     33
     547.6   507.5   40.1
-----------------------------------------------------------------------------
 8   547.6   502.9   44.7
 1    IPS1                  22.3   0.38     83.9    304.0    12.4    1     25
     544.3   442.5  101.9
-----------------------------------------------------------------------------
 9   544.3   507.5   36.8
 2    HPE2                  22.3   1.30     83.9   3100.6    10.9    4     33
     511.0   439.0   72.0
-----------------------------------------------------------------------------
11   511.0   442.5   68.5
 1    IPB                   22.3   2.89     83.9   4463.6    12.1    6     25
     462.5   442.5   20.0
-----------------------------------------------------------------------------
12   462.5   437.5   25.0
 1    IPE2                  22.3   1.65     83.9   3299.1     9.3    6     33
     426.3   374.5   51.8
-----------------------------------------------------------------------------
14   426.3   378.2   48.1
 0    LPB                   22.3   0.37     83.9    573.5    10.1    1     25
     420.0   378.2   41.8
-----------------------------------------------------------------------------
17   420.0   363.2   56.8
 1    LTE                   22.3   0.78     83.9   2641.0     8.1    4     33
     390.8   311.7   79.1
-----------------------------------------------------------------------------
Totals                             20.01          38919.1    46.0
-----------------------------------------------------------------------------
```

HP pinch = 20.0 K IP pinch = 20.0 K LP pinch = 41.8 K
HRSG gas-side mass flux = 3.756 kg/m²-s

Exhaust loss = 26.62 millibar:
Duct = 5.00, HRSG = 20.01 millibar
Stack leaving loss = 1.84, Friction = 0.22, Buoyancy = -0.46 millibar
Stack velocity = 20.4 m/s
DB fuel = 0.1005 kg/s; Fuel=CH4 @ 298 K; LHV = 50046.71 kJ/kg; MW = 16.042
Gas mole composition: N2=69.38% O2=12.46% CO2=5.823% H2O=11.51%
AR=0.8355%
Flue gas dew point = 322 K M.W.= 28.39

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	10682	20888	7059	38629
UA kW/K	244	340	101	685
A sq.m	5150	8099	2767	16016

Tube length = 8.103 m, HRSG width = 2.756 m, Aspect ratio = 2.94

HRSG WATER SIDE - Plant total flow

	P bar	T K	h kJ/kg	M kg/s	UA kW/K	Q kW	A sq.m
HP Circuit:							
from FW Pump	73.50	438.8	704.3	10.007			
HPFW	60.68	439.0	704.3	10.007			
HPE1				10.007	0.00	0	0
6	60.68	439.0	704.3	0.000			
HPE2				10.007	59.11	3078	1200
7	59.80	507.5	1011.9	0.000			
HPE3				10.007	55.46	1709	1061
8	58.92	542.5	1182.6	0.000			
HP blowdown	58.92	547.5	1208.4	0.099			
HPB1				9.908	214.22	15889	4912
9	58.92	547.5	2786.0	0.000			
HPS0				9.908	0.00	0	0
22	58.92	547.5	2786.0	0.000			
HPS1				9.908	0.00	0	0
10	58.92	547.5	2786.0	0.000			
HPS2				9.908	0.00	0	0
18	58.92	547.5	2786.0	0.000			
HPS3				9.908	93.98	6615	2410
11	56.93	785.1	3453.6	0.000			
HP steam	56.93	785.1	3453.6	9.908			
Aft HP pipe	55.00	783.2	3451.1	9.908			
To HPT	55.00	783.2	3451.1	9.908			

HRSG WATER SIDE (contd.)

	P	T	h	M	UA	Q	A
	bar	K	kJ/kg	kg/s	kW/K	kW	sq.m
IP Circuit:							
from FW Pump	12.30	374.4	425.4	12.167			
IPFW	8.02	374.5	425.4	12.167			
IPE1				12.167	0.00	0	0
19	8.02	374.5	425.4	0.000			
IPE2				12.167	89.71	3275	1895
1	7.79	437.5	694.6	0.000			
to HP pump	7.79	437.5	694.6	10.007			
IP blowdown	7.79	442.5	716.4	0.021			
IPB				2.138	113.30	4430	2816
2	7.79	442.5	2766.3	0.000			
IPS1				2.138	4.38	302	268
3	7.64	502.9	2907.4	0.000			
IPS2				2.138	3.03	142	89
4	7.49	533.1	2973.8	0.000			
IP steam	7.49	533.1	2973.8	2.138			
Aft IP pipe	7.00	531.2	2971.3	2.138			
Feedwater:							
Cond return	0.43	311.9	162.2	12.043			
After pump	1.09	312.0	162.7	12.043			
Makeup	3.45	288.1	63.3	0.126			
FW to LTE	1.09	311.7	161.6	12.169			
LTE				12.169	39.23	2621	994
13	1.05	363.2	377.0	0.000			
LTE to D/A	1.05	363.2	377.0	12.169			
Deaerator:							
LPB to D/A	1.21	378.2	2683.5	0.252			
FW to LP	1.05	374.3	423.8	0.254			
FW to IP/HP	1.05	374.3	423.8	12.167			
LP circuit:							
from FW Pump	1.44	374.3	423.9	0.254			
LPFW	1.21	374.3	423.9	0.254			
LP blowdown	1.21	378.2	440.2	0.003			
LPB				0.252	12.77	569	370
12	1.21	378.2	2683.5	0.000			
Steam made	1.21	378.2	2683.5	0.252			
Stm to D/A	1.21	378.2	2683.5	0.252			

Boiler feedpumps = 130.5 kWe: HP = 107.7 kWe IP = 22.5 kWe LP = 0.3067 kWe
Condensate pump(s) = 6.346 kWe

0

STEAM TURBINE FLOWS

	P bar	T K	h kJ/kg	M kg/s	s kJ/kg-K	Super-heat K	x	Work kW	Eff %
From boiler	55.00	783.2	3451.1	9.908	6.9575	240.1			
Aft stop vlv	53.63	782.5	3451.1	9.908	6.9686	241.0			
-VS leak 1			3451.1	0.032					
-VS leak 2			3451.1	0.008					
-HP inlet leak 1			3451.1	0.444					
HPT inlet	53.63	782.5	3451.1	9.425	6.9686	241.0			
HP/IP/LP Casing: Group HPTL									
IN	53.63	782.5	3451.1	9.425	6.9686	241.0			83.15*
OUT	7.00	535.1	2979.6	9.425	7.1541	97.0		4443	83.15**
IP induction	7.00	531.2	2971.3	2.138	7.1386	93.1			
+VS leak 1			3451.1	0.032					
+HP inlet leak 1			3451.1	0.444					
	7.00	543.1	2996.8	12.039	7.1855	105.0			
HP/IP/LP Casing: Group LPTL									
IN	7.00	543.1	2996.8	12.039	7.1855	105.0			83.28*
OUT	0.069	311.9	2351.8	12.039	7.5763		0.909		84.11**
After LL	0.07	311.9	2358.2	12.039	7.5965		0.911	7689	
To condenser	0.069	311.9	2358.2	12.039	7.5965		0.911		

* : Group overall efficiency (including control valve and/or leaving losses)
**: Group blading efficiency

1

STEAM TURBINE DESIGN

Casing	Group name	No. of stages	Dry step eff. %	Blading eff. %	Overall eff. %	Exit quality	Work kW
HP/IP/LP Casing	HPTL	10	79.83	83.15	83.15	Sup.	4443.1
HP/IP/LP Casing	LPTL	7	83.53	84.11	83.28	0.909	7688.5

Number of physical casings = 1
Gross power = 12132 kW
ST mech. loss = 42.46 kW. No gear box
Gen. elec. loss= 233.7 kW. Gen. mech. loss= 28.31 kW.
ST/Generator mech. x elect. efficiency = 97.49 %
Generator output = 11827 kWe. ST auxiliaries = 23.65 kWe
Annulus velocity = 124 m/s, RPM = 3600
Dry exhaust loss = 8.496 kJ/kg, corrected exhaust loss = 6.317 kJ/kg

Exhaust volume flow per path = 227.8 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.837 sq.m
Last stage bucket length = 409.6 mm, pitch dia. = 1427.4 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	57.51	122	8.25	244	57.30
46	45.96	137	11.10	274	73.65
53	35.55	152	16.14	305	91.74
61	27.49	168	22.67	335	107.71
76	16.58	183	29.79	366	120.01
91	10.55	198	36.75	396	127.09
107	7.97	213	43.31	427	127.38

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2358.16	12.04
Saturation	0.0689	311.90		
SSR steam		756.10	3451.07	0.00
Condensate out	0.4279	311.90	162.21	12.04
Cooling water in		288.20		631.83
Cooling water out		298.20		631.83

Number of passes = 2 UA = 1446.3 kW/K Surface area = 432.5 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.924 m Number = 1445
CW vel. = 2.134 m/s DP = 0.9367 bar (0.3385 condenser + 0.5982 piping)
CW pump(s) = 76.57 kWe Condensate pump(s) = 6.346 kWe

2

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.93

IPB to LPT induction pipe 0.49

----

* Non-heat balance pipes are shown in PEACE output

Page 1
GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW @ gen.term.	Power Output kW net	LHV Heat Rate kJ/kWh @ gen.term.	LHV Heat Rate kJ/kWh net	Elect. Eff. LHV% @ gen.term.	Elect. Eff. LHV% net
Gas Turbine(s)	18360		9540		37.74	
Steam Turbine(s)	7202					
Plant Total	25561	22395	8515	9719	42.28	37.04

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
43.16	49.28	42.65	7793

GT fuel HHV/LHV ratio = 1.1801 DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 71353 kWth = 243476 kBTU/h
Fuel LHV chemical energy input = 60462 kWth = 206314 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 60462 kWth = 206314 kBTU/h
Energy chargeable to power = 52507 kWth = 179170 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	18360	37.74	9540	97	671
Total	18360			97	

Fuel chemical HHV per gas turbine = 57417 kWth = 195926 kBTU/h
Fuel chemical LHV per gas turbine = 48654 kWth = 166021 kBTU/h

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STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
85.29	7202	16.22	13.84	7398	25244

Fuel chemical HHV to duct burners = 13935 kWth = 47551 kBTU/h
Fuel chemical LHV to duct burners = 11808 kWth = 40293 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 52053 kWth = 177621 kBTU/h
Net process heat output = 24.83% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2711	0	0	44	115	47	0	14

HVAC = 8.5 kW, Lights = 11 kW
Additional auxiliaries from PEACE running motor/load list = 204.5 kW
Miscellaneous plant auxiliaries = 12.78 kW
Program estimated overall plant auxiliaries = 3167 kW
Actual (user input) overall plant auxiliaries = 3167 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 3167 kW

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GT PRO 13.0 Ting Wang

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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 298 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.47 millibar
Duct = 4.98, HRSG = 15.01 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.57 millibar
Stack velocity = 20.16 m/s

# Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27		K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
SIE GT 10	15.8	1163	671	81	18360	9540	97	68.10	13.68	4.28	13.93

Fuel compressor = 2710.8 kWe, Q rejected = 542.7 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION %				
	K	bar	kg/s		N2	O2	CO2	H2O	AR
Ambient air in	298	1.01	80.85	28.86	77.35	20.75	0.03	0.94	0.93
Comp. inlet	298	1.00	80.85	28.86	77.35	20.75	0.03	0.94	0.93
Turbine coolant	misc.		6.46						
Comp. discharge	719	15.89	74.39	28.86	77.35	20.75	0.03	0.94	0.93
Fuel flow	905	19.29	11.27401						
Comb. steam inj	589	41.37	4.63						
Turbine inlet	1163	15.26	90.29	27.89	66.60	13.20	4.58	14.83	0.80
Turbine coolant			6.46						
Turbine exhaust	671	1.03	96.75	27.95	67.29	13.68	4.28	13.93	0.81

Steam Injection / Fuel Flow = 0.4104
Compressor = 35208 Turbine = 54794 kW
Turbine coolant = 7.987% compr in
Mech loss = 224.7 kW Gear box loss = 333.9 kW Generator loss = 667.3 kW
Mech eff. = 98.85% Gear box eff. = 98.28% Generator eff. = 96.49%
GT specific power @ gen term = 227.1 kW per kg/s
GT efficiency @ gen term = 31.98% HHV = 37.74% LHV
GT eff. @ gen term adjusted for fuel temp. = 27.512% HHV = 32.47% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 84743 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy

```
  2048         1183           0         13883        67629
```

Energy out = 84500 kW

```
  Misc  Mech  Gbox   Gen   Turb(Q1) Exhaust   Exhaust
Electric  Proc   Steam(Q2)
  Loss  Loss  Loss   Loss  Coolant  Sensible  Latent
Output    Air   Coolant

   321   225   334    667       0     42861    21733
18360       0        0
```

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 243.2 kW = 0.2869 %

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GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 82211 kW

```
GT Exhaust/Air Addn. DB Fuel  Makeup  Process  Pump
Steam    Ext.   GT
 Sensible   Latent   Enthalpy         Return   Work
/Heat    Water  Return

   42861    21733    15986      302     1226   103
0       0       0
```

Energy out = 82211 kW

```
 Heat      Blow Mech/Elec Stack  Stack  Condnsr  Steam   To
GT   Proc. Electric
Radiated  down  Losses   Sens.  Latent          /Heat
Water   Output

    729    147    197   11579   23911   15939    8624
13883       0    7202
```

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.3493 kW = -0.0004 %

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HRSG GAS SIDE - Plant total gas flow cross-section.

```
Zone  Tg K   Tw K    DT K   Afrn   DELTA P   Mg     Qg
Vg    Tube   Tubes
/path  /HX                  sq.m   millibar  kg/s    kW
m/s  rows   /row

 0   774.2   757.2    17.0
 2    HPS3                   29.0   3.23    99.5   6849.2
15.7      6     35
     716.4   529.6   186.8

 5   716.4   529.6   186.8
 2    HPB1                   29.0   5.49    99.5  19229.6
14.3     11     29
     549.6   529.6    20.0
```

```
 7   549.6   524.6    25.0
 2    HPE3                       29.0   1.05     99.5   2025.4
10.7       3      38
     531.6   486.8    44.8
```

```
 9   531.6   479.1    52.5
 1    IPS1                       29.0   0.23     99.5    410.5
10.7       1      29
     528.0   416.3   111.7
```

```
10   528.0   486.8    41.2
 2    HPE2                       29.0   0.87     99.5   3727.7
9.5       4     38
     494.7   412.4    82.3
```

```
11   494.7   416.3    78.4
 1    IPB                        29.0   2.43     99.5   6467.2
10.5       7      29
     436.3   416.3    20.0
```

```
12   436.3   411.3    25.0
 1    IPE2                       29.0   0.85     99.5   2175.9
8.2       4     38
     416.5   377.7    38.7
```

```
17   416.5   377.6    38.9
 1    LTE                        29.0   0.85     99.5   3955.1
7.5       5     38
     380.2   315.8    64.4
```

```
Totals                                  15.01            44840.6
41.0
```

HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.435 kg/m²-s
Exhaust loss = 21.47 millibar:

Duct = 4.98, HRSG = 15.01 millibar
Stack leaving loss = 1.82, Friction = 0.22, Buoyancy = -0.57 millibar
Stack velocity = 20.16 m/s
DB fuel = 2.7362 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66 kJ/kg; MW = 25.439
Gas mole composition: N2=66.55% O2=12.57% CO2=5.17% H2O=14.91% AR=0.8015%
Flue gas dew point = 327 K   M.W.= 27.95

TOTALS (per HRSG)	Economisers	Evaporators	Superheaters	TOTAL
Q kW	11766	25442	7188	44397
UA kW/K	270	409	102	781
A sq.m	5757	9874	3040	18671

Tube length = 9.232 m, HRSG width = 3.137 m, Aspect ratio = 2.943

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HRSG WATER SIDE - Plant total flow

```
                      P        T        h          M          UA
Q         A
                     bar       K      kJ/kg       kg/s       kW/K
kW      sq.m

HP Circuit:
-----------
from FW Pump   55.75   412.2   588.7    12.105
HPFW           45.64   412.4   588.7    12.105
To desup       45.64   412.4   588.7     0.824
HPE1                                    11.281      0.00
0         0
    6          45.64   412.4   588.7     0.000
HPE2                                    11.281     62.79
```

	P	T	h	M	UA
3691 1239					
7	44.98	486.8	915.9	0.000	
HPE3				11.281	59.66
2005 1326					
8	44.31	524.6	1093.6	0.000	
HP blowdown	44.31	529.6	1118.1	0.112	
HPB1				11.169	257.60
19039 6041					
9	44.31	529.6	2797.9	0.000	
HPS0				11.169	0.00
0 0					
22	44.31	529.6	2797.9	0.000	
HPS1				11.169	0.00
0 0					
10	44.31	529.6	2797.9	0.000	
HPS2				11.169	0.00
0 0					
18	44.31	529.6	2797.9	0.000	
HPS3				11.169	96.69
6781 2807					
11	42.82	757.2	3405.1	3.966	
HP steam	42.82	757.2	3405.1	7.203	
Aft HP pipe	41.37	755.4	3402.8	7.203	
To HPT	41.37	755.4	3402.8	7.203	

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HRSG WATER SIDE (contd.)

Q A	P	T	h	M	UA
kW sq.m	bar	K	kJ/kg	kg/s	kW/K

IP Circuit:
----

from FW Pump	5.83	377.7	438.6	15.105	
IPFW	4.06	377.7	438.6	15.105	
IPE1				15.105	0.00
0 0					
19	4.06	377.7	438.6	0.000	
IPE2				15.105	69.35
2154 1505					
1	3.94	411.3	581.2	0.000	
to HP pump	3.94	411.3	581.2	12.105	
IP blowdown	3.94	416.3	602.6	0.030	
IPB				2.970	151.27
6403 3833					
2	3.94	416.3	2737.0	0.000	
IPS1				2.970	5.23
406 233					
3	3.79	479.1	2873.8	0.000	
IPS2				2.970	0.00
0 0					
4	3.79	479.1	2873.8	2.970	

Feedwater:

Cond return	0.43	311.9	162.2	7.202	
After pump	1.22	312.0	162.5	7.202	
Proc stm ret	3.45	366.5	391.2	3.133	
Makeup	3.45	288.1	63.3	4.769	
FW to LTE	1.22	315.8	178.6	15.105	
LTE				15.105	78.20
3916 1687					
13	1.18	377.6	437.9	0.000	
LTE exit	1.18	377.6	437.9	15.105	

LTE Exit:

FW to IP/HP	1.18	377.6	437.9	15.105

Boiler feedpumps = 111.9 kWe: HP = 100.1 kWe IP = 11.79 kWe
Condensate pump(s) = 2.693 kWe

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PROCESS STEAM FLOWS - Plant Totals

Superheat Quality	P	T	h	M	s

```
               bar        K      kJ/kg       kg/s     kJ/kg-K
K

Main HP Process:
----------------
main desup.             412.4    588.7      0.661
From source    42.82    591.1   3003.0      4.627     6.4076
63.6
Main stream    41.37    588.7   3000.7      4.627     6.4184
63.2

Main IP Process:
----------------
main desup.             412.4    588.7      0.164
From source     3.79    424.5   2754.5      3.133     6.9582
9.6
Main stream     3.45    422.0   2752.2      3.133     6.9946
10.5
```

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STEAM TURBINE FLOWS

```
                P         T        h          M       s
Super-    x    Work    Eff
               bar        K      kJ/kg      kg/s   kJ/kg-K
heat K         kW      %

From boiler    41.37    755.4   3402.8     7.203   7.0211
229.9
Aft stop vlv   40.33    754.8   3402.8     7.203   7.0323
230.8
-VS leak 1                      3402.8     0.022
-VS leak 2                      3402.8     0.003
-HP inlet leak 1                3402.8     0.289

HPT inlet      40.33    754.8   3402.8     6.888   7.0323
230.8
```



```
HP/IP/LP Casing: Group HPTL
IN                40.33   754.8  3402.8    6.888  7.0323
230.8                 84.26*
OUT                3.55   478.5  2873.7    6.888  7.2531
65.9          3644 84.26**
----------------------------------------------------------
---------------------

+VS leak 1                       3402.8    0.022
+HP inlet leak 1                 3402.8    0.289
                   3.55   489.4  2896.6    7.200  7.3002
76.9

HP/IP/LP Casing: Group LPTL
IN                 3.55   489.4  2896.6    7.200  7.3002
76.9                 82.66*
OUT                0.069  311.9  2370.6    7.200  7.6365
0.916         83.37**
After LL           0.07   311.9  2375.1    7.200  7.6510
0.918   3754
----------------------------------------------------------
---------------------
To condenser       0.069  311.9  2375.1    7.200  7.6510
0.918

* : Group overall efficiency (including control valve
and/or leaving losses)
**: Group blading efficiency
```

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STEAM TURBINE DESIGN

```
Casing             Group   No. of  Dry step  Blading
Overall  Exit       Work
                   name    stages  eff. %    eff. %   eff.
%   quality    kW
```

HP/IP/LP Casing   HPTL   9   80.28   84.26   84.26
Sup.   3644.5
HP/IP/LP Casing   LPTL   6   83.06   83.37   82.66
0.916   3754.3

Number of physical casings = 1
Gross power = 7399 kW
ST mech. loss = 25.9 kW. No gear box
Gen. elec. loss= 153.8 kW. Gen. mech. loss= 17.26 kW.
ST/Generator mech. x elect. efficiency = 97.34 %
Generator output = 7202 kWe.   ST auxiliaries = 14.4 kWe
Annulus velocity = 104.3 m/s,   RPM = 3600
Dry exhaust loss = 6.004 kJ/kg, corrected exhaust loss = 4.527 kJ/kg
Exhaust volume flow per path = 137.4 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.318 sq.m
Last stage bucket length = 344.2 mm, pitch dia. = 1218.6 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	32.74	122	9.58	244	60.35
46	25.00	137	14.78	274	75.12
53	18.39	152	20.91	305	86.63
61	13.57	168	26.97	335	92.99
76	7.75	183	32.66	366	92.99
91	5.57	198	38.61	396	92.99
107	6.30	213	45.01	427	92.99

Annulus velocity in   m/s, exhaust loss in   kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2375.13	7.20
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	7.20
Cooling water in		288.20		380.73
Cooling water out		298.20		380.73

Number of passes = 2   UA = 871.5 kW/K   Surface area = 260.6 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 %   Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm   Length = 3.922 m   Number = 871
CW vel. = 2.134 m/s DP = 0.9366 bar (0.3384 condenser + 0.5982 piping)
CW pump(s) = 46.59 kWe   Condensate pump(s) = 2.693 kWe

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PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
HP process pipe	1.45

IP process pipe	0.34

* Non-heat balance pipes are shown in PEACE output

Page 1
GT PRO 13.0 Ting Wang
1263 11-27-2004 12:32:54
file=C:/Tflow13/MYFILES/20case24_1.gtp

Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

SYSTEM SUMMARY

	Power Output kW		LHV Heat Rate kJ/kWh		Elect. Eff. LHV%	
	@ gen.term.	net	@ gen.term.	net	@ gen.term.	net
Gas Turbine(s)	20975		9124		39.46	
Steam Turbine(s)	9442					
Plant Total	30417	27020	6771	7622	53.17	47.23

PLANT EFFICIENCIES (%)

PURPA eff.	CHP (Total) eff.	Power gen. eff. on chargeable energy	Canadian Class 43 Heat Rate, kJ/kWh
52.71	58.19	53.54	6625

GT fuel HHV/LHV ratio = 1.1801   DB fuel HHV/LHV ratio = 1.1801
Total plant fuel HHV heat input / LHV heat input = 1.1801
Fuel HHV chemical energy input = 67513 kWth = 230376 kBTU/h
Fuel LHV chemical energy input = 57209 kWth = 195213 kBTU/h
Total energy input (chemical LHV + ext. addn.) = 57209 kWth = 195213 kBTU/h
Energy chargeable to power = 50469 kWth = 172215 kBTU/h (93.0% LHV alt. boiler)

GAS TURBINE PERFORMANCE (SIE GT 10) - 1 unit(s)

	Gross power output, kW	Gross LHV eff., %	Gross LHV Heat Rate kJ/kWh	Exh. flow kg/s	Exh. temp. deg. K
per unit	20975	39.46	9124	86	735
Total	20975			86	

Fuel chemical HHV per gas turbine = 62737 kWth = 214076 kBTU/h
Fuel chemical LHV per gas turbine = 53161 kWth = 181402 kBTU/h

Page 2

STEAM CYCLE PERFORMANCE

HRSG eff,%	Gross power output, kW	Internal gross elect. eff., %	Overall elect eff, %	Net process heat output kWth	kBTU/h
82.10	9442	25.53	20.96	6268	21389

Fuel chemical HHV to duct burners = 4777 kWth = 16299 kBTU/h
Fuel chemical LHV to duct burners = 4048 kWth = 13812 kBTU/h
DB fuel chemical LHV + HRSG inlet sens. heat = 45047 kWth = 153714 kBTU/h
Net process heat output = 18.83% of total output

ESTIMATED PLANT AUXILIARIES (kW)

Gas Turbine Auxiliaries				Steam Cycle Auxiliaries			
Fuel comp.	Sup. fan	Elect. chlr	Other GT aux.	Feed pumps	C.W. pumps	C.T. fans	Other SC aux.
2962	0	0	44	94	59	0	19

HVAC = 9 kW, Lights = 12 kW
Additional auxiliaries from PEACE running motor/load list = 182.8 kW
Miscellaneous plant auxiliaries = 15.21 kW
Program estimated overall plant auxiliaries   = 3397 kW
Actual (user input) overall plant auxiliaries = 3397 kW
Transformer losses = 0 kW, Total aux. & transformer losses = 3397 kW

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GT PRO 13.0 Ting Wang

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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6

ESTIMATED G.T. SITE PERFORMANCE

Fuel=Syngas, supplied @ 803 K, LHV = 5015.66 kJ/kg
G.T. @ 100 % rating, direct TIT control model, Surge limit
Site ambient conditions: 1.013 bar, 298 K, 30% RH
Total inlet loss = 10 millibar, Exhaust loss = 21.50 millibar
Duct = 4.98, HRSG = 15.00 millibar
Stack leaving loss = 1.80, Friction = 0.22, Buoyancy = -0.51 millibar
Stack velocity = 19.99 m/s

#	Model	PR	TIT	TET	Mair	kW	H.R.LHV	Mex	N2+Ar	O2	CO2	H2O
27			K	K	kg/s		kJ/kWh	kg/s	%	%	%	%
	SIE GT 10	14.6	1275	735	74	20975	9124	86	72.52	13.73	5.39	8.37

Fuel compressor = 2961.9 kWe, Q rejected = 593 kW , exit temperature = 904.5 K
Fuel molecular weight = 25.44; LHV @ combustor = 5172 kJ/kg
G.T. auxiliary power = 43.6 kWe.

ESTIMATED G.T. CYCLE

STREAM	TEMP.	PRESS.	MASS FLOW	M.W.	MOLE COMPOSITION % N2	O2	CO2	H2O	AR
	K	bar	kg/s						
Ambient air in	298	1.01	73.72	28.86	77.35	20.75	0.03	0.94	0.93
Comp. inlet	298	1.00	73.72	28.86	77.35	20.75	0.03	0.94	0.93
Turbine coolant	misc.		5.89						
Comp. discharge	690	14.60	67.83	28.86	77.35	20.75	0.03	0.94	0.93
Fuel flow	905	19.29	12.31844						
Comb. steam inj	589	41.37	0.18						
Turbine inlet	1275	14.01	80.33	28.68	71.25	13.21	5.77	8.91	0.86
Turbine coolant			5.89						
Turbine exhaust	735	1.03	86.21	28.69	71.66	13.73	5.39	8.37	0.86

Steam Injection / Fuel Flow = 0.0145
Compressor = 29785 Turbine = 51991 kW
Turbine coolant = 7.987% compr in
Mech loss = 227 kW Gear box loss = 337.3 kW Generator loss = 667.3 kW
Mech eff. = 98.98% Gear box eff. = 98.47% Generator eff. = 96.92%
GT specific power @ gen term = 284.5 kW per kg/s
GT efficiency @ gen term = 33.43% HHV = 39.46% LHV
GT eff. @ gen term adjusted for fuel temp. = 28.766% HHV = 33.95% LHV

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GAS TURBINE/GENERATOR HEAT BALANCE

Energy in = 77375 kW

Inlet Air Sensible	Inlet Air Latent	Water Injection	Steam Injection	Fuel Enthalpy

1867 1079 0 534 73894

Energy out = 77143 kW

Misc Mech Gbox Gen Turb(Q1) Exhaust Exhaust
Electric Proc Steam(Q2)
Loss Loss Loss Loss Coolant Sensible Latent
Output Air Coolant

350 227 337 667 0 43254 11332
20975 0 0

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = 231.8 kW = 0.2995 %

Page 5
GT PRO 13.0 Ting Wang
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Plant Configuration: GT, HRSG, and condensing non-reheat ST
One SIE GT 10 Engine, One Steam Turbine, GT PRO Type 6, Subtype 6
Steam Property Formulation: Thermoflow - STQUIK

STEAM CYCLE HEAT BALANCE

Energy in = 61207 kW

GT Exhaust/Air Addn. DB Fuel Makeup Process Pump
Steam Ext. GT
Sensible Latent Enthalpy Return Work
/Heat Water Return

43254 11332 5480 19 1039 84
0 0 0

Energy out = 61207 kW

Heat Blow Mech/Elec Stack Stack Condnsr Steam To
GT Proc. Electric
Radiated down Losses Sens. Latent /Heat
Water Output

617 126 249 10416 12078 20438 7307
534 0 9442

Zero enthalpy: dry gases & liquid water @ 32 F (273.15 K)
Heat Balance Error = In - Out = -0.3646 kW = -0.0006 %

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HRSG GAS SIDE - Plant total gas flow cross-section.

Zone Tg K Tw K DT K Afrn DELTA P Mg Qg
Vg Tube Tubes
/path /HX sq.m millibar kg/s kW
m/s rows /row

0 774.2 757.2 17.0
2 HPS3 24.9 3.36 87.2 5795.8
15.7 6 32
716.4 529.6 186.8

5 716.4 529.6 186.8
2 HPB1 24.9 5.48 87.2 16272.0
14.2 11 27
549.6 529.6 **20.0**

```
 7   549.6   524.6    25.0
 2    HPE3                       24.9   1.05     87.2   1713.9
10.6       3      35
     531.7   486.8    44.8
```

```
 9   531.7   479.1    52.5
 1    IPS1                       24.9   0.25     87.2    347.8
10.7       1      27
     528.0   416.3   111.7
```

```
10   528.0   486.8    41.2
 2    HPE2                       24.9   0.87     87.2   3154.4
9.4       4     35
     494.7   412.4    82.3
```

```
11   494.7   416.3    78.4
 1    IPB                        24.9   2.43     87.2   5479.4
10.4       7      27
     436.3   416.3    20.0
```

```
12   436.3   411.3    25.0
 1    IPE2                       24.9   0.79     87.2   1764.9
8.0       4     35
     417.3   377.7    39.6
```

```
17   417.3   377.6    39.7
 1    LTE                        24.9   0.76     87.2   2824.1
7.6       4     35
     386.8   323.2    63.6
```

```
Totals                                  15.00            37352.1
40.0
```

```
HP pinch = 20.0 K   IP pinch = 20.0 K
HRSG gas-side mass flux = 3.502 kg/m²-s
Exhaust loss = 21.50 millibar:
Duct = 4.98, HRSG = 15.00 millibar
Stack leaving loss = 1.80, Friction = 0.22, Buoyancy = -
0.51 millibar
Stack velocity = 19.99  m/s
DB fuel = 0.9379 kg/s; Fuel=Syngas @ 803 K; LHV = 5015.66
kJ/kg; MW = 25.439
Gas mole composition: N2=71.31%  O2=13.28%  CO2=5.729%
H2O=8.82%  AR=0.8588%
Flue gas dew point = 317 K    M.W.= 28.68
```

```
  TOTALS (per HRSG)    Economisers   Evaporators
Superheaters     TOTAL
```

```
  Q    kW                  9364          21536            6083
36982
  UA   kW/K                 215            346              86
647
  A  sq.m                  4610           8384            2684
15677
```

```
Tube length = 8.539  m,  HRSG width = 2.915  m,  Aspect
ratio = 2.93

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```

HRSG WATER SIDE - Plant total flow

```
                   P        T        h          M         UA
Q        A
                  bar       K      kJ/kg       kg/s      kW/K
kW     sq.m
```

```
HP Circuit:
-----------
from FW Pump   55.75   412.2   588.7     9.710
HPFW           45.64   412.4   588.7     9.710
To desup       45.64   412.4   588.7     0.164
HPE1                                     9.546      0.00
0         0
    6          45.64   412.4   588.7     0.000
HPE2                                     9.546     53.11
```

```
3123       1050
    7          44.98   486.8   915.9     0.000
HPE3                                     9.546     50.48
1697       1127
    8          44.31   524.6  1093.6     0.000
HP blowdown    44.31   529.6  1118.1     0.095
HPB1                                     9.451    218.00
16111       5133
    9          44.31   529.6  2797.9     0.000
HPS0                                     9.451      0.00
0          0
   22          44.31   529.6  2797.9     0.000
HPS1                                     9.451      0.00
0          0
   10          44.31   529.6  2797.9     0.000
HPS2                                     9.451      0.00
0          0
   18          44.31   529.6  2797.9     0.000
HPS3                                     9.451     81.82
5738       2469
   11          42.82   757.2  3405.1     0.153
HP steam       42.82   757.2  3405.1     9.299
Aft HP pipe    41.37   755.4  3402.8     9.299
To HPT         41.37   755.4  3402.8     9.299
```

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HRSG WATER SIDE (contd.)

```
                 P       T       h          M         UA
Q        A
                bar      K      kJ/kg      kg/s      kW/K
kW      sq.m

IP Circuit:
-----------
from FW Pump    5.83   377.7   438.6    12.251
IPFW            4.06   377.7   438.6    12.251
IPE1                                    12.251      0.00
0          0
   19           4.06   377.7   438.6     0.000
IPE2                                    12.251     55.61
1747       1181
    1           3.94   411.3   581.2     0.000
to HP pump      3.94   411.3   581.2     9.710
IP blowdown     3.94   416.3   602.6     0.025
IPB                                      2.516    128.14
5425       3251
    2           3.94   416.3  2737.0     0.000
IPS1                                     2.516      4.43
344        215
    3           3.79   479.1  2873.8     0.000
IPS2                                     2.516      0.00
0          0
    4           3.79   479.1  2873.8     2.516
```

```
Feedwater:
----------
Cond return     0.43   311.9   162.2     9.297
After pump      1.22   312.0   162.5     9.297
Proc stm ret    3.45   366.5   391.2     2.655
Makeup          3.45   288.1    63.3     0.299
FW   to LTE     1.22   323.2   209.7    12.251
LTE                                     12.251     55.70
2796       1252
   13           1.18   377.6   437.9     0.000
LTE exit        1.18   377.6   437.9    12.251
```

```
LTE Exit:
---------
FW to IP/HP     1.18   377.6   437.9    12.251
```

Boiler feedpumps = 90.25 kWe: HP = 80.62 kWe IP = 9.625 kWe
Condensate pump(s) = 3.444 kWe

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PROCESS STEAM FLOWS - Plant Totals

```
                P       T       h          M        s
Superheat  Quality
```

```
                  bar        K      kJ/kg       kg/s     kJ/kg-K
K
________________________________________________________________________
___________________________

Main HP Process:
----------------
main desup.                412.4   588.7      0.025
From source     42.82      591.1  3003.0      0.178      6.4076
63.6
Main stream     41.37      588.7  3000.7      0.178      6.4184
63.2
________________________________________________________________________
___________________________

Main IP Process:
----------------
main desup.                412.4   588.7      0.139
From source      3.79      424.5  2754.5      2.655      6.9582
9.6
Main stream      3.45      422.0  2752.2      2.655      6.9946
10.5
________________________________________________________________________
___________________________
```

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STEAM TURBINE FLOWS

```
________________________________________________________________________
___________________________

                   P         T        h          M        s
Super-    x     Work    Eff
                  bar        K      kJ/kg      kg/s   kJ/kg-K
heat K            kW      %
________________________________________________________________________
___________________________

From boiler     41.37      755.4  3402.8     9.299   7.0211
229.9
Aft stop vlv    40.33      754.8  3402.8     9.299   7.0323
230.8
-VS leak 1                        3402.8     0.025
-VS leak 2                        3402.8     0.004
-HP inlet leak 1                  3402.8     0.329
________________________________________________________________________
___________________________

HPT inlet       40.33      754.8  3402.8     8.941   7.0323
230.8
```

```
________________________________________________________________________
___________________________

HP/IP/LP Casing: Group HPTL
IN                40.33   754.8  3402.8    8.941  7.0323
230.8                86.10*
OUT                3.55   473.0  2862.2    8.941  7.2291
60.5          4833 86.10**
--------------------------------------------------------------
---------------------
________________________________________________________________________
___________________________

+VS leak 1                       3402.8    0.025
+HP inlet leak 1                 3402.8    0.329
                   3.55   482.8  2882.8    9.295  7.2719
70.3
________________________________________________________________________
___________________________

HP/IP/LP Casing: Group LPTL
IN                 3.55   482.8  2882.8    9.295  7.2719
70.3               83.50*
OUT                0.069  311.9  2354.9    9.295  7.5861
0.910         84.34**
After LL           0.07   311.9  2360.2    9.295  7.6031
0.912   4857
--------------------------------------------------------------
---------------------
To condenser       0.069  311.9  2360.2    9.295  7.6031
0.912
________________________________________________________________________
___________________________

* : Group overall efficiency (including control valve
and/or leaving losses)
**: Group blading efficiency
```

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STEAM TURBINE DESIGN

```
________________________________________________________________________
___________________________

Casing              Group   No. of  Dry step  Blading
Overall  Exit        Work
                    name    stages  eff. %    eff. %   eff.
%   quality    kW
________________________________________________________________________
___________________________
```

HP/IP/LP Casing HPTL 9 82.44 86.10 86.10
Sup. 4833.4
HP/IP/LP Casing LPTL 6 84.59 84.34 83.50
0.910 4857.3

Number of physical casings = 1
Gross power = 9691 kW
ST mech. loss = 33.92 kW. No gear box
Gen. elec. loss= 192.5 kW. Gen. mech. loss= 22.61 kW.
ST/Generator mech. x elect. efficiency = 97.43 %
Generator output = 9442 kWe. ST auxiliaries = 18.88 kWe
Annulus velocity = 113.5 m/s, RPM = 3600
Dry exhaust loss = 7.115 kJ/kg, corrected exhaust loss = 5.302 kJ/kg
Exhaust volume flow per path = 176.1 m^3/s
No. of LPT paths = 1, exhaust annulus area per path = 1.552 sq.m
Last stage bucket length = 374.8 mm, pitch dia. = 1317.9 mm

DRY EXHAUST LOSS

Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss	Annulus Vel.	Exh. Loss
39	43.46	122	8.50	244	58.47
46	33.97	137	12.77	274	75.57
53	25.63	152	18.71	305	90.80
61	19.35	168	25.34	335	102.44
76	11.27	183	31.81	366	108.76
91	7.37	198	37.91	396	108.06
107	6.57	213	44.24	427	108.06

Annulus velocity in m/s, exhaust loss in kJ/kg

CONDENSER

	P bar	T K	h kJ/kg	M kg/s
LPT exit	0.0689	311.90	2360.19	9.29
Saturation	0.0689	311.90		
SSR steam		733.20	3402.76	0.00
Condensate out	0.4279	311.90	162.21	9.30
Cooling water in		288.20		488.17
Cooling water out		298.20		488.17

Number of passes = 2 UA = 1117.5 kW/K Surface area = 334.2 sq.m
Pr = 6.888 Re = 49001 Nu = 281.3
Cleanliness = 90.0 % Fouling factor = 0.0282 * 10^-3 [W/sq.m-K]^-1
h.t.c. [W/sq.m-K]: Overall = 3344 Internal = 7433 External = 12748
Tubes: OD = 24.28 mm Length = 3.922 m Number = 1117
CW vel. = 2.134 m/s DP = 0.9366 bar (0.3384 condenser + 0.5982 piping)
CW pump(s) = 59.44 kWe Condensate pump(s) = 3.444 kWe

Page 12

PIPES

Pipe name	Pressure loss [bar]
HPB to HPT pipe	1.45
HP process pipe	1.45

IP process pipe	0.34

* Non-heat balance pipes are shown in PEACE output

Vita

Roy Yap is originally from Malaysia and has obtained his Bachelors of Science in Mechanical Engineering from the University of New Orleans, Louisiana, U.S.A. in 2001.