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Environmental Performance of Coal Slag and Garnet as Abrasives

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ENVIRONMENTAL PERFORMANCE
OF
COAL SLAG AND GARNET AS ABRASIVES

A Thesis

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List of Abbreviations

EPA: Environmental Protection Agency

SPC: Society for Protective Coatings

PSI: Per Square Inch (Pressure Unit)

PM: Particulate Matter

HAP: Hazardous Air Pollutants

DGM: Dry Gas Meter

CFR: Code of Federal Register

NSRP: National Shipbuilding research Program

Abstract

This study was aimed at understanding the environmental performance of two abrasives, coal slag and garnet which are commonly used by shipyards and many other industries in surface preparation of metallic surfaces. Environmental performance evaluated in this study included, (1) productivity (ft^2/hr), (2) consumption and or used-abrasive generation rate (ton/2000 ft^2; lb/ ft^2), (3) particulate emission factors (mg/ft^2; mg/lb; lb/lb; lb/kg; lb/ton).

In order to achieve the study objectives, an emission test facility was built and necessary equipment and materials were procured. Blasting was performed on rusted steel panels inside the test facility and emissions were measured using EPA Source Test Method to quantify particulate emissions. By measuring the area cleaned, blasting time, and the abrasive consumed, environmental performance of coal slag and garnet was evaluated. Simple mathematical models were developed to predict performance based on feed rate and blast pressure.

Garnet was observed to be more productive, less consuming, and more environmentally-friendly compared to coal slag. These study findings will be

valuable in reducing costs, improving productivity, and protecting the environment.

1. Introduction

Abrasive blasting is the process of propelling abrasive particles (material) from blast machines, using the power of compressed air. Abrasive blasting is the main operation in surface preparation in shipyards around the world. There are innumerable applications of abrasive blasting, but broadly they can be summarized into three major categories: 1) surface preparation, 2) surface cleaning and finishing, and 3) shot peening.

Blasting for surface preparation removes unwanted material and leaves a surface ready for coating or bonding. The impact of an angular abrasive roughens the surface to produce a profile or etch. Beyond steel and masonry, blast cleaning under controlled circumstances can strip layers of paint from wooden houses and boats. Along with this, with the advancements in blasting technology with lightweight media (like plastic and wheat starch) and low pressures, blast equipment allows stripping of airplanes, helicopters, cars, trucks and boats without using rotary sanding tools that might damage the surface[1].

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. Surface cleaning includes removing production contaminants and heat scale.

Surface finishing includes deflashing and deburring molded parts, and enhancing visual features. Abrasive blasting can improve a products appearance by removing stains, manufacturing compound residue, corrosion, and tool marks.
To make a metal product or component, manufacturers must cast, cut, bend, stamp, and roll, or weld metal stock to produce the desired shape. Sometimes these processes leave residual stresses in the metal that, if not removed, can cause 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, for example, steel shot, ceramic shot, and glass beads.

The use of abrasive blasting seems to be varied and innumerable, but this process generates a lot of waste in the form of used abrasives and emissions, paint removed, or metal eroded. A fraction by weight of used abrasives escapes into the atmosphere as used abrasives. The waste generated during the abrasive blasting process seems to be a problem for waste management because of the waste disposal laws. The shipyard has to follow a certain track to treat the waste generated depending upon whether it is toxic or not, or hazardous or non hazardous.

Most commonly used abrasives are sand, coal slag, copper slag, garnet, hematite, and steel shot depending on the purpose and cost estimates involved in the project. The main problem of the waste generation is mismanagement and

lack of proper understanding of the intricate relationships between various parameters in the process.

The blasting process is basically composed of three main elements namely an air compressor, a blast machine and the abrasive. Each component contributes towards the overall performance of the system. The saying “No chain is stronger than its weakest link,” applies appropriately to abrasive blast equipment. Within each of the three major components of the blast system, the quality and performance of key elements affect that component’s effectiveness and the effectiveness of the entire system.

1.1 Need for the Research

A survey[2] was conducted by National Shipbuilding Research program (NSRP) for the shipyards regarding the popular blasting material and general blast pressures used. The important points considered for the survey are as follows:

1. Total Particulate Matter (TPM) Emissions
2. Selection of abrasive material
3. Selection of pressure for blasting
4. Emission of particulate matter less than 10 microns in size. (PM_{10})

Table 1.1: Abrasive Usage Table[2]

Table 1.1. Abrasive Blast Media Usage, Unconfined Abrasive Blasting[2]

Type of Abrasive	Reported Annual Usage (tons)	Percentage of Total Usage (%)	Projected Usage in United States (tons)
Coal Slag	39,065	39.75	208,331
Copper Slag	24,309	24.74	129,663
Sand	12,358	12.58	65,932
Steel Shot	10,236	10.42	54,611
Nickel Slag	4,692	4.77	24,999
Garnet	3,459	3.52	18,448
Other	1,864	1.9	9,957
Steel Grit	1,556	1.58	8,280
Glass	151	0.52	2,725
Other Minerals	168	0.17	891
Iron Grit	40	0.04	209
Iron Grit	6	0.01	52
Totals	97,904	100	524,098

The table above shows the most popular blasting media as coal slag, copper slag, sand, and hematite. The study showed the range of blast pressures used as 80 PSI (per square inch) to 120 PSI.

Very limited information is available on emission factors for particulate emissions resulting from dry abrasive blasting. Also, the data quality rating for the available data is of poor quality, as assigned by the EPA in its evaluation. Additionally, for the life cycle costing and life cycle assessment of abrasive blasting processes, simultaneous data sets are required on (1) emissions or emission factors, (2) consumption, (3) productivity, as all of them relate to life cycle costs and environmental performance.

Shipyards are required to (1) obtain environmental permits and (2) maintain compliance, which require knowledge of the materials and processes used. Knowing environmental performance of abrasives and abrasive blasting processes, shipyards will be able to manage their environmental matters efficiently.

Based on the above discussion, it can be stated that there is a strong need for establishing environmental performance of abrasives which will (1) reduce shipyard costs by reducing consumption, (2) improve productivity, and (3) minimize damage to the environment and public health.

1.2 *Research Objectives*

The main objective of this study is to generate the dataset that will help the shipbuilding industry in determining the right alternative that will optimize the process of blasting.

Dry abrasive blasting is the main process in most shipyards. As for every process these processes require energy, material, labor, and at some point produce enormous cost figures if considered on a global scale. The process as a whole takes energy, material, and labor savings in any one of these parameters will benefit the whole industry by savings in energy, material, and labor, which

ultimately results in savings in monitory terms that will again be used for the benefit of society.

The materials selected for the study were coal slag and garnet, coal slag being widely used in the industry as a popular abrasive material and garnet being considered as gaining popularity.

Each material was tested with three turns of a Schmidt Valve (3, 4 and 5) and for three pressures (80 PSI, 100 PSI, and 120 PSI). Each test was run in triplicate for each material.

Total runs for each material:

= (One Material) *(Three Pressures) * (Three Turns) * (Three Test Runs)

= (1) * (3) * (3) * (3) = 27 runs per material.

2. Background of the Study

Blasting is the process of propelling a jet of blast material through a medium which serves as a carrier to help the blast material obtain the adequate velocity and strength at the time of collision. The abrasive can be propelled as a mixture with air and water and by Mechanical means.

The mechanical method uses centrifugal wheels. The other method of propelling is with water, which the blast material is mixed with water and the slurry is forced towards the surface to be prepared.

The third method entails mixing the blast material with compressed air, the compressed air will be used as a medium through which the blast material can be carried with the adequate velocity and strength to get the desired effect. The pressure of the compressed air can be varied to obtain the desired output which depends on the type and quality of the work.

In the present study compressed air is used as a carrier, commonly known as dry abrasive blasting. (Since compressed air is the only medium, the term dry abrasive blasting is used.)

To prepare the assembly, the main equipment used consists of:

1) Compressor (propelling device)
2) Hose
3) Blast pot
4) Blasting nozzle

In this study the compressed air from the compressor is mainly carried through the hose to the blast pot. In the blast pot, the compressed air mixes with the blast material and is again guided through the hose towards the nozzle. Then, through the nozzle, the fine blend of blast material and compressed air are bombarded onto the surface to be prepared.

As explained earlier, this process generates a lot of airborne particles because the blast material bombarded on the surface to be prepared disintegrates into small particles and becomes airborne, which, if inhaled, might be very harmful to human health. The exposure limits and exposure time will determine the severity of the illness. Along with this issue, the material used plays an important part.

Solid waste disposal is always an issue at all the facilities. Lots of money and time goes into proper disposal of the wastes generated by these processes. By optimizing the process as a whole a facility can minimize the amount of solid waste generated at the source. This is an important factor affecting budgetary considerations. Optimization of a process means optimization of individual

parameters directly related to the generation of solid waste, which, in turn, optimizes the blasting material used, the pressure and feed rate.

The material used affects the process in many ways. Very importantly, it affects the selection of equipment to be used in the process. It determines the nozzle size to be used and the operating frequencies of the compressor. It also affects the amount of blast material to be used in the process. Finally, it also affects the desired finish. From this discussion, it is clear that the choice of the proper blasting material for the proper process is very important as it is a governing factor.

Along with the environmental effects of the blasting process there are some economical issues also. If we choose the wrong material for the process then it may consume greater amounts of materials than required. On a large scale, we might lose millions of dollars. On other hand, the labor hours incurred and the machinery capital can be equally important. The cost of fines due to increased emissions or using stringent limitations due to increased emissions is another important consideration affecting cost.

Presently there are a number of blasting materials available and are being used widely throughout the world for different processes. The general classification of the blasting materials can be sand, slag, metallic shot or grit, synthetic or other. The abrasive to be used is usually selected based on the cost and properties of

the material. Silica sand is commonly used for abrasive blasting where reclaiming is not feasible. Sand has a rather high breakdown rate, which can result in substantial dust generation. Worker exposure to free crystalline silica is of concern when silica sand is used for abrasive blasting. Coal and smelter slag are commonly used for abrasive blasting at shipyards. Coal slag, which consists of crushed slag from coal-fired boilers, is commonly used. Slag has the advantage of low silica content, but has been documented as releasing other contaminants, including hazardous air pollutants (HAP), into the air.

Metallic abrasives include cast iron shot, cast iron grit, and steel shot. Cast iron shot is hard and brittle. Steel shot is not as hard as cast iron shot, but is much more durable. These materials are typically reclaimed and reused.

Synthetic abrasives, such as silicon carbide and aluminum oxide, are becoming popular substitutes for sand. These abrasives are more durable and create less dust than sand. These materials are also typically reclaimed and reused.

Other abrasives include mineral abrasives (such as garnet, olivine), cut plastic, glass beads, crushed glass, and nutshells. Mineral abrasives are reported to create significantly less dust than sand and slag abrasives. The type of abrasive used in a particular application is usually specific to the blasting method. Dry abrasive blasting is usually done with slag, sand, metallic grit or shot, aluminum

oxide (alumina), or silicon carbide. Wet blasters are operated with sand, glass beads, or other materials that remain suspended in water.

Particulate matter (PM) and particulate HAPs are the major concerns relative to abrasive blasting. Emissions of particulate matter (PM_{10}) of these size fractions are not significantly wind-speed dependent. These emissions are dependent on both the abrasive material and the targeted surface.

The tests were conducted on the campus of the University of New Orleans within a fenced area located north of the Engineering Building. The main parameters studied were the emissions from the process for different feed rates (3, 4, 5 turns) and at different blast pressures (80,100, and 120 PSI). For this study the two materials (Coal slag and Garnet) widely used as blasting material were selected.

The study was conducted in a closed environment (a chamber specially constructed for the tests).

Abrasive blasting presents some risks for worker health and safety, because blasting operations have the potential to produce air emissions. Although abrasives used in blasting booths are not hazardous in themselves (steel shot, and grit, etc.), their use can present a serious danger to operators, such as burns due to projections, cuts due to walking on round shots scattered on the

ground, exposure to hazardous dust, creation of an explosive atmosphere, and exposure to a detrimental noise level. Both blasting booths and blaster equipment have to be adapted to these dangers.

3. Objectives of the Study

The overall objectives of this study were to understand the environmental performance of two abrasives, namely, coal slag and garnet and evaluate the optimum process conditions to minimize consumption, and particulate emissions as well as to increase productivity.

In order to reach the overall objectives of this study, the following specific objectives were targeted during the study:

- Design and construct emission test facility to simulate shipyard enclosed blast conditions
- Identify and procure necessary materials and equipment
- Develop field test protocol
- Evaluate the performance parameters namely:
    - Productivity (area cleaned per unit time)
    - Feed rate (# of turns on feed valve; mass flow rate of abrasive through the nozzle)
    - Consumption (mass of abrasive material used per unit area cleaned)

- Emission factors (mass of particles emitted/area cleaned; mass of particulates emitted/mass of abrasive used).

4. Equipment and Materials

4.1 Test Chamber Design and Construction

The test chamber (12’ long x 10’ wide x 8’ High) was designed as per specified guidelines of EPA method 204. The chamber was constructed using plastic sheets joined together with the connectors and riveted firmly to the floor. The floor was made up of seasoned wood and the wooden floor is then treated with waterproofing materials. And gaps were sealed with the silicon to prevent any seepage of the water that may interfere with the test process. The test chamber was constructed in an enclosed fence on the north side of the engineering building on the main campus of the University of New Orleans (UNO). A wooden ramp was used to move the panel cart (Fig.10) in and out of the chamber smoothly before and after blasting.

A tent was erected adjacent to the chamber to house the sampling equipment and test aids. The tent also provided protection to sampling equipment from rain and storm events.

Provisions were made for make-up air, i.e., the air needed to replace the air being exhausted by the exhaust fan. 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 is capable of operating at various speeds and corresponds to a maximum flow of 5000 cubic feet per minute (CFM). The particles then collected through a two-stage particulate collection system (gravimetric and bag filters) with an efficiency of 90% in the first stage in a drum and then through the filter bags released into the air. The different parts of the assembly are explained in depth in subsequent paragraphs.

The schematic of the test chamber is shown in Figure 1

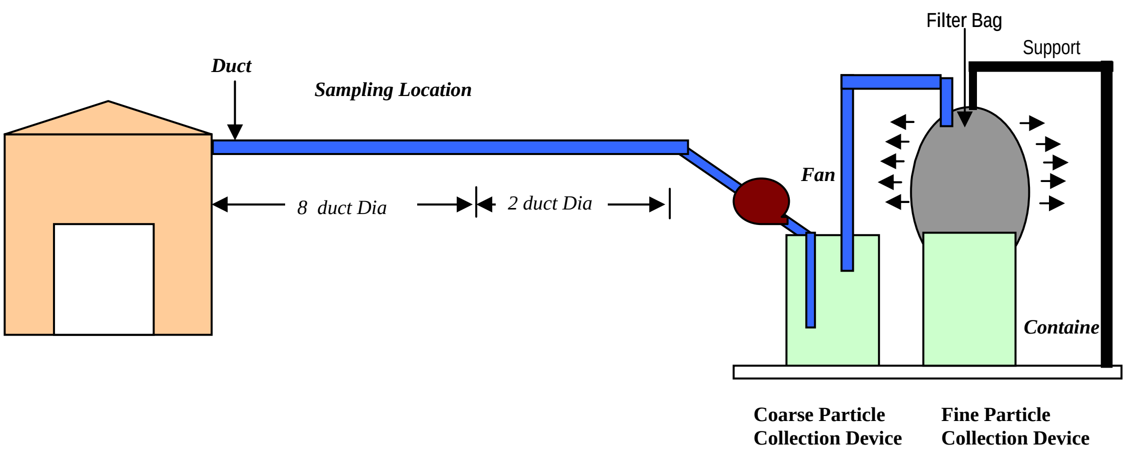


Figure 1: Schematic Diagram of Test Facility (Not to Scale)

4.2 Blasting Equipment (Blast Pot)

This is the most important piece of equipment in the process. The action of propelling the blast material with the help of a propeller (in this case air) takes place in this piece of equipment. The blast material mixes with compressed air and gains its strength in the blasting equipment. The blasting equipment known as a blast pot used in this experiment is of 600 lbs capacity and with 1.25 inches

piping, remote control equipped, with moisture separator, air filter, and helmet with air conditioning unit.

The hopper located at the top of the blast pot serves as an opening for feeding the blast material. Before pouring any material in to the blast pot, the pot must be cleaned thoroughly through the opening provided in the side wall of the pot. Refer to (Fig. 2), which shows the schematic diagram of the blast pot

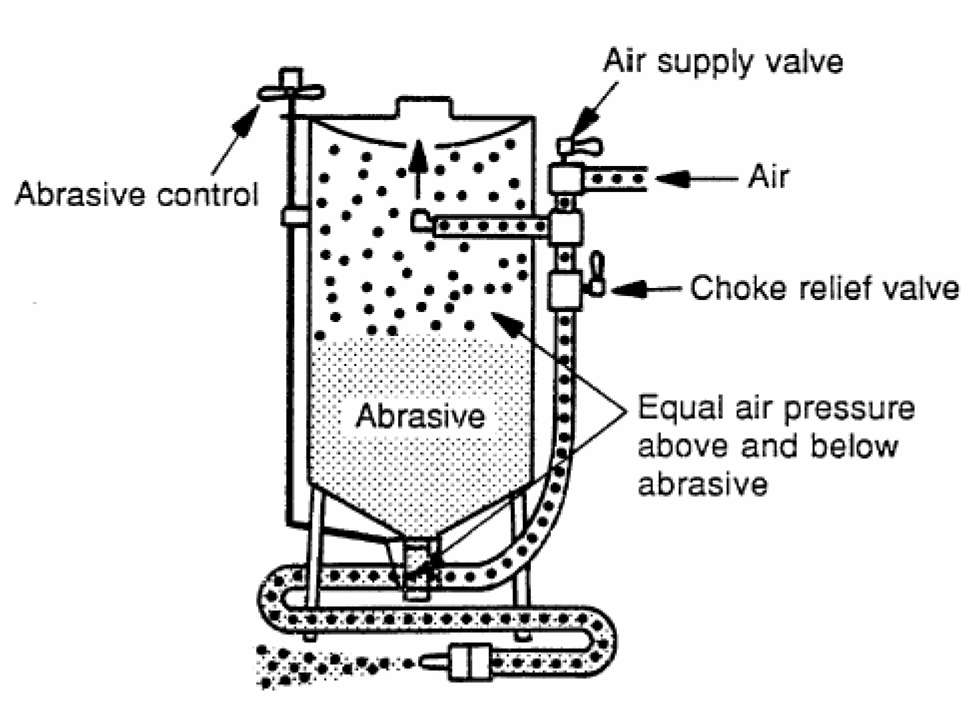


Figure 2: Schematic Diagram of Blast Pot

After cleaning, the side opening (a small window on the side of the blast pot, as shown in Fig. 3) must be closed tightly. After the desired amount of blast material is poured into the pot, the opening and side walls of the hopper have to be

cleaned thoroughly. Moreover the material used should be free from lumps and dust, which may obstruct the free flow of the material during the process of blasting. 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. If the flow is obstructed, then immediately the path of the flow must be cleared.

All of the hose joints must be fastened properly with the help of fasteners and must be checked before each run.

Figure 3: Blast Pot

4.3 Compressor

The compressor provides the air pressure to the blasting material. The compressor is joined to the assembly by a hose which connects 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 but the velocity at which the blasting material strikes or bombards to the surface to be prepared plays an important role.

The compressor used for the study was a SULLAIR 375H, which is capable of providing the maximum pressure of 150 pounds per square inch (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.

Figure 4: Compressor Sullair 375 H

4.4 Exhaust and Duct

The exhaust is an important component of the test set up. It is the basic window through which the particulate matter and emissions emitted from the process of dry abrasive blasting enters in the duct and eventually in the sampling train.

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.

The exhaust window is directly connected to the duct, which carries the emissions collected from the test process and through an exhaust. The inner portion of the duct should be smooth and free of undulations and fairly straight. The design of the duct is governed by EPA method 1, which ultimately determines the number of sampling points depending on the geometry and size of the duct and the disturbance to the flow.[3] (Appendix B). The detailed explanation of these methods is in Appendix B.

Figure 5: Exhaust Duct Entrance

Figure 6: Exhaust Duct Outside

The diameter of the exhaust duct is 12 inches. A sampling port was located at a distance of 8 duct diameters from the exhaust window to minimize the disturbance to the flow. The variable speed fan was positioned at 2 duct diameters from the sampling port on the downstream end to minimize the disturbance to the flow. Velocity measurements were made with a standard S-type pitot tube at a number of positions in a cross-sectional plane perpendicular to the flow direction in the duct to get the actual velocity of the flow. According to EPA method 1, the minimum number of locations needed to make measurements depend on the extent of disturbance or turbulence to the flow. A change in the diameter of stack or change in the direction of flow is considered as turbulence or disturbance to the flow.

A total of eight traverse points were chosen for our test set up for the circular duct. The traverse points were measured and marked on the sampling probe to ensure the accuracy and ease of traversing. For ensuring isokinetic flow

conditions, a nozzle of size of 0.18 inch was chosen for the runs. Isokinetic sampling means the sampling at a condition at which the velocity of the gas in the stack is equal (in mathematical terms) to the velocity of the gas in the sampling probe. 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).

Isokinetic sampling should be ensured throughout each and every test run. Isokinetic sampling helps in getting the representative sample from the duct and in getting accurate test results. Getting Isokinetic sampling is one of the important steps in obtaining accurate results.

4.5 Stack Sampling Equipment

Stack sampling equipment is equipped with two manometers or pressure gauge and a control box of sampling equipment is connected to the sampling train through the umbilical cord to the pitot tube. The dry gas meter and thermometers mounted on stack sampling equipment help in measuring the key parameters required for the emission calculation (refer to Figure 8).

This sampling equipment is designed in accordance with EPA standards and is governed by the EPA stack sampling method 4. In this method we need to attach a sampling train with this equipment. The final outcome will be the particulate

emissions collected during the sampling time and the flow velocity of the stack gas.

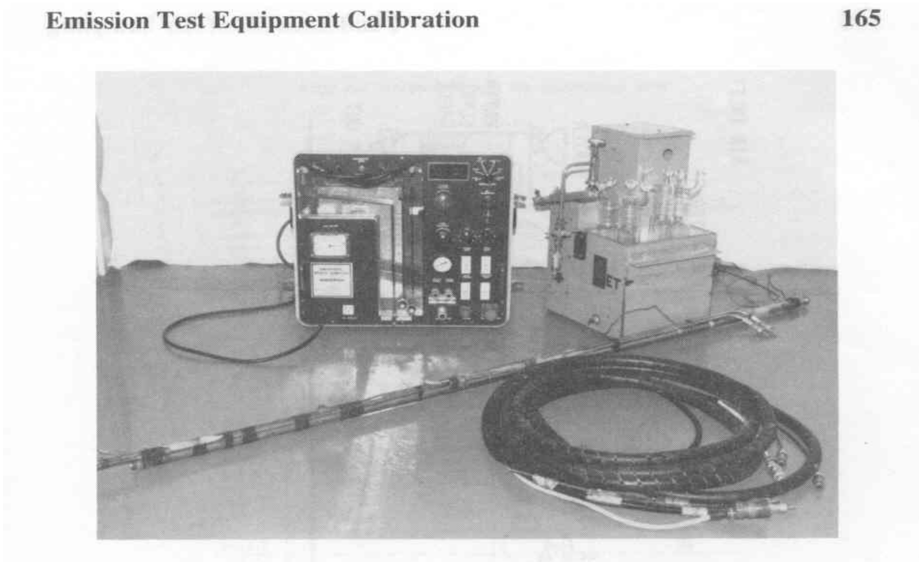


Figure 7: Stack Sampling Equipment

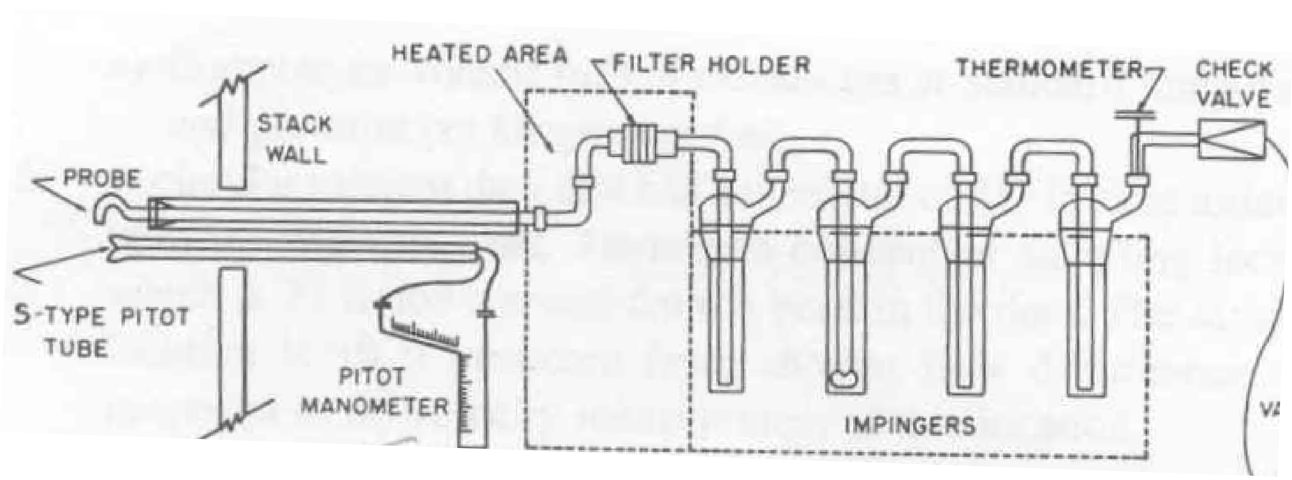


Figure: 8 Sampling Train

4.6 Plate Size Specifications

The test plates used for blasting operations were made of cast iron (8’x5’), similar to those used in shipyards. The experiments were conducted on blasting surfaces with flash rust. A total of 4 plates were used and they were mounted on a panel cart (refer to Figure 10).

Typically, the plates were allowed to rust after every blasting run for around 12 hours to ensure uniform rust.

Figure 9: Test Plate

4.7 Panel Cart

To support the plates during the experiment a panel cart was used. Figure 8 shows the panel cart, which 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.

Figure 10: Panel cart

4.8 Schmidt Valve

A Schmidt valve was mainly used for controlling the flow of blast material. The number of turns controls the flow of the material. The range of turns was a minimum of one turn to a maximum of nine and half turns.

The number of turns used in the experiment ranged from a minimum of three to a maximum of five. The Schmidt valve is shown in Fig. 11.

Figure 11: Schmidt Valve

4.9 Sampling Train

The sampling train, an important piece of equipment, 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 separates from the sample gas volume.

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.

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.

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.

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.

4.10 Particulate Collection System

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-gallons 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. Then the outlet from the 55-gallon drum becomes the inlet of the filters in the second stage of the collection system. (Refer to Figure 12). 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 (refer Fig. 13) that help in trapping more and more emissions and preventing them from becoming airborne, thus increasing the efficiency of the overall collection system.

Figure 12: Two stage Particulate Collection System

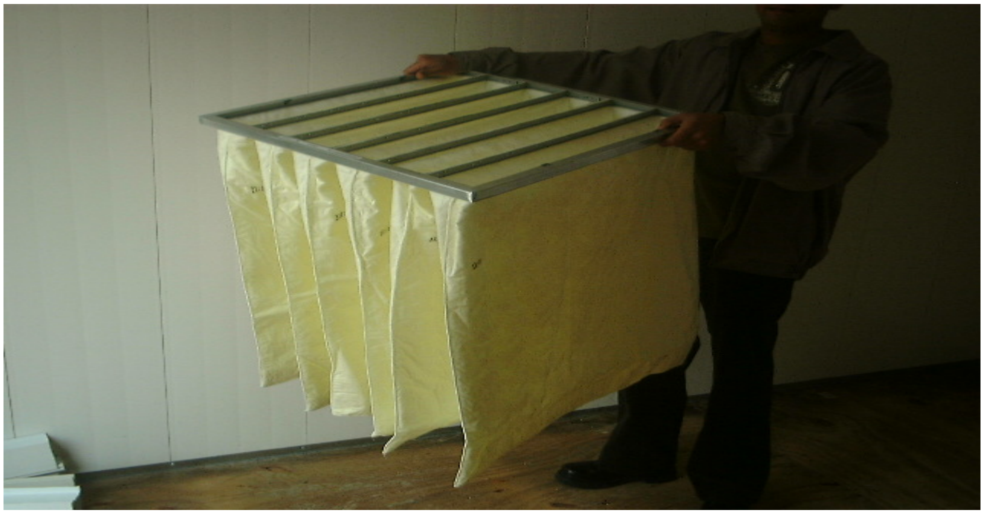


Figure 13: Filter

4.11 Test Constraints

It is important to recognize that particulate emissions depend on a number of factors, such as, (1) blast pressure, (2) feed rate, (3) blast nozzle size, (4) abrasive grading, (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 for all test runs.
- Medium grade coal slag and medium grade garnet 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. Figure 14 illustrates the plate orientation used in the study.
- 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.

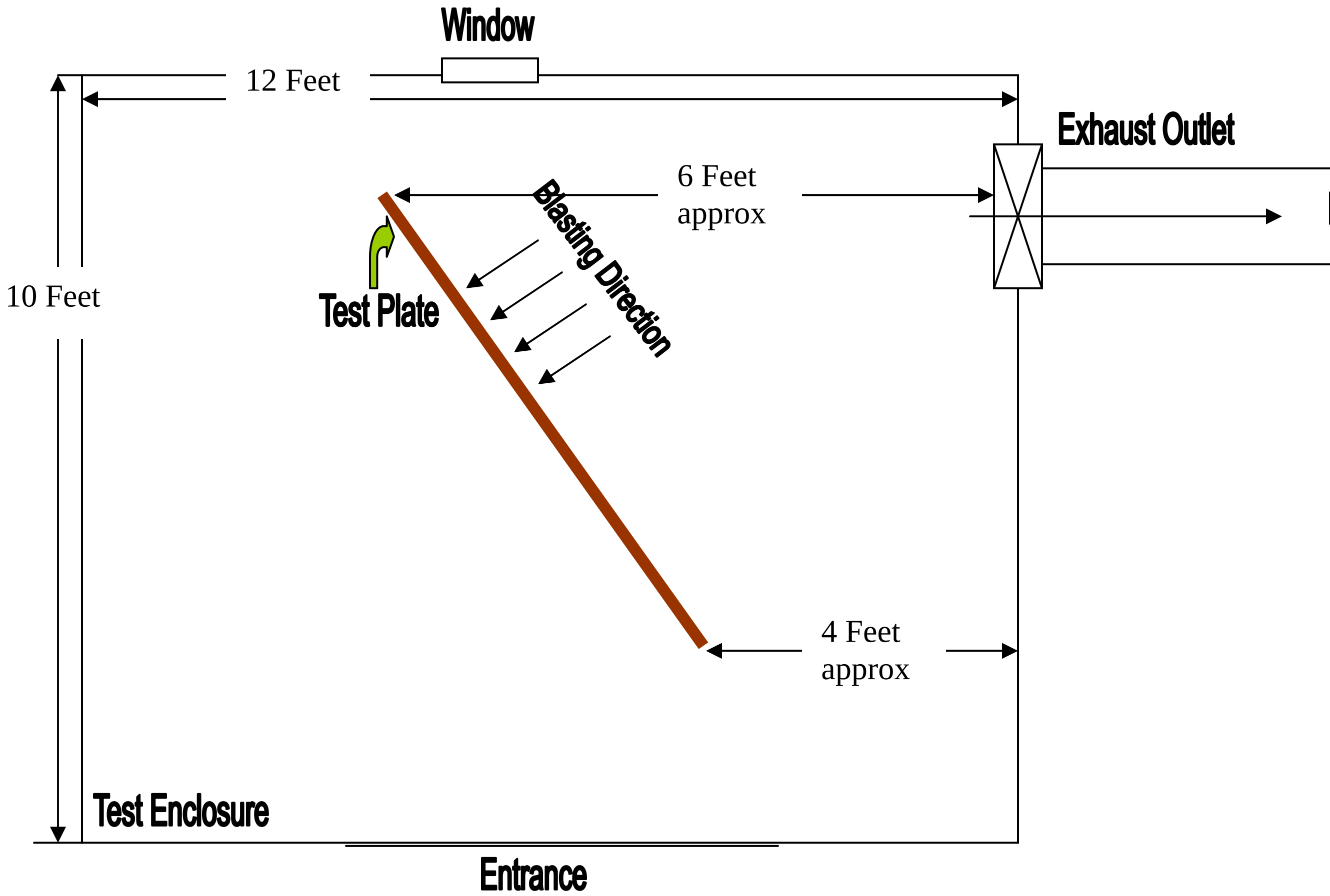


Figure 14: Test Set Up Plan View (figure not to scale)

5. Field Test Procedure

Field testing included two parts: (1) blasting the test panels using coal slag and garnet, and (2) source sampling to evaluate particulate emissions. For blasting purposes, commonly observed shipyard blasting procedures including Society of Protective Coating (SPC) recommendations were followed. SPC has visual standards to characterize the metal surface that is cleaned using abrasives. These guidelines are presented in Section 5.2. For source sampling, EPA's emissions test methods, Methods 1 through 5[3] were used. Methods 1 through 5 are presented in Appendix B. This section presents general procedures used for the field tests.

First the test plates were mounted on the cart. The desired amount of blasting material was poured into the blast pot through a sieve to remove any foreign material that may interfere with the smooth flow of the material. Blast nozzle size # 6 was used in all the field tests in this study. The compressor was kept ready to supply compressed air to the blast pot. Stack sampling equipment was also kept ready 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 compressor was turned on and the Schmidt valve was adjusted to a specific selection (number of turns) and 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 isokinetic sampling conditions at the time. Then 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.

The following sequence was used to perform various field activities:

- Obtain the values for barometric pressure and temperature.
- Using these values and the nozzle diameter calculate the K factor necessary for isokinetic sampling. (Delta H = K* Delta P).
- Set up the instrument and sampling train on site.

- Perform leak check (pre test).
- Note down various parameters needed for the run viz., velocity head, stack temperature, vacuum, DGM readings, box temperature, etc.
- Perform leak check (post test).
- 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 in the laboratory and acetone blank.

5.1 Important Variables Monitored

This section lists the important variables monitored in the field study:

Blast Pressure: The tests were conducted at three blast pressures, namely, 80 PSI, 100 PSI, and 120 PSI.

Feed Rate: Feed rate of the abrasive was varied using a Schmidt valve connected to the bottom of the blast pot, corresponding to 3, 4, and 5 turns in an open condition of the valve.

Stack Sampling Nozzle Size: A nozzle of diameter 0.18 inch was used to ensure isokinetic sampling conditions as described earlier.

Blasting Time: The total blasting time was measured for each run using a stopwatch. 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.

Area Cleaned: The blasted area was calculated using a measuring tape. Necessary corrections were made for accurately measuring the area cleaned.

Productivity: Productivity is a measure of blasting speed and is defined as:

Productivity (sq ft/hr) = Area Cleaned (sq ft) / Total Blasting Time (hours)

Emission Factors: The emission factors are expressed in this report in terms of the following units:

a. Mass of particles emitted (mg) / Area cleaned (ft^2)
b. Mass of particles emitted (mg) / Quantity of abrasive used (lb)
c. Mass of particles emitted (lb) / Quantity of abrasive used (lb)
d. Mass of particles emitted (lb) / Quantity of abrasive used (kg)
e. Mass of particles emitted (lb) / Quantity of abrasive used (ton)

Consumption: Defined as

Consumption = Quantity of Abrasive Used (lb) / Area Cleaned (sq ft)

5. 2 Surface Preparation Standards[8]

The SPC developed visual standards for the finished surface use a range between SP-1 to SP-11. In this study, the test panels' finish varied approximately according to SP-5, SP-6, and SP-10 grades. The finish depended on the blast pressure and the feed rate of abrasive. The surface characteristics are illustrated in Figures 15 through 17. Figure 15 illustrates a rusted panel before blasting. Figures 16 and 17 illustrate finished surfaces.

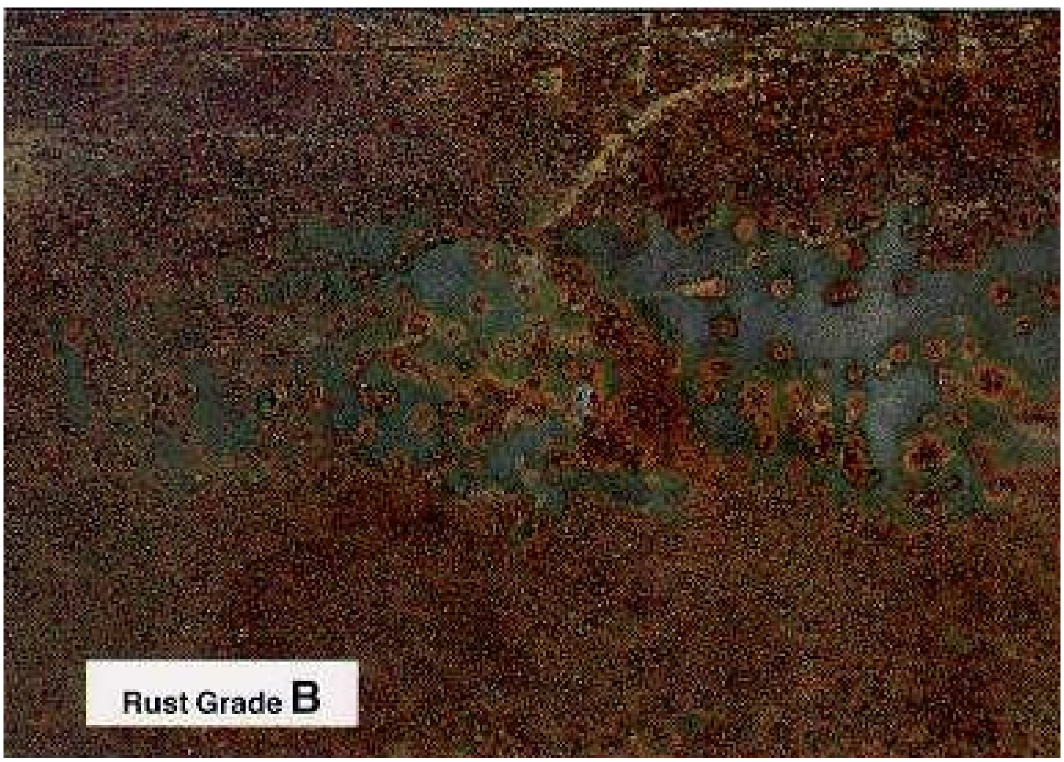


Figure 15: Plate before Blasting

5.2.1 SP-5 SPC Standards

5.2.1. A White Metal Blasting SPC-SP5 Definition[8]

The removal of all visible rust, mill scale, paint and contaminants, leaving the metal uniformly white or gray in appearance. This is the ultimate in blast cleaning.

Figure 16: White Metal Blasting SSPC-SP5 (SSI-Sa3)

5.2.1. B Commercial Blast SPC-SP6 Definition[8]:

All oil, grease, dirt, rust scale, and foreign matter 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 resides 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.

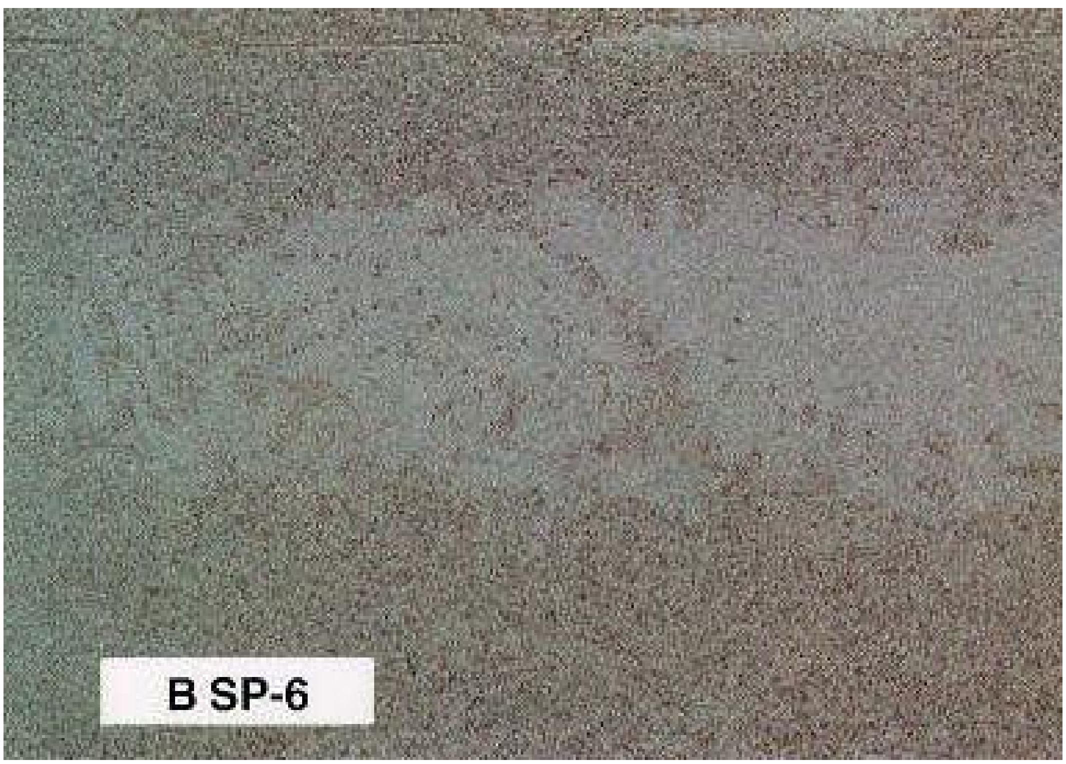


Figure 17: Commercial Blast SP-6 SPC

5.2.1 C Brush Off Blast SSPC-SP10 Definition[8]

In this method, all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, or other foreign matter have been completely removed from the surface by abrasive blasting, 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. 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 18: SP-10 Brush-off Blast SPC Standard

6. Results and Analysis

This chapter presents the field results obtained in the study**.** Table C1 gives the field data observed for coal slag and Table C2 shows the statistical parameters (mean and standard deviations) of productivity (sq. ft/hr), consumption (lb/sq. ft) and emission factors (mg/sq. ft, mg/lb, and lb/ton) for coal slag. Tables C3 and C4 show the same data for garnet.

The columns in these tables can be read as follows:

Column 1: Press: Pressure (PSI).

Column 2: Turns: Number of turns.

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

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

Column 5: A: Cleaned area of the plate (square feet).

Column 6: E: Quantity of emissions obtained in the sampling train (grams of pollutant mass collected).

Column 7: P: Productivity (sq ft/hr).

Column 8: C: Consumption (lb/sq ft).

Column 9: EF1: Emission factor represented as mass of pollutant per area cleaned (mg/sq ft).

Column 10: EF2: Emission factor represented as mass of pollutant per amount of abrasive consumed (mg/lb, lb/lb, lb/kg, lb/ton).

Table C1: Field Data for Coal Slag

Press	Turns	Wt	BT	A	E	P	C	EF1	EF2			
PSI	Number	Lbs	min	sqft	gm	sqft / hr	lb/sqft	mg/sqft	mg/lb	lb/lb	lb/kg	lb/ton
120	3	300	24	25	1.3139	62.50	12.00	52.56	4.38	9.63527E-09	4.81763E-12	9.64
120	4	300	24	24.4	0.8242	61.00	12.30	33.78	2.75	6.04413E-09	3.02207E-12	6.04
120	5	600	24	35	2.3584	87.50	17.14	67.38	3.93	8.64747E-09	4.32373E-12	8.65
120	3	400	24	25	1.576	62.50	16.00	63.04	3.94	8.668E-09	4.334E-12	8.67
120	4	100	16	15	0.6945	56.25	6.67	46.30	6.95	1.5279E-08	7.6395E-12	15.28
120	5	100	16	17.5	0.7812	65.63	5.71	44.64	7.81	1.71864E-08	8.5932E-12	17.19
120	3	100	16	13.75	0.5423	51.56	7.27	39.44	5.42	1.19306E-08	5.9653E-12	11.93
120	4	100	10	18.5	0.6693	111.00	5.41	36.18	6.69	1.47246E-08	7.3623E-12	14.72
120	5	100	16	15.75	0.6583	59.06	6.35	41.80	6.58	1.44826E-08	7.2413E-12	14.48
100	3	100	16	13.75	0.7522	51.56	7.27	54.71	7.52	1.65484E-08	8.2742E-12	16.55
100	4	100	10	16.5	0.7513	99.00	6.06	45.53	7.51	1.65286E-08	8.2643E-12	16.53
100	5	100	10	15	0.6125	90.00	6.67	40.83	6.13	1.3475E-08	6.7375E-12	13.48
100	3	100	10	13.75	0.6137	82.50	7.27	44.63	6.14	1.35014E-08	6.7507E-12	13.50
100	4	100	10	16.75	0.7235	100.50	5.97	43.19	7.24	1.5917E-08	7.9585E-12	15.92
100	5	100	16	17.5	0.7134	65.63	5.71	40.77	7.13	1.56948E-08	7.8474E-12	15.69
100	3	100	16	18.5	0.6731	69.38	5.41	36.38	6.73	1.48082E-08	7.4041E-12	14.81
100	4	100	16	15.75	0.6672	59.06	6.35	42.36	6.67	1.46784E-08	7.3392E-12	14.68
100	5	100	10	16	0.6138	96.00	6.25	38.36	6.14	1.35036E-08	6.7518E-12	13.50
80	3	100	10	18.5	0.7234	111.00	5.41	39.10	7.23	1.59148E-08	7.9574E-12	15.91
80	4	100	16	18.5	0.7673	69.38	5.41	41.48	7.67	1.68806E-08	8.4403E-12	16.88
80	5	100	16	20	0.6547	75.00	5.00	32.74	6.55	1.44034E-08	7.2017E-12	14.40
80	3	100	16	15	0.6189	56.25	6.67	41.26	6.19	1.36158E-08	6.8079E-12	13.62
80	4	100	16	17.5	0.7356	65.63	5.71	42.03	7.36	1.61832E-08	8.0916E-12	16.18
80	5	100	16	18	0.7019	67.50	5.56	38.99	7.02	1.54418E-08	7.7209E-12	15.44
80	3	100	12	15.5	0.6917	77.50	6.45	44.63	6.92	1.52174E-08	7.6087E-12	15.22
80	5	100	16	20	0.7219	75.00	5.00	36.10	7.22	1.58818E-08	7.9409E-12	15.88
80	4	100	15	18.5	0.6782	74.00	5.41	36.66	6.78	1.49204E-08	7.4602E-12	14.92

BT= Blasting Time, A = Area, E= Emission, P=Productivity, EF1= Emission Factor 1 (mass/unit surface area cleaned) in mg/ ft^2
EF2= Emission Factor 2 (mass/unit material used) mg/lb, lb/lb, lb/kg, lb/ton)

Table C2: Productivity, Consumption and Emission Factors for Coal Slag

Press	Turns	Wt	Productivity			Consumption			Emission Factors								
PSI	Number	lbs	Sq ft / hr	Mean	SD	lb/sq ft	Mean	SD	mg/sqft	Mean	SD	mg/lb	Mean	SD	lb/ton	Mean	SD
120	3	300	63			12.00			52.56			4.38			9.64		
120	3	400	63			16.00			63.04			3.94			8.67		
120	3	100	52	58.85	6.31	7.27	11.76	4.37	39.44	51.68	11.82	5.42	4.58	0.76	11.93	10.08	1.68
120	4	300	61			12.30			33.78			2.75			6.04		
120	4	100	56			6.67			46.30			6.95			15.28		
120	4	100	111	76.08	30.33	5.41	8.12	3.67	36.18	38.75	6.65	6.69	5.46	2.35	14.72	12.02	5.18
120	5	600	88			17.14			67.38			3.93			8.65		
120	5	100	66			5.71			44.64			7.81			17.19		
120	5	100	59	70.73	14.89	6.35	9.74	6.42	41.80	51.27	14.02	6.58	6.11	1.98	14.48	13.44	4.36
100	3	100	52			7.27			54.71			7.52			16.55		
100	3	100	83			7.27			44.63			6.14			13.50		
100	3	100	69	67.81	15.53	5.41	6.65	1.08	36.38	45.24	9.18	6.73	6.80	0.69	14.81	14.95	1.53
100	4	100	99			6.06			45.53			7.51			16.53		
100	4	100	101			5.97			43.19			7.24			15.92		
100	4	100	59	86.19	23.50	6.35	6.13	0.20	42.36	43.70	1.64	6.67	7.14	0.43	14.68	15.71	0.94
100	5	100	90			6.67			40.83			6.13			13.48		
100	5	100	66			5.71			40.77			7.13			15.69		
100	5	100	96	83.88	16.09	6.25	6.21	0.48	38.36	39.99	1.41	6.14	6.47	0.58	13.50	14.22	1.27
80	3	100	111			5.41			39.10			7.23			15.91		
80	3	100	56			6.67			41.26			6.19			13.62		
80	3	100	78	81.58	27.60	6.45	6.17	0.67	44.63	41.66	2.78	6.92	6.78	0.54	15.22	14.92	1.18
80	4	100	69			5.41			41.48			7.67			16.88		
80	4	100	66			5.71			42.03			7.36			16.18		
80	4	100	74	69.67	4.20	5.41	5.51	0.18	36.66	40.06	2.96	6.78	7.27	0.45	14.92	15.99	0.99
80	5	100	75			5.00			32.74			6.55			14.40		
80	5	100	68			5.56			38.99			7.02			15.44		
80	5	100	75	72.50	4.33	5.00	5.19	0.32	36.10	35.94	3.13	7.22	6.93	0.35	15.88	15.24	0.76

Table C3: Field Data for Garnet

Press	Turns	Wt	BT	A	E	P	C	EF1	EF2			
PSI		lbs	min	Sq ft	Gm	Sq ft / hr	lb/sq ft	mg/sq ft	mg/lb	lb/lb	lb/kg	lb/ton
120	3	100	12	24	0.4259	120.00	4.17	17.75	4.26	9.3698E-09	4.6849E-12	9.37
120	4	100	11	20	0.4887	109.09	5.00	24.44	4.89	1.07514E-08	5.3757E-12	10.75
120	5	100	8	16	0.5217	120.00	6.25	32.61	5.22	1.14774E-08	5.7387E-12	11.48
120	3	100	14	22	0.4138	94.29	4.55	18.81	4.14	9.1036E-09	4.5518E-12	9.10
120	4	100	11	19	0.4771	103.64	5.26	25.11	4.77	1.04962E-08	5.2481E-12	10.50
120	5	100	9	17	0.5318	113.33	5.88	31.28	5.32	1.16996E-08	5.8498E-12	11.70
120	3	100	16	22	0.4357	82.50	4.55	19.80	4.36	9.5854E-09	4.7927E-12	9.59
120	4	100	10	20	0.4635	120.00	5.00	23.18	4.64	1.0197E-08	5.0985E-12	10.20
120	5	100	8	15	0.5187	112.50	6.67	34.58	5.19	1.14114E-08	5.7057E-12	11.41
100	3	100	10	14	0.4278	84.00	7.14	30.56	4.28	9.4116E-09	4.7058E-12	9.41
100	4	100	12	24	0.4598	120.00	4.17	19.16	4.60	1.01156E-08	5.0578E-12	10.12
100	5	100	12	20	0.4215	100.00	5.00	21.08	4.22	9.273E-09	4.6365E-12	9.27
100	3	100	16	22	0.4187	82.50	4.55	19.03	4.19	9.2114E-09	4.6057E-12	9.21
100	4	100	13	25	0.4478	115.38	4.00	17.91	4.48	9.8516E-09	4.9258E-12	9.85
100	5	100	13	25	0.4594	115.38	4.00	18.38	4.59	1.01068E-08	5.0534E-12	10.11
100	3	100	10	24	0.4253	144.00	4.17	17.72	4.25	9.3566E-09	4.6783E-12	9.36
100	4	100	11	26	0.4451	141.82	3.85	17.12	4.45	9.7922E-09	4.8961E-12	9.79
100	5	100	12	31	0.4494	155.00	3.23	14.50	4.49	9.8868E-09	4.9434E-12	9.89
80	3	100	2	3	0.4854	90.00	33.33	161.80	4.85	1.06788E-08	5.3394E-12	10.68
80	4	100	11	25	0.4325	136.36	4.00	17.30	4.33	9.515E-09	4.7575E-12	9.52
80	5	100	15	30	0.4783	120.00	3.33	15.94	4.78	1.05226E-08	5.2613E-12	10.52
80	3	100	4	10	0.4732	150.00	10.00	47.32	4.73	1.04104E-08	5.2052E-12	10.41
80	4	100	11	26	0.4415	141.82	3.85	16.98	4.42	9.713E-09	4.8565E-12	9.71
80	5	100	16	31	0.4903	116.25	3.23	15.82	4.90	1.07866E-08	5.3933E-12	10.79
80	3	100	5	12	0.4572	144.00	8.33	38.10	4.57	1.00584E-08	5.0292E-12	10.06
80	5	100	15	30	0.5107	120.00	3.33	17.02	5.11	1.12354E-08	5.6177E-12	11.24
80	4	100	10	25	0.4512	150.00	4.00	18.05	4.51	9.9264E-09	4.9632E-12	9.93

BT= Blasting Time, A = Area, E= Emission, P=Productivity, EF1= Emission Factor 1 (mass/unit surface area cleaned) in mg/ ft^2
EF2= Emission Factor 2 (mass/unit material used) mg/lb, lb/lb, lb/kg, lb/ton)

Table C4: Productivity, Consumption and Emission Factors for Garnet

Press	Turns	Wt	Productivity			Consumption			Emission Factors								
PSI		lbs	Sqft / hr	Mean	SD	lb/sq ft	Mean	SD	mg/sqft	Mean	SD	mg/lb	Mean	SD	lb/ton	Mean	SD
120	3	100	120			4.17			17.75			4.26			9.37		
120	3	100	94			4.55			18.81			4.14			9.10		
120	3	100	83	98.93	19.18	4.55	4.42	0.22	19.80	18.79	1.03	4.36	4.25	0.11	9.59	9.35	0.24
120	4	100	109			5.00			24.44			4.89			10.75		
120	4	100	104			5.26			25.11			4.77			10.50		
120	4	100	120	110.91	8.33	5.00	5.09	0.15	23.18	24.24	0.98	4.64	4.76	0.13	10.20	10.48	0.28
120	5	100	120			6.25			32.61			5.22			11.48		
120	5	100	113			5.88			31.28			5.32			11.70		
120	5	100	113	115.28	4.11	6.67	6.27	0.39	34.58	32.82	1.66	5.19	5.24	0.07	11.41	11.53	0.15
100	3	100	84			7.14			30.56			4.28			9.41		
100	3	100	83			4.55			19.03			4.19			9.21		
100	3	100	144	103.50	35.08	4.17	5.28	1.62	17.72	22.44	7.06	4.25	4.24	0.05	9.36	9.33	0.10
100	4	100	120			4.17			19.16			4.60			10.12		
100	4	100	115			4.00			17.91			4.48			9.85		
100	4	100	142	125.73	14.12	3.85	4.00	0.16	17.12	18.06	1.03	4.45	4.51	0.08	9.79	9.92	0.17
100	5	100	100			5.00			21.08			4.22			9.27		
100	5	100	115			4.00			18.38			4.59			10.11		
100	5	100	155	123.46	28.38	3.23	4.08	0.89	14.50	17.98	3.31	4.49	4.43	0.20	9.89	9.76	0.43
80	3	100	90			33.33			161.80			4.85			10.68		
80	3	100	150			10.00			47.32			4.73			10.41		
80	3	100	144	128.00	33.05	8.33	17.22	13.98	38.10	82.41	68.91	4.57	4.72	0.14	10.06	10.38	0.31
80	4	100	136			4.00			17.30			4.33			9.52		
80	4	100	142			3.85			16.98			4.42			9.71		
80	4	100	150	142.73	6.86	4.00	3.95	0.09	18.05	17.44	0.55	4.51	4.42	0.09	9.93	9.72	0.21
80	5	100	120			3.33			15.94			4.78			10.52		
80	5	100	116			3.23			15.82			4.90			10.79		
80	5	100	120	118.75	2.17	3.33	3.30	0.06	17.02	16.26	0.66	5.11	4.93	0.16	11.24	10.85	0.36

Environmental performance data presented in the above tables correspond to various blast pressures and various feed rates.

Because shipyards often use maximum productivity conditions by adjusting feed valve, it was felt important to determine emission factors at the feed rate that gives maximum productivity. This was evaluated for each tested pressure condition. Table C5 shows minimum emissions at maximum productivity (at a feed rate that yields maximum productivity) for 80, 100, and 120 PSI.

Table C5: Minimum Emissions at Maximum Productivity

S No	Pressure	Feed rate	Maximum Productivity	Emission Factors			Consumption
	(PSI)	(no of turns)	(ft^2 /hr)	mg/ ft^2	mg/lb	lb/ton	lb/ft^2 (= ton/2000 ft^2)
Coal Slag							
	80	3	81.58	41.66	6.78	14.92	6.17
	100	4	86.19	43.7	7.14	15.71	6.13
	120	4	76.08	38.75	5.46	12.02	8.12
Garnet	80	4	142.73	17.44	4.42	9.72	3.95
	100	4	125.73	18.06	4.51	9.92	4
	120	5	115.28	32.82	5.24	11.53	6.27

Among the three pressures studied, 120 PSI produces lowest emissions and maximum productivity for Coal Slag. Similarly, Garnet produced (1) lowest emissions, (2) maximum productivity, and (3) lowest consumption at 80 PSI.

Table C6 shows the absolute minimum emissions without considering productivity.

Table C6: Absolute* Minimum Emissions

S No	Pressure	Feed rate	Emission Factors			Consumption
	(PSI)	(no of turns)	mg/ ft^2	mg/lb	lb/ton	lb/ft2 (= ton/2000 ft2)
Coal Slag						
	80	5	35.94	6.93	15.24	5.19
	100	5	39.99	6.47	14.22	6.21
	120	4	38.75	5.46	12.02	9.74
Garnet	80	5	16.26	4.93	10.85	3.3
	100	5	17.98	4.43	9.76	4.08
	120	3	18.79	4.25	9.35	4.42

Coal slag produced the lowest emissions (35.94 mg/ft2) and the lowest consumption (5.19 lb/ft2) at 80 PSI. Similarly, Garnet produced the lowest emissions (16.26 g/ft2) and the lowest consumption (3.3 lb/ft2) at 80 PSI.

Figures C1, C2, and C3 show the productivity variation at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for coal slag. Figure C4 shows the parameter variation with pressure at maximum feed rate for coal slag.

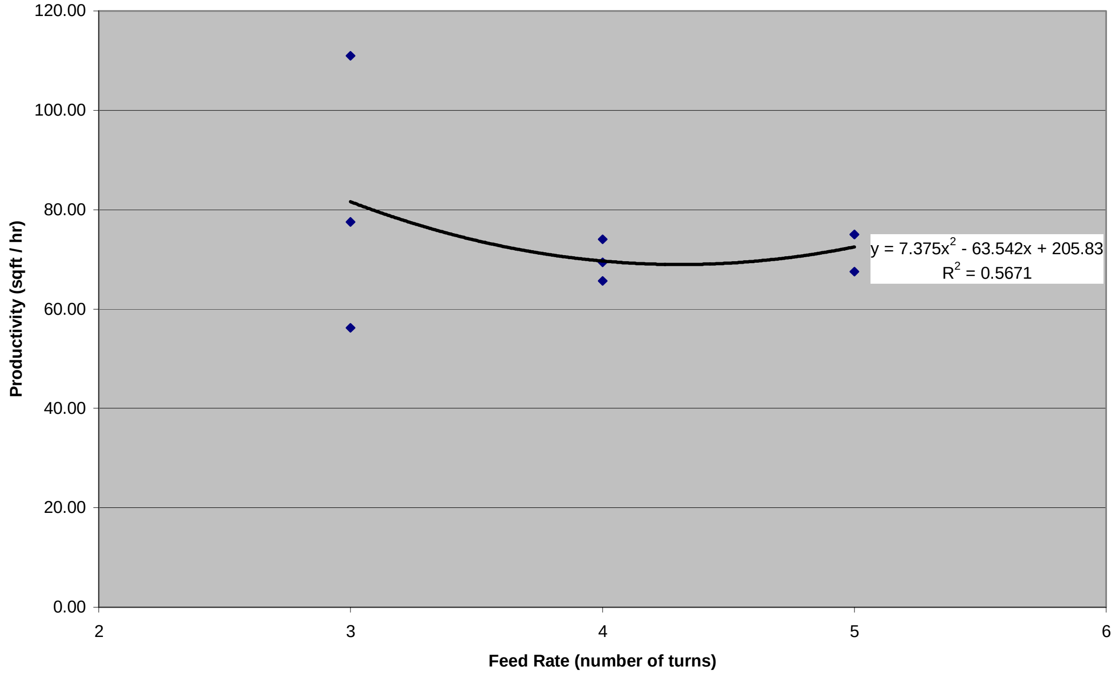


Figure C1: Coal Slag Productivity vs. Feed Rate at 80 PSI

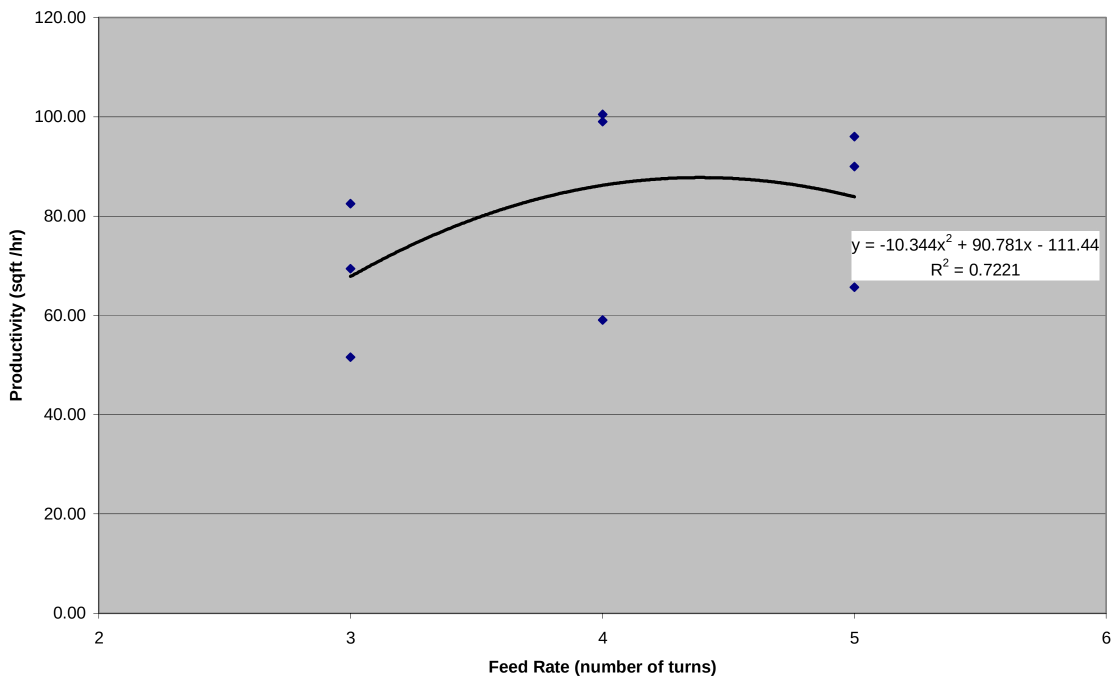


Figure C2: Coal Slag Productivity vs. Feed Rate at 100 PSI

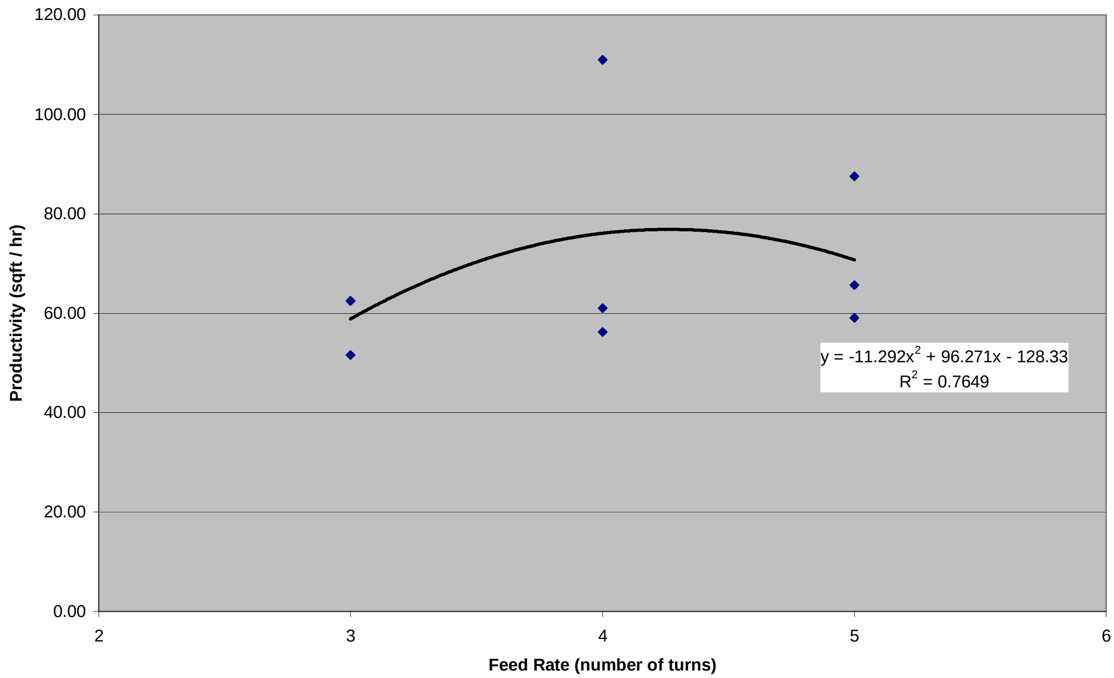


Figure C3: Coal Slag Productivity vs. Feed Rate at 120 PSI

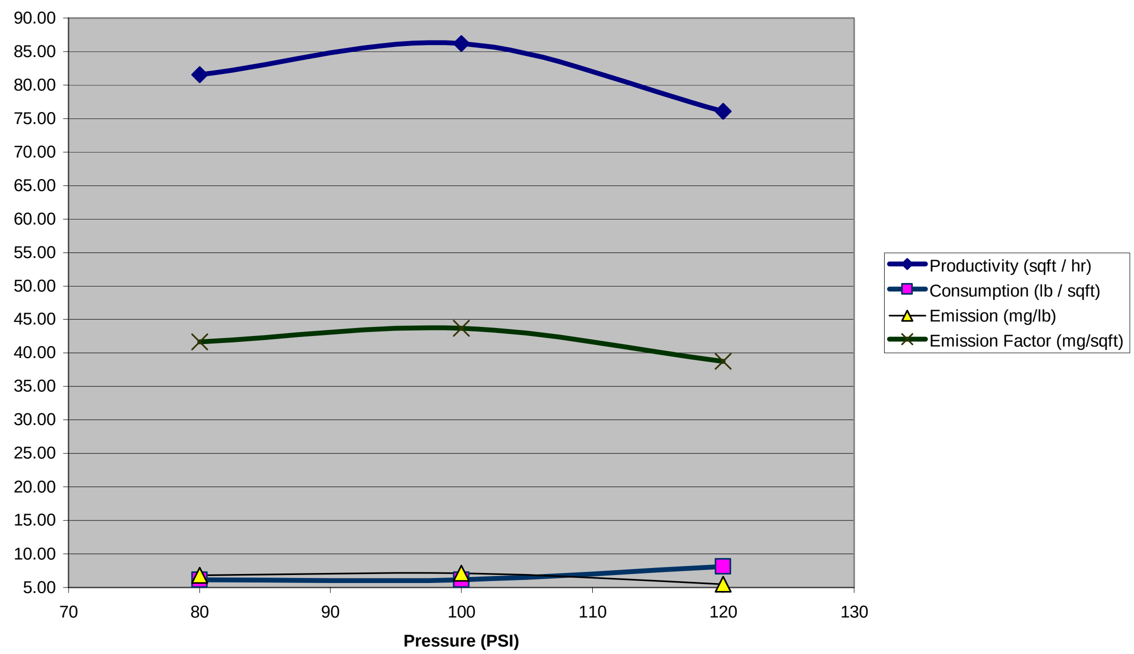


Figure C4: Parameter Variation with Pressure at Maximum Feed Rate for Coal Slag

Figures C5, C6, and C7 show the productivity variation at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for garnet. Figure C8 shows the parameter variation with pressure at maximum feed rate for garnet.

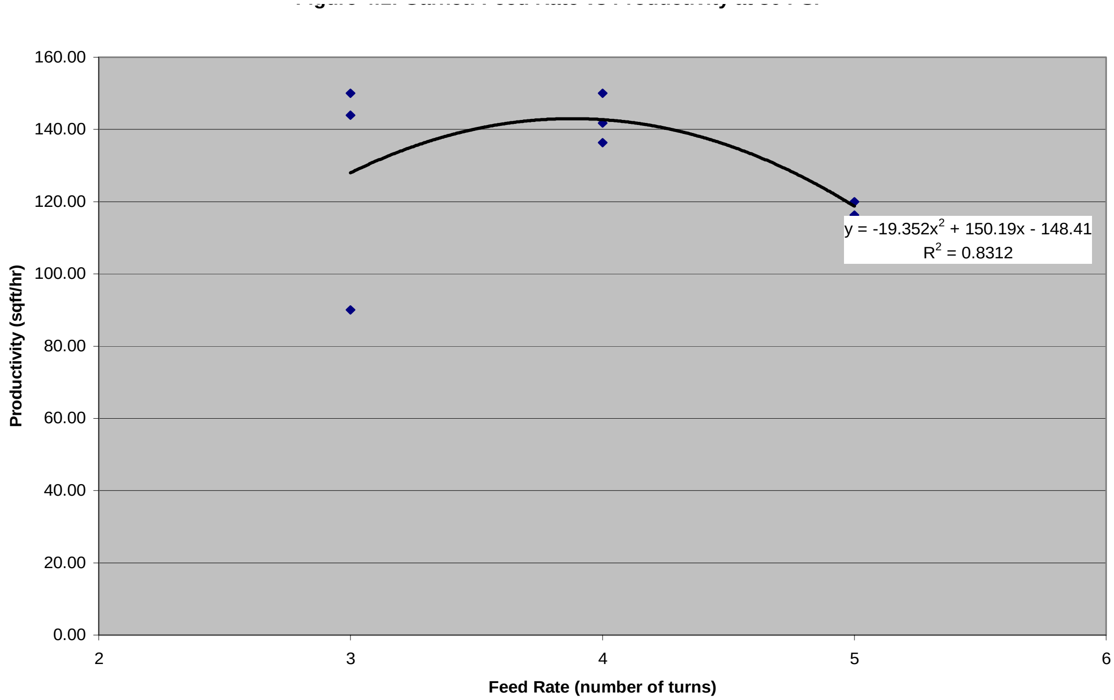


Figure C5: Garnet Productivity vs. Feed Rate at 80PSI

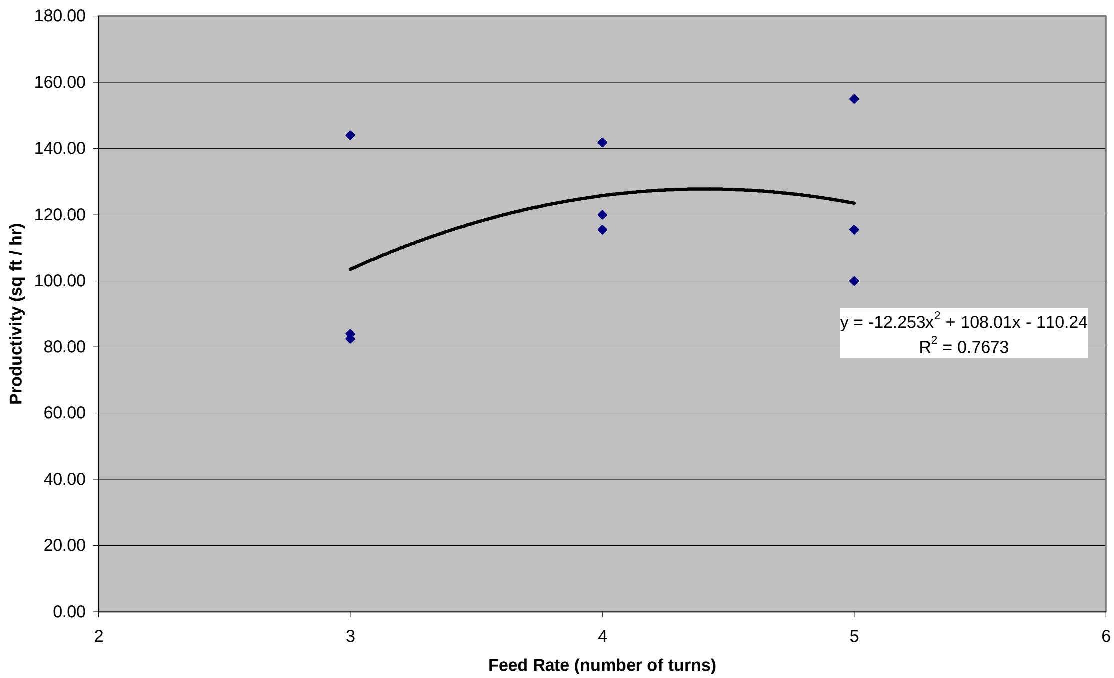


Figure C6: Garnet Productivity vs. Feed Rate at 100PSI

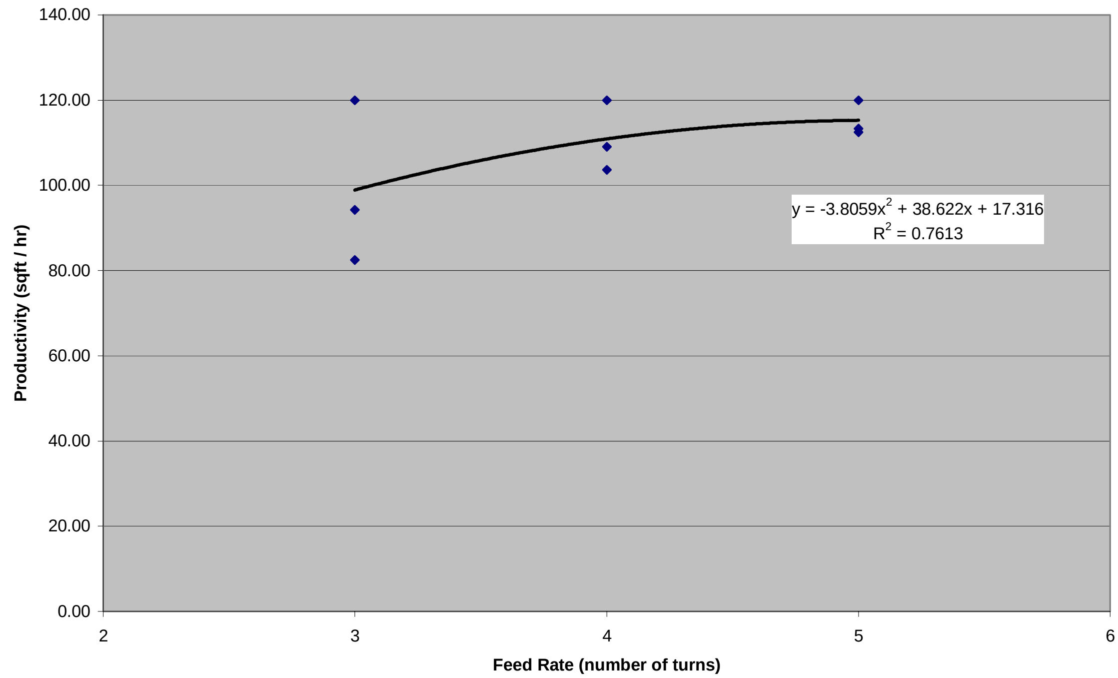


Fig C7: Garnet Productivity vs. Feed Rate at 120PSI

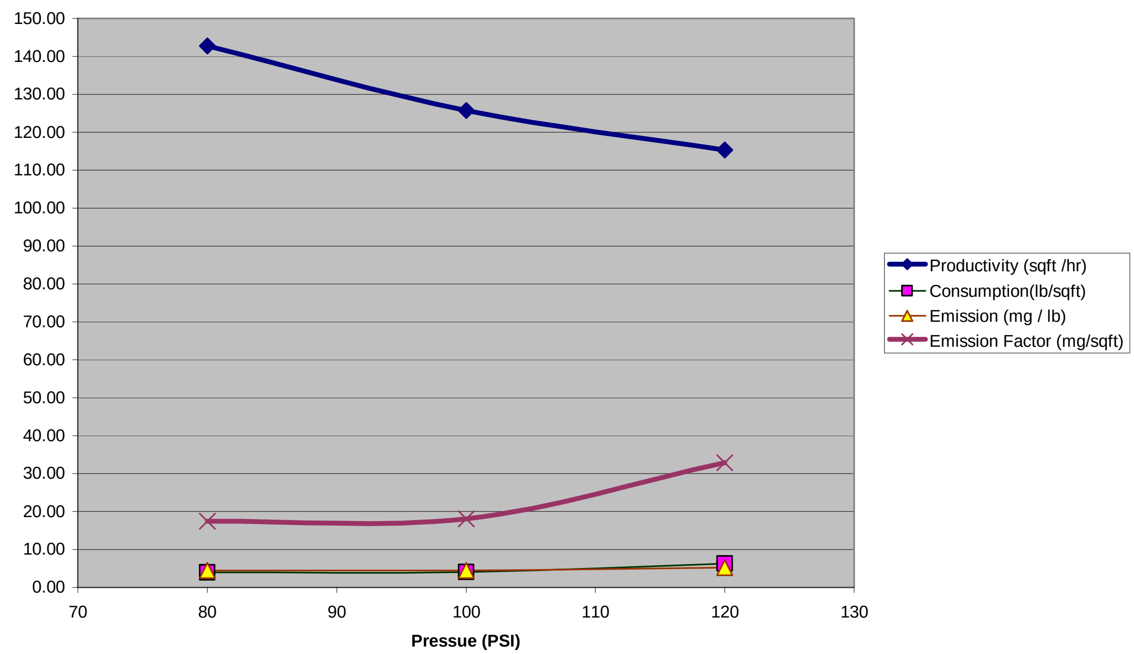


Figure C8: Parameter Variation with Pressure at Maximum Feed Rate for Garnet

7. Conclusions

This study provides valuable field observations on productivity, consumption, and particulate emissions for two abrasives: coal slag and garnet for a combination of feed rate and blast pressure changes. Also, simple mathematical models developed in this study will be valuable in minimizing (1) dry abrasive overall costs, (2) abrasive consumption, (3) generation of used abrasives, and (4) particulate emissions. Specific conclusions of the study are listed below:

- This study provides the productivity, consumption, and emission factors data for dry abrasives, coal slag, and garnet.

- The general trend observed shows that productivity (sq ft/hr) increases with feed rate and then decreases. The maximum productivity was observed in most of the cases at a feed rate corresponding to a 4-turn open condition of the Schmidt valve. This can be read from the productivity vs. feed rate plots for the individual abrasives. Except for coal slag at 80 PSI, all other charts indicate this observation. Productivity read at three turns (80 PSI) had a very high standard deviation, possibly due to some field error.

- Emission factors increase with the increase in feed rate at a constant pressure. But this trend is not quite uniform for all abrasives.

- From the feed rate vs. productivity plots, it can be observed that at 80 PSI, 100 PSI, and 120 PSI, garnet gives the maximum productivity compared to coal slag.

- From the feed rate vs. emission factors (mg/sq ft) plots, the following observations can be made for the emission factor:
    - 80 PSI: coal slag >> garnet
    - 100 PSI: coal slag > garnet
    - 120 PSI: coal slag > garnet

- From the feed rate vs. emission factors (mg/lb) plots, the following observations can be made for the emission factor:
    - 80 PSI: coal slag > garnet
    - 100 PSI: coal slag > garnet
    - 120 PSI: coal slag > garnet.

- There is no clear cut trend with respect to an increase or decrease in productivity with pressure at maximum productivity. However, the pressure vs. productivity (at maximum productivity) plots clearly demonstrate the following trend with respect to productivity:
    - garnet > coal slag

- The minimum emissions corresponding to maximum productivity for each abrasive at the individual pressures are summarized in Table C5.

- Table C6 summarizes the minimum absolute emissions (without considering productivity maxima) for the chosen abrasives at the three pressures. These two tables would be helpful to shipyards for choosing the cleanest abrasive based on their needs.

8. Recommendations

The following recommendations are offered which should help in further understanding of the dry abrasive blasting process, as well as a variety of abrasives available in the market.

- Additional studies should be performed on other abrasives such as steel grit, hematite, sand, and copper slag to generate a master database which will help the shipbuilding industry.

- Additional studies should be carried out to include not only the flash rust but the painted surfaces also, as shipyards perform both blasting of flash rust and painted panels.

- In this study, tests were done for the first use of an abrasive with no recycling. Reusable materials like garnet should be tested for second and third passes to see how its productivity, consumption, and particulate emissions change with subsequent uses.

9. Benefits

This research has several benefits to many agencies involved. The data can be used while considering economic as well as environmental factors.

- This research helps in lowering shipbuilding and ship repair costs. As blasting is a major process in shipyards, this process can be optimized by using environmental performance models generated in the research.

- This research helps protect the environment by the selection of appropriate abrasives and process parameters.

- This research helps shipyards in obtaining air permits based on true emission factor data.

- This research helps environmental regulatory agencies in their permitting activities.

- This research helps in health risk assessment studies

10. References

1. Blast Off Clemco Industries Corporation. Blast Off. 1994.
2. National Shipbuilding Research Program, Facilities and Environmental Effects Panel SP-1. Particulate Emission Factors for Blasting Operations and Other Potential Sources. Project No. N1-97-04. September 1999.
3. EPA Methods 1 to 5
4. EPA. Method 204-Criteria for and Verification of a Permanent or Temporary Total Enclosure.
5. EPA. The Plain English Guide to Clean Air Act. http://www.epa.gov/oar/oaqps/peg_caa/pegcaa03.htm
6. Fundamentals of Air Sampling, Gregory D. Wight, 1994
7. Air Pollution Control
8. SPC Standards, http://www.blastal.com/blasting.html

Appendices

Appendix A

A1.Background Study Data

Table A.1. Abrasive Blast Media Usage, Unconfined Abrasive Blasting[2]

Type of Abrasive	Reported Annual Usage (tons)	Percentage of Total Usage (%)	Projected Usage in United States (tons)
Coal Slag	39,065	39.75	208,331
Copper Slag	24,309	24.74	129,663
Sand	12,358	12.58	65,932
Steel Shot	10,236	10.42	54,611
Nickel Slag	4,692	4.77	24,999
Garnet	3,459	3.52	18,448
Other	1,864	1.9	9,957
Steel Grit	1,556	1.58	8,280
Glass	151	0.52	2,725
Other Minerals	168	0.17	891
Iron Grit	40	0.04	209
Iron Grit	6	0.01	52
Totals	97,904	100	524,098

Table A2 State wise Data Availability

	Type of Abrasive									
Agency	**Sand**			**Coal Slag**			**Mineral**			
	TPM/TSP	PM10	PM2.5	TPM/TSP	PM10	PM 2.5	TPM/ TSP	PM1 0	PM2.5	
Alabama										
Alaska										
Arizona										
California ARB										
CA-Bay Area		0.04								
CA-South		0.04					0.004			
CA-San	0.0125									
Connecticut										
Delaware										
Florida										
Georgia										
Hawaii										
Indiana										
Louisiana										
Maine										
Maryland										
Minnesota										
Mississippi										
New Mexico										
New York										
North Carolina										
Ohio										
Oregon										
Pennsylvania										
Texas	0.043	0		0.0023	0					
Federal EPA										

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.

B1 Method 1: Location of sampling sort in the duct

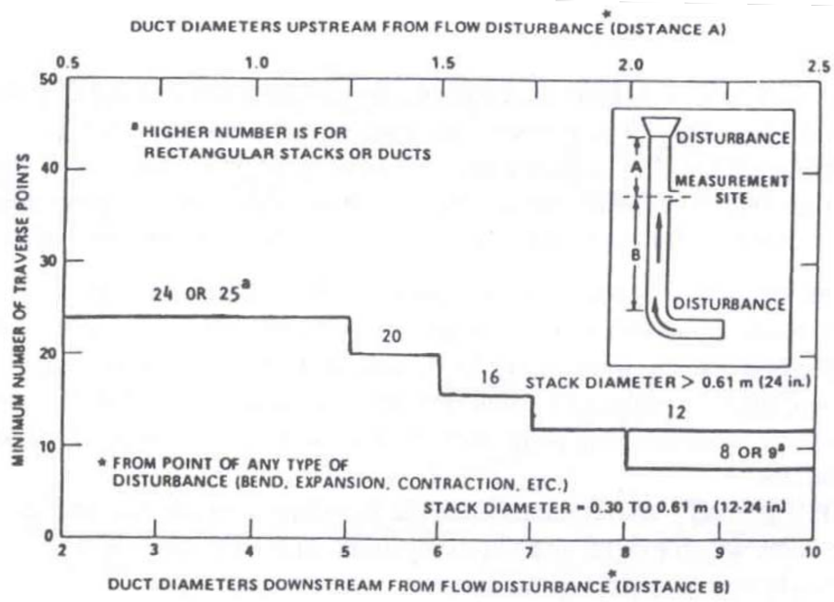
The sampling port is the small cross sectional area cut on the surface of the duct. Through the sampling port the pitot tube can be inserted to take the representative sample of the gas stream flowing through the duct.

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.



Minimum number of traverse points for particulate traverses.

Figure B1: 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).

B2 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.

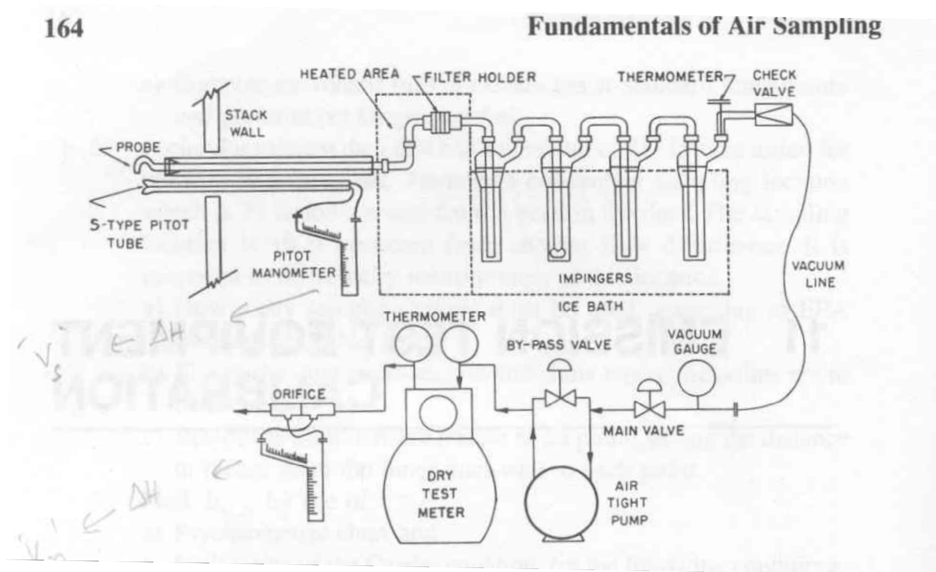


Figure B2: Arrangement of Pitot Tube and Sampling Probe

The pitot tube along with the sampling probe are 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 (Vn) should be equal to velocity in the stack (Vs).

In the experiment, IsoKinetic sampling achieved at the nozzle size of 0.018 inch

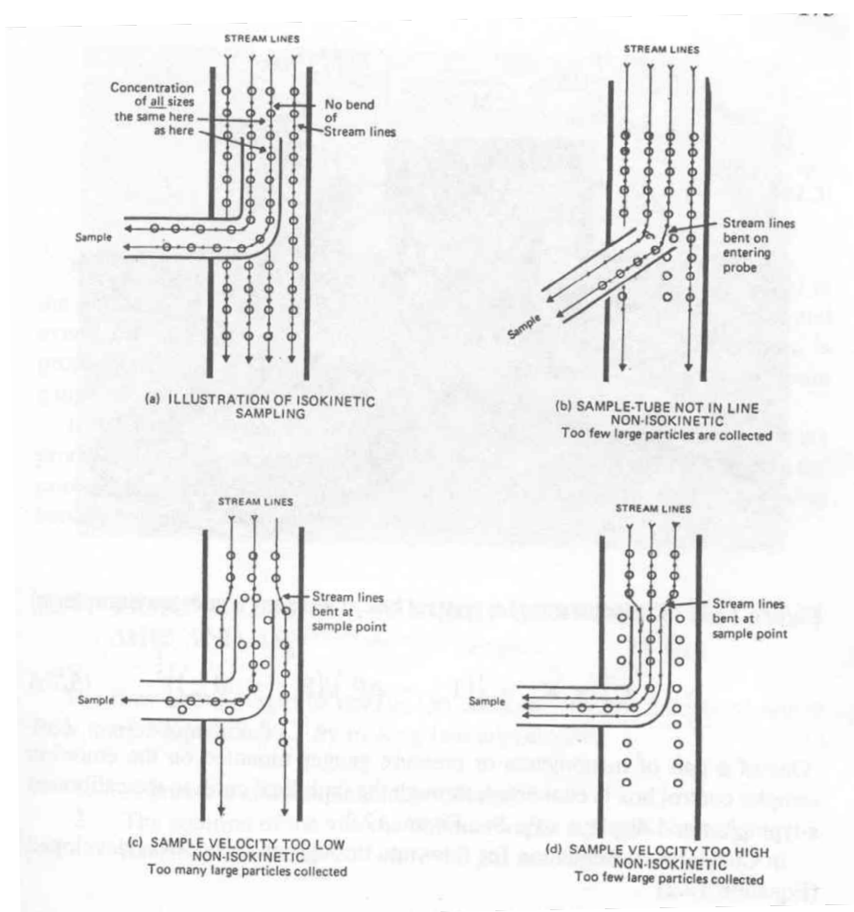


Figure B3: Isokinetic Sampling

B.3 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 H_2O 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.

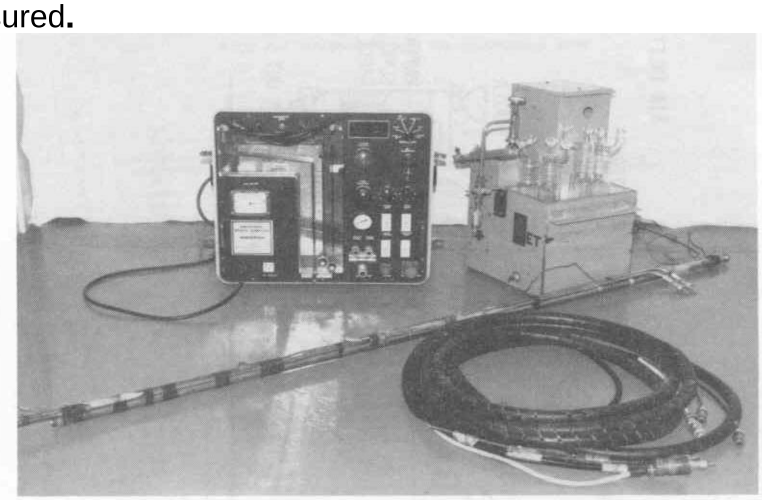


Figure B4: Sampler

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 H_2O 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.

B4 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

Sanjay Datar was born in Miraj, a small town in Sangli district Maharashtra State, India. He graduated with a Bachelors Degree in Civil Engineering from JJMCOE Shivaji University, Kolhapur. Then he completed his Masters degree, Master of Engineering in Urban Planning from Government College of Engineering, Pune, Pune University, India. He worked as Assistant Valuer with Thite Valuers and Engineers, a real estate consultant firm and as Site Engineer with Joshi Home Makers, a civil construction firm at Pune, India. His areas of interest are air pollution, software solutions for environmental issues, risk assessment, water quality modeling, and GIS.

UNIVERSITY OF NEW ORLEANS

MASTER'S EXAMINATION REPORT
Thesis

CANDIDATE: SANJAY RAVINDRA DATAR

MAJOR PROGRAM: MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

TITLE OF THESIS: ENVIRONMENTAL PERFORMANCE OF COAL SLAG AND GARNET AS ABRASIVES

APPROVED

DR. BHASKAR KURA
Major Professor (typed) — Signature

DR KENNETH L. McMANIS
Committee Member (typed) — Signature

DR. DONALD E' BARBE'
Committee Member (typed) — Signature

Committee Member (typed) — Signature

Robert C. Cashner
Dean of the Graduate School — Signature

DATE OF EXAMINATION:

TUESDAY, 2ND DECEMBER 2003