WATER- BASED DUST SUPPRESSION: PRE, DURING AND POST CHARACTERISATION OF RESPIRABLE COAL DUST AT A POWER STATION IN SOUTH AFRICA

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Declaration

I, **Eric Mohlodine (student number: 0617011H)**, declare that the research project entitled "Water-based dust suppression: Pre, during and post characterisation of respirable coal dust at a Power station in South Africa" is my research work undertaken under the supervision of Dr Daniel Masekameni. The main reason for submitting this work is for partial fulfilment of degree (Master of Public Health in the field in Occupational Hygiene) at the School of Public Health, University of the Witwatersrand, Johannesburg. This work was never presented for examination at any other university. The author designed the study, carried out field data collection, data analysis, and writing the research report. Parts of this research report have been planned to be published in peer-reviewed journals and presented at conferences. All the sources cited in this study have been acknowledged through comprehensive references. The senate plagiarism policy is signed and attached as Appendix A: Plagiarism Declaration Form.

Signature — 24/06/2022 (date)

Dedication

This is study dedicated to my late mother (Mmachanka Modjadji Mohloding) who at my early age supported and encouraged me to study hard.

Abstract

Background

Exposure to coal dust may lead to serious health risks such as coal workers' pneumoconiosis (CWP), lung cancer and premature death (Han et al., 2017; Pollock et al., 2010). Therefore, the negative impacts of coal exposure on human health necessitated control strategies to prevent or minimize exposure. Literatures indicated that, despite the availability of various dust control strategies, occupational diseases from coal dust exposure still exists in large numbers particularly among the coal related employees (Almberg et al., 2018; Joy & Colinet, 2012; Perret et al., 2017; Shekarian et al., 2021). Coal workers pneumoconiosis (CWP) remains an important occupational lung disease in many parts of the developing world (Hulshof et al., 2019). "Based on International Labour Organisation (ILO) on global occupational health and safety (OHS), more that more than 2 million deaths occur in the workplace worldwide due to several occupational incidents"(Hulshof et al., 2019).

This report further states that about 6 300 workers die daily due to exposure to dangerous occupations (Hulshof et al., 2019). To date, despite the inherent health burden associated with hazardous exposure to coal dust there is paucity of studies focusing on the efficacy of engineering controls in reducing dust emissions(Qi & Echt, 2016).

Aim of the study

The study aim was to evaluate the efficacy of the water based dust suppression method in reducing airborne coal dust exposure at the coal stockyard at a Power station.

This study hypothesised that water suppression methods do not reduce concentrations of coal dust submicron and nanoparticles at coal stockyard scenario.

Methods

This study is a quasi experimental study design whereby measuring results from various locations in the Coal stockyard was taken to determine dust concentration before, during and after water dust suppression. The measuring was based on three possible exposure scenarios (pre or before, during and post or after). Three measuring points (point A –C) within the coal stockyard were identified for the efficacy determination. The measuring was carried out for 30 minutes in each of the exposure scenario. To qualify the scientific validity and reduce uncertainty/ increase data quality, triplicates measuring were conducted in each point.

A direct reading instrument for area dust measuring, Nanozen (DustCount 9000-Z1) was used to obtain respirable coal dust particle of (PM_1) before, during and after water dust suppression method.

Results

The study evaluated the efficacy of water suppression as a control measure used at the coal stockyard area. The dust concentrations recorded were 8, µm 6, 9 micrometre (µm) and 13, 1 µm for the pre, during and post treatment, respectively. After evaluating and comparing results, it was observed that during the application of water dust suppression method, 80 to 90% dust particle of the size ranging between 1, 1 -5, 5 µm were effectively reduced and 40 -60% dust particles of smallest size between 375 nm to 732 nanometre (nm) were reduced.

Conclusion

The findings indicated that the efficacy of water dust suppression method increases where there are an increase in number of larger dust particle diameter in size. When comparing the three exposure scenarios namely pre, during and post treatment, it was found out that high concentration of fine and course particles were emitted during water suppression scenario, which was more than any other scenarios. Through observation activities leading to the emissions of coal dust particles included tipping of coal in the stockyard, coal stockpiling using bull-dozers while resuspension of dust particles was due to high wind speeds, workers movements and truck/ vehicles movement. This finding was expected since there are several activities which influences dust resuspension prior or after water suppression treatment. Therefore, it may be necessary to utilise the water sprinklers around a coal stock yard area due to the frequent entry and exits of the heavy vehicular movement for larger particles. However, as for submicron particles it is recommended that the use of fogging be considered as a long-term intervention. On the road surface design, the use of tarred road may assist in reducing the resuspension potential due to increase in the particle binding force.

The hypothesis of this study confirmed that dust water suppression methods do not reduce concentrations of coal dust submicron and nanoparticles. The efficacy of coal dust water suppression method depend on the size of particles released. The bigger the particle, the more the effectiveness and the smaller the particle, the less effective. In this study it was found out that water dust suppression at coal stockyard have led to a 90% reduction of particles above 1 micron while a reduction percentage of about 40% was found for submicron particles.

This dissertation laid the groundwork both for improvement in the design of existing coal dust suppression methods and the development of improved dust control interventions such the use of fogging to suppress submicron particles. The insights gained from this study may assist in the selection of appropriate strategies and technologies to mitigate hazardous exposures in coal storage facilities.

Acknowledgments

I would like to thank and show my appreciation to some organisations and several individuals who have made this study possible. My sincere gratitude goes firstly to my supervisor Dr Masilu Daniel Masekameni who has been guiding me from the start until the end, Eskom for permitting and allowing me to undertake a study in their premises. Goitsemang Keretetse, (Program Coordinator) for your support throughout the study period. Dr Steven Mathetsa and Dr RM Moila for encouraging me to continue with my studies. Finally, my wife, Victoria Mohlodine, for providing me with support and allowing me to continue with my studies

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List of abbreviations

CSV	Comma separated value
CWP	Coal workers Pneumoconiosis
DEL	Department of Employment and Labour
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DRI	Direct Reading Instrument
EIA	Environmental Impact assessment
EMP	Environmental Management Plan
Eskom	Electricity Supply commission
IHD	Ischemic heart disease
ILO	International Labour Organization
Mg/m3	Milligram per cubic meter
Mt	Million tons
OHS Act	Occupational Health and Safety Act no 85 of 1993
OHS	Occupational Health and Safety
PPE	Personal Protective closing
PS	Power station
PM	Particulate Matter
SA	South Africa
SASOL	Suid-Afrikaanse Steenkool-, Olie- en Gasmaatskappy/ South African Coal, Oil and Gas Company
Si	Silica
WHO.	World Health Organization
$\mu g/m^3$	Microgram per cubic meter

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CHAPTER 1: INTRODUCTION

This chapter gives an overview of the importance of the use of coal, coal dust control and the identification of health hazards associated with the handling of coal. The focus will be on prevention of the release of coal dust by using water as a coal dust suppressant. Included in this chapter are also the legal requirements as contained in the South African legislation and regulations on how to comply with the control of coal dust. Other types of coal dust control that are most common in the mining industry which may also be applicable in an electricity power plant as identified by various literature are highlighted in this study. This chapter further explains what led to the decision for the study or, motivation and why is it important or justified. The outcome or finding from other related international and national literature reviews are discussed and important factors summarised. Study objectives are also covered as the closing part of this chapter.

1.1 Background

Coal use as fuel energy in South Africa and other parts of the world has been happening for many years to date. In general, coal has been used since the older days as the primary source of fuel for domestic heating and cooking (Kerimray et al., 2017). Millions of South African from urban and rural areas depend on electricity as the main source of energy on daily basis and due to growing in population the demand continue to increase from back then until now (Gasparotto & Da Boit Martinello, 2021; Kruger & Krueger, 2005).

Driven by strong need for electricity due to population and economic growth (Eberhard, 2015), South Africa's Power stations' coal stockyards are supplied with thousands of tons of coal on a daily basis from the coal mines. In the process of coal delivery to the Power stations, coal dust is released into the air which has negative impacts on the workers as well as the environment. There have been calls from Non-governmental organisations to switch to renewable energy to minimize coal pollution impact to the environment and the people, but currently in South Africa the available alternative energy source to substitute coal energy is not enough to can do so. (Kerimray et al., 2017). This means that as long as we are still more dependent on coal as a means to produce electricity, the risk of exposure to coal dust and pollution will still exist.

Due to the large amount of coal being transported and stored at the coal stockyards, there is a need for effective control of the risk of exposure to coal dust. If we look only at the year 2020 period, the total amount of coal used by the South African 's coal Power station(s) was about

108.61 million tons (Mt) per annum (Report, 2020). Apart from the coal burnt mentioned above, the Power stations still needed to maintain their coal stock level, requiring continuous coal delivery. As more and more coal are transported to coal Power stations, there is a need to identify and control the amount of coal dust generated in order to protect the workers against coal dust related diseases. More studies have proven that coal dust in the form of airborne particles matter are responsible for most coal related respiratory diseases (Finkelman et al., 2002; Ross & Murray, 2004) . In figure 1, there are more than twelve Coal fired Power stations which are found in various parts of the South African provinces, with Mpumalanga leading in the number of coal Power station and coal mines (Eskom Holdings Ltd, 2019). The coal stock yard selected for this study is found in one of the Power station (Tutuka) in Mpumalanga province.

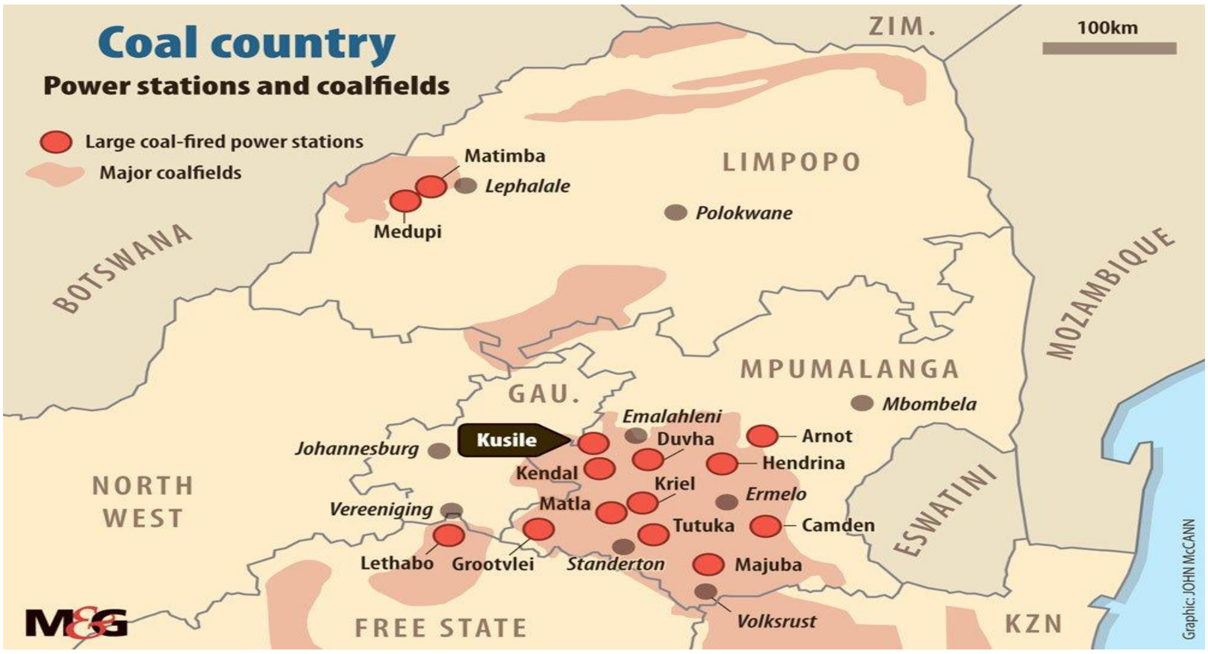

Figure 1: Map of SA Power stations & Coalfields, by John McCann M&G, 25 October 2019

Historical studies on South Africa's coal fired Power stations gave more attention to air pollution caused by coal combustion and few on the impact of coal dust or how coal dust remains to be one of the causes of occupational diseases (Gasparotto & Da Boit Martinello, 2021; Rautenbach et al., 2021; Sumbane-Prinsloo et al., 2021).

In countries such as South Africa and China, the use of coal is high because only a small percentage (not more than 30%) of electricity are generated through means other than coal (Eberhard, 2015; Mathu & Chinomona, 2013).

Current factors encouraging the continuous use of coal as an energy source in South Africa include, accessibility, affordability and lack of reliable alternatives (International Energy Agency, 2016). The demand by the export market such as India and China further contribute to the mining of large amount of coal on daily basis (Peatfield, 2003). Despite challenges that come with the production, transportation and the use of coal, it is estimated that the usage of coal in SA will continue for a few more decades as the processes and policies for energy mix are at an infant stage (Department & of Energy, 2020). The high demands of coal for electricity Power stations are a big factor that forces the continuous supply and storage (via coal stockpiles).

The coal Power stations use coal as its main fuel used for combustion in the boiler to produce electrical power. To meet the daily large coal demand by a Power station, a coal stockyard is needed to handle the coal in large quantities which comes with its challenges, particularly with regards to coal dust and associated risks (Hamelmann & Schmidt, 2003). The proper control of coal dust need to take place in all processes, starting from mining to transportation until handling in the coal stockyard area (Shah et al., 2010).

One of the challenges associated with the coal handling and storage process is the risk of developing respiratory diseases due to exposure to coal dust. For example, employees working with coal have a bigger chance of developing simple Coal workers Pneumoconiosis (CWP) where at first may not appear as illness until a proper diagnosis is done. Coal related diseases is a serious problem in the mining industry across the world. In 2014 China had the high percentage of coal-related deaths than any other country in the world (Xi et al., 2014).

The main problem associated with the inhalations of coal dust is black lung diseases. Black lung diseases include CWP and obstructive lung diseases, such as chronic bronchitis and emphysema as defined by the Federal Coal Mine Health and Safety Act of 1969 (Finkelman et al., 2002).

The main route of entry of fine coal dust particles into the lungs of those exposed is through inhalation or ingestion. When an individual is exposed to coal dust for a longer period of time, there will be a continues accumulation of fine dust particles in the lungs until to the point where the ability of body system to remove it is affected (Gasparotto & Da Boit Martinello, 2021).

To prevent or minimize excessive exposure to coal dust, actions such as periodical screening of exposed employees is needed. This will help to diagnose or detect coal-related disease before the impact becomes worse. This will also help in putting proper control in place and where necessary minimize the exposure time. To minimize impact of CWP, employers must continue to seek practical and sustainable initiatives to further improve the control needed to reduce the number of CWP incidents.

The basis for any law in South Africa is the Constitution. According to Chapter 2 (bill of rights) of the South African constitution, "everyone has the right to an environment that is not harmful to their health or well-being". Other South African legislations like Mine Health and Safety Act, 1996 (No. 29 of 1996) in the mining industry and Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) in other industries touch partly on the control of dust. The role of these legislations may be not fully effective because they focus more on enforcement. The enforcement will work well when there is a commitment by employers, employees and government. In SA, various government departments manage risks of exposure by enforcing the compliance through legislation within their respective areas. This study could not get evidence of intergovernmental coordination in the enforcement of coal dust control in various work environment. It was found that some government departments has their own area of interest or focus when coming to the enforcement. Department of Mineral Energy and Resources (DMER) through Mine health and safety Acts, deals with the issues of dust relating to mining. Department of Employment and Labour (DEL), focuses more on Health and safety of workers in other industries through Occupational Health and safety act , whereas on the other hand, Department of Forestry, Fisheries and the Environment (DFFE) deals mainly with issues relating environmental through National Environment and Management Act. The roles and relationship of difference sphere of government (National, Provincial and local) is sometimes not clear (Development, 1999).

1.2 Literature review

1.2.1 Coal mining areas in South Africa

Currently, in South Africa large quantity of coal are found in few provinces like Mpumalanga (Highveld area), Free State in the Vaal Triangle (Vereeniging and Vanderbijlpark), Kwazulu Natal (primarily in the northern areas of the province and in Zululand) and Limpopo (Waterberg and Vhembe districts). Some years back, Fransch-Hoek in Western Cape, was the first place known to be having coal (Peatfield, 2003). Currently Western Cape is not counted among coal areas. The discovery of coal in that area led to more discoveries in various parts of South Africa which include Eastern Cape, Natal (Kwazulu Natal), Vereeniging and Boksburg (Peatfield, 2003).

In the early 1890's more coal mines started mushrooming in the Mpumalanga area, formerly known as Eastern Transvaal (Peatfield, 2003). The need for electricity by many industries led to the increase in coal mines in Mpumalanga province, especially in the Highveld area. The availability of more coal resulted in more coal fired Power stations being built in that part of Mpumalanga than any other province in South Africa as shown in Figure 1. The coal power stations and mines in the Mpumalanga Highveld area presented environmental challenges such as air and water. In late 2008, this area was declared a “pollution hotspot” by the Department of Forestry, Fisheries and the Environment (Highveld Priority area Air Quality, 2011).

1.2.2 The use of coal

In South Africa, the large amount of coal is mostly used for electricity generation by the national government utility company called Electrical supply commission (Eskom) and other companies like Suid-Afrikaanse Steenkool-, Olie- en Gasmaatskappy (SASOL) which in English means South African Coal, Oil and Gas Company (Makgetla et al., 2021) . The main types of mines found in SA are open cast and pit or underground mines. Coal from the mine is transported either by conveyor belts, trains or by coal trucks to the coal stockyard of the Power stations. In the coal stock yards, it will further be stockpiled before being used as reflected in Figure 7.

Coal is used in small amounts for domestic purposes by a few households, especially those close to mining areas (Balmer, 2007) . The 2011 census reported that about 18 million people who live in informal settlements had no electricity leading them to burn raw coal for cooking (Le Roux et al., 2004; Kimemia et al., 2010). In general, the high demand for coal usage is mainly influenced by the increase in the need for energy source by industries and households to support economic development and population growth (Balmer, 2007).

Coal in South Africa is one of the highest export commodities because in 2019 more than twenty-five percent (25%) of coal was exported to other countries in the world through its terminal of Richards bay (Makgetla et al., 2021)

In Asia, particularly in a country like China, coal usage is almost like in SA as they use about seventy percentage of coal for power generation and steel production (Boland et al., 2012). South Africa rely electricity for growing its economy and improvement of the standard of living of their people and with the; with the other sources of energy coming at a slow pace, the face out of coal for generating electrify will take long (Finkelman et al., 2002).

It is anticipated that in the year 2040, coal will still be the leading source of electricity generation with close to forty percent more than other sources like renewables and natural gas (US EIA, 2013)

When comparing the overall usage of coal in the world for the year 2011 to 2012, the figure as contained in the World Coal Association 2012 statistics showed that the use or the demand of coal increased by less than three percent (3%), which is an indication that coal was still the preferred energy source (Beer et al., 2017).

South Africa is amongst the highly ranked countries in terms of coal demand because it contributed to about eighteen percent (18%) of world coal consumption (Ma et al., 2018). It is ranked high in the use of coal as the primary energy needs are provided for by coal (Department & of Energy, 2020).

The high demand for coal especially during seasons like winter and the rainy season coupled with the fact that some of the coal mines are a distance away from the Power stations has seen most of the Power stations increasing their coal stockyards to accommodate more tonnages from other sources to guard against shortages during high demand. It is important to also note that coal stockyards may present other challenges which include spontaneous combustion, negative impact on the environment and occupational diseases for humans (Widder et al., 2011).

1.2.3 Dust emission and deposition mechanism

Particle size plays a role in the emission and deposition of coal dust. When dust particle are suspended in air, the bigger particle will fall shortly and the smaller particle will remain suspended in the air for longer period of time (Chen et al., 2017). The small particle will move by diffusion and later deposit by interception or impaction, while the larger particle deposit by gravity (Zhang et al., 2015). The respirable dust fraction migrate by going up and when they return to the surface they attach either horizontally or vertically (Zhang et al., 2015)..

In taking steps to control dust exposure, factors that influence emission transportation, diffusion and settlement or accumulation of dust particles must be taken into consideration as this may have negative impact in the effectiveness of your control measures (Sarver et al., 2019).

1.2.4 Coal dust exposure

Factors that contribute to the workers' coal dust exposure are coal mining, processing, drilling, blasting, transportation and storage (Onder & Yigit, 2009). During the above processes or activities, coal dust may be dispersed into the air when not properly controlled.

In the power generation industry, coal is transported from the mine to the Power stations' stockyards whilst already crushed into small sizes. The crashed coal increases the chance of producing more coal dust into the air, which under normal circumstances cannot be easily prevented unless proper controls are in place (Mandal et al., 2012). Figure 3 shows coal stockpile of stockyards in the study area. When coal trucks are in the process of tipping coal to the ground in the coal stockyards, it may be difficult to suppress dust using water because after tipping, there will be excessive dust that is immediately released into the air before the water can be sprayed (Ghose, 2007). The movement of trucks going in and out of coal stockyards contribute to increase in coal dust to which employees and communities can be highly exposed if no proper and effective controls are put in place (Chaulya et al., 2011). Coal is stored in large quantities in the coal stockyards and one of the activities needed is to control the release of coal dust as more coal is received (West, 2011). The release of coal dust during tipping, loading and resuspension of coal dust, may affect the effectiveness of the dust control (Ghose & Majee, 2007) Furthermore, activities such as usage of dozer machine continue to produce dust during the pushing of coal to compacting to create more space as part of stockpile management (Keleher et al., 1998)

The most important way to provide the basis for planning effective coal dust exposure control to prevent occupational diseases such as CWP is the measuring and characterisation of coal respirable dust (Ghose & Majee, 2007). Coal dust measuring is one of the means to identify the factors that may interfere with the quality of air in the workplace (Chaulya et al., 2019).

Dust measuring in the coal stockyard may be affected by dust from other locations such as conveyor belts, coal stockyards area and haulage roads. In the coal stockyard, there may be other activities taking place that can release more coal dust concentration that will affect other areas that emit low coal dust concentration. The emitted dust will affects the quality of air in that area which in turn may affect the health of workers and the surrounding communities. Figure 2 shows typical example of activity that may contribute to dust pollution. It is a bull dozer pushing coal in the stock pile and in the process dust is released to the areas already sprayed with water. In one of the studies conducted in 2007 to Characteristics of hazardous airborne coal dust in the underground mine, it was suggested that coal supplied to a certain region was responsible for the increase in the number CWP in that specific region depending on it is hazardous properties (Ghose, 2007).

Figure 2: Typical Bull dozer working on coal stockpile.

In South Africa, drinking water sources can be exposed to uncontrolled coal dust that can lead to pollution since most of the water is drawn from rivers, dams and other surface sources (Ochieng et al., 2010) As water is sprayed to suppress dust, some of the water may end up in the water drainage system which could affect agricultural activities within that specific area (Du, 2018). The stockyard serves as a coal reserve storage area, which is not enclosed leading to the release or resuspension of fine dust particles. An example of a typical stockyard with coal piled up is shown in figure 3.

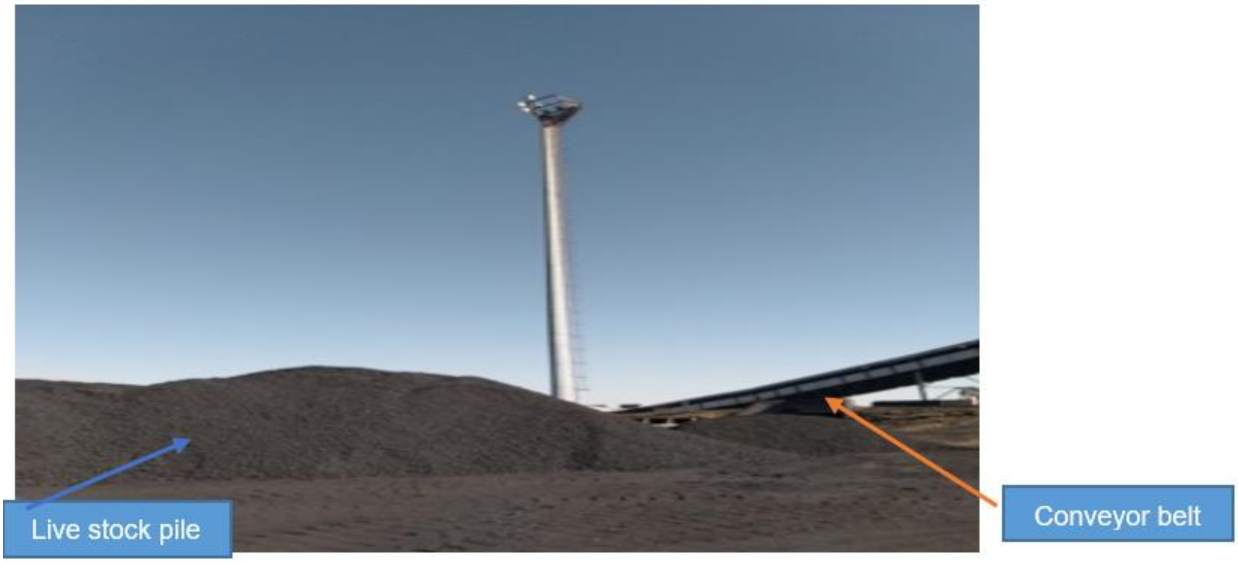

Figure 3: Typical coal stockpile in a Coal stockyard.

1.2.5 Health effects of coal dust

Coal dust pose health risks because it contain harmful amount of respirable silica. (Listak & Reed, 2007). International and national studies reveal that prolonged exposure to respirable coal dust will lead to lung diseases (Hamatui et al., 2016; Lewis & Moorman, 1989; Stanton et al., 2006; Stayner & Graber, 2011). The most common lung disease caused by coal dust is known as coal workers Pneumoconiosis (CWP) or Anthracnosis which can be identified during medical screening of the exposed individual. Autopsy may also be used to identify carbon deposits on the lung (Beer et al., 2017). The other latest risk factor associated with coal dust is called dust-related diffuse fibro (DDF) (Beer et al., 2017).

Beside the fact that there are other health impact or risk presented by coal dust, coal workers Pneumoconiosis (CWP) is still considered one of the worst occupational diseases because it cannot be reversed (Han et al., 2015).

Most of the coal dust-related diseases are caused by prolonged exposure to coal dust from dust-generating sources (Stanton et al., 2006). Other types of coal lung diseases include silicosis and mixed dust pneumoconiosis (Beer et al., 2017).

In one study conducted for coal dust exposure and mortality, it was found out that long time exposure to coal dust can contribute to an increased risk of mortality from ischemic heart disease among coal workers, particularly in the coal mines (Landen et al., 2011). It was also highlighted that the risks level varies from one region to another because of differences in coal dust particles compositions from the various regions (Landen et al., 2011). It was further highlighted that coal dust is one of the contributors to the negative occupational health impact to the coal handling workers as well on the receiving environment (Chaulya et al., 2011). Some studies that were conducted to understand the relationship between coal dust exposure and coal workers' pneumoconiosis, has concluded that coal dust is the cause of coal workers' pneumoconiosis (R. N. Naidoo & Chb, 2008; Wang et al., 2016).

The study called "investigation into dust exposures and mining practices in mines" which was conducted in 2010 has concluded that CWP affect people, particularly workers as results of exposure to higher coal dust concentration for longer periods of time, especially without effective control measures (Pollock et al., 2010). In 2009, one study which was aimed at "assessing respirable dust exposures in an opencast coal mine" has described the cause of CWP as inhalation of a coal dust particle, which is very small; usually less than 10 microns in diameter, and further called CWP with another name of "black lung" (Onder & Yigit, 2009). The study to "characterize hazardous airborne dust around an Indian surface coal mining area" suggested that particles of smaller diameter present the most risk due to the its ability to remain in suspension mode for a prolonged duration (Ghose & Majee, 2007; Wu et al., 2011).

In South Africa, some studies conducted in the mining industry has proved that there were more respiratory diseases in the coal mining industry than any other type of industries with the statistics showing coal dust as the major cause of CWP respiratory diseases (R. N. Naidoo & Chb, 2008; Stanton et al., 2006). Based on the literatures reviewed for this study, it can be concluded without doubt that prolonged exposure to coal dust without effective control will certainly cause CWP on those exposed (Brodny & Tutak, 2018; Hamatui et al., 2016; Kumari et al., 2011; Lowe, 1989).

The results of another study conducted in 2016 indicated that exposure to coal dust is the cause of negative impact on lung functioning because of its effect on the exposed individuals as compared to the non-exposed (Hamatui et al., 2016) Furthermore, another study by Hobson and Guy (2014), suggest that a particle of a small diameter can penetrate the lower region of the respiratory tract and cause severe health effects (Hobson & Guy, 2014). The long exposure to the low concentration of coal dust may also cause the accumulation of dust in the lungs as time goes, which in turn end up causing health risks (Stanton et al., 2006). In 2017 in a study to “investigate the relationship between pneumoconiosis and respirable dust in U.S. coal miners,” it was found that time plays and important role in exposure and cause of diseases because the more time spent in working with coal, the high the chance of developing coal dust related respiratory disease (Phillips & Belle, 2003; Ross & Murray, 2004). The 2017 study called “mine dust lung disease in the modern era” further emphasizes that the accumulation of coal dust is an important factor in the cause of CWP (Perret , et al., 2017).

In addition, a study that aimed to “assess human health risks from heavy metals in outdoor dust samples” found out that inhalation and ingestion of dust particles were the major routes of exposure which mostly results in higher health risks (Rout et al., 2013)

The 2004 study for “radiographic outcomes among South African coal miners” indicated that the number of CWP among coal mine workers were decreasing but taking into considering that SA is one of the main coal producer, the lower number of CWP still had impact on the and coal production.(G. Naidoo & Chirkoot, 2004). In 2013 the number of worldwide work related CWP cases were estimated to be increasing by nearly twenty percent as stated in the guidelines published by International Labour Organization (ILO) (Beyan et al., 2021).

Apart from the health effect posed by coal dust in the coal stockyard, the problem of spontaneous coal combustion may occur when certain environmental conditions present themselves depending (Özden & Üt, 2006).

1.2.6 Coal dust control

Due to the negative impacts caused by dust especially respirable coal dust, there is a need to have a clear strategy to prevent the occurrence of occupational respiratory diseases by first taking the basic steps such as identification and assessment before proper control is put in place (Stanton et al., 2006). Without dust exposure evaluation, it may be difficult to understand the level of coal dust generated by any process in any work environment, which may be a challenge for the management of that particular environment to come up with proper dust control measures to either prevent or minimize the exposure. Given the challenge presented by coal dust hazards there is a need to come up with effective control measures.

Unlike in Queensland, Australia, where there is a specific code practice that was approved to manage hazards as a results of exposure to respirable dust in their coal-fired Power stations, South Africa has no such specific guidelines (Queensland Government, 2020).

On daily basis, there are trucks that transport coal from difference mines to power stations’ coal stockyard across Mpumalanga and Limpopo provinces. During offloading process , more airborne coal dust particles are produced to the surrounding area which may be lead to exposure to the workers (Onder & Yigit, 2009). Due to the number CWP cases in the coal mining, there are some control measures in place to minimize the coal dust exposure from mining to coal handling or stock piling (Stanton et al., 2006). The control of the release of coal dust during the offloading of coal at the power station need to give similar attention to that of coal miners at the mining industry. Industries such as construction, mining, steel and others have some common control methods in place to minimize or suppress dust. These methods include but not limited to engineering, administrative, personal protective clothing (dust musk) and worker training (Cecala et al., 2012).

The common personal protective equipment (PPE) used by most industries to control or minimizes dust exposure is dust mask. The observation during the site visit to the study area was that they also provide their coal stockyard workers with disposable dust masks (FFP1) as shown in figure 4. These dust masks is used to cover the mouth and nose.

Figure 4: Illustration of a disposable dust mask typically used in coal stockyards by workers.

The most commonly used method to control dust l in most of the industries including coal fired power station is the use of water to suppress dust (Swanson & Langefeld, 2015) Figure 5 illustrate the typical water tanker used for dust suppression.

The control of coal dust through water suppression can also contribute to an increase in water usage but it will be difficult to quantify the total water consumption of coal-fired power plants because water is used for the various purposes (Widder et al., 2011).

The use of water suppression as a means for dust control in power stations has been applied in many countries worldwide, for example, in Australia, this method was found to be effective in suppressing the coal dust thus reducing the level of exposure by more that 60 percent (Rasul & Nunen, 2007).

In the mining industry in particular the spraying of water to prevent airborne dust has been a widely used practice since the 1960s (Tessum & Raynor, 2017). Water dust suppression has helped in reducing airborne dust but some gaps have being identified (Xi et al., 2014). With this method, it may be difficult guarantee effectiveness because there are some factors that play a role (Hermanus, 2007). This factors include but not limited to weather conditions, water pressures, spray nozzle, other dust generating activities and water flow. The amount of water required to cover specific may be difficult to measure because water is usually sprayed in the direction where dust visible. (Cecala et al., 2012).

A study by Swanson & Langefeld, (2015) suggested that using the water dust suppression method may be inadequate in reducing the concentration of respirable dust because certain dust particle size and weight may be difficult to control due to its inability or difficulty in dissolving or making contact with water droplets (Swanson & Langefeld, 2015). The same study further highlight that spraying water may cause some dust to disperse way above the level of water spray (Swanson & Langefeld, 2015). The same study by Swanson & Langefeld (2015) suggested that the use of water spray systems must be specific to the area by taking into consideration the conditions like the type of activities and frequency of water spray need in that area (Swanson & Langefeld, 2015). The other reason for the method to be not always highly efficient is because it is difficult to measure the amount of water needed for an area as water is usually sprayed in the direction of visible dust at one area at a particular time (Cecala et al., 2012). A study by Tessum & Raynor, (2017) on "the effects of spray surfactant and particle charge on respirable coal dust capture", has suggested that moisture content, ambient humidity, dust components process method, and particle size may affect electric charges which in turn will affect the efficiency of coal dust suppression by using water sprays (Tessum & Raynor, 2017).

The concern raised in a study by Listak & Reed, (2007) is that the spray of water may affect the surrounding equipment which may cause wear and tear (Listak & Reed, 2007).

"Dust Control Handbook for Industrial Minerals Mining and Processing" (2012) suggest that wet spray system for controlling dust will work well when it is done at the source to immediately prevent dust from becoming airborne (Cecala et al., 2012). In an area like coal stockyard, the control of dust from the source may be difficult because of multiple source of coal dust. In this type of area the control of dust by using water dust suppression method to wet dust airborne particles to force them to settle back to the ground seems to be suitable (Cecala et al., 2012).

In 2007 study called "feasibility of grey water reuse for coal dust suppression in a coal-fired power station" which was conducted in Australia's power stations there was a difference concern about the use of water to suppress dust because they regarded coal water suppression as one of the contributor to the contamination of potable water sources (Rasul & Nunen, 2007). The study further raised concern about the amount of water used to control dust as it is estimated that the amount of water used was up to three per cent of the total water supplied for the power station (Rasul & Nunen, 2007). The amount of water usage was also highlighted by the “dust control handbook for industrial minerals mining and processing” (2012) which suggested that because of lack of water usage guidelines for dust suppression, the application is not always the same as in most of the cases others may end up using a lot of water as sometimes there may be a need to repeat spraying water several times so as to capture most of the airborne dust in the area (Cecala et al., 2012).

In other cases, the spraying of water may be ineffective because water spray nozzle may be affected by coal dust particle and become blocked leading to it being unable to release water in a normal way and fail to suppress coal as anticipated (Chan et al., 2012). In the study called “new respirable dust suppression systems for coal mines” (2007), it was established that when using water sprays over the years, the nozzle must always be changed and designed in such a way that it is able to increase the pressure and produce smaller droplets in order to be effective in collecting small dust particles (XIE et al., 2007). This study has also has suggested that smaller water droplets are more effective in suppressing small dust particles out of the air to the ground (XIE et al., 2007).

Figure 5 shows a typical water tanker used at the coal stockyard. Based on concern raised by some studies regarding effectiveness and amount of water used, it is clear that these methods need to be evaluated further to identify areas of improvement (Cecala et al., 2012; Chan et al., 2012; XIE et al., 2007).

Figure 5: Typical coal dust suppression method using 1800L water tanker.

The measuring and control of the submicron particles are critical because of their ability to penetrate deeper into other organs in the human respiratory systems (Cecala et al., 2012). In addition, most studies have focused on larger particles (PM 2.5 and PM10) in diameter in exposure assessment due to the compatibility with the gravitational analytical method (Englert, 2004; Pope et al., 2004).

Measuring of coal dust is the most important step to determine the source and level of employee exposure so that proper and relevant control measures can be implemented (Colinet et al., 2017)

Measuring coal dust in the coal stockyard may also assist the researchers in finding other alternative methods that can be used to minimize exposure to the coal dust (Stanton et al., 2006). Dust exposure level information may help in prioritizing control measures in a specific area (Morfeld et al., 1997). The representative measured sample can be analysed to get concentrations of coal dust to assess the impact of the coal in a coal stockyard which will help to further ensure the correct action as well as awareness and enforcement of the safety rules (Moskovaya et al., 2017).

1.3 Problem statement

Exposure to coal dust may lead to serious health risks such as coal workers' pneumoconiosis, lung cancer and premature death (Han et al., 2017; Pollock et al., 2010). Therefore, the negative impacts of coal exposure on human health necessitated the need for control strategies to prevent or minimize exposure.

Literature indicates that, despite the availability of various dust control strategies, occupational diseases from coal dust exposure still exists particularly among the coal related employees (Beer et al., 2017; Han et al., 2015; Mukherjee et al., 2005).

CWP remains an important occupational lung disease in many parts of the developing world (Hulshof et al., 2019). Global Occupational Health and Safety (OHS) Statistics – ILO stated that, more than 2 million deaths occur in the workplace worldwide due to several occupational incidents. This report further states that about 6 300 workers die daily due to exposure to dangerous occupations (Hulshof et al., 2019). Based on this observation, Hulshof et al (2019) suggested that one person dies every minute due to hazardous occupational environment. In addition, exposure to coal dust was found to be amongst the leading cause of lung infections in larger industrial operations (Colinet, Rider, Listak, Organiscak, & Wolfe, 2010). In a survey carried out in United State in 2016, CWP was regarded as the underlying cause of death among coal workers and contributed to the increase in the years of potential life lost (Mazurek et al., 2018).

It has been observed that the most common controls of dust used at the coal stockyard are personal protective equipment in a form of dust mask (N95) and water suppression method. The availability of documented information about the use of water as a means of dust suppression methods does not give full confidents that the method has the ability to completely protect those exposed to submicron particles, this is because effectiveness may be affected by other factors (Chang et al., 2019).

1.4 Justification

The use of coal to generate electricity is still dependable because the current available alternative energy sources cannot match the amount of energy from coal and finances may be a challenge during transition for some developing country (Best, 2017; Leonard et al., 2018). Although it is now well known that respirable coal dust is the primary contributor of CWP as a result of prolonged exposure, it leaves most country with no choice but to tolerate coal and find a way to control its dust (Driscoll et al., 2004). Coal industries such as mining have introduced dust controls measures, of which the most common is the use of water spray. However, information about the level of effectiveness after the use of water dust control method is not well documented because most of the information was basing the results on samples from mining. Conducted in that specific area. Presently, personal measuring or measuring is widely used to investigate exposure to airborne particles. However, the use of personal measuring, particularly the gravimetric technique is not always effective especially in measuring the respirable and submicron particles (Kissell et al., 2002). The other factor that possibly contributes to the exposure being under- or over-estimated is the movement of people in difference areas that depends on the areas visited. Based on these observations, this study intends to apply area measuring that uses real-time monitors to determine the concentration of submicron and respirable particles prior, during and after the application of the control (water suppression). Information acquired from the three test scenarios (pre, during and post treatment) may assist in determining the efficacy of water suppression method for the two difference particle fractions (respirable and submicron). The dust sample results from Nanozen can help in choosing the best control measures to reduce dust exposure because it can identify high and low dust areas (Exis, 2019).

This study is necessary to provide baseline data on the efficacy of the current dust control measures so as that will be to help occupational hygienists and management to improve, maintain or develop suitable and more effective dust prevention controls in the South African Power station operation

1.5 Study Aim

The study aim was to evaluate the efficacy of the water based dust suppression method in reducing airborne coal dust exposure at the coal stockyard at a Power station.

1.6 Hypothesis

The study hypothesizes that dust water suppression methods do not reduce concentrations of coal dust submicron and nanoparticles at coal stockyard scenario.

1.7 Objectives

a) To determine and compare respirable coal dust concentrations at the coal stockyards of a Power station before, during and after the use of water suppression method;
b) To identify activities that contribute to the increase in the release of respirable coal dust concentrations for the three exposure scenarios (pre, during and post treatment).

CHAPTER 2: METHODOLOGY

The aim of this chapter is to provide background information on the materials and method used for this study. It will begin with Study design followed by the description of the study area and the characterisation of the study parameters of the coal stockyard used in the study. Included in this chapter are, study methods and materials, study area, and conclude by describing data analysis, quality control and ethics approval.

2.1 Methods and materials

The study conducted was quasi-experimental study, which used respirable coal dust result as the source of primary data to be analyzed. The study did not consider personal measuring, but only performed area measuring. The study used nine results of respirable coal dust samples taken from the three sets (triplicates) of measuring. The study used samples taken on each measuring point to determine dust concentration before, during and after water dust suppression. The collection of dust sample results was over the period of two days during the months of July and August 2021. It took about 30-minute time to collect each sample. The means of collecting samples was by direct reading-measuring instrument called Nanozen (DustCount 9000-Z1).

Measuring took place during the day while the normal coal stockyard activities which included but not limited to coal truck deliveries, coal offloading monitoring (checking) coal compacting, bulldozer operation and mobile dust water suppressions.

2.1.1 Description of the study area

This study was carried out at a coal stockyard of a power station located in the Gert Sibande district in Standerton (Mpumalanga province) in South Africa. Farms and coalmine dominated the area around the power station. Figure 6 shows geographical map of Standerton in Gert Sibande district (Mpumalanga) which include the study area location.

Coal stockyard is an area within the Power station's yard where they stock pile coal. It is located approximately 800 meters away from the power generating units. Coal are taken from coal stockyards to power generating units by means of a conveyor belt

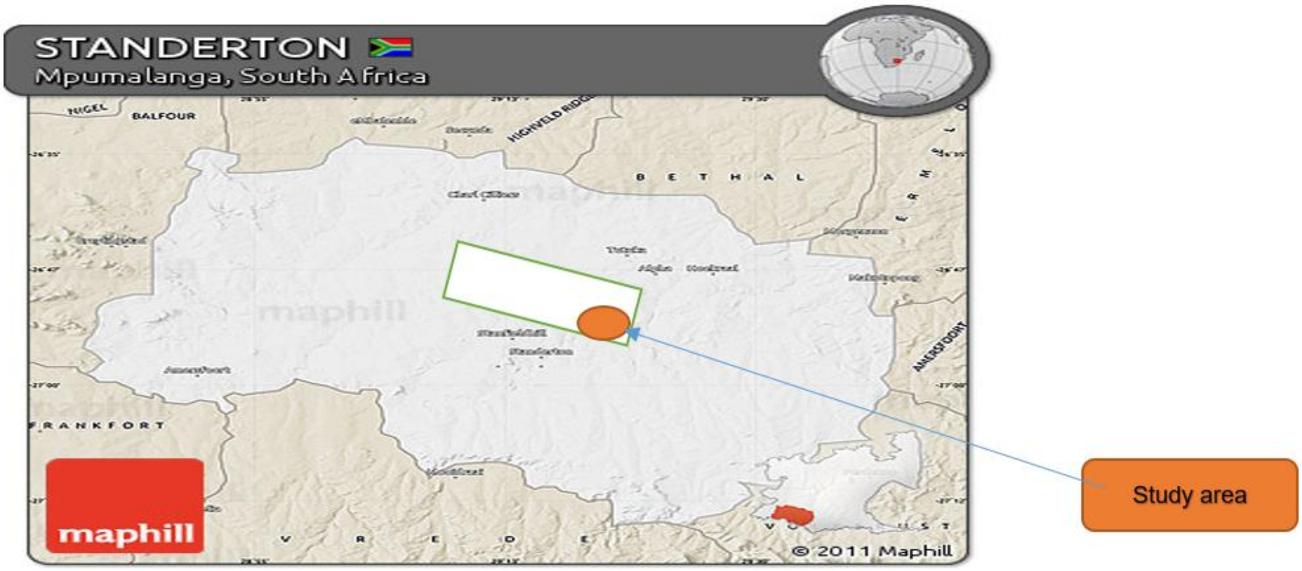

Figure 6: Geographical map of the study area (Standerton, Gert Sibande District) Mpumalanga.

Figure 7 shows a schematic diagram of activity areas in a coal stockyard. The area is divided in to three major zones where point A indicates the vehicle entry and exit point , Point B indicates the area between the two coal stock pile while C indicate the coal offloading area.

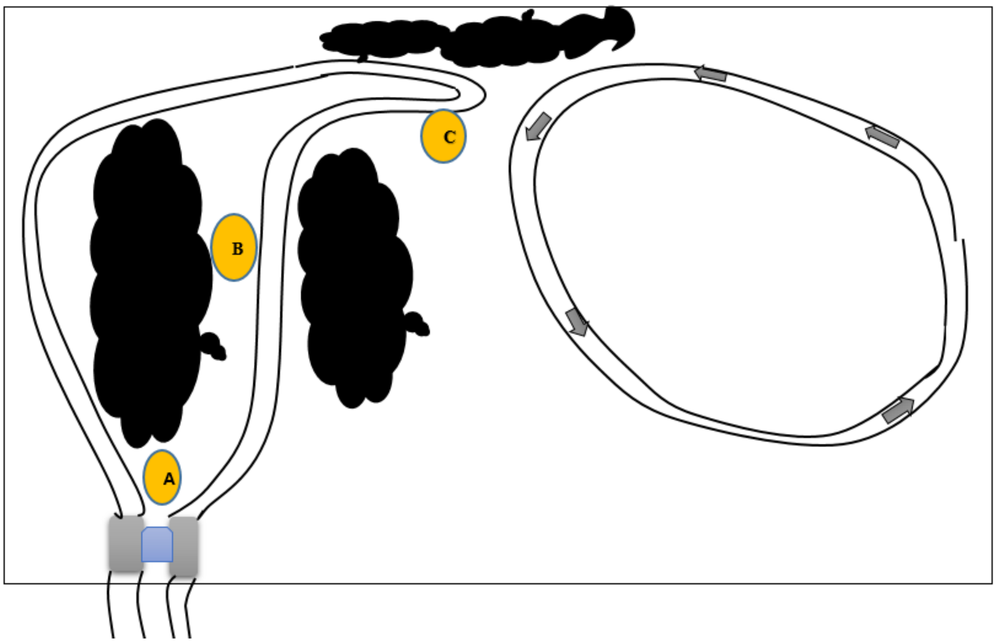

Figure 7: Schematic diagram of coal stockyards layout (A; B; and C).

Coal stockyard is an open area. During the coal dust measuring it was observed that due to uncontrolled wind movements, it is difficult to control the release of coal dust. There are about fifty to one hundred, (50 -100) coal trucks that enter the coal stockyard to offload on a temporary stockpile daily. On the road leading to the coal stockyard, they control dust by means of suppression with water sprays trucks.

The operations at the coal stock yard is a 24 hours periods with two shifts. The number of employees (Eskom and contractors) to cater for the two shifts are about sixty, (60). During dust measuring, it was observed that there were three difference stockpiles. Stockpile one (Strategic stockpile) which is in a form of compacted coal that are intended to be used in emergency situations when there is coal supply shortage. Stockpile two (newly build stockpile) where coal trucks offload. Stockpile three (live stockpile) is the one next to conveyor belt where coal are pushed to the conveyor belt by bulldozer and transported to the power station. Samples were collected from three points (A – C) within the coal stockyards area as listed in table 1.

Table 1: Description of measuring points**.**

Measuring areas/ locations	**Area description**	**Activities**
Point A	Next to Weighbridge	• Weighbridge administration • Trucks weighing load • Tarpaulin opening • Directing movement of trucks
Point B	On the road between Strategic stockpile and life stock pile	• Bulldozer operating • Coal compacting • Measuring movement of trucks
Point C	Next to Coal offloading point	• Trucks offload coal • Measuring of trucks offloading • Movements of measuring personnel

In Figure 8, the measuring instrument is mounted on a stand to monitor the dust concentration around weighbridge area (point A). This is the entry and exit point for coal trucks exit. The measuring were done for three scenarios.

Figure 8: Typical coal dust measuring instrument placed at Point A (next to Weighbridge).

Figure 9, the measuring instrument is placed at point B in the area between the two stockpiles. It is in this area were the machine such as bull dozer and compactors are moving up and down.

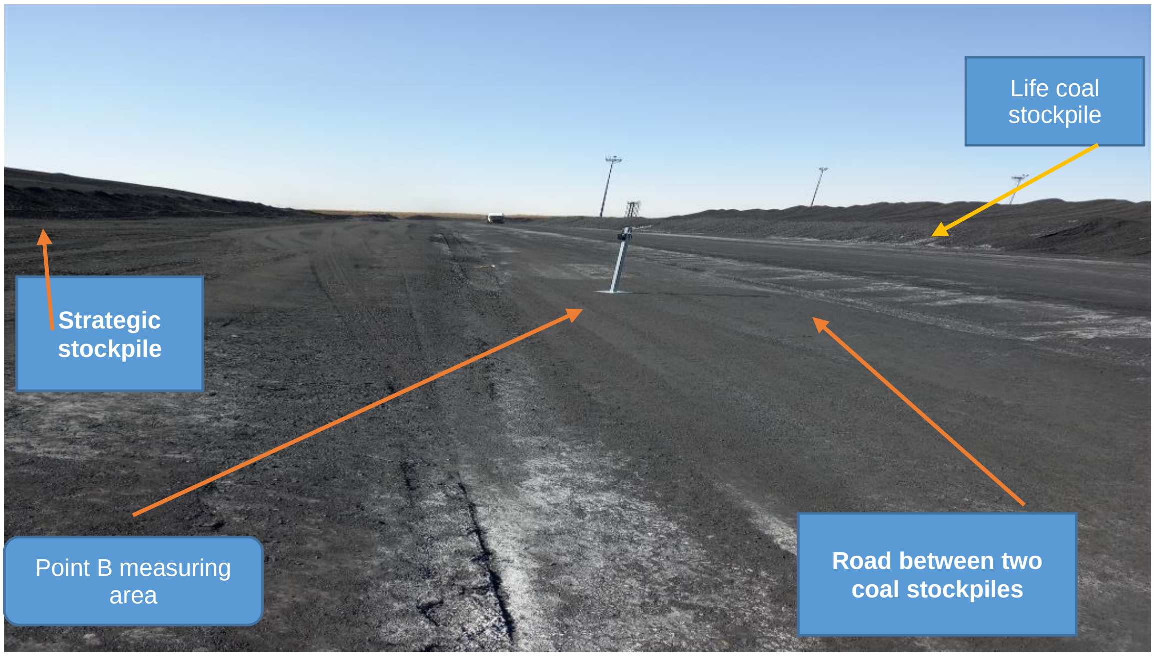

Figure 9: Typical coal dust measuring instrument placed at Point B (between 2 stock piles).

Figure 10, the measuring instrument is mounted on a stand to monitor the dust concentration in point C. This is the tipping or offloading area where coal trucks offload coal and go. In this area there were truck movement.

Figure 10: Typical coal dust measuring at Point C (Next to offloading zone).

2.1.2 Measuring strategy

Having considered that in the South African legislations, there is no specific coal dust measuring guidelines to follow, this study used measuring strategy that will ensure that best coal dust concentration results are reflected. The study looked at various options and came up with conducting area or stationary measuring as the best one. This option was chosen because of cost saving and that it does not disturb or interfere with the work in the coal stockyard and does not involve the workers. It is the strategy that suggested by one study as more cost effective and simple (Witschger, 2000). The strategy used also considered setup of the coal stockyard. Encouraging to use this strategy because the results may be applicable for generalizing whole coal stockyard. The measuring instrument was placed in a sampling point or area for a 30 minutes period. This was done for the three measuring scenarios.

2.1.3 Measuring

The method used was area simple random measuring where three point were randomly selected. This method helped in providing measuring of coal dust concentration (before, during and after) dust water suppression. The results was then used to provide the estimate level of dust water suppression effectiveness in reducing coal dust in the coal stockyard.

This study used the direct reading instrument call Nanozen (DustCount 9000-Z1). In Figure 11, the dust sampler clearly depicts various parts of Nanozen (DustCount 9000-Z1) instrument which was used for the study. The DustCount 9000-Z1 is real-time dust measuring instrument which is able to measure the ambient level of dust particles in real-time continuously as determined by the user. (Exis, 2019) This instrument can also be used for personal measuring but in this study static measuring was considered. “The DustCount IS unit detects and counts particles and displays their mass concentration in µg/m^3.” It can also “provide real-time information on the mass concentration distribution over the PM2.5, respirable, PM10.0 fractions of the particle size range” (Exis, 2019).

Figure 11: Typical Nanozen instrument (DustCount 9000-Z1)

Figure 12 shows coal dust measuring where the direct reading instrument (DustCount 9000 Z1) was mounted on a 1.5 meters portable steel hanger. Cable ties were used to tie the instrument to prevent it from falling. This stand was then placed on the measuring point for a period of 30 minutes. This process is repeated in all sampling points per all three scenarios.

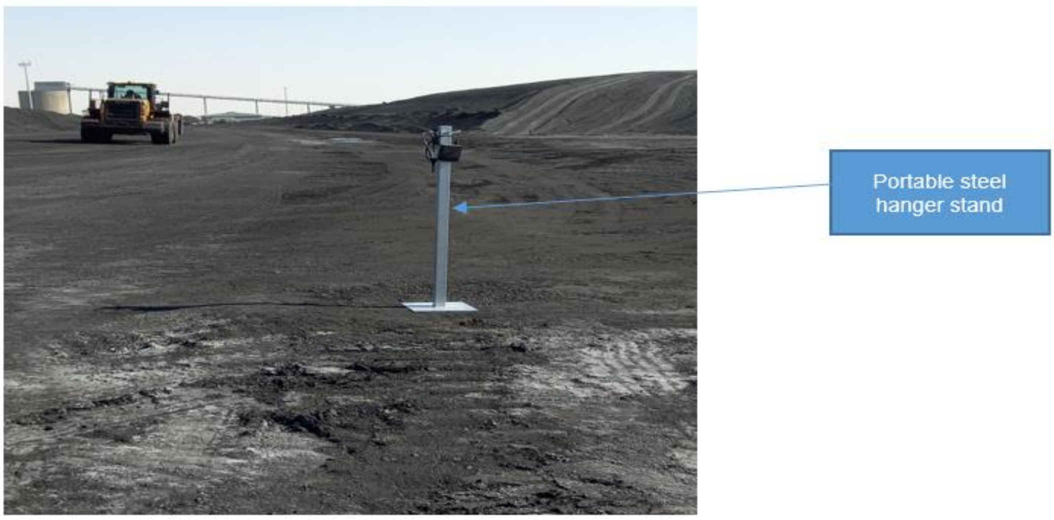

Figure 12: Illustration of the portable steel hanger stand with the measuring instrument mounted

2.1.4 Number and measuring frequencies

The measuring frequency and number of samples of the data received was the same for all areas or measuring points selected and its related scenario. The measuring frequency per area per scenario is shown in table 2.

Table 2: Measuring frequencies

Measuring point	Minimum Frequency and No. of samples
A	Area sample for 30 minutes for each scenario (pre, during and post) with minimum of 3 samples per point.
B	
C	

The number of measuring done on each measuring point were three (3). This meant there were nine (9) measuring in total. The measuring were done by dividing them into three categories as scenarios. The first set of three, were taken before application of water, one on each sampling points. Each sample was taken over a period of 30 minutes on measuring point.

Coal dust measuring took place over two days, on the 21st of July 2021 from 09:45 until 13:20 and the 2nd August 2021 from 09:15 to 16:40. Each sample was done over 30 minute's period (continuously) followed by five (5) to ten (10) minutes break of moving instrument to the next measuring point.

2.2 Data analysis

2.2.1 Determining and comparing respirable coal dust concentration

The statistical analysis were done using the excel 2016 version 22 by first connecting DustCount IS unit to PC by means of USB port and download data and converted into excel. $P \leq 0.05$ were considered statistically significant. This was done after data was extracted from DustCount 9000-Z1, The graphs and tables were used to evaluate differences between coal dust concentration before, during and after application of dust water suppression method.

The first graph analysis was done by comparing coal dust concentration sample results per area per scenario. This was followed by analysing average sample results per scenario which was also done in graph. The third graphical analysis was for average samples per measuring points. Further analysis were carried out to determine number of coal dust particle concentration (m^3) during before, and after the application of dust water suppression.

2.2.2 Identifying activities that contribute to the increase in respirable dust concentration

The objective number two is analysed by identifying type of activities at each measuring point. This activities are then grouped per sampling point in a table form. The average measuring results was ranked from highest to lowest. The activities at the point with highest average results concentration was considered to be contributing more exposure concentration. The analysis of all points were done without considering other temporary variabilities like wind speed and activities as well as other factors.

The second analysis on the activities was done by using graphs to describe particle distribution at various measuring points by using pairwise comparison.

2.3 Quality control

Before commencement of measuring, the instrument (DustCount 9000-Z1) was calibrated by first leaving it to run for a minute to validate that a particle detector is reading zero under clean-air conditions. After being turned on, the unit's Average mass concentration (AvMC) readings on the LCD was less than 0.001 $\mu g/m^3$ within 2 minutes. The per-second mass concentration (MC) readings on the LCD was between 0.0 and 0.1 $\mu g/m^3$

2.4 Ethics

Written permission to conduct the study was request and provided by Eskom. Furthermore ethics waiver was obtained from the University of the Witwatersrand, Faculty of Health Sciences Human Research Ethics Committee (HREC) on the 30th March 2021 Clearance number HC/03330. The measurement results was taken from the study area and did include or involve other people or animals. The direct reading instrument was used and operated by the researcher. During measurement there was no interference to the site activities.

CHAPTER 3: RESULTS

The main aim of this chapter is to present the measurement results that was taken from coal stockyard of a power station. The results were then interpreted in order to provide clarity and the meaning. This chapter covered the study objectives which started by determining and comparing respirable coal dust concentrations pre, during and post water suppression method. It is then followed second objective which is to identify activities that contribute to the increase in the release of respirable coal dust concentrations for the three exposure scenarios (before, during and after treatment).

Data used was obtained from all three measuring (points) areas of the coal stockyard. This data were taken from actual measuring results which were taken over a period of two difference days in the month of July and August 2021. The results were obtained directly from DustCount 9000-Z1 and converted into excel in order to analyse coal dust concentration

3.1 Objective one discussion

The first objective of the study is addressed by figure 13, present and compare the results of coal dust concentration that were taken pre (before), during and post (after) dust water suppression of the areas within the coal stockyard. The results were presented in a form of a graph. The results indicates point A contain the highest reading when compared to all measuring scenarios at B and C.

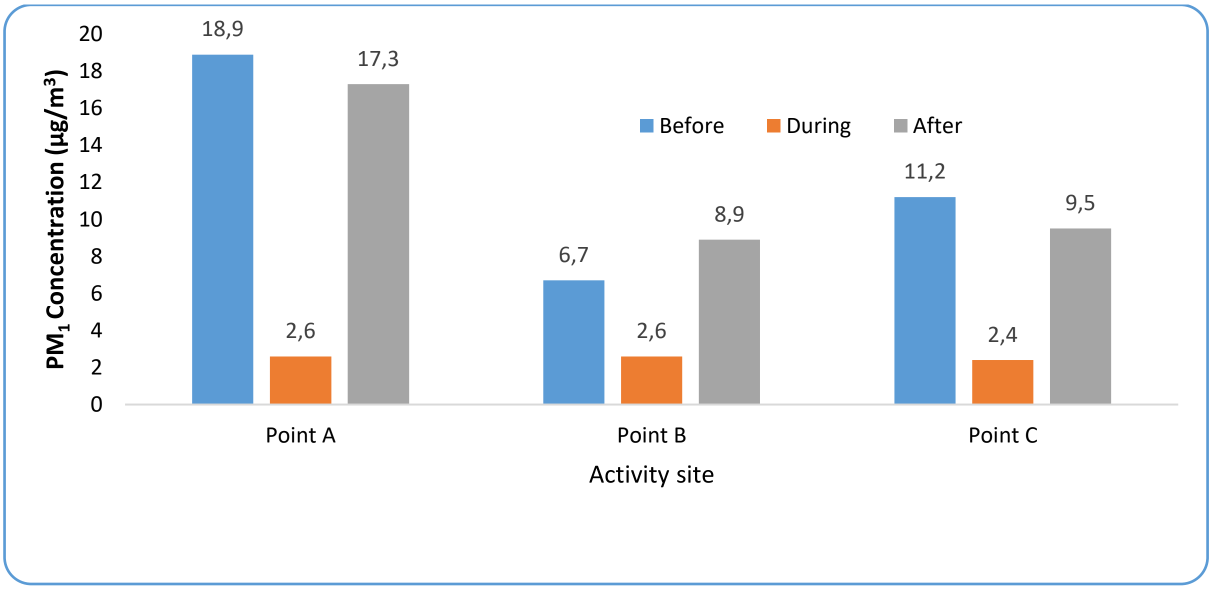

Figure 13: Coal dust concentration sample results per area per scenario

The second part of objective one was presented in figure 14. Respirable dust concentration in each measuring scenario were compared by ranking average coal dust concentration results of scenario before, during and after. The average coal dust concentration results after application water to suppress dust, was the higher than before and during. This is as a results of dust re-suspension which is caused by coal trucks movement as they enter the coal stockyard to offload coal.

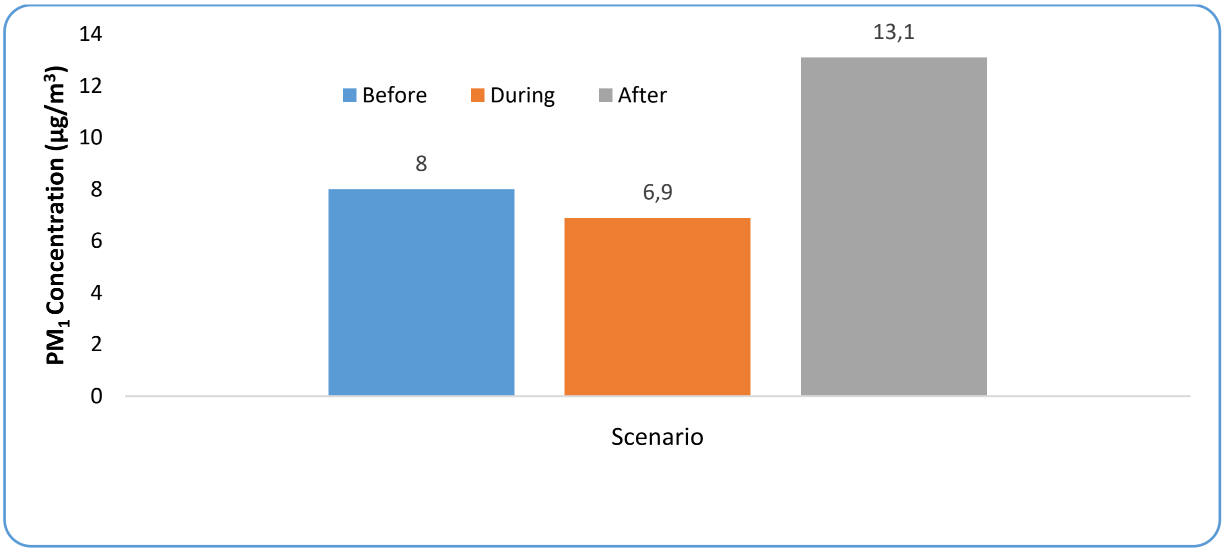

Figure 14: Average sample results per scenario

Figure 15 present the average coal dust concentration results per measuring point and compare them. The results shows that point A had the highest coal dust concentration reading as compared to B and C. This is the area around weighbridge where trucks enter and exit. This suggested the employees working in that area are likely to be exposed to high level of dust.

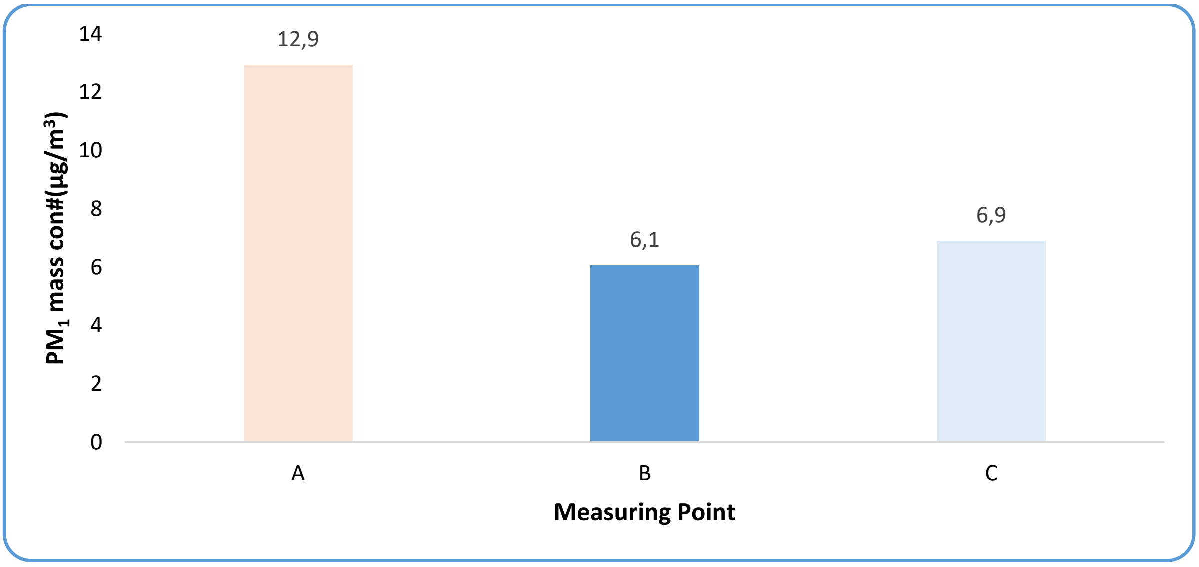

Figure 15: Average samples per measuring points.

Figure 16 shows particle distribution at point B before dust water suppression method was applied. In this Figure 16, it can be observed that dust Particle mode move towards the right, meaning that most particle suspended are falling around 300 -500 nanometres.

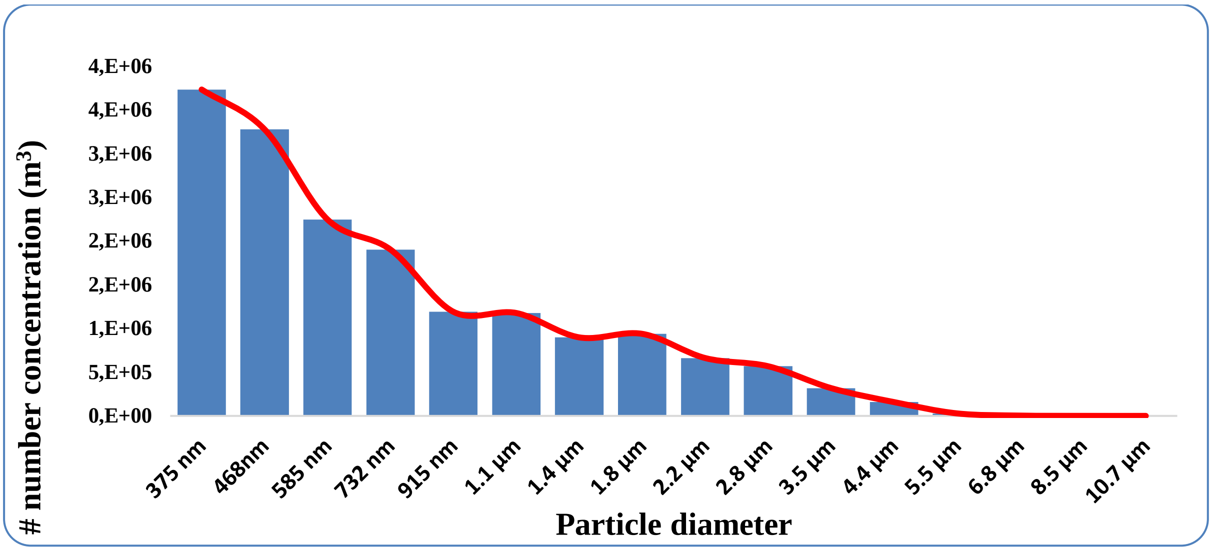

Figure 16: Number of Coal Dust particle Concentration (m^3) at Point B before application of dust water suppression**.**

Figure 17, describe particle distribution during the application of dust water suppression method at point B. In this case the manometer dust particle seen to be increasing at around 375nm where number goes up 10 million. This is an indication that the measuring instrument also counted water droplets of smaller diameter because the increase was only observed during the application of water. The water droplets slightly increased humidity in the air compartment to allow for agglomeration.

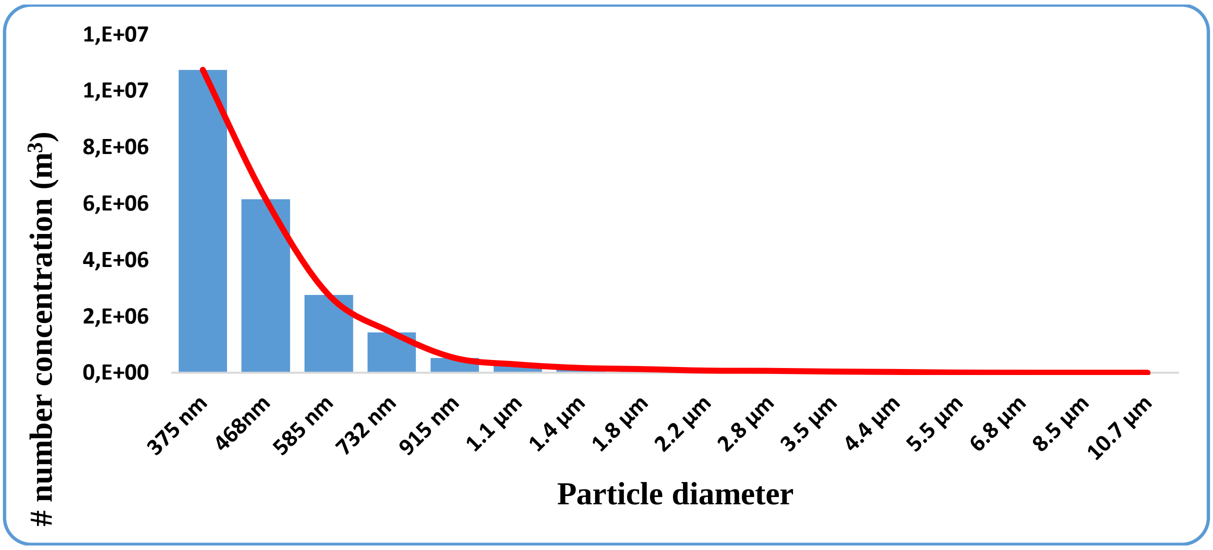

Figure 17: Number of Coal Dust particle Concentration (m^3) at Point B during application of dust water suppression.

Figure 18 describes particle distribution at point B after the application of water for of dust suppression. Re-suspending of dust particle started to occur soon after the application of water. This is caused by movement of trucks. Moisture start to evaporate as the movement of trucks continue to increase.

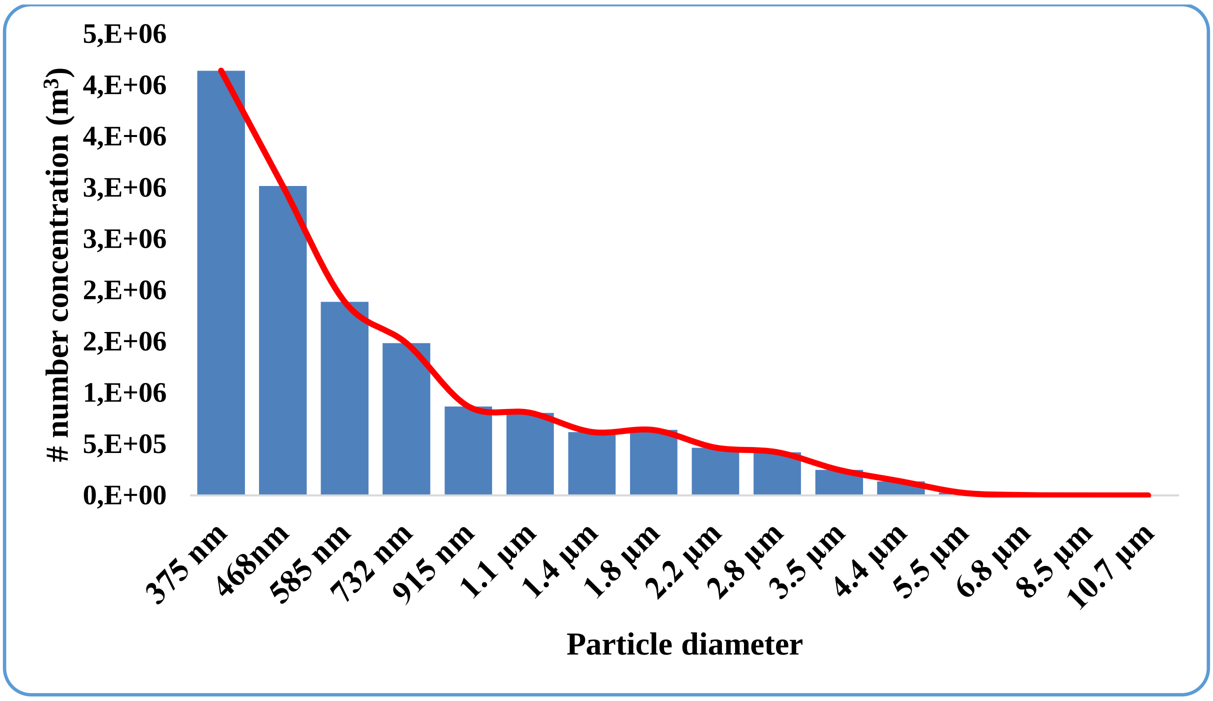

Figure 18: Number of Coal Dust particle Concentration (m^3) at Point B after application of dust water suppression.

3.2 Objective two discussion

Objective two was addressed by ascertaining the type of activities at each measuring point followed by identifying activities that contribute to the increase in the release of respirable coal dust concentrations.

In table 3, the activities within coal stockyard are summarised per measuring point or areas. In addition average concentrations of submicron particles are presented.

Table 3: Description of activities per scenario area and measured concentrations.

Coal stockyard	Activities	worker categories	Number of samples	Sample duration	Average (µg/m^3)
Point A	• Truck load weighing • Tarpaulin opening	Administrator/ clerk Tarpaulin openers	3	30 minutes for each sample	12,9

	• Movement of coal trucks (entry and Exit)				
Point B	• Bulldozer operating • Coal compacting • Measuring movement of trucks	Machine drivers monitors	3	30 minutes for each sample	6,1
Point C	• Trucks offload coal • Measuring of trucks offloading • Movements of measuring personnel	Truck drivers Monitors	3	30 minutes for each sample	6,9

Point A, Pairwise comparison of three difference scenarios are shown in table 4. The results shows statistical significant differences in two of the possible pairing (pre & during as well as during & after). There was no statistical significant difference in dust concentrations between pre and after treatment.

Table 4: Pairwise comparison on statistical significance difference on PM concentrations at Point A for the three exposure scenarios (pre, during and after).

Scenario	Respirable dust ($\mu g/m^{3)}$)	F-Test	P-value (0,05)	Statistical sig. 95%
Pre During	18,9± 8 2,6±1,1	0,04	0,01	Yes
Pre After	18,9± 8 17,3± 4,7	0,68	0,79	No
During After	2,6±1,1 17,3± 4,7	0,07	0,01	Yes

Pairwise comparison of three difference scenarios at point B are shown in table 5. The results shows that there was no statistical significant differences in two of the possible pairing. The P-value for pre versus during and pre versus after was 0, 24 and 0, 17 respectably. There was statistical significant difference in dust concentrations between during versus after treatment.

Table 5: Pairwise comparison on statistical significance difference on PM concentrations at Point B for the three exposure scenarios (pre, during and after)

Scenario	Respirable dust (µg/m³)	F-Test	P-value (0,05)	Statistical sig. 95%
Pre	18,9± 8	0,29	0,24	No
During	2,6±1,1			
Pre	18,9± 8	0,13	0,17	No
After	17,3± 4,7			
During	2,6±1,1	0,21	0,02	Yes
After	17,3± 4,7			

Point C pairwise comparison of three difference scenarios are shown in table 6 and results shows statistical significant differences in two of the possible pairing. The P-value for pre versus during and during versus after was 0, 00 and 0, 1 respectably. There was no statistical significant difference in dust concentrations between pre and after treatment. The P-value for pre versus after was 0, 30. This results were the same as at Point A.

Table 6: Pairwise comparison on statistical significance difference on PM concentrations at Point C for the three exposure scenarios (pre, during and after)

Scenario	Respirable dust (µg/m³)	F-Test	P-value (0,05)	Statistical sig. 95%
Pre	18,9± 8	0,60	0,00	Yes
During	2,6±1,1			
Pre	18,9± 8	0,13	0,30	No
After	17,3± 4,7			
During	2,6±1,1	0,28	0,01	Yes

After	17,3± 4,7

CHAPTER 4: DISCUSSION

This chapter discusses the analyzed results of the two objectives that were presented in chapter three. It also provides the measuring results aimed at addressing the objectives of the study and provide the finding regarding the hypothesis.

4.1 Objective 1: Determining and comparing respirable coal dust concentrations

In this objective results of respirable coal dust concentrations taken from difference measuring points at the coal stockyards were analysed and compared. The comparison considered difference exposure scenarios which was before, during and after the use of the water suppression method.

During the comparison of the exposure scenarios point A had highest dust concentration before application of water followed by Point C (before) the lowest being point B. Observation made during measuring was that there were continuous movement of coal trucks coming in and out of coal stock yard. This results were not surprising since they were taken before dust control interventions. The results also signify the need for proper dust control. The comparison of coal dust concentration results for during and after scenarios from all measuring points showed the results of 2, 6 µg/m^3 (during) for both Point A and B respectively, while Point C had a lower results of 2, 4 µg/m^3. The after scenario results for point A were the highest with 17, 3 µg/m^3 and point B as the lowest with the results of 8, 9 µg/m$^{3.}$ Dust concentration. The results suggest that water dust suppression method is more effective during the application of water as compared to before and after. This was supported by the results which showed lower dust concentration in all points during the application of water. However the high dust concentration after the application indicate that most of the dust particular those of smallest size are re-suspended shortly afterwards.

The average results per scenario in figure 14 were lower during the application of water which suggestion that water dust suppression methods is more during than after application. The average coal dust concentration results for during was 6, 9 µg/m^3 which was the lowest and the highest was after with 13, 1 µg/m^3. The average for before was 8, 0 µg/m^3

The analysis of collected results showed that they followed a lognormal distribution pattern. When analysis of the point B (before, during and after) were completed, the results showed some difference in dust concentrations between difference scenarios. The results of dust

particle concentration at point B before treatment as shown in Figure 15, indicated that about 1 to 4 million of the smaller ranging from 915 nm (manometer) to 375 nm are suspended in air as compared to between 0 to 2,5 million m^3 with size between 1,1 -5,5 micro meter (µm).
During the use of water suppression methods at point B, dust concentration results as shown in Figure 16 suggest that the method was more effective in controlling dust particle of bigger size that range between 1,1 -5,5 µm as there were still residual of smaller size that range between 375 – 732 nm. More of the dust concentration residual of about one (1) million is for smaller particle size of 375 nm and less.
The results of this study are similar to Luo et al. (2019), which suggested that in order to effectively suppress smaller dust particles, efforts must be focused on creating condition for particle agglomeration. Since water suppression is often used as a dust control method, the water droplets used must be smaller than the targeted particle diameters (Luo et al., 2019). The water spray nozzles should be designed and adjustable in such a way that it is able to produce smaller droplets (Colinet et al., 2017). Moreover, the smaller particle size have the ability to enter the nozzle, accumulate and later blocking the water release point rendering the intervention ineffective (Kiran et al., 2021; *Kissell, F. N. 2003. Handbook for Dust Control in Mining. DHHS (NIOSH) Pub. No. 2003-147, IC 9465, Pittsburgh.*, 2003).
The results of the dust particle size concentration taken after the use of water dust suppression method at point B as shown in Figure 13suggested that a large amount of smaller particle size between 375 -585 nm are re-suspended after the application of water.
This was supported by Swanson & Langefeld, (2015) who suggested that applying the water suppression method may be inadequate in reducing the concentration of respirable dust because certain dust particle size and weight may be difficult to control due to its inability to dissolve or to make contact with water droplets (Swanson & Langefeld, 2015).

4.2 Objective 2: Identifying activities that contribute to the increase in respirable dust concentration

The average results per measuring point as indicated in Objective two was addressed by ascertaining the type of activities at each measuring point followed by identifying activities that contribute to the increase in the release of respirable coal dust concentrations.

In table 3, the activities within coal stockyard are summarised per measuring point or areas. In addition average concentrations of submicron particles are presented.

Table 3, suggest that one out of three selected areas has the activities that contribute to high emission of dust concentration than the rest. The point with highest dust concentration is point A. The activities at this point includes tarpaulin opening, coal truck load weighing, and movement of coal trucks (entry and exit). Points B & C contributed to the lowest dust concentration, with each having concentration of about 50% less as compared to point A.

The results of pairwise comparison of three difference scenarios as shown in Table 4 suggest a statistical significant differences in two of the possible pairing. The P-values in point A (pre versus during and during versus after) was 0, 01 for both pairs, which suggested that there is significant evidence that water suppression methods reduce coal dust concentrations of submicron and nanoparticles. The P-value for pre versus after was 0, 79 which suggested that there was no statistical significant difference in dust concentrations.

When comparing statistical significance difference on dust concentrations at Point B, the P-values for the two pairs of scenarios (pre versus during & pre versus after) were 0, 24 and 0, 17 respectively as shown in Table 5. This suggest that there was no sufficient evidence to proof that water suppression methods reduce concentrations of coal dust submicron and nanoparticles. The only scenario that suggested significant evidence of water suppression methods being able to reduce coal dust concentrations of submicron and nanoparticles was o for during versus after because the P-value was 0.02.

The results at point C for the two pairs of scenarios (pre versus during and during versus after) as shown in Table 6, present almost the same P value of 0, 1 respectively as the one at point A. This results suggest that there is significant evidence that water suppression methods reduce coal dust concentrations of submicron and nanoparticles while the results of pre and after like Point A suggest that there was no evidence to show that water dust suppression methods reduce coal dust concentrations of submicron and nanoparticles.

4.3 Limitations

This study did not account for temporary variations, such as number of trucks that enter the site, the influence wind speed and other activities taking within the coal stockyard. The other limitation is that during measuring the amount of traffic volume was not considered.

4.4 Conclusion and Recommendation

This study was done to analyse the efficacy of the water based dust suppression method in reducing airborne coal dust exposure at the coal stockyard at a power station. The conclusion is driven by study objectives.

4.4.1 Conclusions

This study indicated that the effectiveness of water dust suppression method is dependent on the size of particles released. During the application of water for dust suppression, particles with the size ranging between 1, 1 - 5, 5 µm can be reduced by 80 - 90% and smaller dust particles with size between 375 to 732 nm can be reduced by 40 to 60%. When comparing two scenarios which are during and after the application of water, there were about 50% more of suspended dust particle in the after than during scenario.

The effectiveness of water dust suppression method does not last long because soon after the application of water, smaller dust particle start to be re-suspended.

When comparing statistical significance difference on PM concentrations for the results of two pairs of scenarios (pre versus during and pre versus after) there were enough evidence to suggest that water dust suppression method reduces coal dust concentrations of submicron and nanoparticles in selected scenarios particularly during (scenario).

When analyzing the average results of each measuring points, point A had high average dust concentrations than B and C which suggest that the activities in that area which include tarpaulin opening and coal trucks entering and exiting maybe contributing to dust emissions. The other contributory factor observed was that water spraying started about 30 metres from the weighbridge.The movement of coal trucks was a common activity in all measuring points (A-C), this made it difficult to pinpoint exactly which activity contribute to more dust generation in a specific sampling area.

In the coal stockyard they use a number of water tankers which rotate at difference time. The size of water spray nozzles and spraying capacity could not verified and therefore the analysis of effectiveness of water dust suppression in this study did not consider other factors.

The fact that there was no guidelines on how many time or when the water tanker must start with dust suppression also could have an impact on the dust control.The time taken to spray might have influence on the amount of dust released in certain areas within coal stockyard.

The difference in the results is an indication that there are other factors that were present during measuring. Those factors may include those that relate to other activities outside the area selected for measuring points, for example pushing coal to the conveyor belt by the bulldozer.

4.4.2 Recommendations

In order for coal power stations to improve the control of coal dust in their coal stockyards, this study proposed the following recommendations:

- It may be necessary to for power station to consider utilizing the water sprinklers around a coal stock yard area to control larger particle due to the frequent entry and exits of the heavy vehicles movement.
- For submicron particles it is recommended that the use of fogging be considered as a long-term intervention.
- On the road surface design, the use of tarred road may assist in reducing the potential of dust re-suspension due to increase in the particle binding force.
- Management of the coal stockyard should have documented schedule of water tanker spraying frequencies.

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APPENDICES

Appendix A: Plagiarism

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Eric Mohlodine (Student number: 0617011H) am a student registered for the degree of MPH - Occupational Hygiene in the academic year 2022.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: ______________ Date: 24 June 2022

1

Appendix B: HREC (medical) ethical approval

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Office of the Deputy Vice-Chancellor (Research & Post Graduate Affairs)

03/03/2021

Ref: W-CBP-210303-01

TO WHOM IT MAY CONCERN

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical)

Investigator: Mr E Mohlodine
Student No. (if appropriate): 4187251 D6ITDI1H
Staff No. (if appropriate):

Supervisor: Dr DM Masekameni

School: Public Health
Department: Occupational Health
Medical School
University

Project title: *Water-based dust suppression: pre-, during and post-characterization of respirable coal dust at a power station in South Africa*

Reason: Air quality study
No human participants will be involved in the study

CB Penny

Dr CB Penny
Chairperson: Human Research Ethics Committee (Medical)

Research Office Secretariat:
Third Floor, Phillip Tobias Building, corner of St Andrews and York Roads, Parktown, Johannesburg 2193
Postal address: Private Bag 3, Wits 2050
Tel Nos: +27 (0)11 717 1234/1252/2656/2700
Office E-mail: HREC-Medical.ResearchOffice@wits.ac.za
Website:
https://www.wits.ac.za/research/researcher-support/research-ethics/ethics-committees/

Appendix C: Turn-it-in report

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