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Environmental Performance of Copper Slag and Barshot as Abrasives

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ENVIRONMENTAL PERFORMANCE
OF
COPPER SLAG AND BARSHOT AS ABRASIVES

A Thesis

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

Master of Science
in
Environmental Engineering

by

Sandhya Naidu Potana
B. TECH (Civil) Jawaharlal Nehru Technological University, 2001

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LIST OF ABBREVIATIONS

EPA: Environmental Protection Agency

GCRMTC: Gulf Coast Region Maritime Technology Center

MERIC: Maritime Environmental Research and Information Center

UNO: University Of New Orleans

SSPC: Society for Protective Coatings

PSI: Pounds per Square Inch (Pressure Unit)

MPH: Miles per hour

CFM: Cubic Feet per Minute

PM: Particulate Matter

HAP: Hazardous Air Pollutants

DGM: Dry Gas Meter

CFR: Code of Federal Register

NSRP: National Shipbuilding Research Program

ABSTRACT

The basic objective of this study was to evaluate the environmental performance of two abrasives Copper Slag and Barshot in terms of productivity (in terms of area cleaned- ft^2/hr), consumption and or used-abrasive generation rate (of the abrasive- ton/2000ft^2; lb/ft^2) and particulate emissions (mg/ft^2; mg/lb; lb/lb; lb/kg; lb/ton). This would help in evaluating the clean technologies for dry abrasive blasting and would help shipyards to optimize the productivity and minimize the emissions by choosing the best combinations reported in this study to their conditions appropriately.

This project is a joint effort between the Gulf Coast Region Maritime technology Center (GCRMTC) and USEPA. It was undertaken to simulate actual blasting operations conducted at shipyards under enclosed, un-controlled conditions on plates similar to steel plates commonly blasted at shipyards.

1. INTRODUCTION

Abrasive blasting is the most common method, which is used in majority of the shipyards for paint removal and surface preparation. Abrasive blasting is used to remove mill scale, rust, and old coatings, as well as to provide the surface profile necessary for good adhesion of the thermal spray coating (paint) to the substrate. Many materials can be used as abrasives. Sand is the most commonly used blasting abrasive. Other common abrasives, which provide a range of particle size and hardness are Copper Slag, Coal Slag, Steel Grit, Steel Shot, Glass and Garnet.

In conventional abrasive blasting also called as air-nozzle blasting or dry abrasive blasting, abrasive is conveyed to the surface to be prepared in a medium of high pressure compressed air (90-100 psi) through the nozzle at high velocity (450 mph). The abrasive particle's mass and high velocity combine to produce kinetic energy sufficient to remove rust, mill scale, and old coatings from the substrate while simultaneously producing a roughened surface. The cost and properties associated with the abrasive material dictate its application.

Industries that use abrasive blasting expansively include the,
1) Shipbuilding Repair and Maintenance industry 2) Steel cast fabrication 3) Metal cleaning 4) Automotive industry, and other industries that involve cleaning, polishing, surface preparation and conditioning a surface. Silica sand is commonly used for abrasive blasting where reclaiming is not feasible, such as in unconfined abrasive blasting operations. 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. 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.

1.1 Applications of Abrasive Blasting

Abrasive blasting is the main operation in surface preparation in shipyards around the world. The innumerable applications of abrasive blasting can be categorized into standard applications and special applications. Standard applications can be summarized into three major categories:

1) Surface preparation,
2) Surface cleaning and finishing, and
3) Shot peening.

1.1.1 Surface preparation:

Surface preparation is a very important step in the shipbuilding industry. Without proper surface preparation subsequent surface coatings will prematurely fail due to poor adhesion. The purpose of surface preparation is to roughen the surface, creating increased surface area for mechanical bonding of the paint spray coating to the substrate.

The performance and service life of a protective coating system is dependent upon a number of criteria. These criteria include factors such as choice of coating system, ambient conditions under which the system is to be applied and the standard of surface preparation to be undertaken prior to application of the paint. Of these considerations, the most important factor is in establishing and maintaining a high standard of surface preparation. Failure to ensure high standards of surface preparation will inevitably have a detrimental effect on the eventual life and performance of the coating system applied.

1.1.2 Surface cleaning and finishing:

Surface cleaning and finishing differ from surface preparation. While surface preparation is to improve the product appearance, surface cleaning is done to clean surfaces by removing the product contaminants and heat and preparing them for thermal spray coating. Surface treatment methods are done to alter the surface properties in order to increase corrosion resistance or abrasion resistance (Kura, 1996). 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.

1.1.3 Shot Peening:

Shot Peening is used to lengthen the fatigue life of any part that is subjected to stress. It is a cold-working method accomplished by pelting the surface of a metal part with round metallic shot (steel shot/ cast iron shot) thrown at high velocity. Each shot acts as a tiny peen-hammer, making a small dent in the surface of the metal and stretching the surface radially as it hits. 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.

The primary wastes resulting from abrasive blasting operations are hazardous air pollutants, typically particulate metals, and mixture of paint chips and used abrasives. These emissions are dependent on both the abrasive material and the targeted surface (e.g. coated with paint, rust, scale dirt, grease etc.) Abrasive blast wastes may be designated as hazardous due to heavy metal content. One way of volume reduction of the waste generated is by using a blast media that is relatively easy to reuse.

Abrasive Blasting operations do not need to apply for legislative permits to operate under *The Clean Air Act* as industrial sources. However, they are required to follow state regulations and guidelines proposed by the Occupational Safety & Health Administration, which should reduce or eliminate any environmental risk associated with abrasive blasting. Louisiana State is more specific and states that adequate containment methods shall be employed during sandblasting or other similar operations. All reasonable precautions shall be taken to prevent particulate matter from becoming airborne.

Waste minimization can be done by using controls at all times, when abrasive blasting is being conducted. For indoor blasting, system should be exhausted through control equipment with a particulate matter outlet grain loading of 0.30 gdscf or less. (Ref Deq/L.A) Blast cabinet exhaust should be re-circulated to the cabinet or vented to emission control equipment.

1.2 Principle of Abrasive Blasting:

The principle of air-supported abrasive blasting is very elementary. Compressed air propels abrasive particles at high velocities to impact and clean a substrate. All the equipment between the air compressor and the emission of abrasive particles is used to supply, convey, and accelerate the abrasive. Three basic components of abrasive blasting operations are: the equipment, the abrasive, and the personnel. Careful attention to these three basic components is the key to the success or failure of the entire operation.

1. 3 Need for the Research

Maritime industry has several processes such as blasting, painting, welding, metal cutting, and others, which are important with respect to their emission potential for airborne pollutants. Emission factors (mass of pollutant/unit amount of work done or unit amount of product produced) are not available for all the processes. EPA has certain emission factors that are published in AP-42; but their quality rating is very low.

If various production alternatives can be optimized to achieve high productivity, lower consumption and lower emissions, the research will be very valuable for the maritime industry in minimizing costs and reducing the environmental burden. Evaluation of environmental performance of abrasives can be achieved by analyzing the characteristics of abrasives and their effect on blasting productivity, cleaning rates, recyclability, surface profile, dust, and waste generation.

Very limited information is available on emission factors for particulate emissions resulting from dry abrasive blasting. It is vital to evaluate emissions as it relates to life cycle costing and life cycle assessment. Shipyards are required to obtain environmental permits and 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.

Besides emission factors, other parameters such as productivity (speed at which production can be achieved) which influence consumption of natural sources and raw materials are also important for evaluation of environmental performance of abrasives. Productivity and consumption directly relate to generation of multimedia waste quantities (solid wastes and air emissions).

For this research, MERIC designed and installed an emission test facility at University of New Orleans with partial funding received through a research project funded by EPA Region VI. The dimension of the test facility is 12' x 10' x 8' and is equipped with a fume extraction system and a two stage particle collection system (coarse and fine particle collection). Fumes from the emission test facility will be extracted with a variable ventilation rate, up to a maximum of 5400 cubic feet per minute (CFM) allowing capture of particles with different sizes generated during blasting, welding, metal cutting, and others. Two-stage particle collection system installed at test facility includes an inertial separator for coarse particles followed by bag house for fine particles. 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 discussion above clearly indicates that evaluation of environmental performance of abrasives will reduce shipyard costs by reducing consumption, improve productivity, and minimize damage to the environment and public health.

1.4 Research Objectives

This research is aimed at optimization of dry abrasive blasting process and various production alternatives that will result in regulatory compliance, high productivity, lower consumption, and cost optimization. This research will be very valuable for the maritime industry in minimizing costs and reducing the environmental burden. Abrasive blasting is used widely in most of the shipyard repair and maintenance industry. Feed rate (lb/hr), blast pressure (PSI), types of abrasive materials, abrasive material gradation, and number of reuses will influence the material consumption, thus solid waste generation as well as atmospheric emissions. Also, it has a bearing on shipyard costs, namely, labor, material, cleanup, disposal, environmental fees, and other types of costs.

The 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 Abrasives (Independent Parameters):

- Abrasive feed rates (lb/hr),
- Blast pressures (PSI),
- Gradations of abrasives (coarse, medium, and fine).

Environmental/Cost Parameters (Dependent Parameters):

- Solid waste generation potential (lb/ft2),
- Atmospheric emissions (lb/1000 ft2),
- Productivity (ft2/hr) - assists in cost computations by shipyards.
- Consumption

2. BACKGROUND OF THE STUDY

Abrasive blasting is used for a variety of surface cleaning and texturing operations, mostly involving metallic target materials. It is the process of propelling a jet of blast material through a medium (compressed air) to propel the abrasive using either a suction-type or pressure-type process. The medium serves as a carrier to help the blast material obtain the adequate velocity and strength at the time of collision.

In 1991, about 4.5 million tons of abrasives, including 2.5 million tons of sand, 1 million tons of coal Slag, 500 thousand tons of smelter Slag, and 500 thousand tons of other abrasives were used for domestic abrasive blasting operations. Traditionally sand was used as the abrasive, but it is replaced by a metallic grit due to adverse health and environmental effects of silica dust associated with sand blasting.

Abrasive blasting system consists of three essential components:

- Abrasive container/ Blasting pot
- Propelling device and
- Blasting nozzle

The exact equipment used depends to a large extent on the specific application and type of abrasive used. Abrasive blasting can be either dry blasting or wet blasting. Three basic methods can be used to project the abrasive towards the target:

1) Air pressure 2) Centrifugal wheels or 3) Water pressure.

In dry abrasive blasting or air nozzle blasting, the abrasive is conveyed to the surface to be prepared in a medium of high pressure air through a nozzle at high velocities. This process generates a lot of airborne particles because the abrasive which is propelled at high velocity disintegrates into small particles and becomes airborne, which, if inhaled, might be very harmful to human health.

Centrifugal wheel systems also called as roto-blasting or automatic blasting, use a rotating impeller/spinning wheel to mechanically propel the abrasive by a combination of centrifugal and inertial forces. This process allows easy recovery of abrasive materials for reuse and recycling which will reduce the material and disposal costs.

Wet abrasive blasting involves blasting with a mixture of water, air and solid abrasives. It is generally performed on ships to remove chipping paint from ship's hull. Hydro-blasting is a widely used wet blasting technique which uses only high pressure water.

Abrasive materials used in blasting can generally be classified as sand, Slag, metallic shot or grit, synthetic, or other. The cost and properties associated with the abrasive material dictate its application. Hazardous air pollutants, typically particulate metals, are emitted from some abrasive blasting operations. These emissions are dependent on both the abrasive material and the targeted surface. Abrasive selection depends on the desired quality of the product.

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 can be used 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 Slag, which consists of crushed Slag from coal-fired boilers, is commonly used in shipyards. Slag has the advantage of low silica content, but releases hazardous air pollutants (HAP's) 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 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 e.t.c. 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), HAP's and 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. Optimization of dry abrasive blasting process and abrasive materials which will result in waste minimization, regulatory compliance, and cost optimization.

The abrasive used affects the product quality. It determines the nozzle size, operating frequencies of the compressor, and amount of blast material to be used in the process. From this discussion, it is conspicuous that the choice of the proper blasting material is the most governing factor.

Apart from the environmental effects of the blasting process there are some economical issues also. The cost of fines due to increased emissions or using stringent limitations due to increased emissions is another important consideration affecting cost.

The test facility at University of New Orleans, located north of the engineering building was used for development of emission factors for Copper Slag and Barshot with the help of maritime industry, regulatory agencies, equipment vendors, and materials suppliers. The environmental performance of these two abrasives was evaluated at different feed rates (3, 4, 5 turns) and at different blast pressures (80,100, and 120 PSI).

The Environmental Protection (Abrasive Blasting) Regulations 1998 (U.S.A) require abrasive blasting to be carried out in a blasting chamber unless such a chamber cannot reasonably be used because of the size, shape, position or location of the object being blasted. The study was conducted in a closed environment (a chamber specially constructed for the tests) and under controlled conditions (filter bags were used to restrict release of emissions into atmosphere).

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.

2.1 Sources and Applications of Copper Slag

2.1.1 Sources of Copper Slag:

Copper Slag is a dark grey powder with a specific gravity of 3.5 produced during the processing of Copper metal from natural ores. Copper Slag is a molten by-product of high temperature processes that are primarily used to separate the Copper metal and nonmetal constituents contained in the bulk ore. Arizona produces in excess of 20,000 tons of Slag per year

Figure 1: Copper Slag and major blasting application using Copper Slag

2.1.2 Applications: Copper Slag can be used as

- Granular base and embankment materials,
- Aggregate substitutes in hot mix asphalt,
- Mine backfill materials,
- Railway ballast materials,
- Grit blast abrasives,

Roofing granule material,

- Manufacture of blended cements

2.2 Sources and Applications of Barshot

2.2.1 Sources of Barshot: Barshot is an economical, recyclable, blast cleaning abrasive, manufactured from the natural mineral – specular hematite - a totally inert form of ferric oxide. Unlike metallic abrasives, the Barshot particles do not rust when subjected to moist or humid operating conditions. Barshot abrasive results in minimum dust level as it contains less than 0.3% free silica. Barshot when used at higher pressures (120 psi) aggressively removes old coatings, mil scale, and corrosion, quickly, leaving a near white to white metal preparation. It is recommended that proper abrasive metering valves be used to reduce abrasive consumption and maximize production speed.

Figure 2: Specular Hematite/Barshot

It is a cost effective and an environmentally friendly abrasive for the reason that

- Significantly less abrasive per square foot
- Fast blast rate (density 180 lbs/ft3)
- Recyclable 3-5 times reducing media and disposal costs
- California Air Resources Board Approved.
- Non toxic guaranteed - less than 0.3% free silica.
- Pure iron oxide (mineral not metallic) easily recyclable for cement manufacture.
- Has 80% less dust then Sand and Slag Products and even less then Garnet - proven by the NSRP.

Figure 3: Blasting using silica based abrasive / Using Barshot (dust free)

2.2.2 Applications: Barshot can be used as

- Alloying agent in raw material feed stock industries
- Additive in Cement manufacturing industries,
- Critical abrasive in surface preparation and polishing applications,

3. OBJECTIVES OF STUDY

The main objectives of this study were:

- Evaluation of clean technologies for dry abrasive blasting
- To study the environmental performance of Copper Slag and Barshot.
- Optimization of dry abrasive blasting process and abrasive materials which will result in waste minimization, regulatory compliance, and cost optimization.
- Establish relationships among process conditions/materials and the cost/environmental parameters by measuring productivity and waste quantities (solid/hazardous wastes and air emissions)

The specific objectives of the project were:

- Design and construction of the test chamber to be used for simulating actual blasting operations conducted at shipyards under enclosed, controlled conditions on plates similar to steel plates commonly blasted at shipyards
- Evaluation of performance parameters which include:
  - Abrasive feed rates: Corresponds to no. of turns on feed valve; mass flow rate of abrasive through the nozzle under given pressure conditions.
  - Productivity (lb/hr): mass of abrasive material per unit area cleaned
  - Blast pressures (PSI),
  - Gradations of abrasives (coarse, medium or fine),
  - Types of abrasives (Copper Slag and Barshot) and
  - Number of reuses
  - Material consumption: Defined as the amount of abrasive material used per unit area cleaned.

  - Emission Factors – this is indicative of the pollutant mass emitted in terms of input or output parameters, and can be defined as follows:
    - ✓ Mass of pollutant / area cleaned,
    - ✓ Mass of pollutant / mass of abrasive used.
- Analysis of the experimental results and the estimation of the cleaner abrasive and process parameter combinations resulting in least emissions and maximum productivity.

4. EQUIPMENT AND MATERIALS

4.1 Test Chamber Design and Construction

An emission test facility was installed on the rear end of the engineering building on the main campus of UNO in New Orleans with partial funding received through a research project funded by EPA region VI. Test facility is of size 12 x 10 x 8 feet (length x width x height) 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 then treated with waterproofing materials. Gaps were sealed with the silicon to prevent any seepage of the water that may 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 was erected adjacent to the chamber to house the sampling equipment and test aids. The cover was also used to shield the sampling equipment against rain and storm events.

The test chamber is equipped with a fume extraction system and a two stage particle collection system (coarse and fine particle collection). Fumes from the emission test facility will be extracted with a variable ventilation rate, up to a maximum of 5500 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. Emission test facility is equipped with a long 12” diameter duct to allow measurement of particles under isokinetic conditions as recommended by the EPA for particle collection from stationery sources.

Figure 4: Emission test facility at UNO

Blast chamber consists of a room with internal lighting that holds both the work piece and the operator. The operator may hold the blasting nozzle on the end of the hose. The work piece rest on wooden flooring that allows used abrasive to drop through for recycling. Provisions were made for 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.

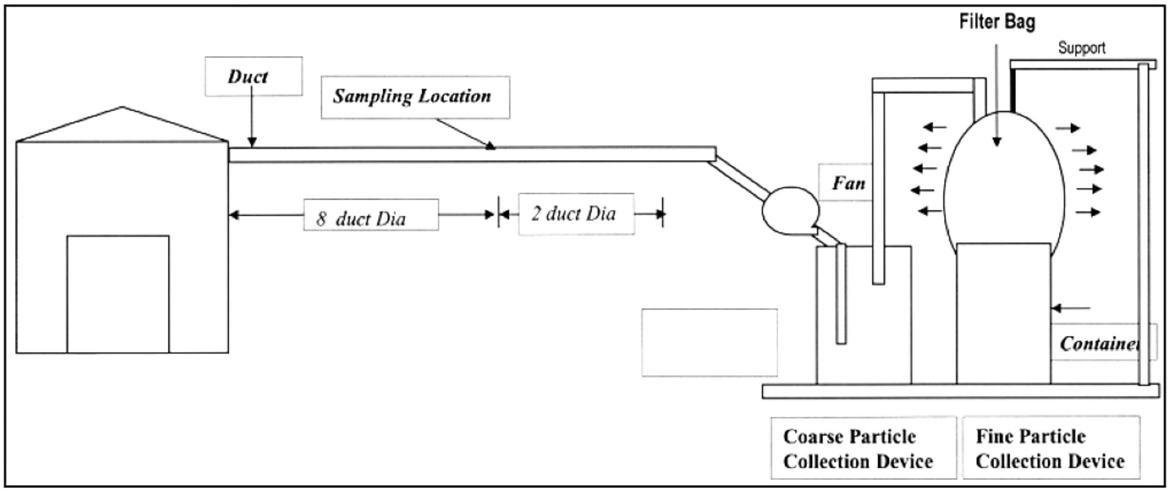

Figure 5: Complete Assembly of the Test Facility

The exhaust fan is capable of operating at various speeds and corresponds to a maximum flow of 5500 cubic feet per minute (CFM). The operating conditions at UNO test facility are varying between 2800-3600 CFM. It has a variable speed meter which was operated at 60 HZ. The particles are 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.

4.2 Blasting Equipment (Blastpot)

The action of propelling the blast material with the help of air takes place in this blastpot. The abrasive as well as the air will be at the same pressure, which sweeps the abrasive towards the hose. The blast material mixes with compressed air and gains its strength in the blasting equipment. The blasting equipment known as blast pot used in this experiment is of 600 lbs capacity and with 1.25 inches piping, with moisture separator, air filter, and helmet with air conditioning unit.

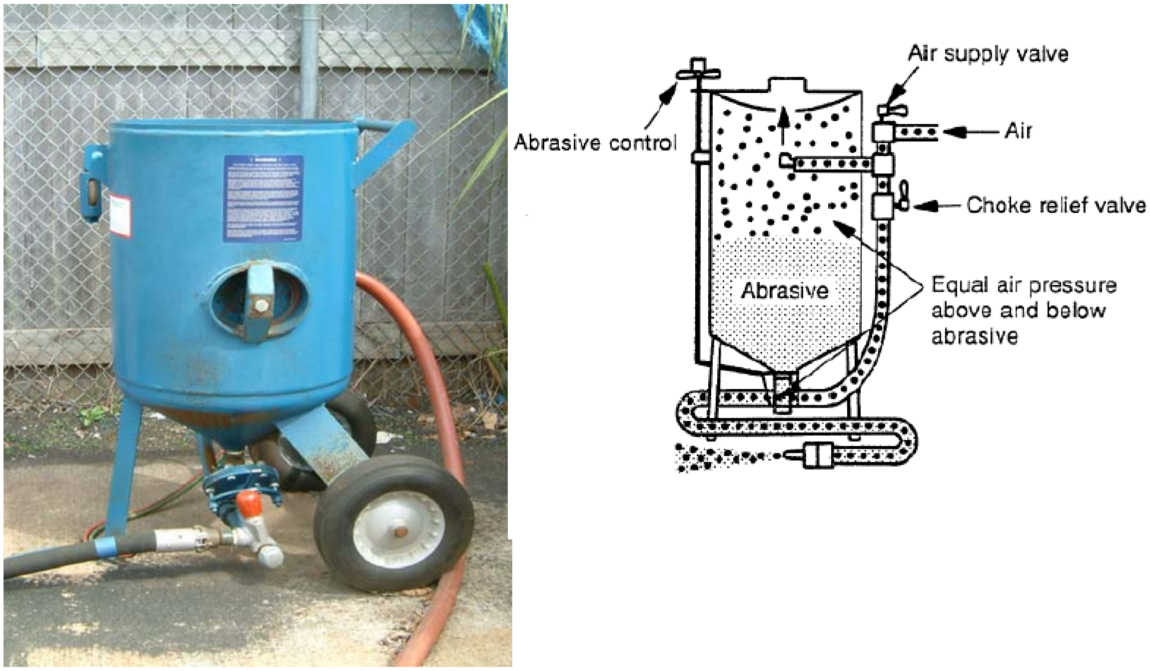

Figure 6: Schematic Diagram of Blastpot

The abrasive 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. A known quantity of abrasive is put in the blast pot.

Figure 7: Blast pot; Hose with nozzle holder; Respirator, air purifier and air supply hose kit;

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. 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. After cleaning, the side opening, a small window on the side of the blastpot, as shown in Fig. 5 must be closed tightly.

4.3 Compressor

Compressed air is, with abrasive, one of the most important components of the entire abrasive blast system. The compressor provides the air pressure to the blasting material. A hose 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 such as grain size and shape of the abrasive, pressure of the compressed air, e.g., 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 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 8: Compressor Sullair 375 H

4.4 Exhaust Duct

The exhaust duct was designed strictly based on EPA method 1 for stack monitoring and testing. 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 and free of undulations and fairly straight. 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 9: Exhaust Duct Entrance

Figure 10: Exhaust Duct Outside

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 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 should be ensured throughout each and every test run. Iso-kinetic sampling helps 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

This sampling equipment is designed in accordance with 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.

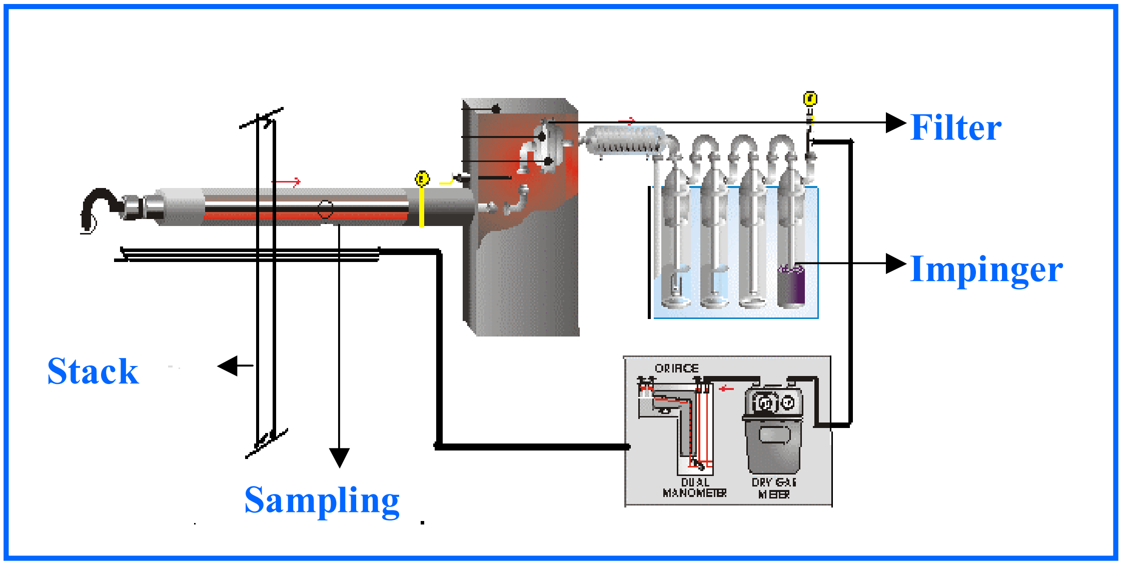

Figure 11: Sampling Train

Since the objective is to measure accurately 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 leak free. 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 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 as the gas passes through before finally exiting.

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 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 12: 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.

4.7 Schmidt Valve

Schmidt valve was used to vary the feed rates in terms of the number of turns by which the valve is open. A 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. The

Figure 13: Schmidt Valve

The number of turns used in the experiment ranged from a minimum of three to a maximum of five.

4.8 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.

4.9 Particulate Collection System

Two-stage particle collection system installed at test facility includes an inertial separator for coarse particles followed by bag house for fine particles. 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 (Refer to Figure 13) 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.

Figure 14: Two stage Particulate Collection System

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 (refer Fig. 14) that help in trapping more and more emissions and preventing them from becoming airborne, thus increasing the efficiency of the overall collection system.

Figure 15: Filter Bags

4.10 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 (Bazooka) for all test runs.
- Medium grade Copper Slag and medium grade Barshot 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. FIELD TEST PROCEDURE

Field testing at UNO included two major mechanisms (1) Blasting the rusted panels using Copper Slag and Barshot, and (2) Stack sampling to evaluate particulate emissions.

For source sampling, EPA's emissions test methods 1 through 5 were used. Methods 1 through 5 is presented in Appendix B. Commonly observed shipyard blasting procedures (Society for Protective Coatings- SSPC) recommendations were followed for blasting. SSPC has visual standards to characterize the metal surface that is cleaned using abrasives. These guidelines are presented in Section 5.2. This section presents general procedures used for the field tests.

To begin with, rusted substrates were mounted on the cart (one on each side). The desired amount of abrasive was poured into the blast pot through a sieve to remove any foreign material that may interfere with the smooth flow of the abrasive. 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 (feed rate- 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 iso-kinetic 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, 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 (Hr)

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

a. Mass of particles emitted (mg) / Area cleaned (ft2)
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

The SSPC 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, SP-7 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.

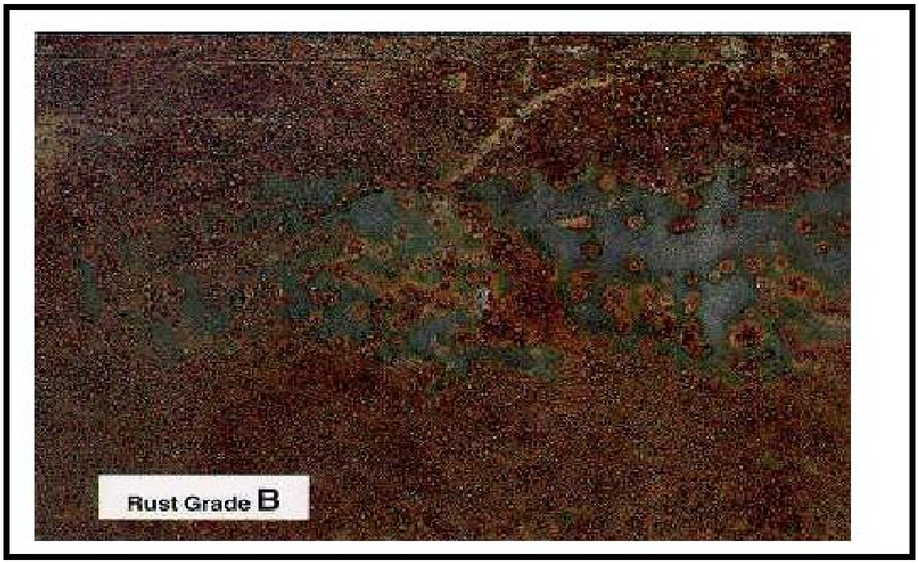

Figure 16: Plate before Blasting

5.2.1 SP-5 SPC Standards

5.2.1. A White Metal Blasting Cleaning ***SSPC SP- 5 Definition:*** White metal blast cleaning is a method of preparing steel surfaces by use of abrasive blasting. Using an abrasive along with compressed air, water, or both, removes all dirt, dust, loose mill scale, loose rust, and loose paint. The completed surface shall be cleaned to a gray-white metallic color. Uniformity of color may be affected by the grade of the metal, original surface condition, or shadowing from blast cleaning patterns

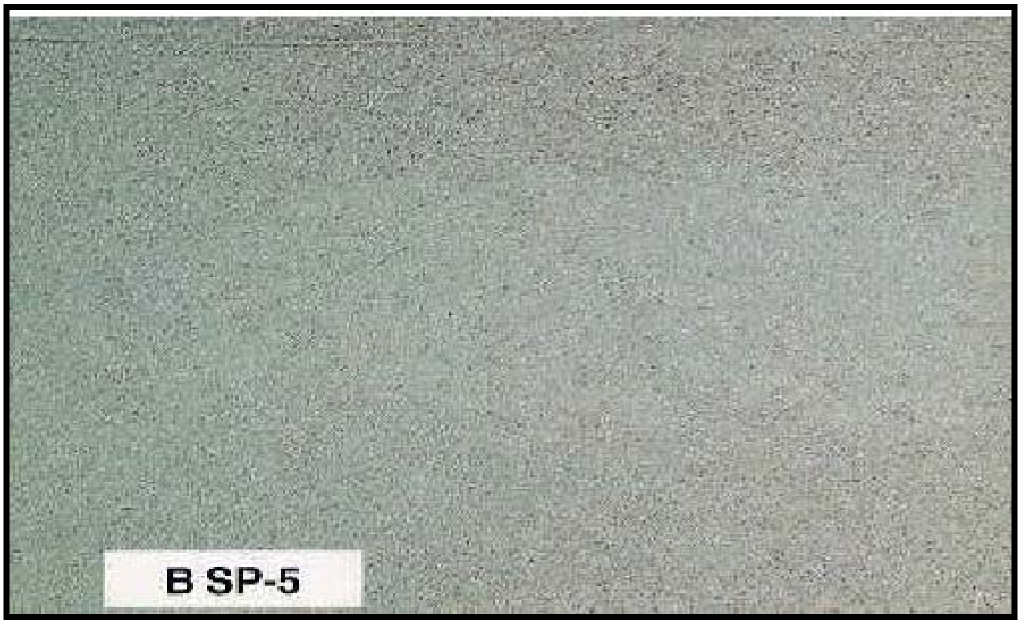

Figure 17: White Metal Blast Cleaning SSPC SP-5

5.2.1. B Commercial Blast Cleaning SSPC SP-6 Definition: Commercial blast cleaning is a method of preparing steel surfaces by use of abrasive blasting. Using an abrasive along with compressed air, water, or both, removes all dirt, dust, loose mill scale, loose rust, and loose paint. Evenly dispersed, very light shadows, streaks or discolorations caused by stains of rust or stains of previously applied paint may remain on no more than 33% of each square inch of surface area.

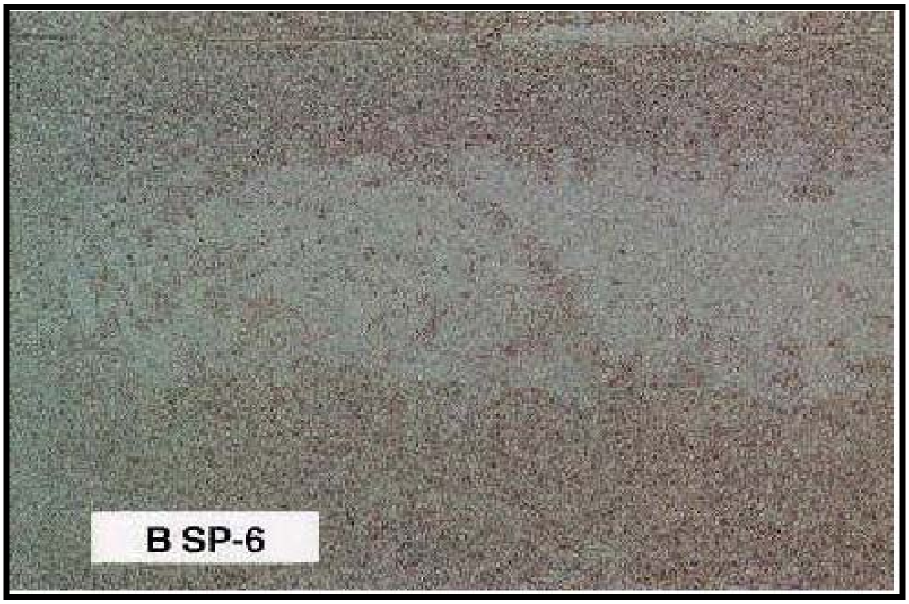

Figure 18: Commercial Blast Cleaning SSPC SP-6

5.2.1 C Brush-off Blast Cleaning SSPC SP-7 Definition: Brush-off blast cleaning is a method of preparing steel surfaces by use of abrasive blasting. Using an abrasive along with compressed air, water, or both, removes all dirt, dust, loose mill scale, loose rust, and loose paint. Tightly adherent mill scale, rust, and paint may remain on the surface. Mill scale, rust and paint are considered adherent if they cannot be removed by a dull putty knife.

5.2.1 D Near-White Blast Cleaning SSPC-SP10 Definition: Near-white blast cleaning is a method of preparing steel surfaces by use of abrasive blasting. Using an abrasive along with compressed air, water, or both, removes all dirt, dust, loose mill scale, loose rust, and loose paint. Evenly dispersed, very light shadows, streaks or discolorations caused by stains of rust or stains of previously applied paint may remain on no more than 5% of each square inch of surface area. 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 19: Near-White Blast Cleaning SSPC-SP10

6. RESULTS AND ANALYSIS

This chapter presents the field results obtained in the study. Table S1 gives the field data observed for Copper Slag and Table S2 shows the statistical parameters (mean and standard deviations) of productivity (sq. ft/hr), consumption (lb/sqft) and emission factors (mg/sq. ft, mg/lb, and lb/ton) for Copper Slag. Tables S3 and S4 show similar data for Barshot.

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: BT: 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 S1: Field Data for Copper Slag

Press	Turns	Wt	BT	MCR	A	E	P	C	EF1	EF2			
PSI		Lbs	min	lbs/min	sqft	gm	sqft / hr	lb/sqft	g/sqft	g/lb	lb/lb	lb/kg	lb/ton
120	3	100	10	10.00	28	3573.95	168.00	3.57	127.6	35.7	0.079	0.173733	158
120	4	100	9	11.11	27	4674.05	180.00	3.70	173.1	46.7	0.103	0.227211	206
120	5	100	12	8.33	25	5942.15	125.00	4.00	237.7	59.4	0.131	0.288855	262
120	3	100	9	11.11	26	3801.92	173.33	3.85	146.2	38.0	0.084	0.184816	168
120	4	100	12	8.33	38	5017.84	190.00	2.63	132.0	50.2	0.111	0.243923	221
120	5	100	8	12.50	20	6540.91	150.00	5.00	327.0	65.4	0.144	0.317961	288
120	3	100	11	9.09	30	3791.32	163.64	3.33	126.4	37.9	0.084	0.1843	167
120	4	100	10	10.00	28	4937.27	168.00	3.57	176.3	49.4	0.109	0.240006	218
120	5	100	13	7.69	30	5541.10	138.46	3.33	184.7	55.4	0.122	0.269359	244
100	3	100	11	9.09	26	3733.54	141.82	3.85	143.6	37.3	0.082	0.181492	165
100	4	100	8	12.50	28	6604.31	210.00	3.57	235.9	66.0	0.146	0.321043	291
100	5	100	9	11.11	24	6775.42	160.00	4.17	282.3	67.8	0.149	0.329361	299
100	3	100	12	8.33	27	4593.59	135.00	3.70	170.1	45.9	0.101	0.223299	203
100	4	100	9	11.11	29	5893.23	193.33	3.45	203.2	58.9	0.130	0.286477	260
100	5	100	10	10.00	27	5941.67	162.00	3.70	220.1	59.4	0.131	0.288831	262
100	3	100	13	7.69	29	4424.41	133.85	3.45	152.6	44.2	0.098	0.215076	195
100	4	100	11	9.09	32	6429.16	174.55	3.13	200.9	64.3	0.142	0.312529	284
100	5	100	11	9.09	29	7562.42	158.18	3.45	260.8	75.6	0.167	0.367617	334
80	3	100	15	6.67	34	2298.39	136.00	2.94	67.6	23.0	0.051	0.111727	101
80	4	100	13	7.69	38	2817.61	175.38	2.63	74.1	28.2	0.062	0.136967	124
80	5	100	15	6.67	32	3594.64	128.00	3.13	112.3	35.9	0.079	0.174739	159
80	3	100	12	8.33	28	2050.83	140.00	3.57	73.2	20.5	0.045	0.099693	90
80	4	100	11	9.09	32	2833.42	174.55	3.13	88.5	28.3	0.062	0.137736	125
80	5	100	12	8.33	28	3546.39	140.00	3.57	126.7	35.5	0.078	0.172394	156
80	3	100	11	9.09	25	2254.12	136.36	4.00	90.2	22.5	0.050	0.109575	99
80	5	100	13	7.69	30	3061.60	138.46	3.33	102.1	30.6	0.068	0.148828	135
80	4	100	10	10.00	29	3272.67	174.00	3.45	112.9	32.7	0.072	0.159088	144

BT= Blasting Time, A = Area, E= Emission, P=Productivity, EF1= Emission Factor 1 (mass/unit surface area cleaned) in mg/ ft2, EF2= Emission Factor 2 (mass/unit material used) mg/lb, lb/lb, lb/kg, lb/ton)

Table S2: Productivity, Consumption and Emission Factors for Copper Slag

Press	Turns	Wt	Productivity			Consumption			Emission Factors								
PSI		Lbs	sqft / hr	Mean	S D	lb/sqft	Mean	S D	g/sqft	Mean	SD	g/lb	Mean	SD	lb/ton	Mean	SD
120	3	100	168.00	168.32	4.85	3.57	3.58	0.26	127.6	133.40	11.10	35.7	37.20	1.30	158	164.33	5.51
120	3	100	173.33			3.85			146.2			38.0			168		
120	3	100	163.64			3.33			126.4			37.9			167		
120	**4**	**100**	**180.00**	**179.33**	**11.02**	**3.70**	**3.30**	**0.58**	**173.1**	**160.47**	**24.70**	**46.7**	**48.77**	**1.83**	**206**	**215.00**	**7.94**
120	**4**	**100**	**190.00**			**2.63**			**132.0**			**50.2**			**221**		
120	**4**	**100**	**168.00**			**3.57**			**176.3**			**49.4**			**218**		
120	5	100	125.00	137.82	12.51	4.00	4.11	0.84	237.7	249.80	71.92	59.4	60.07	5.03	262	264.67	22.12
120	5	100	150.00			5.00			327.0			65.4			288		
120	5	100	138.46			3.33			184.7			55.4			244		
100	3	100	141.82	136.89	4.31	3.85	3.67	0.20	143.6	155.43	13.48	37.3	42.47	4.55	165	187.67	20.03
100	3	100	135.00			3.70			170.1			45.9			203		
100	3	100	133.85			3.45			152.6			44.2			195		
100	**4**	**100**	**210.00**	**192.63**	**17.74**	**3.57**	**3.38**	**0.23**	**235.9**	**213.33**	**19.58**	**66.0**	**63.07**	**3.71**	**291**	**278.33**	**16.26**
100	**4**	**100**	**193.33**			**3.45**			**203.2**			**58.9**			**260**		
100	**4**	**100**	**174.55**			**3.13**			**200.9**			**64.3**			**284**		
100	5	100	160.00	160.06	1.91	4.17	3.77	0.37	282.3	254.40	31.59	67.8	67.60	8.10	299	298.33	36.00
100	5	100	162.00			3.70			220.1			59.4			262		
100	5	100	158.18			3.45			260.8			75.6			334		
80	3	100	136.00	137.45	2.21	2.94	3.50	0.53	67.6	77.00	11.77	23.0	22.00	1.32	101	96.67	5.86
80	3	100	140.00			3.57			73.2			20.5			90		
80	3	100	136.36			4.00			90.2			22.5			99		
80	**4**	**100**	**175.38**	**174.64**	**0.69**	**2.63**	**3.07**	**0.41**	**74.1**	**91.83**	**19.61**	**28.2**	**29.73**	**2.57**	**124**	**131.00**	**11.27**
80	**4**	**100**	**174.55**			**3.13**			**88.5**			**28.3**			**125**		
80	**4**	**100**	**174.00**			**3.45**			**112.9**			**32.7**			**144**		
80	5	100	128.00	135.49	6.53	3.13	3.34	0.22	112.3	113.70	12.36	35.9	34.00	2.95	159	150.00	13.08
80	5	100	140.00			3.57			126.7			35.5			156		
80	5	100	138.46			3.33			102.1			30.6			135		

Table S3: Field Data for Barshot

Press	Turns	Wt	BT	MFR	A	E	P	C	EF1	EF2			
PSI		Lbs	Min	lbs/min	sqft	gm	sqft/hr	lb/sqft	g/sqft	g/lb	lb/lb	lb/kg	lb/ton
120	3	100	10	10.00	36	3906.76	216.00	2.78	108.5	39.1	0.086	0.189912	172
120	4	100	8	12.50	34	4796.34	255.00	2.94	141.1	48.0	0.106	0.233155	212
120	5	100	9	11.11	32	5531.46	213.33	3.13	172.9	55.3	0.122	0.26889	244
120	3	100	12	8.33	38	3462.34	190.00	2.63	91.1	34.6	0.076	0.168308	153
120	4	100	9	11.11	38	5745.37	253.33	2.63	151.2	57.5	0.127	0.279289	253
120	5	100	11	9.09	38	5447.72	207.27	2.63	143.4	54.5	0.120	0.26482	240
120	3	100	11	9.09	34	5126.07	185.45	2.94	150.8	51.3	0.113	0.249184	226
120	4	100	8	12.50	34	5238.17	255.00	2.94	154.1	52.4	0.116	0.254633	231
120	5	100	10	10.00	37	5953.31	222.00	2.70	160.9	59.5	0.131	0.289397	263
100	3	100	10	10.00	26.5	3334.04	159.00	3.77	125.8	33.3	0.074	0.162071	147
100	4	100	11	9.09	36	4164.21	196.36	2.78	115.7	41.6	0.092	0.202427	184
100	5	100	12	8.33	28	5257.03	140.00	3.57	187.8	52.6	0.116	0.25555	232
100	3	100	11	9.09	26	3931.40	141.82	3.85	151.2	39.3	0.087	0.19111	173
100	4	100	9	11.11	30	4750.03	200.00	3.33	158.3	47.5	0.105	0.230904	209
100	5	100	11	9.09	28	4294.59	152.73	3.57	153.4	42.9	0.095	0.208765	189
100	3	100	13	7.69	34	2516.04	156.92	2.94	74.0	25.2	0.055	0.122308	111
100	4	100	10	10.00	36	4182.48	216.00	2.78	116.2	41.8	0.092	0.203315	184
100	5	100	13	7.69	30	5801.01	138.46	3.33	193.4	58.0	0.128	0.281993	256
80	3	100	14	7.14	29	3300.61	124.29	3.45	113.8	33.0	0.073	0.160446	146
80	4	100	10	10.00	36	3751.02	216.00	2.78	104.2	37.5	0.083	0.182341	165
80	5	100	9	11.11	28	4479.80	186.67	3.57	160.0	44.8	0.099	0.217768	198
80	3	100	12	8.33	28	3504.36	140.00	3.57	125.2	35.0	0.077	0.170351	155
80	4	100	11	9.09	38	3256.57	207.27	2.63	85.7	32.6	0.072	0.158306	144
80	5	100	12	8.33	36	5163.62	180.00	2.78	143.4	51.6	0.114	0.251009	228
80	3	100	12	8.33	28	3782.47	140.00	3.57	135.1	37.8	0.083	0.18387	167
80	4	100	11	9.09	38	4117.96	207.27	2.63	108.4	41.2	0.091	0.200179	182
80	5	100	10	10.00	27.5	5519.55	165.00	3.64	200.7	55.2	0.122	0.268312	243

BT= Blasting Time, A = Area, E= Emission, P=Productivity, EF1= Emission Factor 1 (mass/unit surface area cleaned) in mg/ ft2, EF2= Emission Factor 2 (mass/unit material used) mg/lb, lb/lb, lb/kg, lb/ton)

Table S4: Productivity, Consumption and Emission Factors for Barshot

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	216.00	197.15	16.48	2.78	2.78	0.16	108.5	116.80	30.70	39.1	41.67	8.64	172	183.67	37.87
120	3	100	190.00			2.63			91.1			34.6			153		
120	3	100	185.45			2.94			150.8			51.3			226		
120	**4**	**100**	**255.00**	**254.44**	**0.96**	**2.94**	**2.84**	**0.18**	**141.1**	**148.80**	**6.82**	**48.0**	**52.63**	**4.75**	**212**	**232.00**	**20.52**
120	**4**	**100**	**253.33**			**2.63**			**151.2**			**57.5**			**253**		
120	**4**	**100**	**255.00**			**2.94**			**154.1**			**52.4**			**231**		
120	5	100	213.33	214.20	7.40	3.13	2.82	0.27	172.9	159.07	14.84	55.3	56.43	2.69	244	249.00	12.29
120	5	100	207.27			2.63			143.4			54.5			240		
120	5	100	222.00			2.70			160.9			59.5			263		
100	3	100	159.00	152.58	9.38	3.77	3.52	0.50	125.8	117.00	39.35	33.3	32.60	7.08	147	143.67	31.13
100	3	100	141.82			3.85			151.2			39.3			173		
100	3	100	156.92			2.94			74.0			25.2			111		
100	**4**	**100**	**196.36**	**204.12**	**10.45**	**2.78**	**2.96**	**0.32**	**115.7**	**130.07**	**24.45**	**41.6**	**43.63**	**3.35**	**184**	**192.33**	**14.43**
100	**4**	**100**	**200.00**			**3.33**			**158.3**			**47.5**			**209**		
100	**4**	**100**	**216.00**			**2.78**			**116.2**			**41.8**			**184**		
100	5	100	140.00	143.73	7.83	3.57	3.49	0.14	187.8	178.20	21.66	52.6	51.17	7.65	232	225.67	33.95
100	5	100	152.73			3.57			153.4			42.9			189		
100	5	100	138.46			3.33			193.4			58.0			256		
80	3	100	124.29	134.76	9.07	3.45	3.53	0.07	113.8	124.70	10.66	33.0	35.27	2.41	146	156.00	10.54
80	3	100	140.00			3.57			125.2			35.0			155		
80	3	100	140.00			3.57			135.1			37.8			167		
80	**4**	**100**	**216.00**	**210.18**	**5.04**	**2.78**	**2.68**	**0.09**	**104.2**	**99.43**	**12.08**	**37.5**	**37.10**	**4.31**	**165**	**163.67**	**19.04**
80	**4**	**100**	**207.27**			**2.63**			**85.7**			**32.6**			**144**		
80	**4**	**100**	**207.27**			**2.63**			**108.4**			**41.2**			**182**		
80	5	100	186.67	177.22	11.10	3.57	3.33	0.48	160.0	168.03	29.48	44.8	50.53	5.28	198	223.00	22.91
80	5	100	180.00			2.78			143.4			51.6			228		
80	5	100	165.00			3.64			200.7			55.2			243		

Environmental performance data presented in the tables above correspond to various blast pressures and various feed rates. As shipyards often use maximum productivity conditions by adjusting feed valve, it was felt vital 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 S5: Minimum Emissions at Maximum Productivity

S No	Pressure	Feed rate	Maximum Productivity	Emission Factors			Consumption
	(PSI)	(No. of turns)	(sqft/hr)	g/sqft	g/lb	lb/ton	lb/sqft
Copper Slag	80	4	174.64	91.83	29.73	131.00	3.07
	100	4	192.63	213.33	63.07	278.33	3.38
	120	4	179.33	160.47	48.77	215	3.3
Barshot	80	4	210.18	99.43	37.1	163.67	2.68
	100	4	204.12	130.07	43.63	192.33	2.96
	120	4	254.44	148.8	52.63	232.00	2.78

Based on the study, it was observed that 80 PSI has resulted in lowest emissions for Copper Slag and minimum consumption for Barshot

i.e. At 80 PSI Copper Slag } Lowest Emissions
Barshot Minimum Consumption

Table S6 shows the absolute minimum emissions without considering productivity.

Table S6: Absolute* Minimum Emissions

S No	**Pressure (PSI)**	**Feed rate (No. of turns)**	**Emission Factors**		
			g/sqft	**g/lb**	**lb/ton**
Copper Slag	80	3	77	22	96.67
	100	3	155.43	42.47	187.67
	120	3	133.4	37.2	164.33
Barshot	80	4	99.43	37.1	163.67
	100	3	117	32.6	143.67
	120	3	116.8	41.67	183.67

* Minimum Emissions without considering Productivity

Copper Slag produced the lowest emissions (77 g/sqft) and the lowest consumption (5.19 lb/ft2) at 80 PSI. Similarly, Barshot produced the lowest emissions (99.43 g/sqft) and the lowest consumption (3.3 lb/ft2) at 80 PSI.

Figures D1, D2, and D3 show the productivity variation at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag. Figure D4 shows the parameter variation with pressure at maximum feed rate for Copper Slag.

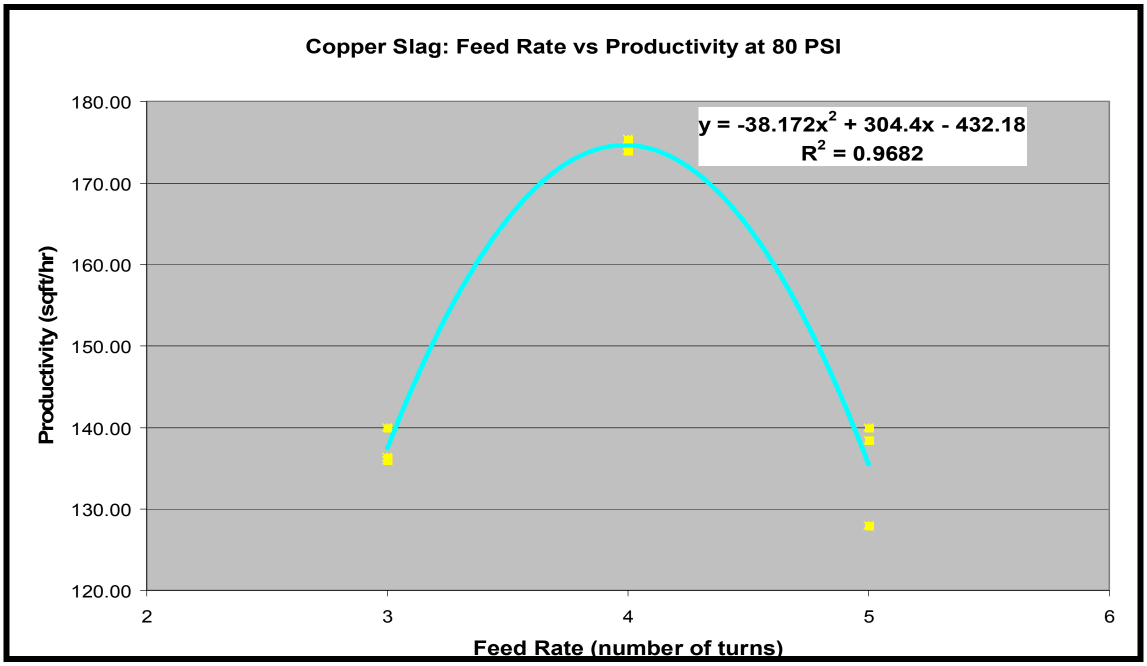

Figure D1: Copper Slag Productivity vs. Feed Rate at 80 PSI

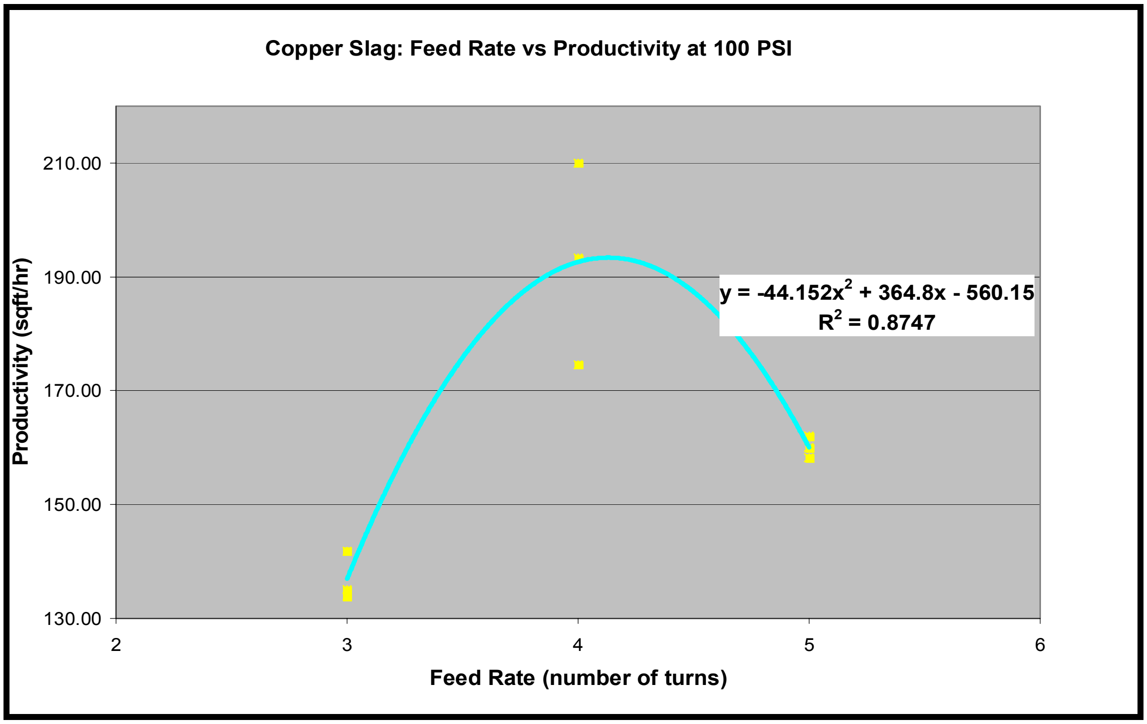

Figure D2: Copper Slag Productivity vs. Feed Rate at 100 PSI

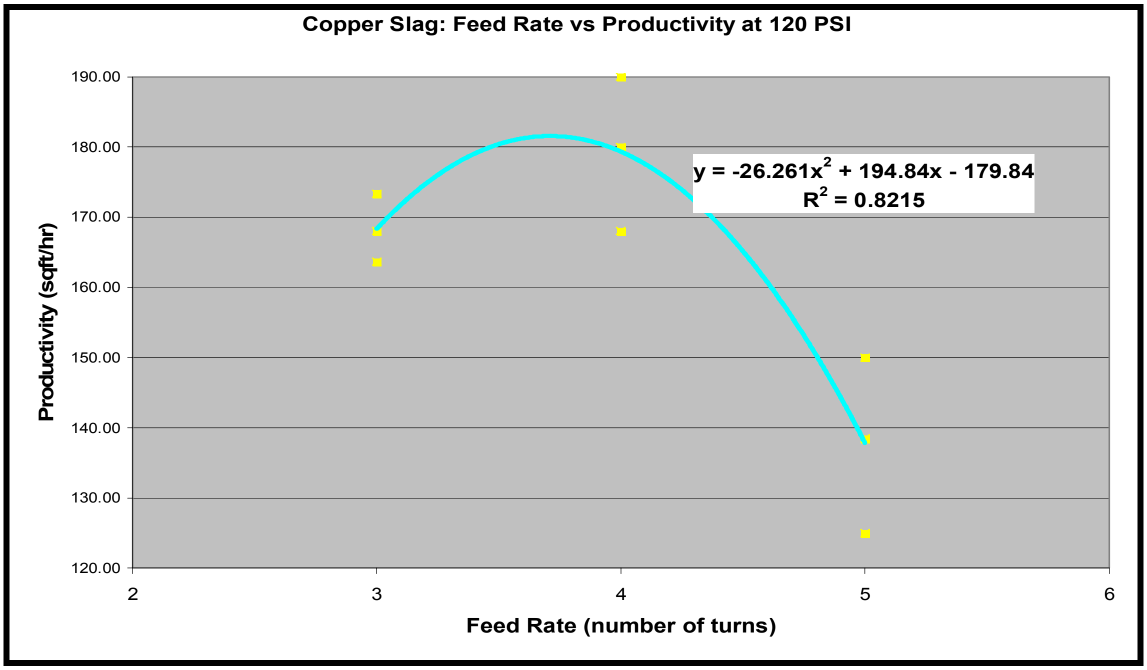

Figure D3: Copper Slag Productivity vs. Feed Rate at 120 PSI

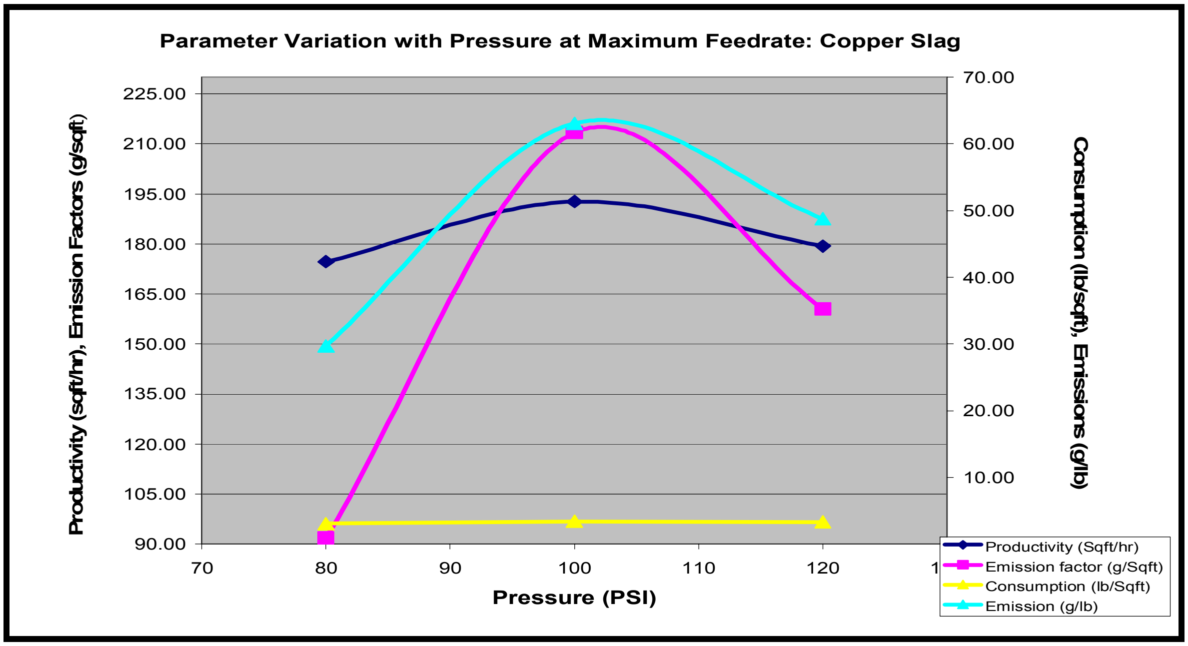

Figure D4: Parameter Variation with Pressure at Maximum Feed Rate for Copper Slag

Figures D5, D6, and D7 show the productivity variation at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Barshot. Figure D8 shows the parameter variation with pressure at maximum feed rate for Barshot.

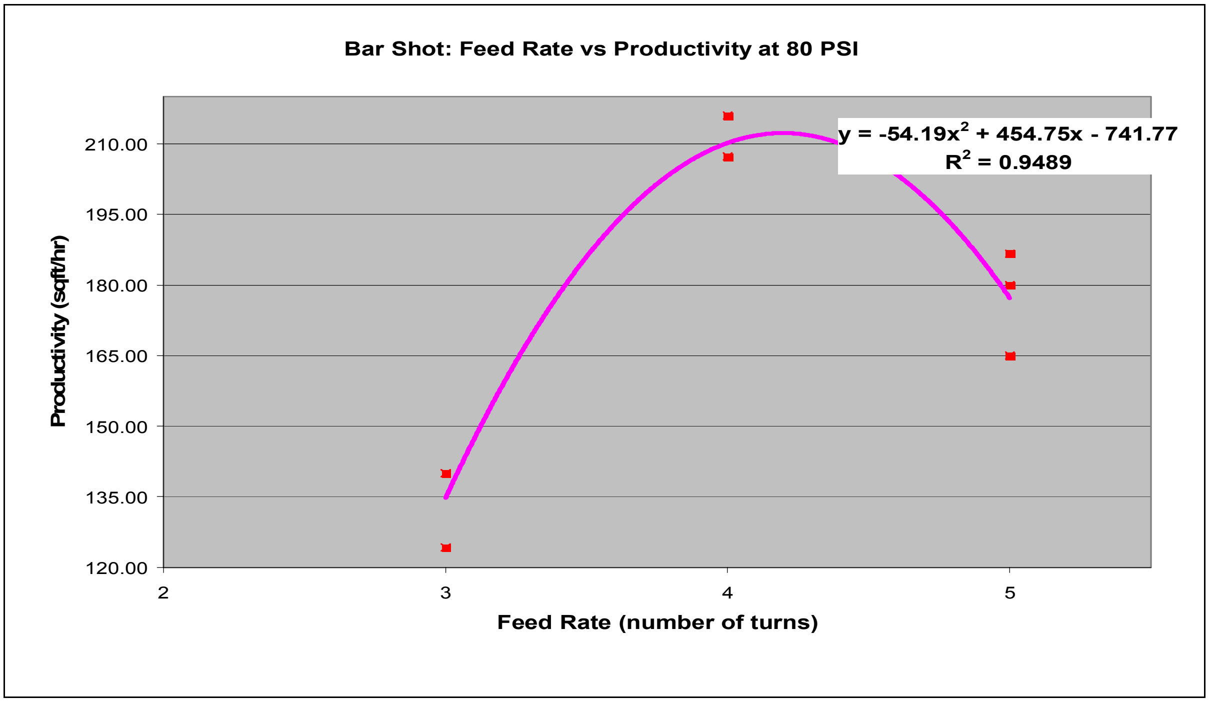

Figure D5: Barshot Productivity vs. Feed Rate at 80PSI

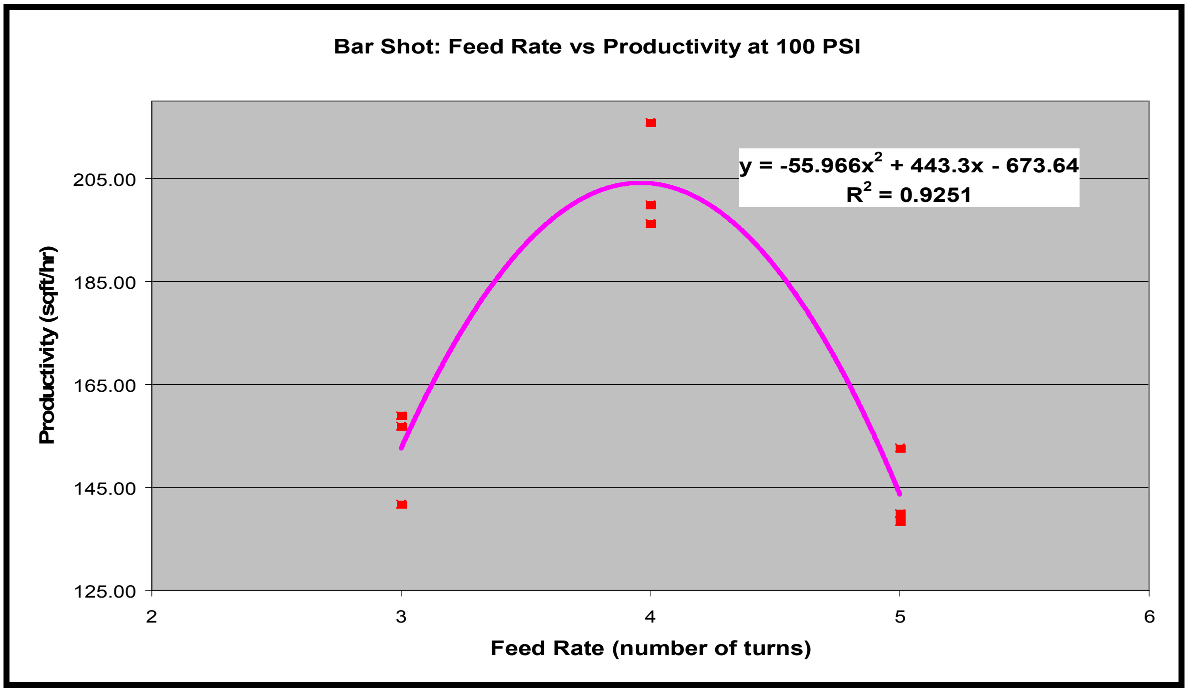

Figure D6: Barshot Productivity vs. Feed Rate at 100PSI

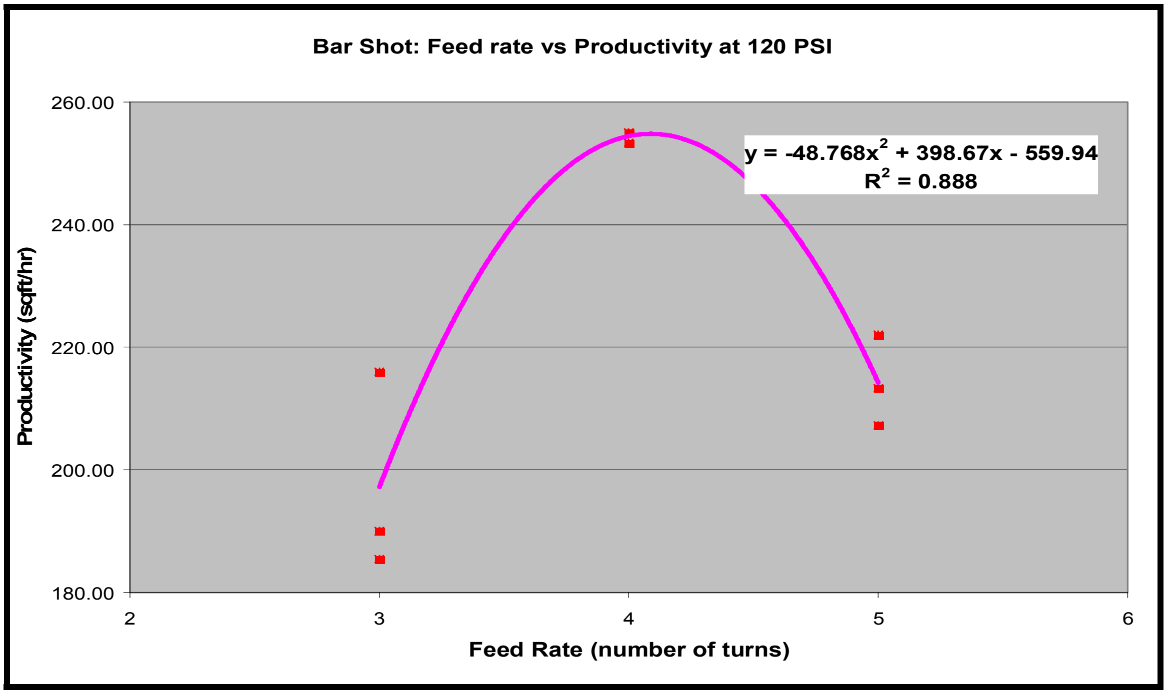

Fig D7: Barshot Productivity vs. Feed Rate at 120PSI

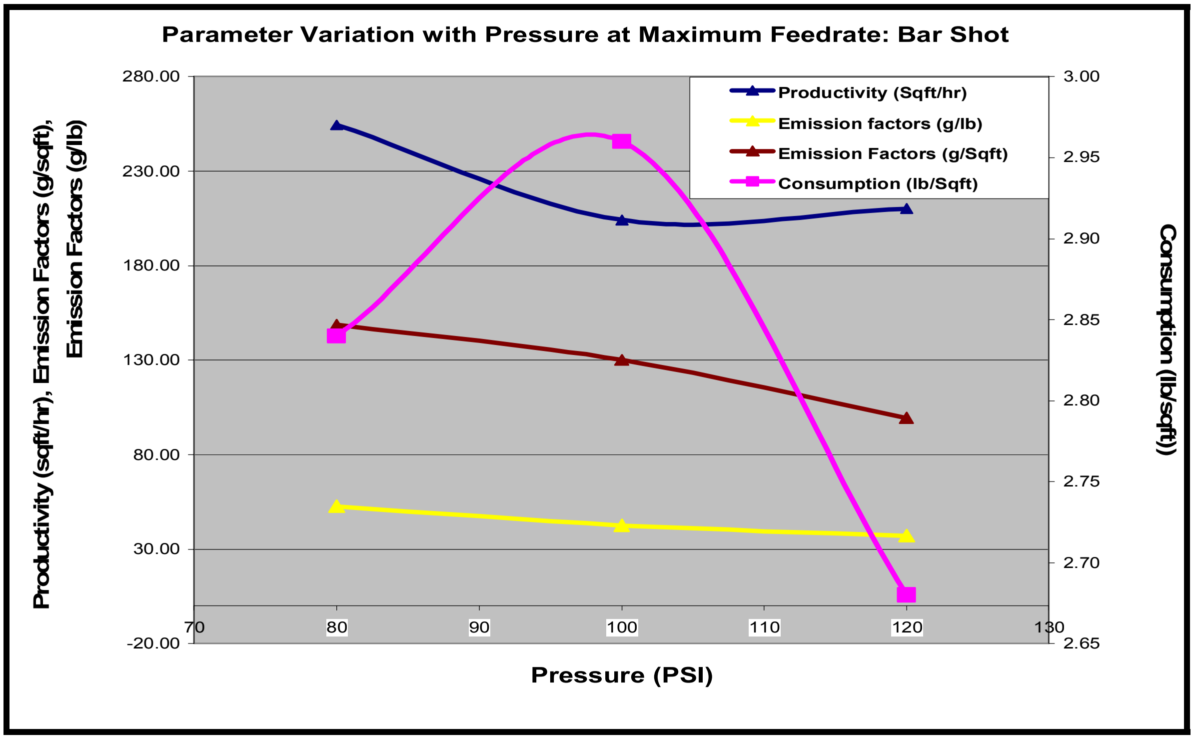

Figure D8: Parameter Variation with Pressure at Maximum Feed Rate for Barshot

The figures D9, D10, and D11 show the productivity variation for different feed rates at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag and Barshot.

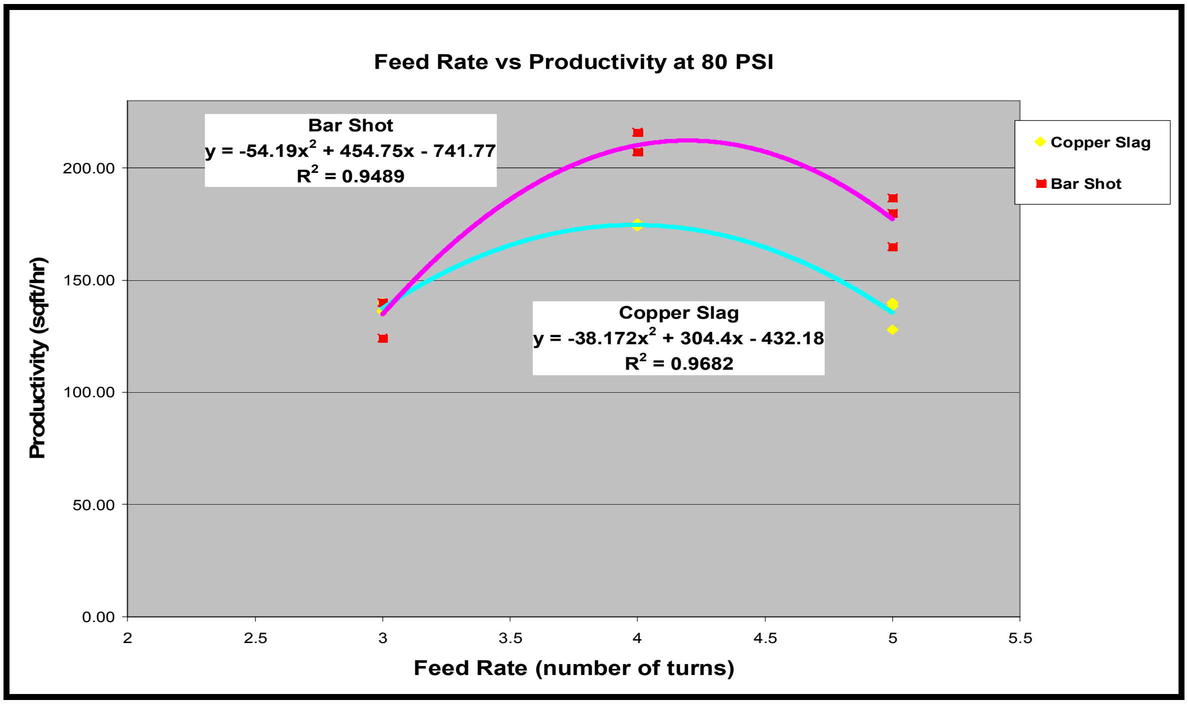

Figure D9: Feed Rate vs. Productivity at 80 PSI for Copper Slag and Barshot

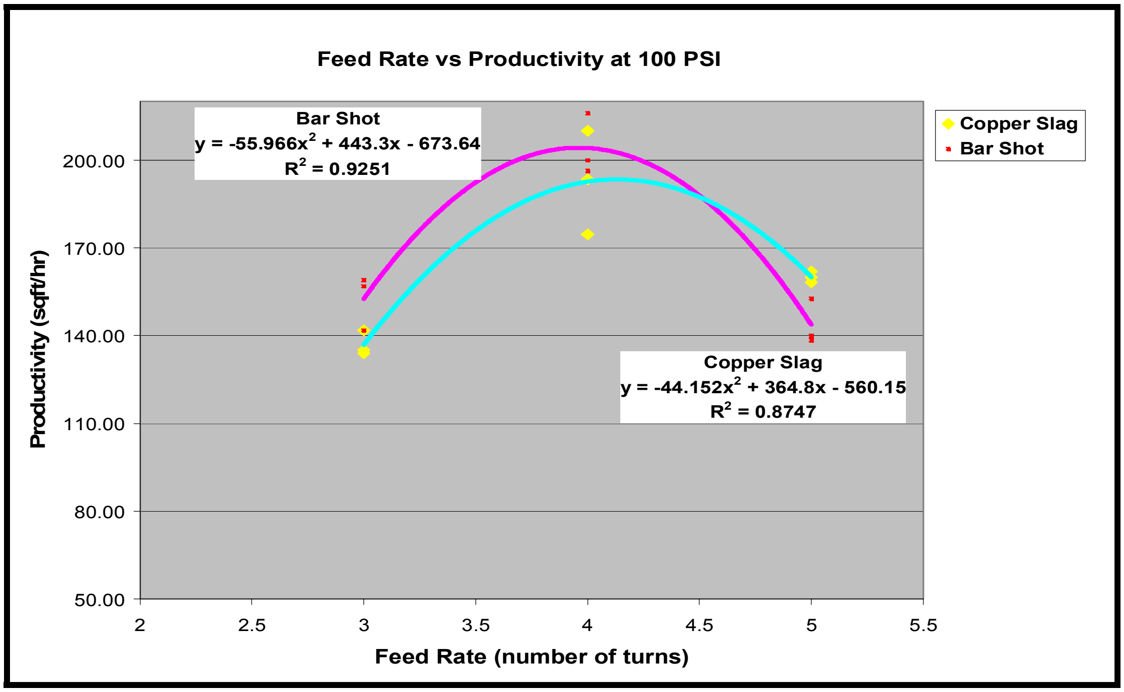

Figure D10: Feed Rate vs. Productivity at 100 PSI for Copper Slag and Barshot

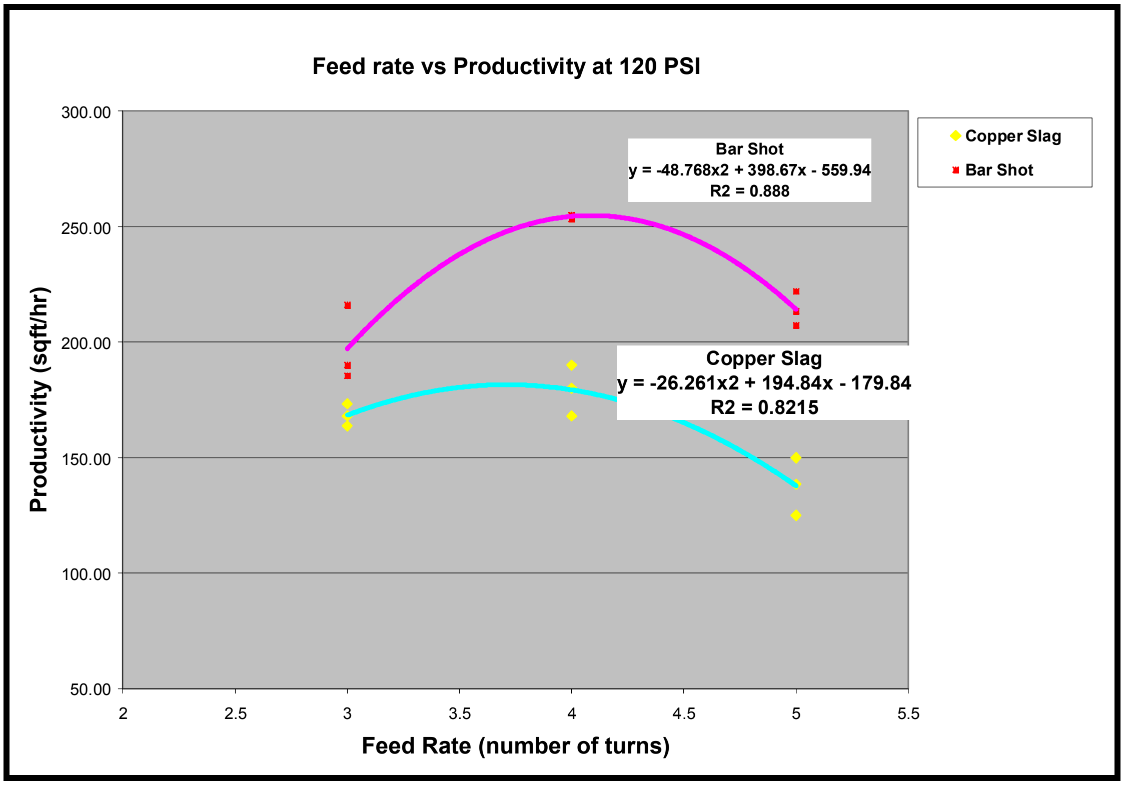

Figure D11: Feed Rate vs. Productivity at 120 PSI for Copper Slag and Barshot

Figures D12, D13, and D14 show the variation in emission factors (g/sqft, in terms of area cleaned) for different feed rates at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag and Barshot.

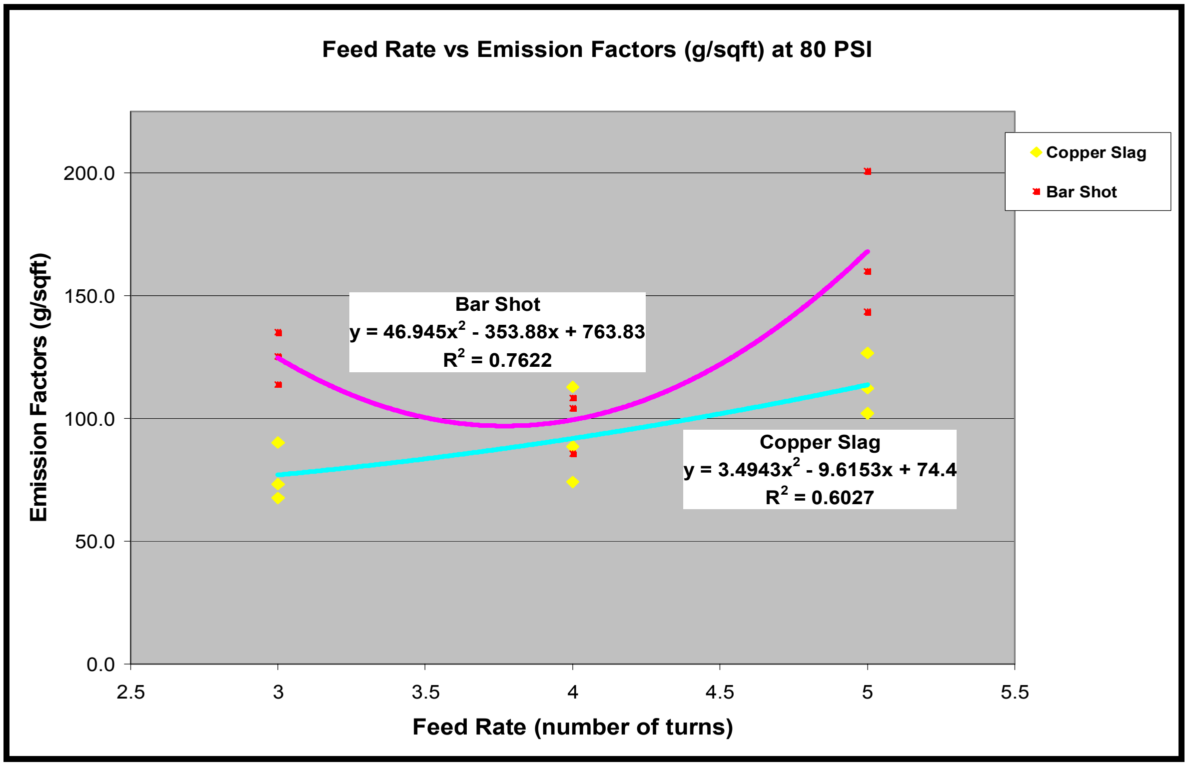

Figure D12: Feed Rate vs. Emission Factors (g/sqft) at 80 PSI

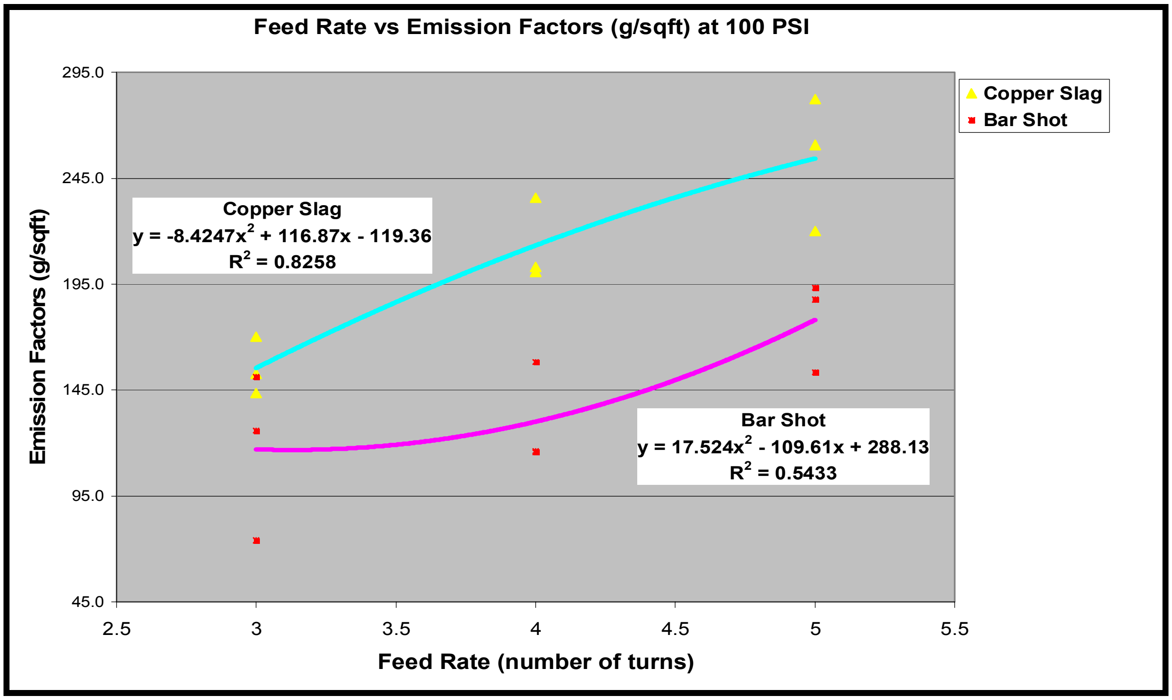

Figure D13: Feed Rate vs. Emission Factors (g/sqft) at 100 PSI

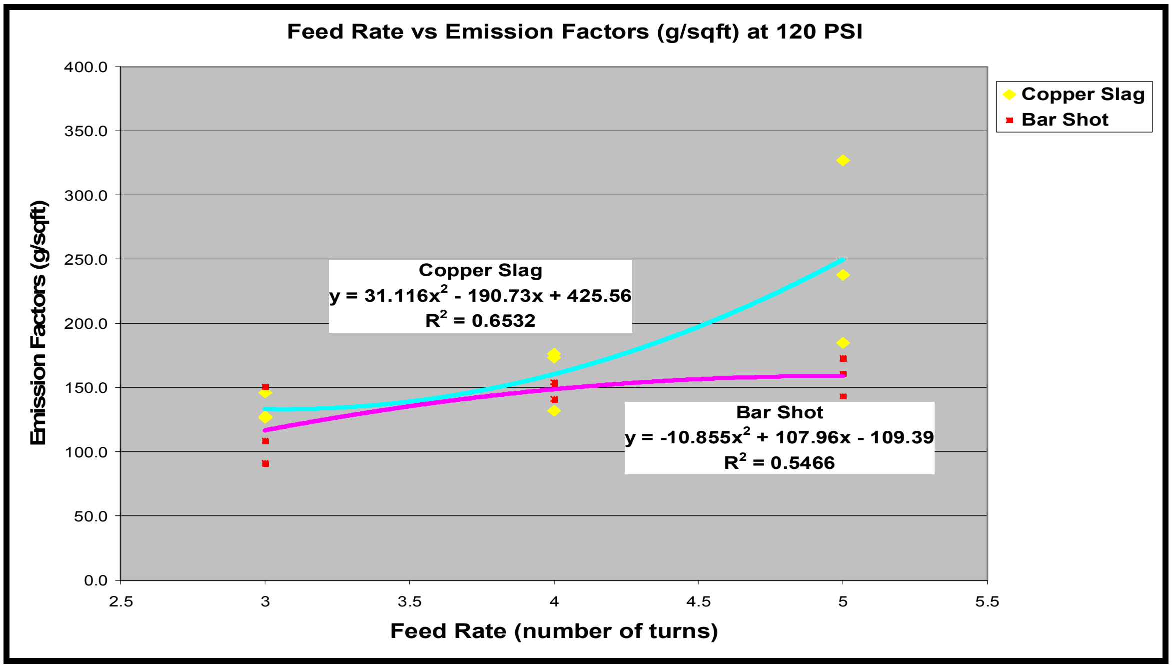

Figure D14: Feed Rate vs. Emission Factors (g/sqft) at 120 PSI

Figures D15, D16, and D17 show the variation in emission factors (g/lb, in terms of abrasive used) for different feed rates at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag and Barshot

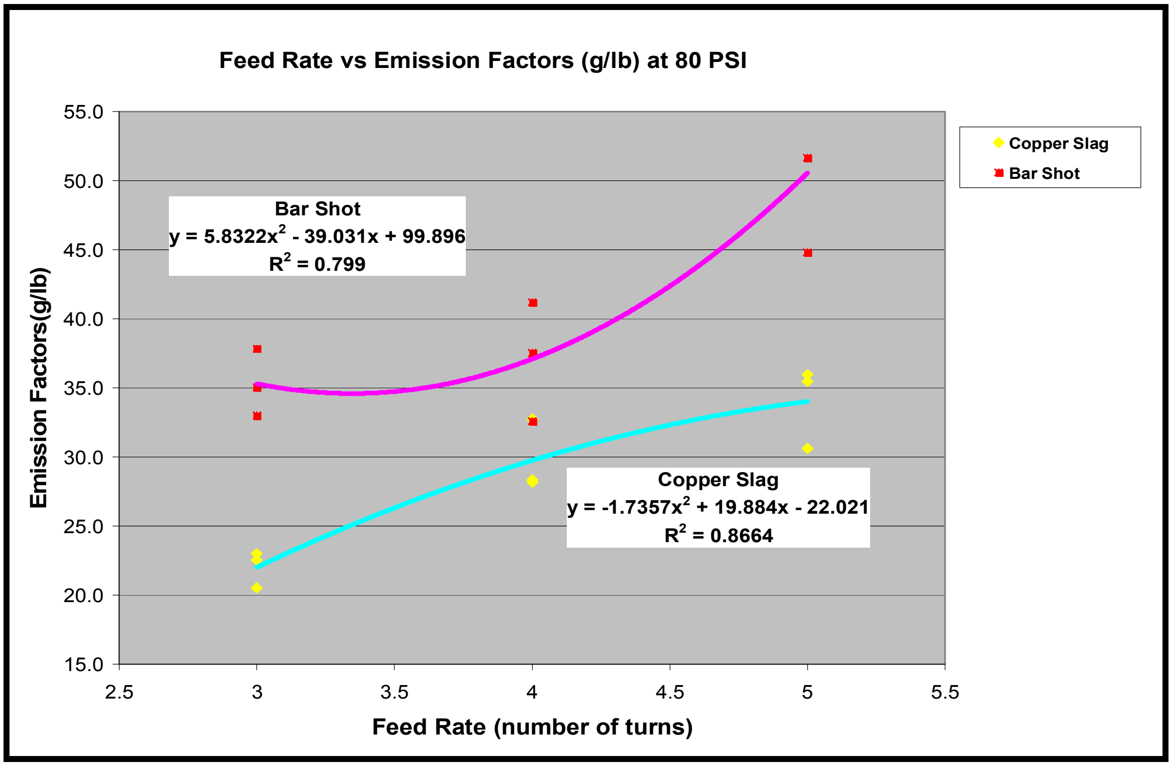

Figure D15: Feed Rate vs. Emission Factors (g/lb) at 80 PSI

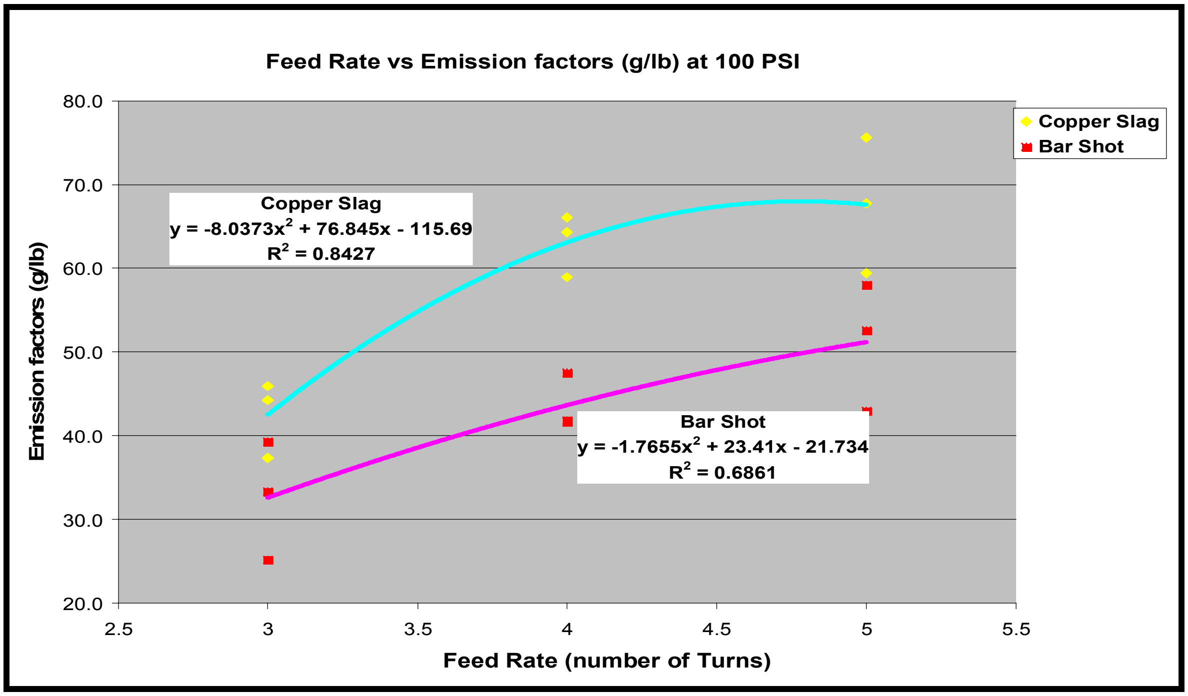

Figure D16: Feed Rate vs. Emission Factors (g/lb) at 100 PSI

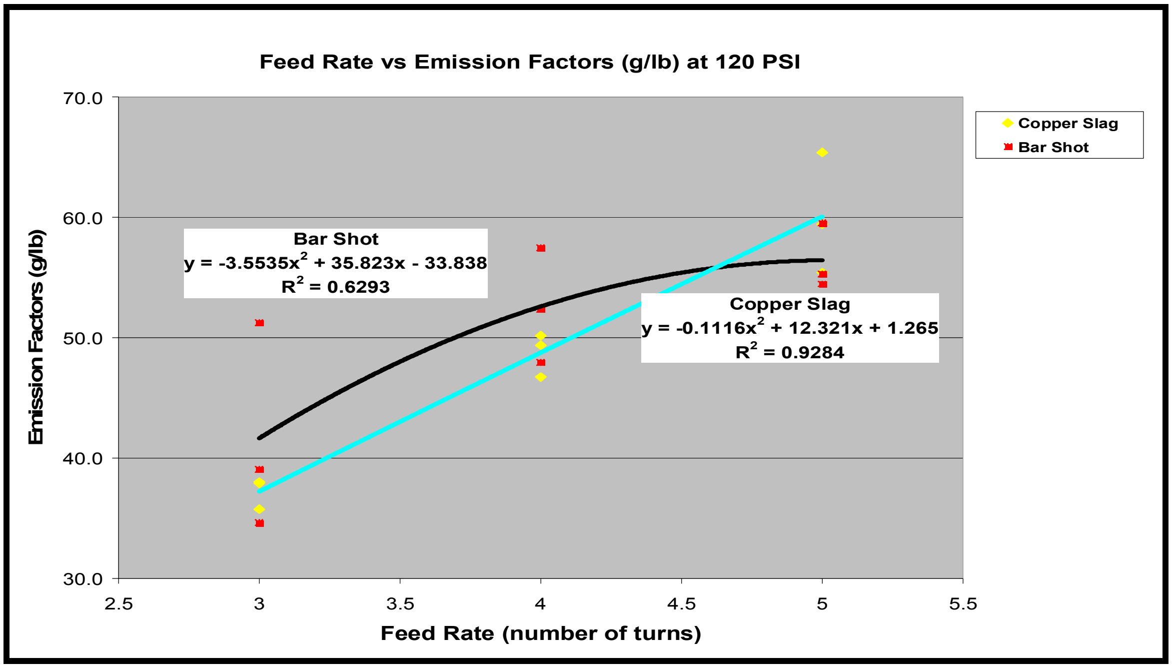

Figure D17: Feed Rate vs. Emission Factors (g/lb) at 120 PSI

Figure D18 shows the variation in productivity with pressure (80 PSI, 100 PSI, and 120 PSI), at Max. Productivity, for Copper Slag and Barshot.

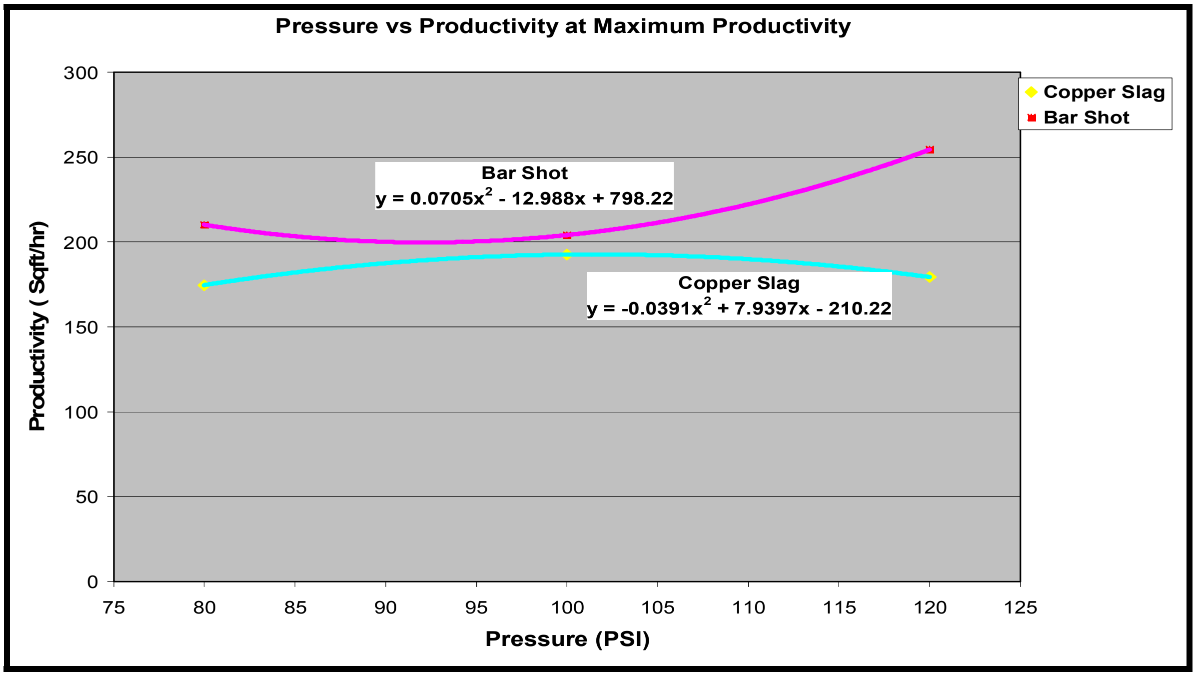

Figure D18: Pressure vs. Productivity at Max. Productivity

Figure D19 shows the emission factor variation (g/sqft, in terms of area cleaned) with pressure (80, 100, and 120 PSI), at Max. Productivity, for Copper Slag and Barshot.

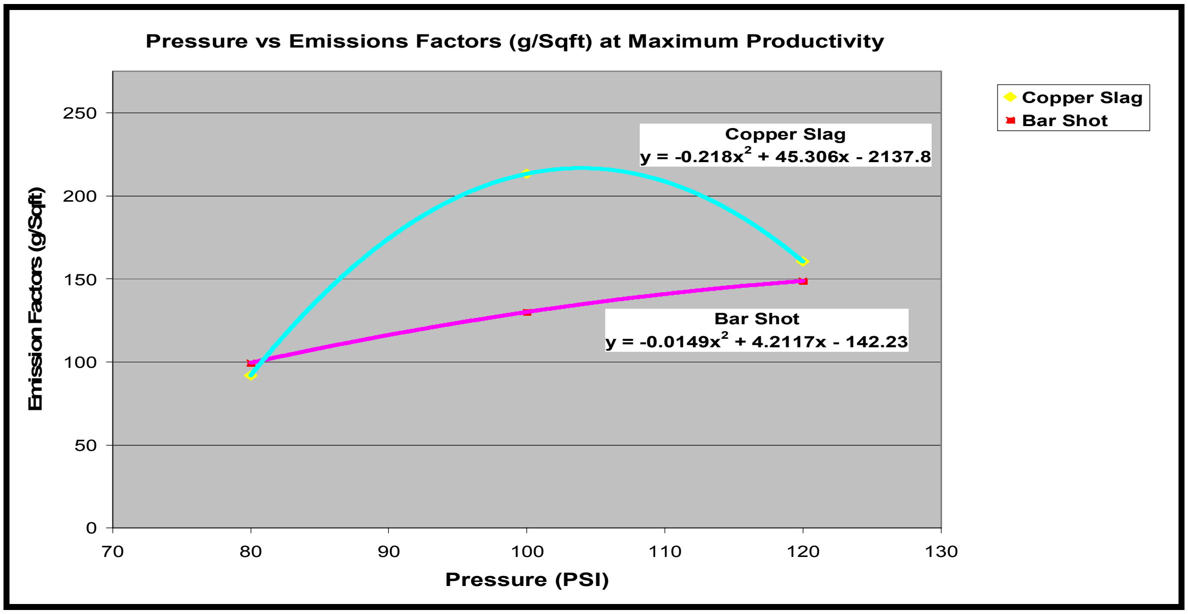

Figure D19: Pressure vs. Emissions Factors (g/Sqft) at Max. Productivity

Figure D20 shows the variation in emission factors (g/lb, in terms of abrasive used) with pressure (80, 100, and 120 PSI), at Max. Productivity, for Copper Slag and Barshot.

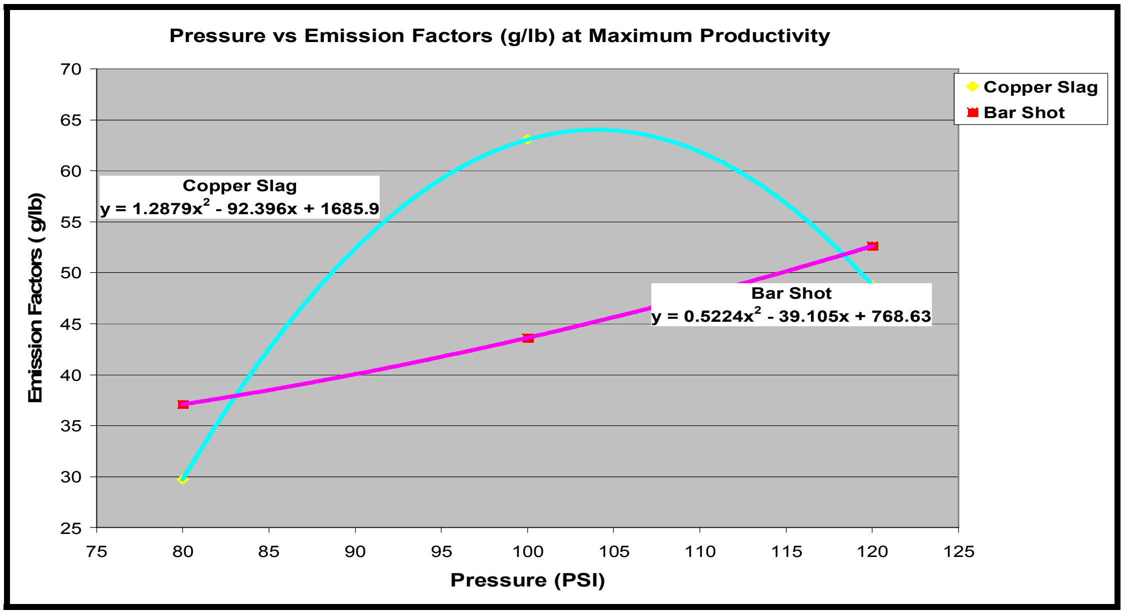

Figure D20: Pressure vs. Emissions Factors (g/lb) at Maximum Productivity

Figures D21, D22, and D23 show productivity variation with material feed rate at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag and Barshot.

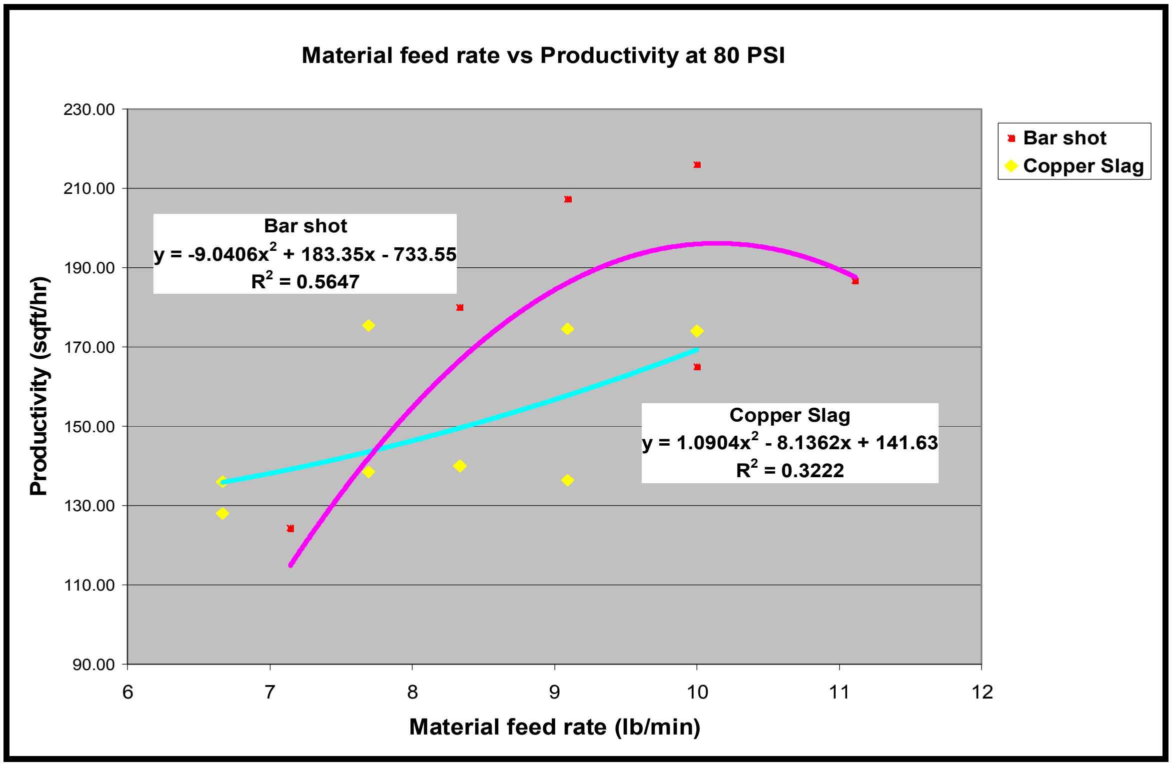

Figure D21: Material feed rate vs. Productivity at 80 PSI

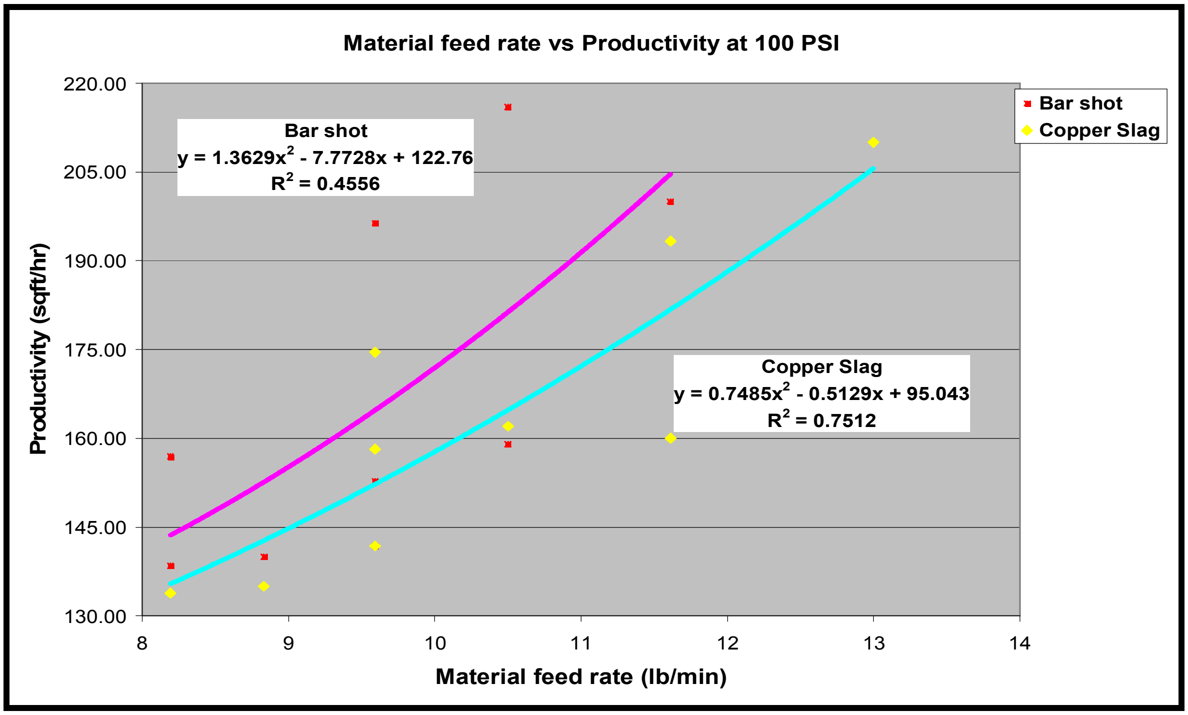

Figure D22: Material feed rate vs. Productivity at 100 PSI

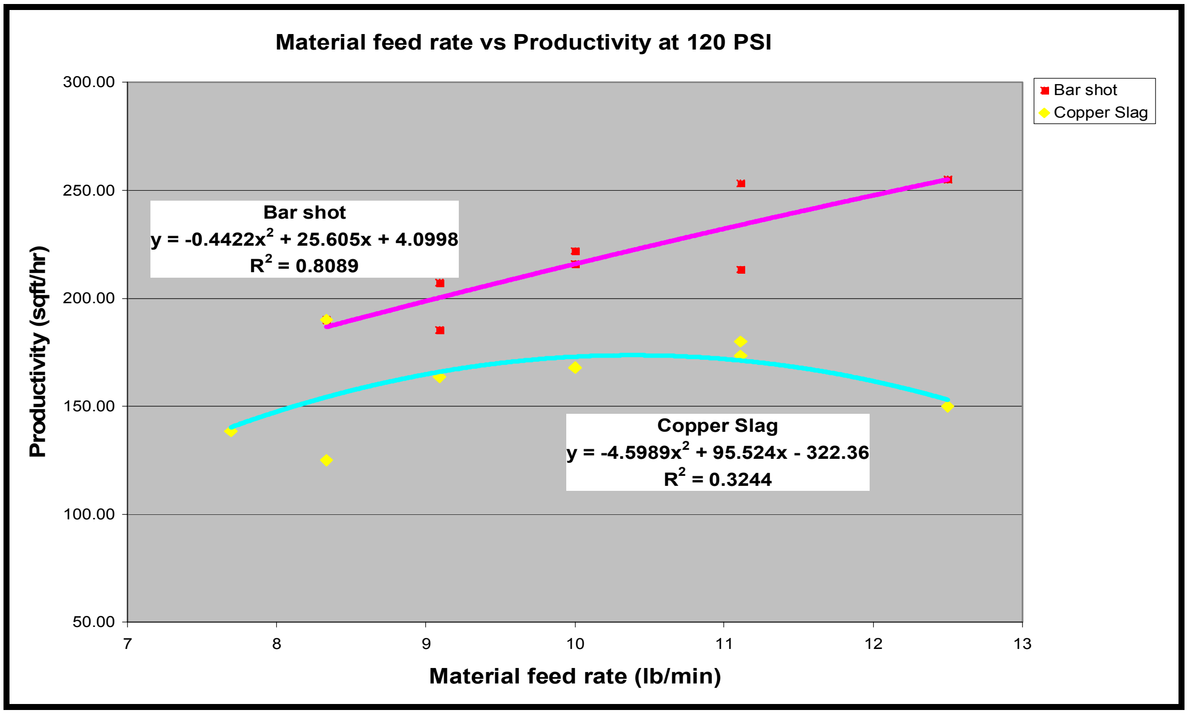

Figure D23: Material feed rate vs. Productivity at 120 PSI

Figures D24, D25, and D26 show emission factor variation (g/sqft, in terms of area cleaned) with material feed rate at pressures 80 PSI, 100 PSI, and 120 PSI, for Copper Slag and Barshot.

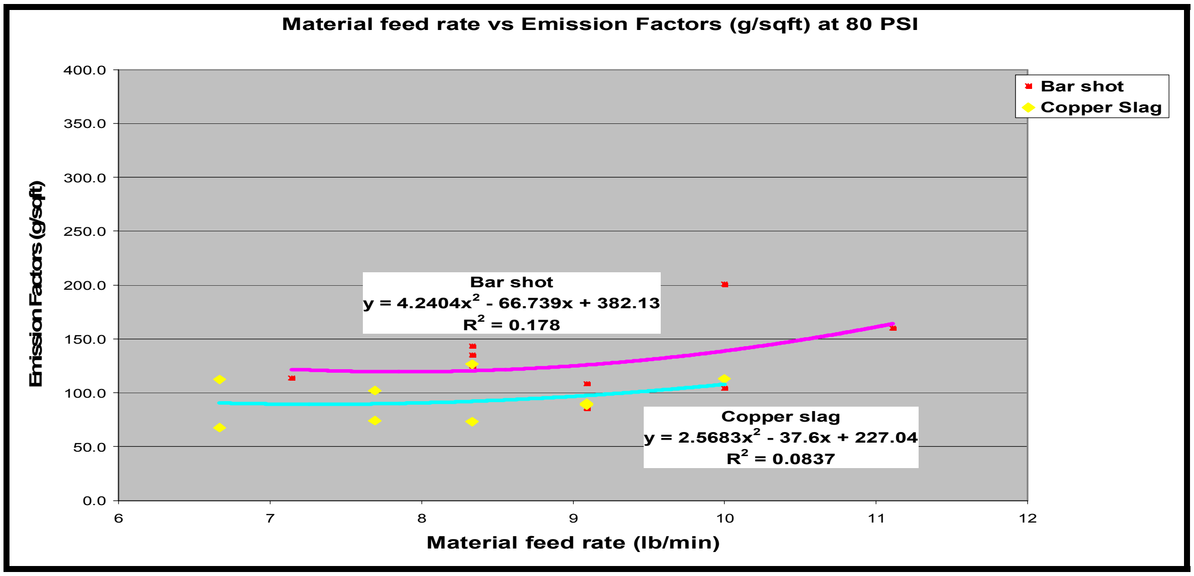

Figure D24: Material feed rate vs. Emission Factors (g/sqft) at 80 PSI

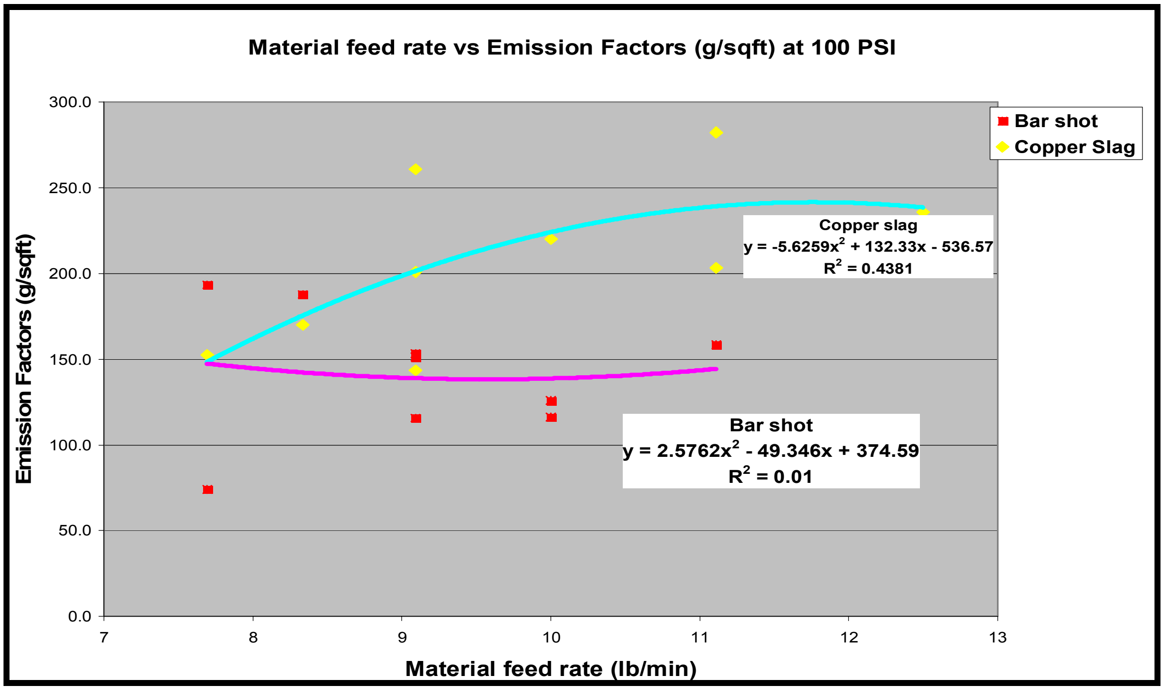

Figure D25: Material feed rate vs. Emission Factors (g/sqft) at 100 PSI

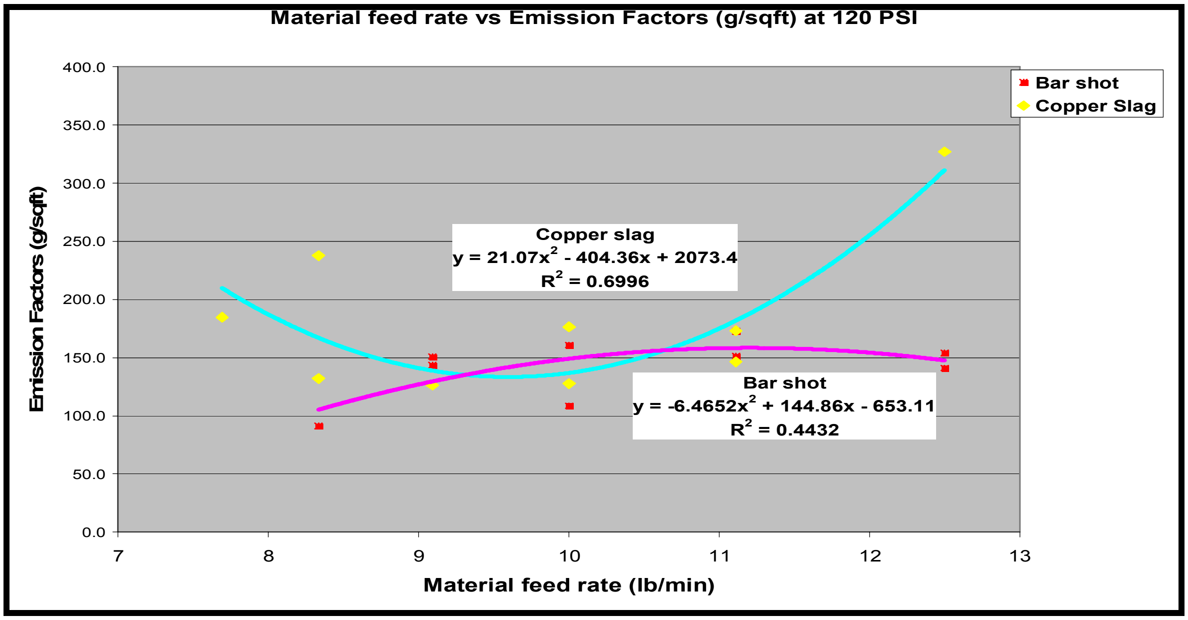

Figure 26: Material feed rate vs. Emission Factors (g/sqft) at 120 PSI

Figures D27, D28, and D29 show emission factor variation (g/lb, in terms of abrasive used) with material feed rate at pressures 80 PSI, 100 PSI, and 120 PSI, respectively, for Copper Slag and Barshot.

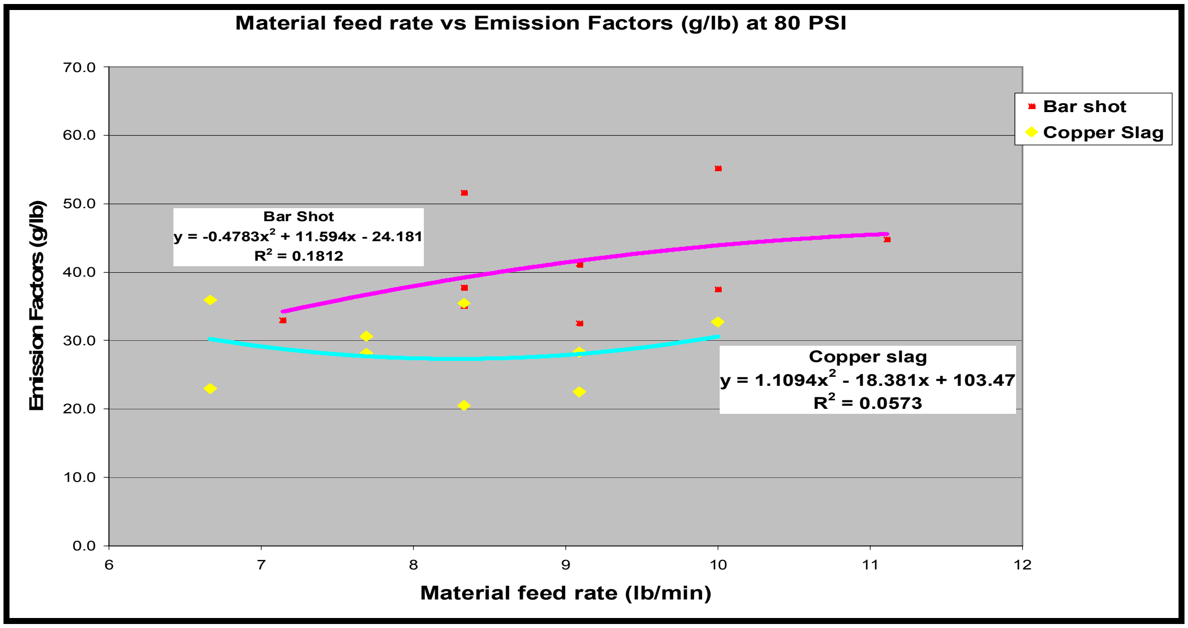

Figure D27: Material feed rate vs. Emission Factors (g/lb) at 80 PSI

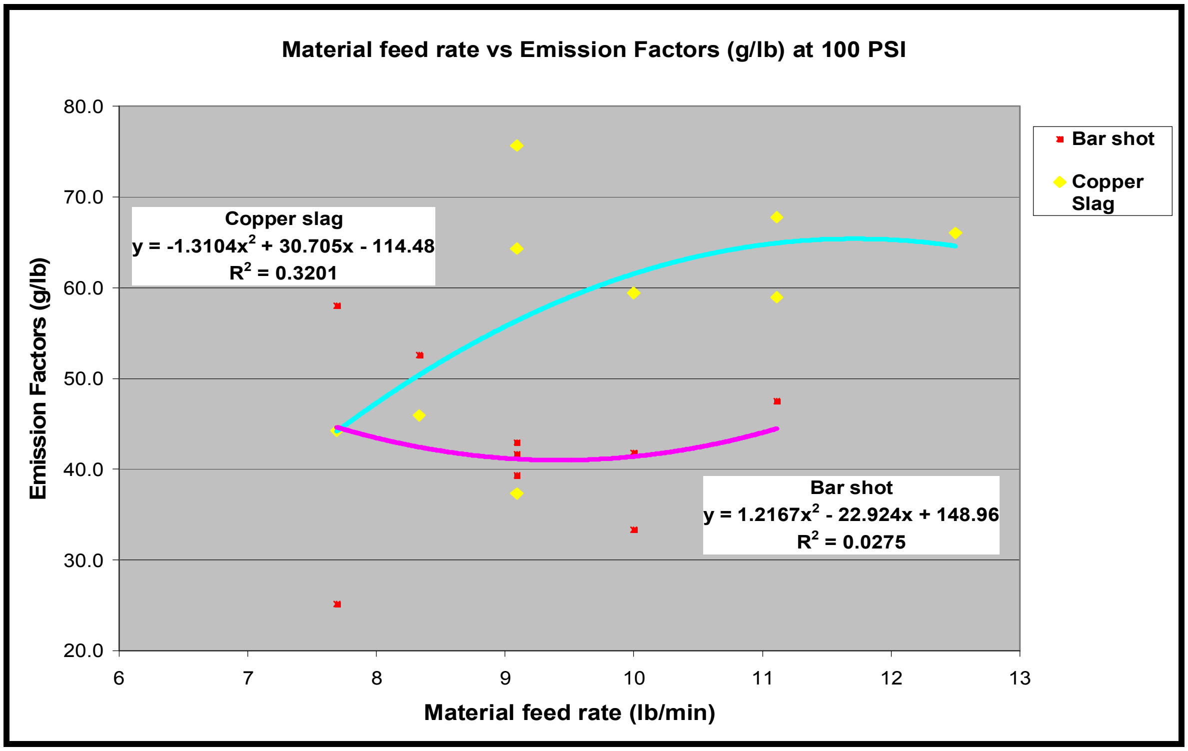

Figure D28: Material feed rate vs. Emission Factors (g/lb) at 100 PSI

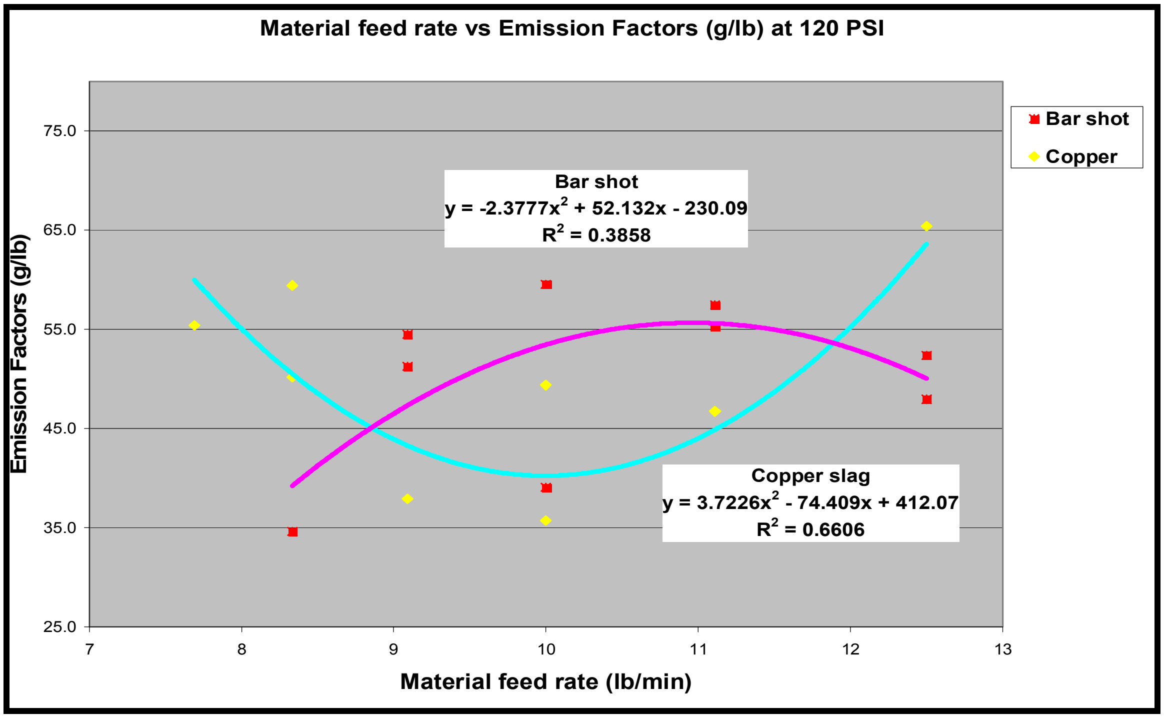

Figure D29: Material feed rate vs. Emission Factors (g/lb) at 120 PSI

Figure D30 shows the variation in consumption with pressure (80PSI, 100 PSI and 120 PSI) for Copper Slag and Barshot.

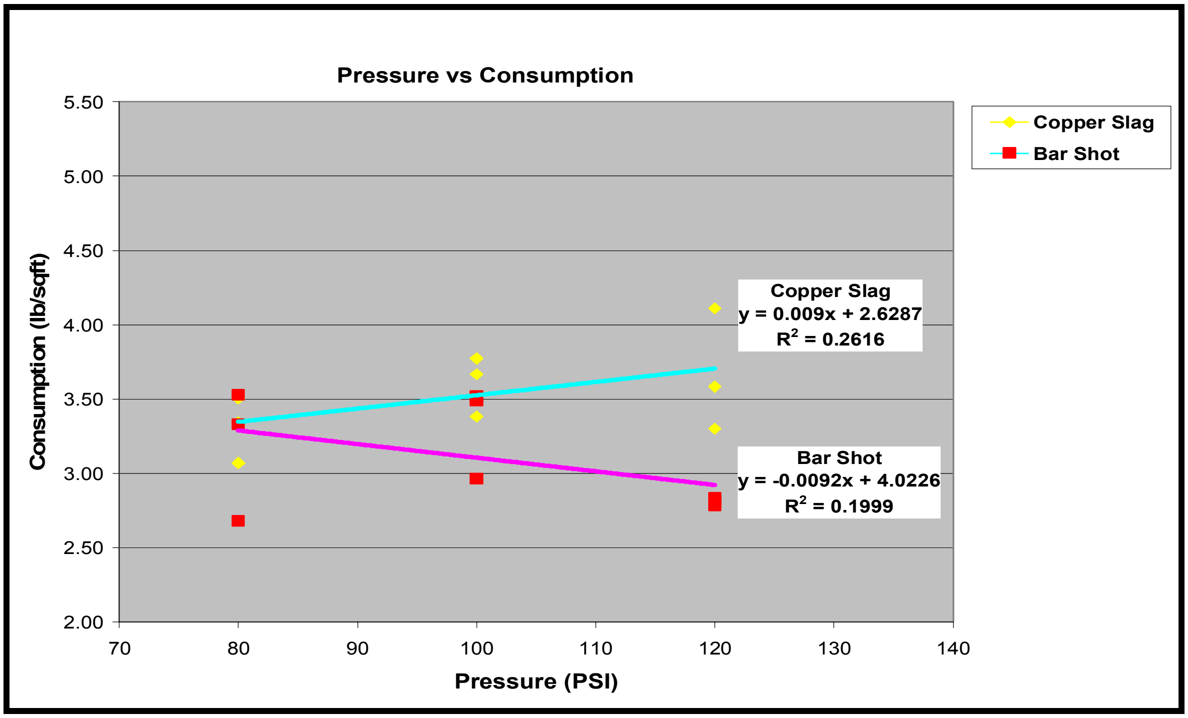

Figure D30: Pressure vs. Consumption

Figures D31, D32 and D33 show the consumption variation with feed rate (number of turns) at pressures 80 PSI, 100 PSI and 120 PSI respectively, for Copper Slag and Barshot

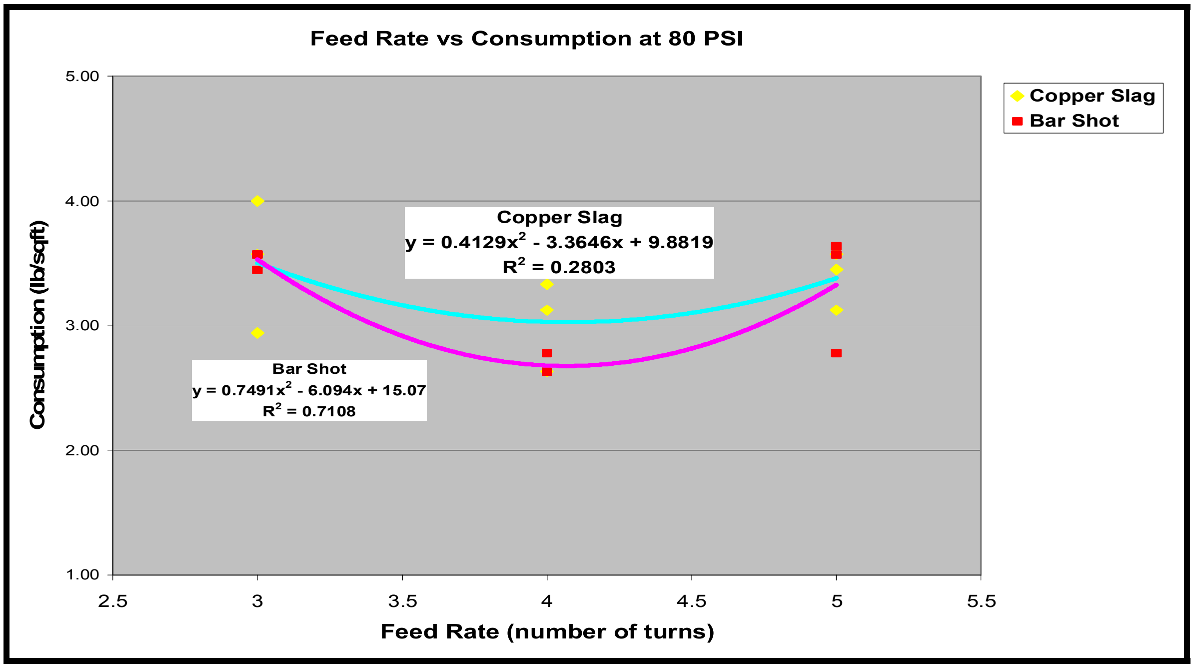

Figure D31: Feed Rate vs. Consumption for at 80 PSI for Copper Slag and Barshot

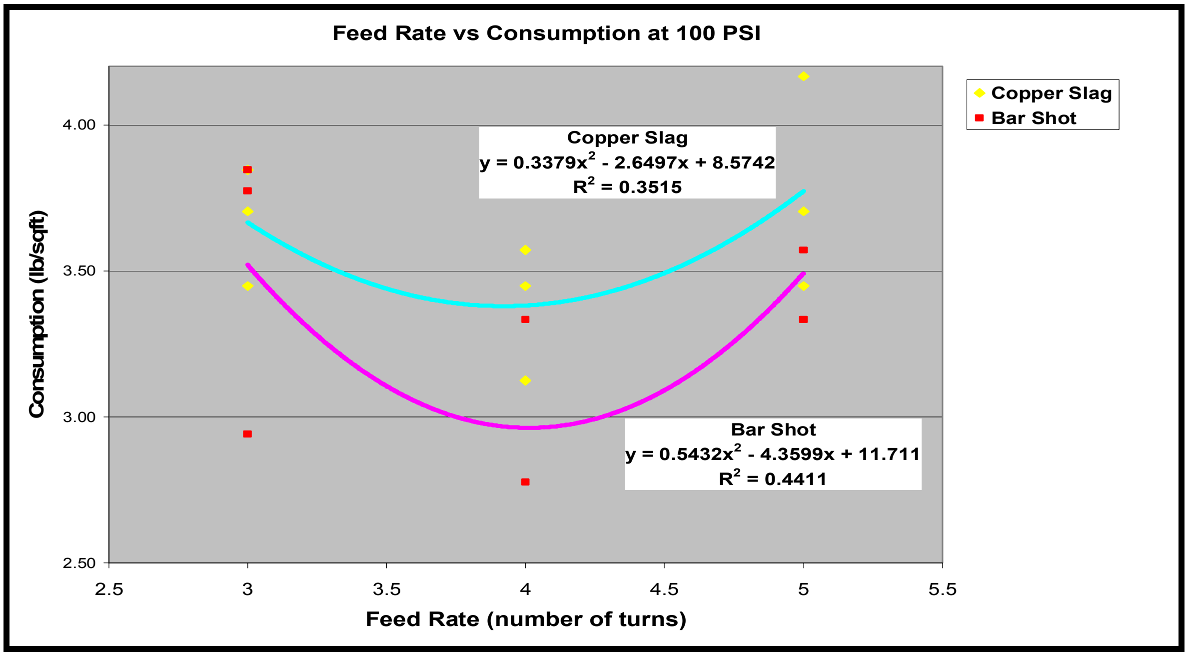

Figure D32: Feed Rate vs. Consumption at 100 PSI for Copper Slag and Barshot

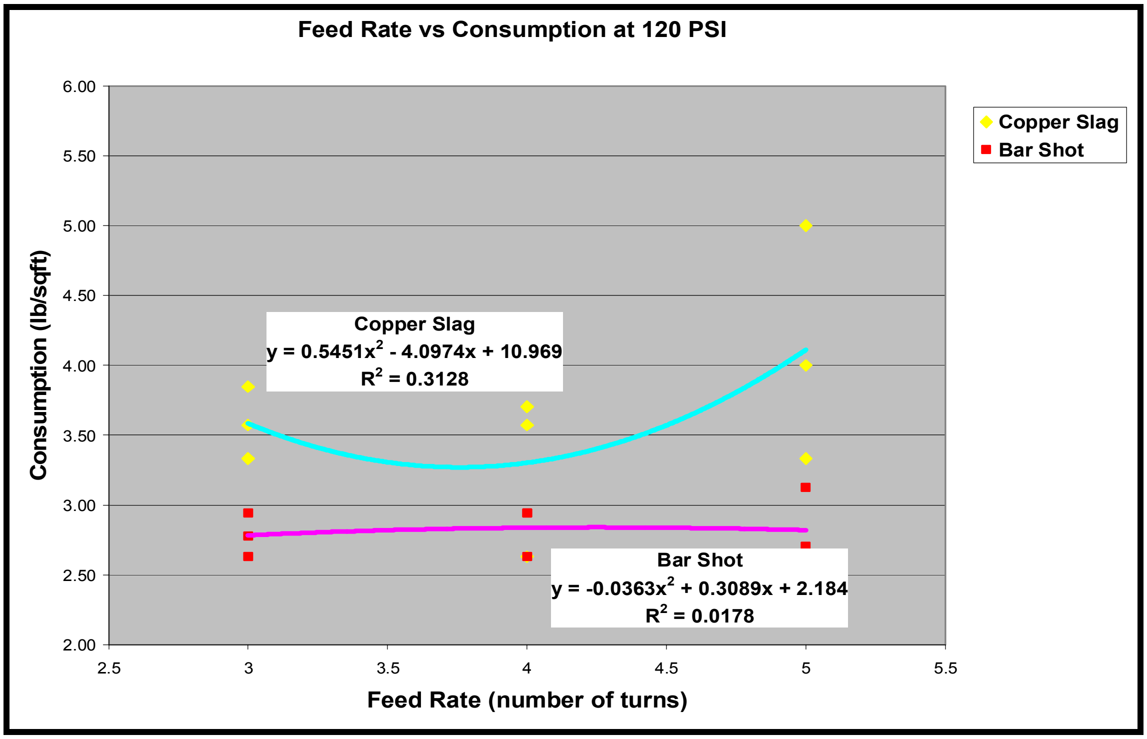

Figure D33: Feed Rate vs. Consumption at 120 PSI for Copper Slag and Barshot

Figures D34, D35 and D36 show the consumption variation with material feed rate (lb/min) at pressures 80 PSI, 100 PSI and 120 PSI respectively, for Copper Slag and Barshot.

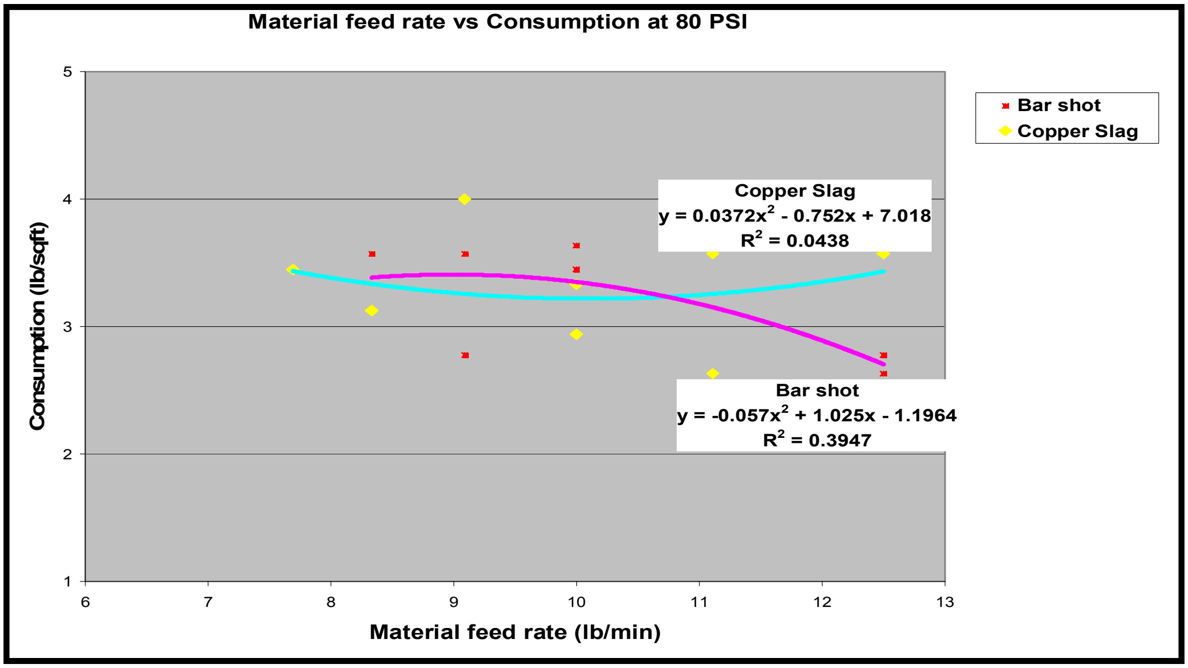

Figure D34: Material Feed Rate vs. Consumption at 80 PSI for Copper Slag and Barshot

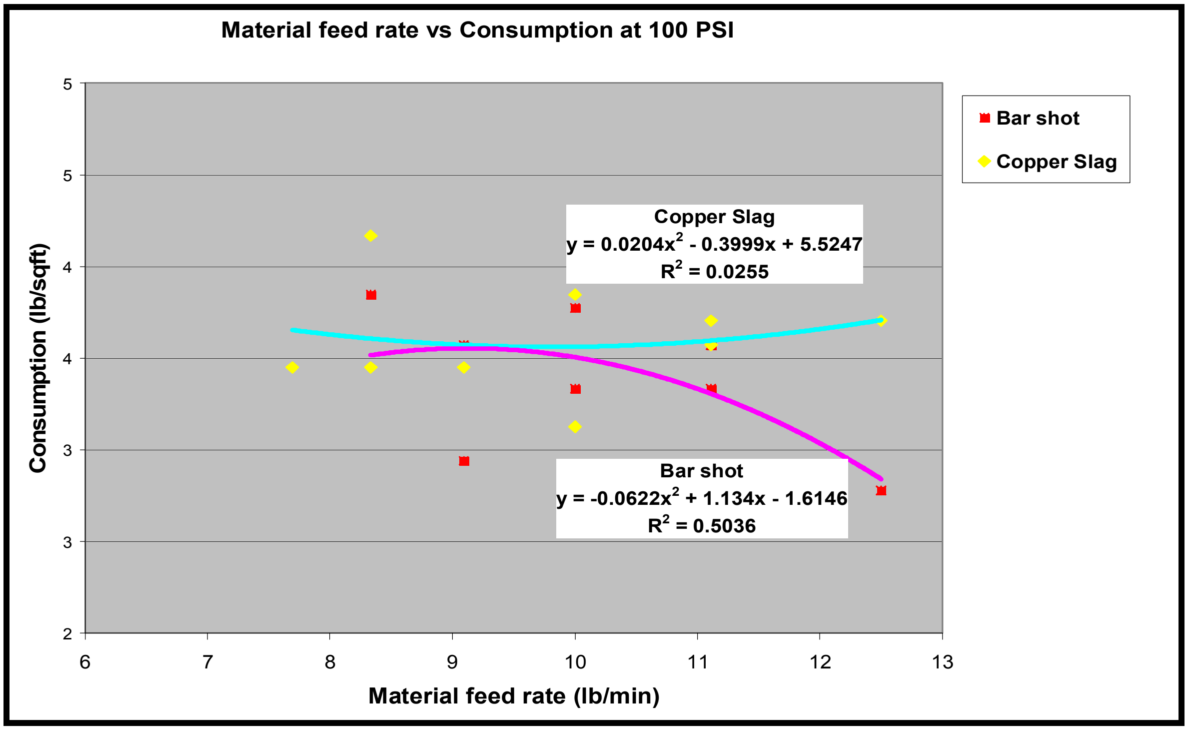

Figure D35: Material Feed Rate vs. Consumption at 100 PSI for Copper Slag and Barshot

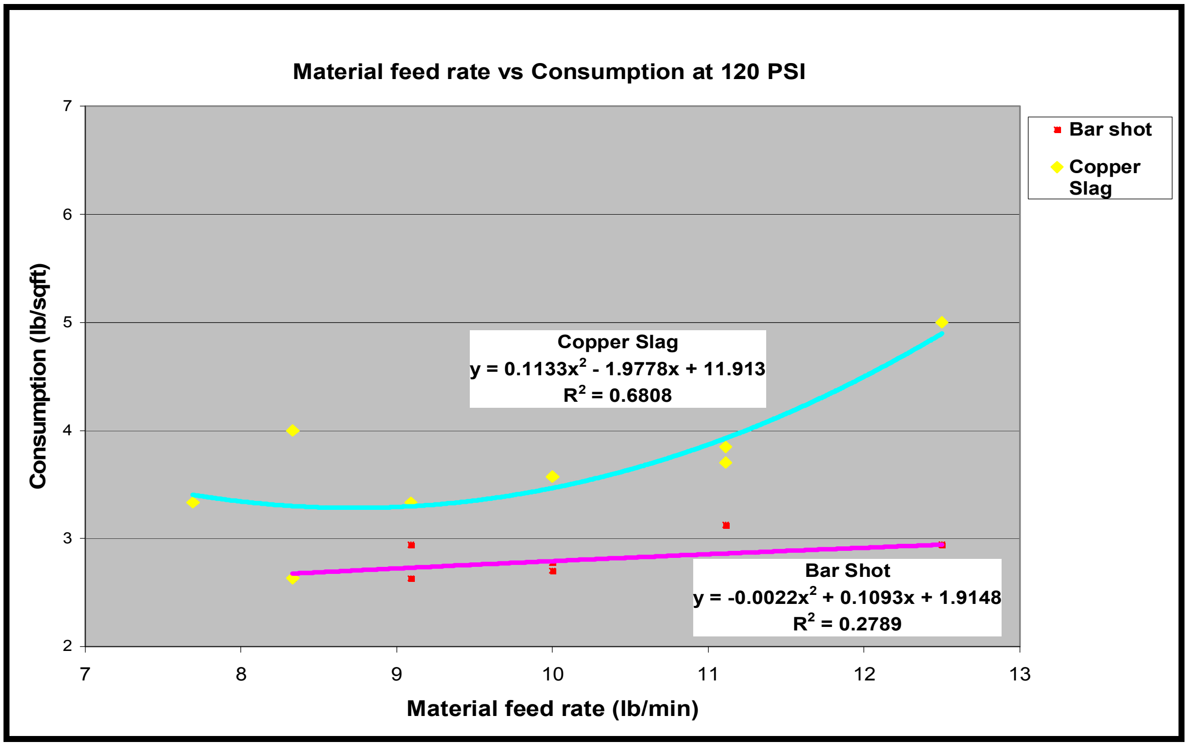

Figure D36: Material Feed Rate vs. Consumption at 120 PSI for Copper Slag and Barshot

Figures D37, D38 and D39 show the emission factor variation (g/sqft, in terms of area cleaned) with material feed rate (lb/min) at Max. productivity, for pressures 80 PSI, 100 PSI and 120 PSI respectively, for Copper Slag and Barshot

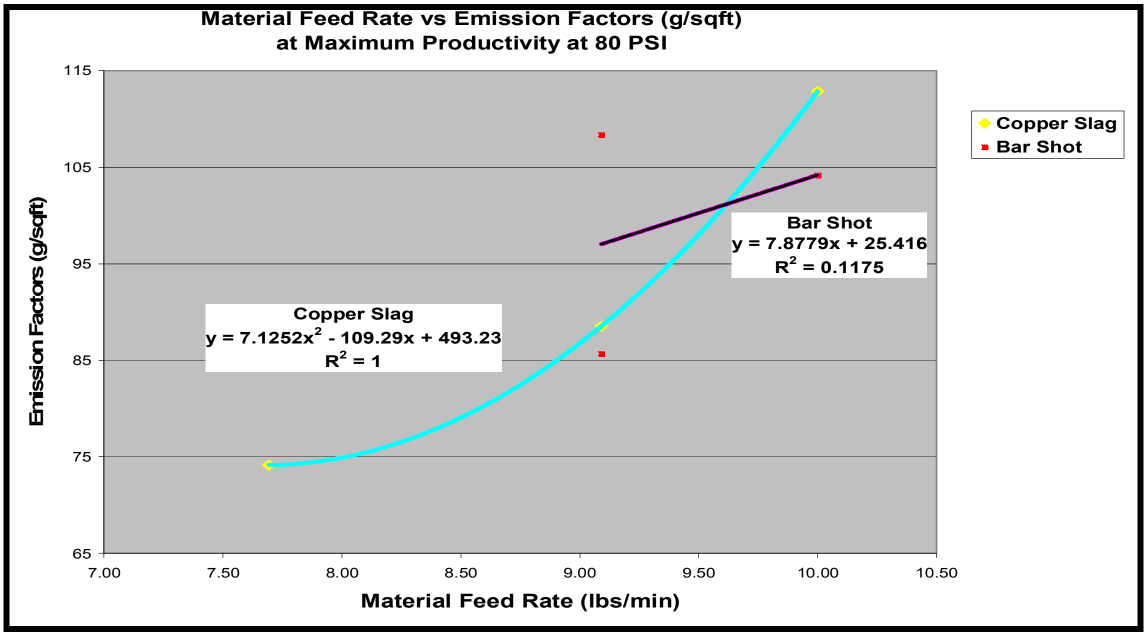

Figure D37: Material Feed Rate vs. Emission Factors (g/sqft) at Max. Productivity at 80 PSI

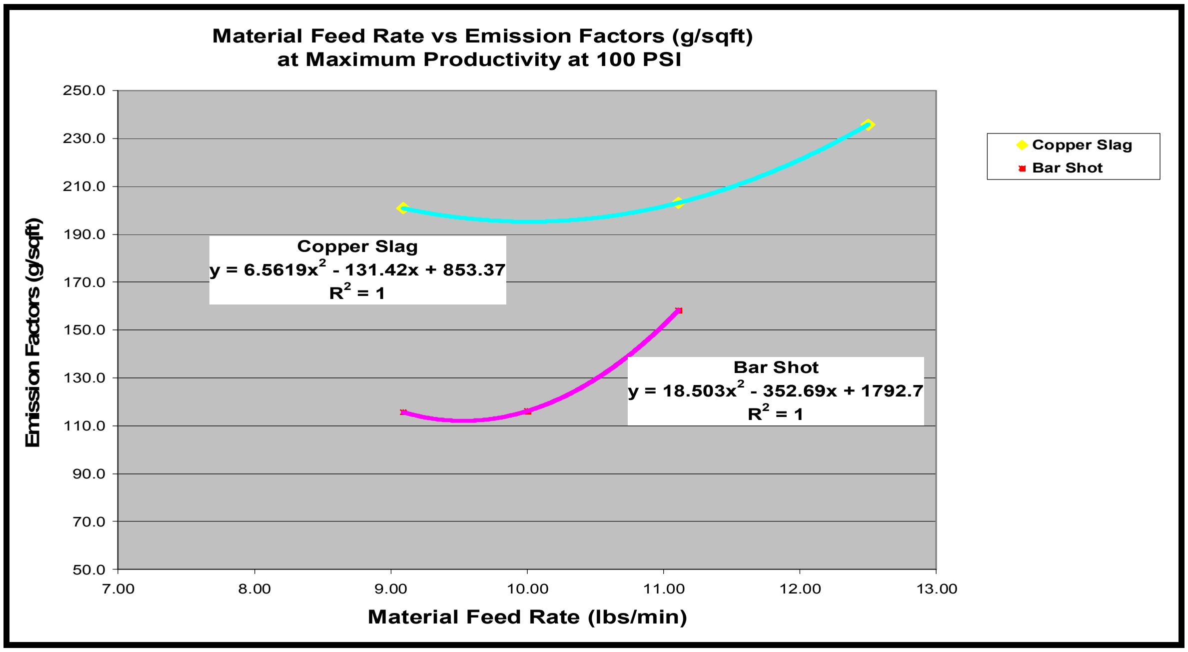

Figure D38: Material Feed Rate vs. Emission Factors (g/sqft) at Max. Productivity at 100 PSI

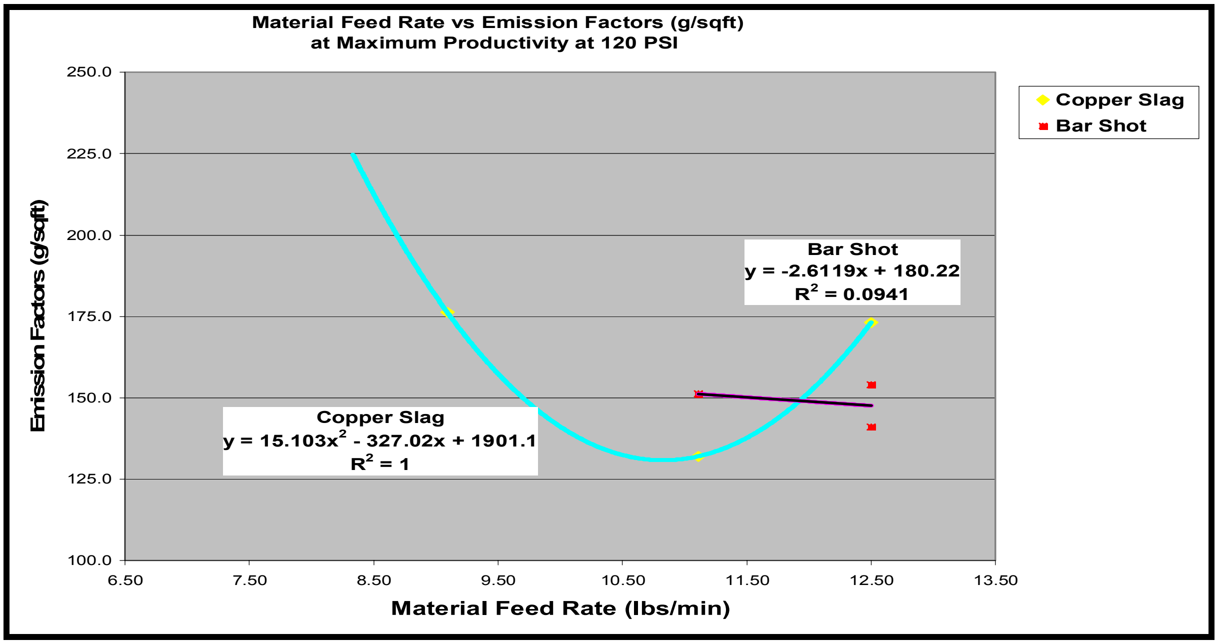

Figure D39: Material Feed Rate vs. Emission Factors (g/sqft) at Max. Productivity at 120 PSI

Figures D40, D41 and D42 show the emission factor variation (g/lb, in terms of abrasive used) with material feed rate (lb/min) at Max. Productivity, for pressures 80 PSI, 100 PSI and 120 PSI respectively, for Copper Slag and Barshot

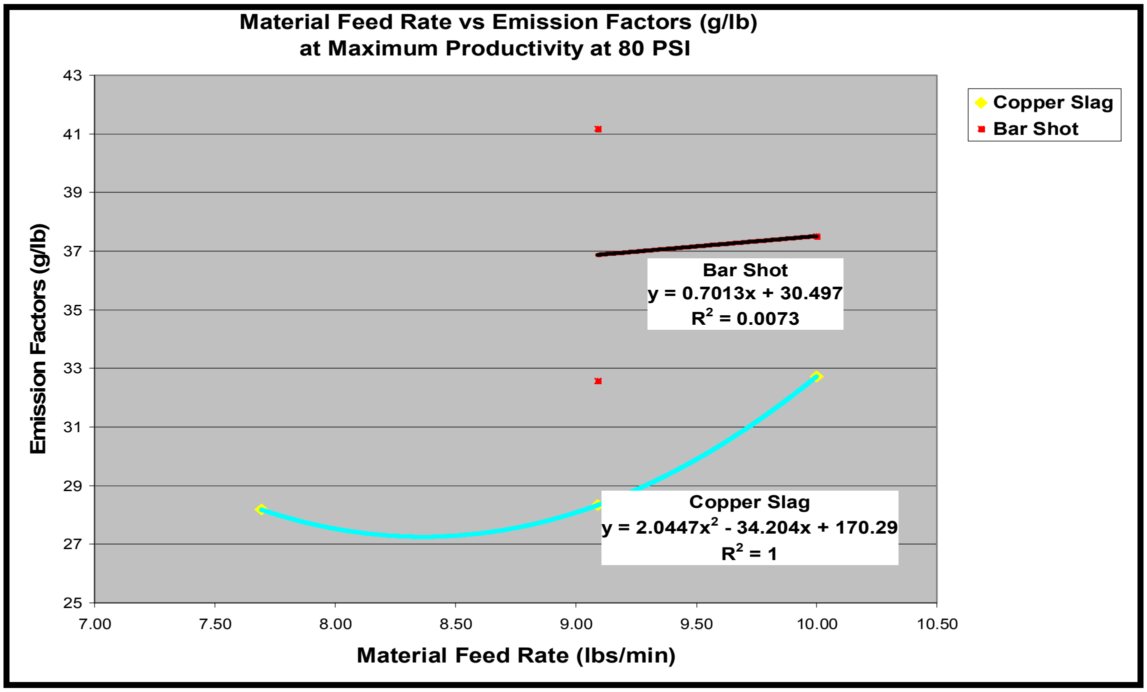

Figure D40: Material Feed Rate vs. Emission Factors (g/lb) at Max. Productivity at 80 PSI

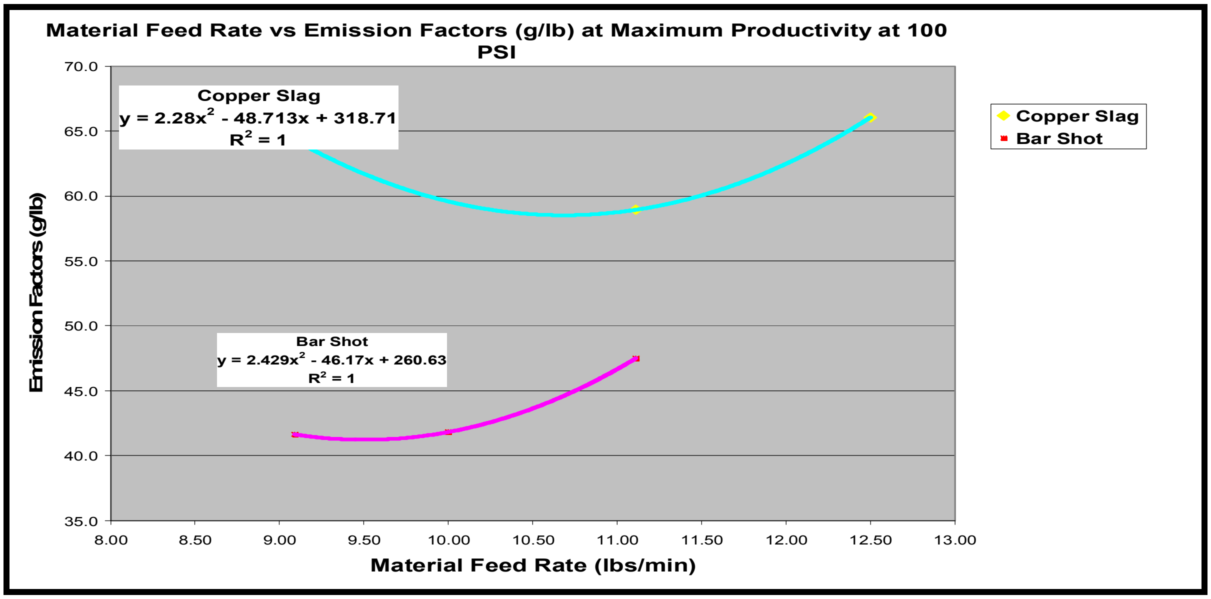

Figure D41: Material Feed Rate vs. Emission Factors (g/lb) at Max. Productivity at 100 PSI

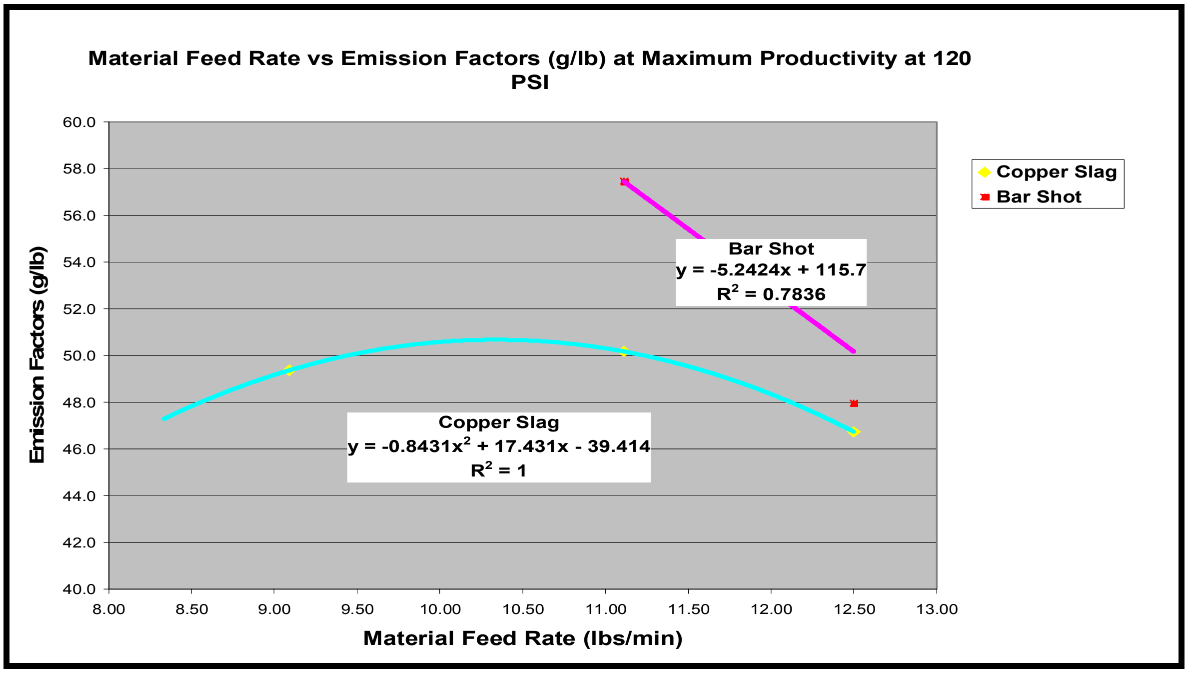

Figure D42: Material Feed Rate vs. Emission Factors (g/lb) at Max. Productivity at 120 PSI

7. CONCLUSIONS

This study provides valuable field observations on productivity, consumption, and particulate emissions for two abrasives: Copper Slag and Barshot 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- Copper Slag, and Barshot.
- The general trend observed shows that productivity (sqft/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.
- 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, Barshot gives the maximum productivity compared to Copper Slag.
- From the feed rate vs. emission factors (mg/sqft) plots, the following observations can be made for the emission factor:
    - 80 PSI: Barshot > Copper Slag
    - 100 PSI: Barshot > Copper Slag
    - 120 PSI: Barshot > Copper Slag
- From the feed rate vs. emission factors (mg/lb) plots, the following observations can be made for the emission factor:
    - 80 PSI: Barshot > Copper Slag
    - 100 PSI: Copper Slag > Barshot
    - 120 PSI: Barshot > Copper Slag.

- For Barshot, productivity decreases with pressure (at maximum productivity) and then increases.
- For Copper Slag, productivity increases with pressure (at maximum productivity).
- Pressure vs. productivity (at maximum productivity) plots clearly demonstrate the following trend with respect to productivity:

  Barshot > Copper Slag.
- The minimum emissions corresponding to maximum productivity for each abrasive at the individual pressures are summarized in Table S5.
- Table S6 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 and specialty sand to analyze the environmental performance and economical impact on 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

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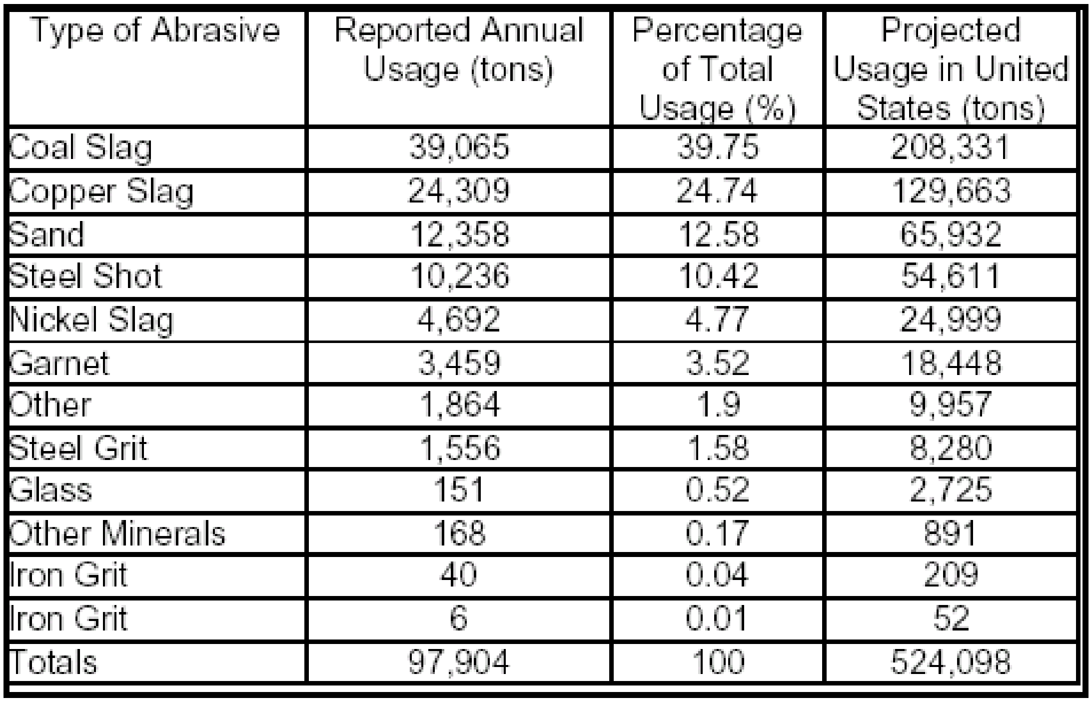
11.APPENDICES

Appendix A

Table A1. Annual Usage Data for various abrasives in United States



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 for different abrasives

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									

Table A3 Physical Properties of Blasting Abrasives

Table 1. Physical Properties of Blasting Abrasives

Abrasive	Shape	Hardness (MOHS)	Bulk Density (lbs/ft^3)	No. Uses
Sand	Rounded Irregular	5.0-7.0	100	1
Staurolite	Rounded Irregular	6.5-7.0	128-148	1* 5**
Garnet	Subangular	7.0-8.0	130-147	3-5* 4-10**
Olivine	Angular	6.5-7.0	90-109	1
Specular hematite	Semi-rounded	6.5-7.0	183.5	6-7**
Coal Slag	Angular	6.0-7.0	75-100	1
Copper Slag	Angular	7.0-8.0	110	1* many**
Nickel Slag	Angular	7.0-8.0	110	1
Crushed Glass	Angular Irregular	5.5-6.5	75	1
Steel Grit	Angular	40-70 Rockwell C	260	50-100* 200-1500**
Aluminum Oxide	Irregular	9.0	120-131	3-5* 15-20**

*Some of the more conservative number of uses that have been listed for steel grit, aluminum oxide, and garnet are 50-100, 3-5, and 4-10 [Austin 1991 and Williams, 1986].

**Abrasive blasting suppliers estimates for the number of times that steel grit, aluminum oxide, and garnet may be reused are: 1500, 20, and 10 times; depending on the grade of material that is used. However the maximum number of uses listed by suppliers often rely on ideal field conditions in abrasive blasting such as low moisture, etc. that do not always exist.

If supplier did not mention abrasive as capable of being recycled in product brochures, it was assumed to be an expendable abrasive which could not be recycled.

Source of data is from [Austin 1991; Williams 1986; company brochures and material safety data sheets from suppliers listed in the Supplemental Reference Section XV].

Table A4 NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients

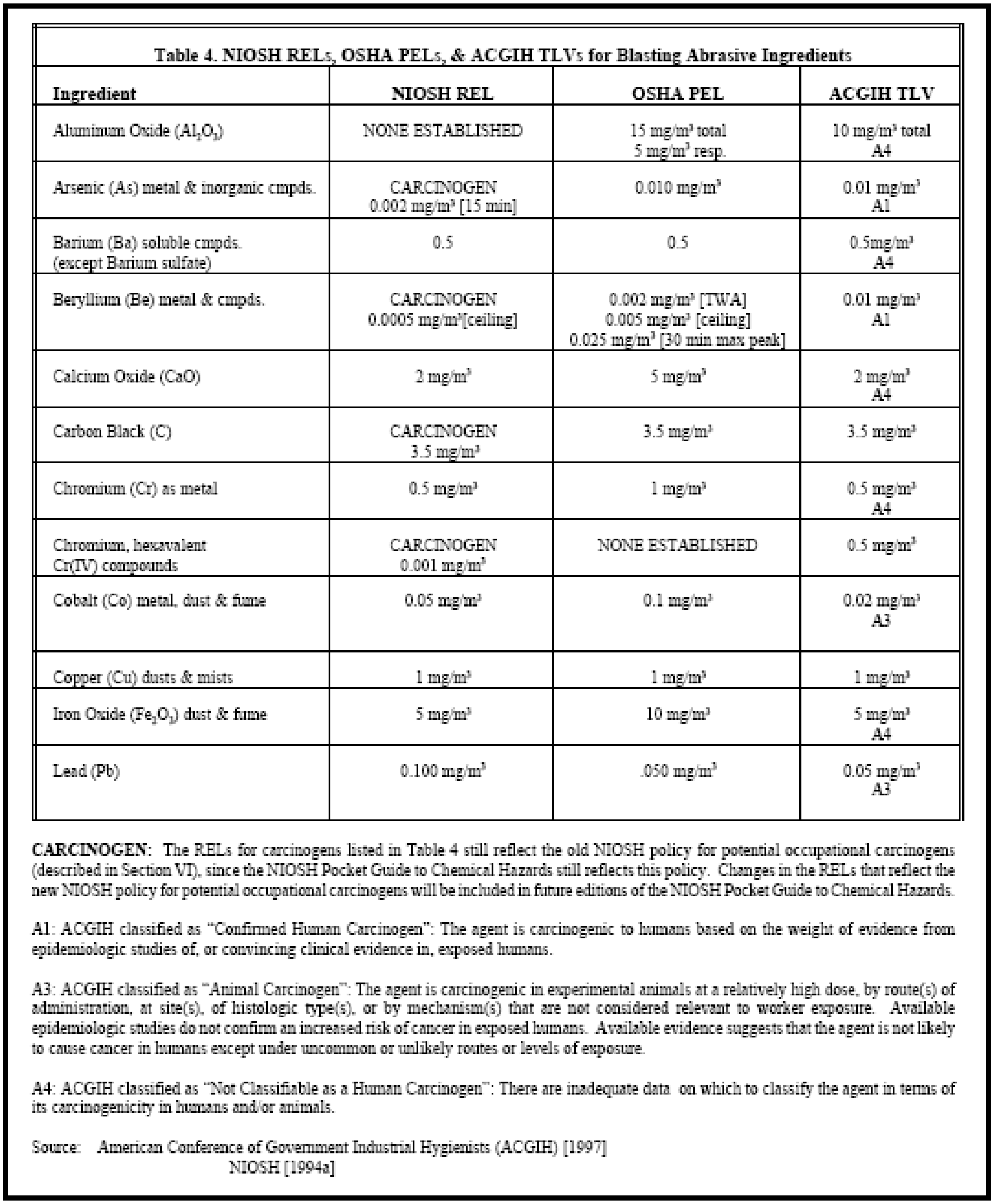


Table 4. NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients

Ingredient	**NIOSH REL**	**OSHA PEL**	**ACGIH TLV**
Aluminum Oxide (Al_2O_3)	NONE ESTABLISHED	15 mg/m³ total 5 mg/m³ resp.	10 mg/m³ total A4
Arsenic (As) metal & inorganic cmpds.	CARCINOGEN 0.002 mg/m³ [15 min]	0.010 mg/m³	0.01 mg/m³ A1
Barium (Ba) soluble cmpds. (except Barium sulfate)	0.5	0.5	0.5mg/m³ A4
Beryllium (Be) metal & cmpds.	CARCINOGEN 0.0005 mg/m³[ceiling]	0.002 mg/m³ [TWA] 0.005 mg/m³ [ceiling] 0.025 mg/m³ [30 min max peak]	0.01 mg/m³ A1
Calcium Oxide (CaO)	2 mg/m³	5 mg/m³	2 mg/m³ A4
Carbon Black (C)	CARCINOGEN 3.5 mg/m³	3.5 mg/m³	3.5 mg/m³
Chromium (Cr) as metal	0.5 mg/m³	1 mg/m³	0.5 mg/m³ A4
Chromium, hexavalent Cr(IV) compounds	CARCINOGEN 0.001 mg/m³	NONE ESTABLISHED	0.5 mg/m³
Cobalt (Co) metal, dust & fume	0.05 mg/m³	0.1 mg/m³	0.02 mg/m³ A3
Copper (Cu) dusts & mists	1 mg/m³	1 mg/m³	1 mg/m³
Iron Oxide (Fe_2O_3) dust & fume	5 mg/m³	10 mg/m³	5 mg/m³ A4
Lead (Pb)	0.100 mg/m³	.050 mg/m³	0.05 mg/m³ A3

CARCINOGEN: The RELs for carcinogens listed in Table 4 still reflect the old NIOSH policy for potential occupational carcinogens (described in Section VI), since the NIOSH Pocket Guide to Chemical Hazards still reflects this policy. Changes in the RELs that reflect the new NIOSH policy for potential occupational carcinogens will be included in future editions of the NIOSH Pocket Guide to Chemical Hazards.

A1: ACGIH classified as "Confirmed Human Carcinogen": The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies of, or convincing clinical evidence in, exposed humans.

A3: ACGIH classified as "Animal Carcinogen": The agent is carcinogenic in experimental animals at a relatively high dose, by route(s) of administration, at site(s), of histologic type(s), or by mechanism(s) that are not considered relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence suggests that the agent is not likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.

A4: ACGIH classified as "Not Classifiable as a Human Carcinogen": There are inadequate data on which to classify the agent in terms of its carcinogenicity in humans and/or animals.

Source: American Conference of Government Industrial Hygienists (ACGIH) [1997]
NIOSH [1994a]

NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients (continued)

Table 4. Continued. NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients

Ingredient	NIOSH REL	OSHA PEL	ACGIH TLV
Magnesium Oxide (MgO)fume	NONE ESTABLISHED	15 mg/m³	10 mg/m³
Manganese (Mn) cmpds. & fume	1 mg/m³ 3 mg/m³[15 min]	5 mg/m³ [ceiling]	0.2 mg/m³
Molybdenum (Mo)	NONE ESTABLISHED	15 mg/m³	5 mg/m³ Soluble 10 mg/m³Insoluble
Nickel (Ni) metal & other compounds	CARCINOGEN 0.015 mg/m³	1 mg/m³	1 mg/m³ Insoluble 0.1 mg/m³ Soluble
Phosphorous (P)	0.1 mg/m³	0.1 mg/m³	0.1 mg/m³
Platinum (Pt)	1 mg/m³	NONE ESTABLISHED	1 mg/m³ metal 0.002 mg/m³ soluble salts
Selenium (Se)& cmpds	0.2 mg/m³	0.2 mg/m³	0.2 mg/m³
Crystalline Silica (SiO_2): as respirable quartz	CARCINOGEN .05 mg/m³	[illegible]	0.1 mg/m³
Crystalline Silica (SiO_2): as total quartz	CARCINOGEN .05 mg/m³	[illegible]	0.1 mg/m³
Crystalline Silica (SiO_2): as cristobalite	CARCINOGEN .05 mg/m³	½ x Quartz formula	0.05 mg/m³
Crystalline Silica (SiO_2): as tridymite	CARCINOGEN .05 mg/m³	½ x Quartz formula	0.05 mg/m³
Titanium Dioxide (TiO_2)	CARCINOGEN	15 mg/m³	10 mg/m³ A4
Vanadium (V) as V_2O_5 dust	0.05 mg/m³ [15 min.]	0.5 mg/m³ (resp.)	0.05 mg/m³ resp. dust or fume A4
Vanadium (V) as V_2O_5 fume	0.05 mg/m³ [15 min.]	0.1 mg/m³ (resp.)	0.05 mg/m³ resp. dust or fume A4
Yttrium (Yt)& cmpds.	1 mg/m³	1 mg/m³	1 mg/m³
Zirconium (Zr) & cmpds.	5 mg/m³ 10 mg/m³ [15 min.]	5 mg/m³	10 mg/m³ A4

CARCINOGEN: NIOSH has not identified thresholds for carcinogens that will protect 100% of the population. NIOSH usually recommends that occupational exposures to carcinogens be limited to the lowest feasible concentration.

A4: ACGIH classified as "Not Classifiable as a Human Carcinogen": There are inadequate data on which to classify the agent in terms of its carcinogenicity in humans and/or animals.

Reference: American Conference of Government Industrial Hygienists (ACGIH) [1997]
NIOSH [1994a]

Table 2. Chemical Composition of Blasting Abrasives* (by Percent Weight)**

Chemical	Sand*	Staurolite	Garnet	Olivine	Specular hematite	Coal Slag	Copper Slag	Nickel Slag	Crushed Glass	Steel Grit	Aluminum Oxide
Silicon Dioxide (SiO_2)**	90-100%	29%	36-38%	39-46%	<1.0%	45-51%	45%	37-51%	72.5%	0.3-1.3%	0.5-1.7%
Crystalline-silica(SiO_2)	49-96%	<5.0%	<.8%	<0.3%	<1.0%	<1.0%	0.1%	<0.1%			
Aluminum Oxide (Al_2O_3)		45%	20-26%	0.2-2.3%	0.34%	14-26%	7.2%	1.5-6.6%	0.16%		92-97%
Specular hematite (Fe_2O_3) or (FeO)		14% (Fe_2O_3)	30-33% (FeO) or (Fe_2O_3)	6-11% (FeO) or (Fe_2O_3)	98.18% (Fe_2O_3)	18-21% (Fe_2O_3)	23.3% (Fe_2O_3)	12-20% (Fe_2O_3)	0.2% (Fe_2O_3)		0.1-1.5% (Fe_2O_3)
Calcium Oxide (CaO)		0.07%	1.0-2.0%	0.2-1.2%	0.060%	4.3-8.2%	19.6%	0.5-2.5%	9.18%		0.14-0.18%
Magnesium Oxide (MgO)		0.75%	1.0-6.0%	39-49%	0.05%	1.0-2.0%	3.7%	4.7-33%	3.65%		0.23-0.30%
Titanium Oxide TiO_2)		4.2%	<=2.0%		0.18%	<1.3%					1.6-4.0%
Potassium Oxide (K_2O)		0.1%				<1.9%		<1.3%	0.12%		0.05-0.08%
Sodium Oxide (Na_2O)		0.18%				<1.1%			13.2%		0.07-0.12%
Manganese Oxide (MnO)		0.1%	1.0%			<0.06%					
Iron (Fe)										>95.0%	
Carbon (C)						<0.4%				0.7-1.3%	
Manganese (Mn)					0.026%					0.5-1.3%	
Sulfur (S)					0.026%			<1.2%		<0.05%	
Sulfur Trioxide (SO_3)						<0.6%			0.39%		
Zirconium (Zr)		3.3%	<0.20%								
Zircon Oxide (ZrO)			<=1%								
Phosphorous (P)					0.011%					<0.05%	
Chromium(Cr)				0.1-0.4%	0.002%					<0.2%	
Nickel (Ni)				0.1-0.3%	0.009%			0.1-0.45%		<0.2%	
Radioactivity Picocuries/gram						15-19.8					
#MSDS's for results	2	1	3	2	1	5	1	2	1	4	8

*The remaining portion of the silica sand abrasive composition consists of water or moisture content and loss on ignition.

**The silicon dioxide chemical includes both non-crystalline and crystalline silica.

***Source of data is from company brochures and material safety data sheets from suppliers listed in the Supplemental Reference Section XV.

Table A5: Range of Prices for Abrasives in 1997

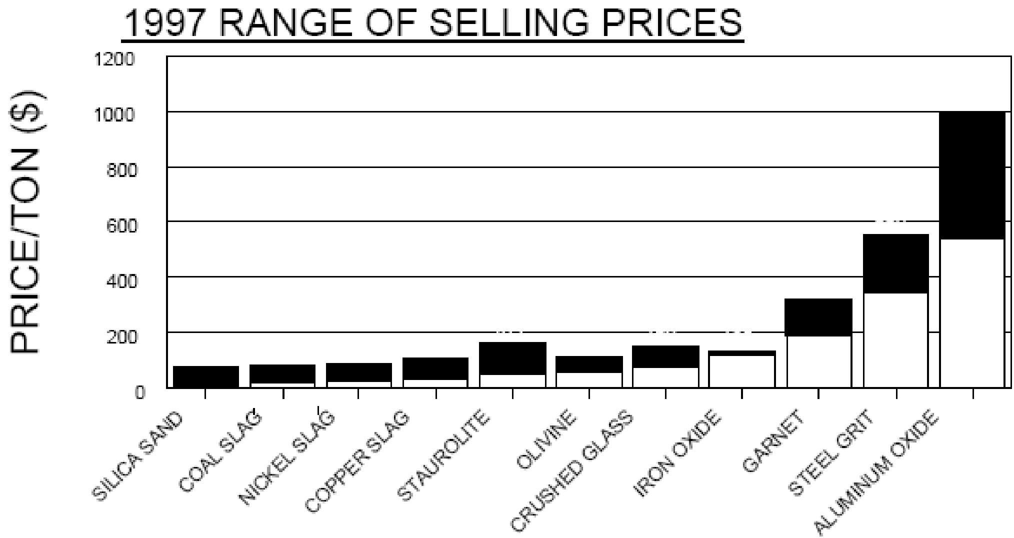


FIGURE 1

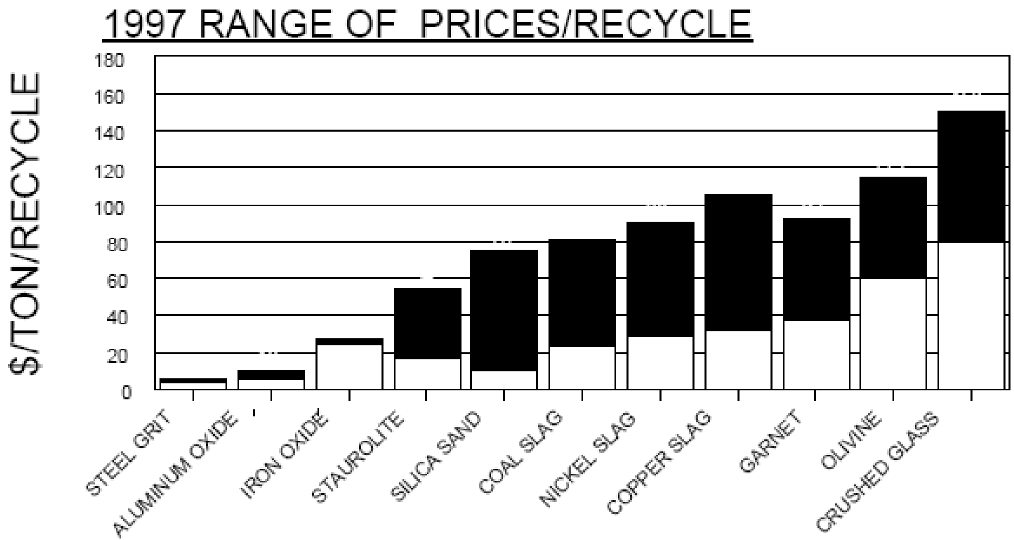


FIGURE 2

Table A6: Applications of Abrasives

ALUMINUM OXIDE	Cleaning Hard Metals (e.g. Titanium) Removing Metal Etch Glass Carve Granite	Recyclable
BAKING SODA (Sodium Bicarbonate)	General Paint Removal Stripping Aircraft Skins Cleaning Surfaces in Food Processing Plants Removing Paint from Glass	Less Material Used/Less Cleanup Low Nozzle Pressures (35-90 PSI) Non-Sparking Water Soluble
COAL SLAG	General Paint, Rust & Scale Removal from Steel Paint Removal from Wood Exposure of Aggregates	Less Than 1% Free Silica Inert Fast Cutting Creates Anchor Profile
COPPER SLAG	General Paint, Rust & Scale Removal from Steel Paint Removal from Wood	Rapid Cutting
CORN COB GRANULES	Deburring Paint & Rust Removal from Wood & Metal	Low Consumption Low Dust Levels Biodegradable
DRY ICE (Carbon Dioxide)	Cleaning Aircraft Parts Cleaning Exotic Metals	No Residue Remains Minimal Cleanup
GARNET	General Paint, Rust & Scale Removal from Steel	Lower Nozzle Pressures (60-70 PSI) Low Dust Levels Fast Cleaning Rates Can be Recycled 6-7 Times Low Free Silica

GLASS BEADS	Cleaning & Polishing Deburring	Uniform Size and Shape Recyclable Provide High Luster Polished Surface
NICKEL SLAG	General Paint, Rust & Scale Removal from Steel	Rapid Cutting
NUT SHELLS	Cleaning Soft Materials (e.g. Aluminum, Plastic, Wood) Cleaning Surfaces in the Petroleum Industry	High Removal Speed Non-Sparking Low Consumption
OLIVINE	Clean Light Mill Scale & Rust from Steel 2.5 MIL Profile & Finer	Low Chloride Ion Level Low Conductivity
PLASTIC MEDIA	Cleaning Soft Metals & Composites Cleaning Metal Fabric Screens	Inert Recyclable Does Not Damage Metal Surfaces Low Nozzle Pressures (20-40 PSI)
STAUROLITE	Cleaning Corroded, Pitted, Weathered Steel Creating Anchor Profile on New Steel	Lack of Imbedment Good Feathering Low Dust Levels Recyclable 3-4 Times
STEEL GRIT & SHOT	Paint, Rust & Scale Removal from Steel Surface Preparation of Structural Steel in Centrifugal Wheel Units	Can be Recycled 100-200 Times Low Dust Levels Superior Visibility Portable Blast Rooms Available Creates Anchor Profile

Table A7: Toxicology Rating for Abrasives

	Fibrogenic	Carcinogenic	Other
Iron oxide	--	-	In vitro toxicity (+)
Nickel slag	-	+/-	Contains carcinogenic metals (+)
Copper slag	-	+	Contains carcinogenic metals (+)
Aluminum oxide	+	0	Neurotoxicity (++)
Olivine	+	++	Immune effects (+)
Coal slag	++	0	Cytotoxic, inflammatory (+++)
Silica Sand	++++	++	Acute silicosis, cytotoxic, inflammatory (+++)
Crushed glass	0	0	Acute inflammation (+)
Staurolite	0	0	In vitro & in vivo toxicity (++)
Garnet	0	0	In vitro & in vivo toxicity (++)
Treated sand	0	0	In vitro & in vivo toxicity (++)
Steel grit	0	0	0

Scoring:

Highly positive	++++
Highly negative	----
Equivocal data	+/-
Insufficient data	0

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

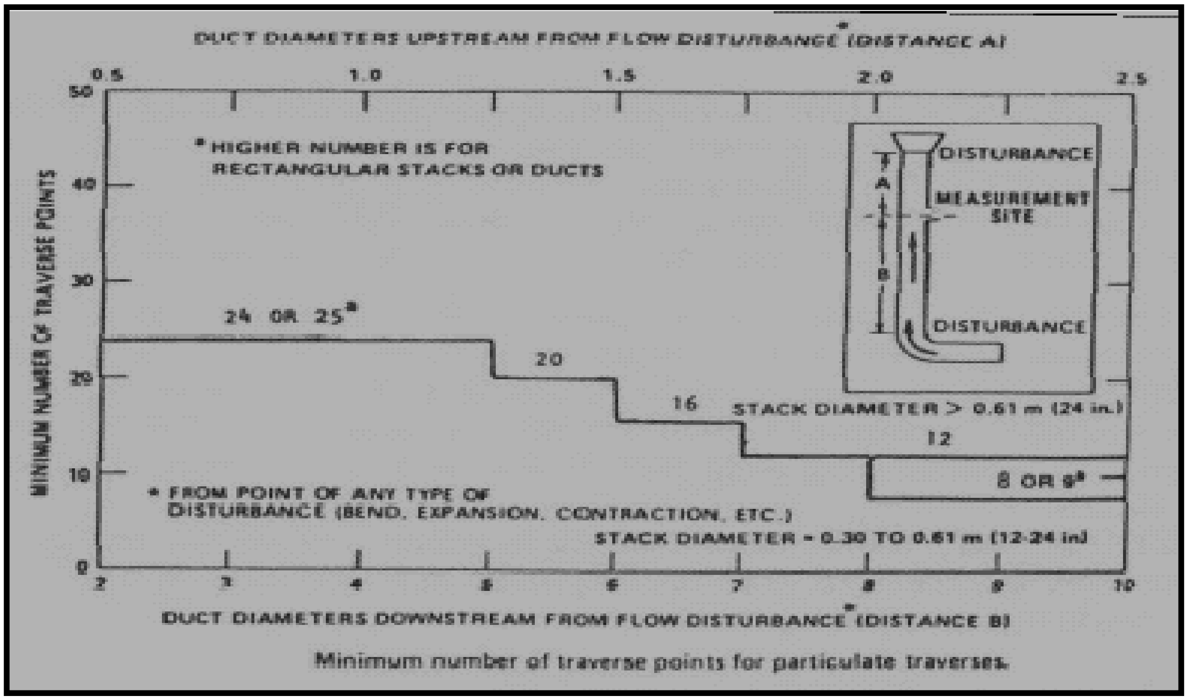
These methods are explained in short in the following paragraphs with significance to the project.

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.

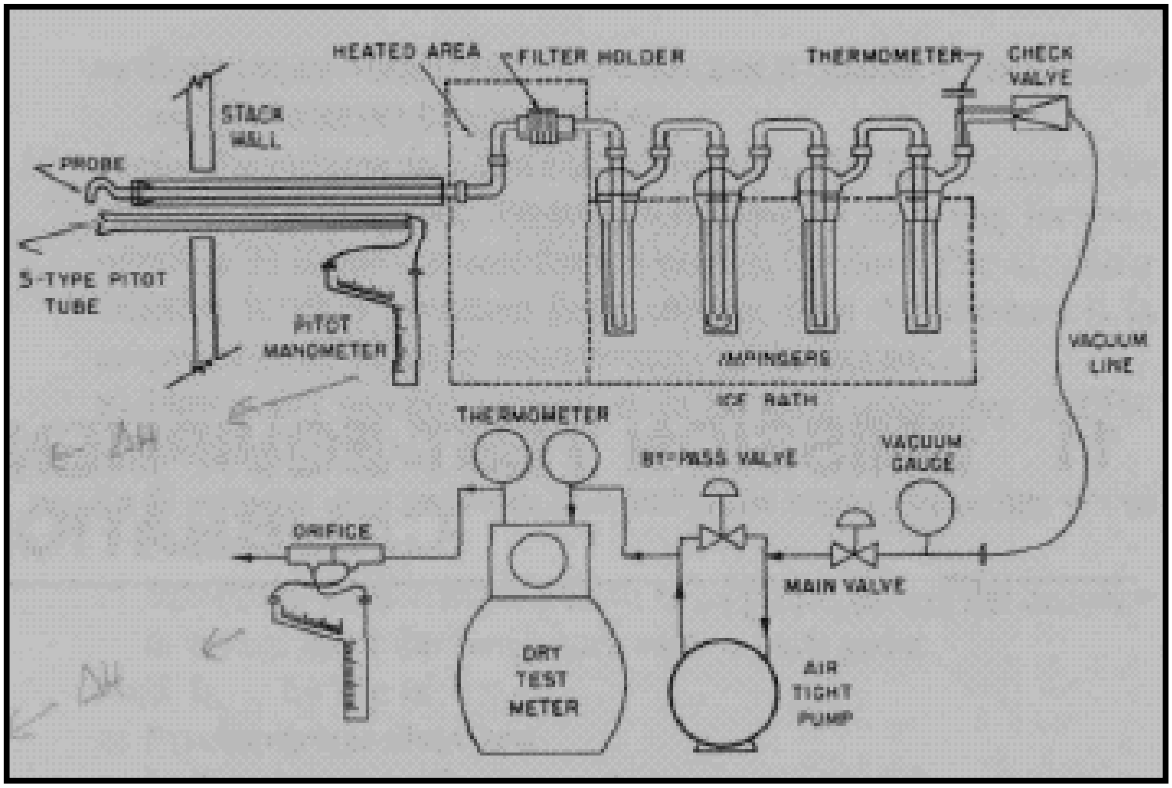


Figure B2: Arrangement of Pitot tube and Sampling Probe

The pitot tube along with the sampling probe 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 (Vn) should be equal to velocity in the stack (Vs). In the experiment, Isokinetic sampling achieved at the nozzle size of 0.018 inch

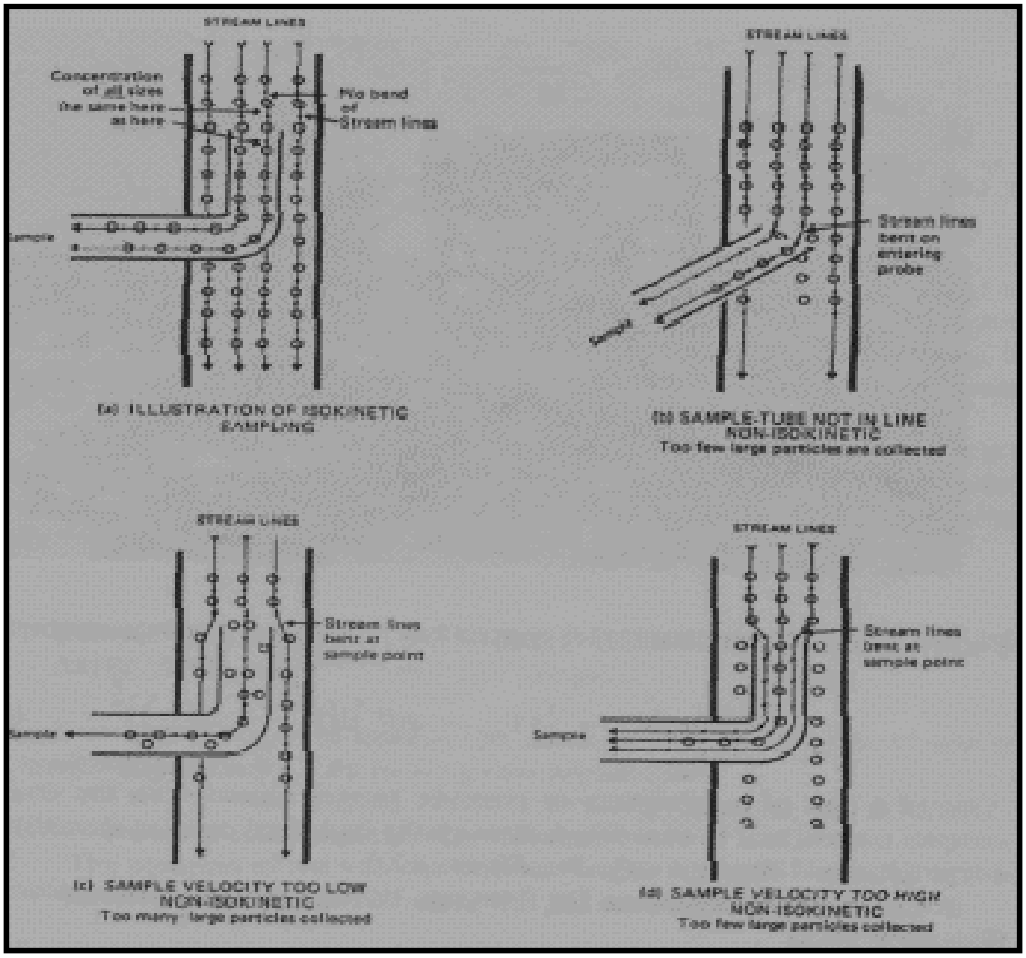


Figure B3: Isokinetic Sampling

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 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. 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.

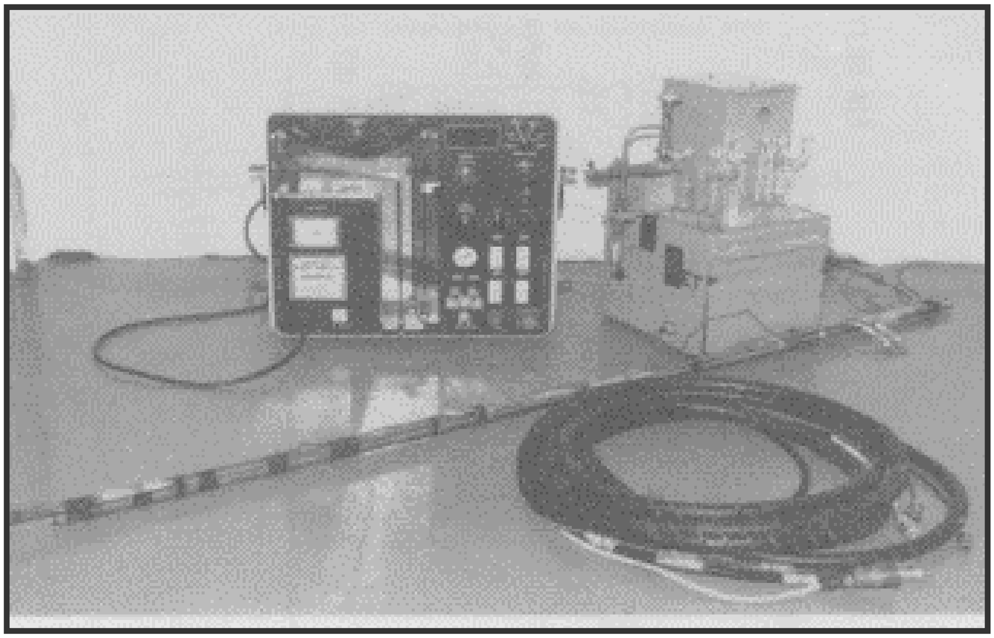


Figure B4: Sampler

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 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.

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.

Appendix C

Table C1 Field observations during stack sampling

				Field Observations						
Area ft^2	28			**Abrasive:**	Copper Slag					
Finish	Near White			**Blast Time:**	10 min					
K factor =	1.12									
Leak Check	OK									
Initial meter reading =	**301.43**									
Traverse Pt	**Meter Reading (dcf)**	**Delta P (in.H2O)**	**Delta H (in. H2O)**	**DGM in (F)**	**DGM Out (F)**	**Avg Meter Temp.(F)**	**Stack temp (F)**	**Vacuum**	**Hot Box temp**	**Cold Box temp**
1	302.23	0.85	0.953	85.00	86.00	89.00	71.00	8.00	153	43
2	303.05	0.96	1.077	86.00	87.00	90.00	72.50	8.50	155	45
3	304.62	1.11	1.245	87.00	87.00	86.50	73.00	9.00	157	46
4	305.37	1.13	1.267	87.00	87.50	84.00	74.00	9.00	158	47
5	306.86	1.09	1.222	87.50	88.50	86.50	74.50	10.50	159	51
6	308.15	1.04	1.166	89.00	89.00	86.00	75.00	11.00	160	54
7	309.68	0.97	1.088	89.00	89.50	87.00	76.50	11.50	162	55
8	310.94	0.95	1.065	90.00	90.00	91.00	77.00	12.00	163	57
	Avg Delta P =	**1.01**			**Avg Temp =**	**87.5**	**74.19**			

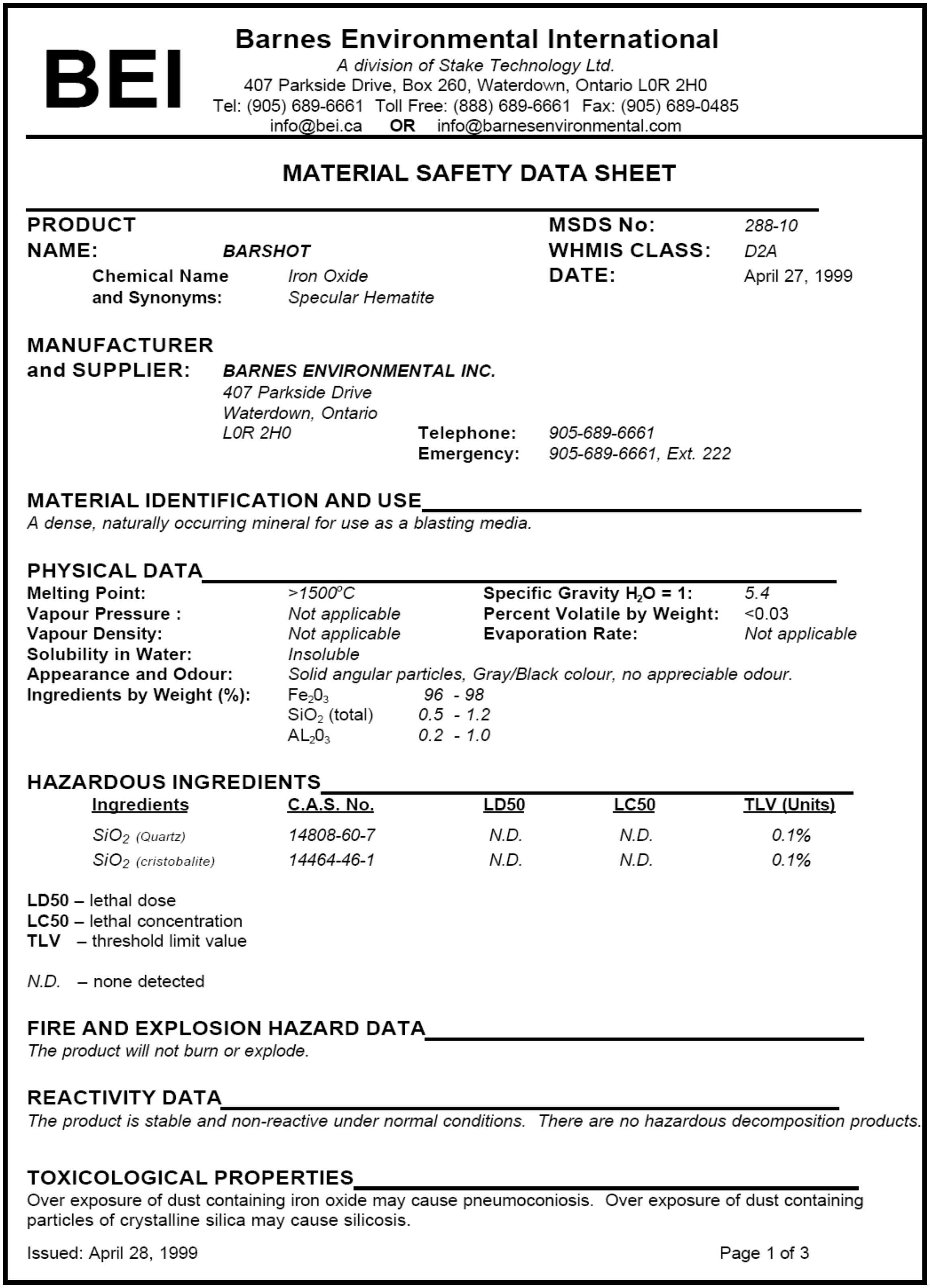
Impinger Data	**Impinger 1**	**Impinger2**	**Impinger 3**	**Impinger 4**						
Final	543.4	535.7	436.9	623.8						
Initial	542.1	534.9	436.3	622.7						
Diff	1.3	0.8	0.6	1.1						
Net Gain	**3.8**									
Filter Data	**Initial Mass**	0.4239	gm							
	Final Mass	1.1434	gm							
	Mass Collected	0.7195	gm							

Table C2 Stack Calculations

Symbol	Description	Comments	Units	Value
V1	Initial Meter Reading		dcf	**301.43**
V2	Final Meter Reading		dcf	**310.94**
Vm	Actual Volume of gas measured by the DGM	(Final-Initial) meter reading	dcf	9.51
Tstd	Standard Temperature	$25^{o}C = 298^{o}K$	R	527.70
P_B	Barometric Pressure	from weather report	in Hg	30.06
Δ P	Average Δ P		in. H20	**1.01**
		Δ P/13.6	in Hg	0.07
Pstd	Standard Pressure		mm of Hg	760.00
Δ H@	Reference Δ H	From DGM Calibration	in. H20	1.80
K	K Factor for Δ H	Assuming Pdgm ~ Pbar		1.12
Δ H	Average Δ H	K*Δ P	in. H20	1.14
Pdgm	Pressure of DGM	$P_B + \Delta P/13.6$	in Hg	30.13
Tdgm	Temperature of the DGM		F	**87.5**
Vm(std)	Volume of gas at standard conditions	$\frac{(Vm*Y*(P_B+(\Delta P/13.6))*25.4*Tstd)}{(Pstd*(Tdgm+459.69))}$	DSCF	9.13
$V_{W,cond}$	Water collected in the 3 impingers		ml	2.70
$V_{W, SG}$	Mass Increase in silica gel impinger	_	gm	1.10
$V_{w,cond(std)}$	Vol. of water vapor at Standard Conditions	K*(Vw) where K=0.04707 std ft^3/mL	scf	0.13
$V_{w,sg(std)}$	Vol. of water vapor absorbed on Silica Gel at Standard Conditions	K*(Vw) where K=0.04715 std ft3/g	scf	0.05
B_{H20}	Moisture Content by Volume			0.02
P_{MOS}		$1 - B_{H20}$	--	0.98
MW_D	Molecular Weight Dry Gas		--	29.84

T_S	Average Stack Temp		DEG F	**74.19**
P_S	Stack Pressure Absolute	$P_B + \Delta P$ (in Hg)	in Hg	30.13
Cp	Pitot Tube Coeff			0.84
V_S	Average Stack Gas Velocity	Kp * Cp* sqrt(Tgas/(Ps*MWw))*sqrt(Δ P) where Kp = 85.49* 60	fpm	3353.48
Astack	Stack Area(sq.in)		sq in.	113.10
Astack	Stack Area(sq ft)		sq.ft	0.79
Qactual	Stack Flow Rate Actual Conditions	Vs*As	cfm	2633.81
Qstd	Stack Flow Rate Dry, Std Conditions	$\frac{(Qactual*Pactual*Tstd)}{(Tactual*Pstd*(1-B_{H2O}))}$	dscfm	2673.25
TT	Net time of run	sampling time = (2min*8 traverse points)	min	16.00
Dia(nozzle)	Nozzle Diameter		in	0.18
Anozzle	Nozzle Area		sqft	0.0002
% Iso-Kinetic	Percent Isokinetic	$\frac{100*(Ts+459.69)*Vm(std)*Pstd}{(Tstd*Vs*TT*Ps*25.4*MF_D*Anozzle)}$	%	**98.67**
MF	Particulate Weight (Total)	filter(final wt-initial wt)	g	0.7195
q_{std}	gas flow collected at standard conditions	$V_{m(std)}$ / TT	dscfm	0.57
EF_{std} (grams)	Emissions		g	3369.19

Table C3: Barshot MSDS



BEI

Barnes Environmental International
A division of Stake Technology Ltd.
407 Parkside Drive, Box 260, Waterdown, Ontario L0R 2H0
Tel: (905) 689-6661 Toll Free: (888) 689-6661 Fax: (905) 689-0485
info@bei.ca **OR** info@barnesenvironmental.com

MATERIAL SAFETY DATA SHEET

PRODUCT NAME:	***BARSHOT***	**MSDS No:**	*288-10*
Chemical Name and Synonyms:	*Iron Oxide* *Specular Hematite*	**WHMIS CLASS:**	*D2A*
		DATE:	April 27, 1999

MANUFACTURER and SUPPLIER:
BARNES ENVIRONMENTAL INC.
407 Parkside Drive
Waterdown, Ontario
L0R 2H0

Telephone: *905-689-6661*
Emergency: *905-689-6661, Ext. 222*

MATERIAL IDENTIFICATION AND USE

A dense, naturally occurring mineral for use as a blasting media.

PHYSICAL DATA

Melting Point:	*>1500°C*	**Specific Gravity H_2O = 1:**	*5.4*
Vapour Pressure :	*Not applicable*	**Percent Volatile by Weight:**	<0.03
Vapour Density:	*Not applicable*	**Evaporation Rate:**	*Not applicable*
Solubility in Water:	*Insoluble*		
Appearance and Odour:	*Solid angular particles, Gray/Black colour, no appreciable odour.*		

Ingredients by Weight (%):

Fe_20_3	*96 - 98*
SiO_2 (total)	*0.5 - 1.2*
AL_20_3	*0.2 - 1.0*

HAZARDOUS INGREDIENTS

Ingredients	C.A.S. No.	LD50	LC50	TLV (Units)
SiO_2 (Quartz)	*14808-60-7*	*N.D.*	*N.D.*	*0.1%*
SiO_2 (cristobalite)	*14464-46-1*	*N.D.*	*N.D.*	*0.1%*

LD50 – lethal dose
LC50 – lethal concentration
TLV – threshold limit value

N.D. – none detected

FIRE AND EXPLOSION HAZARD DATA

The product will not burn or explode.

REACTIVITY DATA

The product is stable and non-reactive under normal conditions. There are no hazardous decomposition products.

TOXICOLOGICAL PROPERTIES

Over exposure of dust containing iron oxide may cause pneumoconiosis. Over exposure of dust containing particles of crystalline silica may cause silicosis.

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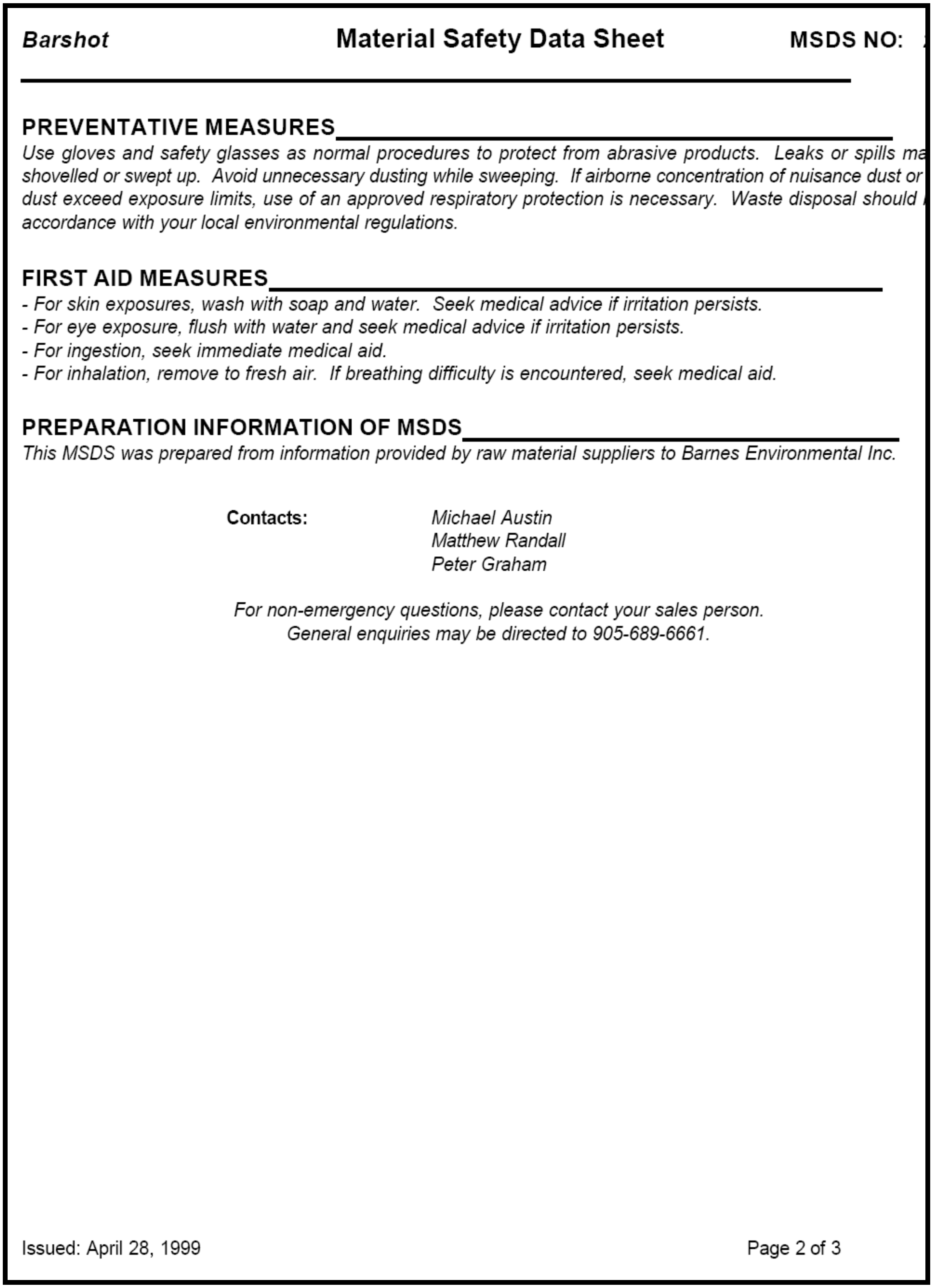

PREVENTATIVE MEASURES

Use gloves and safety glasses as normal procedures to protect from abrasive products. Leaks or spills ma shovelled or swept up. Avoid unnecessary dusting while sweeping. If airborne concentration of nuisance dust or dust exceed exposure limits, use of an approved respiratory protection is necessary. Waste disposal should accordance with your local environmental regulations.

FIRST AID MEASURES

- For skin exposures, wash with soap and water. Seek medical advice if irritation persists.
- For eye exposure, flush with water and seek medical advice if irritation persists.
- For ingestion, seek immediate medical aid.
- For inhalation, remove to fresh air. If breathing difficulty is encountered, seek medical aid.

PREPARATION INFORMATION OF MSDS

This MSDS was prepared from information provided by raw material suppliers to Barnes Environmental Inc.

Contacts:	*Michael Austin* *Matthew Randall* *Peter Graham*

For non-emergency questions, please contact your sales person.
General enquiries may be directed to 905-689-6661.

BEI

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TECHNICAL DATA SHEET

BARSHOT 20

Barshot is produced from the natural mineral "Specular Hematite" (ferric oxide). This is a chemically inert minera which cannot rust as the particles are in a fully oxidized form. In addition to producing a low dusting environment the high level of toughness and hardness makes Barshot an ideal choice in many abrasive applications. Barshot high specific gravity offers a fast blast rate and low abrasive consumption.

Typical Chemical Analysis:

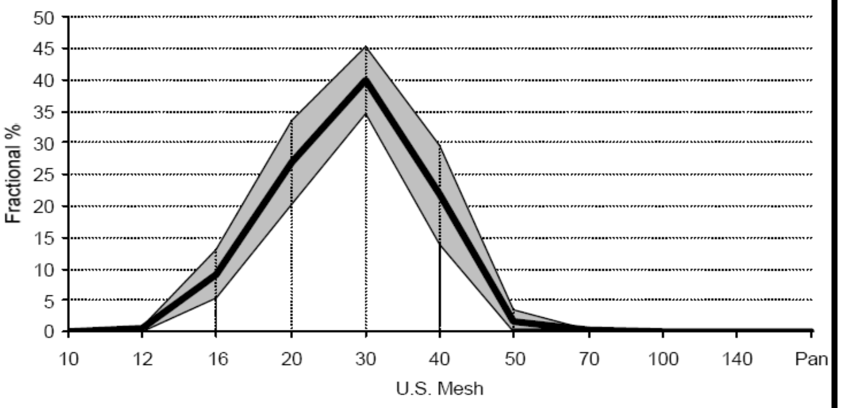
Ferric Oxide	Fe_2O_3	96-98%
Silicon Dioxide (total)	SiO_2	<1.2%
Respirable Silica-Quartz		*ND **
Respirable Silica-Cristobalite		*ND **
Aluminum Oxide	Al_2O_3	<1.0%
Titanium Oxide	TiO_2	0.10%

* *Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting (NIOSH, Contract 200-95-2946, Sept. 1998)*

Colour:	Bright solid grey/black particles	**Bulk Density:**	183 lbs./ft.^{3}
Melting Point:	>1500°C	**Specific Gravity:**	5.4
Moh Hardness:	Between 6.5 and 7.0	**Knoop100:**	850
Grain Shape:	Sub-angular / no cleavage (uncrushed particles)	**Moisture:**	<0.20%
Solubility:	Insoluble in water and common organic solvents		
Profile (est):	90 – 100 psi 3.5 – 4.0 mil 100 – 130 psi 4.0 – 5.0 mil		

Typical Screen Analysis:

U.S. Mesh	% Retained
10 Mesh	Trace
12 Mesh	0.4
16 Mesh	9.1
20 Mesh	26.9
30 Mesh	40.0
40 Mesh	21.7
50 Mesh	1.7
70 Mesh	0.1
100 Mesh	Trace
140 Mesh	0.0
Pan	0.0
-12 / +40	**97.7%**



Chemical
Copper, wire Cu

Prepared 30/11/01
By Dr. B. Dunlevy
Page 1 of 4

Section 1. Chemical identification

Name: Copper, wire, 2.0mm diam., 99.999%

Section 2. Composition/information on ingredients

CAS #: 7440-50-8 EINECS NO:231-159-6 MF: Cu

Synonyms

Allbri natural copper; arwood copper; bronze powder; copper; copper-airborne; copper bronze; copper-milled; copper slag-airborne; copper slag-milled; Raney Copper;

Section 3. Hazards identification

Label precautionary statements

- Irritant
- Irritating to eyes, respiratory system and skin.
- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- Wear suitable gloves and eye/face protection.
- Sensitive to air
- Keep tightly closed.

Irritant

Section 4. First aid measures

In case of eye contamination, immediately flush with copious amounts of water for at least 15 minutes, and seek medical advice. Assure adequate flushing of the eyes by separating the eyelids with fingers.

In case if skin contact, wash with soap and water after handling and especially before eating.

If swallowed, wash out mouth with water provided person is conscious. Call a physician. Do not induce vomiting.

Section 5. Fire fighting measures

Extinguishing media

Non-combustible. Use extinguishing media appropriate to surrounding fire conditions.

Special fire fighting procedures

For fires involving copper, do not enter any enclosed or confined fire space without proper protective equipment. This may include self-contained breathin apparatus to protect against the hazardous effects of the normal products of combustion or oxygen deficiency.

Unusual fire and explosions hazards

Emits toxic fumes under fire conditions.

Section 6. Accidental release measures

Sweep up, place in a bag and hold for waste disposal.

Section 7. Handling and storage

Store in **GREY** school chemicals storage area
Refer to Section 8.

Section 8. Exposure controls/personal protection

- Chemical safety goggles.
- Use protective clothing, gloves.
- Safety shower and eye bath.
- Avoid contact.
- Wash after handling.
- Irritant.
- Keep container closed.


Goggles


Gloves


Wash hands

Section 9. Physical and chemical properties

Physical properties

Specific gravity: 8.960

Section 10. Stability and reactivity

Stability

Stable.

Incompatibilities

- Strong acids, Strong oxidizing agents, Acid chlorides, Halogens

- May discolour on exposure to air and moisture.
- Violent reaction may occur with acetylene, ammonium nitrate, bromates, chlorates, iodates, chlorine, chlorine trifluoride, ethylene oxide, fluorine, hydrogen peroxide, hydrazine mononitrite, hydrogen sulphide, hydrazoic acid, lead azide, potassium peroxide, sodium azide, and sodium peroxide.
- Reaction of copper wool, trichloroacetic acid in dimethyl sulphoxide is ver exothermic.

Hazardous combustion or decomposition products

Nature of decomposition products not known.

Section 11. Toxicological information

Acute effects

- May be harmful if swallowed.
- Causes irritation.

Additional information

Chronic copper poisoning is typified by hepatic cirrhosis, brain damage and demyelination, kidney defects, and copper deposition in the cornea as exemplified by humans with Wilson's disease. It has also been reported that copper poisoning has lead to haemolytic anaemia and accelerates arteriosclerosis.

Toxicity data

ipr-mus LD_{50}:3500 µg/kg

Target organ data

- Lungs, thorax or respiration (fibrosis, focal) (tumours)
- Gastrointestinal (nausea or vomiting)
- Maternal effects (uterus, cervix, vagina)
- Effects on fertility (female fertility index) (pre-implantation mortality) (post-implantation mortality)
- Effects on embryo or fetus (fetotoxicity)
- Specific developmental abnormalities (central nervous system) (musculoskeletal system)
- Tumorigenic (equivocal tumorigenic agent by rtecs criteria)

Section 12. Ecological information

Data not yet available.

Section 13. Disposal considerations

Copper in the elemental state should be recovered for reuse or recycling. Observe all European, Irish and Local Environmental Regulations.

Section 14. Transport information

Contact chemical supplier for transportation information.

Section 15. Regulatory information

European information

Irritant

R 36/37/38	Irritating to eyes, respiratory system and skin.
S 26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S 37/39	Wear suitable gloves and eye/face protection.

Irritant

OEL-IRL: TWA 0.2 mg/m^3 (fume) (1999), TWA 1.0 mg/m^3 (dusts & fumes)(1999)

Section 16. Other information

This MSDS has been prepared in DkIT and is designed for Irish Second Level School Science Laboratories use only where quantities handled are less than 50g. The above information is believed to be correct but does not claim to be all inclusive and shall be used only as a guide. Every effort has been made to ensure that this information provided conforms with the latest available data. DkIT, the Department of Education & Science, Limerick Education Centre, Sigma, Aldrich, Fluka, Dr. Dunlevy or Ms. F. Dunlevy shall not be held liable for any information errors in this MSDS or for any damage resulting from handling or from contact with the above product.

Please address any comments or error observations to: brian.dunlevy@dkit.ie

REFERENCES

Sigma Aldrich Fluka MSDS CD-ROM
Sax CD-ROM
MSDS on Internet

VITA

Sandhya Naidu Potana was born on May 15, 1980 and grew up in Hyderabad, India. She graduated from "St.Alphonsa's High School" in 1995. She received a Bachelor of Technology in Civil and Environmental engineering in 2001 from "JNTU college of Engineering", Hyderabad, India. Later, she joined the graduate program at University of New Orleans in August, 2002 and conducted a research on the environmental performance of Copper Slag and Barshot at an emission test facility at UNO, a project funded by GCRMTC and EPA. Her fields of interest are air emissions monitoring, air quality analysis, air quality modeling, risk assessment, and occupational safety & health. She graduated with an overall GPA of 3.7.