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Environmental Performance of Steel Grit and Specialty Sand as Abrasives

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ENVIRONMENTAL PERFORMANCE OF STEEL GRIT AND SPECIALTY SAND AS ABRASIVES

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

by

Xavier Silvadasan

B. E. (Civil Engineering), Nagpur University, India, 1999
M. S. (Engineering Management), University of New Orleans, 2002

December 2004

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Abstract

Dry abrasive blasting is a surface preparation process used in shipyards for cleaning the surfaces of the metal plates to be used in various components of the ship. Commonly used abrasives include sand, steel grit, mineral abrasives, metallic abrasives, and synthetic abrasives.

The basic objective of this study was to understand the environmental performance of two abrasives, Steel Grit and Specialty Sand. The project was funded by the Gulf Coast Region Maritime technology Center (GCRMTC) and USEPA. It simulated actual blasting operations conducted at shipyards under enclosed, controlled conditions on plates similar to steel plates commonly blasted at shipyards. The emissions were measured using EPA Source Test Method to quantify particulate emissions.

Steel Grit was observed to be more productive, less consuming, and more environmentally friendly compared to Specialty Sand. The findings obtained in this study will be valuable in reducing costs, improving productivity, and protecting the environment.

1.0 Introduction

Abrasive blasting is the use of abrasive material to clean or texturize a material such as metal or masonry. Abrasive blasting is used in industries such as the shipbuilding industry, automotive industry, and other industries that involve surface preparation and painting. Dry abrasive blasting is a surface preparation process used in shipyards for cleaning the surfaces of the metal plates to be used in various components of the ship. The majority of shipyards no longer use sand for abrasive blasting because of concerns about silicosis, a condition caused by respiratory exposure to crystalline silica.

Abrasive blasting presents some risks for workers' health and safety, since it has the potential of producing air emissions. Although abrasives used in blasting booths are not hazardous in themselves, their use can present serious danger to operators, such as burns, falls, exposure to hazardous dusts, creation of an explosive atmosphere, and exposure to detrimental noise. Hence it is important that both blasting booth and blaster's equipment have to be adapted to these dangers.

The basic objective of this study was to understand the environmental performance of two abrasives, Steel Grit and Specialty Sand. The project undertaken was a joint effort between the Gulf Coast Region Maritime technology Center (GCRMTC) and USEPA. It simulated actual blasting operations conducted at shipyards under enclosed, controlled conditions on plates similar to steel plates commonly blasted at shipyards. The details of the experimental set up and the blast equipment used are described in subsequent chapters. In order to achieve the study objectives, an emission test facility was built and necessary equipment and materials were procured. The emissions were measured

using EPA Source Test Method to quantify particulate emissions. Simple mathematical models were developed to predict performance based on feed rate and blast pressure.

1.1 Uses of Abrasive Blasting

There are numerous uses of abrasive blasting but this process usually generates a lot of waste in the form of used abrasives and emissions. A fraction by weight of used abrasives escapes into the atmosphere as used abrasives. The waste generated during the abrasive blasting process is a major problem for waste management facilities due to inconsistent waste disposal laws. Shipyards have to follow a certain track to treat the waste generated based on its toxicity and degree of hazard. Based on the purpose and cost estimates the most commonly used abrasives in dry blasting is usually done with sand, metallic grit or shot, aluminum oxide (alumina), or silicon carbide.

1.2 Need for Research

Data on the productivity and emissions from the commonly used abrasives is very limited. EPA has documented the emission factors for some of the abrasives. The first step of their investigation was a search of the available literature relating to the particulate emissions associated with open abrasive blasting. This search included data contained in the open literature (e.g., National Technical Information Service); source test reports and background documents located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS); data base searches (e.g., SPECIATE); and MRI's own files (Kansas City and North Carolina). The quality of the emission factors developed from analysis of the test data was rated from A (excellent) to E (poor). The available data for abrasive blasting operations is shown in Table X1.

Reference document	Type of operation tested	Type of abrasive	Sampler location	Particle size fraction, $\mu\text{m A}^b$	Time weighted average concentration, mg/m^3	Data quality rating	Emission factor, mass/source extent	Comments
WhiteMetal Inc., 1987	Outdoor blasting of steel panels coated with lead-based paint	30-60 mesh (0.59-0.25 mm) silica sand	5 ft (1.5 m) downwind	TSP	257.61	NR	N/A	Hi-vols installed downwind of dry blasting operation to demonstrate control effectiveness of "Jet Stripper"; no sampling time or process data reported
			50 ft (15 m) downwind	TSP	45.99	NR	N/A	
			100 ft (30 m) downwind	TSP	6.18	NR	N/A	
			200 ft (61 m) downwind	TSP	2.71	NR	N/A	
			500 ft (152 m) downwind	TSP	0.90	NR	N/A	
South Coast Air Quality Management District, 1988	Outdoor abrasive blasting	Sand	In ventilation system duct	TP	N/A	D	0.041 lb/lb sand	Emission factors determined by source test of an uncontrolled indoor blasting operation using a quasi-stack technique; original test report not available
		Grit		TP	N/A	D	0.010 lb/lb grit	
		Shot		TP	N/A	D	0.004 lb/lb shot	
		Other		TP	N/A	D	0.010 lb/lb abrasive	
Kinsey et al., 1995	Blasting of molded steel panels, painted, cleaned, or rusted	30-50 mesh silica sand	40 ft (12 m) downwind	TP, < 10, < 2.5	See Reference 1	A	See Table 4-4	Emission factors determined by source tests in low speed wind tunnel using standard test methods for total particulate, particle size distribution, and iron and 10 HAP metals
NEESA 2-161, 1990	Enclosed blasting of aircraft parts	Plastic	Fabric filter stack	TP	3.61	NR	N/A	Fabric filter-controlled plastic media blast room. No process data. Chromium conc. of $0.00187 \text{ mg}/\text{m}^3$ and Cr^{+6} conc. of $0.00095 \text{ mg}/\text{m}^3$
Hunter Schlessor Sandblasting, 1993	Enclosed blasting of motor shields and handrails	Glass beads	Fabric filter stack	TP	2.3	NR	N/A	Fabric filter-controlled glass bead blast room. No process data.
Poly Engineering, 1990	Enclosed blasting of unspecified parts	Garnet	Fabric filter stack	TP	126	C	0.00069 lb/lb garnet	1,740 lb/hr of abrasive used to blast 700 lb/hr of parts

Table X-1: Abrasive Blasting Operations Summary for Test Data (AP42 reference)

AP-42 for abrasive blasting operations shows that the quality rating for the available data for sand and steel grit blasting is not better than C (average). Hence, streamlined research for generating emission factors with better data quality rating would help shipyards choose the cleaner abrasive. Shipyards are required to obtain environmental permits and maintain compliance that requires knowledge of the materials and processes used. They will be able to manage the environmental matters efficiently by knowing environmental performance of abrasives and abrasive blasting processes.

As per this discussion, it is obvious that there is a strong need for establishing environmental performance of abrasives that would reduce shipyard costs by reducing consumption, improve productivity, and also minimize damage to the environment and public health.

1.3 Research Objectives

The main objective of this study was generating the dataset which would help the shipbuilding industry in determining the right alternative that will optimize the blasting processes. Maritime industry can use these research findings to minimize costs and reduce the environmental factors such as pollution. Abrasive blasting is being used widely in most shipyards. Types of abrasive materials, abrasive material gradation, number of reuses, feed rate (lb/hr), and blast pressure (PSI) will influence the material consumption, solid waste generation and atmospheric emissions to the ambient air. Even the shipyard costs will be affected such as the labor costs, material costs, cleanup and disposal costs, environmental fees, and other types.

Other objectives of this research are to establish relationships among process conditions/materials and the cost/environmental parameters by measuring productivity and waste quantities (solid/hazardous wastes and air emissions) in conjunction with the process parameters to develop necessary mathematical relationships/models to minimize costs and waste quantities. The specific goals of the project are to identify relationships among process parameters/types of abrasives (independent parameters) and environmental/cost parameters (dependent parameters) through optimization studies. The parameters to be evaluated include:

Process parameters/Types of Abrasive:

- Abrasive feed rates (lb/hr),
- Blast pressures (PSI), and
- Gradation of abrasives.

Environmental / Cost Parameters

- Solid waste generation potential,
- Atmospheric Emissions,
- Productivity, and
- Consumption.

2.0 Background of Study

Abrasive blasting by definition is a method of cleaning by propelling an abrasive material through a machine and into a hose at high pressure. The main operation in surface preparation in shipyards around the world is abrasive blasting. Abrasive blasting can be broadly classified into three major categories:

- a) Surface preparation,
- b) Surface cleaning and finishing, and
- c) Shot peening.

Abrasive-blasted surfaces are characterized by two kinds of information: cleanliness and roughness. Cleanliness reflects the degree of presence of undesirable residual contaminants on the surface. Roughness refers to the micrometric shape of the surface, called the surface profile.

Surface preparation using blasting operations removes unwanted material and leaves a surface ready for coating or bonding. The surface is roughened by the impact of an angular abrasive to produce a profile. Surface cleaning and finishing differ from surface preparation. In surface preparation, the desired result is to improve a products appearance and usefulness rather than to condition it for coating or bonding.

To remove production contaminants and heat scale surface cleaning is used extensively. Surface finishing includes deflashing and deburring molded parts, and enhancing visual features. Abrasive blasting can improve the appearance of a product by removing stains, corrosion, and tool marks. These marks are created when metal stocks are cast, cut, bended, stamped, rolled, or welded to produce the desired shape.

Sometimes these processes leave residual stresses in the metal which causes those parts to fail when stressed. By shot peening, we can increase the strength and durability of high stress components by bombarding the surface with high velocity spherical media namely, steel shot, ceramic shot, and glass beads.

Blasting operations basically comprise of three main elements: a propelling device, an abrasive container, and blasting nozzle. Each component contributes towards the overall performance of the system. The exact equipment used depends to a large extent on the specific application and type(s) of abrasive. Air blast (or dry) systems use compressed air to propel the abrasive using either a suction-type or pressure-type process. The compressed air pressure system used in this project consists of a pressure tank (pot) in which the abrasive is contained. Pressure tank is used to force the abrasive through the blast hose rather than siphoning it. The compressed air line is connected to both the top and bottom of the pressure tank. This allows the abrasive to flow by gravity into the discharge hose without loss of pressure. Details of the equipment used are described in the following chapters. The cost and properties associated with the abrasive material dictate its application. Particulate matter (PM) and particulate hazardous air pollutants (HAP) are the major concerns relative to abrasive blasting. Higher wind speeds increase emissions by enhanced ventilation of the process and by retardation of coarse particle deposition. Emissions of PM of these size fractions are not significantly wind-speed dependent. HAPs, typically particulate metals, are emitted from some abrasive blasting operations. These emissions are dependent on both the abrasive material and the targeted surface.

2.1 Applications of Steel Grit

Steel Grit is commonly used today as the most powerful tool for cutting granite blocks by gang-saws in granite industry. Steel Grit is very heavy in nature and possesses high density as compared to other materials. The angular edges of Steel Grit are sharp and the stability of the hardness of Steel Grit makes the cutting operation effective. Sand-removing of large and medium sized castings, deoxidization of forgings, heat-treated pieces, steel plates, steel pipes, sections and steel structures, intensification of springs, surface treatment before plating, improving roughness, enhancing adhesiveness are other applications of using Steel Grit.



Figure X-1: Steel Grit

The usefulness of Steel Grit is further glorified by the fact that it can be recycled and reused for future experiments. On an average, the Steel Grit can be recycled over 50 times for reuses.

2.2 Applications of Specialty Sand

Specialty Sand must meet stringent quality requirements as the principal ingredient in the manufacture of glass, and foundry cores and molds used for metal castings. This sand is also an ingredient in paints, refractory products and specialty fillers. It is used in water filtration, for enhancing production of oil and gas, and in specialty construction applications. It also satisfies recreational needs, such as golf courses, tennis courts and ball fields. It is used in residential pool filters and sand boxes.



Figure X-2: Specialty Sand

Nearly all industries use Specialty Sand or products made with it, and for the majority of these applications there are no known suitable substitutes. Their special properties -- purity, inertness, hardness, resistance to high temperatures, grain size and color -- make it critical to a variety of industrial applications.

3.0 Objectives

The primary objectives of this study were:

- To study the performance of Steel Grit and Specialty Sand when used in blasting processes for enclosed conditions.
- To evaluate process parameters that can be useful for shipyards to maximize productivity and minimize emissions.
- To estimate performance parameters related to blasting such as:
 1. Productivity (defined as the area cleaned per unit time),
 2. Consumption (defined as the amount of abrasive material used per unit area cleaned),
 3. Feed Rate (corresponds to the flow rate of the abrasive under given pressure conditions), and
 4. Emission Factors (defined as: (a) mass of pollutant per area cleaned, (b) mass of pollutant per mass of abrasive used).
- To analyze the experimental results and estimate the combinations of process parameters which would result in maximum productivity and least emissions.

4.0 Equipments Used

4.1 *Test Chamber Design and Construction*

Using the partial funding received through a research project funded by EPA Region 6, an emission test facility was installed adjacent to the Engineering Building at UNO main campus in New Orleans. The test facility measures 12 ft x 10 ft x 8 ft and was designed as per the guidelines of EPA method 204. The chamber was constructed using plastic sheets which were connected and riveted firmly to the wooden floor. The floor was made up of seasoned wood and was then treated with waterproofing materials. Gaps were sealed with silicon to prevent any seepage of the water that could interfere with the test process. A wooden ramp was used to move the panel cart in and out of the chamber smoothly before and after blasting. A plastic tarpaulin shed was erected adjacent to the chamber to house the sampling equipment and test aids. More tarpaulin sheets were used to shield the sampling equipment against rain and storm events.



Figure X-3: Emission test facility at UNO

The test chamber was equipped with a fume extraction system and a two stage particle collection system (coarse and fine particle collection). Fumes from the emission test facility would be extracted with a variable ventilation rate, up to a maximum of 6500 cubic feet per minute (CFM) allowing capture of particles with different sizes generated during abrasive blasting. Installed two-stage particle collection system includes an inertial separator for coarse particles followed by bag house for fine particles. The emissions test facility was also equipped with a 12" diameter duct to allow measurement of particles under iso-kinetic conditions as recommended by the EPA for particle collection from stationery sources.

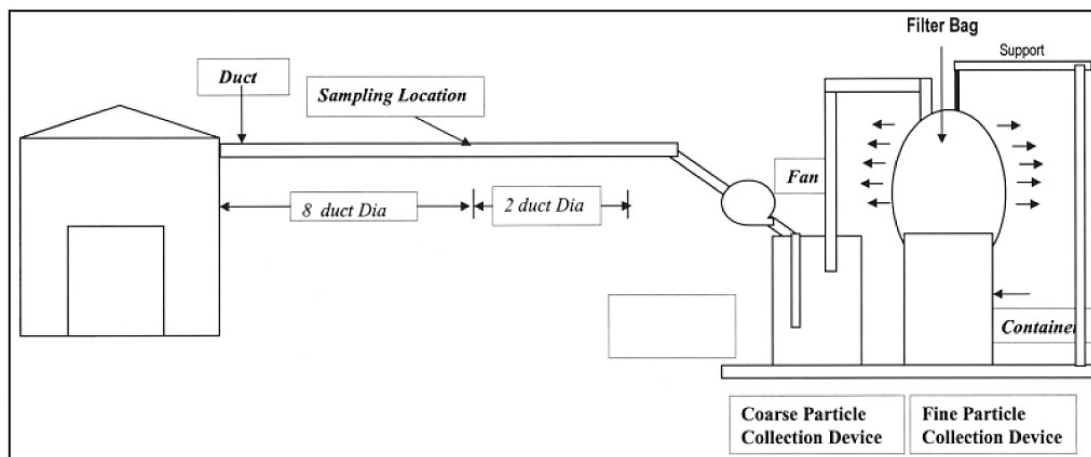


Figure X-4: Complete Assembly of the Test Facility

The Blast chamber consisted of a room with internal lighting that holds both the work piece and the operator. The operator would hold the blasting nozzle at the end of the hose. The rusted panel rests on the wooden flooring which allowed used abrasive to drop down for recycling. Provisions were made for proper ventilation of the blast chamber. An exhaust window located at one end of the chamber leads to the sampling duct through which the particulates would be collected using a variable speed fan. The fan capability for operating at various speeds corresponded to a maximum flow of 6500

cubic feet per minute (CFM). The particles were then collected through a two-stage particulate collection system (gravimetric and bag filters) with an efficiency of 90%, the first stage in a drum and then through the filter bags.

4.2 Blasting Equipment (Blast Pot)

Blast pot performs the action of propelling the blast material using compressed air which comes from the compressor. The abrasive as well as the air will be at the same pressure, which sweeps the abrasive towards the hose. The blast material gets mixed with compressed air and gains its strength in the blasting equipment. The blasting equipment known as the blast pot used in this experiment is of 600 lbs capacity and has a 1.25 inches piping and comes with a moisture separator, air filter, and a helmet with an air conditioning unit.

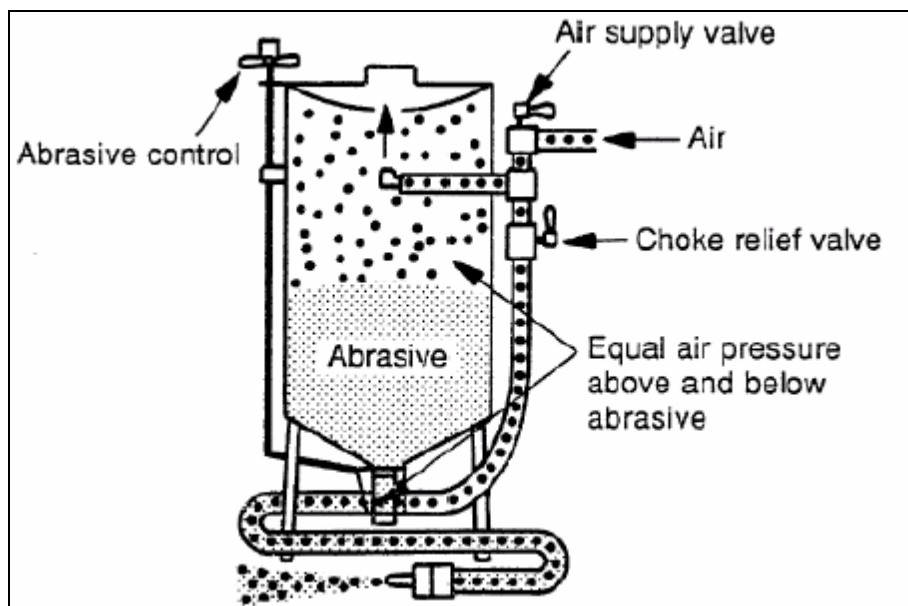


Figure X-5: Schematic Diagram of Blast Pot



Figure X-6: Blast pot; Blast hose with nozzle holder; Respirator, air purifier and air supply hose kit.

Any lumps, dust, or other foreign material present in the material obstructs the flow by choking the valves and interrupts the smooth flow of material. Hence proper care was taken to make sure that there was no dust or foreign matter present in the abrasive materials. All of the hose joints were fastened properly with the help of fasteners and checked before each run. After the desired amount of blast material is poured into the pot, the opening and side walls of the hopper had to be cleaned thoroughly. After cleaning, the side opening, a small window on the side of the blast pot, as shown in Fig. 5 had to be closed tightly.

4.3 Compressor

Apart from the abrasive used, compressed air is also considered an important component of the entire abrasive blast system. The compressor provides the air pressure to the blasting material. A hose is used to connect the blast pot and compressor. In the blast pot, the compressed air becomes mixed with the blasting material. The compressor provides the medium to propel the blast material, which

imparts its velocity to the blast material. The desired effect depends on many parameters such as grain size and shape of the abrasive, pressure of the compressed air but the velocity at which the blasting material strikes the target to be prepared is the focal factor. The compressor used for the study was the model SULLAIR 375H, which has a capability of providing a maximum pressure of 150 PSI. The pressures used for the study were 80 PSI, 100 PSI and 120 PSI. The compressor is diesel operated and wheel based with a swing down cooler, circuit breaker, two-stage air filters, and a high/low pressure selector.

4.4 Exhaust Duct

EPA method 1 for stack monitoring and testing was used to design the exhaust duct. The diameter of the stack is 12 inches. A sampling port was located at a distance of 8 diameters from the exhaust window and the variable speed fan was positioned at 2 diameters from the port to minimize the turbulence on the downstream end. The exhaust window is directly connected to the duct, which carries the emissions collected through the exhaust. The inner portion of the duct should be smooth, straight and free of undulations. A nozzle size of 0.18 inches turned out to be best for the test set up, which gave fairly balanced results. (Pilot tests were conducted to determine the size of the nozzle).



Figure X-7: Exhaust Duct

A standard S-type pitot tube was used for velocity measurements. It was used at a number of positions in a cross-sectional plane perpendicular to the flow direction in the duct to fully depict the flow. According to EPA method 1, a minimum number of locations needed to make measurements depend on the extent of disturbance or turbulence in the flow. A total of eight traverse points were chosen for testing for the circular duct. The traverse points were measured and marked on the sampling probe to ensure accuracy and ease of traverse. Iso-kinetic sampling was ensured throughout each and every test run. Iso-kinetic samplings help in getting the representative sample from the duct and in getting accurate test results. Getting Iso-kinetic sampling is one of the important steps in obtaining accurate results. For ensuring iso-kinetic flow conditions a nozzle of size of 0.18 inches was chosen for the runs. A change in the diameter of stack or change in the direction of flow is considered as turbulence or disturbance to the flow. The exhaust should be properly protected with mesh of proper size to remove the coarser particles, but allow the fine particles to go smoothly into the duct.

4.5 Stack Sampling Equipment

Stack sampling equipment was designed according to EPA standards and is governed by the EPA stack sampling method 4. Stack sampling equipment has to be connected to the sampling train and the whole arrangement can be used to collect the particulate emission during the sampling time. The dry gas meter and thermometers mounted on stack sampling equipment help in measuring the key parameters required for the emission calculation.

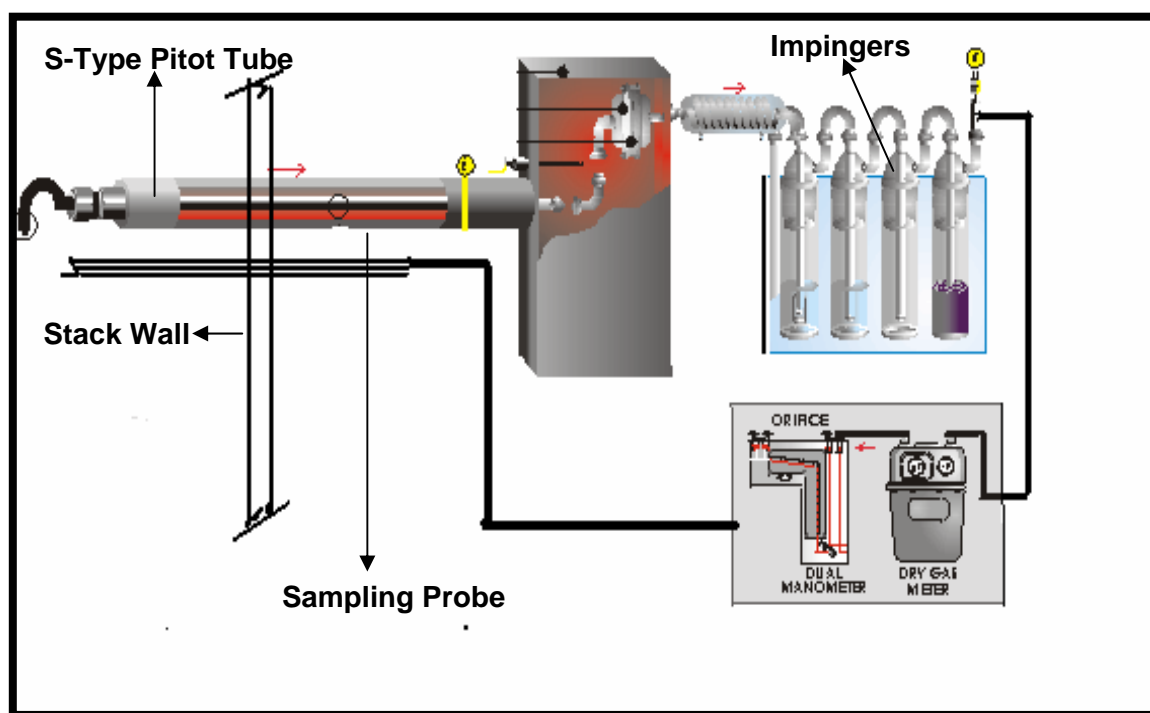


Figure X-8: Sampling Train

For accurate measurement of the water vapor in the condenser/absorber section of the apparatus, the probe and sample lines upstream of this section must be inert and heated to avoid condensation, and the whole system must be free of leaks. The apparatus consists of four glass impingers connected in series and installed in an ice bath. The first two impingers are filled with an accurately measured quantity (100 ml) of

distilled water and act as bubblers; the gas is drawn down through the cold water and bubbles up, then travels out to the next impinger. The third impinger is left dry for further condensation. The fourth impinger contains a quantity of silica gel (adsorbent) that removes nearly all the remaining water vapor when the gas passes through it before finally exiting.

4.6 Sampling Train Parts

The sampling train consists of the following parts: nozzle, the sampling probe, the filter holder, connectors, and the impinger. In this part of the set up, the moisture gets separated from the sample gas volume.

1. **Probe and Nozzle:** The probe and nozzle should be of aluminum with a sharp tapered leading edge. The angle of taper should be on the outside to preserve a constant internal diameter. The probe and nozzle shall be constructed of seamless tubing.
2. **Filter Holder:** The filter holder is of aluminum with a screen and silicone rubber gaskets. The holder is attached directly to the outlet of the probe. The probe and filter holder must be constructed to be leak free.
3. **Connectors:** The glass connectors are used to connect the impingers with each other and to assure air tight sealing clamps are used. Each joint is clamped properly and securely to provide air tightness throughout the test run.
4. **Impingers:** There are a total of four impingers in the sampling train. The first two impingers are filled with an accurately measured quantity of water and act as bubblers; the impingers are known as Greenburg-Smith or modified impingers based on the design. The third impinger is left dry for further condensation; the fourth

impinger contains a quantity of silica gel adsorbent. It helps in determining the moisture content in the extracted sample.

4.7 Plate Size Specifications

The test panels used in these blasting operations were made of cast iron of area 40 sqft. (8'x5'). The experiments were conducted for surfaces with flash rust. A total of four plates were used and they were mounted on a panel cart. The results presented in this document correspond to blasting of plates having flash rust generated by the action of moisture and air on the exposed plates. Typically the plates were allowed to rust after every blasting run for around 24 hours (average over all the runs) to ensure uniform rust.

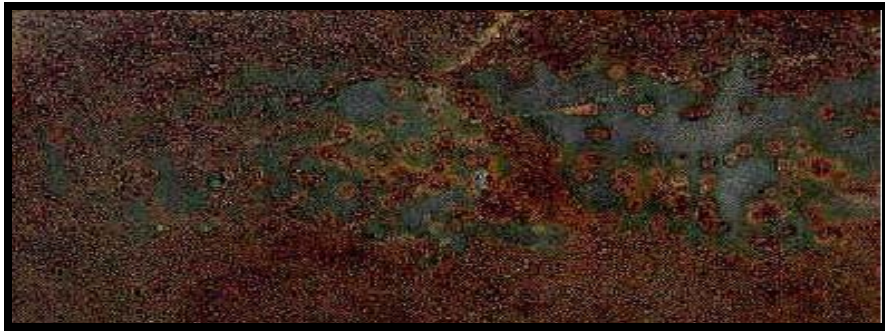


Figure X-9: Test Plate

To support the plates during the experiment a panel cart was used. The panel cart was chosen in such a way that two plates can be mounted at a time and can be turned using the castors during the experiment if needed.

4.8 Schmidt Valve

Feed rate of the abrasive used was governed by the number of turns of Schmidt valve when it is open. Schmidt valve controls the flow of blast material. The range of turns was a

minimum of one turn to a maximum of nine and half turns. In this study, the turns used were 3, 4, and 5 turns of the open Schmidt valve to specify the feed rate used.

4.9 *Particulate Collection System*

For collecting the particles emitted during the blasting experiments, a two-stage particle collection system (Refer to Figure 13) is installed at test facility which includes an inertial separator for coarse particles followed by bag house for fine particles. The emission test facility is equipped with a long 12" diameter duct to allow measurement of particles under iso-kinetic conditions as recommended by the EPA for particle collection from stationery sources. The two stage particulate collection system is designed to trap the maximum amount of emissions and to prevent it from becoming airborne. In the first stage the exhaust duct is diverted into a 55-gallon drum after passing the sampling train. In this process the coarser particles settle down at the bottom of the drum and thus will be removed from the system.



Figure X-10: Two stage Particulate Collection System

The second stage of the collection system is used for the finer particles. In the second stage of the collection system, the particles from the outlet of the 55-gallon drum are diverted towards the inlet of the filter bags. In this stage, the coarser particles escaped from the first stage with the finer particles becoming trapped in the side wall of the filters. In the study, four filter panels were used. Each filter panel consisted of five individual filters that help in trapping more and more emissions and preventing them from becoming airborne, thus increasing the efficiency of the overall collection system.

4.10 Test Constraints

Number of different factors rule the particulate emissions such as, (1) blast pressure, (2) feed rate, (3) blast nozzle size, (4) grade of abrasive used, (5) exhaust rate, (6) exhaust flow pattern, (7) orientation of the plate inside the test chamber, (8) distance between the plate and the blast nozzle, (9) angle of the blast nozzle with respect to the test plate, (10) surface finish required, and (11) surface contamination at the beginning. Though every effort was made to simulate field conditions, it is important to note the conditions of this study.

- Blast pressure and feed rates were measured for all runs in the study and the results are expressed with respect to these parameters.
- Blast nozzle used was size # 6 (Bozzuka) for all test runs.
- Medium grade Steel Grit and 20-40 grade Specialty Sand were used without a recycling option.
- Exhaust rate of 3200 cfm (average) was used.
- Exhaust flow pattern maintained same for all test runs by maintaining the plate orientation with respect to exhaust opening.

- An average distance of 12" was maintained between the test plate and the blast nozzle.
- Blast nozzle was kept perpendicular to the plate as much as possible.
- Surface finish quality maintained was near to commercial finish (SPC-6).
- Flash rusting was used as the surface contamination for all test plates.
Approximately 24 hours of flash rusting was allowed on the test plates.

5.0 Field Test Procedure

Field testing at UNO Emissions test facility included two major steps:

1. Perform the blasting of test panels using Steel Grit and Specialty Sand, and
2. Stack/Source sampling for evaluation of particulate emissions.

Blasting was performed by following the commonly observed shipyard blasting procedures including Society of Protective Coating (SPC) recommendations. SPC has visual standards (section 5.2) to characterize the metal surface that is cleaned using abrasives. For source sampling, EPA's emissions test methods 1 through 5 were used which are discussed in Appendix B.

First, the rusted test panels were mounted on the cart with one on either side. A measured amount of abrasive was transferred into the blast pot through a sieve to remove any foreign material that may interfere with the smooth flow of the abrasive. The compressor was used to supply compressed air to the blast pot. Stack sampling equipment was used for the sample collection at various traverse points which were marked on the probe in advance. The sampling train was connected properly with impingers in position and leak tests were done to make sure the connections were tight. The Schmidt valve was adjusted for the desired number of turns, the compressor was turned on, the blasting pressure was adjusted to the desired setting (80, 100, 120 PSI at the nozzle), and then the blasting was initiated.

The sampling probe was inserted into the sampling port and the necessary parameters, namely, velocity head, stack temperature, vacuum, DGM readings, and box temperature were recorded for the iso-kinetic sampling conditions for each of the

traverse points. After the blasting and source sampling, the filters used in the test along with sampling probe were taken to the laboratory for analysis.

The filter was weighed and the sampling probe was rinsed thoroughly with acetone to get the remaining particulates stuck on the side of the wall in a pre-weighed beaker. The difference between the final weight of the filter and the initial weight of the filter plus the final weight and initial weight of the beaker after evaporating the acetone and acetone blank test gives the particulate loading for the volume of gas sampled. After this step, the leak test was performed again to check for leakage in the sampling train.

Below sequence was used to perform various field activities:

- Obtain the values for barometric pressure and temperature.
- Calculate K factor necessary for iso-kinetic sampling. ($\Delta H = K \times \Delta P$) using these values and the nozzle diameter. Set up the instrument and sampling train on site.
- Perform leak check on sampling train before the actual tests.
- Note down various parameters needed for the run such as velocity head, stack temperature, vacuum, DGM readings, box temperature, etc.
- Perform leak check on sampling train after the actual tests.
- Obtain the percentage isokinetic from the observed parameters and formulae listed in the EPA methods (within 90% to 110%).
- Get the particulate loading by weighing the filters and beaker, in the laboratory.

5.1 *Input and Output Variables*

Dry abrasive blasting results are influenced by primary parameters such as initial surface conditions, final surface conditions desired, abrasive type, abrasive grade, blast pressure, feed rate, surface conditions, angle of abrasive jet, blast nozzle size, distance from nozzle to the surface, worker training, worker awareness on environmental issues, worker weariness, ventilation conditions, fan capacity in case of blast houses, and wind speed in case of open-air conditions.

Blasting and source sampling was carried out in a trained way to minimize the human errors by maintaining the conditions uniform and ensuring that site parameters and blasting conditions are consistent across different runs.

The parameters that formed input variable set are defined as follows:

1. Abrasive: The abrasives tested were Steel Grit and Specialty Sand.
2. Blast Pressure: The tests were conducted at 3 blast pressures which were 80 PSI, 100 PSI, and 120 PSI.
3. Feed rate: Feed rate of the abrasive was varied using Schmidt valve connected to the bottom of the blast pot. The number of turns used was 3, 4 and 5 turns in open condition of the valve.
4. Nozzle Size: A nozzle of diameter 0.18 inches was chosen to ensure iso-kinetic sampling conditions.
5. Blasting Time: The total blasting time was measured for each run using a stop watch. The sampling time was constant for all the runs: 2 minutes at each traverse point adding up to a total of 16 minutes for an entire run.

The parameters measured in the field specific to each run form the output parameter set and are defined as follows:

1. Area Cleaned: The blasted area was calculated using a measuring tape. Necessary corrections were made for accurately measuring the area cleaned.
2. Productivity: Productivity is a measure of blasting speed and is defined as
$$\text{Productivity (sqft/hr)} = \text{Area Cleaned (sqft)} / \text{Total Blasting Time (hours)}$$
3. Emission Factors: The emission factors are expressed in this report in terms of the following units:
 - a. Mass of pollutant emitted (g) / Area Cleaned (sqft)
 - b. Mass of Pollutant emitted (g) / Quantity of abrasive used (lb)
 - c. Mass of Pollutant emitted (lb) / Quantity of abrasive used (lb)
 - d. Mass of Pollutant emitted (lb) / Quantity of abrasive used (ton)
4. Consumption: It is defined as
$$\text{Consumption} = \text{Quantity of Abrasive Used (lb)} / \text{Area Cleaned (sqft)}$$

5.2 Surface Preparation Standards

The SPC developed visual standards for the finished surface using a range between SP-1 to SP-11. In this study, the finish of test panels varied between SP-5, SP-6, and SP-10 grades. The finish depended on the blast pressure and the feed rate of abrasive. The surface characteristics of rusted panels and blasted panels are illustrated in the following figures.



Figure X-11: Test Plate - Before Blasting

5.2.1 SP-5 SPC Standard (White Metal Blasting)

This standard is defined as the removal of all visible rust, mill scale, paint and contaminants which leaves the metal uniformly white or gray in appearance. It is the ultimate in blast cleaning.



Figure X-12: Test Plate - SP-5 SPC Finish

5.2.2 SP-6 SPC Standard (Commercial Blast)

Foreign matter like oil, grease, dirt, and rust scale are completely removed from the surface and all rust, mill scale, and old paint are completely removed by abrasive blasting except for slight shadows, streaks or discolorations caused by rust stain, mill scale oxides, or slight, tight residues of paint or coating that remain. If the surface is pitted, slight residue of rust or paint may be found in the bottom of pits; at least two-

thirds of each square inch of the surface area shall be free of all visible residues and the remainder shall be limited to the light residues mentioned above.

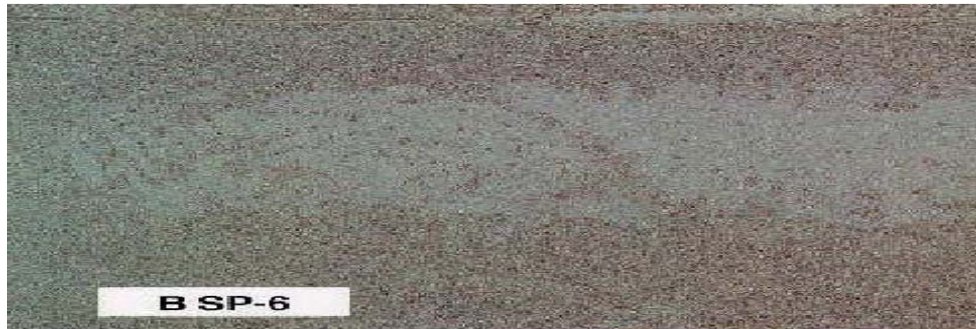


Figure X-13: Test Plate - SP-6 SPC Finish

5.2.3 SP-10 SPC Standard (Brush-off Blast)

Except for very light shadows, very slight streaks or slight discolorations caused by rust stain, mill scale oxides, or slight, tight residues of paint or coating all other foreign matter such as oil, grease, dirt, mill scale, rust, corrosion products, oxides, and paint, are completely removed from the surface by abrasive blasting. At least 95% of each square inch of surface area shall be free of all visible residues, and the remainder shall be limited to the light discolorations mentioned above. From a practical standpoint, this is probably the best quality surface preparation that can be expected today for existing plant facility maintenance work.



Figure X-14: Test Plate - SP-10 SPC Finish

6.0 Results

Field results of the blasting project are listed in this section. Table X-2.1 gives the field data observed for Steel Grit and Table X-2.2 shows the statistical parameters (mean and standard deviations) of productivity (sqft/hr), consumption (lb/sqft) and emission factors (g/sqft, g/lb, and lb/ton) for Steel Grit. Tables X-3.1 and X-3.2 show corresponding data for Specialty Sand. The columns in these tables can be read as follows:

Column 1: Pressure: Pressure (Pounds per Square Inch).

Column 2: No. of Turns: Number of turns of the open Schmidt valve.

Column 3: Weight (or Wt): Weight of the abrasive used (pounds).

Column 4: B Time: Blasting time (minutes).

Column 5: MCR: Material Consumption Rate (pounds per minute).

Column 6: A: Cleaned area of the plate (square feet).

Column 7: E: Quantity of emissions obtained in the sampling train (grams of pollutant mass collected).

Column 8: P: Productivity (square feet per hour).

Column 9: C: Consumption (pounds per square feet).

Column 10: Emission Factors: Emission factor represented as:

- Mass of pollutant per area cleaned (grams per square feet).
- Mass of pollutant per amount of abrasive consumed. (gm/lb, lb/lb, lb/kg, lb/ton).

[1 US ton = 2000 lb].

Table X-4.1 shows the Steel Grit and Specialty Sand producing minimum emissions with respect to maximum productivity at a corresponding pressure and number of turns. Table X-4.2 summarizes the absolute minimum emissions (gm/sqft) without considering productivity for the two abrasives at the three pressures. These two tables would be helpful to shipyards for choosing the cleaner abrasive among these two based on their needs. For steel grit at 120 PSI, the valve opening was not a constraint. Also, the material consumption rate was constant and the blasting time solely depended on pressure.

Figures X-15.1, X-15.2, X-15.3 show the productivity variation at pressures 80 PSI, 100 PSI, and 120 PSI respectively for Steel Grit and Figure X-15.4 shows the parameter variation with pressure at maximum feed rate for Steel Grit. A similar numbering convention is being followed for Specialty Sand in figures X-16.1 to X-16.4.

Press	Turns	Wt	BT	MCR	A	E	P	C	EF1	EF2		
PSI		lbs	min	lbs/min	sqft	g	sqft/hr	lb/sqft	g/sqft	g/lb	lb/lb	lb/ton
120	3	50	6	8.33	20	223.58	200.00	2.500	11.179	4.472	0.0099	19.72
120	3	50	6	8.33	22	217.47	220.00	2.273	9.885	4.349	0.0096	19.18
120	3	50	6	8.33	18	202.85	180.00	2.778	11.269	4.057	0.0089	17.89
120	4	50	6	8.33	26	221.26	260.00	1.923	8.510	4.425	0.0098	19.52
120	4	50	6	8.33	28	203.61	280.00	1.786	7.272	4.072	0.0090	17.96
120	4	50	6	8.33	27	199.67	270.00	1.852	7.395	3.993	0.0088	17.61
120	5	50	6	8.33	25	247.84	250.00	2.000	9.914	4.957	0.0109	21.86
120	5	50	6	8.33	24	227.51	240.00	2.083	9.480	4.550	0.0100	20.07
120	5	50	6	8.33	26	237.65	260.00	1.923	9.140	4.753	0.0105	20.96
100	3	50	5	10.00	22	163.04	264.00	2.273	7.411	3.261	0.0072	14.38
100	3	50	5	10.00	21	171.11	252.00	2.381	8.148	3.422	0.0075	15.09
100	3	50	6	8.33	20	157.74	200.00	2.500	7.887	3.155	0.0070	13.91
100	4	50	10	5.00	22	187.78	132.00	2.273	8.535	3.756	0.0083	16.56
100	4	50	11	4.55	24	190.76	130.91	2.083	7.948	3.815	0.0084	16.83
100	4	50	10	5.00	24	176.77	144.00	2.083	7.365	3.535	0.0078	15.59
100	5	50	4	12.50	18	194.63	270.00	2.778	10.813	3.893	0.0086	17.17
100	5	50	5	10.00	22	193.30	264.00	2.273	8.786	3.866	0.0085	17.05
100	5	50	5	10.00	19	198.13	228.00	2.632	10.428	3.963	0.0087	17.48
80	3	50	6	8.33	18	148.77	180.00	2.778	8.265	2.975	0.0066	13.12
80	3	50	6	8.33	18	139.12	180.00	2.778	7.729	2.782	0.0061	12.27
80	3	50	6.5	7.69	19	167.64	175.38	2.632	8.823	3.353	0.0074	14.79
80	4	50	6	8.33	20	168.29	200.00	2.500	8.415	3.366	0.0074	14.84
80	4	50	6	8.33	19.5	187.17	195.00	2.564	9.598	3.743	0.0083	16.51
80	4	50	6	8.33	19	170.81	190.00	2.632	8.990	3.416	0.0075	15.07
80	5	50	9	5.56	27	191.16	180.00	1.852	7.080	3.823	0.0084	16.86
80	5	50	9	5.56	30	200.98	200.00	1.667	6.699	4.020	0.0089	17.73
80	5	50	9	5.56	28	186.02	186.67	1.786	6.644	3.720	0.0082	16.41

Table X-2.1: Field Data for Steel Grit

Press	Turns	Wt	P			C			Emission Factors								
PSI		lbs	sqft / hr	Mean	SD	lb/sqft	Mean	SD	g/sqft	Mean	SD	g/lb	Mean	SD	lb/ton	Mean	SD
120	3	50	200.00	200.00	20.00	2.500	2.52	0.25	11.179	10.78	0.77	4.472	4.29	0.21	19.72	18.93	0.94
120	3	50	220.00			2.273			9.885			4.349			19.18		
120	3	50	180.00			2.778			11.269			4.057			17.89		
120	4	50	260.00	270.00	10.00	1.923	1.85	0.07	8.510	7.73	0.68	4.425	4.16	0.23	19.52	18.36	1.01
120	4	50	280.00			1.786			7.272			4.072			17.96		
120	4	50	270.00			1.852			7.395			3.993			17.61		
120	5	50	250.00	250.00	10.00	2.000	2.00	0.08	9.914	9.51	0.39	4.957	4.75	0.20	21.86	20.96	0.90
120	5	50	240.00			2.083			9.480			4.550			20.07		
120	5	50	260.00			1.923			9.140			4.753			20.96		
100	3	50	264.00	238.67	34.02	2.273	2.38	0.11	7.411	7.82	0.37	3.261	3.28	0.13	14.38	14.46	0.59
100	3	50	252.00			2.381			8.148			3.422			15.09		
100	3	50	200.00			2.500			7.887			3.155			13.91		
100	4	50	132.00	135.64	7.26	2.273	2.15	0.11	8.535	7.95	0.59	3.756	3.70	0.15	16.56	16.33	0.65
100	4	50	130.91			2.083			7.948			3.815			16.83		
100	4	50	144.00			2.083			7.365			3.535			15.59		
100	5	50	270.00	254.00	22.72	2.778	2.56	0.26	10.813	10.01	1.08	3.893	3.91	0.05	17.17	17.23	0.22
100	5	50	264.00			2.273			8.786			3.866			17.05		
100	5	50	228.00			2.632			10.428			3.963			17.48		
80	3	50	180.00	178.46	2.66	2.778	2.73	0.08	8.265	8.27	0.55	2.975	3.04	0.29	13.12	13.39	1.28
80	3	50	180.00			2.778			7.729			2.782			12.27		
80	3	50	175.38			2.632			8.823			3.353			14.79		
80	4	50	200.00	195.00	5.00	2.500	2.57	0.07	8.415	9.00	0.59	3.366	3.51	0.21	14.84	15.47	0.90
80	4	50	195.00			2.564			9.598			3.743			16.51		
80	4	50	190.00			2.632			8.990			3.416			15.07		
80	5	50	180.00	188.89	10.18	1.852	1.77	0.09	7.080	6.81	0.24	3.823	3.85	0.15	16.86	17.00	0.67
80	5	50	200.00			1.667			6.699			4.020			17.73		
80	5	50	186.67			1.786			6.644			3.720			16.41		

Table X-2.2: Statistical Parameters for Steel Grit

Press	Turns	Wt	BT	MCR	A	E	P	C	EF1	EF2		
PSI		lbs	min	lbs/min	sqft	g	sqft/hr	lb/sqft	g/sqft	g/lb	lb/lb	lb/ton
120	3	100	10	10.00	31	1078.89	186.00	3.226	34.803	10.789	0.0238	47.58
120	3	100	11	9.09	33	992.84	180.00	3.030	30.086	9.928	0.0219	43.78
120	3	100	8	12.50	25	971.01	187.50	4.000	38.840	9.710	0.0214	42.82
120	4	100	9	11.11	34.5	1070.36	230.00	2.899	31.025	10.704	0.0236	47.20
120	4	100	9	11.11	33.5	1053.06	223.33	2.985	31.435	10.531	0.0232	46.44
120	4	100	9	11.11	33	995.01	220.00	3.030	30.152	9.950	0.0219	43.88
120	5	100	8	12.50	25	1217.95	187.50	4.000	48.718	12.180	0.0269	53.71
120	5	100	11	9.09	33.5	1180.27	182.73	2.985	35.232	11.803	0.0260	52.05
120	5	100	10	10.00	31	1240.77	186.00	3.226	40.025	12.408	0.0274	54.72
100	3	100	12	8.33	24	1044.56	120.00	4.167	43.523	10.446	0.0230	46.07
100	3	100	10	10.00	21	1050.01	126.00	4.762	50.000	10.500	0.0232	46.31
100	3	100	11.5	8.70	24	1096.01	125.22	4.167	45.667	10.960	0.0242	48.33
100	4	100	13	7.69	32	1108.09	147.69	3.125	34.628	11.081	0.0244	48.87
100	4	100	12.5	8.00	29	1088.32	139.20	3.448	37.528	10.883	0.0240	47.99
100	4	100	10.5	9.52	26	1111.58	148.57	3.846	42.753	11.116	0.0245	49.02
100	5	100	12	8.33	27	1141.07	135.00	3.704	42.262	11.411	0.0252	50.32
100	5	100	12.5	8.00	28	1127.92	134.40	3.571	40.283	11.279	0.0249	49.74
100	5	100	11.5	8.70	26	1118.85	135.65	3.846	43.033	11.189	0.0247	49.34
80	3	100	15	6.67	32	954.96	128.00	3.125	29.843	9.550	0.0211	42.11
80	3	100	13	7.69	27.5	962.15	126.92	3.636	34.987	9.622	0.0212	42.43
80	3	100	13.5	7.41	27	977.67	120.00	3.704	36.210	9.777	0.0216	43.12
80	4	100	14.5	6.90	31	925.20	128.28	3.226	29.845	9.252	0.0204	40.80
80	4	100	13.5	7.41	29	1025.20	128.89	3.448	35.352	10.252	0.0226	45.21
80	4	100	14	7.14	30	940.98	128.57	3.333	31.366	9.410	0.0207	41.50
80	5	100	13.5	7.41	30	996.80	133.33	3.333	33.227	9.968	0.0220	43.96
80	5	100	12	8.33	26.5	1008.68	132.50	3.774	38.063	10.087	0.0222	44.48
80	5	100	11.5	8.70	26.5	1029.19	138.26	3.774	38.837	10.292	0.0227	45.39

Table X-3.1: Field Data for Specialty Sand

Press	Turns	Wt	P			C			Emission Factors								
PSI		lbs	sqft / hr	Mean	SD	lb/sqft	Mean	SD	g/sqft	Mean	SD	g/lb	Mean	SD	lb/ton	Mean	SD
120	3	100	186.00	184.50	3.97	3.226	3.42	0.51	34.803	34.58	4.38	10.789	10.14	0.57	47.58	44.73	2.52
120	3	100	180.00			3.030			30.086			9.928			43.78		
120	3	100	187.50			4.000			38.840			9.710			42.82		
120	4	100	230.00	224.44	5.09	2.899	2.97	0.07	31.025	30.87	0.66	10.704	10.39	0.39	47.20	45.84	1.74
120	4	100	223.33			2.985			31.435			10.531			46.44		
120	4	100	220.00			3.030			30.152			9.950			43.88		
120	5	100	187.50	185.41	2.44	4.000	3.40	0.53	48.718	41.32	6.84	12.180	12.13	0.31	53.71	53.49	1.35
120	5	100	182.73			2.985			35.232			11.803			52.05		
120	5	100	186.00			3.226			40.025			12.408			54.72		
100	3	100	120.00	123.74	3.26	4.167	4.37	0.34	43.523	46.40	3.30	10.446	10.64	0.28	46.07	46.90	1.25
100	3	100	126.00			4.762			50.000			10.500			46.31		
100	3	100	125.22			4.167			45.667			10.960			48.33		
100	4	100	147.69	145.15	5.18	3.125	3.47	0.36	34.628	38.30	4.12	11.081	11.03	0.13	48.87	48.63	0.55
100	4	100	139.20			3.448			37.528			10.883			47.99		
100	4	100	148.57			3.846			42.753			11.116			49.02		
100	5	100	135.00	135.02	0.63	3.704	3.71	0.14	42.262	41.86	1.42	11.411	11.29	0.11	50.32	49.80	0.49
100	5	100	134.40			3.571			40.283			11.279			49.74		
100	5	100	135.65			3.846			43.033			11.189			49.34		
80	3	100	128.00	124.97	4.34	3.125	3.49	0.32	29.843	33.68	3.38	9.550	9.65	0.12	42.11	42.55	0.51
80	3	100	126.92			3.636			34.987			9.622			42.43		
80	3	100	120.00			3.704			36.210			9.777			43.12		
80	4	100	128.28	128.58	0.31	3.226	3.34	0.11	29.845	32.19	2.84	9.252	9.64	0.54	40.80	42.50	2.37
80	4	100	128.89			3.448			35.352			10.252			45.21		
80	4	100	128.57			3.333			31.366			9.410			41.50		
80	5	100	133.33	134.70	3.11	3.333	3.63	0.25	33.227	36.71	3.04	9.968	10.12	0.16	43.96	44.61	0.72
80	5	100	132.50			3.774			38.063			10.087			44.48		
80	5	100	138.26			3.774			38.837			10.292			45.39		

Table X-3.2: Statistical Parameters for Specialty Sand

S No	Pressure	Feed rate	Maximum Productivity	Emission Factors		
	(PSI)	(No. of turns)	(sqft/hr)	g/sqft	g/lb	lb/ton
Steel grit	80	4	195	9.00	3.51	15.47
	100	5	254	10.01	3.91	17.23
	120	4	270	7.73	4.16	18.36
Specialty Sand	80	5	134.7	36.71	10.12	44.61
	100	4	145.15	38.30	11.03	48.63
	120	4	224.44	30.87	10.39	45.84

Table X-4.1: Minimum Emissions at Maximum Productivity (gm/sqft)

From the above table, it is imperative that Steel Grit is giving higher productivity among the two abrasives compared. This implies that more area can be cleaned in a lesser time frame. It is also worth noting that Specialty Sand is giving out higher emissions when compared to Steel Grit. This implies that the mass of pollutant emitted is higher for a specific mass of Specialty Sand used. Steel Grit emits less pollutant per square feet of cleaned area.

S No	Pressure	Feed rate	Emission Factors		
	(PSI)	(No. of turns)	g/sqft	g/lb	lb/ton
Steel grit	80	5	6.81	3.85	17.00
	100	3	7.82	3.28	14.46
	120	4	7.73	4.16	18.36
Specialty Sand	80	4	32.19	9.64	42.50
	100	4	38.30	11.03	48.63
	120	4	30.87	10.39	45.84

Table X-4.2: Absolute* Minimum Emissions (without considering Productivity)

According to the above table, emission factors with respect to area cleaned for Steel Grit increases with increase in pressure but this trend is not clear for emission factors with respect to abrasive quantity. For Steel Grit, low pressure-high feed rate combination corresponds to the lowest emissions whereas for Specialty Sand, feed rate setting of 4 turns of Schmidt valve offers the least emission factors at all tested pressures.

Figure X-15.1: Steel grit - Feed Rate vs Productivity at 80 PSI

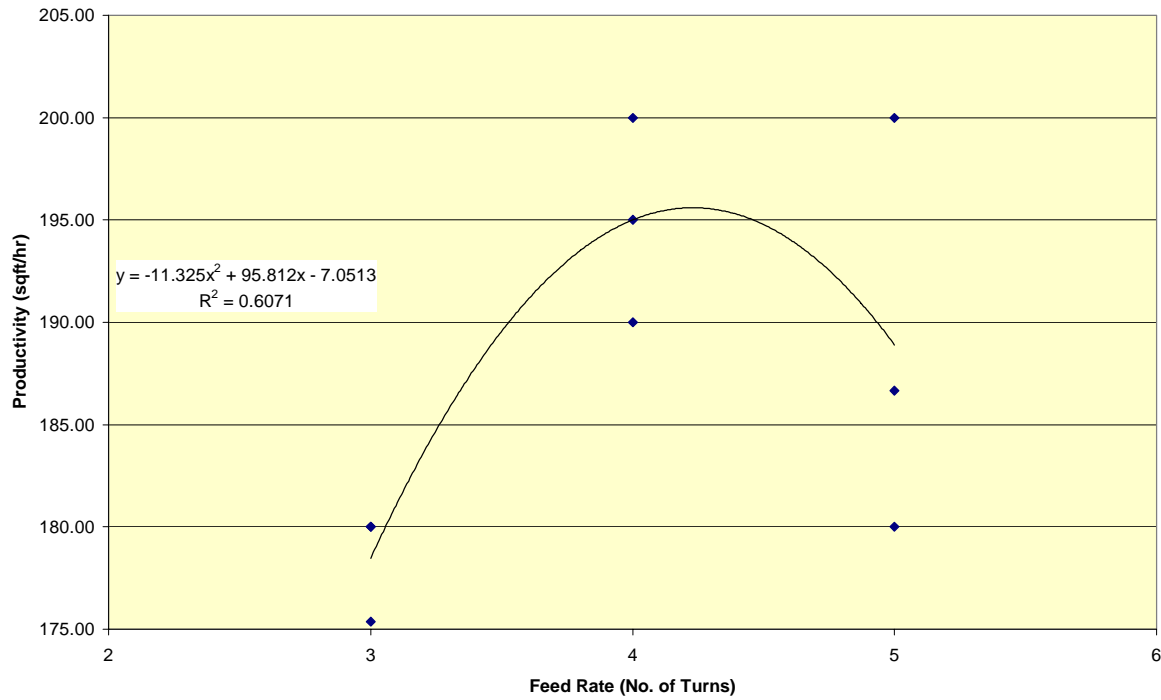


Figure X-15.2: Steel grit - Feed Rate vs Productivity at 100 PSI

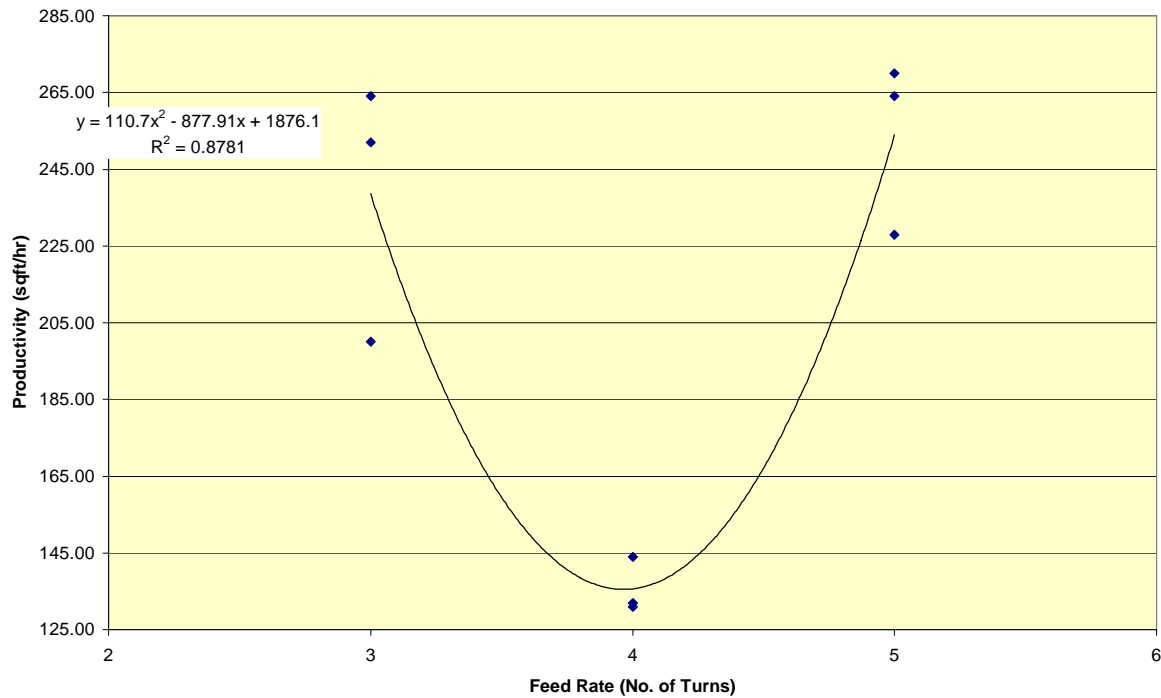


Figure X-15.3: Steel grit - Feed Rate vs Productivity at 120 PSI

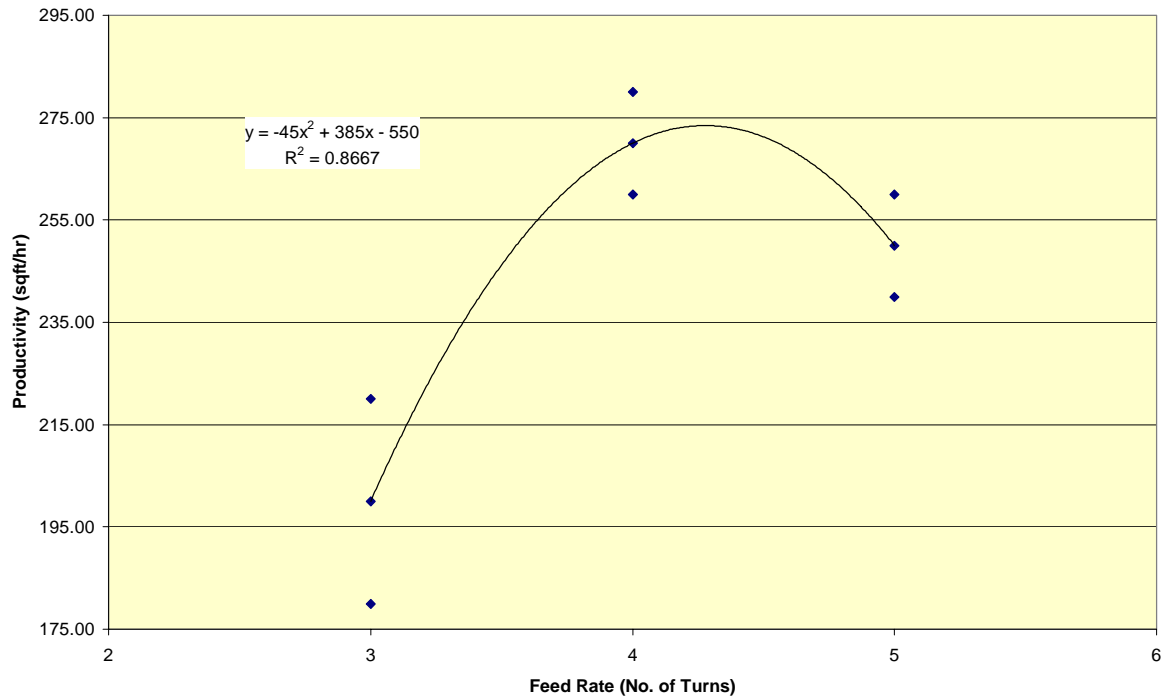


Figure X-15.4: Parameter Variation with Pressure at Maximum Feed Rate: Steel grit

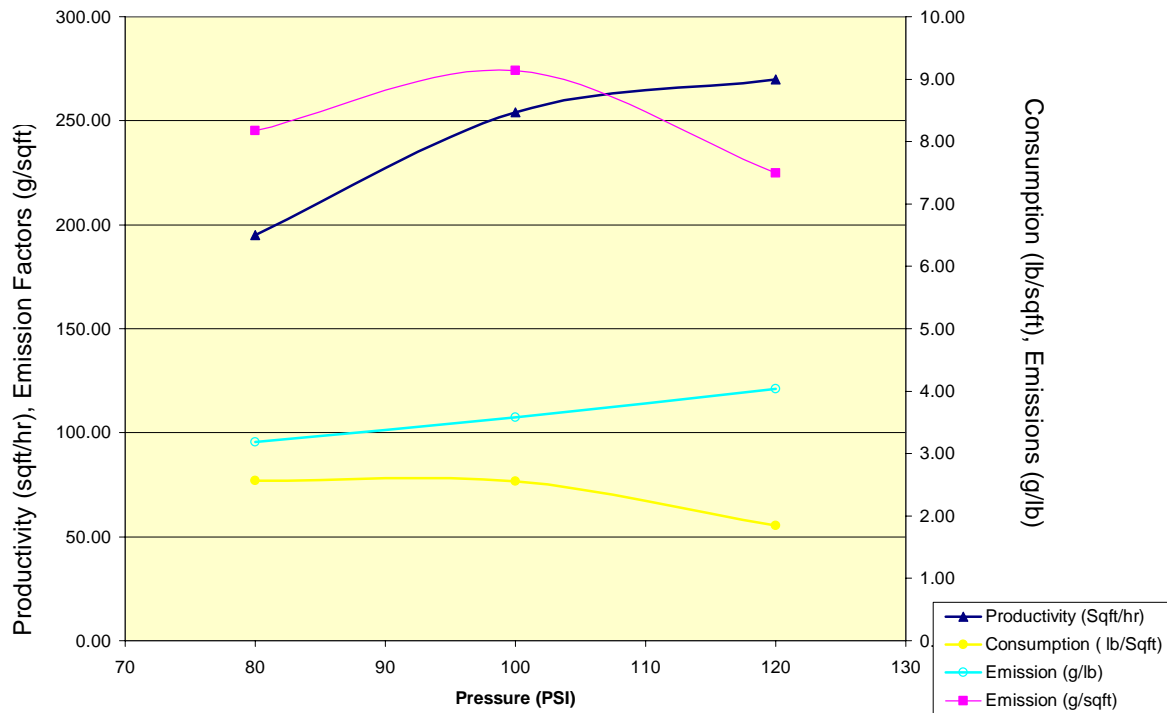


Figure X-16.1: Sand: Feed Rate vs Productivity at 80 PSI

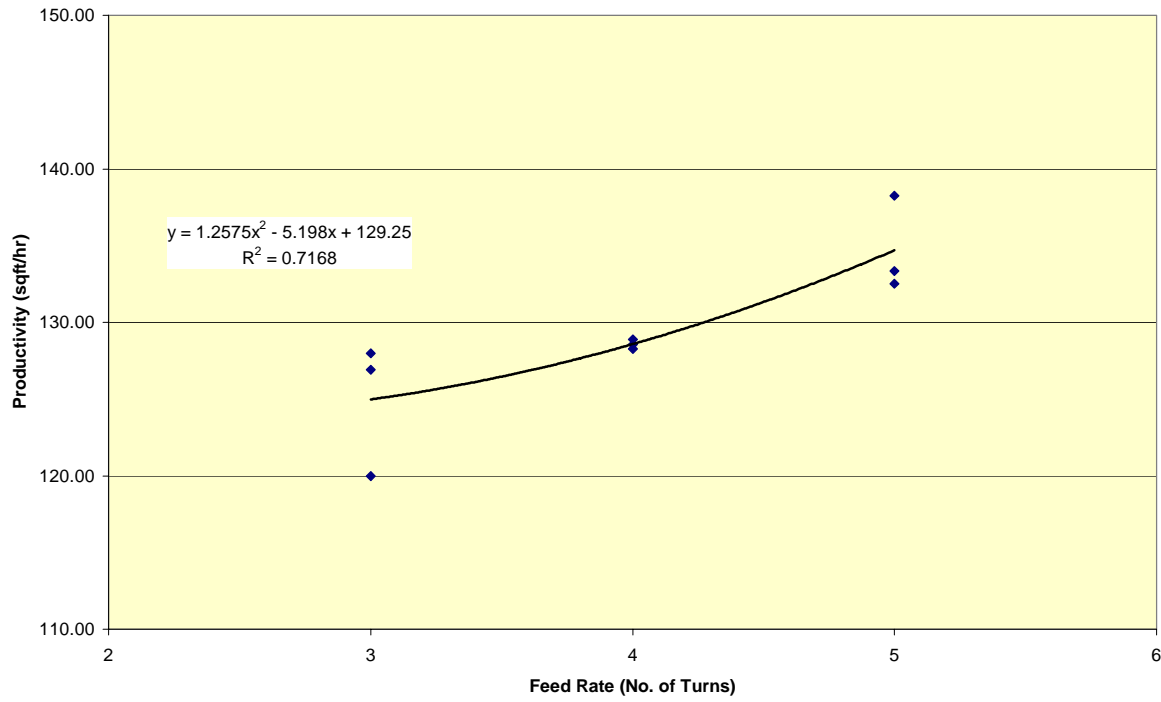


Figure X-16.2: Sand: Feed Rate vs Productivity at 100 PSI

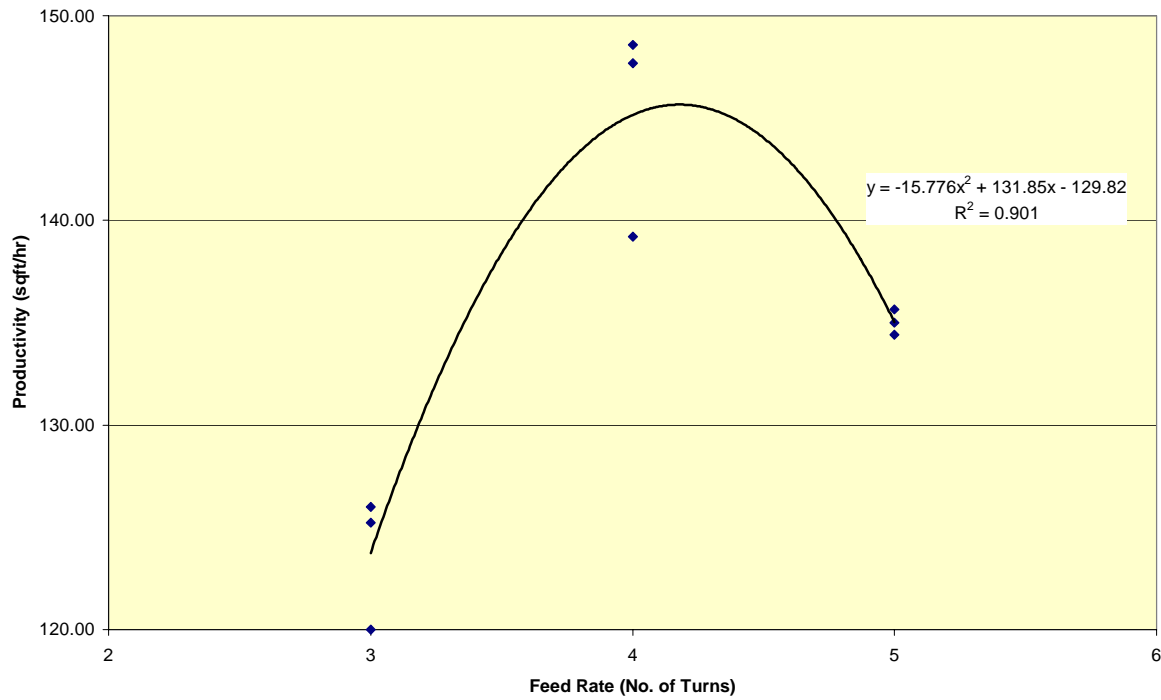


Figure X-16.3: Sand: Feed Rate vs Productivity at 120 PSI

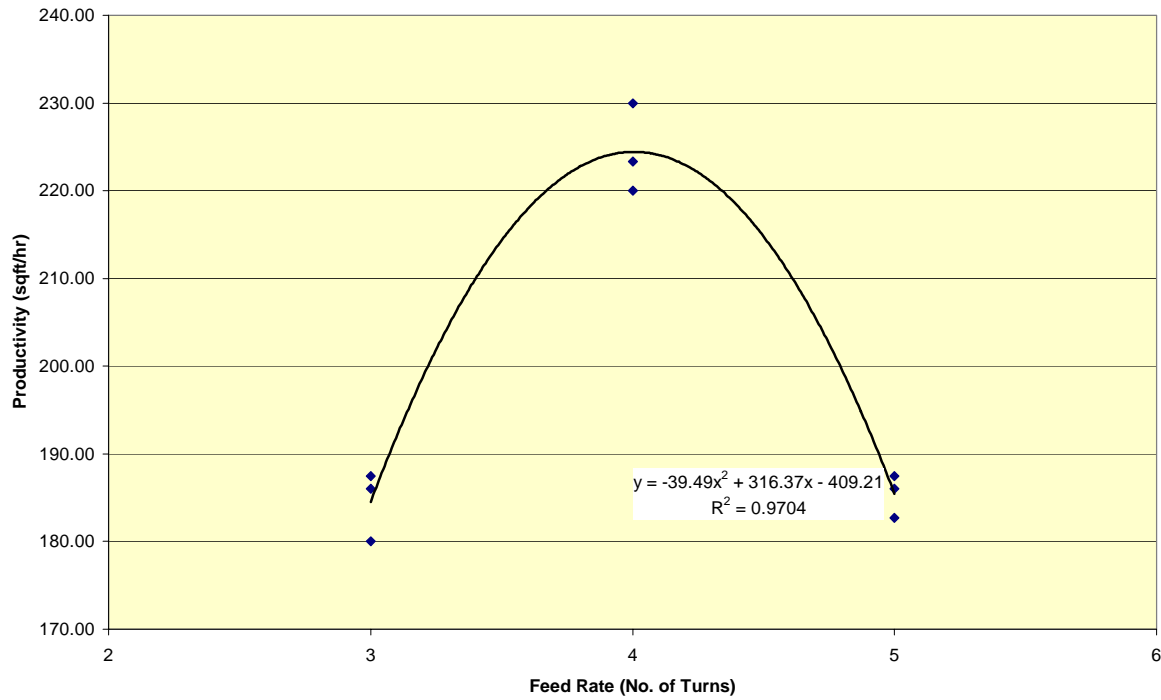


Figure X-16.4: Parameter Variation with Pressure at Maximum Feed Rate: Sand

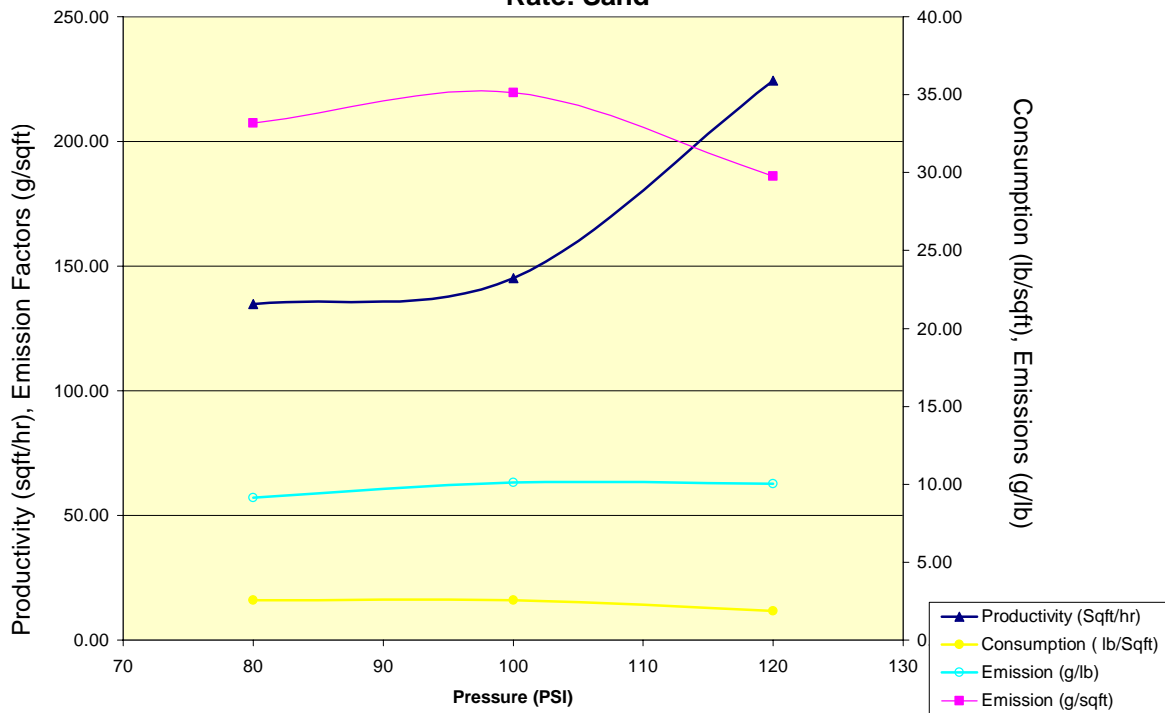


Figure X-17: Feed Rate vs Productivity at 80 PSI

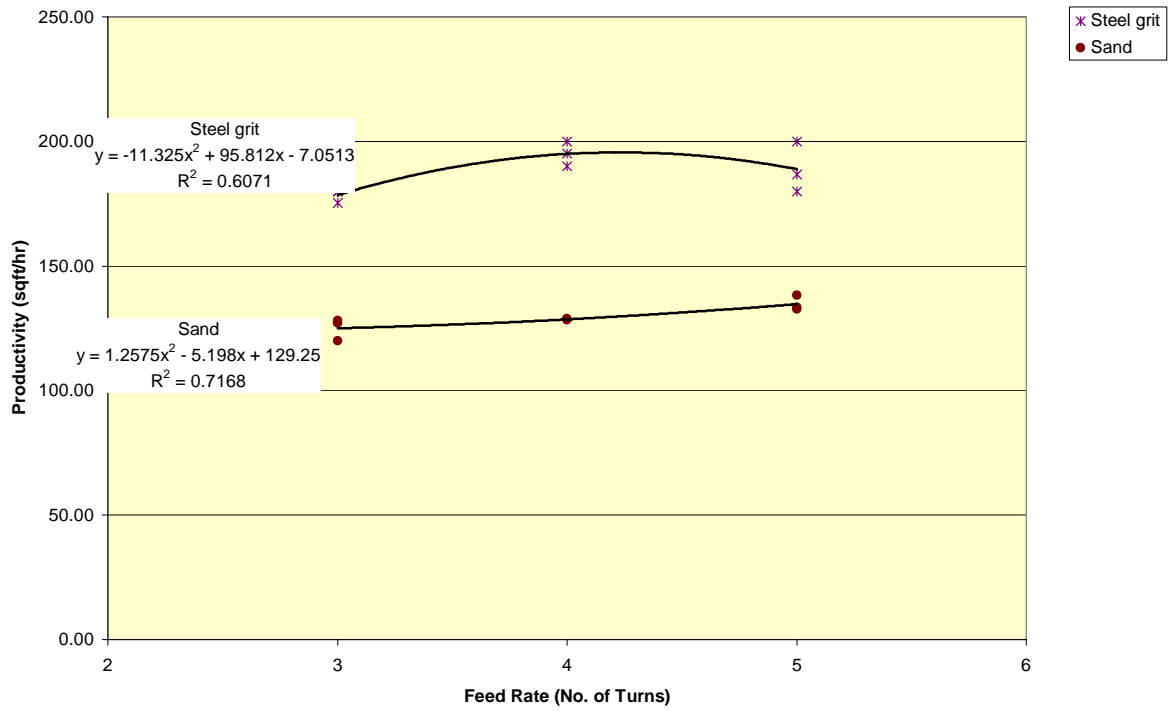


Figure X-18: Feed Rate vs Productivity at 100 PSI

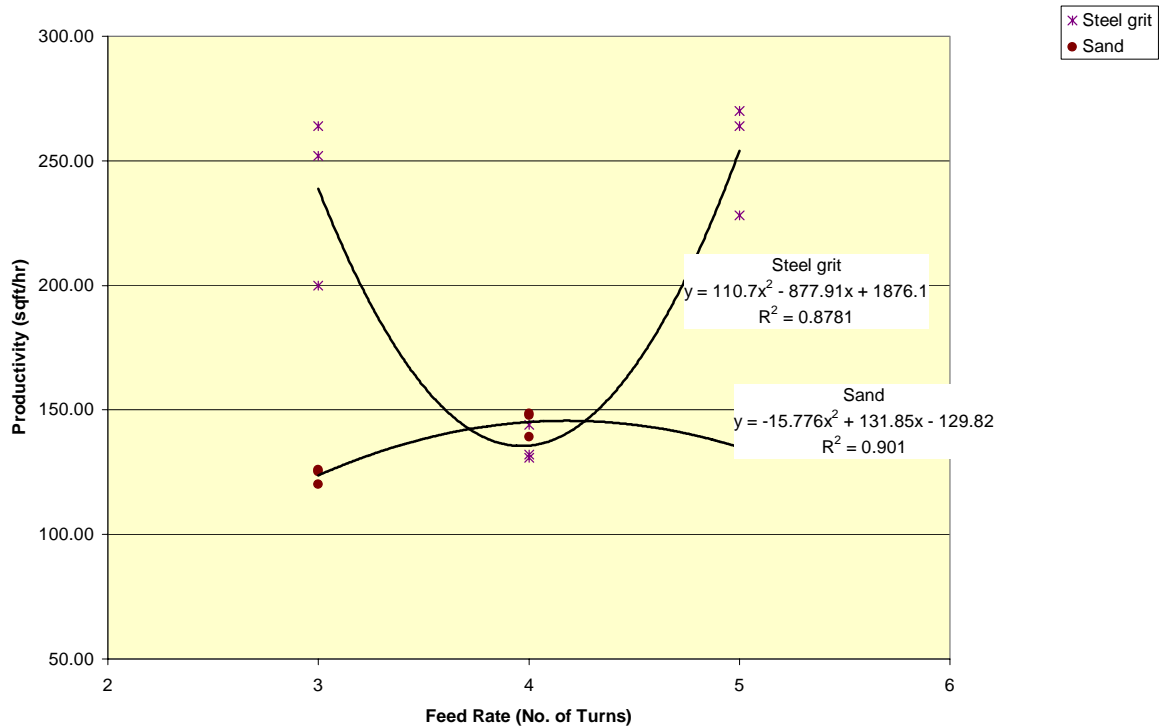


Figure X-19: Feed rate vs Productivity at 120 PSI

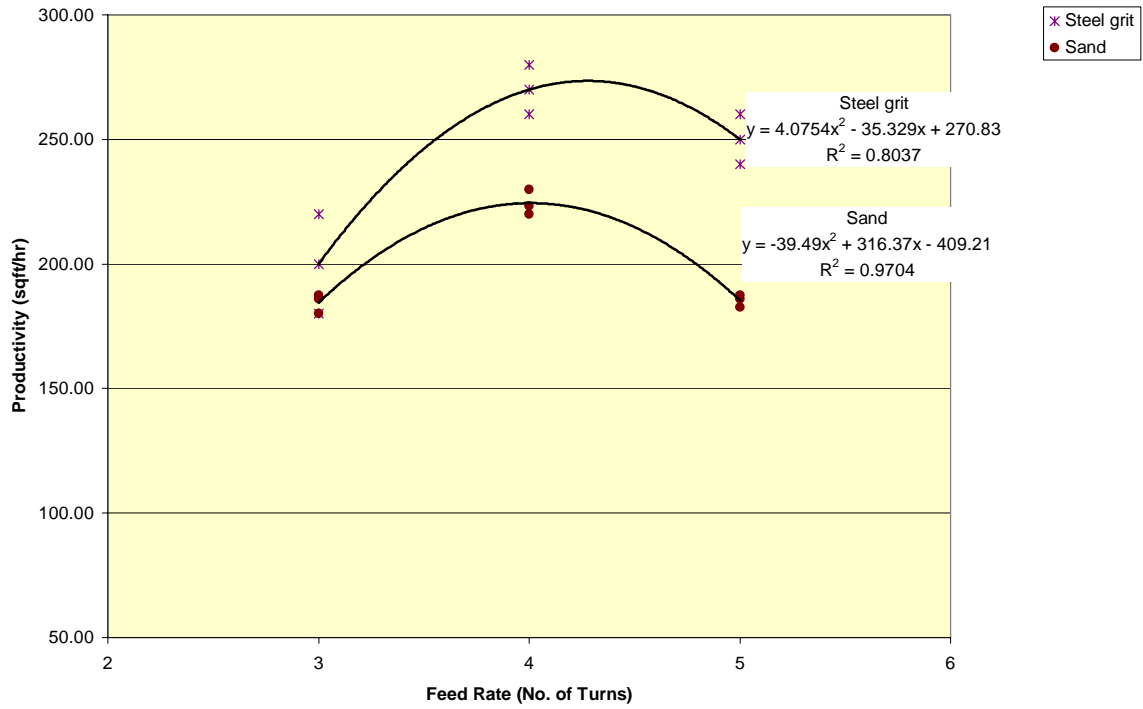


Figure X-20: Feed Rate vs Emission Factors (g/sqft) at 80 PSI

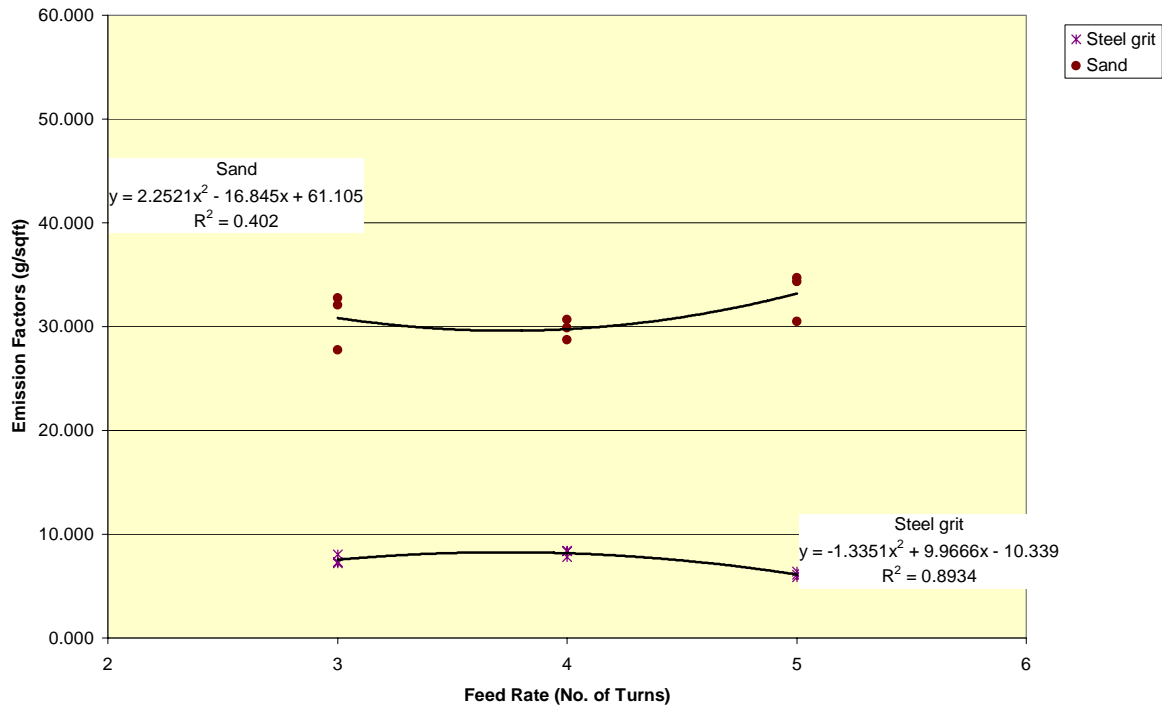


Figure X-21: Feed Rate vs Emission Factors (g/sqft) at 100 PSI

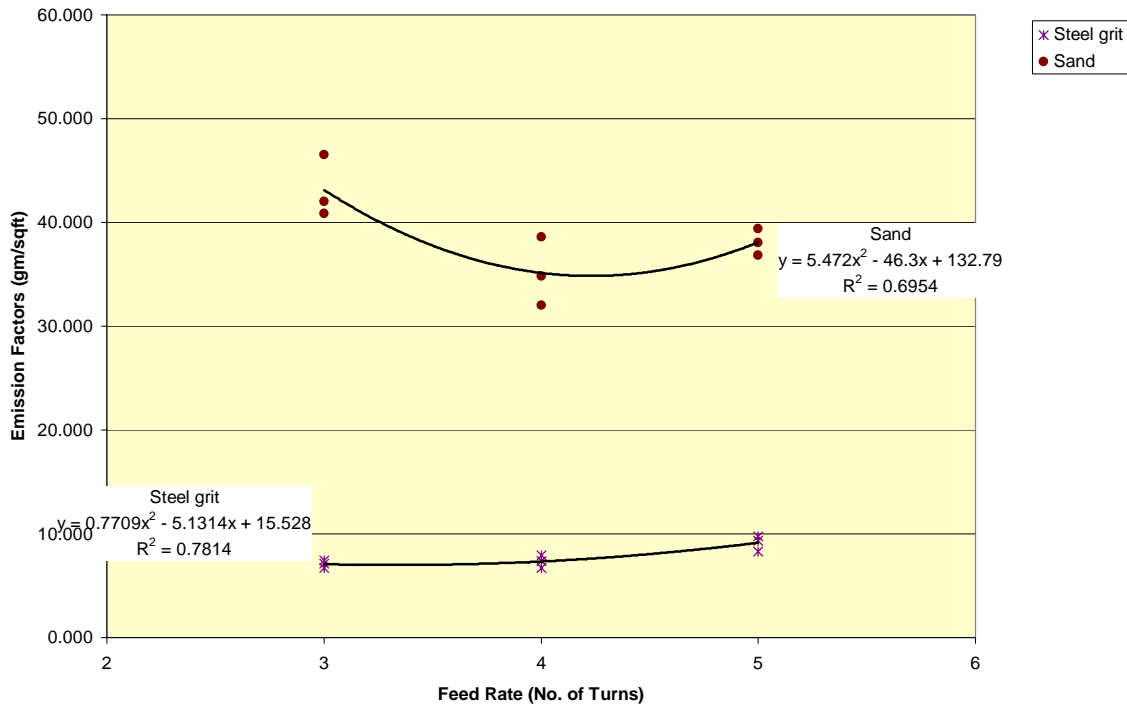


Figure X-22: Feed Rate vs Emission Factors (g/sqft) at 120 PSI

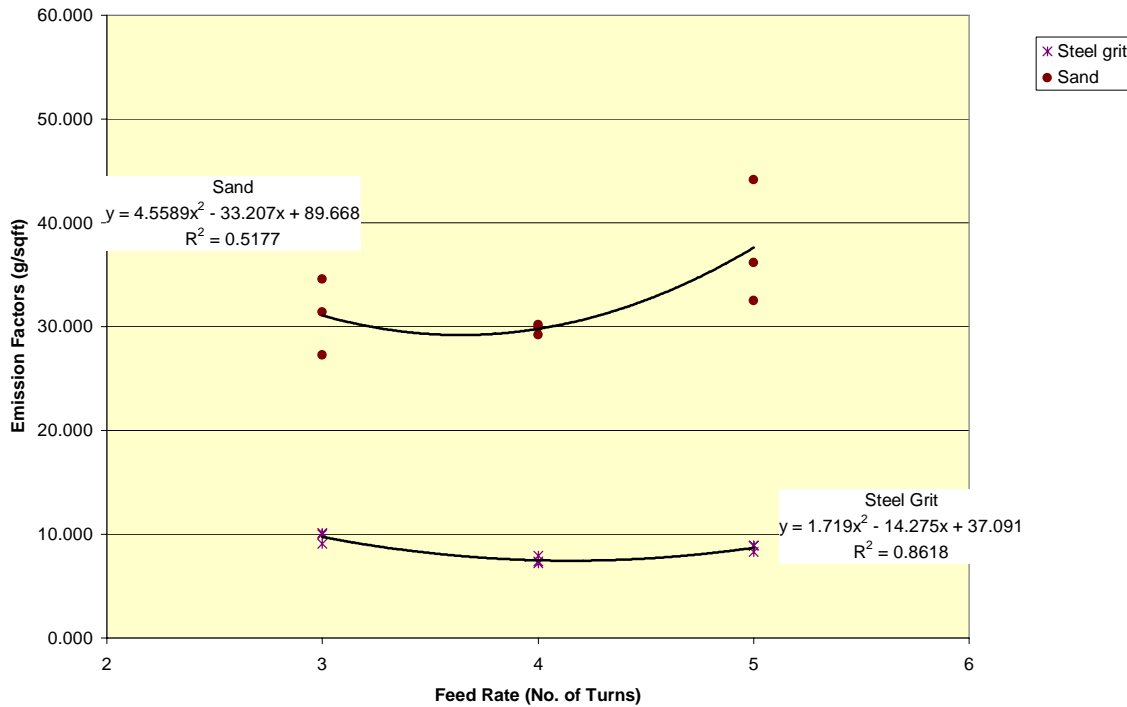


Figure X-23: Feed Rate vs Emission Factors (g/lb) at 80 PSI

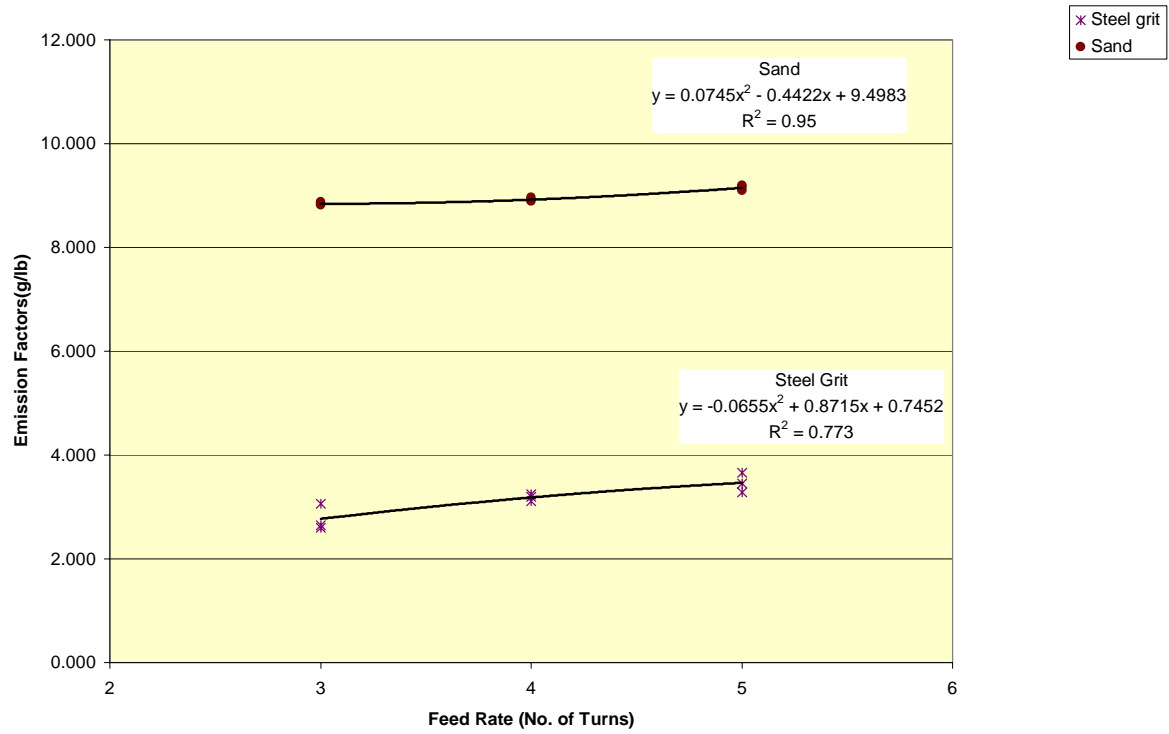


Figure X-24: Feed Rate vs Emission factors (g/lb) at 100 PSI

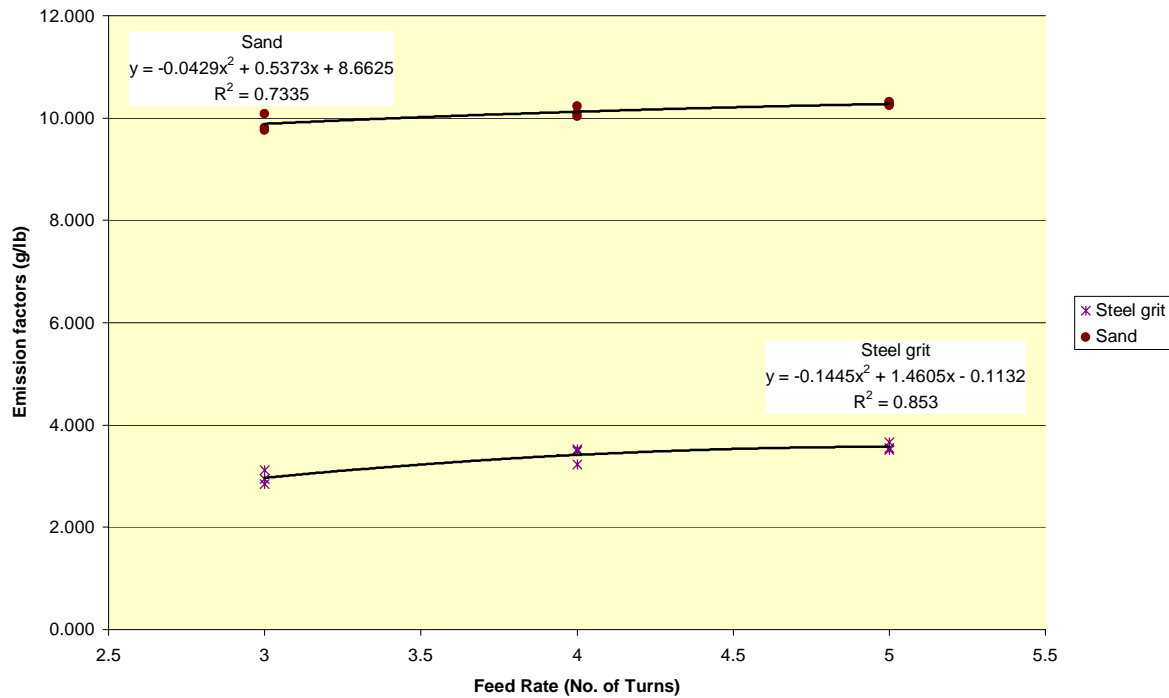


Figure X-25: Feed Rate vs Emission Factors (g/lb) at 120 PSI

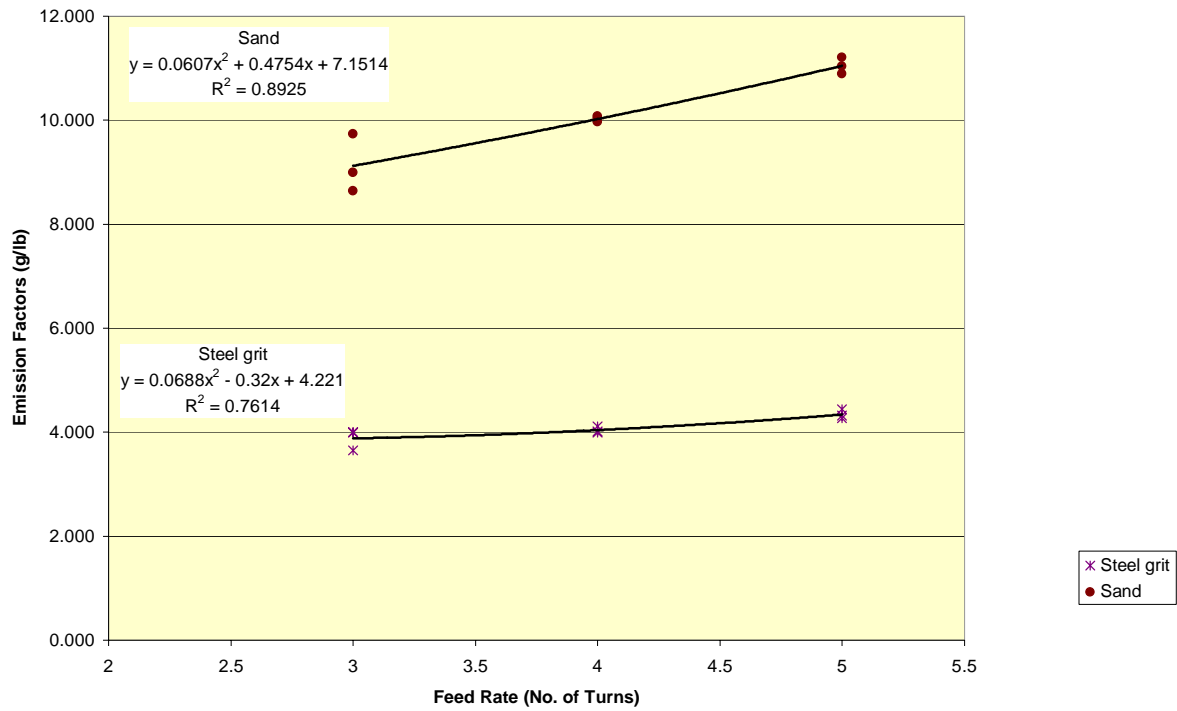


Figure X-26: Pressure vs Productivity at Maximum Productivity

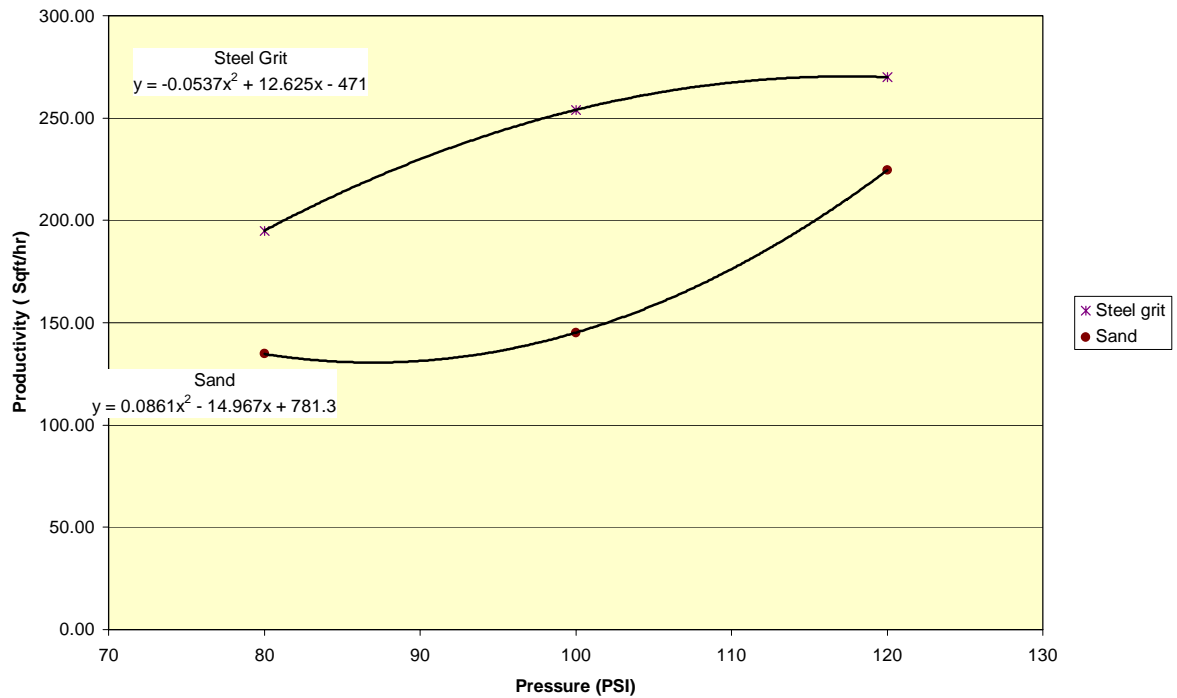


Figure X-27: Pressure vs Emissions Factors (g/Sqft) at Maximum Productivity

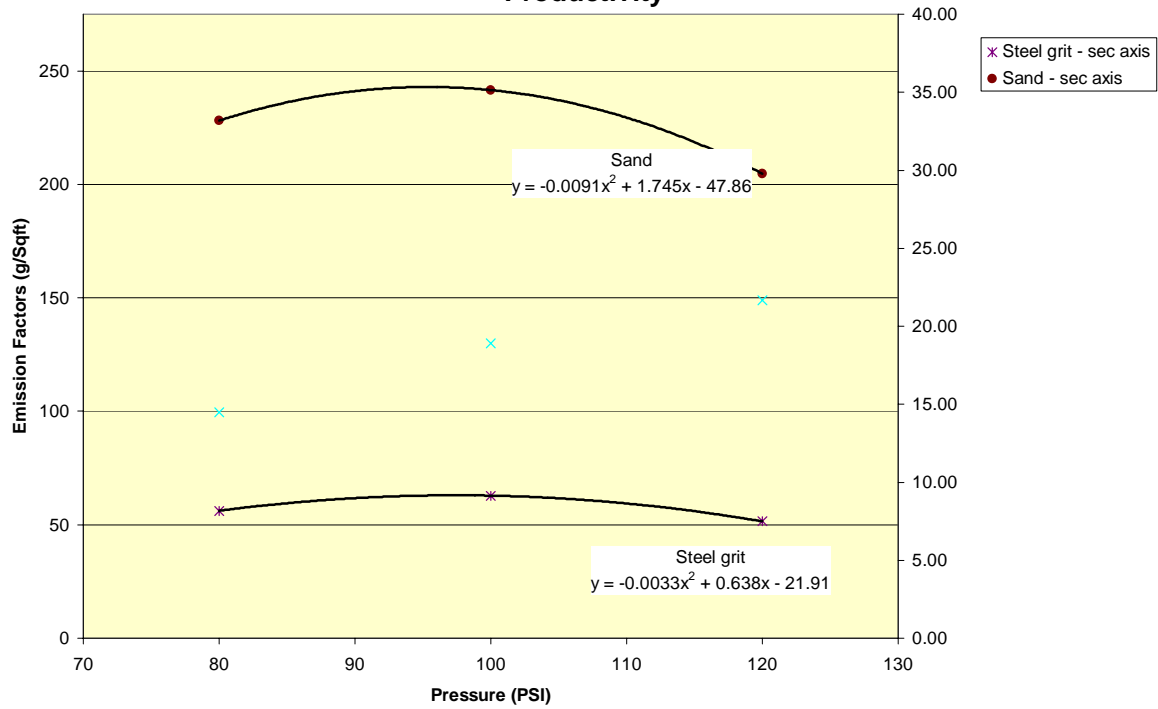


Figure X-28: Pressure vs Emission Factors (g/lb) at Maximum Productivity

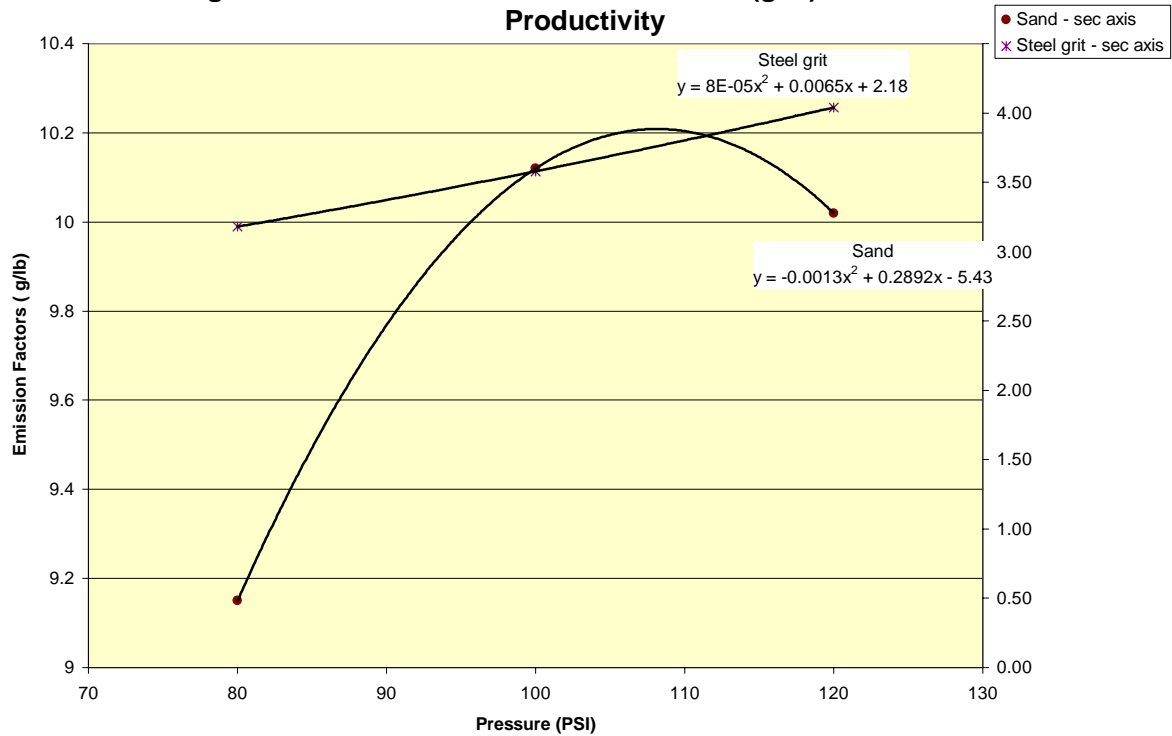


Figure X-29: Feed Rate vs Emission Factors (gm/lb) at Maximum Productivity

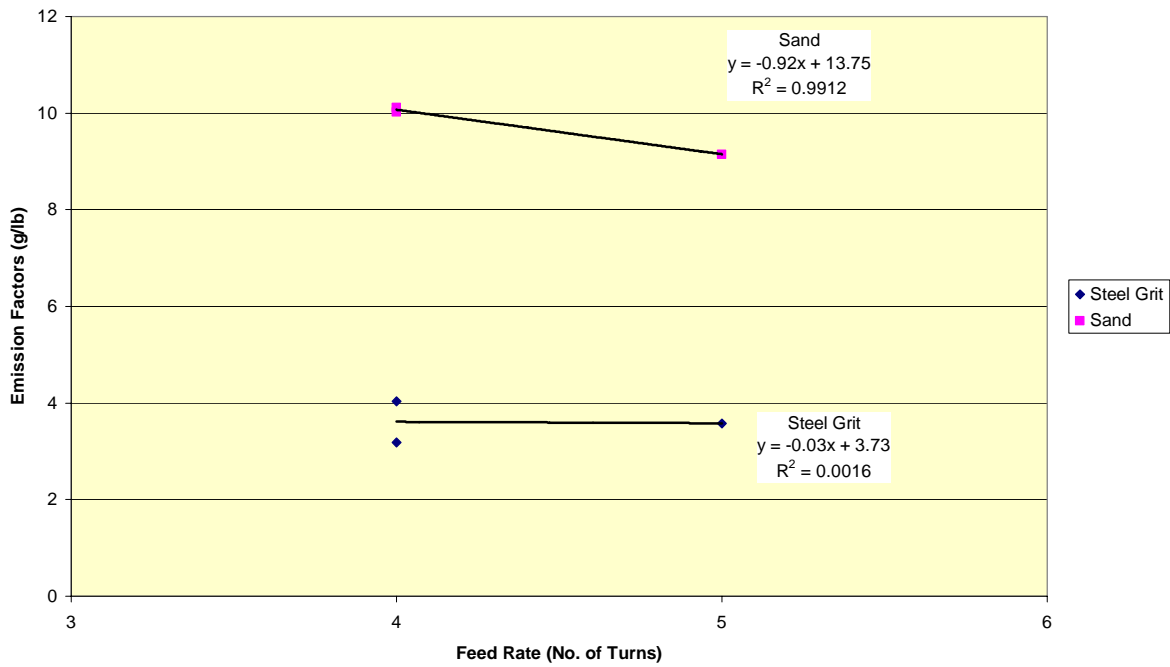


Figure X-30: Pressure vs Consumption

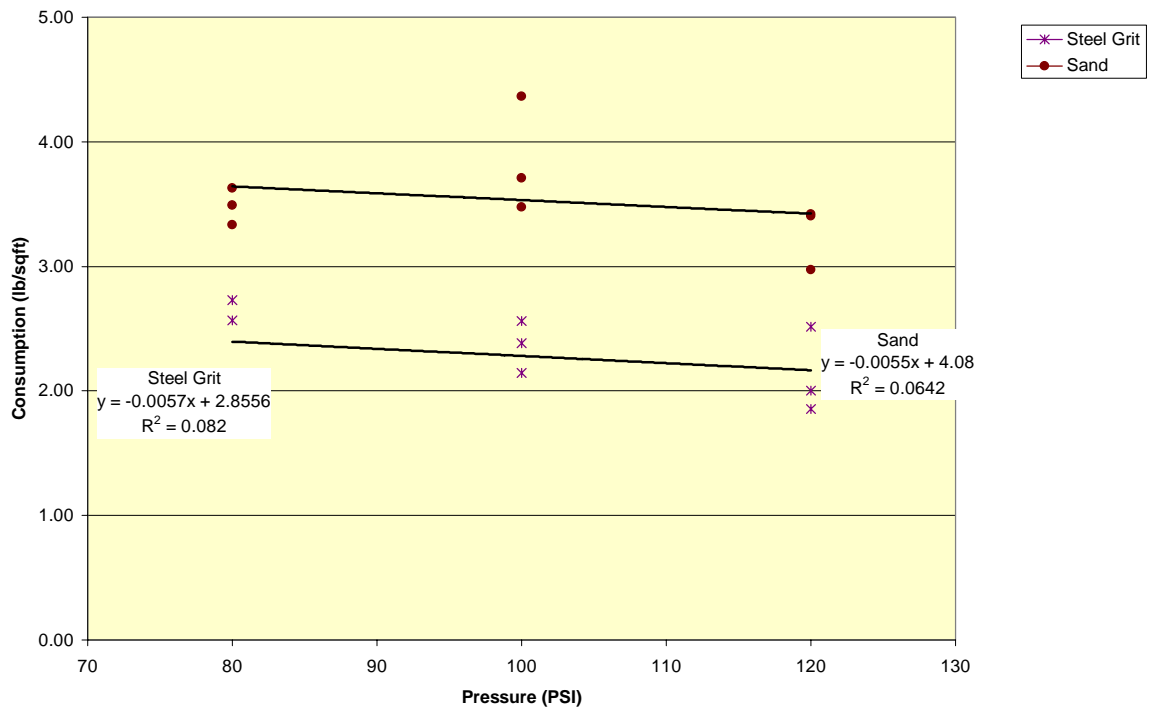


Figure X-31: Feed Rate vs Consumption at 80 PSI

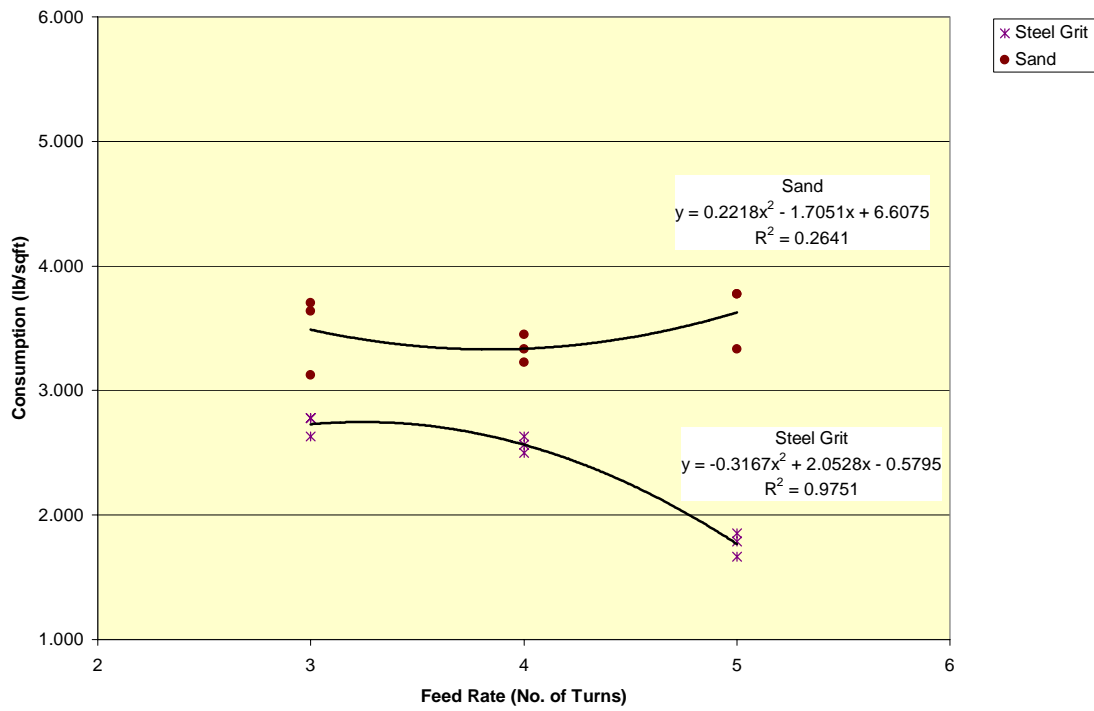


Figure X-32: Feed Rate vs Consumption at 100 PSI

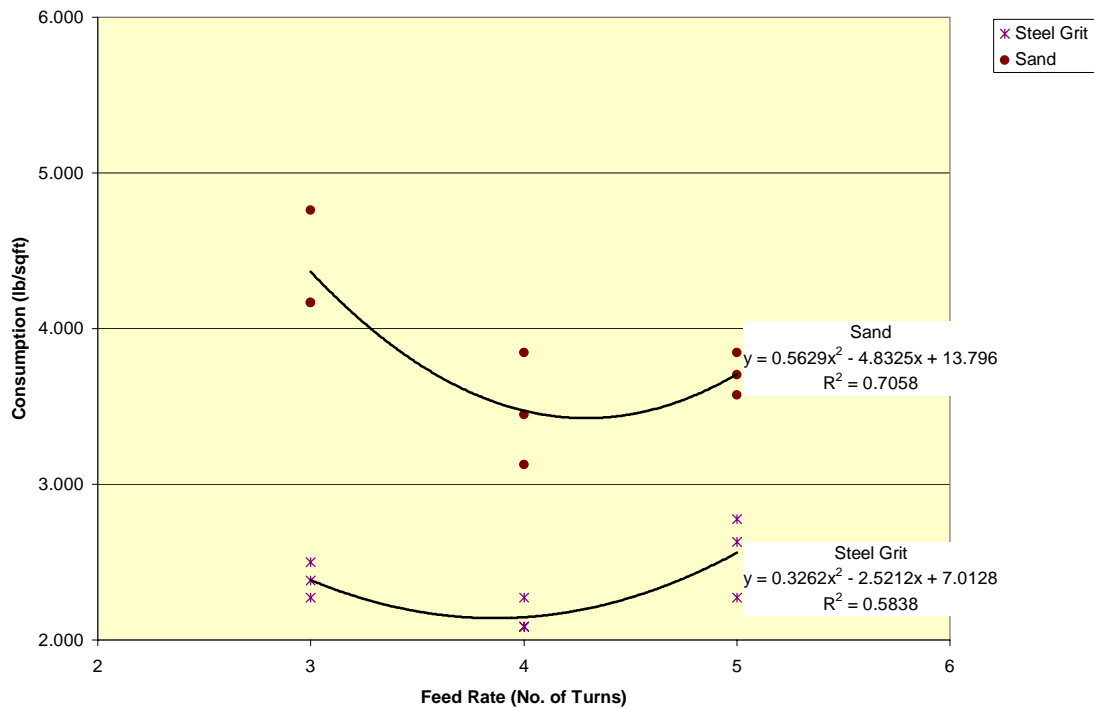


Figure X-33: Feed Rate vs Consumption at 120 PSI

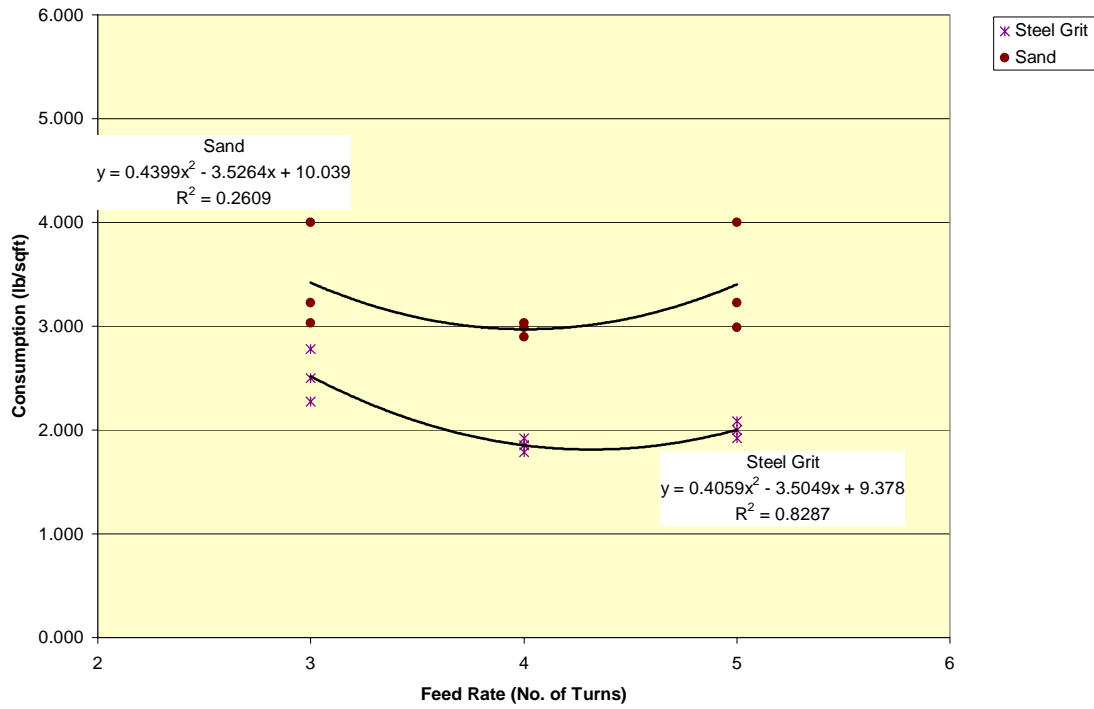
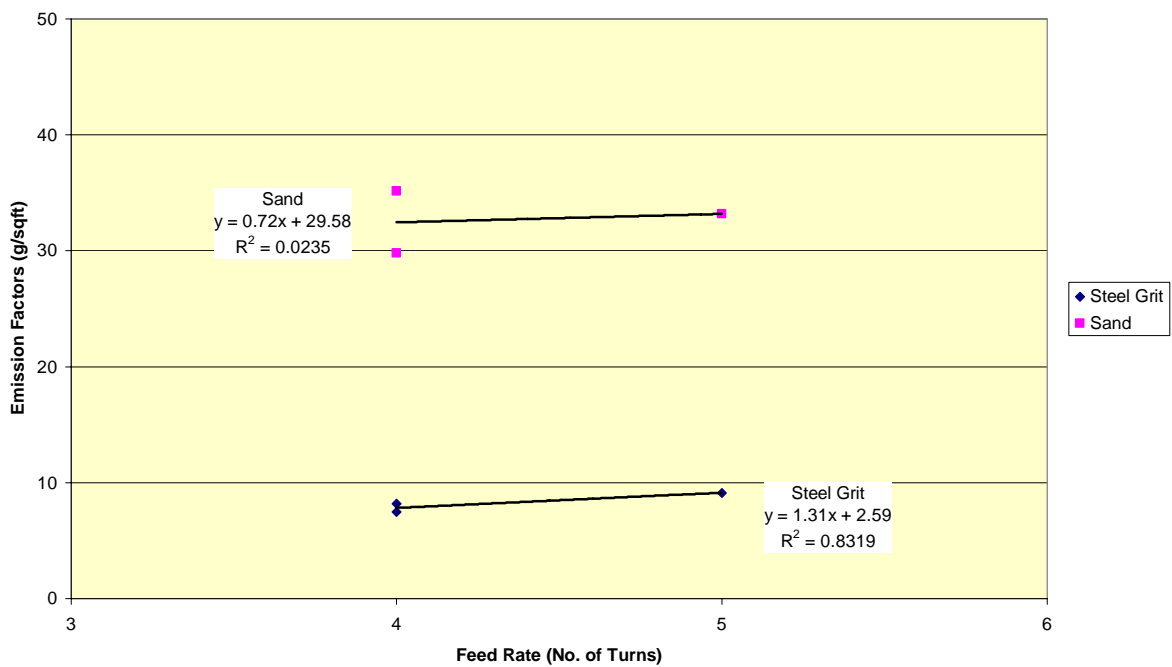


Figure X-34: Feed Rate vs Emission Factors (g/sqft) at Maximum Productivity



Tables X-5 through X-20 shows the equations obtained from the figures X-17 through X-34.

Description		Feed Rate vs. Productivity	
Dependent variable, y		Productivity (sqft/hr)	
Independent variable, x		Feed Rate (No. of Turns)	
Abrasive	Parameter	Equation	R ²
	Pressure		
Steel grit	120	$y = 4.0754x^2 - 35.329x + 270.83$	0.8037
	100	$y = 110.7x^2 - 877.91x + 1876.1$	0.8781
	80	$y = -11.325x^2 + 95.812x - 7.0513$	0.6071
Sand	120	$y = -39.49x^2 + 316.37x - 409.21$	0.9704
	100	$y = -15.776x^2 + 131.85x - 129.82$	0.901
	80	$y = 1.2575x^2 - 5.198x + 129.25$	0.7168

Table X-5: Equations for Feed Rate vs. Productivity graphs.

Description		Feed Rate vs. EF (g/sqft)	
Dependent variable, y		Emission Factors (g/sqft)	
Independent variable, x		Feed Rate (No. of Turns)	
Abrasive	Parameter	Equation	R ²
	Pressure		
Steel grit	120	$y = 1.719x^2 - 14.275x + 37.091$	0.8618
	100	$y = 0.7709x^2 - 5.1314x + 15.528$	0.7814
	80	$y = -1.3351x^2 + 9.9666x - 10.339$	0.8934
Sand	120	$y = 4.5589x^2 - 33.207x + 89.668$	0.5177
	100	$y = 5.472x^2 - 46.3x + 132.79$	0.6954
	80	$y = 2.2521x^2 - 16.845x + 61.105$	0.402

Table X-6: Equations for Feed Rate vs. Emission Factors (g/sqft) graphs.

Description		Feed Rate vs. EF (g/lb)	
Dependent variable, y		Emission Factors (g/lb)	
Independent variable, x		Feed Rate (No. of Turns)	
Abrasive	Parameter	Equation	R ²
	Pressure		
Steel grit	120	$y = 0.0688x^2 - 0.32x + 4.221$	0.7614
	100	$y = -0.1445x^2 + 1.4605x - 0.1132$	0.853
	80	$y = -0.0655x^2 + 0.8715x + 0.7452$	0.773
Sand	120	$y = 0.0607x^2 + 0.4754x + 7.1514$	0.8925
	100	$y = -0.0429x^2 + 0.5373x + 8.6625$	0.7335
	80	$y = 0.0745x^2 - 0.4422x + 9.4983$	0.95

Table X-7: Equations for Feed Rate vs. Emission Factors (g/lb) graphs.

Description	Pressure vs. Productivity at Max. Productivity
Dependent variable, y	Productivity (sqft/hr)
Independent variable, x	Pressure (PSI)
<i>Abrasive</i>	<i>Equation</i>
Steel grit	$y = -0.0537x^2 + 12.625x - 471$
Sand	$y = 0.0861x^2 - 14.967x + 781.3$

Table X-8: Equations for Pressure vs. Productivity at Max. Productivity graphs.

Description	Pressure vs. EF at Max. Productivity
Dependent variable, y	Emission Factors (g/sqft)
Independent variable, x	Pressure (PSI)
<i>Abrasive</i>	<i>Equation</i>
Steel grit	$y = -0.0033x^2 + 0.638x - 21.91$
Sand	$y = -0.0091x^2 + 1.745x - 47.86$

Table X-9: Equations for Pressure vs. EF (g/sqft) at Max. Productivity graphs.

Description	Pressure vs. EF at Max. Productivity
Dependent variable, y	Emission Factors (g/lb)
Independent variable, x	Pressure (PSI)
<i>Abrasive</i>	<i>Equation</i>
Steel grit	$y = 0.0065x + 2.18$
Sand	$y = -0.0013x^2 + 0.2892x - 5.43$

Table X-10: Equations for Pressure vs. EF (g/lb) at Max. Productivity graphs.

Description		Material Feed Rate vs. Productivity	
Dependent variable, y		Productivity (sqft/hr)	
Independent variable, x		Material Feed Rate (lb/min)	
<i>Abrasive</i>	<i>Parameter</i>	<i>Equation</i>	<i>R²</i>
	Pressure		
Steel grit	120		
	100	$y = -1.3029x^2 + 41.05x - 33.567$	0.9492
	80	$y = 9.9216x^2 - 137.76x + 648$	0.237
Sand	120	$y = -10.91x^2 + 240.54x + 1110.8$	0.6659
	100	$y = 5.9119x^2 - 107.16x + 615.93$	0.1242
	80	$y = 5.1334x^2 - 74.554x + 397.86$	0.5195

Table X-11: Equations for Material Feed Rate vs. Productivity graphs.

Description		Material Feed Rate vs. EF (g/sqft)	
Dependent variable, y		Emission Factors (g/sqft)	
Independent variable, x		Material Feed Rate (lb/min)	
Abrasive	Parameter	Equation	R²
	Pressure		
Steel grit	120		
	100	$y = 0.0838x^2 - 1.1297x + 10.83$	0.5159
	80	$y = -0.4703x^2 + 7.1425x - 19.048$	0.8225
Sand	120	$y = 1.3885x^2 - 27.858x + 169.86$	0.4357
	100	$y = -1.6835x^2 + 34.352x - 131.21$	0.6909
	80	$y = -1.1704x^2 + 21.496x + 63.749$	0.9195

Table X-12: Equations for Material Feed Rate vs. EF (g/sqft) graphs.

Description		Material Feed Rate vs. EF (g/lb)	
Dependent variable, y		Emission Factors (g/lb)	
Independent variable, x		Material Feed Rate (lb/min)	
Abrasive	Parameter	Equation	R²
	Pressure		
Steel grit	120		
	100	$y = 0.0247x^2 - 0.3997x + 4.7592$	0.2534
	80	$y = 0.0074x^2 - 0.2854x + 4.8206$	0.5131
Sand	120	$y = -0.0976x^2 + 2.0293x - 0.329$	0.0365
	100	$y = -0.0601x^2 + 0.9023x + 6.8077$	0.4052
	80	$y = 0.0466x^2 - 0.5884x + 10.745$	0.3679

Table X-13: Equations for Material Feed Rate vs. EF (g/lb) graphs.

Description		Feed Rate vs. EF (g/lb) at Max. Productivity	
Dependent variable, y		Emission Factors (g/lb)	
Independent variable, x		Feed Rate (number of turns)	
Abrasive		Equation	
Steel grit		$y = -0.03x + 3.73$	
Sand		$y = -0.92x + 13.75$	

Table X-14: Equations for Feed Rate vs. Emission Factors (g/lb) at Max. Productivity.

Description	Pressure vs. Consumption (lb/sqft)
Dependent variable, y	Consumption (lb/sqft)
Independent variable, x	Pressure (PSI)
Abrasive	Equation
Steel grit	$y = -0.0057x + 2.8556$
Sand	$y = -0.0055x + 4.08$

Table X-15: Equations for Pressure vs. Consumption (lb/sqft)

Description	Feed rate vs. EF at Max. Productivity
Dependent variable, y	Emission Factors (g/lb)
Independent variable, x	Feed rate (number of turns)
Abrasive	Equation
Steel grit	$y = 1.31x + 2.59$
Sand	$y = 0.72x + 29.58$

Table X-16: Equations for Feed rate vs. EF (g/sqft) at Max. Productivity graphs.

Description		Feed Rate vs. Consumption (lb/sqft)	
Dependent variable, y		Consumption (lb/sqft)	
Independent variable, x		Feed Rate (number of turns)	
Abrasive	Parameter	Equation	R²
	Pressure		
Steel grit	120	$y = 0.4059x^2 - 3.5049x + 9.378$	0.8287
	100	$y = 0.3262x^2 - 2.5212x + 7.0128$	0.5838
	80	$y = -0.3167x^2 + 2.0528x - 0.5795$	0.9751
Sand	120	$y = 0.4399x^2 - 3.5264x + 10.039$	0.2609
	100	$y = 0.5629x^2 - 4.8325x + 13.796$	0.7058
	80	$y = 0.2218x^2 - 1.7051x + 6.6075$	0.2641

Table X-17: Equations for Feed Rate vs. Consumption graphs.

Description		Feed Rate vs. Consumption (lb/sqft)	
Dependent variable, y		Consumption (lb/sqft)	
Independent variable, x		Material Feed Rate (lbs/min)	
Abrasive	Parameter	Equation	R²
	Pressure		
Steel grit	120		
	100	$y = 0.0066x^2 - 0.0414x + 2.1998$	0.6384
	80	$y = -0.018x^2 + 0.2125x + 1.9682$	0.2924
Sand	120	$y = 0.1726x^2 - 3.486x + 20.546$	0.8206
	100	$y = 0.16x^2 - 3.561x + 23.403$	0.2966
	80	$y = 0.0918x^2 - 2.0372x + 14.639$	0.3496

Table X-18: Equations for Material Feed Rate vs. Consumption graphs.

7.0 Conclusions

This study provides the productivity, consumption, and emission factors data for dry abrasive blasting for two abrasives namely, Steel Grit which is a metallic abrasive and Specialty Sand which is a non-metallic abrasive.

The general trend observed shows that productivity (sqft/hr) increases with feed rate and then decreases and the maximum productivity was observed in a majority of the cases at a feed rate corresponding to 4 turns open condition of the Schmidt valve. This can be read from the feed rate vs. productivity plots for the individual abrasives. Emission factors increase with the increase in feed rate at a constant pressure but this trend is not quite comparable for these two abrasives.

- From the feed rate vs. productivity plots, it can be observed that at 80 PSI, 100 PSI, and 120 PSI Steel Grit shows maximum productivity.
- From the feed rate vs. emission factors (gm/sqft) plots, the hierarchy can be observed as follows:
 - 80 PSI: Specialty Sand > Steel Grit.
 - 100 PSI: Specialty Sand > Steel Grit.
 - 120 PSI: Specialty Sand > Steel Grit.
- From the feed rate vs. emission factors (g/lb) plots, the hierarchy can be observed as follows:
 - 80 PSI: Specialty Sand > Steel Grit.
 - 100 PSI: Specialty Sand > Steel Grit.
 - 120 PSI: Specialty Sand > Steel Grit.

- Emission factor data documented in AP42 for uncontrolled emissions using Steel Grit in a ventilation system duct is 0.010 lb/lb. This corresponds to a data accuracy ranking of “D”. Our data for Steel Grit under similar conditions falls in the range of 0.0061 lb/lb to 0.010 lb/lb. All the runs were conducted in an enclosed chamber of size 12' x 10' x 8' ventilated with a fan operated at 60 rpm, blasting was conducted using number #6 nozzle.
- Steel Grit has a high density owing to which it gets less air borne. It should be noted that Steel Grit can also be recycled at least 50 times as recommended by the suppliers.

8.0 Recommendations

Following are the recommendations that can be stated after being part of this research. Further understanding of the process involved in dry abrasive blasting is required and more data should be published in order to compare results. Additional studies have to be done and several field experiments should be performed on other metallic and non-metallic abrasives in order to create a bigger database which would facilitate corresponding industries that benefit from these studies. Surface preparation on painted panels is also required in order to solve real life problems or situations in certain industries such as shipyards. Although Steel Grit has recycling capabilities, the tests performed in this study were done for the first use of Steel Grit with no recycling. Such reusable abrasive materials should be tested for second and third passes to observe its change in productivity, consumption, and particulate emissions.

9.0 Benefits

Economic and environmental factors can be influenced by the assistance of the data generated in this study. This research can be beneficial for many agencies involved in the environmental sector. Shipbuilding and ship repair costs can be lowered considerably using the produced data. As blasting is a major process in shipyards, this process can be optimized by using environmental performance models generated in the research. This research aids in protecting the environment by the selection of appropriate abrasives and process parameters. It also helps shipyards in obtaining air permits based on true emission factor data. This research could be helpful to environmental regulatory agencies in their permitting activities. Health risk assessment studies can benefit from this study in figuring out the pollution aspects corresponding to the use of the abrasive materials discussed.

References

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4. National Shipbuilding Research Program, Facilities and Environmental Effects Panel
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Sources. Project No. N1-97-04. September 1999.
5. Applications of Abrasive materials
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7. EPA - The Plain English Guide to Clean Air Act.
http://www.epa.gov/oar/oaqps/peg_caa/pegcaa03.htm
8. Air Pollution Control Engineering, Noel De Nevers (2000)
9. Applications of Steel Grit: <http://www.shengli-abrasive.com/leaf/table8.htm>
10. Air Pollution Control Equipment, Louis Theodore, Anthony J. Buonicore (1998)

Appendices

Appendix A

Material Safety Data Sheet for Steel Grit



METgrit MATERIAL SAFETY DATA SHEET

GENERAL INFORMATION

Manufacturer: Chesapeake Specialty Products, Inc.
5055 North Point Boulevard
Baltimore, MD 21219

Creation Date: November, 1995
Revised Date: May, 2003

For Additional Information, contact:
Occupational Health & Safety Division
(410) 388-5055

MSDS Code: A181

PRODUCT IDENTIFICATION

Product Name: METgrit

Formula: NA

Synonym(s): Metallic Abrasive

Chemical Family: Iron

TYPICAL CHEMICAL COMPOSITION (1)

<u>Ingredients*</u>	<u>CAS No.</u>	<u>Wt. %</u>	<u>OSHA PEL</u>	<u>ACGTH TLV</u>
Iron	7439-89-6	94.0	NA	NA

May contain other trace elements such as Calcium Oxide, CAS No. 1305-78-8; Fused Silica Oxide, CAS No. 60676-86-0; Magnesium Oxide, CAS No. 1309-48-4; Aluminum Oxide CAS No. 1344-28-1; Sulfur, CAS No. 7704-34-9; Manganese Oxide, CAS No. 7439-96-5; Potassium Oxide, CAS No. 12136-45-7; Sodium Oxide, CAS No. 12401-86-4; Titanium Oxide, CAS No. 13463-67-7; and Ferric Oxide, CAS No. 1309-37-1

* Since METgrit is manufactured from materials mined from the earth, and process heat is provided by burning fuels derived from the earth, trace but detectable amounts of naturally occurring metals, and possibly harmful elements may be found during chemical analysis. Ingredients are expressed as oxides for quantitative purposes. Actual oxides do not generally occur in "free form" but rather as complexed silica-based glasses or crystals.

METgrit CHESAPEAKE SPECIALTY PRODUCTS, INC.

PHYSICAL DATA

Physical State:	Specific Gravity
Solid	6.8 – 7.4 g/cm ³
Appearance and Odor:	Vapor Pressure:
Gray / brown particales	NA
Boiling Point:	Vapor Density:
NA	NA
Melting Point:	Evaporation Rate:
NA	NA
Solubility in Water:	% Volatile by Volume:
NA	NA

This product does not meet the criteria of a hazardous chemical as defined by the Federal Occupational Safety and Health Hazard Communication Standard (29 CFR 1910.1200(c). This form is being provided solely as general information and should not be construed as a determination that the product is a hazardous chemical. All sales of this product are subject to CHESAPEAKE'S Standard Terms and Conditions of Sale. CHESAPEAKE MAKES NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING THE IMPLIED WARRANTY OF MERCHANTABILITY, ANY IMPLIED WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR ANY IMPLIED WARRANTIES OTHERWISE ARISING FROM COURSE OF DEALING OR TRADE.

pH:	Particle Size Distribution:
NA	99% of the particles are greater than 100 microns in diameter.

FIRE AND EXPLOSION HAZARD DATA

Flash Point (Method):	Lower Explosive Limit:
NA	NA
Autoignition Temperature:	Upper Explosive Limit:
NA	NA
Fire Hazard:	Explosive Hazards:
NA	NA

METgrit is non-combustible and not explosive. Therefore there are no flammable or explosive limits nor unusual fire and explosion hazards.

METgrit CHESAPEAKE SPECIALTY PRODUCTS, INC.

REACTIVITY DATA

Stability:

Stable

Incompatibilities (Materials to avoid):

Metallic abrasives when wet may react with aluminum powder and other alkali and alkaline earth elements to liberate hydrogen gas. Hydrogen Sulfide gas may be released if the metallic abrasive comes in contact with acids. Hydrogen Sulfide is a toxic gas.

Polymerization:

Will not occur

HEALTH HAZARD DATA

OSHA (Occupational Safety and Health Administration), MSHA (Mine Safety and Health Administration), and ACGIH (American Conference of Governmental Industrial Hygienists), classify the (PEL) Permissible Exposure Limit as 5 mg/m³ for respirable dust and 10 mg/m³ for total dust; for an 8 hour period. Metallic abrasive is not known to cause cancer, however, some people believe crystalline silica can cause cancer. Free titanium oxide has been classified as having limited evidence of causing cancer in animals. Exposure to metallic abrasive dust can affect the skin, the eyes, and mucous membranes.

Acute Exposure:

Powder phase, particularly when in contact with water can dry the skin and can cause alkali burns. The dust can irritate the eyes and upper respiratory system.

Chronic Exposure:

Dust from the powder phase can cause inflammation of the lining tissue of the interior of the nose.

Emergency First Aid Procedures:

Irrigate (flush) eyes immediately and repeatedly with clean water for up to 15 minutes. Get prompt medical attention. Wash exposed skin areas with soap and water. If ingested, consult a physician immediately. Drink water.

OCCUPATIONAL EXPOSURE CONTROL MEASURES

Engineering Controls (Ventilation, etc.):

Ventilation should be sufficient to maintain dust levels below the applicable exposure limit for nuisance dust

Work Practices (Handling and Storage):

Use in such a manner as to avoid creating large amounts of dust

Eye Protection:

Safety glasses or goggles are recommended when dust levels are excessive

Skin Protection:

Barrier creams, impervious gloves, boots, and clothing are recommended when dust levels are excessive. Following work with metallic abrasives, workers should shower with soap and water.

Respiratory Protection:

If ventilation does not control exposure levels below the applicable exposure limit for nuisance dust, an OSHA, MSHA, or NIOSH-approved respirator for dusts should be worn

METgrit CHESAPEAKE SPECIALTY PRODUCTS, INC.

SPILL, LEAK AND DISPOSAL INFORMATION

Procedures to Follow if Material is Released or Spilled:

If metallic abrasive is spilled, it can be cleaned up using dry methods that do not disperse dust into the air. Avoid breathing the dust. Emergency procedures are not required since there are no hazardous substances in the ground slag as supplied.

Waste Disposal Methods:

Landfill disposal and other methods which are in accordance with local, state and federal regulations. Metallic abrasive can be treated as a common waste for disposal.

ADDITIONAL OR MISCELLANEOUS INFORMATION

If material is stored in bulk in a closed or confined area, precautions should be observed prior to entering the area. Oxidizing material may deplete the oxygen content of the storage area creating a hazard to entering personnel. If concern arises regarding the safety of entering the area, the oxygen should be checked and, if low, the enclosure should be ventilated until the oxygen level reaches at least 19.5%.

=====

Footnotes:

- (1) Concentrations may vary somewhat between batches or lots. Where possible, a concentration range is indicated. Occasionally, however, levels may even fall outside of the usual concentration ranges.
- (2) Common names, if applicable, appear in parentheses following the chemical names.
- (3) All values, unless otherwise specified, refer to 8-hour time-weighted average concentrations and units are in mg/M.

Abbreviations:

NA = Not Applicable
NE = Not Established
UK = Unknown (No applicable information was found)
GT = Greater Than
LT = Less Than

Material Safety Data Sheet for Specialty Sand

1. PRODUCT/COMPANY IDENTIFICATION

Manufacturer's Name & Address:

Titan America LLC

1151 Azalea Garden Rd.

Norfolk, VA 23502

Telephone Number for Information:

1.800.468.7622

Emergency Telephone:

1.757.858.6500

2. COMPOSITION INFORMATION

Chemical Name CAS Registry Number % (approx.)

Natural Sand* NA 100

*May contain crystalline silica 14808-60-7 >1

3. PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point N/A

Specific Gravity (H₂O = 1) 2.55-2.80

Vapor Pressure (mm Hg) N/A

Melting Point N/A

Vapor Density (AIR-1) N/A

Evaporation Rate N/A

Solubility in Water Not soluble

Appearance & Odor Fine grains, yellow to white in color; no odor.

4. FIRE AND EXPLOSION HAZARD DATA

Flash Point N/A

Extinguishing Media N/A

Special Fire Fighting Procedures None

Unusual Fire & Explosion Hazards None

Flammable Limits N/A

LEL N/A

UEL N/A

Trade Name:

Sand

Chemical Name and Synonyms

Natural Sand*, Construction Aggregate

Department of Transportation Identification No.:

None

*Composition varies naturally, typically contains crystalline silica

5. REACTIVITY DATA

Stability: Stable. Avoid contact with incompatible materials.

Incompatibility: Contact with powerful oxidizing agents such as fluorine, boron trifluoride, chlorine trifluoride,

manganese trifluoride, and oxygen difluoride may cause fire and/or explosions. Silica dissolves in hydrofluoric acid producing a corrosive gas-silicon tetrafluoride.

Hazardous Decomposition or Byproducts: Respirable dust particles may be generated when sand is moved or ground.

Hazardous Polymerization: Will not occur. No conditions to avoid.

6. HEALTH HAZARD DATA AND FIRST AID

EXPOSURE LIMITS:

Unless specified otherwise, limits are expressed as a time-weighted average (TWA) concentration for an 8-hour work shift of a 40-hour workweek.

Limits for cristobalite and tridymite (other forms of crystalline silica) are equal to one-half the limits for quartz.

ABBREVIATIONS:

ACGIH TLV: Threshold limit value of the American Conference of Governmental Industrial Hygienists (ACGIH).

mg/m₃: Milligrams of substance per cubic meter of air.

NIOSH REL: Recommended exposure limit of the National Institute for Occupational Safety and Health (NIOSH), expressed as a TWA concentration for up to a 10-hour work-day during a 40-hour workweek.

OSHA PEL: Permissible exposure limit of the federal Occupational Safety and Health Administration (OSHA).

Crystalline Silica SiO₂: OSHA PELs (respirable fraction) $[10 \text{ mg/m}_3 \div (\% \text{ SiO}_2 + 2)]$, (total dust) $[30 \text{ mg/m}_3 \div (\% \text{ SiO}_2 + 2)]$; ACGIH TLV (respirable fraction) 0.05 mg/m₃, NIOSH REL (respirable fraction) 0.05 mg/m₃.

Other Particulates: OSHA PEL (total particulate, not otherwise regulated) 15 mg/m₃, (respirable particulate, not otherwise regulated) 5 mg/m₃, ACGIH TLV (nuisance particulates) 10 mg/m₃ (inhalable), 5 mg/m₃ (respirable).

HEALTH HAZARDS:

Primary Route(s) of Entry:

Inhalation: Yes

Skin: No

Ingestion: No

Acute:

Eye Contact: Minor irritation to the eyes or nose.

Inhalation: Dusts may irritate the nose, throat, and respiratory tract by mechanical abrasion. Coughing, sneezing, and shortness of breath may occur following exposures in excess of appropriate exposure limits.

Skin Contact: Direct contact may cause irritation by mechanical abrasion.

Ingestion: Expected to be practically non-toxic. Ingestion of large amounts may cause gastrointestinal irritation and blockage.

Chronic:

Inhalation: Chronic exposure to respirable dust in excess of appropriate exposure limits may cause lung disease. Silicosis may result from excessive exposure to respirable silica dust for prolonged periods. Not all individuals with silicosis will exhibit symptoms. Silicosis is progressive and symptoms can appear at any time, even after exposure has ceased. Symptoms may include shortness of breath, coughing, or right heart enlargement and/or failure. Persons with silicosis have an increased risk of pulmonary tuberculosis infection. Tobacco smoking may increase the risk of developing lung disorders, including emphysema and lung cancer.

Carcinogenicity: Crystalline silica is classified by the International Agency for Research on Cancer (IARC) as a carcinogenic to humans (Group 1). The National Toxicology Program (NTP) has characterized respirable silica as “known to be a human carcinogen”. Prolonged and repeated breathing of silica may cause lung cancer.

Signs & Symptoms of Exposure: Dust irritation of eyes and/or respiratory system.

Medical Conditions Generally Aggravated by Exposure: Inhaling respirable dust may aggravate existing respiratory system disease(s) and/or dysfunctions such as emphysema or asthma. Exposure may aggravate existing eye conditions.

EMERGENCY & FIRST AID PROCEDURES:

Eyes: Immediately flush eye(s) with plenty of clean water for at least 15 minutes, while holding the eyelid(s) open. Beyond flushing, do not attempt to remove material from the eye(s). Contact a physician if irritation persists or later develops.

Inhalation: Remove to fresh air. Dust in throat and nasal passages should clear spontaneously. Contact a physician if irritation persists or later develops.

Skin: Wash with soap and water. Contact a physician if irritation persists or later develops.

Ingestion: If person is conscious, give large quantity of water and induce vomiting; however, never attempt to make an unconscious person drink or vomit. Get immediate medical attention.

7. PERSONAL PROTECTION AND CONTROL MEASURES

Ventilation: Local exhaust or general ventilation adequate to maintain exposures below appropriate exposure limits.

Other: Respirable dust and silica levels should be monitored regularly. Dust and silica levels in excess of appropriate exposure limits should be reduced by all feasible engineering controls, including (but not limited to) wet suppression, ventilation, process enclosure, and enclosed employee work stations.

Respiratory Protection: When dust or silica levels exceed or are likely to exceed appropriate exposure limits, follow MSHA or OSHA regulations, as appropriate, for use of NIOSH-approved respiratory protection equipment.

Skin Protection: Protective gloves should be worn to prevent mechanical injury.

Eye Protection: Safety glasses with side shields should be worn as minimum protection. Dust goggles should be worn when excessive (visible) dust conditions are present or anticipated. Contact lenses should not be worn when working with this product.

Hygiene: Ordinary personal hygiene.

8. STORAGE AND HANDLING PRECAUTIONS

Respirable silica and dust may be generated during processing, handling, and storage. The personal protection and controls identified in Section VII of the MSDS should be applied as appropriate.

9. SPILL, LEAK AND DISPOSAL PRACTICES

The personal protection and controls identified in Section VII of the MSDS should be applied as appropriate.

Steps to Be Taken if Material Is Released or Spilled: Spilled materials, where dust can be generated, may overexpose cleanup personnel to respirable silica and dust. Wetting of spilled material and/or use of respiratory protective equipment may be necessary. Do not dry sweep spilled material.

Waste Disposal Method: Dispose of waste materials only in accordance with applicable federal, state, and local laws and regulations.

NOTICE: Based on research of available data, Titan America LLC believes that the information contained in this Material Safety Data Sheet is accurate. The suggested procedures are based on data and experience as of the date of preparation of the MSDS. The suggestions should not be confused with nor

followed in violation of applicable laws, regulations, rules or insurance requirements. Titan America LLC's voluntary preparation of this MSDS should not be construed, in any way, as an agreement to be subject to OSHA jurisdiction.

Appendix B

Environmental Protection Agency (EPA) has laid down the specific methodologies to be followed. Code of Federal register (CFR) 40 Part 60 summarizes the procedures. These methods are formally known as EPA Reference Methods for Stationary Source Air Emissions Testing. The methods followed in the experiment are Method 1, Method 2, Method 4, and Method 5.

Method 1: Location of sampling port and traverse points.

Method 2: Velocity measurement in the duct.

Method 4: Computation of dry molecular weight.

Method 5: Determination of particulate emissions from stationary sources.

These methods are explained in short in the following paragraphs with significance to the project.

Method 1: Location of sampling sort in the duct

The sampling port is the small cross sectional area cut on the surface of the duct. Through the sampling port the pitot tube can be inserted to take the representative sample of the gas stream flowing through the duct. To help in getting the representative sample of the gas stream, the cross section of the duct is divided into smaller sections and traverse points are marked as the precise sampling points. The minimum number of points needed to make measurements depends on the extent of turbulence or the disturbance to the flow. The turbulence or disturbance is defined as the change in cross section of the duct or change in the direction of the duct.

According to EPA method 1, the disturbance to the flow is considered to be near the site if the measurement location is within eight duct diameters downstream of the disturbance where a change in diameter or direction might disturb the flow lines, or less than two duct diameters upstream of the sampling location. In this study, we achieved the condition of having distances of 8 duct diameters downstream of the disturbance and 2 duct diameters upstream of the disturbance. For applications where it is not possible to meet these criteria to locate sampling ports, the EPA methods provide a procedure for calculating and locating a larger number of measurement locations needed to properly characterize the disturbed flow.

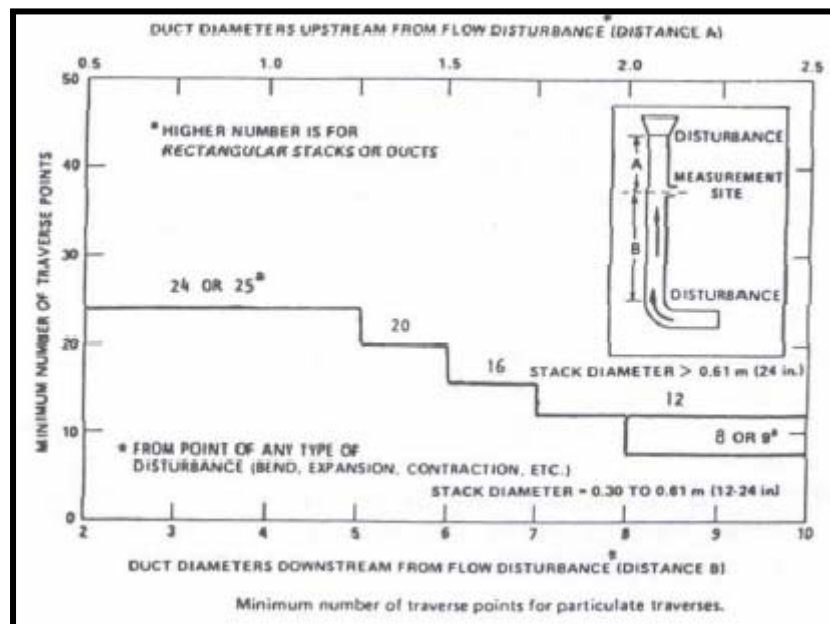


Figure BX-1: Graph Showing Minimum Number of Points.

According to EPA Method 1, the minimum number of points required for the 12-inch diameter and for meeting the 8 duct diameter and 2 duct diameter conditions are 8 traverse points (for circular duct).

Method 2: Velocity Measurement in the Duct

As the name indicates, this method helps in determining the velocity of the gas in the duct and eventually the flow rate of the gas.

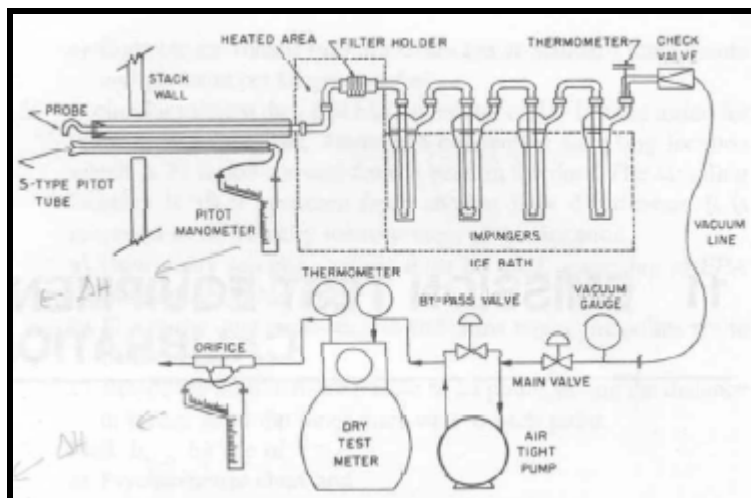


Figure BX-2: Arrangement of Pitot tube and Sampling Probe

The Pitot tube along with the sampling probe is inserted to the desired locations as determined by Method 1 and samples are collected. The pitot tube helps in determining the velocity of the gas stream and the sampling probe helps in getting a representative sample. For the sample to be representative the velocity of the gas in the stack and the velocity of the gas in the nozzle of the sampling probe should be equal. This is called isokinetic sampling. If the velocities are not equal, the gas flow lines around the tip of the nozzle will become disturbed. Achieving the isokinetic sampling was one of the important parts of the project. The velocity in the nozzle (V_n) should be equal to velocity in the stack (V_s). In the experiment, Iso-kinetic sampling achieved at the nozzle size of 0.018 inch.

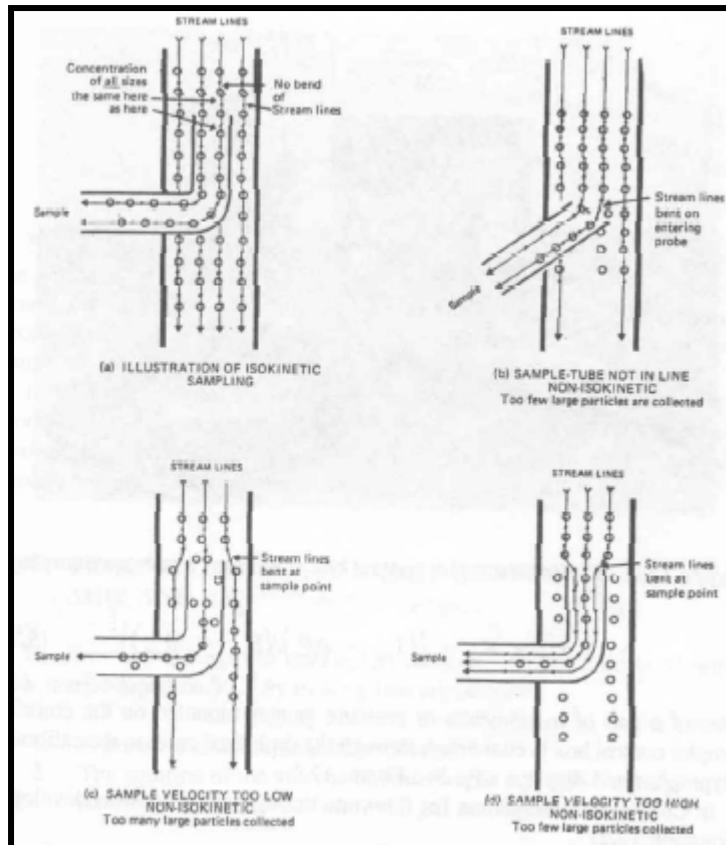


Figure BX-3: Iso-kinetic Sampling

Method 4: Computation of Dry Molecular Weight

In air pollutant emissions testing, the ultimate use of the molecular weight is in the calculation of the gas velocity and flow rate. For this purpose, however, the total or “wet” molecular weight is needed. It is the purpose of EPA Method 4 to measure the gas moisture or H₂O content and allow the calculation of total molecular weight.

EPA reference Method 4 for measurement of moisture content in a gas stream is a combined condensation and adsorption method. The sample is first drawn through a heated probe where its temperature is kept above the dew point to prevent condensation. The gas then passes through the condenser, where its temperature is

brought below the dew point and the vapor is allowed to condense out. Next the gas then passes through a hygroscopic medium (silica gel adsorbent), where the remaining water vapor is removed. The dry gas sample is then passed through a dry gas meter where its temperature, pressure, and volume are measured.

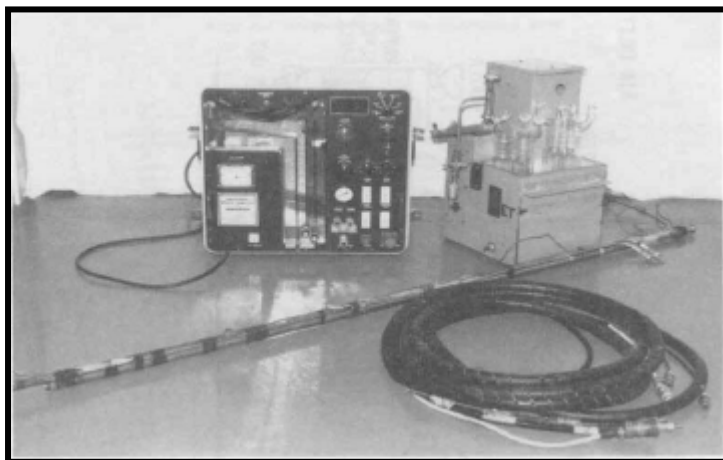


Figure BX-4: Sampler

There are a number of specific requirements for the equipment. Since the objective was to accurately measure the water vapor in the condenser/adsorber section of the apparatus, the probe and sample lines upstream of this section must be inert and heated to avoid condensation. The whole system must be leak free.

Sampling Train

There are totally four impingers in the sampling train. The first two impingers are filled with an accurately measured quantity of water and act as bubblers. The gas is drawn down through the cold water and bubbles up, then travels out to the next impinger. The impingers are known as Greenburg-Smith or modified impingers based on the design. The third impinger is left dry for further condensation; the fourth impinger contains a

quantity of silica gel adsorbent that removes nearly all the remaining water vapor as the gas passes through final exiting.

After sampling is complete, the apparatus is dismantled and the quantity of H₂O collected from sampled gas is measured by the increase in the total volume of water in the first three impingers and the increase in the mass of the silica gel adsorbent.

EPA Method 5

Sample Recovery

After the field tests the sample collected on a filter paper is later analyzed in the laboratory. The method followed in analyzing the test sample is the acetone recovery method. In this method acetone is used to recover the sample. Recover is the word used because using acetone we need to wash the sampling probe and all the parts upstream of filter holder with filter holders. This procedure is repeated until all the visible particles are removed. Then a known amount of sample acetone is kept in the hood until the acetone is evaporated and then the weight of the filter paper and beaker in which the sample is recovered should be noted and, using the emissions equations, the final concentration can be calculated.

Vita

Xavier Silvadasan was born in New Delhi, India in 1977. He graduated with a Bachelor of Engineering in Civil Engineering from Nagpur University, India in 1999 and a Master of Science in Engineering Management from University of New Orleans in 2002. He worked for National Thermal Power Corporation, India as a Civil Engineering Intern from August 1996 to July 1998. His areas of interest are hydrology and hydraulics, water quality, air quality analysis, industrial hygiene and risk assessment.