A Study in Achieving the Proper Cleanliness for a Machined Cast Iron Casting with Complex Geometries

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Abstract

In this study the relationships between cleaning results and seven factors of a casting cleaning process are examined. This was to determine the parameters of an automated cleaning process that should be used to meet requirements for maximum particle size and the maximum total amount of contaminant. Two experiments were performed in order to investigate the influence that the factors and their interactions had on cleaning results in this process. It was concluded that the current cleaning system was capable of consistently meeting the requirement for contaminant amount when factors were adjusted to levels suggested by this study. The requirement for maximum particle size was not able to be met with the current cleaning system and factor settings within the investigated ranges. The system factors for the production process were adjusted to determined settings from this study.

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Chapter I: Introduction

Company XYZ entered into a contract to supply machined cast iron coupling assemblies to Original Equipment Manufacturer (OEM) D. These assemblies were supplied in three variations consisting of standard cartridge style quick couplings installed into custom castings that were developed for OEM D applications. These machined cast iron coupling assemblies had a requirement for internal cavity cleanliness that was very stringent and the machined castings required thorough washing prior to painting the external surface of the casting.

The current processing methods for this product were not able to meet the OEM D cleanliness requirement. Subsequently, OEM D initially allowed a deviation to the specifications. The stipulation to this deviation was that it had an expiration date and that processing methods had to be improved to meet the requirements.

The current processing sequence through external supplier A was: 1) raw casting was machined to accept coupling cartridges, 2) machined casting was washed and dried by external machining supplier, and 3) casting was rewashed when received directly before painting and assembly. Additionally, a second external supplier B to machine the raw castings was being developed to meet the increasing demand for this product. The proposed processing sequence through this additional external supplier B was to be: 1) raw casting was machined to accept coupling cartridges, and 2) casting was washed when received directly before painting and assembly.

Numerous tests and studies were performed with a variety of washing systems from multiple potential vendors. The best performing system was purchased and was installed in the painting facility. This system was capable of cleaning the product to meet the cleanliness requirements of the customer, but it was not consistent and required repeated adjustment to produce product that met the cleanliness specifications.

Statement of the Problem

The current cleaning method for machined cast iron couplings was not reliable or repeatable. This resulted in the requirements for cleanliness of the casting not being consistently met.

Purpose of the Study

The purpose of this study was to improve cleanliness of the castings to meet OEM D specifications. This was to be accomplished by changing processing methods for this product to meet the customer supplied cleanliness requirements. Those requirements that needed to be met as directed by the customer were: 1) the largest particle that was allowed was 0.80 mm as measured in any direction, 2) this size limitation was applicable to both abrasive and non-abrasive particles, and 3) the maximum total amount of contaminant allowed was 44 mg per each square meter of surface area.

Assumptions of the Study

In this study it was assumed that all cleanliness testing was performed according to the OEM D specification requirements. It is also assumed that all data used in this study was measured and recorded accurately.

Definition of Terms

Abrasive particle. An abrasive particle is any solid particle of metallic or mineral base. This would include metal shavings or burrs, casting sands, or any other hard substance that could be used for machining metal.

Burr. A burr is a rough edge on a metallic surface where geometries intersect. Burrs may be slight protrusions of material or large displacements of metal that could be knocked loose during subsequent processing.

Cleanliness. Cleanliness is a measure of the amount of, and/or largest particle size, of contaminant found on the surfaces of a product. These materials would be either abrasive or non-abrasive particles and could include, but are not limited to, items such as dirt, cardboard fibers, iron slivers, or grinding wheel material.

Design of experiment (DOE). A DOE is a systematically developed experimental procedure that is used to solve engineering problems. This experiment is developed to ensure that accurate and efficient data is gathered to support conclusions. This experiment is also developed in a manner to minimize number of runs performed, time, and total cost.

Emulsified. Emulsified refers to the joining together of two liquids that are not typically soluble. Detergents are used to accomplish this and the process is often used for removing oil from surfaces with the use of water.

Ferrous. Any metallic compound or mixture that contains iron as the predominant element.

Gravimetric analysis. A process involving the thorough re-washing of a previously cleaned product and the measurement of amount and size of solid particles washed from the casting using a cleaning solution. The cleaning solution is filtered and the gathered solid particles are weighed and measured.

Green sand. A term used to reference the condition of the sand used to create molds for metal casting. Green sand is that which has moisture in it and is not dry. It is a combination of sand, a binder which is usually clay, and water.

Machinability. Machinability refers to how difficult or easy a metal can be processed. This would include aspects such as actual physical removal of material, the life of tools being used to process the metal, and the time that it takes to process the metal.

Non-abrasive particle. A non-abrasive particle is any solid particle that is not metallic or mineral base. This would include plastic slivers, cardboard, wood splinters, or any other solid substance that is not metallic or mineral in base.

Plating. This is a process where a thin layer of metal is applied to the surface of a base material.

Limitations of the Study

There were four initial limitations to this study. First, the study was limited to testing and analysis of machined cast iron coupling assemblies and did not extend to any other product variations. Also, the study was focused on the current processing method of cleaning castings in the newly purchased parts washer from Ramco Equipment Corporation. This parts washer was a four stage model MK-16T and was located in a facility in Mankato, MN.

Additionally, this study was limited to the washing method used and did not investigate alternate, or secondary, inspection and deburring methods to improve cleanliness. Finally, this study utilized gravimetric testing procedures with pressurized solvent cleansing. The effect of this testing procedure on cleanliness results was not studied.

Methodology

The current processing method was used as a baseline to measure incremental improvements in casting cleanliness due to process changes. An experiment was performed to document the current cleanliness capability of the process. The data that was measured during testing of the cleaned part was the largest particle size found and the amount (mass in milligrams) of contaminant per each square meter of surface area of the casting.

A design of experiment (DOE) was developed and performed on the current washing process to determine the variable settings of the washer that should be used to consistently meet part cleanliness requirements. Not all of the variable settings were clearly defined in the first experiment, so a second experiment was then performed to further define the remaining variable settings. A conclusion and recommendation was then developed based upon the analysis of this data.

Chapter II: Literature Review

With the advances in technology there has been an increase in the precision required for manufactured components and assemblies. This increased precision affects characteristics of manufactured products including material quality, tolerances, and even in the cleanliness of the final product. Cleanliness may seem like an unusual requirement, but according to Korn (2005) a couple of primary reasons that products must be cleaner are decreased clearances between mating parts and smaller fluid orifices being used within systems. This would directly apply to cast iron coupling assemblies that would be part of a fluid transfer system which are the products studied in this paper. Osborn (2005) also noted that cleanliness considerations are rapidly increasing and that changes in tolerances drastically affected the cleanliness requirements of the products. Excessively sized particles can get caught between components causing binding or increased wear. Oversized particles can also partially block or even completely plug fluid orifices. Particles of even of a minute scale can render these products nonfunctional and/or cause them to fail prematurely.

With these more stringent requirements in cleanliness, many original equipment manufacturers (OEM) have developed their own specifications that suppliers must adhere to in order to provide acceptable components. While these OEM specifications alleviate the question of how clean is clean enough, they do not help with the issue of determining what cleaning method is the best process required for each product. They also do not always clarify what Wilson (2005) defines as the other main challenge in cleaning which is defining an appropriate testing procedure to assure that the cleaning has been performed to meet specifications.

There are numerous cleaning methods available and even more possibilities when combinations of these methods are used. To make matters more complicated, a producer must take into consideration not only finding a process that consistently performs as required, but also one that meets ever increasing environmental regulations and requirements ("High precision cleaning," 2000).

In this chapter the three distinct factors that are involved in a cleanliness issue are discussed. The factors are material involved, cleaning method used, and method of verification of cleanliness. The first factor that is examined is the material used. It is focused on the casting of iron, the machining of the iron casting, and the removing of burrs from the final product. The second factor that is examined is the washing method of cleaning. This section will confer information regarding washing methods, ultrasonic cleaning used in washing methods, and chemistry used in washing methods. In the final section a common method of verification of cleanliness will be explained. It will detail gravimetric cleanliness testing and then be followed by a discussion of the pros and cons of using this method of verification.

Machined Iron Castings

It is important to understand the processing of a machined iron casting from start to finish as each process step performed can contribute to the overall cleanliness of the finished product. Machined iron castings are created using three basic steps. The first step is to cast the metal into the near final physical shape. Once the metal is cast and cleaned, the raw casting is machined. The machining focuses on removing material from the as cast condition geometries that either have tight tolerances or that have surface finish requirements that are better than the as cast state can produce. The final step is to remove the burrs that are created when machined surfaces intersect with as cast surfaces.

Casting iron. The most traditional casting method according to Kalpakjian (1995) is sand casting. Sand casting is used to cast metals by means of pouring the molten metal into a cavity that has been formed within the sand and then allowing that metal to cool and solidify. The cavity within the sand is formed with the use of a pattern resembling the final shape of the product. If cavities or passages are required within the casting, sand can be formed into cores that are placed within the open cavity. Heine, Loper, and Rosenthal (1967) notes that these cores allow complex internal shapes that would be extremely difficult or impossible to machine into the metal. Once the metal has solidified, the sand mold and cores are broken apart and the sand removed from the exterior and interior surfaces of the casting.

There are many kinds of sand and sand mixtures that are used for creating the molds. Heine et al. (1967) and Kalpakjian (1995) both state that green sand is used most prevalently due to the low economic investment required. Green sand is simply a combination of sand, a binder which is usually clay, and water. This method is cost effective as the mold can be easily separated from the cast metal and the mold sand can be recycled and reused.

The final step to the casting process is cleaning the casting. According to Heine et al. (1967) this cleaning process includes the removal of all casting sand and any metal not part of the desired final product geometry. The casting gates are ground off along with any excessive flash on the external surfaces of the casting. The casting is then subjected to a vibratory process to shake loose and remove any casting sand that is still present. Finally, a washing operation may be used to further remove any sand particles that remain.

Machining iron castings. One of the characteristics of ductile iron castings is that it is easily machined according to the Gray and Ductile Iron Founders' Society Inc (1971). Rio Tinto Iron & Titanium, Inc. (1990) also states that ductile iron castings provide both a cost effective method to producing complex geometries along with machining benefits versus alternate material options. This means that a product with a complex geometry can be cast and then simply machined to final dimensional and surface finish requirements.

Ductile iron castings can be milled, turned, drilled, tapped, and much more. All of these processing methods take the as cast surface and modify it to finished dimensional specifications. Ductile iron castings actually exhibit improved machinability when compared to steel according to Rio Tinto Iron & Titanium, Inc. (1990). This is quantified by increased useful tool life and reduced machining times. In practical terms, these benefits equate to cost savings versus standard machining of steel.

This machining of the iron casting generates chips, slivers, burrs, and finer particles of metal. Additionally, machining operations typically require the use of coolants and lubricants. The coolants and lubricants can cause the removed metal to adhere to the casting and must be removed in subsequent cleaning operations.

Removing burrs on machined castings. While ductile iron castings with complex geometries are easily cast and machined, they do have one characteristic that can be difficult to manage. That characteristic is the creation of burrs in the locations that machined surfaces and as cast geometries intersect. These burrs are created because the iron is designed to be less brittle than other comparable materials and the rolled up material doesn't break off during machining. If these intersecting features and resulting burrs are external to the product there are numerous methods to remove any burrs that are generated. Some of the processes that may be used are: tumbling, grinding, blasting, brushing, and manual deburring.

Burrs generated internal to the product due to these intersecting features are much more difficult to manage and remove. Constraints such as physical internal space, internal passage geometries, and deburring tool size make many internal burrs difficult to access with conventional low-cost deburring methods such as hand held blades or rotary grinding bits. Consequently, manual deburring is widely used to remove internal burrs. This is because manual deburring is flexible, uses simple tools, and is cost effective (Gillespie, 1999).

Gillespie (1999) also says the major drawbacks to using manual deburring are that it requires excessive labor and does not provide consistency. In many applications these shortcomings may be acceptable, but consistent burr removal is a key to maintaining cleanliness of products. Burrs must be consistently removed so that they do not break free when a product is in use and create a solid contaminant within the product.

There are alternatives to internal manual deburring which include: abrasive flow machining, thermal deburring, water-jet deburring, laser deburring, and deburring with the use of a robot. Multiple methods may work with a particular application, but cost is typically used to decide what deburring method is utilized. All of these options require a substantial capital investment in equipment and fixturing to implement. This investment is usually the deciding factor for choosing to use manual deburring methods.

Washing Type Cleaning Processes

The next factor involved in managing the cleanliness of a product is the cleaning method used and there are many cleaning processes commercially available in the manufacturing market. While Wilson (2005) reports that cleaning techniques are basically categorized into physical and chemical procedures, these definitive lines have grayed with advances in technology. This basic classification is still valid, but most cleaning processes incorporate a combination of both physical and chemical procedures.

According to the American Society for Metals [ASM] (1982), there are numerous things to be considered including the material being cleaned and the contaminant that is being cleaned from the material surface. The primary contaminants found on machined iron castings are chips, scale, and cutting fluids. The cutting fluids may be either oil or water based and are primarily used as coolants and lubricants during the machining process.

Physical washing methods. Physical processes may include wiping, spraying, vapor degreasing, immersion, hydro jet, or flushing. Immersion cleaning also may incorporate additional physical actions in an attempt to improve cleaning results. Product may be moved up and down or side to side to aid in inciting solution movement through and/or past the item. Air or solution may be pushed through and/or past the product with the use of a pump and nozzle arrangement. Rotation can also be used along with these processes to increase their cleaning capabilities. Physical processes tend to be the first option explored to clean products and can be used in combination with chemicals.

Most of these physical processes are incorporated into automated or semi-automated equipment. Alkaline, acidic, or solvent chemicals are exposed to the product by aqueous or vapor means during this physical washing (Sparks, n.d.). Some washing equipment actually utilizes a combination of, or multiple subsequent, physical processes. Each of these subsequent processes may process the product once or the cycle may be repeated to improve cleanliness.

Processing time becomes an important aspect with these physical processes. If the time that is invested in cleaning products is too short the result may be failure to meet cleanliness specifications. The opposite scenario of investing too much time may result in excessive costs and decreased throughput.

According to Sparks (n.d.), another critical aspect of these washing systems is rinsing of the product after it has been exposed to any chemicals. Once the cutting fluids have been cleaned from the product and the majority of the contaminants flushed away, it is important to remove the residual chemicals from the surfaces of the product to ensure that they do not affect any further processing that may be required such as painting or plating. ASM (1982) states that these rinses can be either hot or cold, but they should contain a rust inhibitor if the product being cleaned is a ferrous metal. This is to eliminate or reduce the possibility of the product rusting prior to further processing. Drying of the product may also be required as a final step so that the product is ready for further handling and processing.

Chemicals used in washing methods. A manufacturer must be very cautious of the environmental consequences of using particular chemicals. The Minnesota Pollution Control Agency (2003) sets forth a comprehensive procedure for evaluating, handling, and disposing of generated chemical waste. Extremely basic or acidic chemicals may require the use of sophisticated waste treatment procedures to dispose of the spent chemicals. This requirement would then classify a manufacturer as a "hazardous waste" producer. This can equate to high disposal costs or implementation of expensive systems to safely process the chemical waste.

The ASM (1982) specifically suggests the use of solvents and acids to remove chips and cutting fluids. With these chemicals being acidic they generate corrosive waste when used in a cleaning application. The definition of a corrosive waste is a liquid that is capable of rapidly corroding metal and the Minnesota Pollution Control Agency (2003) states that corrosive wastes are "hazardous" because of this characteristic.

Another highly recommended chemistry to remove oils and cutting fluids is alkaline, or basic, cleaners (ASM, 1982). Sparks (n.d.) also states that the use of an alkaline chemical is preferable when utilized with an automated cleaning method. This is because alkaline cleaning methods are typically less expensive than solvent or acid based cleaning methods. The waste that they generate is also considered corrosive and hazardous and the same considerations for disposal of spent chemicals must be employed.

The concentration of the chemicals that make up a solution must be considered with both solvent or acid based cleaning methods and alkaline cleaning methods. Not enough chemical used in a solution may result in inadequate cleaning results. Excessive chemical used in a solution may affect the overall reactivity of the solution and increase the amount of hazardous waste that is produced.

Alkaline and solvent based chemicals are safer to use in aqueous and vapor processes and thus generally preferred over acids. If solvents are used in an aqueous solution it is called an emulsion cleaning process (Sparks, n.d.). According to ASM (1982), solvents are good at removing some cutting fluids, but not all variations that are used in processing metals. Alkaline chemicals in aqueous solution are good at removing most varieties of cutting fluids so they are the preferred chemistry.

When products are exposed to aqueous alkaline processes, the cutting fluids are displaced from the surfaces and then either dissolved into the solution or emulsified (ASM, 1982; Sparks, n.d.). Any emulsified or dispersed cutting fluids must be removed from the solution with the use of oil skimmers. The use of heat can reduce oil viscosities and greatly increase the reactivity and effectiveness of aqueous alkaline washing processes.

Ultrasonic cleaning. ASM (1982) and Osborn (2005) both report that when standard physical washing methods are not enough, ultrasonic cleaning is another option that can be combined into the overall process to remove the smallest particles that are adhered to the product. This ultrasonic cleaning process is generally used in combination with one or more mechanical washing methods, but may be used alone in some instances. The amount of time that a product is exposed to the ultrasonic cleaning process may affect the cleanliness results achieved. Enough time in this process must be given to allow all of the particles to come free from the surfaces of the product. Too much time in this process may result in increased processing costs and reduced throughput. This process typically requires the use of a chemical solution that will dissolve the binding agent that may be holding a particle to the surface.

Ultrasonic cleaning systems have a panel in the bottom or on the sides that produces a sound wave within a fluid solution (Busnaina & Gale, 1995). These sound waves generate pressure which form physical waves in the fluid. According to both Busnaina & Gale (1995) and Branson Electronics Corporation (1998) the intensity of these rapid waves creates cavitation. Cavitation is the creation and subsequent implosion of tiny gas bubbles within the fluid and on the surfaces of the product being cleaned.

According to the Cleaning Technologies Group (2009a), different ultrasonic frequencies are better at removing varying particle sizes. Lower frequencies are better at removing larger particles and high frequencies are preferred for removing smaller particles (Branson Electronics Corporation, 1998). Another technique that can be used is sweeping or changing frequencies during a cleaning cycle (Cleaning Technologies Group, 2009b). The changing of frequencies during a cleaning cycle allows the targeting and removal of different sized particles.

Testing the Cleanliness of Products

The last factor involved in a cleanliness issue is the method of verification of cleanliness. This final step to the process is verification that the product has been cleaned to meet specifications. This verification is very important in monitoring the cleaning process and providing proof to the customer that the product meets their requirements. Without this verification step there is no way to know if the product was cleaned adequately. This testing process, if performed at regular intervals, can also monitor and signal changes in the cleaning process that need to be investigated and corrected.

Gravimetric testing procedures. A common testing procedure to gage the cleanliness of a product is Millipore or gravimetric testing. This procedure is a means to quantitatively verify that the cleaning process is performing as intended. This testing provides clear exact figures that can be directly compared to specifications or limits. Additionally, gravimetric testing is an easy way to obtain accurate data that is capable of indicating whether a part is clean (Reckhow, 2006; Knapp, 2008).

In order to perform this testing, a previously cleaned product is rigorously re-cleaned and a cleanliness sample is obtained. This sample is a collection of solid particle contaminants that have been removed from the surfaces of the product. The cleanliness sample is then analyzed to determine the total weight of the contaminants, the maximum particle size that was found, and sometimes the total count of particles observed. The results of the analyzed cleanliness sample are then compared against desired limits to determine whether the part is clean enough.

Osborn (2005) discusses the two most common methods of obtaining this cleanliness sample. The first method is by spraying the surfaces of the product with a pressurized solvent and then collecting the solvent to be analyzed. The second method is similar, but instead of using a pressurized spray the product is placed into a bath of the solvent and then subjected to ultrasonic vibrations.

Kenkel (2003) and Knapp (2008) both detail the procedure of separating the solid particulates from the solvent by means of passing the effluent through a filter. This process of removing the particulates from the effluent is done by using a vacuum system to draw the solvent through the filter. Typically, the container that held the solution is rinsed with the same solvent and the wash solvent is also passed through the filter by means of the vacuum system. This is to ensure that all particles of contaminant are accounted for and that none are left within the solvent collection container.

The filters that are used are weighed immediately prior to the testing to record their initial weight. Then after being used, the filters are dried and weighed again to determine the total amount of contamination that was removed from the cleaned product by the solvent. To more accurately analyze the captured particles they can be inspected for composition, counted, and measured for overall size. This portion of the testing is usually performed with a microscope and the images are captured with cameras that have been built in or attached to this testing equipment.

Pros and cons of gravimetric testing. When using any analytical test it is very important to understand the strengths and weaknesses of the procedure. Gravimetric testing has a number of strengths which make it an appropriate choice for verifying cleanliness of a product. As previously mentioned, both Reckhow (2006) and Knapp (2008) refer to gravimetric testing as an accurate analytical method to test for cleanliness of a part. Additionally, gravimetric testing is a relatively easy procedure that is not as costly as other testing methods (Knapp, 2008). Costello (2006) describes gravimetric testing as cost effective in three different ways. The first is in capital investment costs, the second is in sample preparation costs, and finally it is a fairly fast procedure.

There are no glaring weaknesses with gravimetric testing, but there are a couple of considerations that must be mentioned. The first concern is with the method of using a pressurized spray of solution to collect the cleanliness sample. Proper containment and safety equipment must be utilized to protect personnel performing the testing.

Another concern is that to meet some cleanliness testing requirements the gravimetric testing must be performed in a controlled environment such a clean room. This would be in instances where the allowed contaminant is minute and the particles that might be in the air could become part of the collected sample and skew the results.

Finally, extremely small particles could pass through the filter being used to collect the contaminant sample. Careful consideration has to be given to the micron size of the filter that is used for gravimetric testing to ensure that particles are accurately collected. If the collected cleanliness sample contains a lot of small particles that are not collected, the results of the testing will not be accurate.

Summary

There is a requirement for improved cleanliness for manufactured components and assemblies due to increases in precision. Cleanliness is especially important in high precision fluid couplings as excessively sized particles can get caught between mating components causing binding or wear. Oversized particles can also reduce or block fluid flow through orifices. When looking at cleanliness, there are three main factors that affect cleanliness issues which are: material and processing involved, cleaning method used, and method of verification.

Machined iron castings are created using a series of processing steps. The first step is to cast the metal into the basic physical shape and to clean the casting to remove excess metal and/or casting contaminants. The most traditional casting method is sand casting with green sand.

Once the metal is cast and cleaned, the raw casting is machined. One of the characteristics of ductile cast iron castings is that it is easily machined. This means that a product with a complex geometry can be cast and then simply machined to final dimensional and surface finish requirements. Ductile iron castings exhibit better machinability than steel.

While ductile iron castings with complex geometries are easily cast and machined, they do have one characteristic that can be difficult to manage. That characteristic is the creation of burrs in the locations that machined surfaces and as cast geometries intersect. Consequently, the final step to machining an iron casting is removing the burrs that are created where surfaces intersect. Manual deburring is widely used to remove internal burrs because it is flexible, uses simple tools, and is cost effective when compared to alternative methods. Even with the benefits manual deburring provides, there are major drawbacks which are that it requires more direct labor than other processes and does not provide consistency.

Machined iron castings often require a cleaning operation to meet final cleanliness specifications. There are numerous things to be considered when choosing a cleaning process which include the material being cleaned and the contaminant that is being removed from the material surface. Most cleaning processes incorporate a physical procedure with a solvent, acid, or alkaline cleaner.

Most cleaning processes are incorporated into automated or semi-automated equipment. Some washing equipment actually utilizes a combination of, or multiple subsequent, physical processes. The chemistry to use in these washing processes, due to safety concerns, is an alkaline based cleaner in an aqueous solution. Alkaline solutions are highly recommended for removing oils and cutting fluids. Any product that is processed through this washing method must be thoroughly rinsed to remove residual chemicals. This rinse should contain a rust inhibitor to reduce the possibility of rusting when the product is a ferrous metal.

If standard physical washing methods are not enough, ultrasonic cleaning is another option that can be combined into the overall process to remove the smaller particles that are adhered to the product. Different ultrasonic frequencies are can be used as each frequency is better at removing particular particle sizes.

The final step to this entire process is verification that the product has been cleaned to meet specifications. A common testing procedure to gage the cleanliness of a product is gravimetric testing which is an accurate analytical method that is relatively fast, easy, and cost effective. To perform gravimetric testing, products are rigorously re-cleaned and the effluent is collected. The effluent is passed through a dry and weighed filter that removes the particulates from the solvent used to clean the product. The filters are then dried and weighed again to determine the total amount of contaminants that was collected from the testing sample.

Chapter III: Methodology

The requirements for cleanliness of a machined iron casting were not being consistently met due to the current cleaning method not being repeatable. The purpose of this study was to improve cleanliness of the castings by modifying processing methods for this product.

In this chapter the data and collection methods are discussed. This chapter also contains a review of the equipment used for cleaning the castings, the methods of data analysis that were used, and the limitations of this methodology.

Equipment and Chemistry

The cleaning of the casting was performed on a four stage aqueous parts washer built by Ramco Equipment Corporation (See Figure 1). This is the same model MK-16T which is used for production cleaning of the machined iron casting. There is a roller conveyor on the left hand side of the washer that is used as the station to load the castings into a washing basket. The washer is made up of the following internal stations: stage one turbo agitated wash with ultrasonics, stage two turbo agitated rinse, stage three rinse, and stage four hot air drying. Finally, there is a roller conveyor on the right hand side of the washer that is used as the station to unload the castings from the washing basket. Appendix A provides additional photographs of the parts washer.

Figure 1: Ramco Four Stage Aqueous Production Parts Washer

The chemicals used for the experimentation in this report were the same that are used during production operation of this equipment. The stage one wash tank contained a mixture of water and an alkaline cleaner called BB-1818 produced by Ransohoff. The stage two and stage three rinse tanks contained a mixture of water and a rust preventative called Perkote 10-385 produced by Perkins Products Inc. Refer to Appendix B for detailed material safety data sheets for both chemicals used.

The washing baskets used were open wire framed and held ten parts per basket. These baskets were 19” long, 15” wide, and 3” deep. The parts were loaded into the baskets with socket ends down and the side ports to the right (See Figure 2). This was done in an attempt to provide adequate flow of fluid through the castings to remove any contaminants. See Appendix A for additional photos of the washing basket geometry and part loading.

Figure 2: Washing Basket Loaded with Castings

Sample Size

A statistically designed experiment (DOE) was developed based upon the variables that could be adjusted on the Ramco four stage parts washer that was being used. The DOE was randomized and set up using the statistical software Minitab version 16 (Minitab Inc, 2010). Each trial run that was performed consisted of one basket containing ten castings. The objective of this DOE was to determine which of the variables had a significant effect on cleanliness.

There were seven variables, or factors, selected pertaining to the stage one wash that were studied in experiment I. The factors selected were: concentrations of BB-1818, wash fluid temperature, wash turbo on or off, time of wash agitation cycle, time of wash ultrasonic cycle, agitation stroke length, and number of cycles performed.

One of the important aspects in the stage one wash is the chemistry that is used to clean the castings. The factor of concentration of BB-1818 refers to the percentage of alkaline liquid cleaner mixed with water in the wash tank. The chemical vendor suggested using this chemical at an elevated temperature so the wash fluid temperature factor is the operating temperature of the mixed solution in the stage one wash.

There are four manifolds in the bottom of the stage one wash that can be turned on during the wash agitation cycle. These manifolds have nozzles on them that pump out pressurized wash solution to aid in forcing fluid up and through the castings. The factor related to this feature is the wash turbo on or off.

The factor of agitation stroke length is the distance that the baskets full of parts move up and down within the wash solution. The short stroke length is two to four inches of travel and the long stroke length is five to nine inches. The time of wash agitation cycle is the factor which defines the length of time that the parts are moving up in down in the wash solution with the ultrasonics turned off.

The time of ultrasonic cycle factor defines the length of time that the parts are moving up in down in the wash solution with the ultrasonics turned on. During this time the turbos are always turned off, but the parts are still moving up and down as dictated by the agitation stroke length. Finally, the factor of number of cycles performed is the count of how many times the alternation between wash agitation and ultrasonic cleaning is ran.

Previous testing that had been performed during initial installation of the cleaning system had showed that there was no statistical difference in the cleanliness between any of the ten parts that were in a basket when processed. This information, along with reduced cost, supported a decision to randomly choose two samples from each trial run of ten parts that had been washed for cleanliness verification. Hence, the baskets were fully loaded with ten castings to replicate the conditions of fluid flow and movement that would be present during day to day production processing.

The machined cast iron couplings are produced in three variations that are designated “01”, “02”, and “03”. All three variations have the same socket and side port geometries. The difference is in the orientation of the mounting flange and the complexity of the internal passages from the socket to the mounting flange. All variations are approximately 13 pounds and are seven inches long, five and a half inches wide, and three inches thick. This testing was performed using the “01” style castings (See Figure 3). This is believed to be the most difficult cleaning application as the chosen castings contain the most complex internal passages. See Appendix C for additional information on casting geometries.

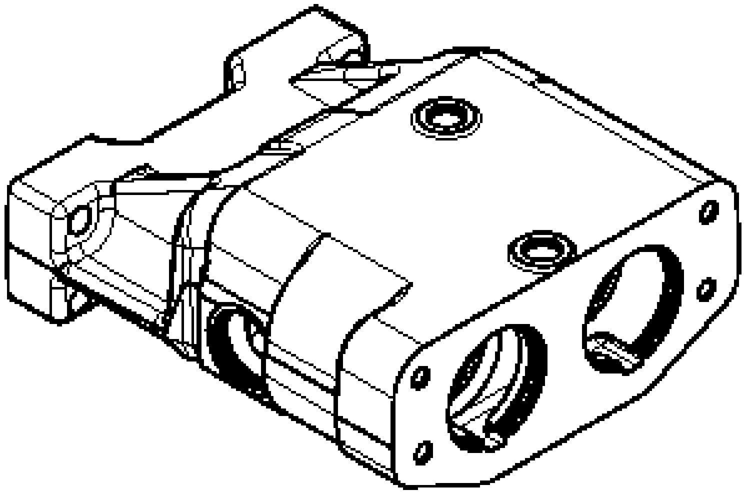

Figure 3: “01” Casting Configuration Model

Experiment I was performed with a one-fourth fractional 2^7 factorial design. There were 32 runs performed on the two samples that were randomly chosen from each basket of ten castings. This resulted in 64 castings being sampled for cleanliness verification testing. Table 1 shows each of the runs, the factors examined, and the settings for each factor per run.

Table 1

Factor Settings for Experiment I

Run Number	BB-1818 Concentration	Temperature (°F)	Turbos On/Off	Agitation Time (Min)	Ultrasonic Time (Min)	Agitation Stroke	Number of Cycles
1	10%	180	On	1	1	Short	10
2	10%	180	Off	1	1	Short	5
3	10%	180	On	1	5	Long	10
4	10%	180	Off	5	5	Short	10
5	10%	180	Off	5	1	Long	10
6	10%	180	On	5	5	Short	5
7	10%	180	On	5	1	Long	5
8	10%	180	Off	1	5	Long	5
9	20%	100	On	5	5	Long	5
10	20%	100	On	1	1	Long	10
11	20%	100	On	5	1	Short	5
12	20%	100	Off	1	1	Long	5
13	20%	100	Off	5	5	Long	10
14	20%	100	On	1	5	Short	10
15	20%	100	Off	1	5	Short	5
16	20%	100	Off	5	1	Short	10
17	20%	180	On	5	1	Short	10
18	20%	180	On	1	5	Short	5
19	20%	180	On	5	5	Long	10
20	20%	180	On	1	1	Long	5
21	20%	180	Off	5	5	Long	5
22	20%	180	Off	5	1	Short	5
23	20%	180	Off	1	1	Long	10
24	20%	180	Off	1	5	Short	10
25	10%	100	Off	5	1	Long	5
26	10%	100	On	1	5	Long	5
27	10%	100	Off	1	1	Short	10
28	10%	100	On	1	1	Short	5
29	10%	100	Off	5	5	Short	5
30	10%	100	On	5	5	Short	10
31	10%	100	Off	1	5	Long	10
32	10%	100	On	5	1	Long	10

Upon analysis of the results of experiment I, an experiment II was developed based upon the significant factors that could be adjusted on the current parts washer. The objective of this second DOE was to determine the settings that should be used for production.

Experiment II was performed with a full 2^3 factorial design. There were 8 runs performed with two replicates and four samples randomly chosen from each basket of ten castings. The decision to test four samples from each trial run was made in order to have sufficient data for analysis.

There were three variables selected pertaining to the stage one wash that were studied in experiment II. The variables selected were: concentrations of BB-1818, time of wash ultrasonic cycle, and number of cycles performed. Table 2 shows each of the runs with the replication, the factors examined, and the settings for each factor per run.

Table 2

Factor Settings for Experiment II

Run Number	BB-1818 Concentration	Ultrasonic Time (Min)	Number of Cycles
1	20%	10	5
2	20%	5	5
3	20%	5	2
4	20%	10	2
5	40%	10	2
6	40%	10	5
7	40%	5	2
8	40%	5	5
9	40%	5	5
10	40%	10	5
11	40%	10	2
12	40%	5	2
13	20%	10	5
14	20%	5	2
15	20%	5	5
16	20%	10	2

The experiments were both performed with the runs in a randomized order. This was to ensure that the experimental data was not skewed or biased.

Data Gathered

The current production processing method was used as a baseline to measure incremental improvements in casting cleanliness due to process modification. An initial study had been performed to document the current cleanliness capability of the process. The data that was measured and studied included the amount of contaminant per each square meter of surface area of the casting (response A) and the largest particle size found (response B). This data was required for comparison to the data generated by experiments I and II.

The cleanliness verification data of experiments I and II were obtained from a certified independent lab on castings washed in the current parts washer. When the developed DOE experiments were performed and the castings shipped to the lab for testing, they were individually bagged and labeled. The parts were carefully handled and separately bagged to keep contaminants from being deposited on the castings while they were in transit to the lab. They were labeled so that the lab could properly correlate results with the correct run number.

Data Analysis

The cleanliness verification data was produced through gravimetric testing of previously “cleaned” product samples. The gravimetric testing procedure included spraying the surfaces of the product with a pressurized solvent and then collecting the solvent and any remaining contaminant to be analyzed. The solvent was sprayed on all external and internal surfaces of the casting and was pressurized to 30 pounds per square inch (PSI).

The cleanliness verification data that was recorded from each casting included the largest particle size of abrasive particles, the largest particle size of non-abrasive particles, and the total amount of all contaminants flushed from the washed casting. As previously defined, abrasive particles are metallic or mineral based and non-abrasive particles are any solids that are not abrasive. Additionally, each casting was flushed and tested a second time to ensure that the first test was performed correctly. If the second test resulted in a total amount equal to or greater than ten percent of the first test, that data was added to the results of the first test for an accumulative total.

The data analysis was performed using only the largest particle size observed regardless of whether that particle was abrasive or non-abrasive because exceeding the specification in either or both of these categories was a failure to meet requirements. Distinctive raw data between the two particles was recorded so that further analysis, outside the scope of this study, might help identify the source of the contaminant.

The lab results were then input into Minitab version 16 for analysis. This is a statistical software program that is used to set up and analyze DOE data. It was used in this study to analyze the effect that the factors and factor interactions had on the responses. It was also used to generate graphical representations of the analysis.

The analysis of experiment I was to determine any significant factors or factor interactions and the settings to use on the system studied. Experiment II was developed based upon the results from experiment I and was focused on factor settings that were not clearly defined. Experiment II was performed and the samples were tested in the same manner. The results of the second DOE were analyzed with the Minitab version 16 software and the improved setting for each factor was determined.

Limitations

The first limitation of this methodology was that it was performed using only "01" style castings. There was no testing performed to qualify the cleaning process with the other two casting configurations. Even though the castings are similar, there is no guarantee that all three variations will be cleaned equally in the current cleaning process.

Another limitation is that the seven factors that were studied were not tested with full ranges of the variables. The ranges investigated were limited and further experimentation might improve the process.

The other limitation of this methodology was that it was performed with a limited sample size and was not performed over a period of time. These experimental results showed the improved machine settings, but did not determine the process capability with respect to time and number of castings processed.

Chapter IV: Results

In this chapter the results of experiment I and experiment II are discussed and analyzed. Table 3 can be found at the end of this chapter and summarizes the factor settings that were indicated by each of the experiments. This summary is with regards to both the response of amount of contaminant mass and maximum particle size allowed. The product cleanliness requirements were that the largest particle allowed was 0.80 mm as measured in any direction and the maximum total amount of contaminant allowed was 44 mg per each square meter of surface area of the casting.

The same analytical logic was used for both experiments I and II. All factors require a decision as to what level to be set at for use in production processing of the castings. Therefore, even factors that are not shown to be significant were reviewed. The first factors that were investigated were those that were found to be significant factors according to the normal plots of the standardized effects. Second, the factors involved in significant interactions according to the same plot were analyzed. Then the factors with the largest variation in data means as represented on the plot of main effects were examined. Finally, the interaction plots of factors were reviewed to support or modify previous factor setting determinations.

After the first analysis was completed, all subsequent analysis reflected upon previous analysis factor setting decisions. The analytical logic remained the same except that this consideration of previously determined settings took place directly after interpretations of significant factor interactions.

Experiment I Analysis

Experiment I was a one-fourth fractional 2^7 factorial design in which 32 runs were performed. Two samples were randomly chosen from each basket of ten castings and the 64 castings were sent out for cleanliness verification testing. The raw data results can be found in Appendix D.

Contaminant Amount Analysis. The data gathered was input into the Minitab version 16 software and analyzed for response A which was amount of contaminant per each square meter of surface area of the casting. Significance references in this section pertaining to analysis of Figure 4 through Figure 9 are at $\alpha = .05$. A plot of the standardized effects on total amount of contaminant per each square meter of surface area is shown in Figure 4. This plot has a ninety-five percent confidence interval and is used to indicate if the collected data is random and normally distributed.

The confidence interval refers to the accuracy of the plotted data. This means that if this experiment was repeated, similar results could be expected ninety-five percent of the time. Only, five percent of the time would the calculated results and plots be statistically different. Also, the plotted points closely resemble a straight line, which indicate that the collected data is normally distributed.

Significant factors or factor interactions are those that have large effects on responses based upon factor settings. Any points that are falling far away from the line, or are located in the upper right or lower left corners, indicate effects that may be significant. This plot showed that the following factors and factor interactions were significant: ultrasonic time, BB-1818 concentration * temperature, temperature * ultrasonic time, agitation time * number of cycles, and turbos on/off * number of cycles.

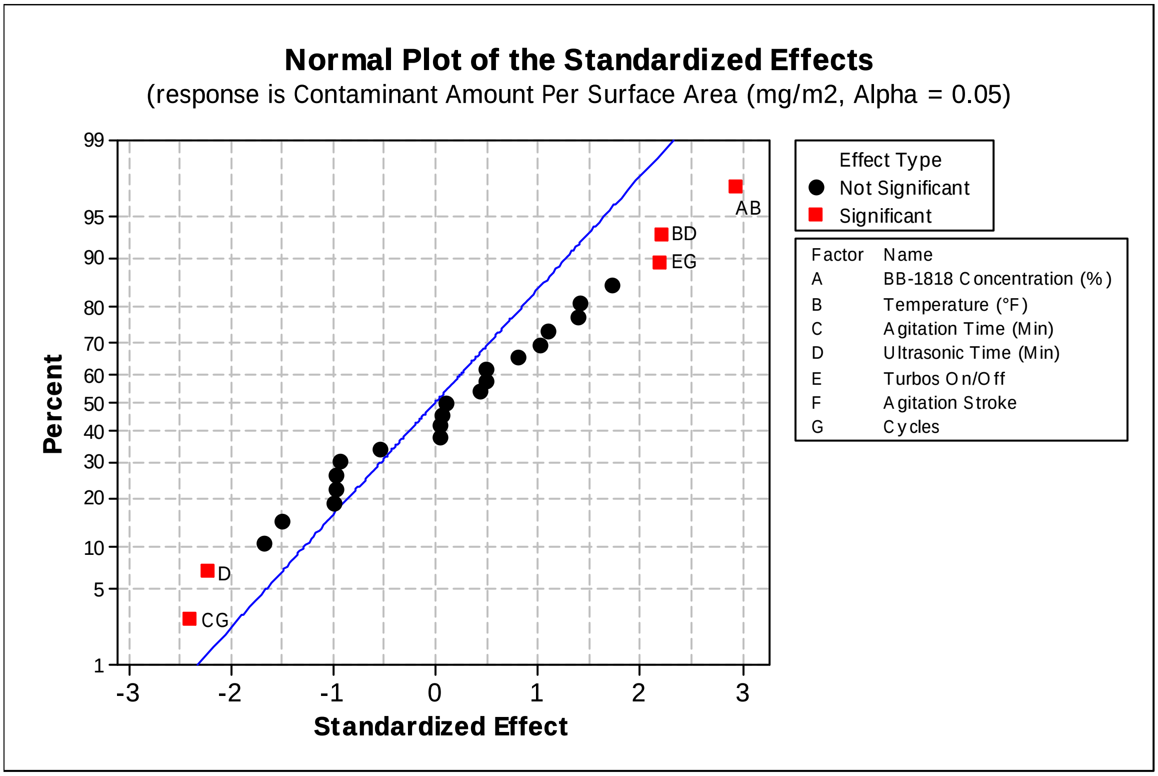

Figure 4: Exp. I Plot of Significant Factors of Contaminant Amount

A plot of the main effects for contaminant amount is shown in Figure 5. This is a plot of means at each level of each factor compared to the overall mean. The points that have the lower mean value had less contaminant amount and would be preferred. This plot showed that ultrasonic time and temperature had the greatest affect due to larger differences between factor levels. From the information in this plot each factor should be set as follows: BB-1818 concentration at 20%, temperature at 180°F, agitation time at five minutes, ultrasonic time at five minutes, turbos on, agitation stroke short, and number of cycles at five.

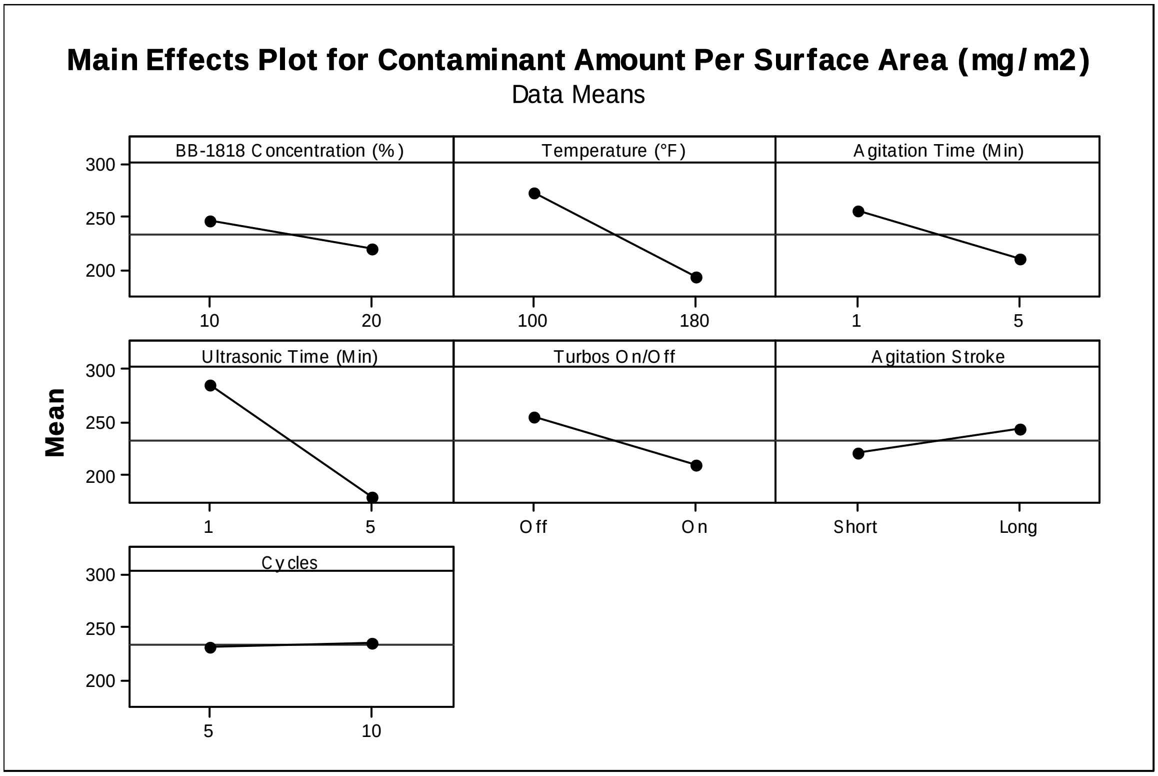

Figure 5: Exp. I Plot of Main Effects of Contaminant Amount

However, Figure 6 shows an interaction plot of the factors and illustrates the mean effects of factors that are not independent. Again, the points that have the lower mean value had less contaminant amount and are preferred. The first data to look at is the factor settings from Figure 5 that had the largest slopes. The plots of temperature with other factors show that temperature should be set at 180°F to yield lower mean values in five of the interaction plots. The only plot that doesn't show this correlation is temperature with BB-1818 concentration when the concentration level is set at 20%. The plots of ultrasonic time with the other factors consistently show that ultrasonic time should be set at five minutes to yield lower mean values.

This plot also shows that based on the setting choices from Figure 5 for BB-1818 concentration, ultrasonic time, and number of cycles the better factor setting for agitation time would be one minute. This decision is based on looking at the lower point on the vertical axis of the chart for each of the interaction plots. As an example, when looking at the plot of BB-1818 concentration and agitation time the lighter line with square points represents a BB-1818 concentration of 20% and the lower of the two points on this line represents an agitation time of one minute. This same interpretation is applicable to the plots of agitation time with ultrasonic time and number of cycles. There is little difference in means between the high and low factor settings for agitation stroke and turbos on or off.

The interaction plots show that number of cycles should be set at five when agitation time is set at one minute, ultrasonic time is set at five minutes, and temperature is set at 180°F. This same correlation is evident with the setting choices from Figure 5 for agitation stroke and turbos on/off. The only plot that doesn't back this correlation is number of cycles with BB-1818 concentration. Also, the interaction plots show that turbos on/off should be set on when agitation time is set at one minute and ultrasonic time is set at five minutes. This correlation holds with the setting choices from Figure 5 for agitation stroke and number of cycles. The plots for turbos on/off with temperature and BB-1818 concentration both show little difference in means with factor settings from Figure 5.

These same interaction plots illustrate that agitation stroke should be set at short with the setting choices from Figure 5 for turbos on/off, number of cycles, ultrasonic time, and BB-1818 concentration. The plots for agitation stroke with agitation time set at one minute and temperature set at 180°F show only a small difference in means. Finally, the interaction plots show that BB-1818 concentration should be set at 20% with agitation time set at one minute and agitation stroke set at short. There is little difference in the means with factors number of cycles, ultrasonic time, and turbos on/off. The plot for BB-1818 concentration with temperature does show the opposite setting choice of 10% should be made when the Figure 5 setting of 180°F is used for temperature.

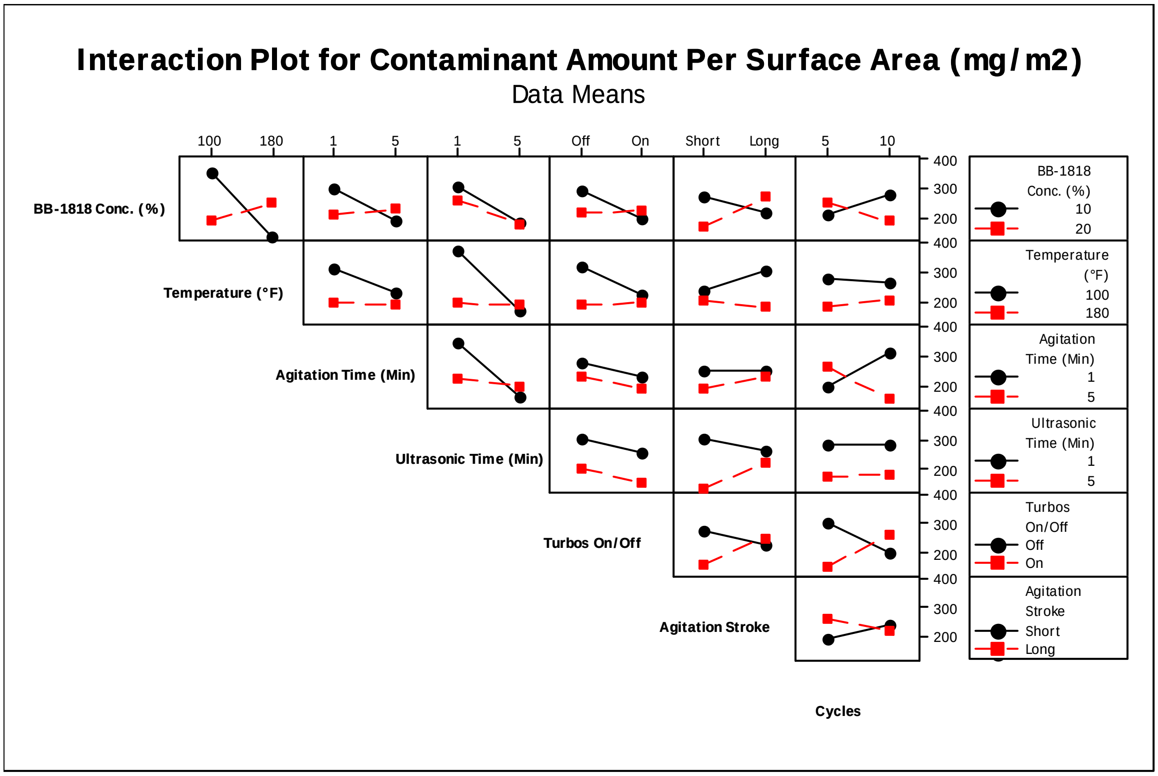

Figure 6: Exp. I Interaction Plot of Factors of Contaminant Amount

Maximum Particle Size Analysis. The data was then analyzed in regards to response B which was the maximum particle size. A plot of the standardized effects on maximum particle size, as shown in Figure 7, showed that the following factor interactions were significant: BB-1818 concentration * temperature, temperature * turbos on/off, temperature * agitation stroke, agitation time * number of cycles, and turbos on/off * agitation stroke.

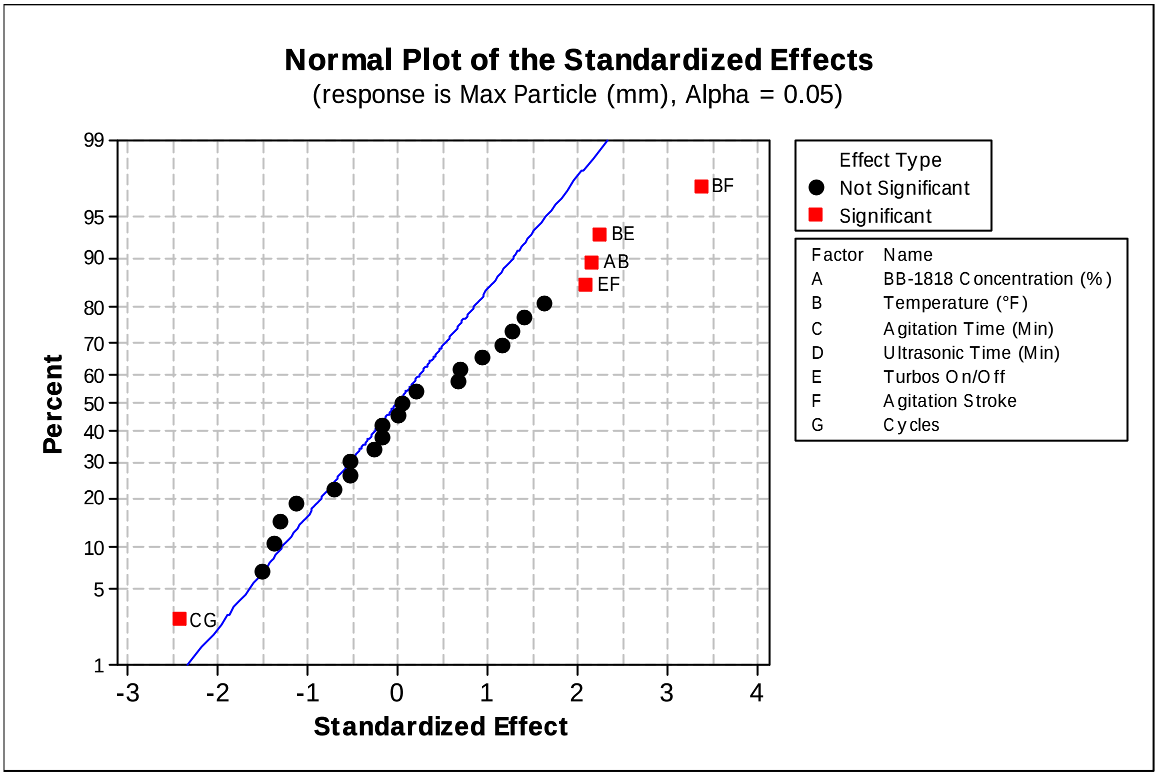

Figure 7: Exp. I Plot of Significant Factors of Max Particle Size

A plot of the main effects for maximum particle size, Figure 8, showed that temperature and number of cycles had the greatest affect. It is desirable to adjust the cleaning process so as to produce the smallest response B. From the information in this plot each factor should be set as follows: BB-1818 concentration at 10%, temperature at 100°F, agitation time at five minutes, ultrasonic time at five minutes, turbos off, agitation stroke is undetermined, and number of cycles at five. Figure 8 also shows that agitation stroke could be set at short as it had no drastic effect on response B. The decision to set it at short was made to benefit response A.

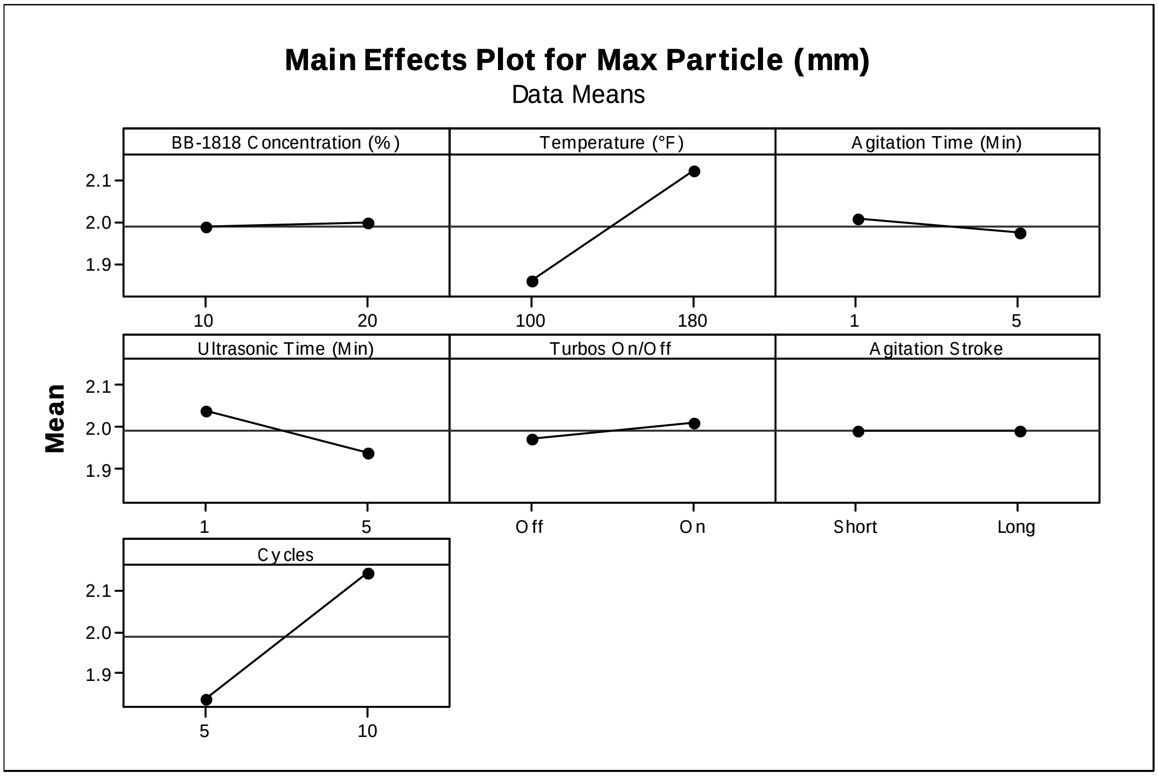

Figure 8: Exp. I Plot of Main Effects of Max Particle Size

Figure 9 shows an interaction plot of the factors and again illustrates the mean effects of factors that are not independent. The plots for temperature show that the setting from Figure 8 of 100°F is appropriate with factor settings of agitation time at one minute, ultrasonic time at five minutes, turbos on/off set at on, and number of cycles at five. The plot for temperature with agitation stroke set at short shows the opposite temperature setting and the plot with BB-1818 concentration is dependent upon the choice that is made for the concentration level. These same interaction plots illustrate that turbos on/off should be set at on with agitation stroke set at short and temperature set at 100°F. They also show the opposite setting should be used with number of cycles set at five and ultrasonic time set at five minutes. There is little difference in the means with factors BB-1818 concentration and with agitation time set at one minute.

The next data to look at is the factor settings from Figure 8 that had the same suggested settings as was determined from the analysis pertaining to contaminant amount. The plots of number of cycles with other factors show that number of cycles should be set at five to yield the lower mean values in five of the interaction plots. The only plot that doesn't show this exact correlation is number of cycles with agitation time. The plots of agitation stroke with the other factors show that agitation stroke should be set at short to yield lower mean values with number of cycles set at five and ultrasonic time set at five minutes. The plots also show that agitation stroke can go either long or short as the means are fairly equal depending on factor settings chosen for BB-1818 concentration, turbos on/off, and agitation time. The plot for agitation stroke with temperature is very dependent upon the factor setting selected for temperature.

The interaction plots show that agitation time should be set at one minute when number of cycles are set at five, agitation stroke is set at short, temperature is set at 100°F, and ultrasonic time is set at five minutes. The plots for agitation time with BB-1818 concentration and with turbos on/off are close to equal depending on which factor settings are chosen for BB-1818 concentration and turbos on/off. Also the interaction plots show that ultrasonic time should be set at five minutes when temperature is set at 100°F, agitation time is set at one minute, and agitation stroke is set at short. The plot for ultrasonic time with number of cycles shows that ultrasonic time set at one minute yielded a slightly better result when number of cycles was set at five. The factor setting for ultrasonic time is not clear in the remaining two plots and is dependent upon the factor selections for BB-1818 concentration and turbos on/off.

Figure 9 also shows that the factor setting for BB-1818 concentration is very close with five of the interactions with other factors. There is a slight benefit to a choice of 20% with agitation time set at one minute, ultrasonic time set at five minutes, and agitation stroke set at short. The opposite is true with turbos on/off set at on and number of cycles set at five. The interaction plot for BB-1818 concentration with temperature shows a more drastic difference in means and with temperature set at 100°F the BB-1818 concentration factor should be set at 20%.

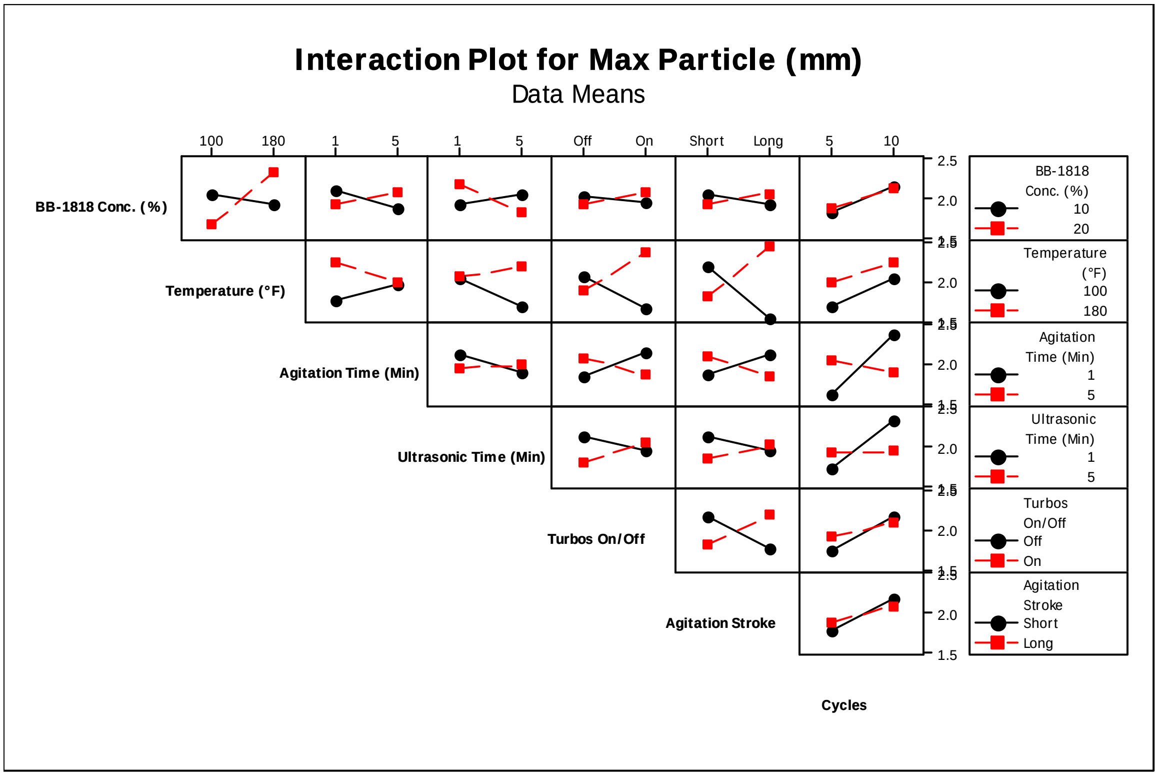

Figure 9: Exp. I Interaction Plot of Factors of Max Particle Size

Further investigation was performed when looking at which factors and factor interactions were significant in experiment I. Significance references in this section pertaining to analysis of Figure 10 and Figure 11 are at α = .15. Another plot of the standardized effects on total amount of contaminant is shown in Figure 10. This plot has an eighty-five percent confidence interval and shows an addition significant factor which is temperature. There are also additional significant factor interactions of BB-1818 concentration * agitation stroke and BB-1818 concentration * number of cycles. Additionally, a second plot of the standardized effects on max particle is shown in Figure 11. This plot also has an eighty-five percent confidence interval and shows an addition significant factor of number of cycles and factor interaction of ultrasonic time * number of cycles.

Looking at this additional data, it becomes evident that temperature is very important as it is a significant factor in amount of contaminant and is part of a significant interaction five places between responses A and B. The number of cycles is also important as it is a significant factor in max particle and is part of a significant interaction five places between responses A and B. Ultrasonic time is important because it is a significant factor in amount of contaminant. Lastly, BB-1818 concentration is crucial as it is part of a significant interaction four places between responses A and B.

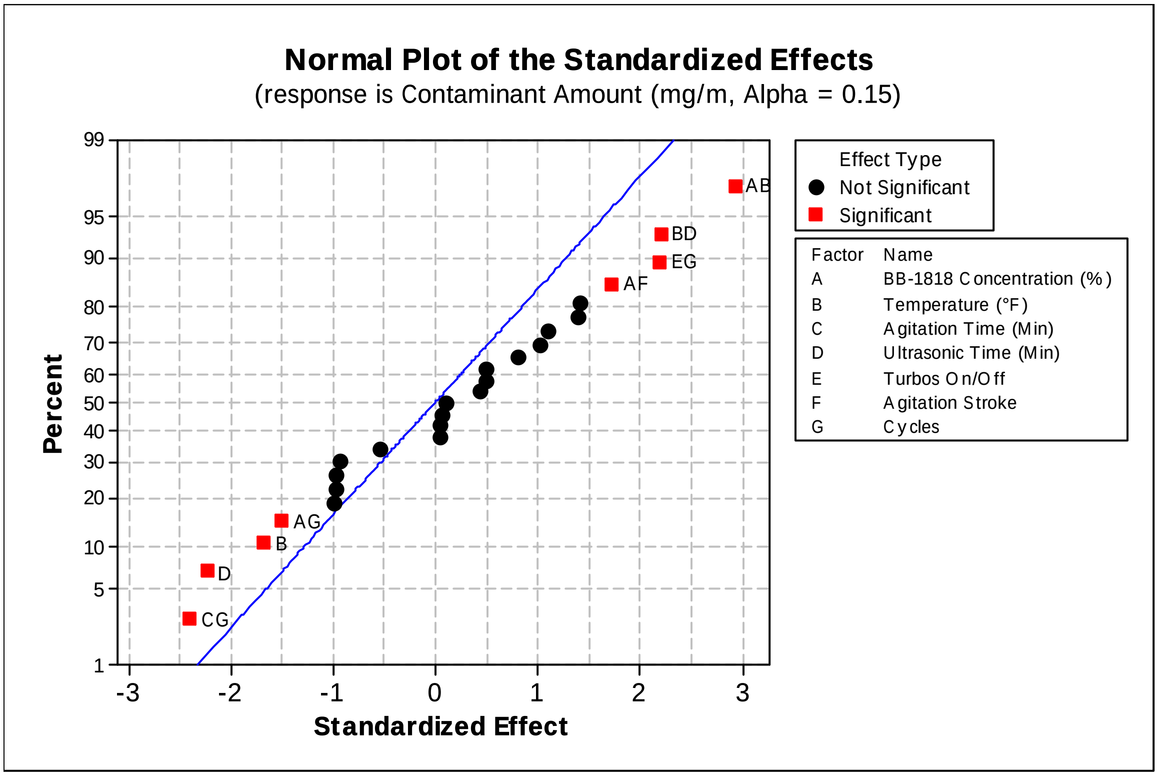

Figure 10: Exp. I Significant Factors of Contaminant Amount – 85% Confidence Interval

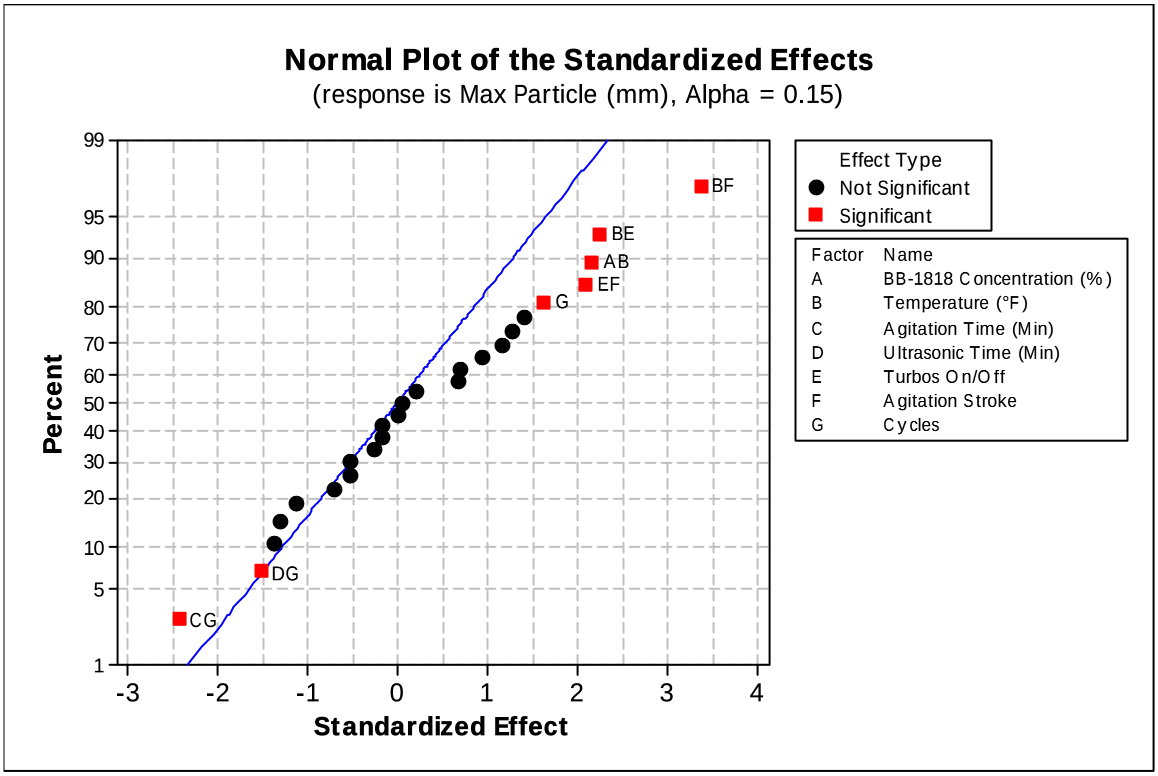

Figure 11: Exp. I Significant Factors of Max Particle – 85% Confidence Interval

Finally, due to the results of the first DOE, the factor of temperature was chosen to be 150°F so to not have a drastic negative effect on contaminant amount or maximum particle size. This was because both responses were divided on which factor setting was best. The factor was skewed to the high side due to the vendor recommended temperature range of 130°F-175°F and the previous setting for this factor having been 150°F. For raw data and graphs pertaining to Experiment I refer to Appendix D.

In summary, this experiment showed that the agitation stroke should be short, the number of cycles should be five, the ultrasonic time should be five minutes, and the agitation time should be one minute. These were all chosen due to effects on both response A and response B. The factor of temperature was chosen to be 150°F to balance between the requirements of response A and response B. The factor setting for turbos on/off should be set at on to benefit response A and because the setting choice with respect to response B was mixed depending on the factor interaction. The factor setting of BB-1818 concentration was not clear and needed more investigation. The factors of ultrasonic time and number of cycles would also be defined better by a second experiment as they both had some inconsistencies. Ultrasonic time showed to be set at five minutes with respect to response A, but it did have a large effect on this response depending on the setting choice. This factor setting also was not heavily favored with respect to response B and the interaction of ultrasonic time with BB-1818 concentration was found to be significant. Finally, the factor of number of cycles showed not to have a discernable main effect on response A, yet had a large main effect on response B.

Experiment II Analysis

The purpose of experiment II was to better define three factors that were not clearly defined by the analyzed data gathered in Experiment I. Experiment II was performed with a full 2^3 factorial design in which 8 runs were performed with two replicates and four samples randomly chosen from each basket of ten castings. The 64 castings sampled from this experiment were sent out for cleanliness testing and the raw data results can be found in Appendix E.

The high and low values chosen for BB-1818 concentration were moved higher than experiment I. This was because there were more interactions for response A and B that favored the higher concentration in experiment I. The low value was kept the same as the high value in experiment I. The values chosen for ultrasonic time were moved higher then experiment because both responses A and B showed more favorable results with the larger time in experiment I. The low value was also kept the same as the high value in experiment I. Finally, the values chosen for number of cycles were moved lower than experiment I. This was due to the large effect that the lower number of cycles had on response B. The high value was kept the same as the low value in experiment I.

Contaminant Amount Analysis. The data gathered was input into the Minitab version 16 software and analyzed. Significance references in this section pertaining to analysis of Figure 12 through Figure 17 are at α = .05. A plot of the standardized effects on total amount of contaminant per each square meter of surface area, as shown in Figure 12, showed that the factor interactions of BB-1818 concentration * ultrasonic time was significant.

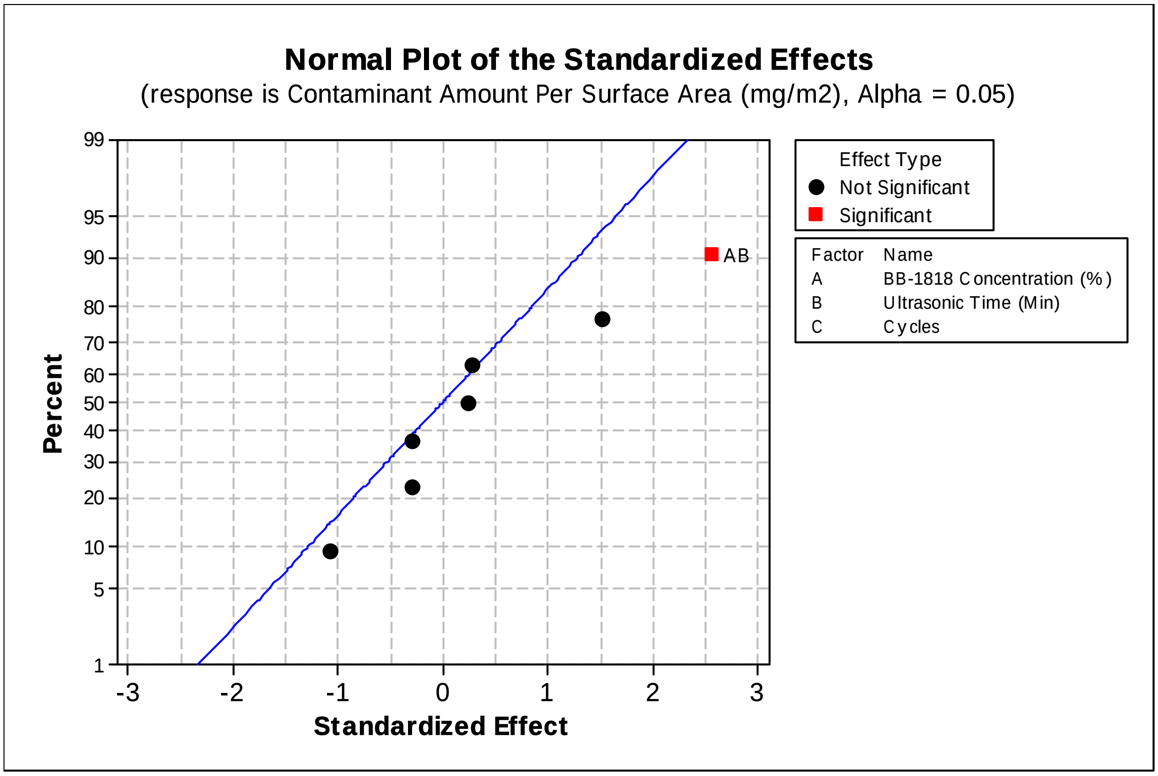

Figure 12: Exp. II Plot of Significant Factors of Contaminant Amount

A plot of the main effects for contaminant amount, Figure 13, showed that each factor should be set as follows: BB-1818 concentration at 20%, ultrasonic time at ten minutes, and number of cycles at five. The points that have the lower mean value had less contaminant amount and would be preferred.

Figure 14 shows an interaction plot of the factors and the same conclusions. The interaction plot for BB-1818 concentration with ultrasonic time shows that one mean data point is significantly lower than the other three. That point is when BB-1818 concentration is set at 20% and ultrasonic time at ten minutes. The interaction plot for BB-1818 concentration and number of cycles also shows one mean data point considerably below the others. That point is when BB-1818 concentration is at 20% and the number of cycles is set at five. The interaction plot for ultrasonic time and number of cycles illustrates that two points are approximately equal and lower than the other two. The mean data point that is slightly below the other is when ultrasonic time is set at ten minutes and the number of cycles is at five.

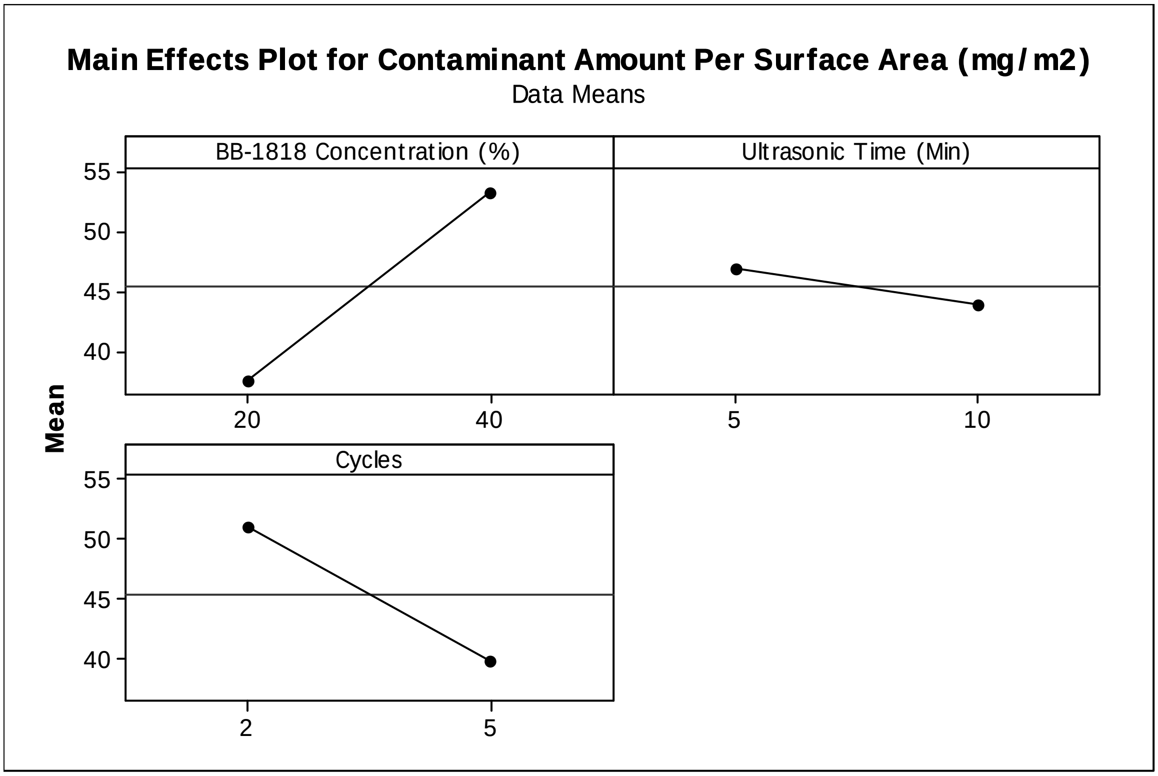

Figure 13: Exp II Plot of Main Effects of Contaminant Amount

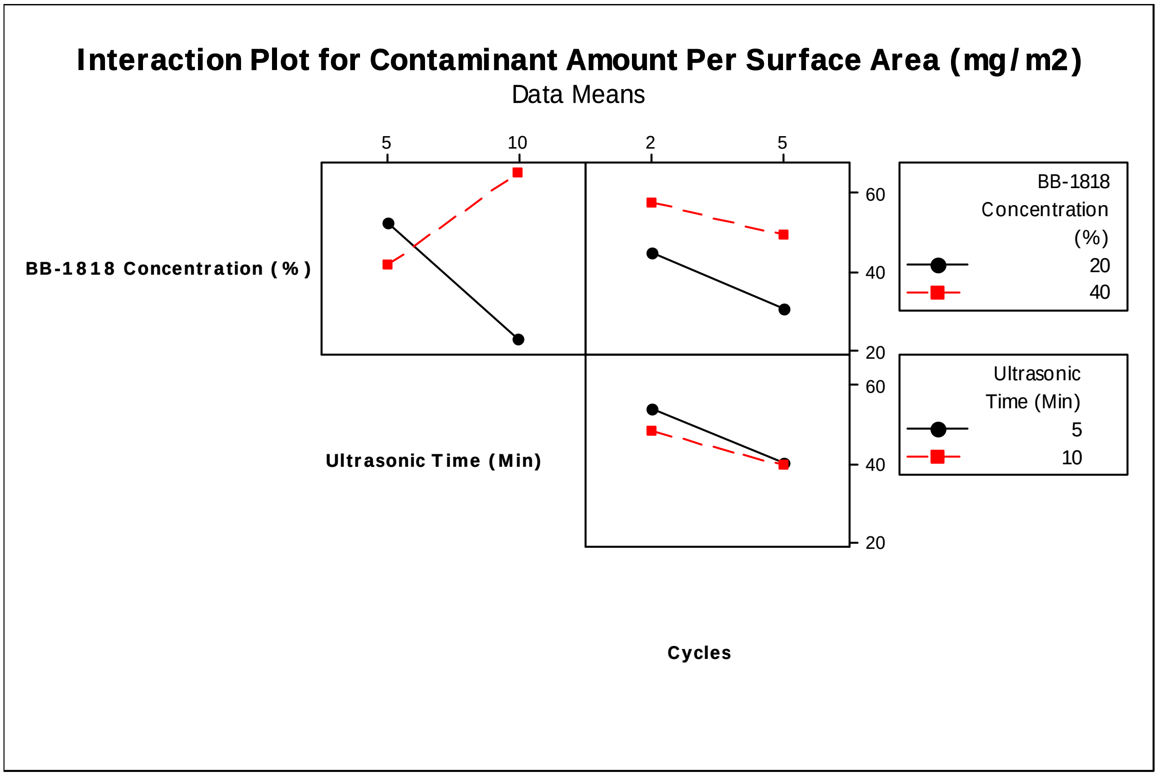

Figure 14: Exp II Interaction Plot of Factors of Contaminant Amount

Maximum Particle Size Analysis. The data was then analyzed in regards to response B which was the maximum particle size. A plot of the standardized effects on maximum particle size, as shown in Figure 15, showed that no factors or factor interactions were significant.

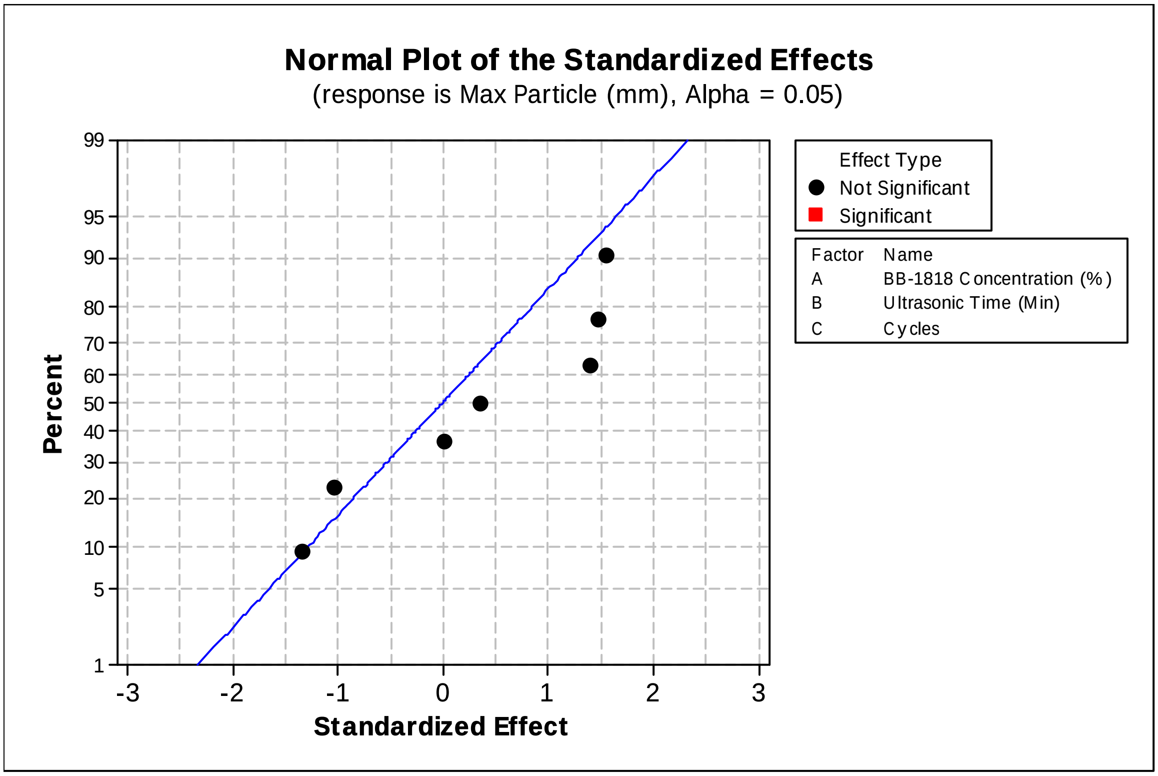

Figure 15: Exp. II Plot of Significant Factors of Max Particle Size

A plot of the main effects for maximum particle size, Figure 16, showed that number of cycles had the greatest affect. From the information in this plot each factor should be set as follows: BB-1818 concentration at 40%, ultrasonic time at five minutes, and number of cycles at two. This information was the exact opposite of the settings required for a positive effect on response A. Figure 17 shows an interaction plot of the factors with each other and again illustrates the strong correlation between BB-1818 concentration and ultrasonic time. A strong interaction between BB-1818 concentration and number of cycles is also indicated.

The interaction plot for BB-1818 concentration with ultrasonic time shows that one mean data point is considerably below the other three. That point is when BB-1818 concentration is set at 40% and ultrasonic time at five minutes. The interaction plot for BB-1818 concentration and number of cycles also shows one mean data point is lower than the others. That point is when BB-1818 concentration is at 20% and the number of cycles is set at two. The interaction plot for ultrasonic time and number of cycles illustrates that one mean data point is lower than the others. The mean data point that is slightly below the others is when ultrasonic time is set at five minutes and the number of cycles is at two.

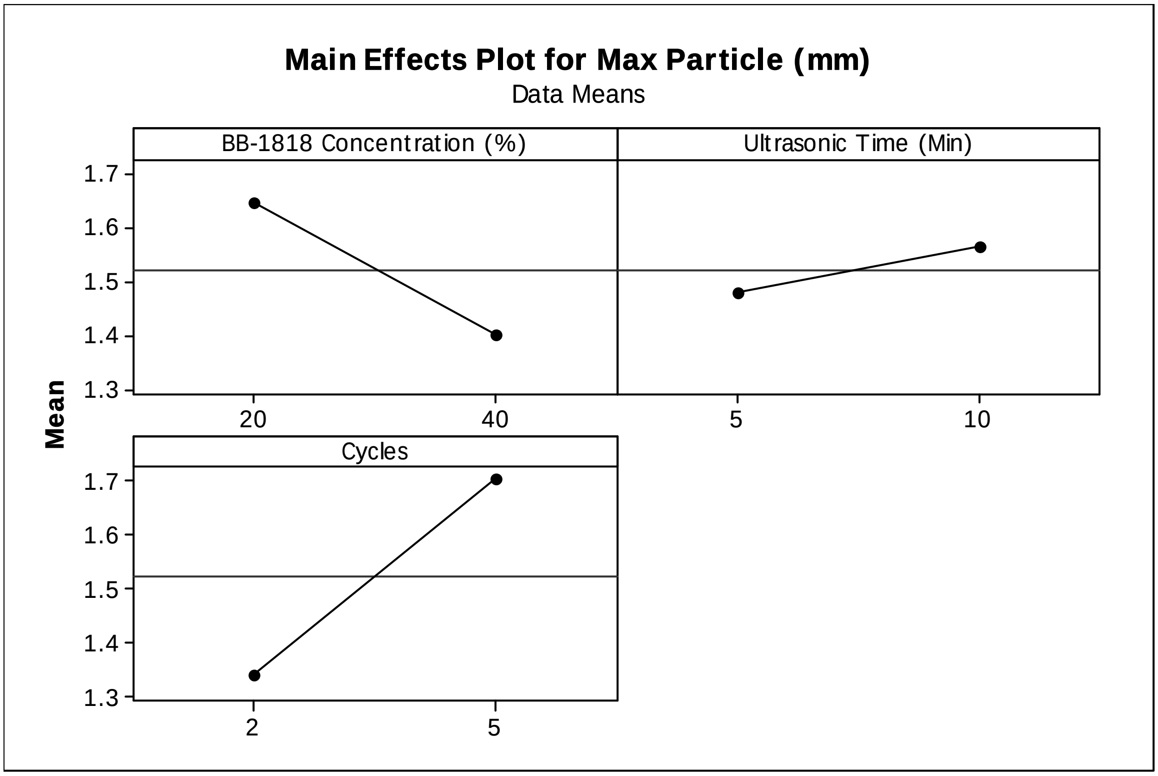

Figure 16: Exp. II Plot of Main Effects of Max Particle Size

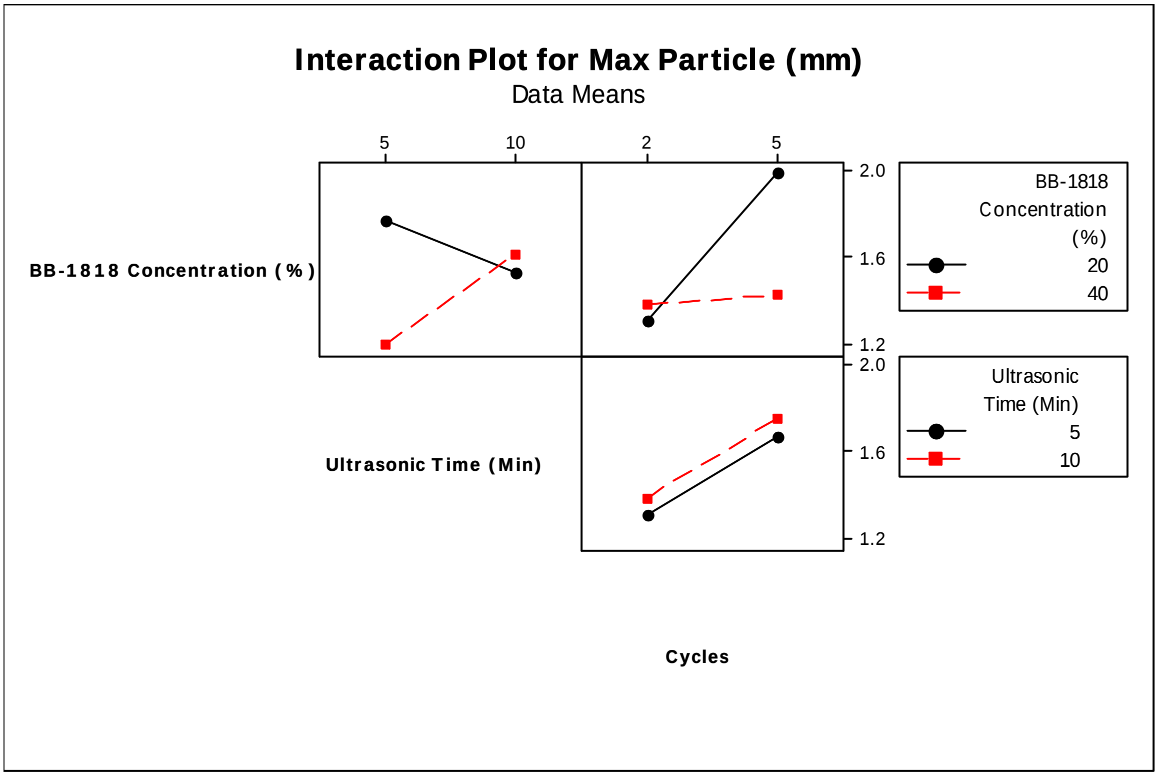

Figure 17: Exp. II Interaction Plot of Factors of Max Particle Size

Additional investigation was also performed when looking at which factors and factor interactions were significant in experiment II. Significance references in this section pertaining to analysis of Figure 18 and Figure 19 are at $\alpha = .15$. A plot of the standardized effects on total amount of contaminant is shown in Figure 18. This plot has an eighty-five percent confidence interval and shows an addition significant factor which is BB-1818 concentration. There is also an additional significant factor interaction of BB-1818 concentration * ultrasonic time. A second plot of the standardized effects on max particle is shown in Figure 19. This plot also has an eighty-five percent confidence interval and shows an addition significant factor of number of cycles and factor interaction of BB-1818 concentration * ultrasonic time * number of cycles.

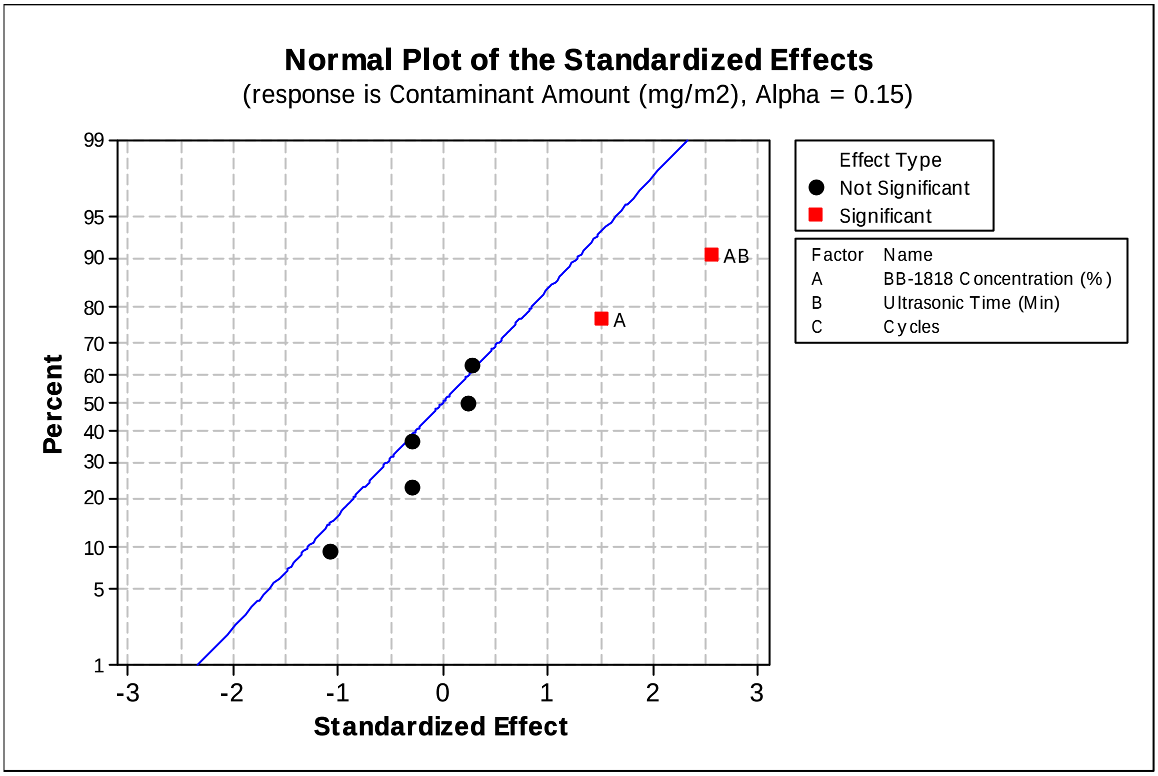

Figure 18: Exp. II Significant Factors of Contaminant Amount – 85% Confidence Interval

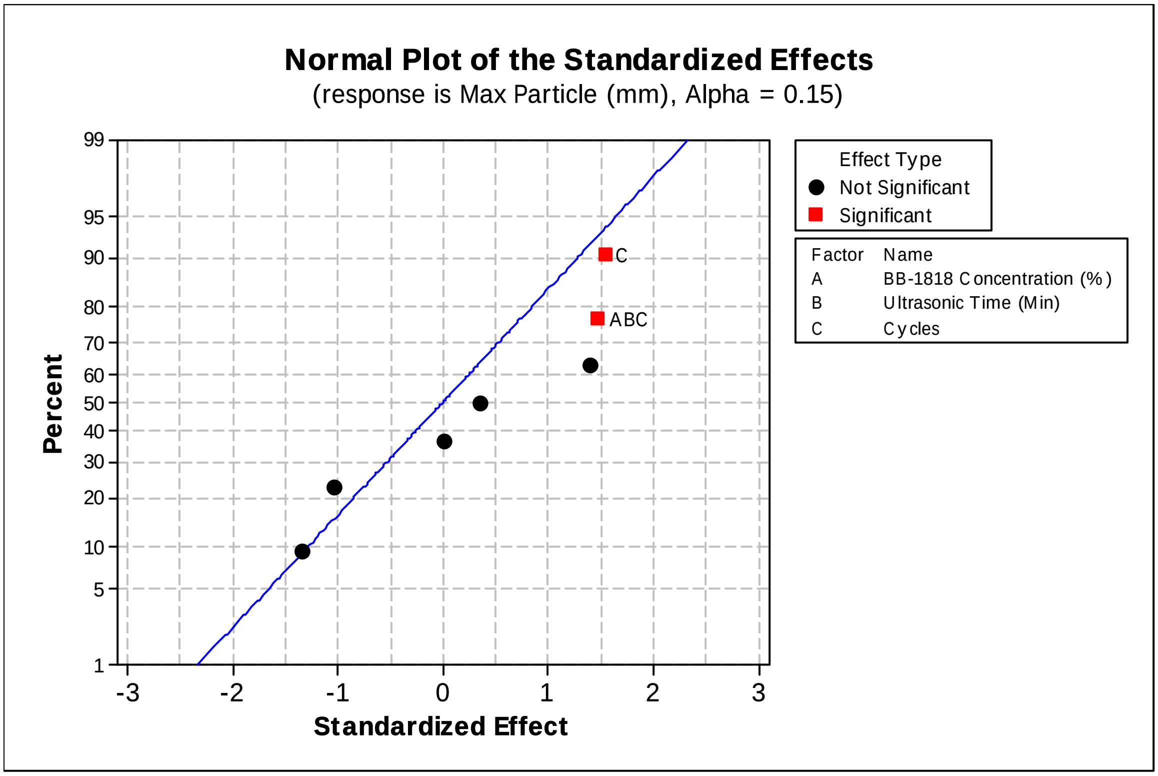

Figure 19: Exp. II Significant Factors of Max Particle – 85% Confidence Interval

This data shows that BB-1818 concentration is important as it is a significant factor in amount of contaminant and is part of a significant interaction two places between responses A and B. The number of cycles is a significant factor in max particle and is part of a significant interaction for responses B. Ultrasonic time is part of an interaction for both responses A and B.

A summary of the factor settings indicated by experiments I and II is shown in Table 3. This table shows the factor settings in regards to responses A and B as suggested by experiment I. It also shows the settings chosen from the analysis of experiment I. Finally, the table shows the choices for these same factors in regards to both responses as dictated by experiment II.

Table 3

Experiment Indicated Factor Settings

	Experiment I Analysis			Experiment II Analysis	
Factor	Amount of Mass	Max Particle Size	After Experiment I	Amount of Mass	Max Particle Size
BB-1818 Concentration	20%	20% **	20% **	20% •	40% •
Wash Fluid Temperature	180°F •	100°F •	150°F	150°F	150°F
Wash Turbos	On	On **	On	On	On
Wash Agitation Time	1 Minute	1 Minute	1 Minute	1 Minute	1 Minute
Wash Ultrasonic Time	5 Minutes	5 Minutes	5 Minutes	10 Minutes •	5 Minutes •
Agitation Stroke Length	Short	Short	Short	Short	Short
Number Of Cycles	5	5	5	5 •	2 •

** = Inconclusive • = Conflicting

Chapter V: Discussion

The current cleaning method for machined cast iron couplings was not reliable and the requirements for cleanliness of the casting were not being consistently met. The purpose of this study was to improve cleanliness of the castings to meet requirements by modifying processing methods for this product.

The literature review discussed the three distinct factors that are involved in a cleanliness issue. The factors are material involved, cleaning method used, and method of verification of cleanliness. This review focused on the specific material, cleaning method, and method of verification of cleanliness that this study utilized.

The first factor of material used focused on the casting of iron including the machining of the iron casting, and the removing of burrs from the final product. The second factor that was examined was the cleaning method used and focused on washing methods, ultrasonic cleaning used in washing methods, and chemistry used in washing methods. Finally, the methods of gravimetric verification of cleanliness were explained. The focus was on the details of gravimetric cleanliness testing and then the pros and cons of using this method of verification.

The methodology used for this study was discussed in depth and then the results of both experiment I and II were outlined. In this chapter the conclusions based on the analysis of the data gathered in both experiments are discussed. This chapter also contains recommendations for further study.

Limitations

The study was limited to testing and analysis of machined cast iron coupling assemblies and did not extend to any other product variations. The study was focused on the current processing method of cleaning castings in the newly purchased parts washer from Ramco Equipment Corporation. This parts washer was a four stage model MK-16T.

This study was also limited to the washing method used and did not investigate alternate, or secondary, inspection and deburring methods to improve cleanliness. Two of the seven factors that were studied have not been completely defined and/or full ranges of these variables were not investigated. The ranges investigated were limited and some additional experimentation might be of benefit. The factor of BB-1818 concentration was only tested at settings of 10%, 20%, and 40%. With the study suggesting a final concentration setting of 20%, additional testing at 15% and 25% might further adjust the performance of the cleaning system. The factor of ultrasonic time was only tested up to a setting of ten minutes. With the final study conclusion of setting the time at ten minutes, additional testing at 15 minutes and 20 minutes may also further define the cleaning system parameters.

Additionally, this study utilized gravimetric testing procedures with pressurized solvent cleansing. Only one solvent was used for this study and no investigation was performed to gauge the effect that other solvents might have on testing results. Also, the possibility of deburring the casting while performing the gravimetric testing was not thoroughly investigated.

There were also limitations to the methodology used for this study. The first limitation was that it was performed using only "01" style castings. There was no testing performed to qualify the cleaning process with the other two casting configurations. Even though the castings are similar, there is no guarantee that all three variations will be cleaned equally in the current cleaning process.

The final limitation of this methodology was that it was performed with a limited sample size and was not performed over a period of time. These experimental results showed the improved machine settings, but did not determine the process capability with respect to time and number of castings processed.

Conclusions

Experiment I showed that the turbos should be on and the agitation stroke should be short to benefit the amount of contaminant. Additionally, due to the results of experiment I, the factor of temperature was chosen to be 150°F so to not have a drastic negative effect on the amount of contaminant or maximum particle size. Temperature was a significant factor ($\alpha = .15$) in the amount of contaminant and was part of a significant interaction ($\alpha = .05$) five places with respect to response A and response B. The factor setting was chosen due to the vendor recommended temperature range and the previous setting had been the same.

This first experiment also demonstrated that the factor of agitation time should be one minute due to the effect on the amount of contaminant. The factor of BB-1818 concentration was not clearly defined from experiment I and would be defined better by a second experiment. BB-1818 concentration was a part of a significant interaction ($\alpha = .15$) four places with respect to responses A and B. Also the factors of ultrasonic time and number of cycles showed inconsistencies and would be investigated further in a second experiment. Both of these factors were also important as they affected both responses A and B. The number of cycles was a significant factor ($\alpha = .15$) affecting max particle and was part of a significant interaction ($\alpha = .15$) five times with respect to response A and response B. Ultrasonic time was a significant factor ($\alpha = .05$) affecting the amount of contaminant.

The results of experiment II showed that the three factors studied were significant in responses A and B. The factor of BB-1818 concentration was a significant factor ($\alpha = .15$) affecting the amount of contaminant and part of a significant interaction ($\alpha = .15$) for both responses A and B. The number of cycles was a significant factor (α = .15) affecting max particle and also part of a significant interaction (α = .15) for response B. Ultrasonic time was part of significant interactions (α = .15) affecting both responses A and B.

Experiment II showed that when investigating the amount of contaminant each factor should be set as follows: BB-1818 concentration at 20%, ultrasonic time at ten minutes, and number of cycles at five. However, when investigating maximum particle size the opposite settings should be used for each factor. Due to this discrepancy, these results required additional scrutiny of the raw cleanliness testing data from experiment II.

When the raw data was examined, it was found that 75% of the castings passed the specifications for maximum amount of contaminant allowed while less than 8% of the castings passed the specifications for maximum particle size. This would suggest that the current cleaning process may be capable of meeting the amount of contaminant specification, but it is not effective at achieving the particle size requirement. This data from the second experiment showed that the current system should focus on meeting the amount of contaminant specification. The factor of BB-1818 concentration should be set at 20% and the ultrasonic time should be at 10 minutes.

Finally, the factor of number of cycles was chosen to be set at two. When examining the raw data it was found that all 16 castings, utilizing the other two factor chosen settings, met the maximum amount of contaminant allowed. Due to the difference in processing time of 55 minutes at five cycles and 22 minutes at two cycles, the decision on the number of cycles was determined by minimizing processing costs and maximizing product throughput. Table 4 provides a summary of the factor setting changes.

Table 4

Factor Settings Before and After

Factor	Settings Before Study	Settings After Study
BB-1818 Concentration	10%	20%
Wash Fluid Temperature	150°F	150°F
Wash Turbos	On	On
Wash Agitation Time	1 Minute	1 Minute
Wash Ultrasonic Time	1 Minute	10 Minutes
Agitation Stroke Length	Short	Short
Number Of Cycles	5	2

Since the modification to the process parameters there have been no rejections of the cleaned castings due to exceeding the amount of contaminant specification. The maximum particle testing results have improved, but regularly exceed the specification. The cleanliness testing procedures have been changed and standardized since these experiments were run. The testing requirements followed during this study specified collecting a cleanliness sample by thoroughly rewashing the entire casting both inside and outside. Discussions with the customer resulted in this requirement being changed to only rewash the inside of the casting.

The cleanliness specification is required to keep contaminants from being washed into the hydraulic circuit of the equipment. The change in testing procedures was because the passages inside are the only areas that are in direct contact with the hydraulic fluid that is passed through this casting. Therefore, no data can be supplied regarding production results, which are a direct comparison to the results obtained in this study.

Recommendations

The limitations of this study point out three recommendations for additional investigation. The first recommendation would be to investigate and develop repeatable and reliable deburring methods for these castings. The current processing methods are not repeatable and may not be adequate for this product. Appropriate deburring methods may help the castings pass the maximum particle size specifications.

The next recommendation would be to perform a DOE on “02” and “03” castings to verify that the developed factor settings will perform the same with these configurations. Finally, variable ultrasonics should be studied and tested. Research suggested that different ultrasonic frequencies targeted the removal of varying particle sizes. If this could be shown effective on the subject castings, modifications to the current washing equipment could be made to vary the ultrasonic frequencies and possibly meet the maximum particle size requirements.

Summary

The seven factors studied in these experiments were all found to affect both responses of the amount of contaminant and the max particle size. The factors of wash fluid temperature, wash turbos on/off, wash agitation time, and agitation stroke length were not modified due to the results of this testing. The factors of BB-1818 concentration, wash ultrasonic time, and the number of cycles were changed due to the results of the experiments. The final settings to be used for processing the castings in this automated cleaning process are: BB-1818 concentration at 20%, wash fluid temperature at 150°F, wash turbos on, wash agitation time at one minute, wash ultrasonic time at ten minutes, agitation stroke length short, and the number of cycles at two.

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Appendix A: Equipment

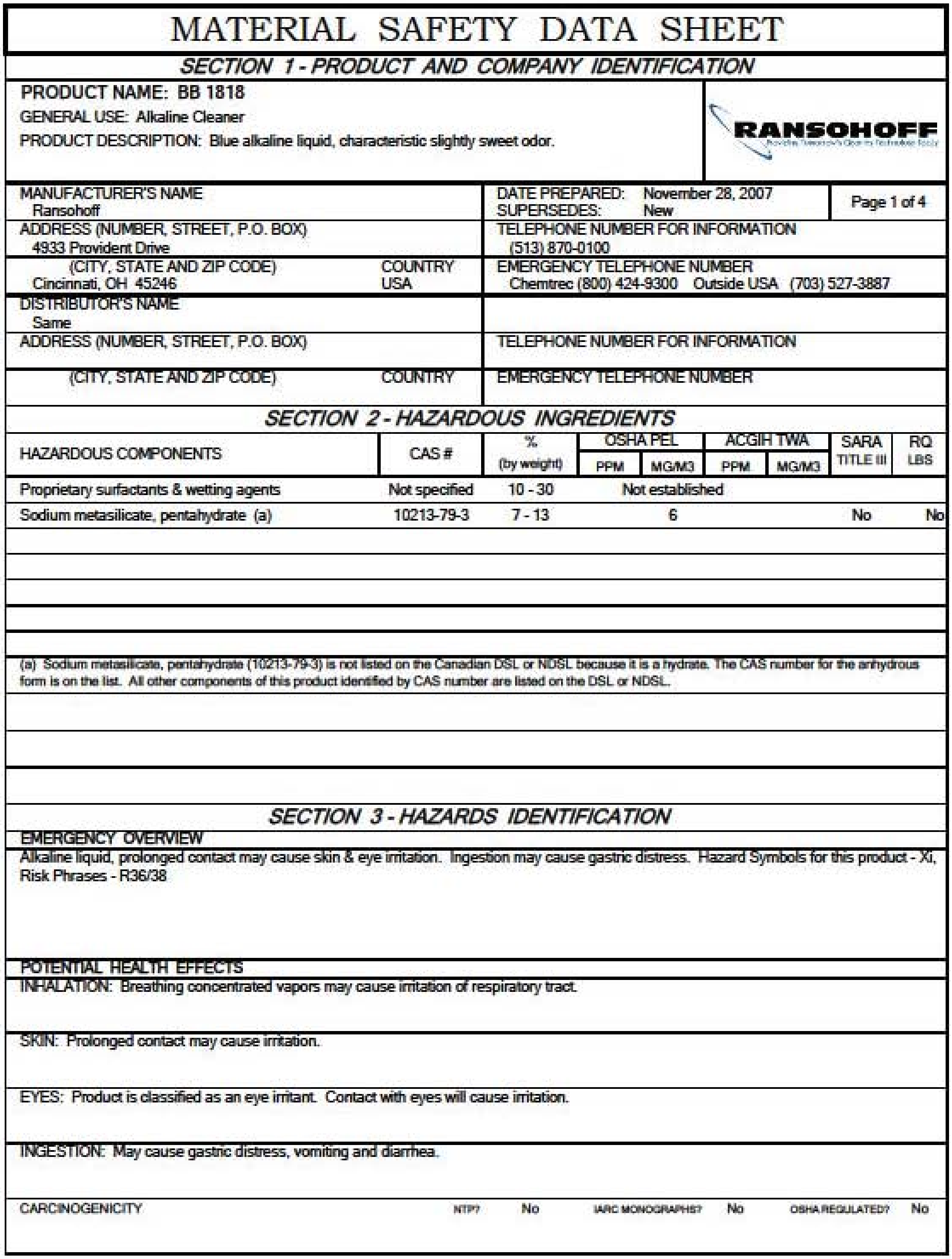
Parts Washer with Lids Open and Parts Basket in Stage 1 Wash

Main Control Panel Timers and Controllers

Empty Washing Basket

Loaded Washing Basket Side View

Appendix B: Chemistry



MATERIAL SAFETY DATA SHEET

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: BB 1818
GENERAL USE: Alkaline Cleaner
PRODUCT DESCRIPTION: Blue alkaline liquid, characteristic slightly sweet odor.

RANSOHOFF

MANUFACTURER'S NAME Ransohoff	DATE PREPARED: November 28, 2007 SUPERSEDES: New	Page 1 of 4
ADDRESS (NUMBER, STREET, P.O. BOX) 4933 Provident Drive	TELEPHONE NUMBER FOR INFORMATION (513) 870-0100	
(CITY, STATE AND ZIP CODE) COUNTRY Cincinnati, OH 45246 USA	EMERGENCY TELEPHONE NUMBER Chemtrec (800) 424-9300 Outside USA (703) 527-3887	
DISTRIBUTOR'S NAME Same		
ADDRESS (NUMBER, STREET, P.O. BOX)	TELEPHONE NUMBER FOR INFORMATION	
(CITY, STATE AND ZIP CODE) COUNTRY	EMERGENCY TELEPHONE NUMBER	

SECTION 2 - HAZARDOUS INGREDIENTS

HAZARDOUS COMPONENTS	CAS #	% (by weight)	OSHA PEL		ACGIH TWA		SARA TITLE III	RQ LBS
			PPM	MG/M3	PPM	MG/M3		
Proprietary surfactants & wetting agents	Not specified	10 - 30	Not established					
Sodium metasilicate, pentahydrate (a)	10213-79-3	7 - 13		6			No	No

(a) Sodium metasilicate, pentahydrate (10213-79-3) is not listed on the Canadian DSL or NDSL because it is a hydrate. The CAS number for the anhydrous form is on the list. All other components of this product identified by CAS number are listed on the DSL or NDSL.

SECTION 3 - HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Alkaline liquid, prolonged contact may cause skin & eye irritation. Ingestion may cause gastric distress. Hazard Symbols for this product - Xi, Risk Phrases - R36/38

POTENTIAL HEALTH EFFECTS

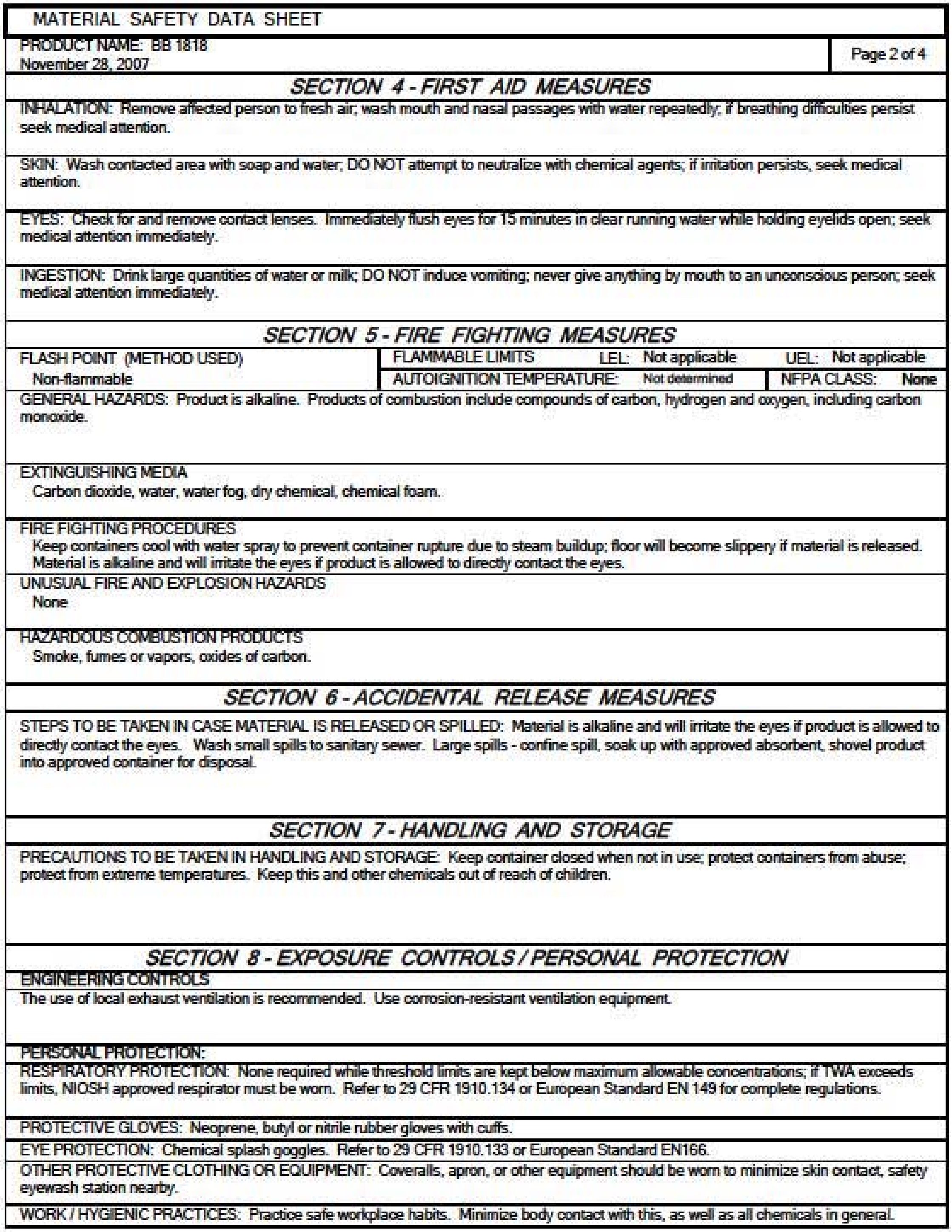
INHALATION: Breathing concentrated vapors may cause irritation of respiratory tract.

SKIN: Prolonged contact may cause irritation.

EYES: Product is classified as an eye irritant. Contact with eyes will cause irritation.

INGESTION: May cause gastric distress, vomiting and diarrhea.

CARCINOGENICITY NTP? No IARC MONOGRAPHS? No OSHA REGULATED? No



MATERIAL SAFETY DATA SHEET

PRODUCT NAME: BB 1818
November 28, 2007

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SECTION 4 - FIRST AID MEASURES

INHALATION: Remove affected person to fresh air; wash mouth and nasal passages with water repeatedly; if breathing difficulties persist seek medical attention.

SKIN: Wash contacted area with soap and water; DO NOT attempt to neutralize with chemical agents; if irritation persists, seek medical attention.

EYES: Check for and remove contact lenses. Immediately flush eyes for 15 minutes in clear running water while holding eyelids open; seek medical attention immediately.

INGESTION: Drink large quantities of water or milk; DO NOT induce vomiting; never give anything by mouth to an unconscious person; seek medical attention immediately.

SECTION 5 - FIRE FIGHTING MEASURES

FLASH POINT (METHOD USED)	FLAMMABLE LIMITS	LEL: Not applicable	UEL: Not applicable	
Non-flammable	AUTOIGNITION TEMPERATURE:	Not determined	NFPA CLASS:	None

GENERAL HAZARDS: Product is alkaline. Products of combustion include compounds of carbon, hydrogen and oxygen, including carbon monoxide.

EXTINGUISHING MEDIA
Carbon dioxide, water, water fog, dry chemical, chemical foam.

FIRE FIGHTING PROCEDURES
Keep containers cool with water spray to prevent container rupture due to steam buildup; floor will become slippery if material is released. Material is alkaline and will irritate the eyes if product is allowed to directly contact the eyes.

UNUSUAL FIRE AND EXPLOSION HAZARDS
None

HAZARDOUS COMBUSTION PRODUCTS
Smoke, fumes or vapors, oxides of carbon.

SECTION 6 - ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Material is alkaline and will irritate the eyes if product is allowed to directly contact the eyes. Wash small spills to sanitary sewer. Large spills - confine spill, soak up with approved absorbent, shovel product into approved container for disposal.

SECTION 7 - HANDLING AND STORAGE

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Keep container closed when not in use; protect containers from abuse; protect from extreme temperatures. Keep this and other chemicals out of reach of children.

SECTION 8 - EXPOSURE CONTROLS / PERSONAL PROTECTION

ENGINEERING CONTROLS

The use of local exhaust ventilation is recommended. Use corrosion-resistant ventilation equipment.

PERSONAL PROTECTION:

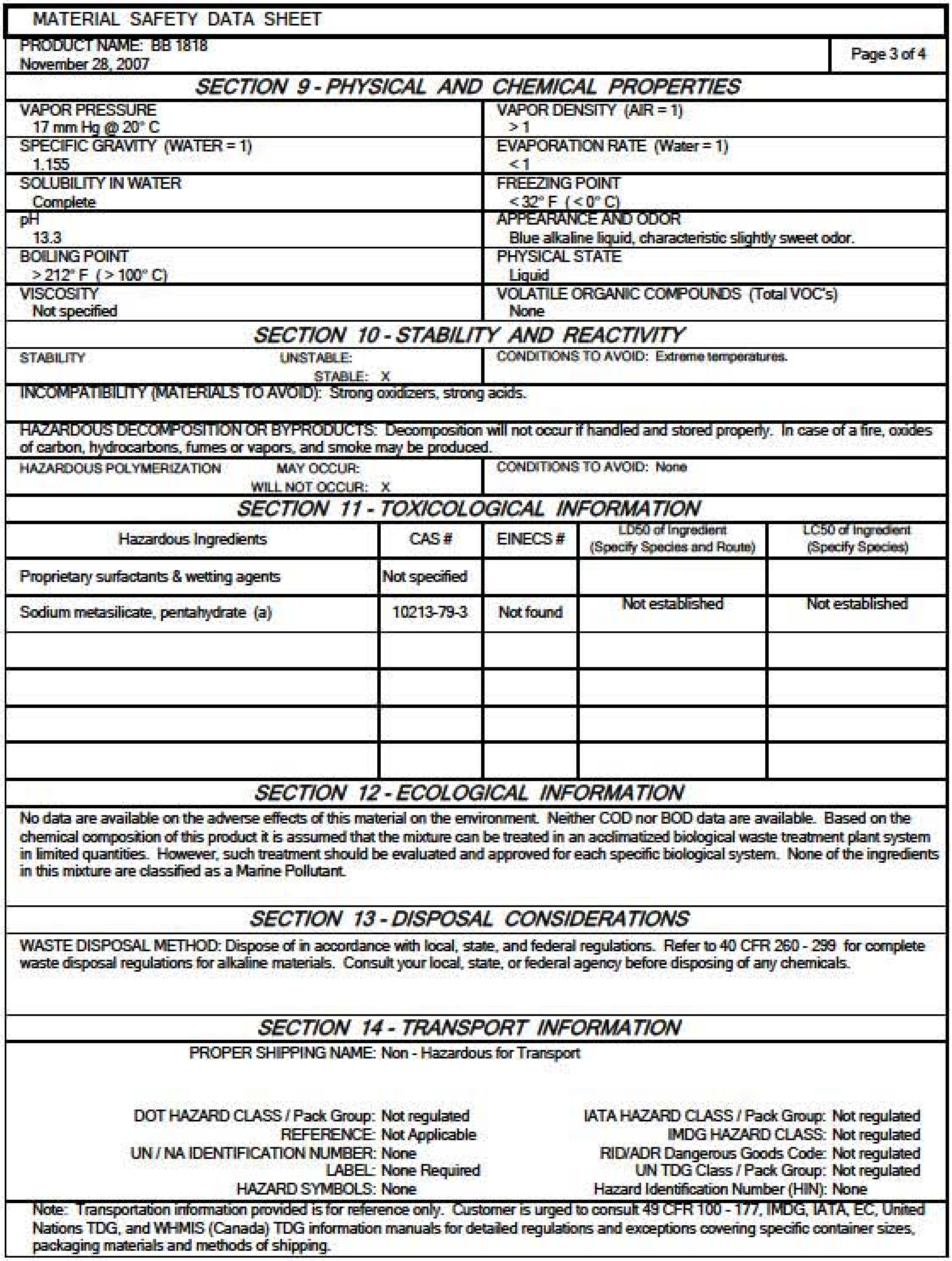
RESPIRATORY PROTECTION: None required while threshold limits are kept below maximum allowable concentrations; if TWA exceeds limits, NIOSH approved respirator must be worn. Refer to 29 CFR 1910.134 or European Standard EN 149 for complete regulations.

PROTECTIVE GLOVES: Neoprene, butyl or nitrile rubber gloves with cuffs.

EYE PROTECTION: Chemical splash goggles. Refer to 29 CFR 1910.133 or European Standard EN166.

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Coveralls, apron, or other equipment should be worn to minimize skin contact, safety eyewash station nearby.

WORK / HYGIENIC PRACTICES: Practice safe workplace habits. Minimize body contact with this, as well as all chemicals in general.



MATERIAL SAFETY DATA SHEET

PRODUCT NAME: BB 1818
November 28, 2007

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SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

VAPOR PRESSURE 17 mm Hg @ 20° C	VAPOR DENSITY (AIR = 1) > 1
SPECIFIC GRAVITY (WATER = 1) 1.155	EVAPORATION RATE (Water = 1) < 1
SOLUBILITY IN WATER Complete	FREEZING POINT < 32° F (< 0° C)
pH 13.3	APPEARANCE AND ODOR Blue alkaline liquid, characteristic slightly sweet odor.
BOILING POINT > 212° F (> 100° C)	PHYSICAL STATE Liquid
VISCOSITY Not specified	VOLATILE ORGANIC COMPOUNDS (Total VOC's) None

SECTION 10 - STABILITY AND REACTIVITY

STABILITY UNSTABLE: STABLE: X	CONDITIONS TO AVOID: Extreme temperatures.

INCOMPATIBILITY (MATERIALS TO AVOID): Strong oxidizers, strong acids.

HAZARDOUS DECOMPOSITION OR BYPRODUCTS: Decomposition will not occur if handled and stored properly. In case of a fire, oxides of carbon, hydrocarbons, fumes or vapors, and smoke may be produced.

HAZARDOUS POLYMERIZATION MAY OCCUR: WILL NOT OCCUR: X	CONDITIONS TO AVOID: None

SECTION 11 - TOXICOLOGICAL INFORMATION

Hazardous Ingredients	CAS #	EINECS #	LD50 of Ingredient (Specify Species and Route)	LC50 of Ingredient (Specify Species)
Proprietary surfactants & wetting agents	Not specified			
Sodium metasilicate, pentahydrate (a)	10213-79-3	Not found	Not established	Not established

SECTION 12 - ECOLOGICAL INFORMATION

No data are available on the adverse effects of this material on the environment. Neither COD nor BOD data are available. Based on the chemical composition of this product it is assumed that the mixture can be treated in an acclimatized biological waste treatment plant system in limited quantities. However, such treatment should be evaluated and approved for each specific biological system. None of the ingredients in this mixture are classified as a Marine Pollutant.

SECTION 13 - DISPOSAL CONSIDERATIONS

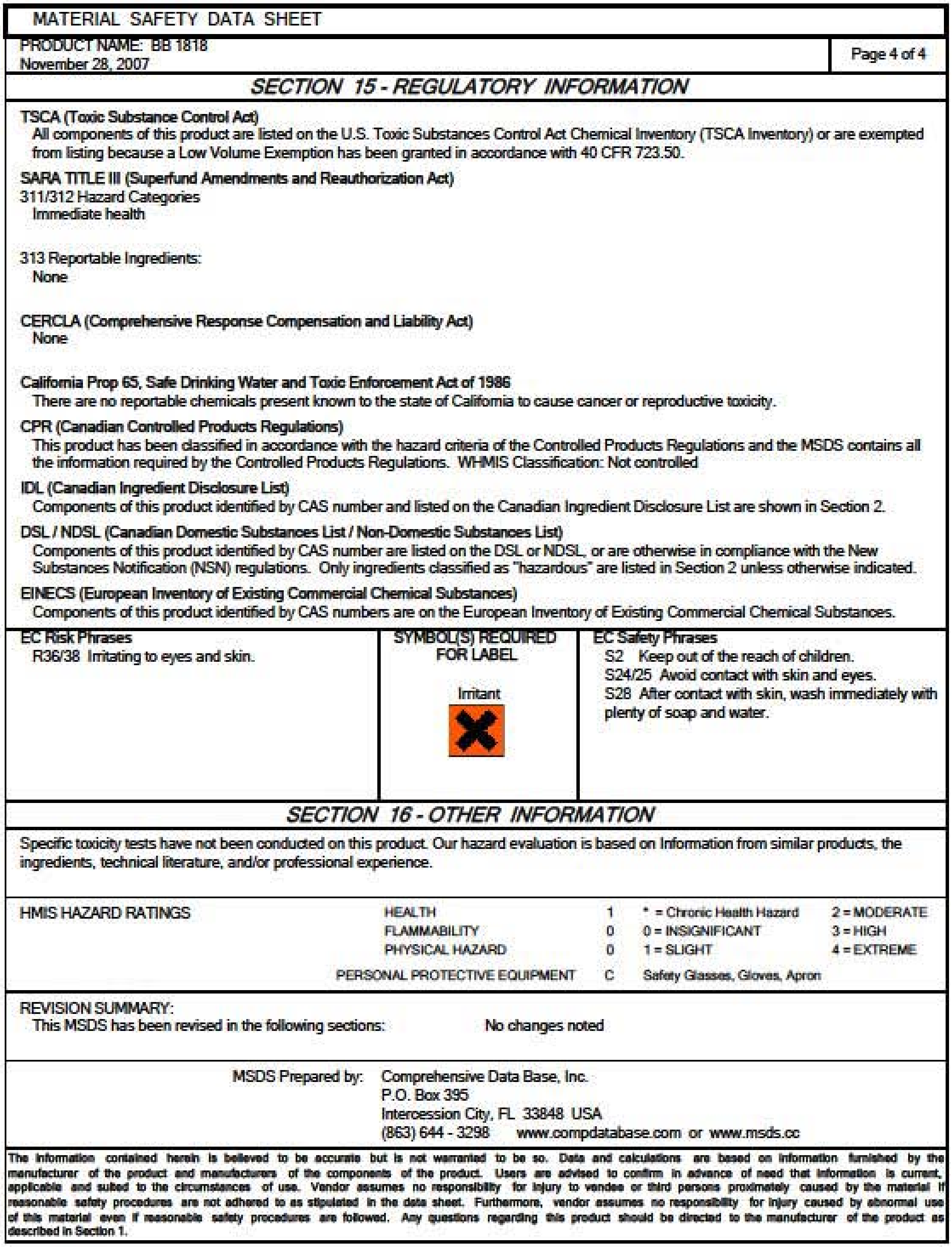
WASTE DISPOSAL METHOD: Dispose of in accordance with local, state, and federal regulations. Refer to 40 CFR 260 - 299 for complete waste disposal regulations for alkaline materials. Consult your local, state, or federal agency before disposing of any chemicals.

SECTION 14 - TRANSPORT INFORMATION

PROPER SHIPPING NAME: Non - Hazardous for Transport

DOT HAZARD CLASS / Pack Group: Not regulated	IATA HAZARD CLASS / Pack Group: Not regulated
REFERENCE: Not Applicable	IMDG HAZARD CLASS: Not regulated
UN / NA IDENTIFICATION NUMBER: None	RID/ADR Dangerous Goods Code: Not regulated
LABEL: None Required	UN TDG Class / Pack Group: Not regulated
HAZARD SYMBOLS: None	Hazard Identification Number (HIN): None

Note: Transportation information provided is for reference only. Customer is urged to consult 49 CFR 100 - 177, IMDG, IATA, EC, United Nations TDG, and WHMIS (Canada) TDG information manuals for detailed regulations and exceptions covering specific container sizes, packaging materials and methods of shipping.



MATERIAL SAFETY DATA SHEET

PRODUCT NAME: BB 1818
November 28, 2007

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SECTION 15 - REGULATORY INFORMATION

TSCA (Toxic Substance Control Act)
All components of this product are listed on the U.S. Toxic Substances Control Act Chemical Inventory (TSCA Inventory) or are exempted from listing because a Low Volume Exemption has been granted in accordance with 40 CFR 723.50.

SARA TITLE III (Superfund Amendments and Reauthorization Act)
311/312 Hazard Categories
Immediate health

313 Reportable Ingredients:
None

CERCLA (Comprehensive Response Compensation and Liability Act)
None

California Prop 65, Safe Drinking Water and Toxic Enforcement Act of 1986
There are no reportable chemicals present known to the state of California to cause cancer or reproductive toxicity.

CPR (Canadian Controlled Products Regulations)
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations. WHMIS Classification: Not controlled

IDL (Canadian Ingredient Disclosure List)
Components of this product identified by CAS number and listed on the Canadian Ingredient Disclosure List are shown in Section 2.

DSL / NDSL (Canadian Domestic Substances List / Non-Domestic Substances List)
Components of this product identified by CAS number are listed on the DSL or NDSL, or are otherwise in compliance with the New Substances Notification (NSN) regulations. Only ingredients classified as "hazardous" are listed in Section 2 unless otherwise indicated.

EINECS (European Inventory of Existing Commercial Chemical Substances)
Components of this product identified by CAS numbers are on the European Inventory of Existing Commercial Chemical Substances.

EC Risk Phrases	**SYMBOL(S) REQUIRED FOR LABEL**	**EC Safety Phrases**
R36/38 Irritating to eyes and skin.	Irritant ✖	S2 Keep out of the reach of children. S24/25 Avoid contact with skin and eyes. S28 After contact with skin, wash immediately with plenty of soap and water.

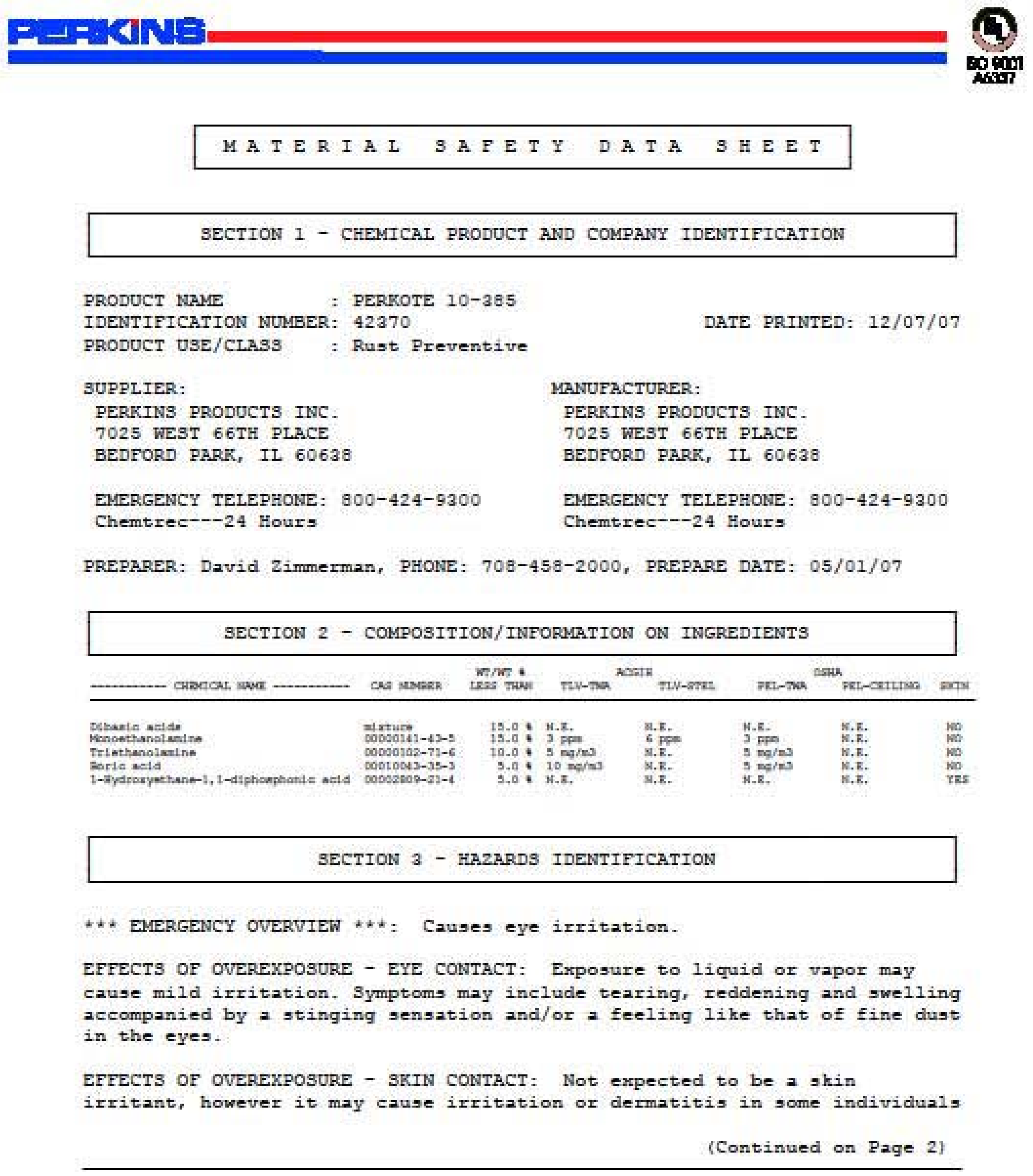
SECTION 16 - OTHER INFORMATION

Specific toxicity tests have not been conducted on this product. Our hazard evaluation is based on Information from similar products, the ingredients, technical literature, and/or professional experience.

HMIS HAZARD RATINGS	HEALTH	1	* = Chronic Health Hazard	2 = MODERATE
	FLAMMABILITY	0	0 = INSIGNIFICANT	3 = HIGH
	PHYSICAL HAZARD	0	1 = SLIGHT	4 = EXTREME
	PERSONAL PROTECTIVE EQUIPMENT	C	Safety Glasses, Gloves, Apron	

REVISION SUMMARY:
This MSDS has been revised in the following sections: No changes noted

MSDS Prepared by:
Comprehensive Data Base, Inc.
P.O. Box 395
Intercession City, FL 33848 USA
(863) 644 - 3298 www.compdatabase.com or www.msds.cc



PERKINS

ISO 9001 A6357

M A T E R I A L   S A F E T Y   D A T A   S H E E T

SECTION 1 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME : PERKOTE 10-385
IDENTIFICATION NUMBER: 42370 DATE PRINTED: 12/07/07
PRODUCT USE/CLASS : Rust Preventive

SUPPLIER:
PERKINS PRODUCTS INC.
7025 WEST 66TH PLACE
BEDFORD PARK, IL 60638

EMERGENCY TELEPHONE: 800-424-9300
Chemtrec---24 Hours

MANUFACTURER:
PERKINS PRODUCTS INC.
7025 WEST 66TH PLACE
BEDFORD PARK, IL 60638

EMERGENCY TELEPHONE: 800-424-9300
Chemtrec---24 Hours

PREPARER: David Zimmerman, PHONE: 708-458-2000, PREPARE DATE: 05/01/07

SECTION 2 - COMPOSITION/INFORMATION ON INGREDIENTS

		WT/WT %	ACGIH		OSHA		
----------- CHEMICAL NAME -----------	CAS NUMBER	LESS THAN	TLV-TWA	TLV-STEL	PEL-TWA	PEL-CEILING	SKIN
Dibasic acids	mixture	15.0 %	N.E.	N.E.	N.E.	N.E.	NO
Monoethanolamine	00000141-43-5	15.0 %	3 ppm	6 ppm	3 ppm	N.E.	NO
Triethanolamine	00000102-71-6	10.0 %	5 mg/m3	N.E.	5 mg/m3	N.E.	NO
Boric acid	00010043-35-3	5.0 %	10 mg/m3	N.E.	5 mg/m3	N.E.	NO
1-Hydroxyethane-1,1-diphosphonic acid	00002809-21-4	5.0 %	N.E.	N.E.	N.E.	N.E.	YES

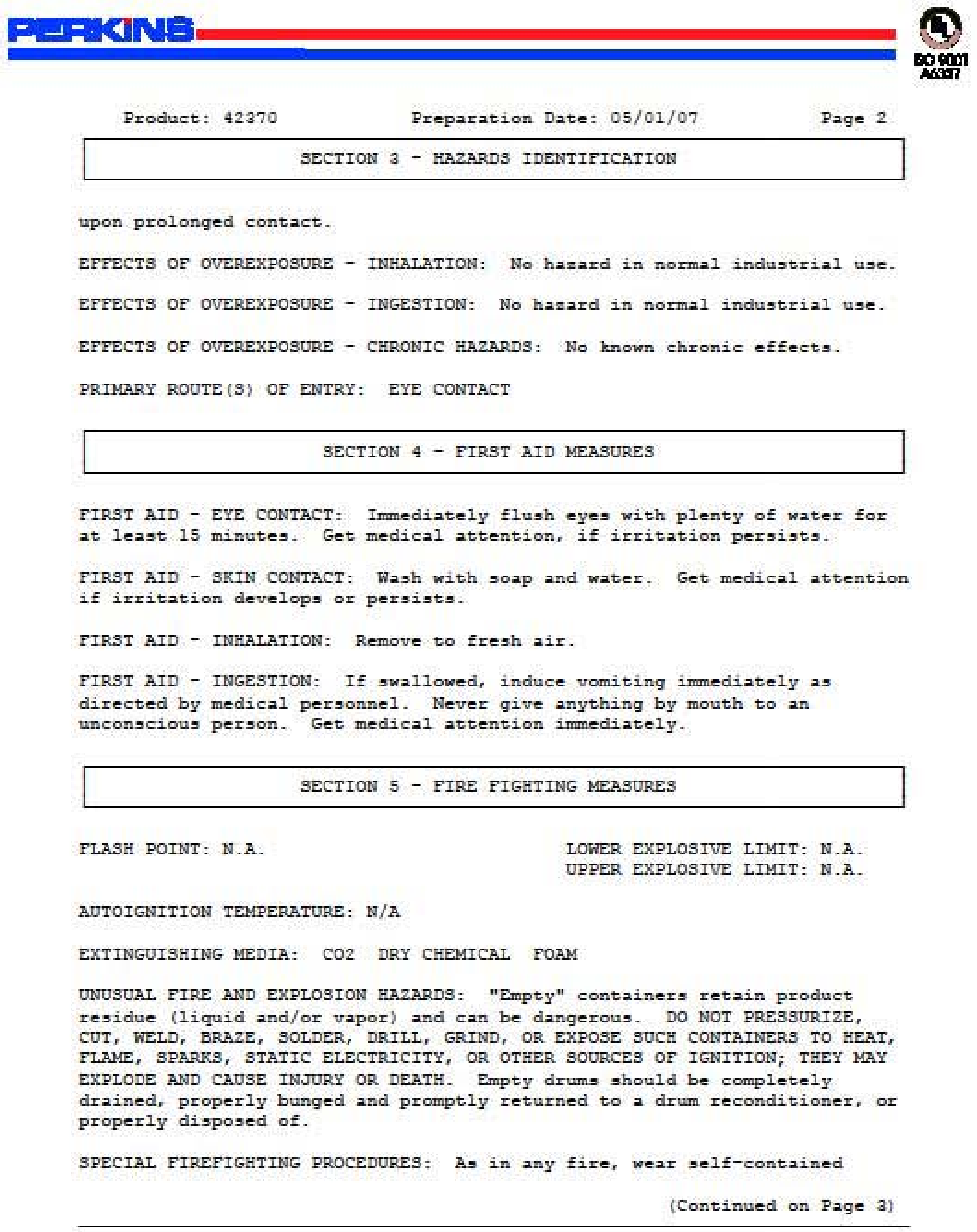
SECTION 3 - HAZARDS IDENTIFICATION

*** EMERGENCY OVERVIEW ***: Causes eye irritation.

EFFECTS OF OVEREXPOSURE - EYE CONTACT: Exposure to liquid or vapor may cause mild irritation. Symptoms may include tearing, reddening and swelling accompanied by a stinging sensation and/or a feeling like that of fine dust in the eyes.

EFFECTS OF OVEREXPOSURE - SKIN CONTACT: Not expected to be a skin irritant, however it may cause irritation or dermatitis in some individuals

(Continued on Page 2)



SECTION 3 - HAZARDS IDENTIFICATION

upon prolonged contact.

EFFECTS OF OVEREXPOSURE - INHALATION: No hazard in normal industrial use.

EFFECTS OF OVEREXPOSURE - INGESTION: No hazard in normal industrial use.

EFFECTS OF OVEREXPOSURE - CHRONIC HAZARDS: No known chronic effects.

PRIMARY ROUTE(S) OF ENTRY: EYE CONTACT

SECTION 4 - FIRST AID MEASURES

FIRST AID - EYE CONTACT: Immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention, if irritation persists.

FIRST AID - SKIN CONTACT: Wash with soap and water. Get medical attention if irritation develops or persists.

FIRST AID - INHALATION: Remove to fresh air.

FIRST AID - INGESTION: If swallowed, induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.

SECTION 5 - FIRE FIGHTING MEASURES

FLASH POINT: N.A.

LOWER EXPLOSIVE LIMIT: N.A.
UPPER EXPLOSIVE LIMIT: N.A.

AUTOIGNITION TEMPERATURE: N/A

EXTINGUISHING MEDIA: CO2 DRY CHEMICAL FOAM

UNUSUAL FIRE AND EXPLOSION HAZARDS: "Empty" containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT PRESSURIZE, CUT, WELD, BRAZE, SOLDER, DRILL, GRIND, OR EXPOSE SUCH CONTAINERS TO HEAT, FLAME, SPARKS, STATIC ELECTRICITY, OR OTHER SOURCES OF IGNITION; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH. Empty drums should be completely drained, properly bunged and promptly returned to a drum reconditioner, or properly disposed of.

SPECIAL FIREFIGHTING PROCEDURES: As in any fire, wear self-contained

(Continued on Page 3)

SECTION 5 - FIRE FIGHTING MEASURES

breathing apparatus pressure-demand (MSHA/NIOSH approved or equivalent) and full protective gear.

SECTION 6 - ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Absorb spill with inert material (e.g. dry sand or earth), then place in a chemical waste container.

SECTION 7 - HANDLING AND STORAGE

HANDLING: Contains alkanolamines, do not mix with nitrite-containing materials due to the possible formation of nitrosamines which have been found to cause cancer in laboratory animals.

STORAGE: Keep from freezing.

SECTION 8 - EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS: Good general ventilation should be sufficient to control airborne levels.

RESPIRATORY PROTECTION: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use.

SKIN PROTECTION: Where contact is likely, chemical resistant gloves and apron may be used to protect some sensitive individuals.

EYE PROTECTION: Wear safety glasses with side shields (or goggles) and a face shield.

OTHER PROTECTIVE EQUIPMENT: Not applicable.

HYGIENIC PRACTICES: Wash hands before eating.

(Continued on Page 4)

SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

BOILING RANGE	212 - 212 F	VAPOR DENSITY	Is heavier than air
ODOR	Mild	ODOR THRESHOLD	N/A
APPEARANCE	Yellow Fluid	EVAPORATION RATE:	Is slower than Butyl Acetate
SOLUBILITY IN H2O	Complete		
FREEZE POINT	32 F	SPECIFIC GRAVITY:	1.0377
VAPOR PRESSURE	< 0.1 mm Hg	pH @ 5.0 %	9.0
PHYSICAL STATE	Liquid	VISCOSITY	< 50 SUS

COEFFICIENT OF WATER/OIL DISTRIBUTION: 100% Water

(See Section 16 for abbreviation legend)

SECTION 10 - STABILITY AND REACTIVITY

CONDITIONS TO AVOID: Avoid strong oxidizing and reducing agents, strong alkali and nitrites.

INCOMPATIBILITY: Avoid strong oxidizing and reducing agents, strong alkali and nitrites.

HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide and unidentified organic compounds may be formed during combustion.

HAZARDOUS POLYMERIZATION: Will not occur under normal conditions.

STABILITY: This product is stable under normal storage conditions.

SECTION 11 - TOXICOLOGICAL PROPERTIES

No product or component toxicological information is available.

TOXICOLOGICAL INFORMATION: No Information.

SECTION 12 - ECOLOGICAL INFORMATION

ECOLOGICAL INFORMATION: None known.

(Continued on Page 5)

SECTION 13 - DISPOSAL CONSIDERATIONS

DISPOSAL METHOD: Dispose of product in accordance with local, county, state, and federal regulations.

SECTION 14 - TRANSPORTATION INFORMATION

DOT PROPER SHIPPING NAME:

DOT TECHNICAL NAME:

DOT HAZARD CLASS: HAZARD SUBCLASS:

DOT UN/NA NUMBER: PACKING GROUP: RESP. GUIDE PAGE:

SECTION 15 - REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS: AS FOLLOWS -

OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200)

CERCLA - SARA HAZARD CATEGORY:
This product has been reviewed according to the EPA 'Hazard Categories' promulgated under Sections 311 and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:

IMMEDIATE HEALTH HAZARD

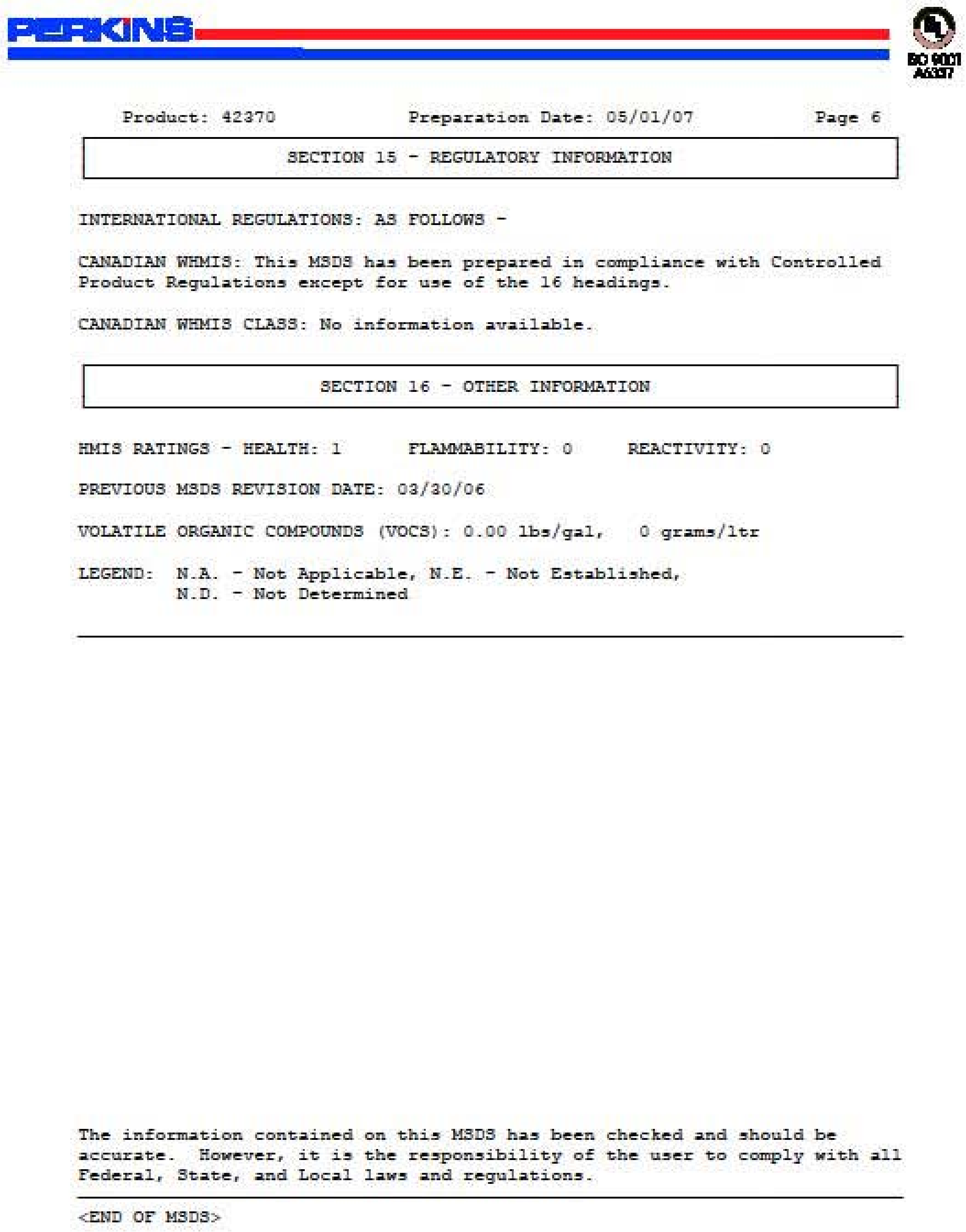
SARA SECTION 313:
This product contains the following substances subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372:

----------- CHEMICAL NAME ----------- CAS NUMBER WT/WT % IS LESS THAN
No SARA Section 313 components exist in this product.

TOXIC SUBSTANCES CONTROL ACT:
This product contains the following chemical substances subject to the reporting requirements of TSCA 12(B) if exported from the United States:

----------- CHEMICAL NAME ----------- CAS NUMBER
No information is available.

(Continued on Page 6)



PERKINS

ISO 9001
A6337

Product: 42370 Preparation Date: 05/01/07 Page 6

SECTION 15 - REGULATORY INFORMATION

INTERNATIONAL REGULATIONS: AS FOLLOWS -

CANADIAN WHMIS: This MSDS has been prepared in compliance with Controlled Product Regulations except for use of the 16 headings.

CANADIAN WHMIS CLASS: No information available.

SECTION 16 - OTHER INFORMATION

HMIS RATINGS - HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 0

PREVIOUS MSDS REVISION DATE: 03/30/06

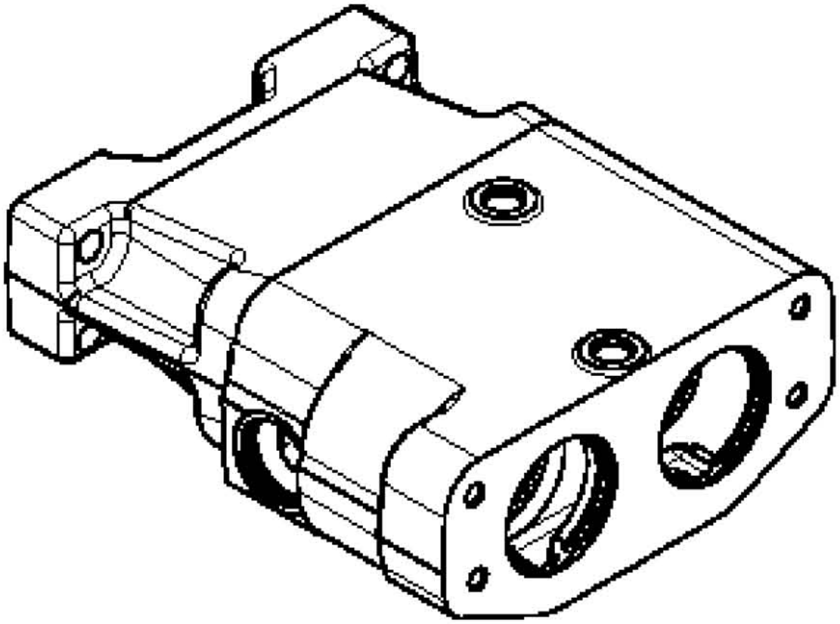
VOLATILE ORGANIC COMPOUNDS (VOCS): 0.00 lbs/gal, 0 grams/ltr

LEGEND: N.A. - Not Applicable, N.E. - Not Established,
N.D. - Not Determined

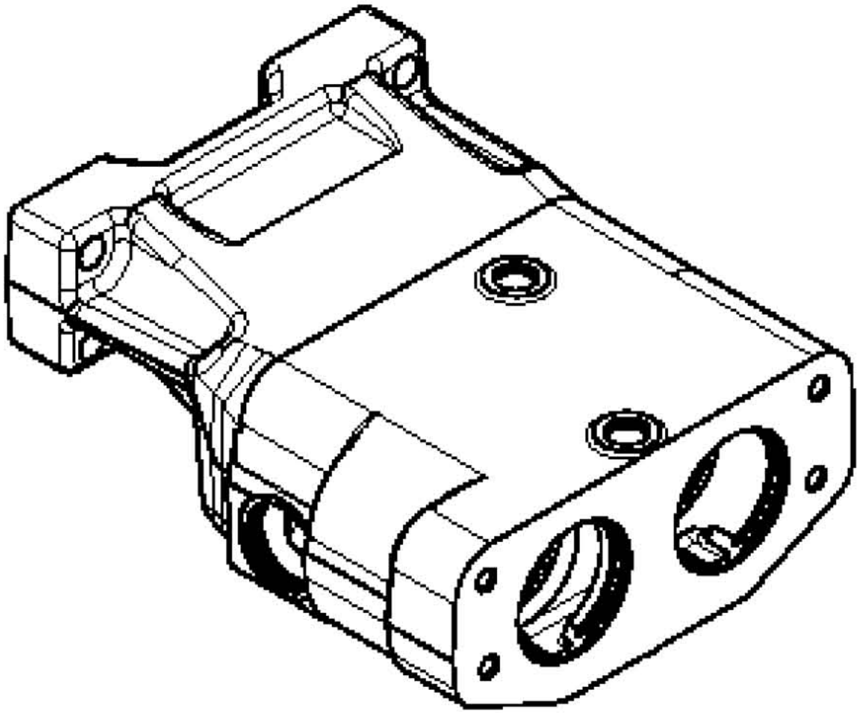
The information contained on this MSDS has been checked and should be accurate. However, it is the responsibility of the user to comply with all Federal, State, and Local laws and regulations.

<END OF MSDS>

Appendix C: Part Geometry



“02” Casting Configuration Model



“03” Casting Configuration Model

“02” Casting

Casting Cartridge Socket Bores

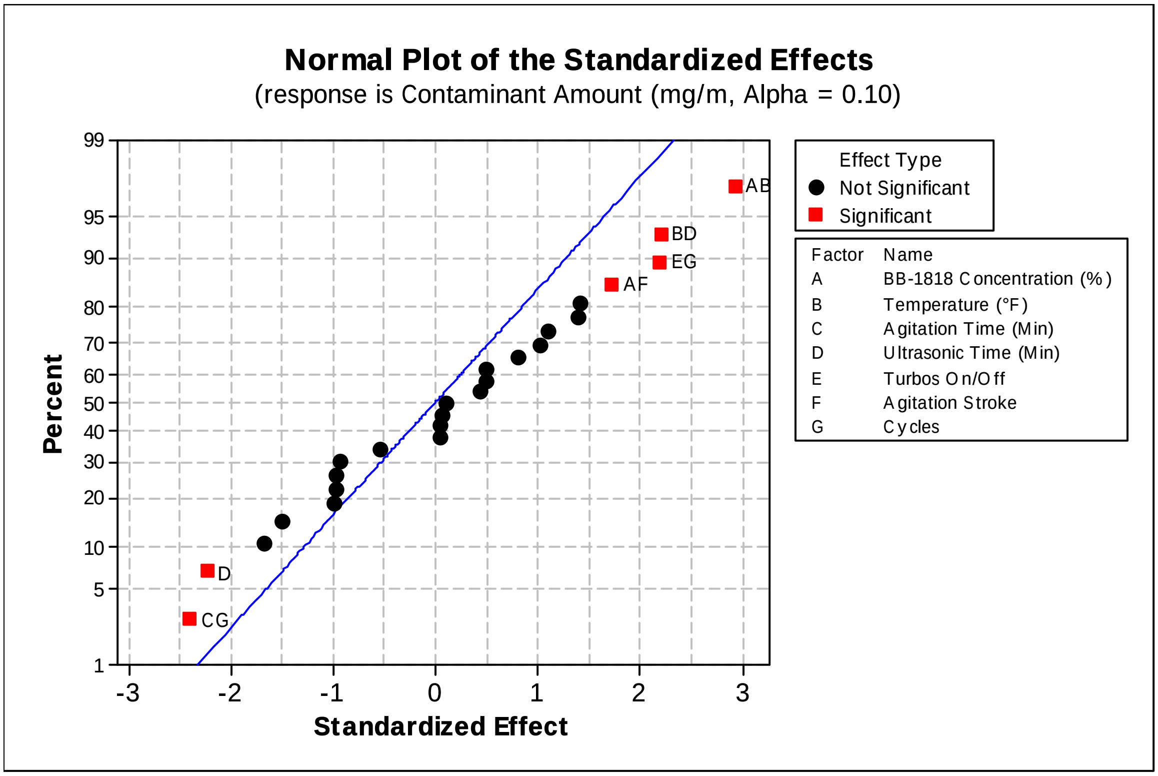
Appendix D: Experiment I Test Data

Experiment I Cleanliness Testing Raw Data

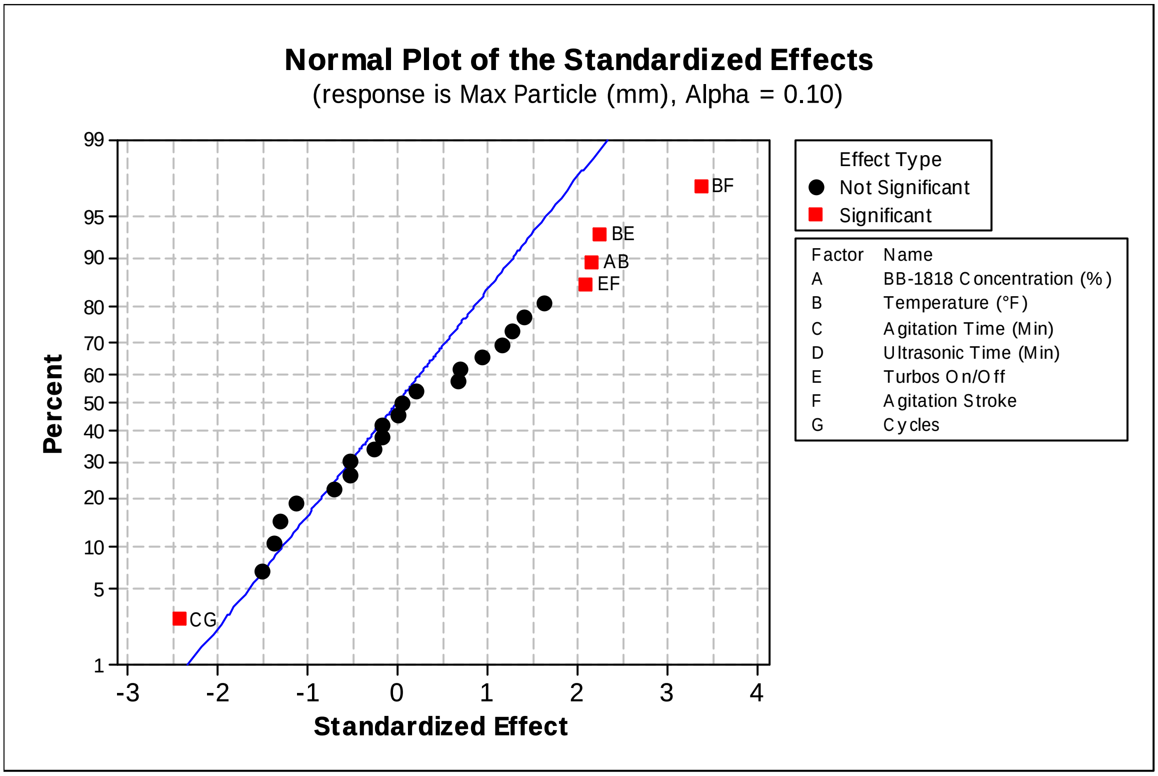
			Abrasives		Non-Abrasives		
Run	Sample	Contaminant Amount (mg/m^2)	Size in X (mm)	Size in Y (mm)	Size in X (mm)	Size in Y (mm)	Max Particle (mm)
1	1	139.98	1.7526	1.0668	0.3048	0.2032	1.7526
1	2	482.50	1.8034	0.2794	0.6604	0.2794	1.8034
2	1	44.07	1.2446	0.5334	0.4318	0.3048	1.2446
2	2	504.33	1.6256	0.4572	0.5588	0.3048	1.6256
3	1	485.28	2.1336	1.8288	3.0226	0.3302	3.0226
3	2	107.85	1.3208	0.2794	4.3434	2.7432	4.3434
4	1	24.04	1.0922	0.6858	0.9906	0.8636	1.0922
4	2	110.87	1.9812	1.0668	0.3048	0.1270	1.9812
5	1	63.78	2.1844	0.5334	0.3048	0.3048	2.1844
5	2	60.10	1.3208	0.4572	0.1524	0.1016	1.3208
6	1	64.10	2.8956	0.5842	0.4064	0.2032	2.8956
6	2	19.46	1.2446	0.4572	0.3048	0.2032	1.2446
7	1	16.68	1.8288	0.3048	1.4224	0.3302	1.8288
7	2	40.47	1.6002	0.3302	0.6350	0.3048	1.6002
8	1	23.71	1.8288	0.3048	0.4064	0.3048	1.8288
8	2	13.82	0.8382	0.6096	0.5080	0.1016	0.8382
9	1	190.35	1.7272	0.7112	0.6604	0.4572	1.7272
9	2	179.89	1.5240	0.4572	0.7620	0.5588	1.5240
10	1	210.79	1.5748	0.3048	0.4572	0.3556	1.5748
10	2	656.58	2.3622	0.9652	0.4572	0.3556	2.3622
11	1	214.88	1.6256	1.0414	0.7874	0.2286	1.6256
11	2	257.15	1.9812	0.7874	0.5334	0.2540	1.9812
12	1	741.62	0.9652	0.4572	0.3810	0.1778	0.9652
12	2	212.67	0.4318	0.2794	0.5334	0.2540	0.5334
13	1	41.21	1.0414	0.5080	0.3048	0.2540	1.0414
13	2	33.36	1.1684	0.5842	0.8636	0.7112	1.1684
14	1	33.12	0.9398	0.5334	1.5494	1.0922	1.5494
14	2	67.87	1.7272	1.6002	0.5842	0.5334	1.7272
15	1	73.10	1.7780	0.9906	0.3810	0.1016	1.7780
15	2	10.47	0.7874	0.7112	0.6604	0.5334	0.7874
16	1	73.02	2.8956	0.6096	0.3048	0.0762	2.8956
16	2	61.82	3.3020	1.0414	0.7112	0.1524	3.3020
17	1	444.81	1.6256	0.3302	3.0988	2.1082	3.0988
17	2	102.04	1.3462	0.5588	0.4318	0.5080	1.3462
18	1	33.03	2.1336	0.6096	0.2540	0.2540	2.1336
18	2	101.39	1.5748	0.7112	0.3810	0.2032	1.5748
19	1	524.78	2.8448	1.0668	0.8128	0.5588	2.8448
19	2	52.49	1.8034	0.5588	0.3556	0.1524	1.8034

Experiment I Cleanliness Testing Raw Data Continued

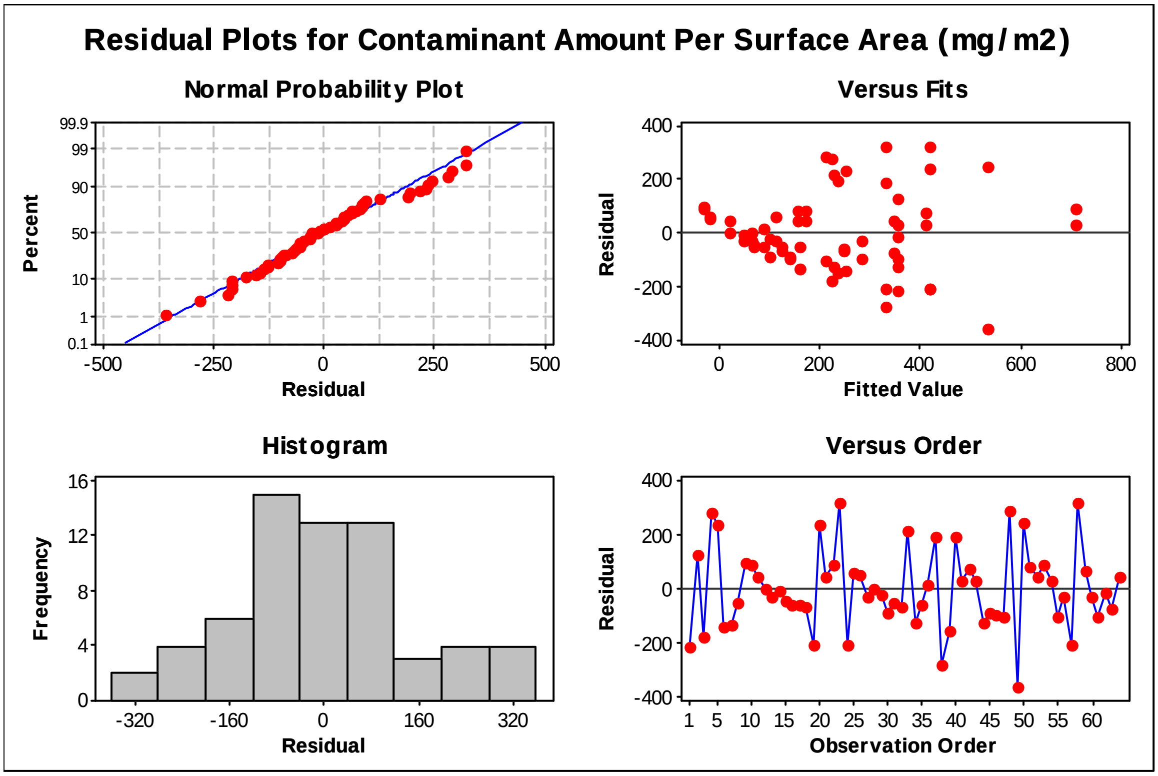
			Abrasives		Non-Abrasives		
Run	Sample	Contaminant Amount (mg/m^2)	Size in X (mm)	Size in Y (mm)	Size in X (mm)	Size in Y (mm)	Max Particle (mm)
20	1	82.01	3.4036	0.7874	0.1016	0.1016	3.4036
20	2	429.84	2.9718	0.7366	0.5842	0.3048	2.9718
21	1	439.00	3.5052	1.2954	0.8128	0.7112	3.5052
21	2	484.55	2.0574	0.3048	0.7874	0.3048	2.0574
22	1	381.93	1.0668	0.3048	0.2794	0.2794	1.0668
22	2	227.06	2.1082	0.9906	0.3302	0.2794	2.1082
23	1	46.20	3.6322	0.4572	0.5842	0.3048	3.6322
23	2	43.42	1.8542	0.3048	0.7366	0.0762	1.8542
24	1	110.47	1.8034	0.9144	0.3048	0.2286	1.8034
24	2	502.04	2.1082	0.7366	0.4064	0.2286	2.1082
25	1	176.37	2.0828	0.5588	0.7620	0.4572	2.0828
25	2	781.36	1.9558	0.5842	0.5334	0.2540	1.9558
26	1	235.81	1.7526	0.6096	0.3810	0.1778	1.7526
26	2	201.31	1.6256	0.8382	0.8382	0.7874	1.6256
27	1	799.51	4.1148	0.3048	0.7874	0.2286	4.1148
27	2	742.35	3.2004	1.0668	1.0414	0.7112	3.2004
28	1	184.22	2.2352	0.5334	0.5588	0.4572	2.2352
28	2	257.40	0.6858	0.2540	0.6096	0.4521	0.6858
29	1	122.57	2.4892	0.8636	4.5974	0.6604	4.5974
29	2	651.19	1.0160	0.4572	0.6096	0.4521	1.0160
30	1	176.37	1.9304	0.4318	0.5588	0.4572	1.9304
30	2	80.21	1.4224	0.3302	0.4064	0.2540	1.4224
31	1	254.95	1.4478	0.6604	1.0414	0.7112	1.4478
31	2	340.88	1.9304	0.7112	1.0414	0.7112	1.9304
32	1	276.53	1.7272	0.8128	0.5588	0.4572	1.7272
32	2	390.84	1.2192	0.8128	0.6096	0.4521	1.2192



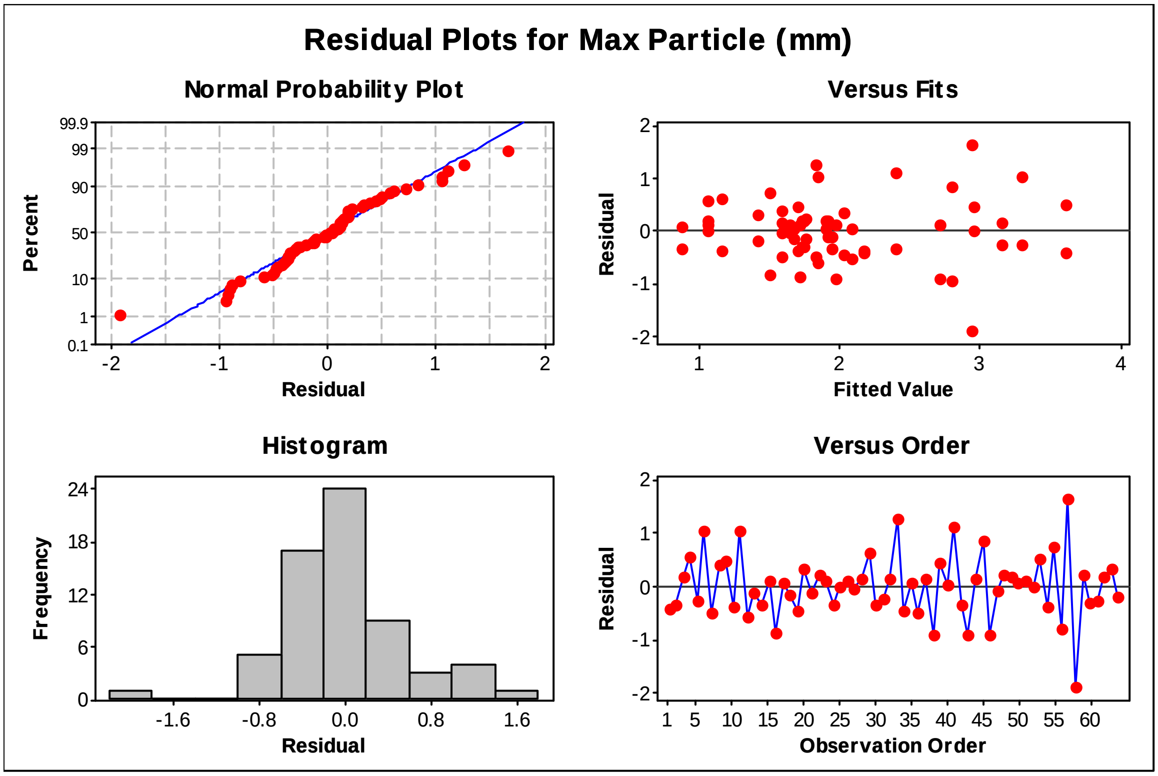
Exp. I Significant Factors of Contaminant Amount – 90% Confidence Interval



Exp. I Significant Factors of Max Particle – 90% Confidence Interval



Exp. I Residual Plots for Contaminant Amount



Exp. I Residual Plots for Maximum Particle

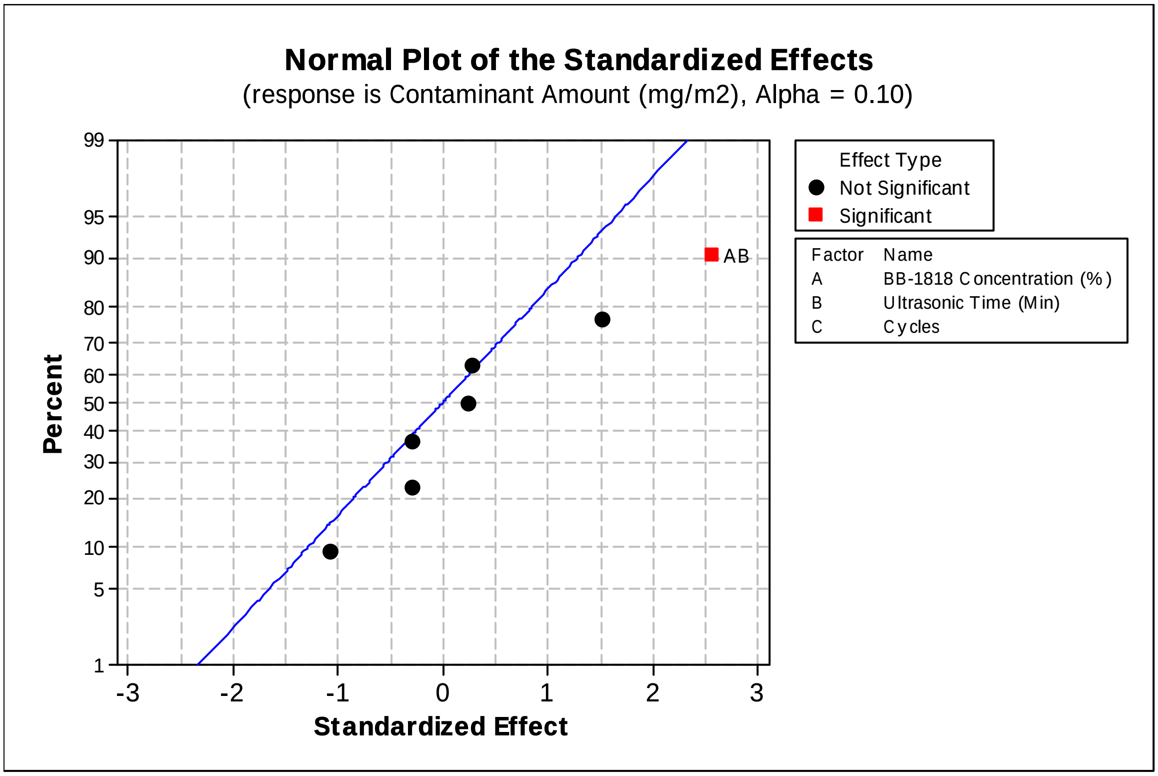
Appendix E: Experiment II Test Data

Experiment II Cleanliness Testing Raw Data

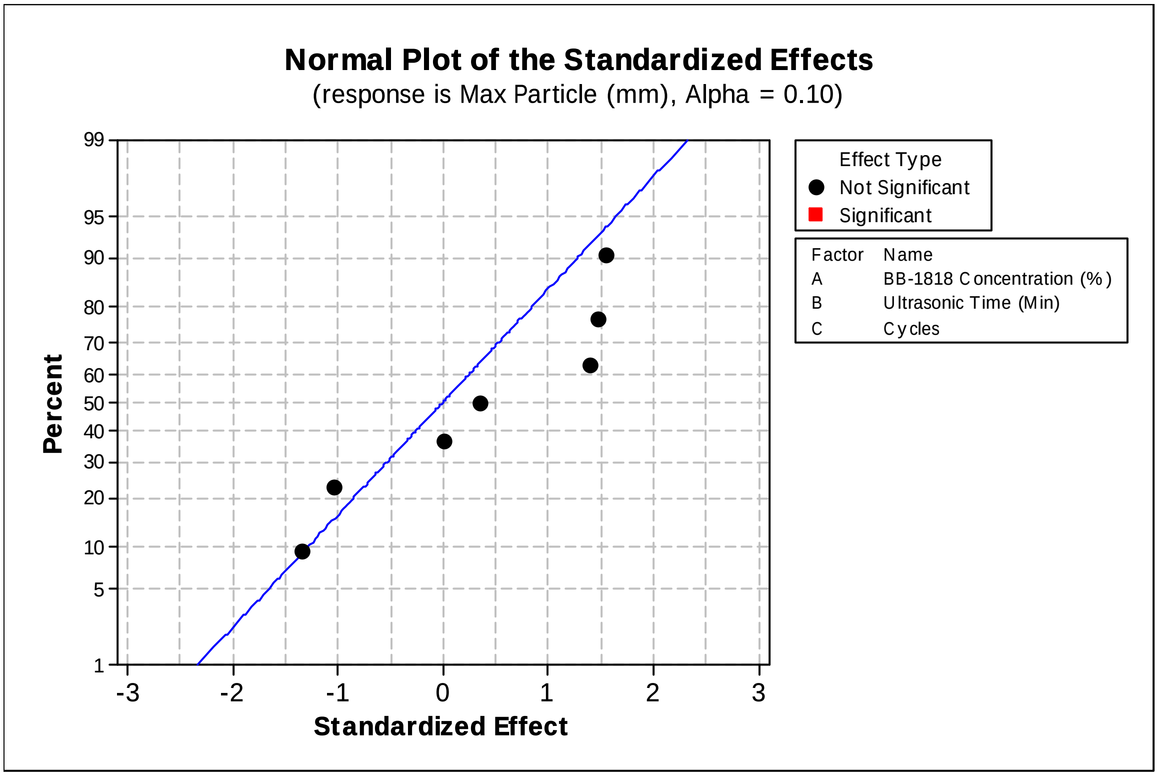
			Abrasives		Non-Abrasives		
Run	Sample	Contaminant Amount (mg/m^2)	Size in X (mm)	Size in Y (mm)	Size in X (mm)	Size in Y (mm)	Max Particle (mm)
1	1	22.98	2.9972	2.4892	0.7874	0.1524	2.9972
1	2	20.52	2.5146	2.1336	1.0668	0.5334	2.5146
1	3	11.37	0.7112	0.4064	0.2540	0.2286	0.7112
1	4	24.53	1.2954	0.8636	0.5334	0.1524	1.2954
2	1	20.44	1.9304	0.5588	0.8128	0.2032	1.9304
2	2	27.47	1.2192	0.3556	0.1778	0.1524	1.2192
2	3	100.16	1.4732	0.4064	1.4986	0.1524	1.4986
2	4	31.73	0.9144	0.3810	0.4318	0.1270	0.9144
3	1	10.87	1.5748	0.5588	0.4064	0.2540	1.5748
3	2	38.35	0.9144	0.9652	0.4572	0.2286	0.9652
3	3	20.36	0.7112	0.5334	0.4064	0.1524	0.7112
3	4	27.23	1.9304	0.4572	0.5334	0.5080	1.9304
4	1	39.17	0.7874	0.6858	1.0414	0.1778	1.0414
4	2	40.88	0.9652	0.3048	0.4572	0.2032	0.9652
4	3	25.27	1.4224	0.4826	0.2794	0.2540	1.4224
4	4	14.64	1.0922	0.3048	0.3810	0.1016	1.0922
5	1	37.04	1.6002	0.4826	0.3048	0.2540	1.6002
5	2	29.35	1.3208	0.5588	0.6604	0.1778	1.3208
5	3	78.74	1.6256	0.6604	0.3556	0.1524	1.6256
5	4	21.50	1.0922	0.3556	0.6096	0.2286	1.0922
6	1	189.45	1.2954	0.3048	0.3810	0.3810	1.2954
6	2	26.66	0.9144	0.5334	2.9972	1.9304	2.9972
6	3	37.61	1.3208	0.5334	0.3048	0.3048	1.3208
6	4	28.37	1.0668	0.4572	0.4318	0.1270	1.0668
7	1	26.74	0.8382	0.3048	0.7112	0.0762	0.8382
7	2	77.02	1.0668	0.5588	0.3302	0.2286	1.0668
7	3	26.57	1.2446	0.2794	0.2032	0.1524	1.2446
7	4	17.50	0.8382	0.6604	0.2286	0.2032	0.8382
8	1	86.92	0.9398	0.4572	0.5588	0.3048	0.9398
8	2	27.80	0.8128	0.2794	0.5334	0.4572	0.8128
8	3	27.23	0.5588	0.4318	0.2794	0.2032	0.5588
8	4	19.71	1.4732	1.0668	0.5334	0.0762	1.4732
9	1	18.48	0.9398	0.4318	0.5588	0.2794	0.9398
9	2	44.24	1.6002	0.5080	0.2286	0.1778	1.6002
9	3	48.73	1.4478	0.5334	1.0922	0.2794	1.4478
9	4	27.06	0.5334	0.5080	0.2032	0.1778	0.5334
10	1	88.14	2.9464	1.3208	0.7366	0.1524	2.9464
10	2	43.83	1.4478	0.5588	0.3048	0.3048	1.4478

Experiment II Cleanliness Testing Raw Data Continued

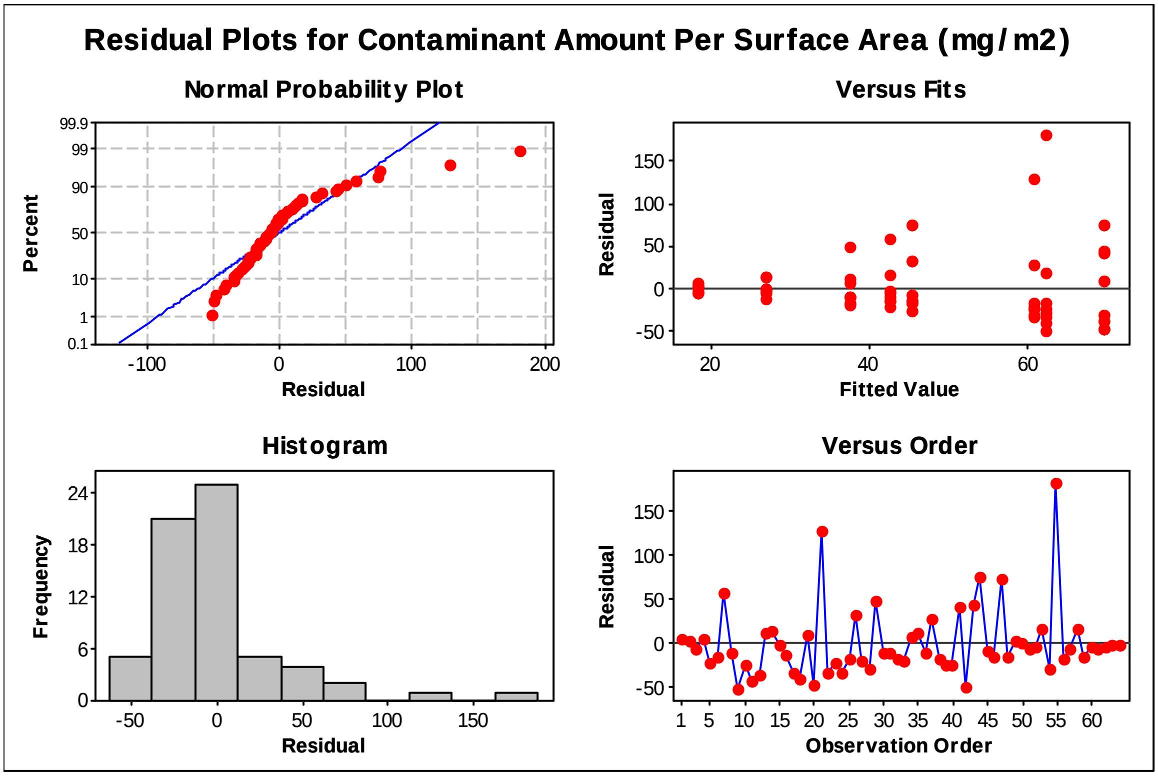
			Abrasives		Non-Abrasives		
Run	Sample	Contaminant Amount (mg/m^2)	Size in X (mm)	Size in Y (mm)	Size in X (mm)	Size in Y (mm)	Max Particle (mm)
10	3	35.24	0.7112	0.5842	1.5748	0.7620	1.5748
10	4	36.96	1.1684	0.3048	1.8034	0.2794	1.8034
11	1	111.37	0.9144	0.3556	1.7526	0.1016	1.7526
11	2	19.95	0.8128	0.5588	0.6858	0.3302	0.8128
11	3	114.23	1.1176	0.3556	0.4572	0.3048	1.1176
11	4	144.64	1.9304	0.3048	1.2700	0.1524	1.9304
12	1	37.12	2.4384	0.8128	0.4572	0.3048	2.4384
12	2	28.95	2.0066	0.4826	0.4826	0.2540	2.0066
12	3	119.30	0.7112	0.4318	0.2032	0.1524	0.7112
12	4	29.93	1.6256	0.4064	0.2540	0.2032	1.6256
13	1	20.20	1.2954	0.4572	0.3556	0.2286	1.2954
13	2	19.30	0.9652	0.4572	0.4064	0.2540	0.9652
13	3	12.59	1.3462	0.3556	0.2540	0.2032	1.3462
13	4	15.37	2.3876	1.7272	1.2192	0.3048	2.3876
14	1	79.07	0.9373	0.4064	0.2032	0.0762	0.9373
14	2	33.12	1.2192	0.4064	0.6604	0.2794	1.2192
14	3	244.40	1.1684	0.6096	1.1430	0.5080	1.1684
14	4	44.40	1.5240	0.5588	0.3556	0.2032	1.5240
15	1	36.06	1.1684	0.3810	0.2032	0.1270	1.1684
15	2	58.54	0.9398	0.4826	7.5184	1.6002	7.5184
15	3	26.74	1.1684	0.7874	2.8448	0.7874	2.8448
15	4	39.00	0.9906	0.3302	1.0668	1.1684	1.1684
16	1	20.44	0.9906	0.3048	0.4572	0.4064	0.9906
16	2	22.89	1.4224	0.3556	0.2286	0.1016	1.4224
16	3	25.92	1.3462	0.4826	2.1082	1.6256	2.1082
16	4	25.51	1.5748	0.9144	1.7780	1.3462	1.7780



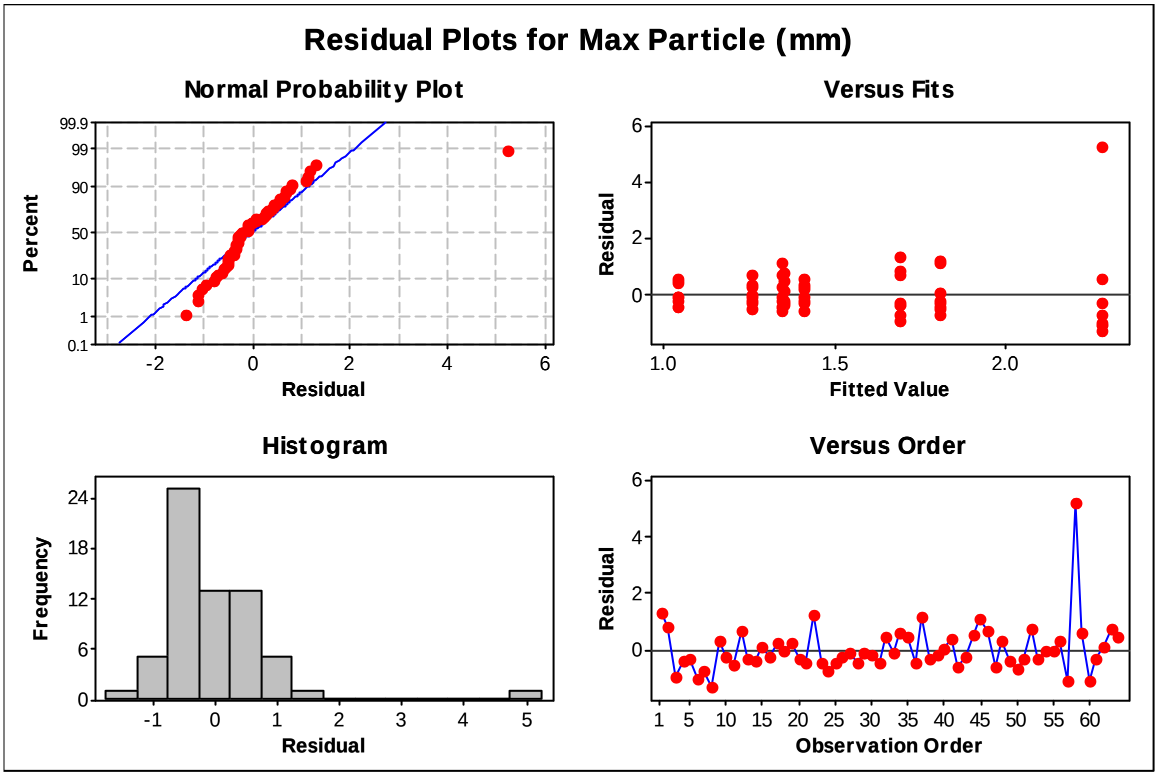
Exp. II Significant Factors of Contaminant Amount – 90% Confidence Interval



Exp. II Significant Factors of Max Particle – 90% Confidence Interval



Exp. II Residual Plots for Contaminant Amount



Exp. II Residual Plots for Maximum Particle