

A Thesis

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Evaluation of Particulate Matter Inside Control Rooms at a Quarry and Processing
Facility

by

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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science Degree in

Occupational Health

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Particulate matter has been a known health concern in all work environments including quarries and lime facilities for nearly 40 years. While a great amount of information is available on silica samples and concentrations at these facilities, there is less information on nuisance dust. The health effects of particulate matter can increase dramatically as the particulate matter decreases in size. Particulate matter of less than 2.5 μm are of particular concern because they can penetrate deep into the lungs. A quarry and its adjacent processing facility in Northwest Ohio was studied for PM₁, PM_{2.5}, PM₅, PM₁₀, PM_{Total}, and ultrafine particulate matter. Additionally, environmental data including temperature and relative humidity were studied. The study focused on four locations at the south side of the plant. The greatest concentration of particulate matter was measured outside near a load-out operation. The least concentration of particulate matter was measured inside an operator's control room. The null hypotheses was rejected for each size category of particulate matter. Twenty-three statistical differences were found in this study. These statistical differences confirm the effective use of a control room to reduce employee exposure.

I would like to acknowledge my brother Elliott Backes for reminding me when to back down and when to push on. I would like to thank my brother Aaron Backes for always being a relatable brother. I am grateful that Aaron was there to listen at hard times and validate my frustration and emotional pain throughout my graduate career.

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List of Abbreviations

A C G I H.....	American Conference of Governmental Industrial Hygiene
A S H R A E..	American Society of Heating, Refrigeration, Air-Conditioning Engineers
A N F O.....	Ammonium Nitrate Fuel Oil Mixture
cm ³ /min.....	Cubic centimeters per minute of Air
C O.....	Carbon Monoxide
C O ₂	Carbon Dioxide
D K D.....	Dry Kiln Dust
L K D	Lime Kiln Dust
M S H A.....	Mine Safety and Health Administration
mg/m ³	Milligrams per Cubic Meter of Air
O S H A	Occupational Safety and Health Administration
P E L	Permissible Exposure Limit
P M	Particulate Matter
pt/cc	Particles per Cubic Centimeter of Air
S D S.....	Safety Data Sheet
T L V.....	Threshold Limit Value
T W A	Time Weighted Average
µm.....	Micrometers

Chapter 1

Introduction

1.1 Overview

Particulate matter, commonly referred to as dust, has historically been a concern due to its presence in a variety of occupational environments (Jimoda, 2012). The study of particulate matter in workplaces continues to be an ongoing field of interest since the early 1970s with the movement of environmental awareness and regulations for workplace safety and health. Mining operations both underground and in open pit quarries face unique challenges for controlling dust levels. This is especially true for surface mining operations that continue to have concerns regarding the amount of particulate matter in the air. Because of uncontrolled particulate matter emissions, a mine operator may experience a number of adverse effects including limited visibility for mobile equipment, adverse health effects for workers, citations from governing agencies, and employee frustration. For these reasons, particulate matter control at surface mining operations is a fundamental process.

At a surface mine airborne particulate matter is expected. For this reason, processing plants may provide control rooms as a safe long-term location for workers. These rooms allow workers to perform the functions of their job for the majority of the day inside a more comfortable and less dusty environment.

A number of agencies publish both recommended and required concentration limits for particulate matter in surface mining operations. Despite control methods such as water systems and dust collectors, being in place at the majority of surface mining operations, employees, visitors, and community members continue to raise concerns regarding the cleanliness and particulate matter concentration in both indoor and outdoor environments at the mine.

1.2 Statement of the Problem

This study was to conduct a survey at a lime quarry that has an attached mill and prep plant. The focus of this study was to conduct a survey on two (2) of the kilns, the adjacent loadout facility, the adjacent burning floor, and control room used by the operator.

At surface mining and mill operations, indoor air quality and particulate matter concentrations affect the comfort, safety and health of the employees. Therefore, indoor environments including control rooms and buildings and outdoor environments in which mobile equipment is operating must be provided with adequate control measures for particulate matter. Within indoor environments, additional factors including relative humidity, temperature, overall cleanliness, and minimization of dust accumulation on flat surfaces are critical to ensuring employee comfort and satisfaction (Newcomer, 2004). Poor ventilation and inadequate controls of outdoor dust from the processing plant can cause the particulate matter concentration to increase inside control rooms. At the time of this study concentrations of particulate matter within various control rooms were not being measured or monitored by the mine operator.

At lime mines and processing plants the kilns have a large amount of Dry Kiln Dust (DKD) that is generated as a byproduct of the process. It is critical to capture this DKD to limit employee exposure and environmental impact. It is important for management to understand if dusty conditions are caused primarily from DKD, quarry particles, loadout particles, or other particles. Furthermore, it is useful to the employees and management to understand if these control rooms are providing a safe and healthy work environment for the employees or if the preference is strictly for employee comfort.

1.3 Purpose and Significance

Evaluation of the levels of particulate matter inside the control room and burning floor at this lime quarrying and processing facility in Northwest Ohio is warranted. The concentrations of the control room are compared to other adjacent locations in this study. The results of the evaluation provide information to the mine operator and management regarding the air quality inside control rooms, on the burning floor, and outside the burning building at the mine.

1.4 Hypotheses

The hypotheses tested were:

1. There is no statistical difference in the mean airborne concentration of ultrafine ($<1\ \mu\text{m}$) particulate matter between the sampling locations.
2. There is no statistical difference in the mean airborne concentration of respirable ($<2.5\ \mu\text{m}$), thoracic ($5\text{-}10\ \mu\text{m}$), or inhalable ($10\text{-}100\ \mu\text{m}$) particulate matter between the sampling locations.

1.5 Objectives

The objectives of this study were to:

1. Conduct air sampling for particulate matter, relative humidity, and temperature inside a control room at a quarry and processing plant located in Northwest Ohio.
2. Determine if a statistical difference exists between the concentration of particulate matter, relative humidity, and temperature between the loadout side, non loadout side, control room, and burning floor.
3. Evaluate the data against existing standards and recommendations for airborne particulate matter concentrations including those for indoor air quality.

Chapter 2

Literature Review

2.1 Theoretical Framework

Noise, silica, and dust are the top three health concerns for the majority of surface mines (Mine Safety and Health Administration (MSHA), 1999). Frequent samples of each are needed at mine sites to evaluate the effectiveness of controls in place and verify compliance with MSHA regulations. Private practice industrial hygienists and MSHA inspectors sample silica and total dust to ensure concentrations are less than permissible exposure limits. When samples are collected and found to be at a level greater than a particular Permissible Exposure Limit (PEL), then MSHA, the safety and health regulatory agency for the mining industry, can issue citations.

Samples are collected either as area samples or as personal samples. Area samples provide general information about an area but are not representative of an employee's exposure. Area samples also allow a mining company to identify specific areas that might need additional controls. Personal samples are collected by equipping a worker with a cartridge connected to a pump in his or her breathing zone for the duration of the shift (Breyse & Lees, 2006). This allows a mining company to see an adequate representation of an employee's exposure during a work shift. Personal Time-Weighted

Averages (TWA) that are set by MSHA are used as the enforcement criteria for personal samples. These personal samples are the only way to make accurate recommendations based on employee exposures and are able to be compared to the enforcement standard set by MSHA. As these TWAs are set forth in Title 30 of the Code of Federal Regulations and are enforceable by law, they are often referred to as Permissible Exposure Limits (PEL).

2.2 Quarrying and Crushing

The basic process of the quarry begins with drilling large boreholes for the entire length of the highwall, followed by blasting agents typically ammonium nitrate fuel oil mixture (ANFO), used to break the rock from the highwall. After the rock falls to the bottom of the pit, it is loaded into haul trucks. Haul trucks drive stone to the crusher area for crushing of the stone. At this particular site, there are a series of three crushers. Each crusher progressively sizes the rock into smaller pieces and screens out the dust, rock that is less than ½” in diameter. The last part of the process is the processing plant or mill prep. At the processing plant, stone is washed, sized, and sent to the kiln system to burn off impurities (US Office of Energy Efficiency and Renewable Energy).

The drilling, blasting, and crushing of the rock creates dust at many different steps within the process. This dust can easily become airborne and travel throughout the facility contributing to the particulate matter concentration. However, most dust is relatively large and can easily settle on flat surfaces and the ground. The dust is more likely to become airborne when vibration, wind, or other motion disturbs the settling process (Blades, Marchant, & Greening, 2007; Vitma Labs Limited).

2.3 Quarry Particles

Quarries produce dust as a byproduct of the quarrying process. If not adequately controlled, the particles can cause excessive wear on machinery and mobile equipment, reduce visibility, contaminate surfaces, and contribute to serious health effects for employees. At various mining operations across the country quarry dust has contributed to serious diseases including pneumoconiosis (MinEx Health & Safety Council , 2008). Outside of the effects on the mine property itself, quarries are governed by The Resource Management Act 1991 which regulates the amount of dust that is allowed to enter the neighboring environments. This can often require regular sampling at various locations off the mine property such as roads, schools, commercial and residential areas.

Drilling, crushing, blasting, plant processing and screening are all mine processes that produce a significant amount of dust. The variety of processes and type of rock that is mined contribute to a range of particle sizes varying from less than 1 μm to greater than 100 μm (MinEx Health & Safety Council , 2008).

2.4 Kiln System

Prior to entering a kiln, crushed limestone is sent to a preheater where it is gradually heated and pushed by a series of rams into the feed end of a high temperature kiln. The kiln heats the limestone from the quarry into a calcite product. At the discharge end of a kiln, there are the burning buildings in which the kilns and their supporting mills are housed. A burning building is typically equipped with a mill that provides fuel to the kiln through combustion of petroleum coke or coal. At the lower levels of a burning building lime is discharged onto a series of coolers (US Office of Energy Efficiency and Renewable Energy).

Kiln-burning floors are one level of a multi-level building providing various operational functions to the rotary kiln. At a kiln-burning floor, the burner pipe is providing the power to the hot process allowing for lime in its molten stage to flow over the grates. Just upstream from the grates is a ventilation hood that provides suction to the process. Through this hood the process contaminated air and gas is collected and sent to the baghouse for emission control (US Office of Energy Efficiency and Renewable Energy). The Kiln-Burning Floor is typically 17 feet above ground level. This kiln-burning floor is the location of most kiln burner control rooms. Additional floors of a burning building might contain discharge belts to carry cooling lime away from the kiln, natural gas piping, and a coal or coke mill (Minggong Rotary Machinery, 2010).

Particulate matter concentrations at the kiln-burning floor arise from positive hood pressure at the burning end of the kiln, DKD discharge from the seals of the kiln, ash-ring removal, and various maintenance processes. On occasion, positive pressure airflow will occur on the kiln creating a surge of DKD onto the burning floor. If the kiln is well sealed and burning efficiently, positive pressure will not occur. However, due to the number of factors affecting the discharge of dry kiln dust, it is not always easy to find a solution to this condition. Positive pressure is often worsened when covers for the discharge end of the kiln are removed for various reasons. Covers are often removed when material is stuck on grates, grates are failing, samples are pulled from the kiln, ash ring removal is necessary, or a visual inspection is needed on the firing process. Additionally, problems with baghouse collection system, fans, motors, or blowers could cause an increase in the dust concentration at the burning floor (US Office of Energy Efficiency and Renewable Energy).

The entire process flow through a typical limestone rotary kiln process is provided in figure 2-1.

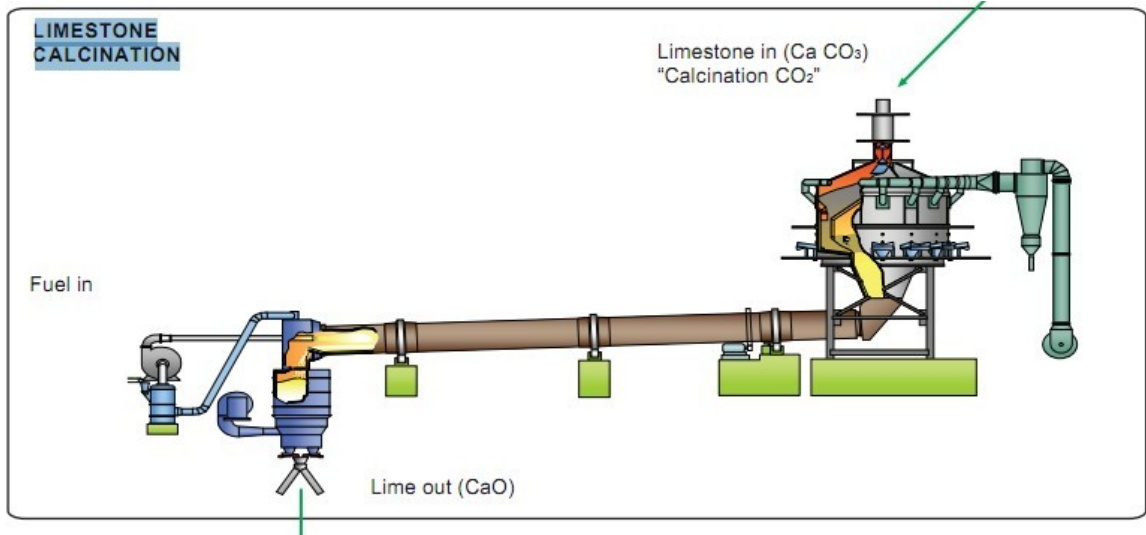


Figure 2-1 Lime Calcination Process

Source: <http://www.raymondgrindingmill.com/solutions/mining-equipment/lime-stone-crushing-plant.html>

2.5 Kiln Dust

Lime kiln dust (LKD) sometimes called dry kiln dust (DKD) are very fine particulates trapped in air pollution control systems of rotary kilns used to manufacture lime. DKD is a combination of fly ash from the coal or coke firing process and fine particles of lime coming from the stone feeding the kilns. DKD is extremely small in size with 100% of particles being less than a ½ inch in aerodynamic diameter.

The chemical content of DKD is similar to the lime itself containing primarily calcium oxide (CaO) and magnesium oxide (MgO). Small amounts of silica dioxide (SiO₂), aluminum oxide (Al₂O₃), iron oxide (Fe₂O₃), and sulfur (S) are in DKD even

though most Safety Data Sheets (SDSs) for DKD do not list any chemicals other than CaO, MgO, and silica (US Department of the Interior US Geologic Surveys, 2004).

The market for DKD exists but the markup on the product is low and the demand for the product is even lower. DKD can be used as for various building materials, in the glass industry, as a neutralizer for acidic products, road construction, steel manufacturing alongside other lime, and most recently used as a municipal sludge pasteurization and stabilization (Naik & Canpolat, 2004). However, due to its extremely small size DKDs uses are vastly limited by challenges in shipment, handling, and application.

Throughout the rotary kiln processing of the lime mine operators attempt to collect DKD and remove it, although there is still likely to be airborne particles due to its extremely small size the controls are often not collecting all of the DKD that is being liberated from the kiln. When unusual conditions such as kiln covers are removed, seals are not tight, positive hood pressure is present, or significant ash ring buildup, DKD can flow out of the openings of the kiln and onto the burning floors.

2.6 Loadout Facilities and Loadout Particles

The final process at a lime facility is the loadout. At a loadout trucks, rail cars, and barges are loaded with the finished product. Lime is typically sold by weight and it is cost effective to load trucks and rail cars to maximum capacity for shipment. Lime flows from a silo on a conveyor belt to a chute to be loaded out. The chute allows for rapid flow of lime to be placed in a container. This process causes particulate matter to be released into the air during the time of active loadout. This particulate matter primarily consists of

the finished products dolomitic lime or high calcium oxide lime (Utah Division of Air Quality, 2013).

2.7 Indoor Air Quality

Since the early 1970s, the significance of indoor air quality on employee health and well-being has been studied. In most cases, indoor air quality only causes discomfort and decreased employee satisfaction. However, there are certain contaminants such as mold, carbon monoxide, formaldehyde, lead, and radon that can cause serious health affects to employees (US Environmental Protection Agency, 2012). In a review of more than 500 indoor air quality cases the National Institute for Occupational Safety and Health (NIOSH) found that inadequate ventilation was the source of the problem in more than 50% of cases (OSHA, 1999).

Throughout history, the indoor environments on mine properties result in very few citations from MSHA and are sampled infrequently by mine operators. There is not a specific mandatory health standard in the Title 30 Code of Federal Regulations (CFR) that references indoor air quality or comfort. While there are many recommendations for indoor air quality environments these are not mandatory enforcement standards in the current regulations (US Dept of Labor Mine Safety and Health Administration, 2013).

2.8 Particulate Matter Characterization

Particulate Matter Not Otherwise Classified is a term used by regulatory agencies to refer to particulate matter that does not have a specific hazard of the dust itself. Despite its benign classification when not airborne, particulate matter can be harmful to the respiratory system depending on its size. “Particles are separated into three categories

based on their size distribution; inhalable, thoracic, and respirable.” (Shomody, 2013). Inhalable particles are the largest of the three categories ranging from 10 to 100 micrometers (μm). These particles are easily filtered out by cilia in the nose and throat; therefore, their risk to human health is relatively low. Thoracic particles range from 5 to 10 μm in size. Thoracic particles are small enough to pass through the nose and throat and enter the lungs becoming lodged in the bronchial region. Respirable particulates are less than 4 μm in diameter and are known to cause the most severe health effects because the particles travel to the deepest portion of the lungs affecting the alveoli. (TSI Inc, 2013)

Ultrafine Particulates are classified as less than 100 nanometers (nm) in aerodynamic size. Ultrafine particles are typically generated from combustion processes. There is not adequate research to make conclusions about ultrafine particles in industrial environments with regards to worker health and safety, yet there has been significant evidence with rats and humans that ultrafine particulate matter is harmful to the lungs (Doladson, Stone, Clouter, Renwick, & MacNee, 2001).

Many regulatory agencies, including the EPA, categorize particulate matter into just two categories, PM₁₀ and PM_{2.5}. The PM₁₀ category includes all particulate matter less than 10 μm in diameter. The PM_{2.5} category includes all particulate matter less than 2.5 μm in diameter. (US Environmental Protection Agency, 2013) Due to the relatively low health risk, most regulatory agencies, including the EPA, do not mandate health standards for particulate matter greater than 10 microns in diameter. However, the EPA does not regulate air quality standards for worker's, it provides regulations for emissions of particles to the community. MSHA regulates quarries and other surface mine sites for particulate matter exposure to employees.

2.9 Health Effects

The health effects from particulate matter vary greatly, yet they can be grave in some cases. The World Health Organization estimates that “3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM (particulate matter) globally” (World Health Organization, 2013). PM₁₀ and PM_{2.5} are the two categories of particles regulated by EPA due to their known health effects. Both sizes of particles can cause a variety of respiratory problems and cardiovascular problems including asthma and shortness of breath. These symptoms may be acute or long-term based on exposure.

Cardiovascular effects are more strongly associated with PM_{2.5}, as the particulates are small enough to enter the gas exchange system of the lungs. Also PM_{2.5} demonstrated a correlation with additional plaque build up in the arteries. Plaque in the arteries of the heart is known to lead to atherosclerosis of the heart, hardening the arteries, and increasing the chances of a person having a myocardial infarction (Pope, et al., 2002).

It is important to note that PM_{2.5} is more strongly associated with acute respiratory effects (Schwartz & Neas, 2000). Also the relative risk of adverse health effects resulting from particulate matter exposure are significantly increased for the young, old, and pre-disposed populations (Schwartz, Laden, & Zanobetti, 2002). The environmental standards attempt to control emissions of PM₁₀ and PM_{2.5} for these special populations.

2.10 Published Guidelines and Standards

OSHA and MSHA set permissible exposure limits which are legally enforceable standards for the industries and operations over which they have jurisdiction. The permissible exposure limit (PEL) is based on an 8-hour Time Weighted Average (TWA) which is defined by OSHA as “TWA is the employee's average airborne exposure in any 8-hour work shift of a 40-hour work week which shall not be exceeded” (US Dept of Labor Occupational Safety and Health Administration, 1996). The intent of this rule from both OSHA and MSHA is protect worker’s health and achieve a level over which an employee can work an 8 hour day in these conditions without adverse health effects. The permissible exposure limit for MSHA and OSHA is 15 mg/m^3 for total dust and 5 mg/m^3 for respirable dust (less than $3.5 \mu\text{m}$).

The American Conference of Governmental Industrial Hygienists (ACGIH) has established more protective recommendations based on recent data. The most current Threshold Limit Value (TLV) from ACGIH includes an inhalable particulate matter concentration of less than 10 mg/m^3 in which inhalable particles are classified as less than $10 \mu\text{m}$ in size. ACGIH also adopted a TLV of 3.5 mg/m^3 for respirable particulate matter, which is defined as less than $4 \mu\text{m}$ in size (SAIF Corporation, 2010).

While it is permissible to have up to 15 mg/m^3 of total dust at a quarry, it is possible to receive citations from MSHA for dust with inadequate controls at levels less than 15 mg/m^3 . MSHA has regulations in 30 CFR § 56.5005 that read “Control of employee exposure to harmful airborne contaminants shall be, insofar as feasible, by prevention of contamination, removal by exhaust ventilation, or by dilution with uncontaminated air. However, where accepted, engineering control measures have not

been developed or when necessary by the nature of work involved (for example, while establishing controls or occasional entry into hazardous atmospheres to perform maintenance or investigation), employees may work for reasonable periods of time in concentrations of airborne contaminants exceeding permissible levels if they are protected by appropriate respiratory protective equipment” (Mine Safety and Health Administration, 2013). MSHA inspectors use professional judgment to determine if dust control is adequate and does not pose a risk to safety and health of the miners. If an MSHA inspector feels that airborne controls are inadequate, citations can be issued and it is up to the mining company to contest a citation.

MSHA mandatory health standards were adapted from the 1973 ACGIH TLVs for all contaminants including total dust that is not otherwise classified and respirable dust (US Dept of Labor Mine Safety and Health Administration, 2013). These standards are significantly outdated and newer evidence demonstrates that the limits may not be protective enough for miners. In the past 3 decades, ample evidence from ACGIH and other organizations demonstrates that acute and chronic health effects can result from particulate levels below the regulatory exposure limits of MSHA. However, due to lobbying and political road blocks lower standards cannot be established (United States Senate, 2012).

The majority of the MSHA standards are performance based standards not specification standards. This means that MSHA does not provide clear guidance as to how to accomplish tasks or levels that must be met. Instead, MSHA provides general practices including fall protection, electrical, moving machinery, visibility, and control of airborne contaminants that mining companies must meet. Based on how effective the

mine is at implementing controls for hazards, MSHA decides whether to issue a citation. This is the strategy that OSHA, which regulates non-mine sites, has declared as well, based on a speech from Charles Jeffress in 1999. Performance standards allow for flexibility and accommodate the needs of the fast changing industrial settings and the various hazards that the work environment presents (Occupational Safety and Health Administration, 1999). However, for more traditional companies that demand specific standards this will pose a challenge.

2.11 Summary

The science and research indicates that the health hazards of particulate matter are serious. Since the early 1970s the health effects have been known, however dust and particulate matter continues to be an issue in today's quarries. Science indicates that the smaller the particle is in aerodynamic diameter the more harmful it can be to a miner's health. The surface mine process poses a definite risk of liberating particulate matter into the air and dust is not easily eliminated (MSHA, 1999). Rather adequate controls are needed to reduce the employee's exposure. Control rooms, enclosed cabs on mobile equipment, watering of roads, and ventilation are common controls provided at surface mines. Despite new scientific and medical research demonstrating the health effects of particulate matter at concentrations below the MSHA permissible exposure limits, no new standards have been established since 1973 by the agency. Employees continue to be more informed of health hazards and regulations, technology continues to improve, and MSHA cites more often on performance rather than quantitative samples. As a result, the mining industry will continue to need quantitative samples and innovative controls to reduce employees' exposures.

Chapter 3

Methods and Materials

3.1 Experimental Design

Area sampling was conducted at various locations in the southern portion of a quarry and processing facility located in Northwest Ohio. This southern portion of the plant houses the oldest kilns, control room, and burning floor which have not been updated since the late 1990s. The south plant contains a burning floor which houses two kilns. Below the kilns is a ball mill which burns coal or petroleum coke to heat the process. At the burning floor there is a control room which is equipped with heating and air conditioning. The air conditioner in the control room pulls ambient air from the burning floor, cools it, and supplies it to the control room, as there is no separate source of supplied air in the control room.

The job of interest was kiln-burning. This job occurs at all times of the day. At the time of sampling, four kiln-burning employees rotate 8-hour shifts, and occasionally work 12-hour shifts. The kiln-burning employee performs the majority of his or her work within the control room in which they remotely control the kiln process. The control rooms are presumed to separate the kiln burning employee from the burning floors since

the burning floors are environments that may be hazardous to employee health due to dust from loadout facilities and process heat.

Area samples of particulate matter, ultrafine particulate matter, wet bulb temperatures, and dry bulb temperatures were collected at four predetermined locations: the loadout side at the external patio, the burning floor, the non-loadout side external patio, and inside the control room. Particulate concentrations were obtained using a TSI PTrak Plus Model 8525 and a TSI DustTrak DRX 8533 (Shoreview, MN). A sling psychrometer was used to measure wet bulb and dry bulb temperatures at the same four locations.

Environmental information including temperature, wind direction, wind speed, precipitation rate, total precipitation, and solar level were obtained from a remote data mining system located near a local high school. The remote data mining system measures various weather parameters and sends them remotely to where the information is logged.

Nonparametric statistical analyses were performed using the collected data to determine if statistical differences existed between the burning floor, the control room, and the outdoor environments on the loadout side and non-loadout side of the building. Non-parametric data is data that is not normally distributed. Particulate matter concentrations in this study are not normally distributed. This is confirmed by observing a box plot of the data and through other particulate matter research. It is an accepted industry practice to use non-parametric analyses for particulate data.

3.2 Sampling Meters and Strategy

The TSI DustTrak DRX Model 8533 was used to monitor for particulate matter. The DustTrak is able to provide real-time measurements of particulate matter on a 90° light scattering sensor of the area for assessment. The DustTrak is also able to datalog measurements over a preset period. The datalogging function was used for this study. The pump draws air through an optical chamber to provide measurements within a sampling range from 0.001 - 100 mg/m³. “The DustTrak uses a patent-pending method to simultaneously measure size-segregated mass fraction concentrations (PM1, PM2.5, PM4, PM10, and PMTotal) over a wide concentration range in real time. This method combines photometric measurement to cover the mass concentration range and a single particle detection measurement to be able to size discriminate sampled aerosol” (TSI, Inc., 2012). The unit was charged in accordance to manufacturer’s guidelines when necessary. Prior to each sample cycle the unit was zero-checked in accordance with manufacturer’s guidelines.

The TSI PTrak Plus Model 8525 was used to measure the number of ultrafine particles per cubic centimeter of air (pt/cc). The PTrak provides one second averages ultrafine particulate matter in pt/cc. The PTrak also has datalogging capacity based on preset periods. The PTrak’s sampling range is from 0 to 50,000 pt/cc. The PTrak is able to capture and measure ultrafine particles ranging from 0.02µm - 1µm in aerodynamic diameter. The flow rate for the unit is approximately 100 cm³/min. The unit was charged with isopropyl alcohol in accordance with the manufacturer’s guidelines prior to sampling. The unit was zeroed prior to each use in accordance with manufacturer’s instructions.

A sling psychrometer was used to measure dry bulb and wet bulb temperatures at each location. The sling psychrometer has a measurement range of 50°-120° F. The sling psychrometer reservoir was filled with purified drinking water prior to each set of sampling. Then the sling psychrometer was spun around manually until the wet bulb temperature stabilized. The dry bulb and wet bulb readings were combined to estimate relative humidity.

Pilot sampling was conducted prior to the start of sample collection in order to determine the length of the sample interval. This preliminary sampling indicated that there was not a significant difference in the particulate matter count over short periods of time. Based on the results from this preliminary sampling, 10-minute averages were used for sampling. Monitoring of temperatures at each location indicated that the burning floor location reached peak temperatures of 118° F. For the integrity of the meters, some alterations to the sampling strategy were made. The DustTrak was placed in an environmental case designed to protect the meter from elevated temperatures while still able to collect particles. The PTrak samples on the burning floor were shortened to 10-second samples since an environmental case was not available.

3.3 Sampling Areas and Times

The four sampling locations were the loadout side at the external patio, the burning floor, the non-loadout side external patio, and inside the control room. Sampling occurred Monday-Friday between 6:00 am and 7:00pm at the start of the day shift, middle of the day shift, and after the end of the shift. Although kiln-burning employees are present 24-hours a day, the majority of quarrying, lime loadouts for rail cars and trucks, and maintenance activities occur during day shift. Therefore sampling was

conducted on day shift. Notes of the activities occurring at the time of sampling was taken at each of the locations. Height of the monitors was kept consistent throughout the study to eliminate any biases. Monitoring was completed in the summer months of June, July, and August 2014.

Three sampling times were selected to address the variability in particle concentrations due to changes in quarrying and maintenance activities. Sampling also occurred multiple days each week until a total of 38 samples were collected at each location.

Each location is presumed to have particulate matter being generated from surrounding processes that may be influencing the total particulate matter concentration in the sample. The loadout side sample was taken on a platform on the north end of the building overlooking a loadout chute. The loadout chute operates intermittently throughout the day shift between the hours of 7:00 am and 3:00 pm Monday through Friday. The kilns are in continuous operation on the burning floor with the exception of unplanned periods of outage. During operation of the kilns, seals surrounding the discharge end of the kiln collect all the DKD being generated from the kilns. The non-loadout side is on the south side of the building overlooking a plant road, the majority of the particulate matter generated from this side would be from traffic on gravel roads. The control room is the most accurate representation of the kiln-burning employees' normal work environment.

Samples were collected beginning at the loadout side, moving to the kiln-burning floor, then to the non-loadout side, and finally to the control room. All samples were

collected on a set of mobile industrial stairs for consistent height between sampling locations and stability of the meters. The top step in of the industrial stair platform measured 52 inches above the ground. Thirty- eight (38) data points were collected at each location. A total of 152 data points were taken throughout the study.

The locations of sampling and the sample cycle are outlined in Table 3.1

Table 3.1 Locations of Sampling

Location	Significance of Location	Exact Location of Sampling
Loadout Side Patio #1 and #2 Burning Building	Contrast Dry Kiln Dust to Loadout particulate matter	On Patio Adjacent to South Plant Loadout Scales
#1 and #2 Burning Floor	Contrast to #1 and #2 Control Room	At #1 and #2 Lock Box Central Station
South Side Patio #1 and #2 Burning Building	Contrast dry kiln dust and quarry dust at South Plant	On Patio Adjacent to #2 Kiln
#1 and #2 Control Room	Location of Kiln Burner	Near Employee's Chair in front of controls

3.4 Records and Forms

During each sampling event a record keeping note was made of the following:

1. Time and Date of Sample
2. Equipment Used including calibration record, serial number, manufacturer, model number

3. Activities Occurring at Location
4. Kiln Status
5. Employee's Presence at Location
6. Weather conditions

Upon entering the data into the spreadsheet, additional weather parameters including solar, ultraviolet (UV), precipitation rate, precipitation accumulation, relative humidity, and temperature were entered. This data was obtained from a weather vane within 1 mile of the subject plant using Weather Underground's Website and was based on times nearest to the sampling end time (Weather Underground).

3.5 Data Analysis

Any unusual measurements were verified with field notes and sampling forms. Descriptive statistics, which included the median, minimum, and maximum measurement of particulate concentrations, were used in the analysis of the data.

To evaluate statistical differences for the stated hypotheses, Kruskal-Wallis nonparametric analyses were used. The Kruskal-Wallis test is a nonparametric test which indicates that no assumptions are made about the distribution of the data. Kruskal-Wallis statistically tests whether three or more independent samples differ. The Kruskal-Wallis test is the equivalent of a one-way ANOVA for parametric data (Green & Salkind, 2008; Northern Arizona University). When the Kruskal-Wallis test provided a statistically significant result, additional testing was done with the Mann-Whitney U test. The Mann-Whitney U test determines which locations are different from each other and is

equivalent to one-way ANOVA post-hoc tests. To account for type I errors (i.e., error of incorrectly declaring a difference to be true due to chance) the alpha value was adjusted downward in the Mann Whitney U test. The adjustment was made in accordance with the Bonferroni t test method in which the alpha (α) value for n comparisons is equal to $\alpha \div n$. In this case, the overall significance level of α was set at 0.10.

Environmental data was analyzed using descriptive statistics. The descriptive statistics include the mean, median, standard deviation, minimum, and maximum for each location. Environmental data is assumed to be normally distributed as this is standard industry practice. Qualitative observations of the environmental data were also made without the use of statistics.

Chapter 4

Results

4.1 Overview

This study was designed to measure the particulate matter, ultrafine particulate matter, temperature, and relative humidity at the south plant of a quarry and processing facility located in Northwest Ohio. Airborne concentrations of particulate matter are ubiquitous in both indoor and outdoor environments. Therefore, some particle concentration is expected at all locations. Temperature and relative humidity were included in the study due to their influence on the perception of the IAQ.

4.2 Summary of Results

A total of 152 data points were collected throughout the study. The descriptive statistics for all parameters are summarized in Table 4.1. The descriptive statistics that are grouped by location are summarized in Table 4.2 for particulate matter and Table 4.3 for temperature and relative humidity. Based on the descriptive statistics it appears that all locations do not have the similar concentrations of particulate matter. The loadout side appears to have the greatest concentration of particulate matter. Additionally, all particulate matter concentrations are measured below the MSHA PEL. The temperatures in the control room appear to be consistent throughout sampling and within normal range

for indoor environments. There is a large difference between the minimum and maximum relative humidity percentages that is seen.

Table 4.1 Descriptive Statistic Summary of Particulate Matter at a Quarry Processing Facility

Descriptive Statistics for Particulate Matter						
	PM1 (mg/m3)	PM2.5 (mg/m3)	PM5 (mg/m3)	PM10 (mg/m3)	PMTotal (mg/m3)	UFP (pt/cc)
N	151	151	151	151	151	145
Median	.008	.008	.011	.023	.030	8202
Minimum	.000	.000	.000	.000	.000	1
Maximum	.771	.858	1.100	2.420	2.740	243000

Table 4.2 Descriptive Statistics by Location of Particulate Matter at a Quarry Processing Facility

		Descriptive Statistics for Particulate Matter by Location					
Location		PM1 (mg/m3) ¹	PM2.5 (mg/m3) ¹	PM5 (mg/m3) ¹	PM10 (mg/m3) ¹	PMTTotal (mg/m3) ¹	UFP (pt/cc)
Loadout side patio	N	38	38	38	38	38	37
	Maximum	.771	.858	1.100	2.420	2.740	37512.000
	Minimum	.000	.000	.000	.000	.000	2547.000
	Median	.039	.028	.050	.089	.118	10273.000
Burn floor	N	38	38	38	38	38	37
	Maximum	.130	.141	.174	.381	.436	243000.000
	Minimum	.000	.000	.000	.001	.003	1850.000
	Median	.013	.014	.017	.032	.052	11100.000
South side patio	N	38	38	38	38	38	37
	Maximum	.204	.230	.298	.645	.736	60171.000
	Minimum	.000	.000	.000	.001	.002	1665.000
	Median	.013	.013	.015	.028	.0365	10653.000
Control room	N	37	37	37	37	37	34
	Maximum	.010	.011	.012	.020	.029	10508.00
	Minimum	.000	.000	.000	.000	.000	1.00
	Median	.000	.000	.000	.001	.003	1725.5000
Total	N	151	151	151	151	151	145
	Maximum	.771	.858	1.100	2.420	2.740	243000.00
	Minimum	.000	.000	.000	.000	.000	1.00
	Median	.008	.008	.011	.023	.030	8202.000

¹ Accuracy of +/- 3% of reading

Table 4.2 Temperature and Relative Humidity by location at a Quarry Processing Facility

Temperature and Relative Humidity		Dry Bulb °F	Wet Bulb °F	% RH
Loadout side patio	Mean	77	67	62.0
	Std. Deviation	8.6	6.6	15.6
	Median	76	66	63
	Minimum	60	52	22
	Maximum	96	82	90
Burn floor	Mean	93	75	46
	Std. Deviation	7.6	7.6	21.0
	Median	92	75	42
	Minimum	80	55	0
	Maximum	116	97	104
South side patio	Mean	76	67	64
	Std. Deviation	8.2	6.5	17.6
	Median	76	67	66
	Minimum	60	52	21
	Maximum	96	79	95
Control room	Mean	70	61	61
	Std. Deviation	2.5	5.3	17.4
	Median	70	61	61
	Minimum	65	44	8
	Maximum	75	71	100

4.3 Summary of Particulate Matter By Location

Monitoring for particulate matter was completed using both the DustTrak and the PTrak at all locations for a maximum of 152 samples. However, PTrak data were successfully recorded for 145 samples and DustTrak data were successfully recorded for 151 samples instead of the 152 as originally designed due to equipment failures.

Figure 4-1 below is a box plot of the PM_{1} measurements at each location. The median for each location is denoted by a thick black horizontal line. The shaded box represents the first and third quartile. The shaded area is much larger and the median is greater for the loadout side than the other locations. The loadout side also has a long upper whisker representing the concentrations of PM_{1} that were greater than other locations. The loadout side also shows outliers that are greater than any other single concentration at the other locations. The control room shows concentrations that are less than other locations based on its position at the bottom of the figure. In addition, the control room has a barely visible shaded area and whiskers indicating there is little variation in the measurements. The Appendix A Figures A-1 through A-4 contains the box plots that represent $PM_{2.5}$, PM_{5} , PM_{10} , and PM_{Total} by locations. The box plots for these particulate sizes are similar to PM_{1} .

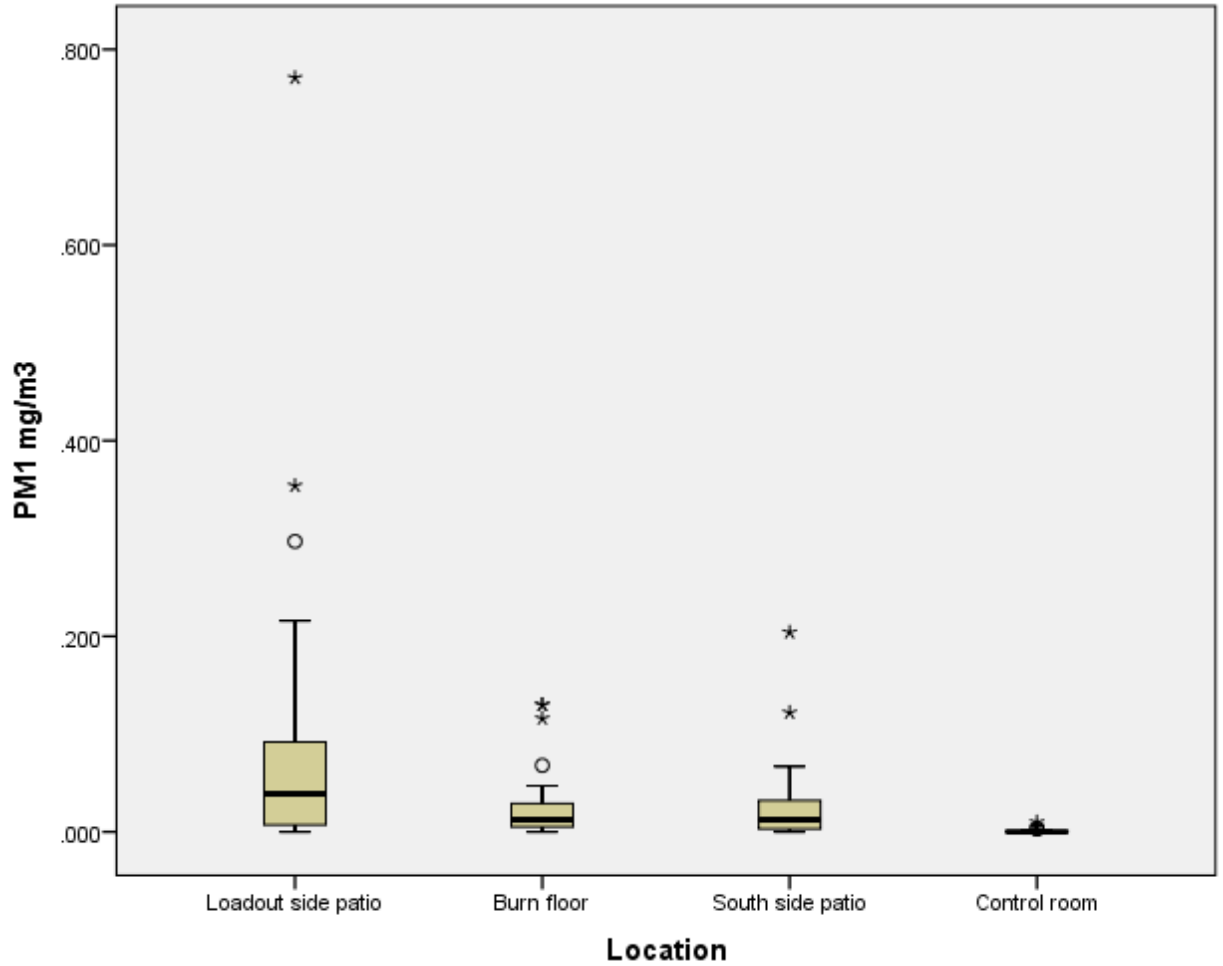


Figure 4-1 PM₁ Box Plot by Location

Figure 4-2 below is a box plot of the ultrafine particulate matter measurements at each location. The ultrafine particulate matter shows a different pattern than the other sizes of particulate matter. Ultrafine particulate matter had the greatest range and the greatest concentration at the burning floor. The south side patio and burning floor show similar ranges and concentrations compared to the other two locations. The control room showed a similar trend of very little fluctuation between measurements.

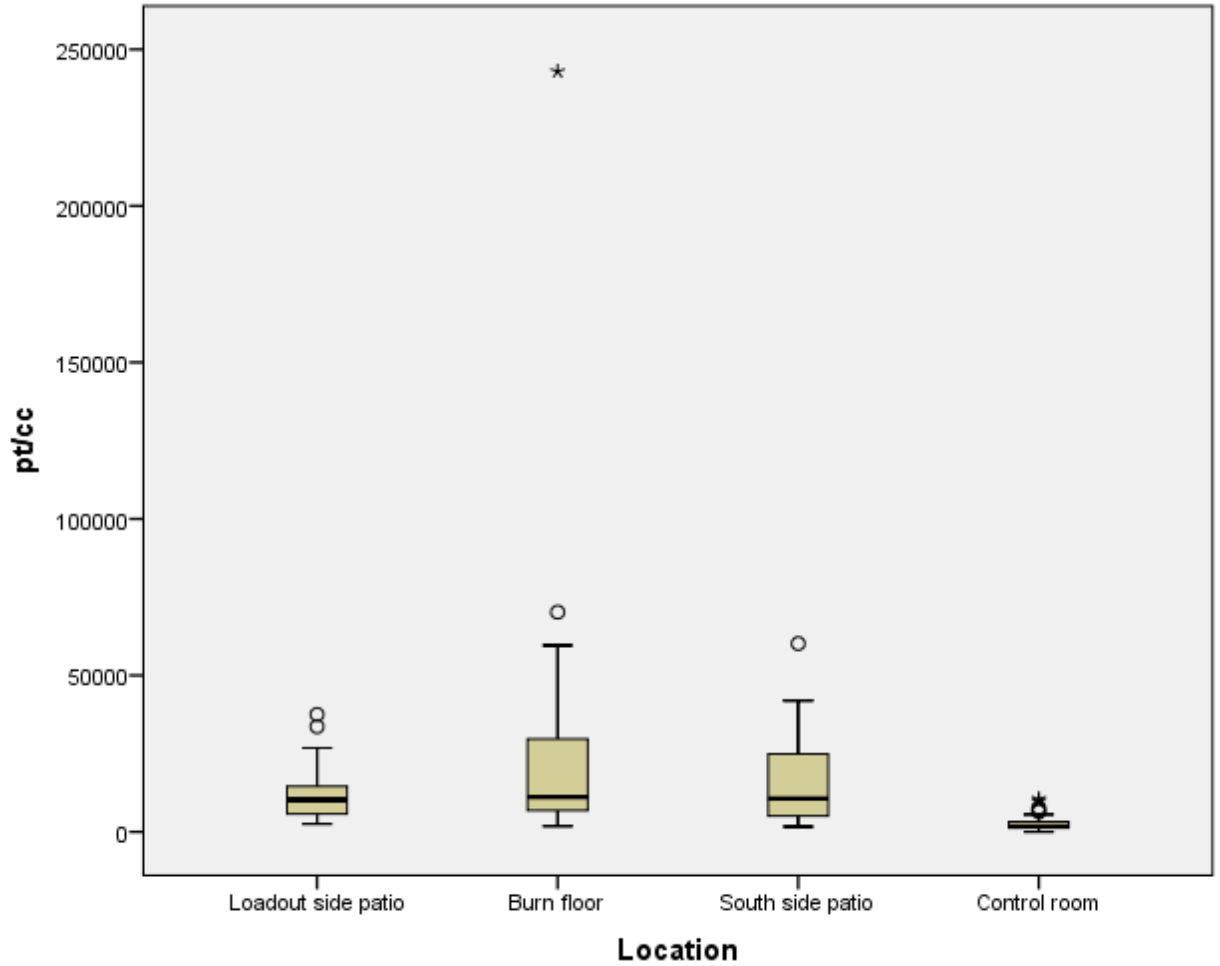


Figure 4-2 Box Plot of Ultrafine Particulate Matter by Location

4.4 Comparing Means of Particulate Matter by Location

Kruskall-Wallis test results comparing the medians of the four independent sample locations tested are displayed in Table 4.4. The level of significance was 0.10. Each particle size category was tested to determine if there were statistical differences between the four locations. Results indicate that the medians for the four locations differed significantly ($p < 0.001$).

Table 4.4 Kruskal-Wallis Test Results for Particulate Matter Measurements

Kruskal Wallis for Medians ^{a,b,c}						
	PM1 (mg/m3)	PM2.5 (mg/m3)	PM5 (mg/m3)	PM10 (mg/m3)	PMTotal (mg/m3)	UFP pt/cc
Chi-Square	64.4	63.9	64.9	64.0	62.7	54.0
df	3	3	3	3	3	3
Asymp. Sig.	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001

a. Kruskal Wallis Test

b. Grouping Variable: Location

c. Statistically Significant, p<0.10

Mann-Whitney U tests were performed to compare each location pair for each particulate size. The Mann-Whitney tests were performed using the Bonferroni adjustment. The adjustment resulted in a α value of 0.017. Table 4.5 shows the results of the Mann-Whitney U tests. Results indicate that the calculated p values differ significantly ($p < 0.017$) between the loadout side and the burning floor only at the PM₅ size category. Results indicate that the calculated p values at the loadout side and the non-loadout side differ significantly ($p < 0.017$) in PM₁, PM₅, PM₁₀, and PM_{Total}. Results indicate that calculated p values differ significantly ($p < 0.017$) between the loadout side and the control room at all size categories. Results indicate that calculated p values differ significantly ($p < 0.017$) between the burning floor and the control room at all size categories. Results indicate that calculated p values differ significantly ($p < 0.017$) between the non-loadout side and the control room at all size categories. Results indicate that calculated p values do not differ significantly ($p > 0.017$) at all size categories comparing the burning floor and the non-loadout side.

Table 4.5 Mann-Whitney U test Results for Particulate Matter Measurements

Test Statistics^{a,b}

Locations Compared	Calculated p value based on Bonferoni adjustment					
	PM1	PM2.5	PM5	PM10	PMTotal	UFP
Loadout Side vs. Burning Floor	.021	.046	.013	.028	.040	.333
Loadout Side vs. Non-Loadout Side	.012	.024	.011	.008	.007	.733
Loadout Side vs. Control Room	.000	.000	.000	.000	.000	.000
Burning Floor vs. Non-Loadout Side	.856	.795	.823	.461	.296	.390
Burning Floor vs. Control Room	.000	.000	.000	.000	.000	.000
Non-Loadout Side vs. Control Room	.000	.000	.000	.000	.000	.000

- a. Grouping Variable: Location
- b. Statistically Significant, $p < 0.017$

4.5 Results Compared to Health Standards

The respirable fraction in accordance with MSHA guidelines measured by the DustTrak is the PM5/Respirable size category according to literature from TSI Inc. For measuring against the MSHA PEL of Total Dust TSI Inc provides the PM_{Total} size category. All of the particulate matter concentrations measured in the study are less than the MSHA PEL of 10 mg/m³ for total dust and 5 mg/m³ for respirable dust. The maximum concentration measured for total dust was 18% of the MSHA PEL. The maximum concentration of respirable dust was 22% of the MSHA PEL. The measurements of particulate matter in this study were all less than ACGIH TLVs as well.

Although these results shall be used cautiously as they are not personal TWA samples in measured in compliance with MSHA sampling strategies.

4.6 Environmental Results

The temperature and relative humidity measured with the sling psychrometer show temperatures are greatest on the burning floor. The burning floor had a greater temperature than the other locations although relative humidity remained lower than the other locations. Temperatures and relative humidity measurements were similar at both outdoor locations. The control room has a relatively small dry bulb temperature range of just 10 degrees on the dry bulb compared to the other locations ($> 36^{\circ}$ dry bulb temperature range). The temperature within the control room was relatively stable with a small range which is beneficial for employee comfort.

The results from the nearby weather station temperature were similar to the dry bulb temperature measured with the sling psychrometer. The mean temperature throughout the study was 76° F. Wind speeds ranged from 0 to 14 miles per hour (mph). Precipitation was generally low throughout the sampling with only 17 samples showing accumulation of precipitation greater than zero.

4.7 Summary of Results

The results indicate a wide range of particulate matter in each size ratio. Maximum results from particulate matter range from 0.771 to 2.740 mg/m^3 . The median results ranged from 0.08 to 0.30 mg/m^3 . The median and maximum results increased with the increased in aerodynamic size, with the least particulate matter being measured at the PM1 and the greatest amount of particulate matter being measured at the PM Total range.

The Kruskal-Wallis Test showed statistical differences ($p < 0.01$) for all locations. The Mann-Whitney U Test with Bonferroni adjustments showed statistical differences in 23 of the 36 comparisons. This is 63% of all comparisons showing statistical differences. The control room comparisons account for much of the statistical differences as the concentrations of particulate matter were significantly less in the control room than other locations. In regards to ultrafine particulate matter, the range was from 1 to 243000 pt/cc with a mean of 13780 pt/cc.

All samples of particulate matter demonstrated a concentration less than the PEL by MSHA. The greatest concentration was 2.740 mg/m^3 at the PM Total range. This sample occurred at the Loadout Side Patio. This maximum concentration is only 27% of the PEL of 10 mg/m^3 as set forth by MSHA.

Chapter 5

Discussion

5.1 Overview of Results

Data collected during this study were analyzed to identify and compare concentrations of particulate matter between different areas of the south plant of a Northwest Ohio Lime Quarry and Processing facility. The descriptive statistics demonstrate a wide range of total particulate matter at all size ratios. Analysis of the data suggests that significant difference exists among the studied areas.

5.2 Discussion of Results

All size ranges for particulate matter recorded at least one 0.000 mg/m³ reading, this is unexpected because particulate matter is ubiquitous. The expected result would be that all samples would demonstrate at least some particulate matter. This result is however, likely attributed to be due to particulate matter being less than the meter's limit of detection. There are several instrumental errors with the pump, tubes, tube connections, and alcohol present on the P Trak wick that could cause particulate matter to be recorded as 0.000 pt/cc because the measurement is less than the limit of detection. Also each meter has a limit of detection in which the meter can only measure certain size ranges of particulate matter. The limit of detection for the DustTrak is estimated to be 0.1

to 10 μm from the operator's manual. The P-Trak's operator's manual indicates a range of 0.02 to 1 μm as the limits of detection. Finally, operator error may affect the measurement or cause the meter to give an error message.

The study suggested that the greatest concentration of particulate matter occurred at the loadout side patio. The mean at this location was greater than all other location's respective means for the particulate matter size ratio. This observation is consistent with the loadout activity of chutes placing material into trucks and rail cars. With comparing the means by location alone it appears that the Burning Floor and the Non-Loadout Patio side demonstrate similar particulate matter concentrations. This is confirmed by the Kruskal Wallis tests with the Bonferoni adjustment in that a comparison of the Non-Loadout Side with the Burning Floor did not yield statistically different results in any size ratio for particulate matter. The Control Room demonstrated the least concentration of particulate matter in all size ratios. This is consistent with expectations because the control room is provided with separate ventilation and a barrier control by means of walls and doors. The Kruskal Wallis tests with the Bonferoni adjustment confirms this result by producing statistically significant differences between all other locations in all size ratios. It is apparent from the concentration of particulate matter in the control room as well as the Non-parametric Statistical Test Results that the control measures for the control room are effective.

There were not statistically significant differences detected between the Burning Floor and the Non-Loadout Side. Additionally, only the PM_5 size ratio was statistically significant from all non-parametric tests between the Loadout Side and the Burning Floor. This suggests that the particulate matter being generated from the kilns may be

contributing to the results. Since the Burning Floor compared to the Non-Loadout Side did not show statistically significant results, it is suspected that the DKD from the kilns may be contributing to the particulate matter on the Burning Floor. Upon comparing the Non-Loadout Side to the Loadout Side only the ultrafine particulate matter and PM2.5 ratio were not statistically significant.

A number of factors could cause particulate matter at a location. Each location has unique characteristics that contribute to the particulate matter and size distribution of that particulate matter at a location. The possible influences of particulate matter at each location are summarized in Table 5.1. While many of the factors influencing particulate matter are similar throughout the locations, the differences in the locations is most significant for statistical purposes.

Table 5.1 Influences of Particulate Matter By Location for a Quarry Processing Facility

Influences of Particulate Matter By Location			
Loadout Side	Burning Floor	Non-Loadout Side	Control Room
Loadouts (Size, Product, etc)	Kiln Seals	Effective Dust control of #2 Kiln	Employees Present
Effective Dust control of #1 Kiln	Effective Dust control of ALL Kilns	Effective other south plant processes	Processes and activities occurring in control room
Effective Dust control of South Loadout System	Processes occurring on burning floor	Traffic on South Side	Seals of Control Room
Traffic on North Side	Foot Traffic through burning floor		

5.3 Limitations

Limitations of this study include areas sample were not all inclusive. One focus area was selected for this sampling. The sampling strategy was vast and time restrictions did not make it possible to include additional areas. There was also a lack seasonal variability. The samples were taken during the summer months and there could be a variation in seasons that would contribute to the results.

The most critical limitation of this study was the lack of additional statistical comparisons that were able to be made. While the objective of the study, to compare particulate matter concentrations on the burning floor, control room, and adjacent areas, was ultimately achieved, additional parameters and statistical comparisons could have been accomplished if time allowed. It would have be beneficial to compare rainfall, wind conditions, temperature, and relative humidity at each location.

5.4 Recommendations for Future Studies

Recommendations for future studies include: (1) using this study to determine if temperature, relative humidity, rainfall and other environmental factors cause a statistically significant difference in the particulate matter concentration; (2) repeating this study at other kilns in the processing facility for comparison; (3) comparing the results of this study to other quarrying facility studies for particulate matter; and (4) repeating this study during a different season for comparison

Chapter 6

Conclusions

1. There is no statistical difference in the mean airborne concentration of ultrafine ($<1 \mu\text{m}$) particulate matter between the sampling locations.

Reject this null hypothesis.

There is a statistical difference in the mean airborne concentration of ultrafine ($<1 \mu\text{m}$) particulate matter between the Loadout Side and the Control Room.

There is a statistical difference in the mean airborne concentration of ultrafine ($<1 \mu\text{m}$) particulate matter between the Burning Floor and the Control Room.

There is a statistical difference in the mean airborne concentration of ultrafine ($<1 \mu\text{m}$) particulate matter between the Non-Loadout Side and the Control Room.

2. There is no statistical difference in the mean airborne concentration of respirable ($<2.5\mu\text{m}$), thoracic ($5-10\mu\text{m}$), or inhalable ($10-100\mu\text{m}$) particulate matter between the sampling locations.

Reject this null hypothesis.

There is a statistical difference in the mean airborne concentration of respirable ($<2.5\mu\text{m}$), thoracic ($5-10\mu\text{m}$), and inhalable ($10-100\mu\text{m}$) particulate matter between the Loadout Side and the Control Room

There is a statistical difference in the mean airborne concentration of respirable ($<2.5\mu\text{m}$), thoracic ($5-10\mu\text{m}$), and inhalable ($10-100\mu\text{m}$) particulate matter between the Burning Floor and the Control Room.

There is a statistical difference in the mean airborne concentration of respirable ($<2.5\mu\text{m}$), thoracic ($5-10\mu\text{m}$), and inhalable ($10-100\mu\text{m}$) particulate matter between the Non-Loadout Side and the Control Room.

There is a statistical difference in the mean airborne concentration of thoracic ($5-10\mu\text{m}$) particulate matter between the Loadout Side and the Burning Floor.

There is a statistical difference in the mean airborne concentration of fine ($<1\mu\text{m}$), thoracic ($5-10\mu\text{m}$), and inhalable ($10-100\mu\text{m}$) particulate matter between the Loadout Side and the Non-Loadout Side.

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Appendix A

Box Plots of Particulate Matter

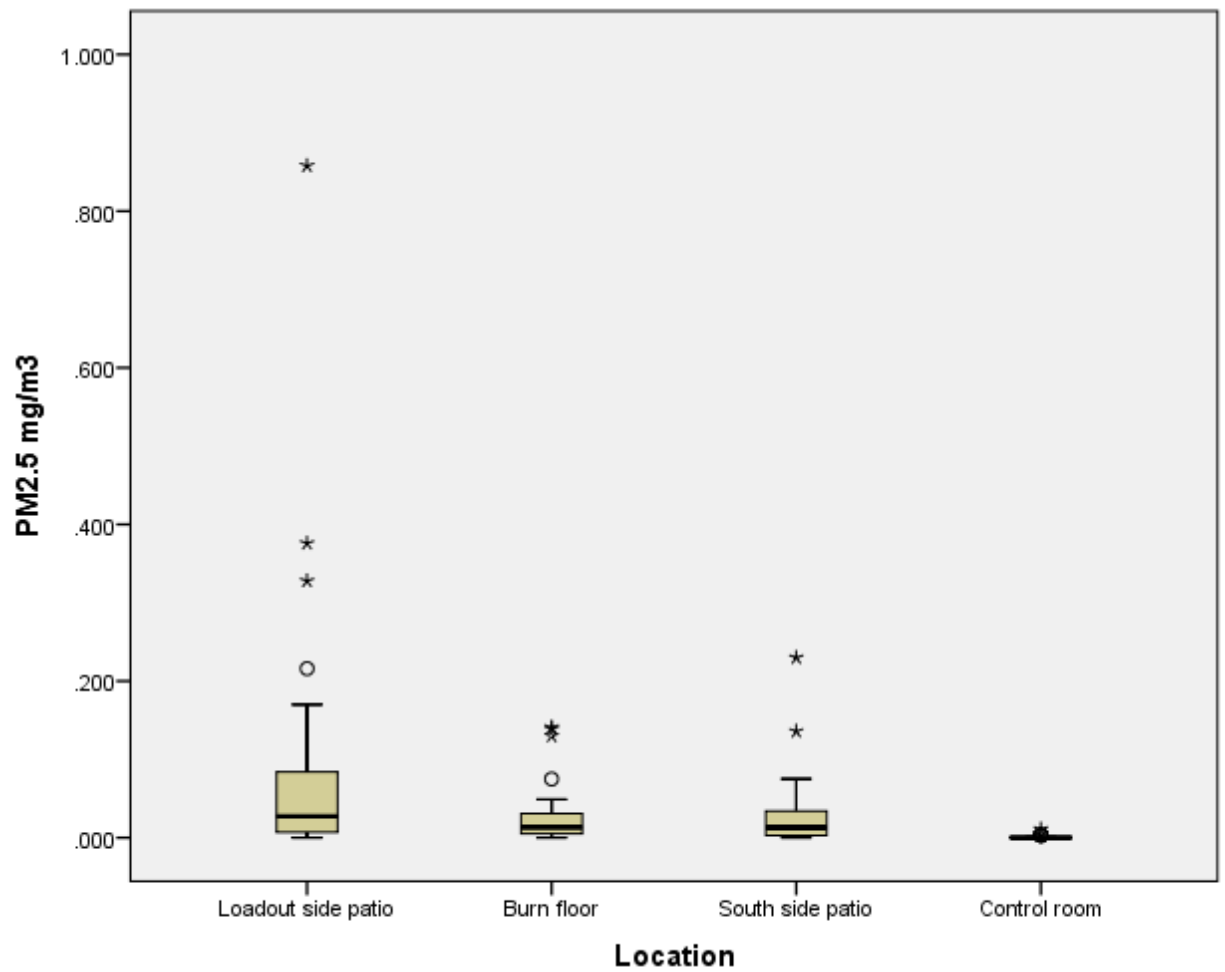


Figure A-1 PM_{2.5} Box Plot by Location

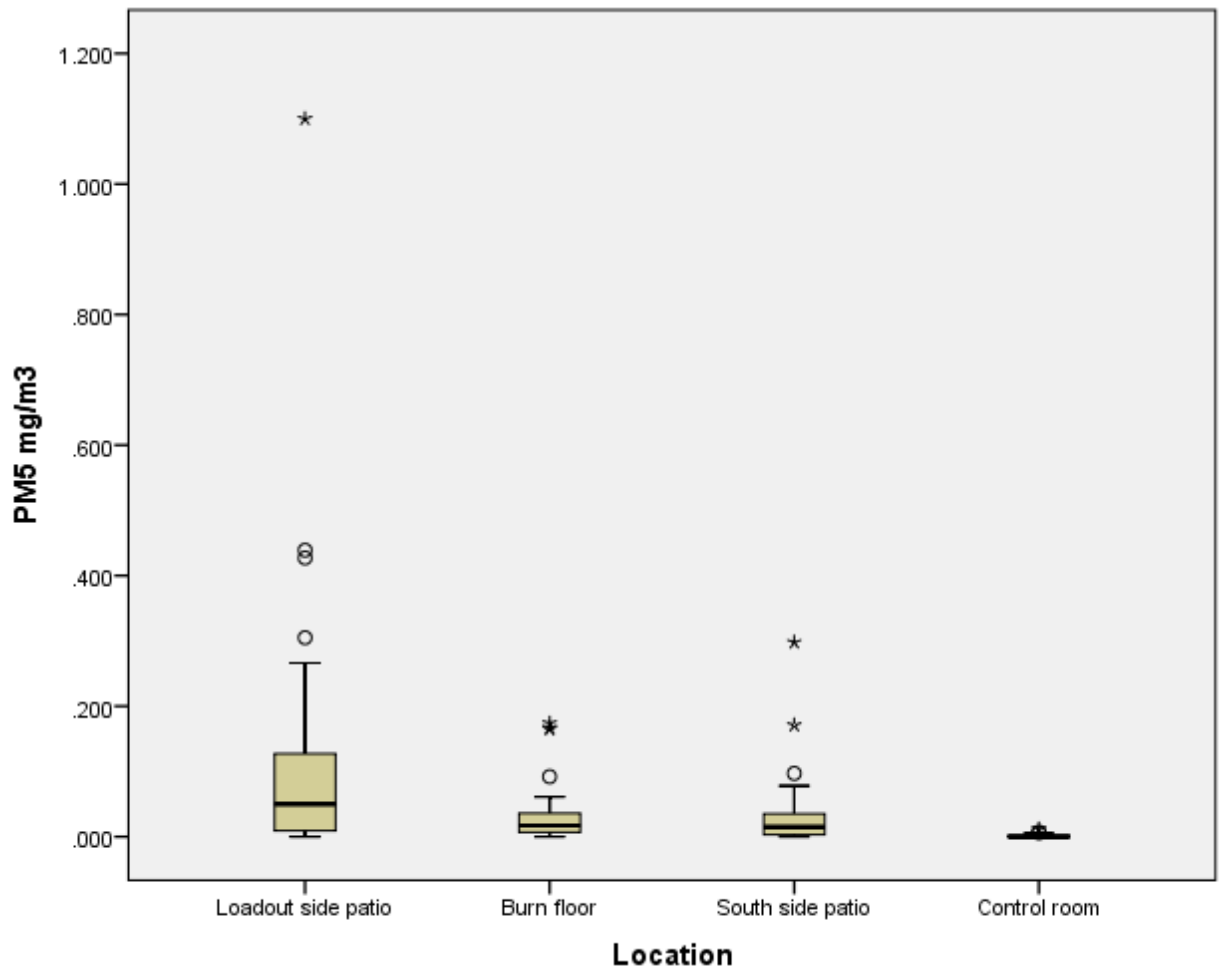


Figure A-2 PM₅ Box Plot by Location

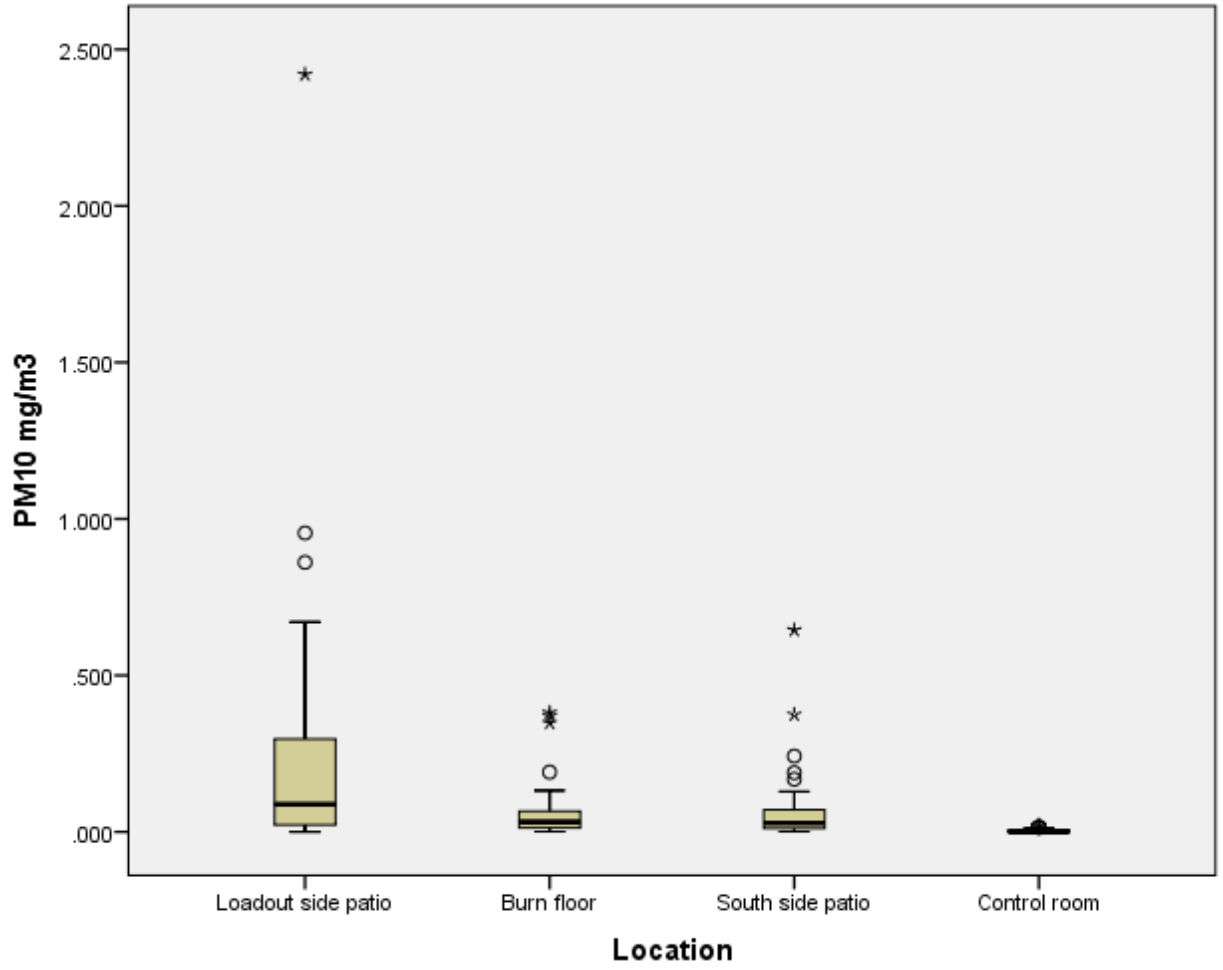


Figure A-3 PM₁₀ Box Plot by Location

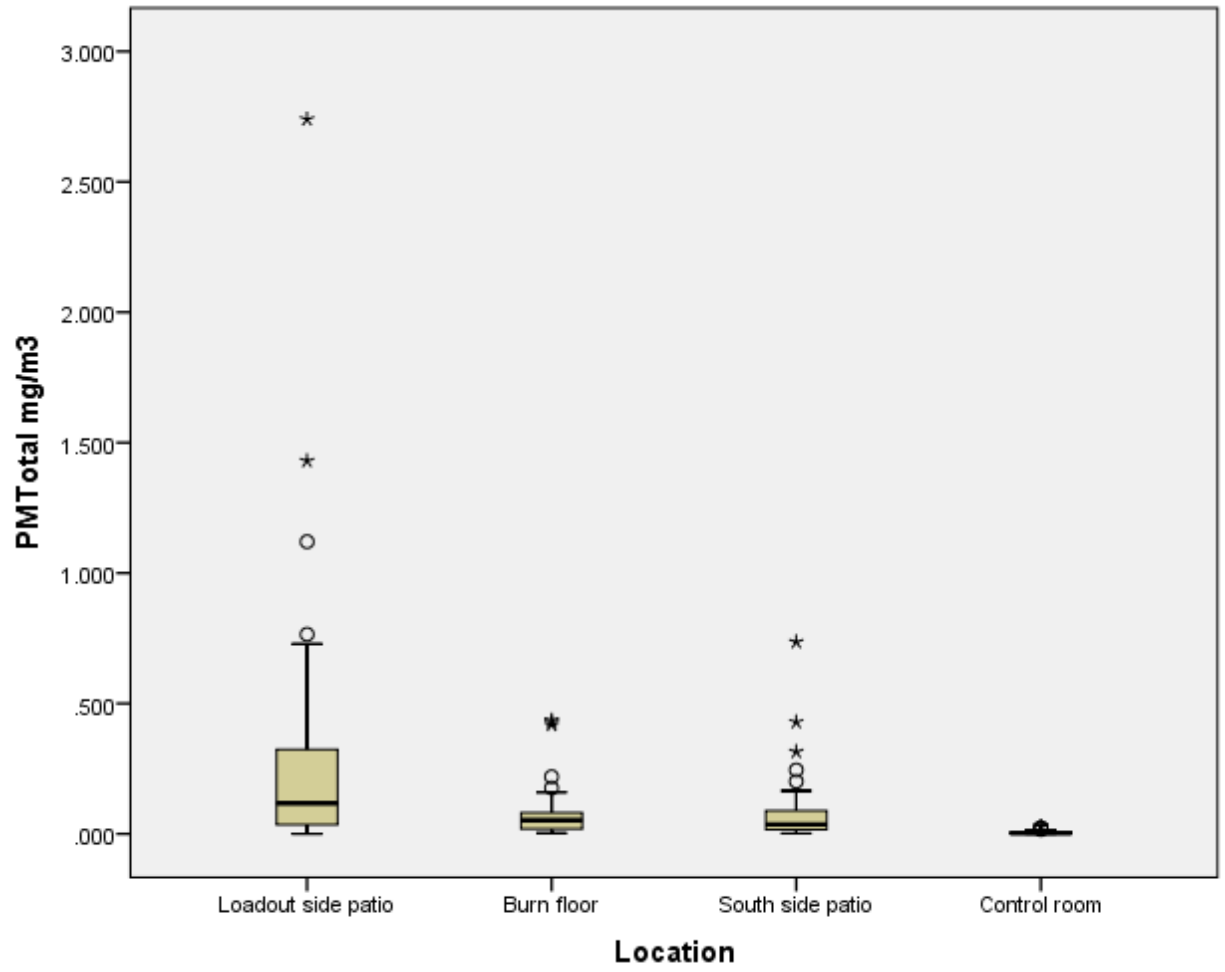


Figure A-4 PM_{Total} Box Plot by Location