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Characterization and comparison of aeolian dust collected by horizontal flux gauges and vertical deposit gauges

M. Sc. Research Report

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Preface

There are many measurements that can be used to quantify dust concentrations. The use of dust level measurements is suitable to the South African economy where finances for instruments that measure continuously from the atmosphere are not usually available. While Single Buckets will accumulate all dust, this does not establish dust emanating from a given direction. Such open buckets are also subject to inaccuracies due to wind conditions and other. This dissertation examines collection efficiencies of directional horizontal flux gauges and non-directional deposit single bucket at higher wind speeds. The single bucket is widely used in South Africa regardless of its flaws, and this dissertation offers a cheaper directional dust monitoring alternative solution.

With respect to my writing this dissertation, I have been fortunate enough to be surrounded by people who affected my motivation to write and finish this dissertation, in a positive way.

My heartfelt thanks goes to Prof Stuart Piketh my supervisor, and Prof Harold Annegarn who guided me with intelligence and expertise which, with each meeting shed more and more light on my dissertation path. With persistence and patience, they challenged me to, think, experiment and critically analyse.
I thank Prof. Mary Scholes for the support and encouragement she gave me throughout the research and the NRF grant holder's bursary she facilitated.

I am also grateful to the staff at Annegarn Environmental Research, for excellent assistance and responsiveness to my technical needs during the dust-sampling period.
I would like to thank the staff at the Wits Physics Workshop who assisted me in manufacturing the Modified Wedge Dust Flux Gauge (MWDFG).
I would like to thank the staff at Wits Glass Blowing Unit in the School of Chemistry who assisted me in the manufacture of the Modified Wilson and Cooke Samplers.

I would also like to thank Mr. Abe Seema, the Technician in the Wits Biology Electron Microscopy Unit who helped me analyze the dust samples in the Scanning Electron Microscope.

I would like to thank the staff at M&L Inspectorate laboratory for carrying out the particle size analysis for the dust samples.

I am grateful for the thoughtful and creative support of my colleagues, who encouraged the analysis from the beginning. Special thanks to Malusi Buthelezi who willingly and cheerfully supported my efforts, and welcomed my unformulated ideas. The task would have been much more difficult without their superb listening skills and their calm and generous natures.

My wife Qinisile, my daughters Anele and Nonsikelelo whose understanding of my focus on the dissertation was a gift to me.

Abstract

Windblown dust is often a major nuisance problem faced in South African urban and near urban areas due to the prevailing dry climatic conditions, extensive surface mining and mineral processing. Dust deposit gauges single and double bucket are widely used in South Africa to monitor fugitive dust. The use of bucket deposit gauges in areas where predominant wind speeds are greater than 2 $m.s^{-1}$, has yielded very poor collection efficiency (typical recoveries being < 20%). A wedge dust flux gauge has been designed and manufactured. The collection efficiency of the Modified Wedge Dust Flux Gauge (MWDFG) is tested against a Single Bucket gauge and, modified Wilson and Cooke (flux gauge) at Landau Colliery in Mpumalanga.

Scanning Electron Microscopy analysis of dust particles obtained from the four samplers, exhibited six clusters of particulate morphology; irregular square, agglomerate, sphere, floccule and column or stick. Based on their shape characteristics most of the samples of the particles under investigation were probably soil and coal particles. The particle size distribution analysis carried out on the dust samples had the MWDFG collecting the largest fraction of particulate matter with 10µm diameter at 23 percent.

The MWDFG in this study recorded more dustfall rates than the other samplers at the sampling site. The Modified Wedge Dust Flux Gauge recorded dustfall rates that were within the INDUSTRIAL range while the other samplers recorded dustfall levels that were within RESIDENTIAL range. The Single Bucket was commissioned at Landau Colliery site RAMP 6 in August 2006, and has been recording dustfall rates in the RESIDENTIAL range. The MWDFG during this study recorded dustfall rates in the INDUSTRIAL range indicating that there are other dust sources from other wind directions which the Single Bucket has been unable to collect over the years. The predominant winds in the Witbank region are from the east and the Single Bucket was installed in such a way that it records dust from the east. The Modified Wedge Dust Flux Gauge should be used in combination with the bucket in Landau Colliery site RAMP 6 to

account for dust generated from others sources other than those located in the east. Further dust collection efficient tests to the MWDFG at different locations and times within Landau Colliery are required.

Declaration

I declare that this research report is my work, unaided work. It is submitted for the Degree of Master of Sciences in Environmental Sciences in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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(Signature of candidate)

_________________day of________________________________2009

Dedication

To my wife and daughters, without whom there would have been no journey. Thank you for helping me keep the priorities straight and to maintain proper perspective

Table of Contents

List of Figures

List of Tables

List of Appendices

Nomencluture

- Aeolian dust is windblown dust
- Aerodynamic diameter is the diameter of a spherical particle that has a density of 1g/cm3 and which has the same terminal settling velocity as the particle of interest.
- Atmospheric dust – Minute particles slowly settling or suspended by slight currents and existing in varying amounts in all air.
- Brownian motion – The continual random movement due to molecular agitation of fine particles suspended in a gas or a liquid.
- d50 – In a sample of dust the d50 diameter is the diameter above which fifty percent of the particles are larger, and below which fifty percent of the particles are smaller.
- Dry deposition – The collection of precipitant dust during periods with no rainfall.
- Export Bucket – The export bucket can be north, south, east or west bucket that is closet to the dust source. When the wind blows over the dust source towards the sampling location then the export bucket is open and dust from the dust source is collected in the bucket
- Fall – out dust – See precipitant dust.
- Fugitive dust – Dust that is not emitted from a point source that can be easily defined such as stacks. Sources are open fields, travel ways, stock piles and process buildings.

- Meteorology - the earth science dealing with phenomena of the atmosphere (especially weather)
- MWAC – Modified Wilson and Cooke sampler
- MWAC D – Modified Wilson and Cooke sampler with double size air inlet and outlet.
- MWAC N – Modified Wilson and Cooke sampler with normal size air inlet and outlet
- WDFG – Wedge dust flux gauge
- MWDFG – Modified Wedge Dust Flux Gauge
- New Bucket - A bucket that is taken to the field to replace and old bucket.
- Nuisance particulates – the course fraction of airborne particulates typically greater than about 20 µm. These particulates tend to be deposited quickly and as such approximates to annoyance, or nuisance dust, such settled particles may show up as a deposit on smooth surfaces such as cars and window ledges.
- Old Bucket - A bucket that has been in the field for thirty days and is being replaced by a new bucket.
- Particulate Matter – Material suspended in the air in the form of minute solid particles or liquid droplets, especially when considered as atmospheric pollutants.
- Petri dish – A container used to keep the precipitant dust samples free of contamination after they have been filtered.
- $PM_{2.5}$ – Dust where the aerodynamic d50 diameter is 2.5 µm.
- PM_{10} – Dust where the aerodynamic d50 diameter is 10 µm.
- Precipitant dust – Any particulate matter that has an aerodynamic diameter below 100 µm.
- Total deposition – The sum of wet and dry deposition.
- Wet deposition – The collection of precipitant dust and any soluble substance in the rainwater during periods of rainfall.

CHAPTER ONE

OVERVIEW

A brief discussion of dust, its effects and dust monitoring gauges is given in the chapter. The study area, problem statement and research goals are also outlined

Introduction

Windblown dust is often a major nuisance problem faced in South African urban and near urban areas due to the prevailing dry climatic conditions, extensive surface mining and mineral processing (Held *et al*., 1994). Aerosol particles have been of major concern as early as 1500s after they were recognized as a threat to human health (WHO, 1998). In its report of 1998, the World Bank stated that particles smaller than 10 µm are a major threat to human health and enhance diseases such as pneumonia, influenza and tuberculosis (Nemmar et al, 2003). Wind-blown dust acts as a secondary pathway for the ingestion of toxic metals (Combes and Warren, 2005). The onset of full-blown AIDS is often precipitated by other occupational disease such as silicosis, which is a result of dust (Hall, 1994; Schwela, 1998). Aerosol particles have also been a major cause of visibility reduction in urban areas. Wet and dry deposition of particulate matter may also cause damage to plants, metal surfaces, fabrics and buildings (Farmer, 1993).

The distribution of aerosols in the atmosphere is influenced by prevailing meteorological conditions of an area (Baumbach, 1996). The meteorological characteristics of an area impact on the rate of emissions from fugitive sources and govern the dispersion and eventual removal of pollutants from the atmosphere. Fugitive dust emission rates are predominantly a function of the wind speed and the intensity and duration of the activity generating the dust (Combes and Warren, 2005). Evaporation rates and precipitation levels also influence fugitive emission rates due to their impact on the moisture content of materials being handled (Combes and Warren, 2005).

The adverse effects that the aerosol particles have impacted on humans, animals, plants and the climate have called for an effective and reliable monitoring processes over the years so as to reduce and avoid their impacts. The directly inhaled dust particle fraction is normally monitored using active samplers, which fractionate the sampler and pull a known volume of air through a filter paper (Garland and Nicholson, 1991). For nuisance dusts it is usually either deposition to the ground or the flux of particles past a point that is of interest (Hall, 1994). Deposition and flux are often monitored with passive gauges. Passive samplers rely on ambient wind conditions when collecting samples. Passive gauges are relatively cheap compared with pump-driven aerosol samplers and installation is not limited by the need for a power supply (Hall, 1994). There are difficulties with sampling the larger end of the atmospheric particle size distribution range (>40 µm), which is of the greatest interest for dust nuisance, with pumped samplers. Apart from the Wide Range Aerosol Classifier (Burton and Lundgren, 1987), whose performance is presently unquantified and of which only three models currently exist, there are no fully effective, commercial designs presently available which measure the total atmospheric suspended particulate up to and beyond 100 µm in size (Hall, 1994).

Measurements of larger size fractions normally associated with nuisance are often made using passive gauges set above the ground. Deposit gauges have a horizontal opening and flux gauges a vertical opening. Deposit gauges are normally in the form of a cylindrical container or funnel of some sort and a fair variety of them are in use worldwide (Hall, 1994). Flux gauges are less common, the most common being the British Standard directional gauge (British Standards Institution, 1972) and the Wedge Dust Flux Gauge, (Hall, 1994). Dust deposit and flux gauges should be used in combination to assess different aspects of wind-blown dust problems (Hall, 1994). Deposit gauges give information on local rates of deposition to the ground, whereas flux gauges indicated the passage of dust past the sampling point. Flux gauges can also possess natural directional properties, which can be used to identify the source direction of wind-blown dust (Hall, 1994). The dust deposit and flux gauges have to be set well above the ground, typically between 1 and 2 m height, in order to avoid collecting locally wind-raised material.

The Standard American Test Method (Egami et al, 1991) for wind blown dust monitoring has found wide application in the South African mining industry in or near urban areas. The deposit gauge used in this method consists of a single bucket half filled with treated de-ionized water for trapping dust.

Study area

Field experiments for this study were carried out at Landau Colliery Schoongezicht Mini - pit, site RAMP 6 (see figures 1.1, 1.2 and 1.3). Dust monitoring at Landau Colliery is carried out by Annegarn Environmental Research (Pty) Ltd on continuous basis. A dust deposition monitoring network of fallout dust monitors at Landau Colliery has been in

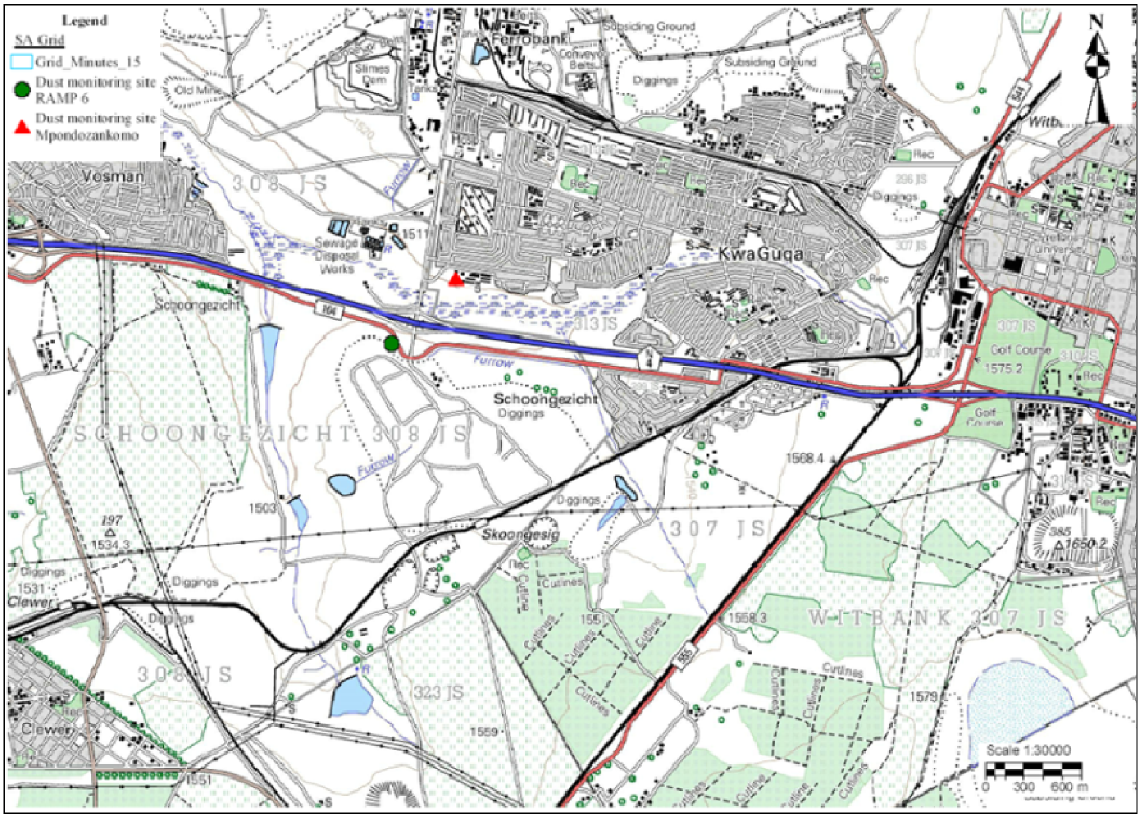


Figure 1.1 Locality map of Landau Colliery Schoongezicht Mini – pit-showing dust monitoring sites RAMP 6 and Mpondozankomo

operation at Landau Colliery – Kromdraai Opencast since November 1992 and at Landau Colliery – Schoongezicht Mini-pit since June 1997. Schoongezicht Mini-pit comprised of seven single bucket and two DustWatch multidirectional monitors. In February 2007 Mpondozankomo twin bucket network was decommissioned and replaced by Mpondozankomo DustWatch multidirectional monitors in March 2007. Other existing dust monitoring sites for Schoongezicht are shown in the table 1.1

Figure 1.2: Photograph of site RAMP 6 (North West) Schoongezicht Mini-pit

Figure 1.3: Photograph of Site Ramp 6 (South) at Schoongezicht Mini-pit

Table 1.1: The Landau colliery monitoring network**:**

Division	Site description	Site number	Commission date
SINGLE BUCKET MONITORS			
Schoongezicht Mini-Pit	West End Bluegum Trees	LAND 01	June 1997
	East End Bluegum Trees	LAND 02	June 1997
	Power Lines	LAND 03	June 1997
	Clewer Crossroads	LAND 04	August 2006
	HTPL	LAND 05	August 2006
	Ramp 6	LAND 06	August 2006
	Ramp 3	LAND 07	August 2006
DUSTWATCH MONITORS			
Schoongezicht Mini-Pit	Mpondozankomo	MPOD	March 2007
	Schoongezicht	SCHOON DW	November 2007

Landau Colliery (Coal) is located 15km north-west to 12km south-west of Witbank in the Province of Mpumalanga. Landau Colliery, an open-cast operation, produces pulverized coal and thermal coal for export; and washed sized coal for the domestic market. Landau Colliery is one of Anglo Coal's South African export mines. It commenced operations in 1992 but the coal reserves were mined as early as 1926. The mine was then known as Coronation Colliery and mining was underground. Underground mining stopped in 1966. Today opencast mining methods are used and the number 1 and number 2 seams are mined in a drill and blast operation with one dragline, two hydraulic shovels and four haul trucks.

Most of the coal produced at Landau is exported through the Richards Bay Coal Terminal. A small portion is supplied to the inland market.

Fugitive dust represents the predominant source of atmospheric emissions from the Landau Colliery. Fugitive dust sources comprise emission of solid particles by the forces of wind or machinery acting on exposed material. Typical examples of such sources include materials handling activities, vehicle entrainment of road dust and wind erosion of stockpiles and tailings impoundments. Particulates may contribute to visibility reduction, pose a threat to human health, or be a nuisance due to their soiling potential.

The main functions of dust monitoring in general include the quantification of the mining operation's contribution to dust deposition in the area, and the identification of possible problem areas. Dustfall monitoring is also useful in tracking progress of control measures and for demonstrating compliance with accepted air quality standards.

Problem statement

It was noted from an emission inventory and modeling study carried out at Landau Colliery by Ecoserve (Pty) Ltd that the predominant size fraction for the nuisance particulates is 10 to 85 µm (Baird, 2007). The modeling study indicated that episodes of dust fallout effects on the community would likely occur at wind speeds greater than 2 $m.s^{-1}$ (Baird, 2007). According to Warren (2000), the Single Bucket at wind speeds greater than 2 $m.s^{-1}$ will collect less dust than in an area with the same atmospheric load but with lower wind speed. The reason being that collected dust is lost easily due the scouring action of the wind driven circulation inside the bucket, which tends to remove material already collected. This is mitigated by filling the bucket with water. The other reason for poor collection efficiency is that the aerodynamic blockage of the gauge produces a rising and accelerating separation streamline over the gauge opening. As a result, particle trajectories are displaced away from the gauge opening and its collection efficiency is reduced (Figure 1.4).

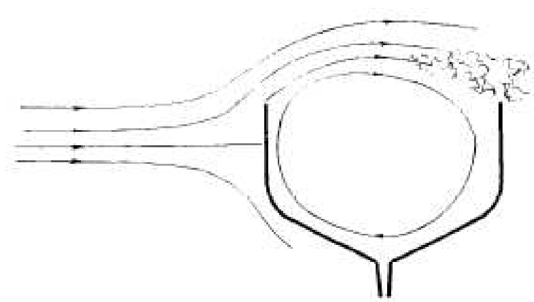


Figure 1.4: Displacement of particle trajectories away from the gauge. (After Hall *et al*., 1994)

The wind speed data obtained from South African Weather Services (SAWS) Witbank weather station indicate that wind speeds in Witbank region are generally above 2 $m.s^{-1}$ over the annual period. The dust monitoring carried by Annegarn Environmental Research (Pty) at Landau colliery using the single bucket could be yielding dustfall rates that are below the actual dust fall load around the colliery. Ecoserve (Pty) Ltd recommended deployment of flux gauges at Landau Colliery for maximum recovery of dust (Baird, 2007).

This research set out to examine the efficiencies of three flux gauges against a single bucket in the Witbank region. It is hoped that the findings of this research will provide a solution to Landau Colliery and also contribute to the growing knowledge on dust monitoring, particularly to the air pollution control and monitoring industry of South Africa

In this study, a dust flux directional monitoring gauge called a Modified Wedge Dust Flux Gauge (MWDFG) to capture dust particles at high wind speeds is designed and manufactured. The dust samples collected from this sampler and those from single bucket and modified Wilson and Cooke (MWAC) samplers are investigated for particle size distribution and morphology.

Research goals

The aim of this study is to develop and test a horizontal flux gauge that will effectively capture dust particles at high wind speeds. This rather broad aim is concentrated on three main objectives.

- To modify the existing Wedge Dust Flux Gauge (WDFG) by incorporating a removable dust deposition tray, wind vane and a bearing to orient the sampler towards different wind directions. The new sampler will be called Modified Wedge Dust Flux Gauge (MWDFG).
- To evaluate the relative efficiencies of the four samplers (single bucket, MWDFG, and Modified Wilson and Cooke (MWAC) – normal and double size).
- To determine the physical properties of the collected dust samples

Structure of the report

The remainder of the report is organized into four chapters.

Chapter two focuses on review of literature relevant to the study, highlighting the classes of dust and health and ecological effects. This chapter also considers the standard methods used for dust monitoring. Included in this chapter is description of various dust sources and effects of climatic conditions on dust levels.

Chapter three discusses the methodology adopted for the study

Chapter four presents' dustfall rates observed for the four dust samplers, particle size analysis and microscopic analysis. Included in this chapter is a comparative analysis of the findings presented.

Chapter five summarizes the research and draws conclusions from the research findings.

CHAPTER TWO

In this chapter dust particles are defined, health and ecological effects are reviewed. The standard methods used for dust monitoring are also presented. This is followed by a description of the various dust sources and how climatic conditions affect dust levels.

Literature review

Dust particles and their classification

Dust consists of finely divided particles that may become airborne (Mody and Jakhete, 1987). These tiny solid particles are formed by a wide range of manufacturing, domestic, and industrial activities. Construction, agriculture, and mining are among the industries that contribute most of the atmospheric dust levels (Mody and Jakhete, 1987). Some of the activities that contribute to dust generation include: vehicle- entrainment of dust from paved and unpaved roads; wind erosion of open areas, stockpiles, and tailings impoundments; material handling (loading and tipping operations); drilling and blasting operations; dozing and scraping operations and agricultural activities like tilling, (Combes and Warren, 2005). The principal modes, sources and particle formation and removal mechanisms of atmospheric aerosols are indicated in figure 2.1.

According to Seinfeld and Pandis, (1998) dust particles ranges in size between 1 – 100 µm in diameter and fall within the course mode range (Figure 2.1), Particle less than 1 µm are classified as smoke or fumes and fall within the fine mode range. The 2.5 µm particles are respirable and are associated with health effects. These particles are small enough to penetrate the nose and upper respiratory system and deep into the lungs. Particles that penetrate deep into the respiratory system are generally beyond the body's natural clearance mechanisms of cilia and mucous and are more likely to be retained, (Mody and Jakhete, 1987). Inhalable dust consists of dust particles with a median aerodynamic diameter of 10 µm which enters the body, but is trapped in the nose, throat, and upper respiratory tract (Mody and Jakhete, 1987). Particles greater than 10 µm are associated with nuisance. According to the Environment Agency, (2003) particles >30 – 50 µm tend to be deposited quickly and may show up as deposit on clean surfaces such as cars and window ledges. Excess concentrations of nuisance dust in the workplace may reduce visibility, may cause unpleasant deposits in eyes, ears, and nasal passages, and may cause injury to the skin or mucous membranes by chemical or mechanical action (Mody and Jakhete, 1987). Another form of dust may be particulate matter that, although may be found resting on the ground or other surfaces, is capable of becoming airborne before returning to the surfaces (Grantz *et al.*, 2003).

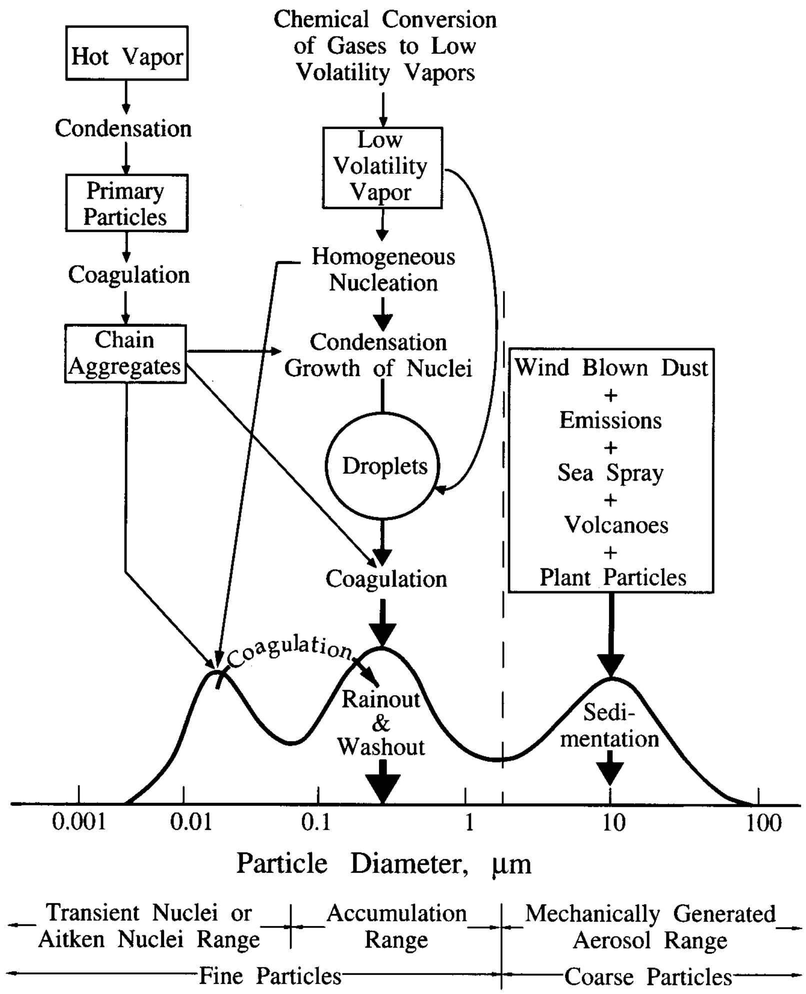


Figure 2.1: Idealized schematic of distribution of surface area of an atmospheric aerosol. Principal modes, sources and particle formation and removal mechanisms are indicated. (After Seinfeld and Pandis, 1998)

Dust in the atmosphere and the removal pathways

The wind assists in keeping between one and three billion tons of dust and other particles airborne at any given time (Envirocast Newsletter, 2003). The atmosphere is continuously being gleaned of its dust load through the different deposition mechanisms (Jiries *et al*., 2002). The deposition of particles can take place by three dominant routes: wet deposition, dry deposition and occult deposition. If the particles settle by gravity then they are collected as dry deposition. Alternatively, if it rains, then the particles are collected as wet deposition. Particles are removed through incorporation into raindrops as condensation nuclei. Particles in the 0.1 μm diameter size range, particularly sulphate, represent effective condensation nuclei. Smaller particles rapidly diffuse to cloud droplets. Larger particles such as ammonium sulphate and sodium chloride are removed beneath the cloud by raindrops. Occult deposition occurs during mist and fog conditions.

There is an interaction between dry deposition and wet deposition in that wet deposition often removes previously deposited dust on exposed surfaces. If the rainfall is very light then it may not be able to wash away the dry deposited material on surface and the content of the wet deposition may be added to the exposed surface when the rain stops.

Dry deposition is a slow process compared to wet deposition, but dry deposition occurs almost continuously.

Particles between 10 and 100 μm usually loose altitude as a result of gravity. These particles can be lifted up by strong winds but when the wind stops lifting the particles up into the air, they begin to settle. Smaller particles (less than 10 μm) are affected by thermals, turbulence and Brownian motion and will not necessarily settle all the way to ground level. These particles are nevertheless present in the atmosphere at all altitudes and they also precipitate when climate conditions are suitable (Countess Environmental, 2005).

Impacts of particulate matter

Dust particles play an important role in the dynamics of the lower atmosphere and on the Earth itself. They also strongly affect, directly or indirectly, the biological and chemical activities in these regions (Goosens, 1999). Dust particles in the atmosphere form an aerosol when they are suspended in a heterogeneous mixture with liquid droplets. Atmospheric aerosol can be either primary or secondary pollutants. Primary particulates such as soil particles are transferred to the atmosphere in the same chemical form as the source material; secondary particulates are derived from condensation of vapours or chemical reactions in the gas phase. Primary pollutants are not subject to any chemical transformations. Particles larger than 1 µm are produced by mechanical disintegration of material such as crushing, grinding and blasting. Primary pollutants like chlorides, fluoride and phosphate in the size range between 0.1 to 1 µm form larger particles through coagulation process through collision and adhesion. The particles are held together by chemical bonds. The secondary and condensation particulate species resulting from chemical conversions are significant on a regional scale (Held *et al*., 1996).

Particulates lifetime in the atmosphere varies from minutes to several days, allowing some components to be transported over thousands of kilometers from their source regions. The dust fall impacts are generally of concern within a 3 km radius of large source. The majority of the environmental and health complaints are generally more pronounced during dry, windy months.

Effects on human health

Pollution problems due to wind-borne dust from human activities are one of the major sources of complaint, alongside odours (Hall *et al.*, 1994). Wind-borne dust is important for health reasons, due to entry into respiratory tract or as a secondary pathway for ingestion of toxic materials (Combes and Warren, 2005). With the rise of large-scale manufacturing, workers are now exposed to new dusts in settings such as steel and textile mills (Combes and Warren, 2005). The onset of full blown AIDS is often precipitated by other occupational disease such as silicosis which is a result of dust (Schwela, 1998). Exposure to particulate matter has been associated with hospitalization for respiratory or cardiovascular disease and exacerbation of respiratory disease, such as asthma (Schwela, 1998). In people who already have respiratory problems asthma and allergic reactions caused by dust may be severe. Breathing a lot of dust over a long period of time can cause chronic breathing and lung problems. Dust also causes coughing, wheezing and runny noses (Schwela, 1998).

The impact of particles on human health is largely depended on (i) particle characteristics, particularly particle size and chemical composition and (ii) the duration, frequency and magnitude of exposure (Dockery and Pope, 1994). The potential of particles to be inhaled and deposited in the lung is a function of the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density (Dockery and Pope, 1994). The deposition of particles in different regions of the respiratory system depends on their size (Lennon *et al*., 1998). The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Large particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM_{10}) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree (Dockery and Pope, 1994). As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (Godish, 1990). Epidemiological research has identified $PM_{2.5}$ as the most damaging size fraction with regard to human health due to their ability to penetrate the deep lung (Godish, 1990). The $PM_{2.5}$ size fraction has a longer residence time and a low gravitational settling velocity thus representing a greater exposure potential. Ambient $PM_{2.5}$ also penetrates more easily into buildings than does coarser particles. Exposures to PM_{10} are related to increases in the prevalence of chronic respiratory disease and increased risk of acute respiratory disease (Dockery and Pope, 1994; Godish, 1990).

Breathing too much dust can potentially harm anyone. However, the following groups are at the highest risk: Infants, children, and teens, the elderly and pregnant women; People with asthma, bronchitis, emphysema, or other respiratory conditions; People with heart disease; and Healthy adults working or exercising outdoors

Ecological effects

Wet and dry deposition of particulate matter may cause damage to plants, metal surfaces, fabrics and building (Grantz *et al*., 2003). Depending on the chemical composition, particulate matter can contaminate soil and water.

The primary effects of particulate matter on vegetation are reduced growth and productivity due to interference with photosynthesis and phototoxic impacts as a result of particulate composition. The mechanisms of action are through smothering of the leaf; physical blocking of the stomata; bio-chemical interactions; and/or indirect effects through the soil (Grantz, *et al.*, 2003). Dust deposited on the ground may produce changes in soil chemistry, which may in the longer-term result in changes in plant chemistry, species competition and community structure (Wayne, 1991). The relative efficiency of these methods will depend upon the plant or soil surface, the micro-climate and ambient (temperature and humidity) conditions (Wayne, 1991). Dust particles can also act as nuclei onto which ammonia, sulphuric acid and hydrogen fluoride may adhere, forming acidic dust, which can burn plants (Wayne, 1991)

The deposition of particulate matter on materials can reduce their aesthetic appeal as well as increase their physical and chemical degradation (Grantz *et al*., 2003). The primary effects of particulate matter on materials are on the rates of corrosion and erosion, and soiling and discoloration. Course particles (2.5-10 µm) contribute more soiling and discoloration horizontal and vertical surfaces than fine particle (<2.5 µm). Course particles are more readily removed by rain (Grantz *et al*., 2003). Particles may act as a catalyst for the conversion of SO_2 and NO_X to sulfuric acid and nitric acid which accelerate the chemical degradation of susceptible material surfaces on which they are deposited (Grantz *et al*., 2003)

Effects on animals

Deposition of acidic dust on aquatic systems alters the pH and this result in acidification of lakes and ponds (Grantz *et al*., 2003). Low pH kills fish and result in lakes with no fish species. Heavy metals that may be contained in dust and transported in water and vegetation may be toxic to animals and fish (Grantz *et al*., 2003). The process by which the animals may be affected by contaminated dust is by them ingesting contaminated vegetation or forage where contaminated dust has accumulated. Carnivores may also consume small animals that have ingested exotic chemical from dust (Grantz *et al*., 2003.

Sources of dust

Dust is caused by a combination of weather conditions, the natural environment and human activities (Grantz *et al*., 2003). High winds can raise large amounts of dust from areas of dry, loose soil. High winds are most common during the late winter and spring months (Dockery and Pope, 1994). Process-generated precipitant dust comes from industrial activities where the actual structure of the material is altered, such as a rock crushing operation (Countess Environmental, 2005). Open sources generate precipitant dust as a result of wind or mechanical contact (Countess Environmental, 2005). The sources of dust can include:
soil disturbance during construction projects; disturbed land areas that are cleared and vacant; unpaved roads, parking lots and playgrounds; windblown emissions from tilted fields; military training exercises; unpaved equipment yards; undisturbed desert areas during the highest winds; ploughing on farms; dust blown from recently ploughed fields; traffic on dirty roads; blasting at opencast mine operations; dust emitted from process buildings (excluding stacks); dust blown from stockpiles of raw and finished materials; crushing operations; and transportation of raw materials and products by rail or roads.

Dust becomes more common where natural soils have been disturbed by human activities (Scotland Government 1998). This tends to be concentrated close to populated areas (Etyemezian *et al*., 2004). Each site is unique and the impact of the precipitant dust emanating for example, from a mine or factory is dependent on many factors: The type of mineral being processed and the methods used (Rodrigues, 2002); Local meteorology and topography (Rodrigues, 2002); and the zoning of the land surrounding the site, as shown in Table 2.1

Table 2.1: Classification of areas in terms of sensitivity to precipitant dust

High Sensitivity	**Medium Sensitivity**	**Low Sensitivity**
Hospitals and Clinics	Schools	Farms
Retirement homes	Residential areas	Light and heavy industry
Hi-tech industries	Food retailers	Outdoor storage
Areas where painting is being done	Greenhouses and nurseries	
Food processing	Horticultural land	
	Offices	

Depending on climatic conditions and topography, fine particles may remain airborne for days or months and may be transported 1000 to 10 000 km or more from their sources (Countess Environmental, 2004). Dust sources can be process or open source generated, but excludes dust emitted from stacks. Dust emitted from stacks is usually constant all year round with wind and rainfall not affecting the amount of dust emitted from the stack (Countess Environmental, 2004)

Climatic conditions

The impact that climatic conditions have on the precipitant dust levels is important and the factors that could be considered are rainfall (drought), wind speed, and the time periods with little or no wind. The meteorology characteristics of a site impact on the rate of emissions from fugitive sources, and govern the dispersion, transformation and eventual removal of pollutants from the atmosphere (Godish, 1990). Fugitive dust emission rates are predominantly a function of the wind speed, and the intensity and duration of the activity generating the dust (e.g. traffic volumes, extent of batch drop operations) (Godish, 1990). Evaporation rates and precipitation levels also influence fugitive emission rates due to their impact on the moisture content of materials being handled or stored (Godish, 1990).

The wind direction and the viability in wind direction determine the general path pollutants will follow, and the extent of cross-wind spreading (Kuhn and Loans, 2003).

Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability and to shifts in the wind field. Spatial variations, and diurnal and seasonal changes, in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales (Kuhn and Loans, 2003). Atmospheric processes at macro- and meso-scales need therefore be taken into account in order to accurately parameterize the atmospheric dispersion potential of a particular area (Kuhn and Loans, 2003).

Meso-scale factors

Mesoscale factors such as regionally induced topographic winds, urban heat island effects and atmospheric stability are important control factors in atmospheric pollution dispersion (Held, 1996 a,b; Tyson et al, 1998). These circulations and atmospheric conditions are major determinates of the low-level field, particularly during the night and winter as they control to a larger extent, the transport and dispersion of low-level emissions of pollutants.

Atmospheric stability is a key factor for plume behavior and dispersion characteristics. Various plume types are shown as a function of atmospheric stability in figure 2.2. Looping plumes in unstable air and fumigating plumes when the air is stable above the emission point produce the highest ground-level concentrations of pollutants. Coning and fanning plumes tend to carry pollutants greater distances from the source in a relatively undiluted form, while lofting plumes disperse emissions released above surface inversions both vertically and horizontally (Held *et al*., 1996).

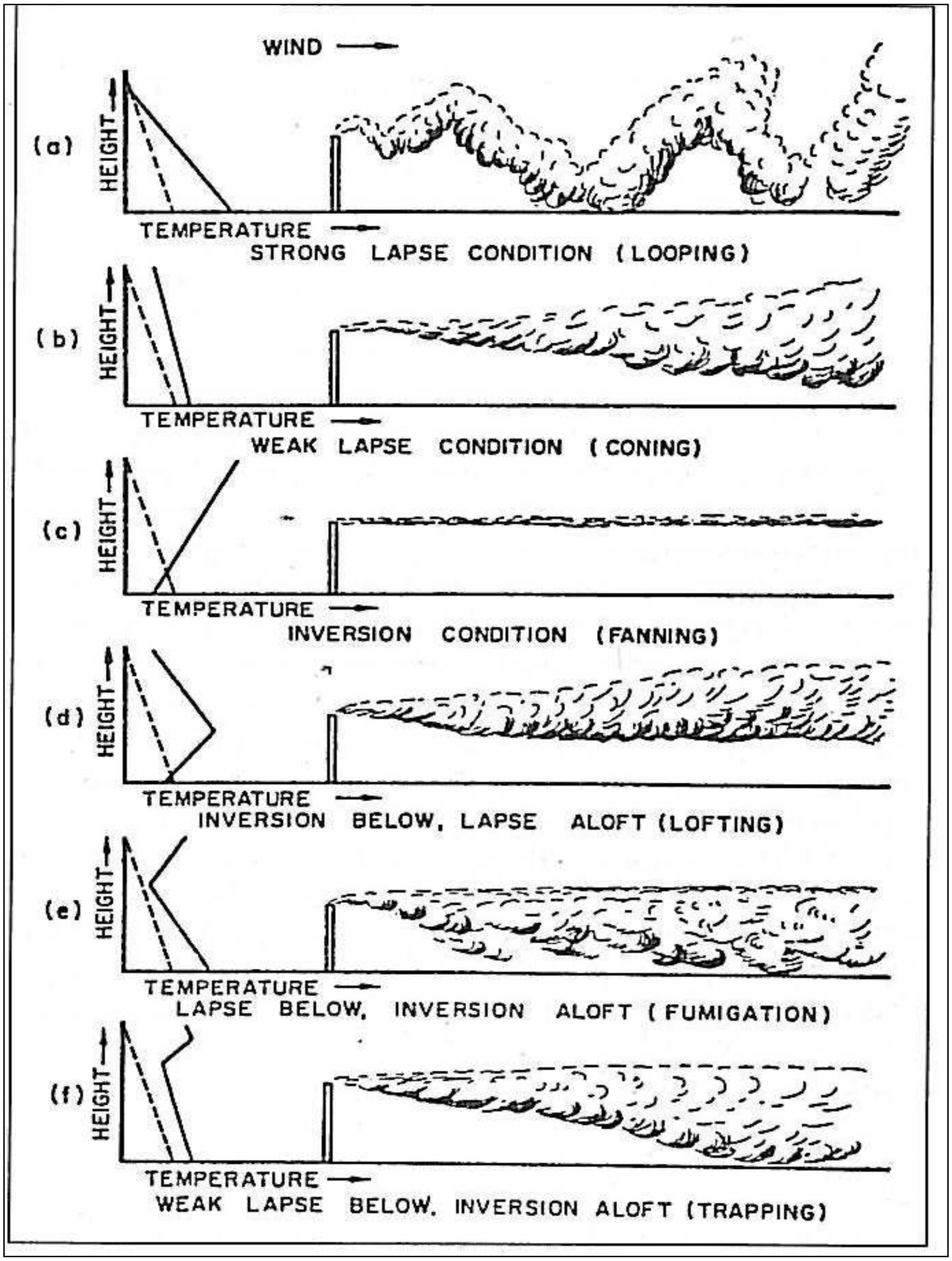


Figure 2.2 The effect of lapse rate on plume type DALR signifies the dry adiabatic lapse rate (dashed line) and ELR the environmental lapse rate (solid line): after Pretorius et al (1986)

Transport mechanism over the Highveld region

The Highveld lies on a plateau some 1600 m above sea level. The regional scale topography slopes gradually downwards towards the west and south. To the east lies the escarpment of the Drakensberg. The southern area of the Highveld is dominated by the Vaal

Basin some 1400 m above sea level, which tends to drain cold air from the surrounding high-lying platea of the Gauteng region (Held *et al*,. 1996).

Boundary layer characteristics of the Mpumalanga Highveld

Over the Mpumalanga Highveld, mean daytime surface winds over much of the region show a predominance of north to north-westerly winds, with easterly winds being the next most frequent. However during winter the frequency of south-westerly winds increase as a result of increased cyclonic occurrences associated with the passage of westerly weather disturbances. During the night a greater incidence of north-easterly winds occur than north-westerly winds. However substantial increases of light topographically induced winds occur from the east and south-easterly sectors during the night. Annual surface wind speeds vary between 2 and 4 $m.s^{-1}$ with maximum velocities of 6 $m.s^{-1}$ occurring during late winter and autumn (August and September) as discussed by (Pretorius *et al*., (1986) and Tyson *et al*., (1988).

Boundary layer winds

The winter season in the Highveld region is dominated by the presence of anticyclonic circulation, mostly sustained by the expansion of the south Indian Ocean anticyclone over the relatively colder interior of Mpumalanga. The “winter mode” 800 hPa wind circulation (about 350m AGL) clearly indicates that the boundary layer winds are dominated by the Indian Ocean anticyclone which extends inland to the Northern Province (Tosen and Jury, 1986). Due to the northward migration of the anticyclonic pressure belts in winter, Mpumalanga is dominated by westerly and west-north-westerly winds. However, in summer, due to the southward migration of these pressure belts, the circulation is characterized by the presence of northerly-component winds over the highveld region (Tosen and Jury, 1988). The winds veer progressively towards north-north-east with the approach of February and thereafter tend to back at the onset of autumn to westerly (figure 2.3)

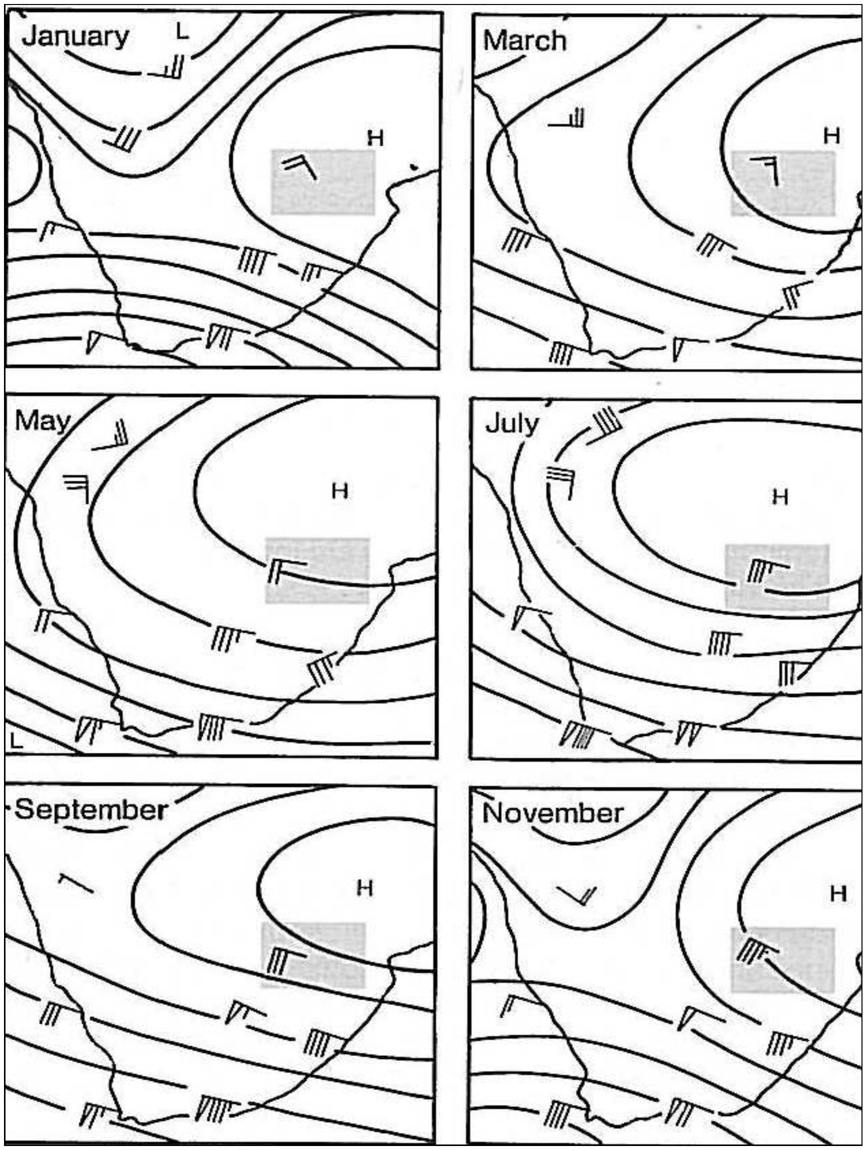


Figure 2.3 Seasonal variation of the mean 800 hPa winds and contours. The 800 hPa surface occurs at around 1950m, i.e. about 350 m above the surface over the industrial highveld region (shaded): after Tosen and Jury (1986).

Dust erosion and subsequent transport

Dust mobilization occurs only for winds velocities higher than a threshold value, and is not linearly dependent of the wind fraction velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameter >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other. Following the exceedance of the necessary threshold friction velocity, the movement of a particle is dependent on the relationship between the weight of the particle acting downward, and the opposite aerodynamic drag on the particle. The particles (<60 µm) are small enough to be transported upward by turbulent eddies. Particles in the range 60 to 2000 µm can be lifted from the surface at a height of some tenths of cm, but the aerodynamic drag is seldom sufficient to exceed the weight, and the particles are carried back to the surface. Such trajectories define a motion called saltation. The maximum height of the saltation layer is generally in the order of 1 m. Particles which are too large or too heavy to be lifted from the surface (>2000 µm) role and creep along the surface in a motion called creeping figure 2.4.

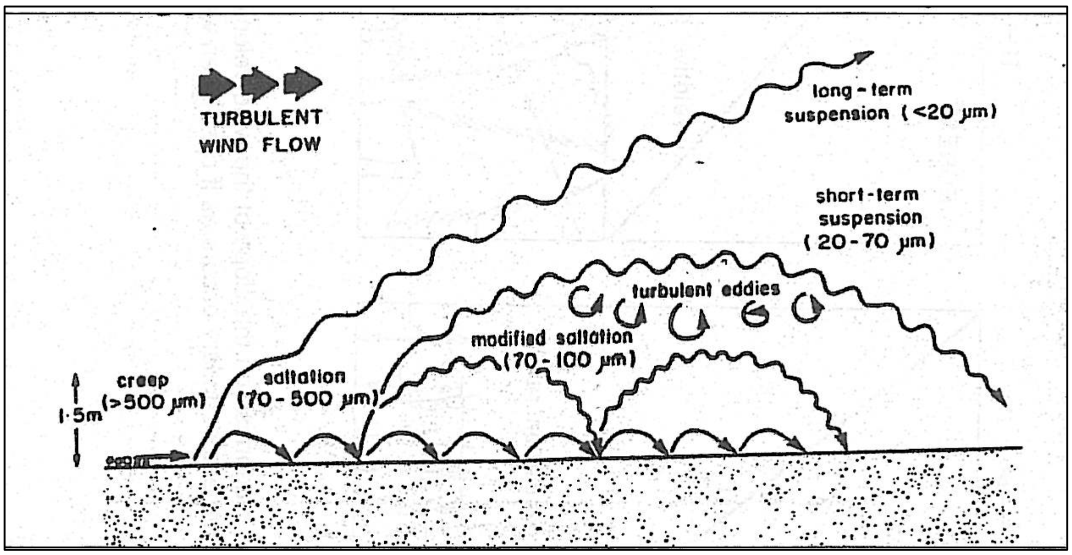


Figure 2.4 Modes of particle transported by wind: after Pye (1987)

Figure 2.5 shows deposition of dust in the lee of topography obstacles due to flow divergence. Dust deposition is prevented on windward slopes where flow convergence and speed-up occurs.

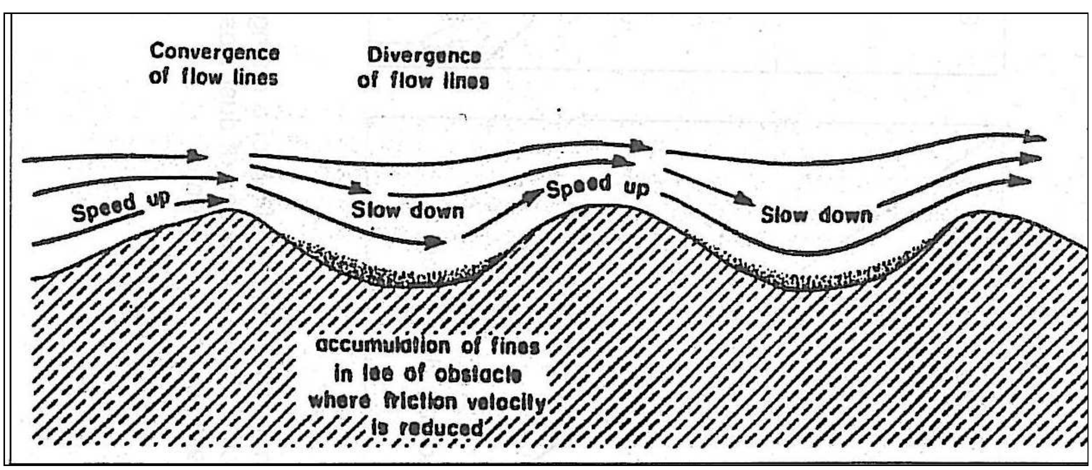


Figure 2.5 Deposition of dust in the lee of topographic obstacles: after Pye (1987)

Fugitive dust abatement

Dust emissions can be controlled by use of preventive and mitigative measures. The preventive measures are aimed at the reduction of the source extent, or process modification and adjusting work practices (Cowherd *et al*., 1998). For example, the extent of the source may be reduced by reduction in the mass of material being handled, or elimination of track-on on paved roads, and the paving of unpaved roads. A mitigative measure includes periodic removal of deposited material. This may involve clean-up of spillage on paved roads (broom and vacuum sweeping) or clean-up spills, for example, at conveyor transfer points. Higher priority should be given to preventive measures rather than cleaning up deposited material (Cowherd *et al*., 1998).

Dust from surfaces may be removed by wet suppression and air atomization suppression. The efficiencies of these treatments can be estimated through the relationships between climatic parameters, material properties and quantities of material transferred (Cowherd *et al*., 1998). Examples of wet suppression systems for materials handling purposes includes sprayers on conveyor belts, spot spraying of stockpile reclaim areas prior to reclaiming and spraying at transfer points. In the wet suppression process, the emissions are prevented through agglomerate formation by combining fine particulates with larger aggregate or with liquid droplets. The coverage of the material by the liquid and the ability of the liquid to wet small particles are the key factors affecting the extent of agglomeration and the control efficiency of dust emission (Cowherd *et al*., 1998).

Liquid Spray suppression utilizes water only or a combination of water and a chemical surfactant as the wetting agent. Surfactants reduce the surface tension of the water thus allowing particles to more easily penetrate the water particles and reducing the quantity of water needed to achieve the control efficiency required. Foam Suppression systems utilizes foam that is generated by adding a chemical to a relatively small quantity of water and vigorously mixing to produce small bubble, high energy foam in 100 to 200 μm size range. The major advantage of foam is that it wets the fines more effectively than untreated water (EPA, 1990). Air Atomizing Spray system uses water and compressed air to produce micron sized droplets that are able to suppress respirable dust without adding substantial moisture to the process. This system is useful when limited water is available or not allowed to be used (EPA, 1990).

Wind sheltering is a dust suppression method that is used at material handling sites. This involves installation of transfer chutes, to avoid spillage and reduce entrainment during transfer by sheltering e.g. at belt-to-belt transfer points and stacking points (EPA, 1990).

Dust monitoring

Ambient particulate monitoring is attracting considerable attention in today's environment as worldwide air quality legislation comes into effect. Dust monitoring is an important practical activity for pollution control purposes. Monitoring is conducted for both health and nuisance purposes and the different monitoring methods can be divided into active systems and passive systems (Colls, 1997). The directly inhaled particle fraction is normally monitored using active samplers, which fractionate the sample and pull a known volume of particle-laden air through the filter (Colls, 1997). For nuisance dusts and those concerned with secondary pathways it is usually either deposition to the ground or the flux of particles past a point that is of interest (Colls, 1997). Deposit gauges have a horizontal opening and flux gauges a vertical opening (US-EPA, 1998). Dust deposit and flux gauges, should be used in combination to assess different aspects of wind-blown dust problems (Hall, 1994). Deposit gauges gives information on local rates of deposition to the ground, whereas flux gauges indicate the passage of material past sampling point. Flux gauges can also possess natural directional properties, which can be used to identify the source direction of wind-blown material (Hall, 1994). Gauges have to be set well above the ground to avoid collecting locally wind-raised material.. The end result is a collection performance, which is strongly wind speed and particle size dependent. The general trend is for collection performance to reduce as wind speed increases, which is doubly unfortunate as the amount of windblown material also tends to increase at higher wind speeds, compounding collection problems for deposit gauges (Hall, 1994).

Other monitoring techniques and methods in use for nuisance dust include: measurement of airborne dust concentrations using gauges which sample air volumes or by using light scattering devices that measure attenuation of light (Environmental Agency, 2003); examining the progressive soiling by dust (Environmental Agency, 2003); and visual monitoring which is subjective and qualitative (Environmental Agency, 2003).

Active systems are best suited for measuring over minutes, hours and days whereas passive systems are best suited for measuring over days weeks and months (British Standards Institute, 1972).

Sampling periodic approach

The periods of sampling are determined by the processes and installations producing dust (US-EPA, 1998). The more variable the emission, the more frequently periodic monitoring is required. When emissions levels vary so frequently and significantly that intermittent sampling would be unrepresentative, or would be required too frequently to be practicable, then sampling should be carried out using a continuous system (US-EPA, 1998).

Averaging period and sampling duration

The duration of sampling must be long enough to allow the results to be expressed as an average over the specified period. In other cases, the choice of suitable averaging periods is strongly influenced by the expected short-time variability in emission levels (Environmental Agency, 2000).

The averaging period determines the monitoring technique to be used. Direct-reading analyzers (automatic monitors) can provide data with a very fine time resolution. The averaging time for a manual technique is often constrained by the need for a sampling run of appropriate duration (often half and hour or more). This is because manual techniques have an associated analytical end-method stage for which a sufficient mass of pollutants must be sampled to achieve an adequate lower detection limit (Environmental Agency, 2000).

Type of dust samplers

Passive samplers

Passive systems focus on the soiling aspect of dust with the monitoring periods of days, weeks and months (Colls, 1997). Deposited dust is collected and measured to assess potential soiling effects. Passive sampling does not involve active movement of air through the sampler. Passive samplers have the advantage of giving good overall picture of average pollutant concentrations. They normally give long averaging periods (typically 1-4 weeks). Neither electricity nor calibration is required for its operation. They have low operational costs thus facilitating the installation of several samplers in non-secure areas to enhance the potential for data collection (US-EPA, 1998). The samplers must be situated in a generally open area, which allows free circulation of air. Examples of passive samplers include single and double bucket fallout monitors (US-EPA, 1998). Passive samplers are further divided into non-directional and directional monitors.

Non-directional monitors

Non-directional methods provide nuisance monitoring using either dustfall or surface soiling. Deposit gauges are designed to collect material deposited over a given monitoring period, typically 1 week to one month and are based on the principle that course particulates suspended in the air will precipitate out either under the influence of gravity (dry deposition) or in contact with water droplets (wet deposition) (Environmental Agency, 2003)

Single Bucket dust fallout monitor

Single bucket monitors are deployed following the American Society for Testing and Materials standard test method for collection and analysis of dustfall (US-EPA, 1998). This method employs a simple device consisting of a cylindrical container half-filled with de-ionized water exposed for one calendar month (~30 days) (US-EPA, 1998). The cylindrical container is supported by a metal stand upward, 1.2 m above the ground. The dust falls into the bucket vertically, as either dry deposition or wet deposition. The water is treated with an organic biocide to prevent algae growth in the buckets. The buckets are also covered with net and a ring that is raised above the rim, to prevent contamination from birds perching. Once returned to the laboratory, the water is filtered, and the residue is dried before the insoluble dust is weighed (US-EPA, 1998). It measures ambient deposition falling vertically, either as dry deposition or wet deposition. The other types of deposit gauges are described in Table 2.2 (Environment Agency, 2003).

Table 2.2: Description of different standard deposit gauges

Standard	**Shape**	**Diameter**	**Depth**	**Extra**
UK BSI, 1969	Funnel	300mm	200mm	
German (VDI, 1990)	Glass jar	100mm	200mm	
US (ASTM, 1990)	Cylindrical	150mm	300mm	Surrounded by a wind deflector at angle 45^0
Irish	Plastic funnel	200 & 250mm		
ISO 1991	Cylindrical	200m	400mm	
Norwegian NILU	Cylindrical	200mm	400mm	

Frisbee gauge

The gauge consists of an Inverted Frisbee mounted horizontally on a pole 1.75m above the ground figure. The shape has superior collecting efficiency and aerodynamic characteristics that make it suitable for short-term sampling periods of about a week (Environment Agency, 2003). The matter deposited on the collection surface and the insoluble matter in the collection bottle is removed and separated by gentle vacuum filtration. The insoluble matter is dried and determined gravitationally. The results are expressed in mg/m^2/day. The gauge requires additional guard to reduce bird-strike, and a polyester foam insert to improve collection efficiency and reduce contamination by leaves (Environmental Agency, 2003)

Figure 2.6 Photograph of Frisbee depositional dust gauge. After Goodquarry (2004)

Twin bucket wind direction sampler

Twin bucket wind direction samplers consists of two collection containers half filled with treated water, mounted 2.5 m above ground level (Kuhn, 2003) . A moveable lid is positioned over the containers; the lid alternating between containers depending on the wind direction recorded by an attached wind sensor. The exposure time of each container is recorded electronically. Following exposure, samples are subject to gravimetric analysis as in the case of single bucket samples. Since the twin bucket wind directional sampler is able to monitor dust deposition by direction, they are useful in identifying source contributions in instances where multiple sources occur (Kuhn and Loans, 2003).

Glass slides

A clean microscope slide is exposed for, typically, one week (Environmental Agency, 2003). The slide is positioned horizontally on a surface between 1m and 2m above the ground. The dustiness of the exposed slide is quantified by measuring the reduction in specular reflectance relative to a clean unexposed slide (Environmental Agency, 2003). A measurement in Soiling Units (SU) is obtained by subtracting the reflectance value from 100. The soiling level can be related to perceived annoyance.

Directional monitors

Directional gauges collect dust in air moving in a given direction (British Standards Institution, 1972). The following is a description of different types of directional gauges.

BS 1747 Part 5 or CERL-type directional gauge

This type of sampler consists of four slotted sampling tubes set at right angles to each other (Environment Agency, 2003), figure 2.7. It is positioned with either each tube lined up with the four ordinate points of the campus, or one slot towards the pollution source. Sampling periods of about 10 days to 1 month are usual and long sampling programs of about one year are necessary. An aqueous suspension of the dust is placed in a water-filled glass cell, and dust loading is estimated by the amount of obscuration of a beam of light passing through the cell. Alternatively, the insoluble deposit material is filtered, dried and determined gravitationally. Results are then expressed in units of $mg/m^2/day$ for each direction. The method has limited efficiency in dust collection (Environment Agency, 2003)

Figure 2.7 Photograph of directional dust gauge After Goodquarry (2004)

Directional frisbee gauge

The gauge is similar to standard Frisbee gauge but differs in that the collection surface is exposed only when the associated meteorological equipment indicates that wind is from a defined direction arc. The matter deposited on the collection surface and the insoluble matter in the collection bottle is removed and separated by gentle vacuum filtration. The insoluble matter is dried and determined gravimetrically. The results are expressed as $mg/m^2/day$. The gauge requires additional equipment and/or a power supply (Environmental Agency, 2003).

Directional sticky pads (DustScan)

The gauge consists of a purpose made adhesive slide mounted on a collection cylinder on a post 2m above the ground (Environmental Agency, 2003), figure 2.8. The gauge is normally exposed for 1-2 weeks. Dust in flux is captured for subsequent analysis using computer-based tools. The software is able to account for foreign objects such as insects. Unlike other methodologies this technique is capable of collecting and assessing dust from multiple sources (of various colors) and from any direction. Reporting of results may be as loss of reflectance through soiling (Effective Area Coverage, or EAC%) (Beaman et al, 1981), or as Absolute Area Coverage (AAC%) (Joint Nature Conservation Committee, 1993), the density of coverage of dust as presence or absence, irrespective of color. A combination of both AAC and EAC is used to assess the quality of dust present and define whether the levels are a nuisance or not (Beaman *et al*., 1984)

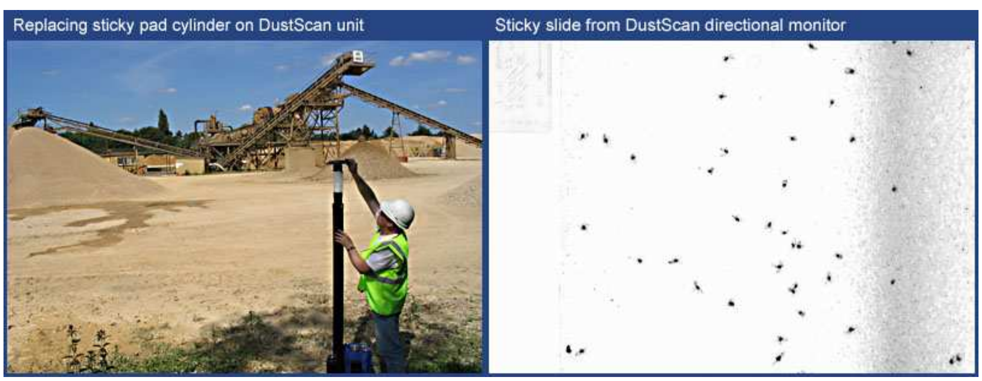


Figure 2.8 Photograph showing sticky pad cylinder and slide on DustScan unit. After Goodquarry (2004)

Active samplers

Active samplers collect pollutant samples, either by physical or chemical means, for subsequent analysis in a laboratory (US-EPA, 1998). A known volume of air is pumped through a collector (filter or chemical solution) for a known period of time, the collector is then removed for analysis (Colls, 1997). The samplers require power supply and are labor intensive. Example of this type of sampler includes Black Smoke and Sulfur Dioxide Monitoring by Bubbler, High-volume Sampling, Active Particulate Sampling by PM10 Sampler and Tapered Element Oscillating Microbalance (TEOM) (ISO, 1970).

Hi-volume sampling

The sampler consist of a collecting glass fiber filter located upstream of a heavy-duty vacuum cleaner type motor which is operated at a high airflow rate (1.13-1.7 m^3/min) (US-EPA, 1998). The sampler is mounted in a shelter with the filter parallel to the ground. The covered housing protects the glass fiber from wind and debris and from the direct impact of precipitation. The sampler collects particles efficiently in the size range 0.3 to 100 µm. The sampler is normally operated on a 6-day sampling schedule, with a 24- hour sample collected every sixth day (US-EPA, 1998). The sampler employs the principle of gravitational settling for dust collection. The mass of Total Suspended Particles (TSP) collected is expressed in µg/m^3 for 24-hour period.

Active particulate sampling (e.g. PM10 Sampler)

The collection of particles in this sampler is through filtration. The air is drawn through a section of filter paper for a specified time. At the end of the exposure period the roll of filter paper is wound on and a clean section exposed. Area of sample is removed and weighed in the laboratory. The excess mass is attributed to collected particles. The type of filter used is dependent on the type of analysis to be conducted, e.g. Teflon filter is used for inorganic element analysis by x-ray fluorescence (ISO, 1970), and quartz/NaCl impregnated filter for analysis of organic and soluble chemical species.

Tapered element oscillating microbalance (TEOM)

TEOM operates by continuously measuring the weight of particles deposited onto a filter (US-EPA, 1998), figure 2.9. The filter is attached to a hollow tapered element which vibrates at its natural frequency of oscillation. As particles progressively collect on the filter, the frequency changes by an amount proportional to the mass deposited. As the airflow through the system is regulated, it is possible to determine the concentration of PM_{10} in the air. The filter requires changing periodically, typically every 2 to 4 weeks, and the instrument is cleaned whenever the filter is changed (US-EPA, 1998). Different inlet arrangements are used to configure the instrument and can monitor PM_{10}, $PM_{2.5}$, PM_1 and TSP continuously.

Data averages and update an interval includes: 5-minute total mass average (every 2 seconds), 10-minute rolling averages (every 2 seconds), 1-hour averages, 8-hour averages, and 24-hour averages (US-EPA, 1998).

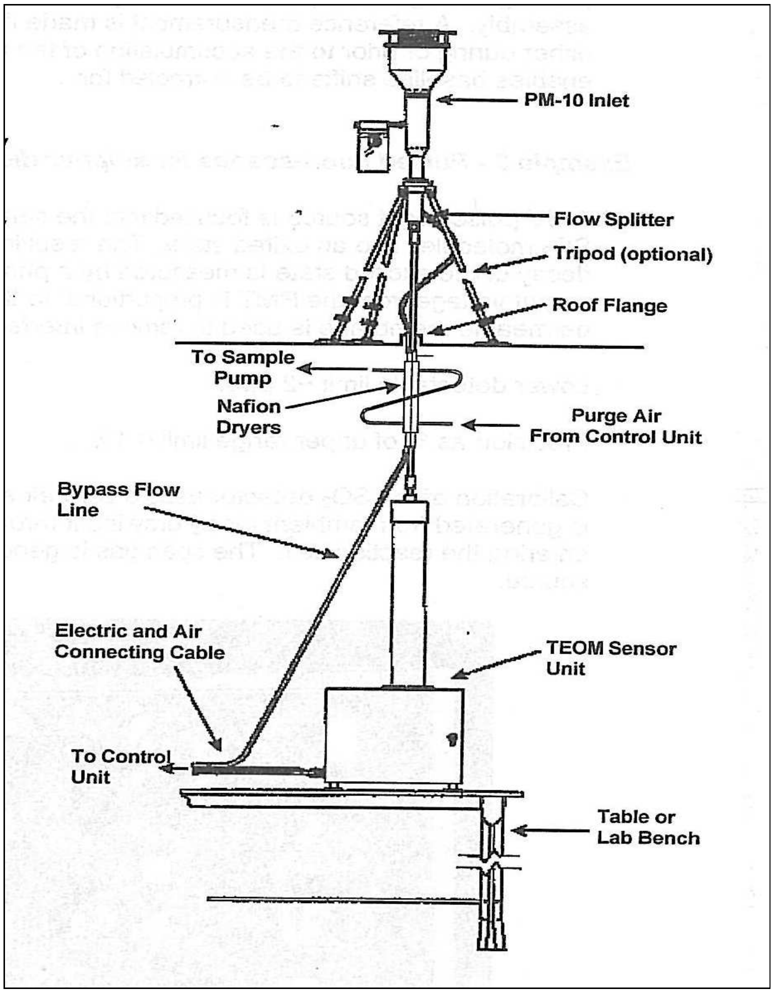


Figure 2.9 Schematic diagram of Tapered Element Oscilating Microbalance (TEOM)

Ambient air quality guidelines and standards

International ambient air quality guidelines and standards

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site (WHO, 2000). The ambient air quality guideline values indicate safe daily exposure levels for the population, including the very young and the elderly, throughout an individual’s lifetime. Air quality guidelines and standards are normally given for specific averaging period. These averaging periods refer to the time-span over which the air concentration of the pollutant was monitored at a location (WHO, 2000).

Generally five averaging periods are applicable, namely an instantaneous peak, 1-hour average, 24-hour average, 1-month average and annual average. Guidelines for particulates are normally given for maximum daily and annual averaging periods. The United States Environmental Protection Agency (US-EPA) has set standards for both PM_{10} (Table 2.3) and $PM_{2.5}$ size fractions. Reference is also made to UK Air Quality Strategy and other regional and national Air Quality Standards and guidelines shown in Table 2.4 (US-EPA, 2000).

Table 2.3: Air quality guidelines and standards for respirable particulates (PM_{10})

Averaging period µg/m³	**South African (SANS 1929:2005) mg/m³**	**World Health Organization mg/m³**	**US-EPA µg/m³**	**European Union µg/m³**
Annual average	40	60-90	50	80
Max 24-hour average	75	150-230	150	130 250

Table 2.4: Nuisance dust mass deposition measurements (US-EPA, 2000)

Authority	**Pollutant**	**Concentration measurement**	**Measured as**	**Relevance**
UK dust deposit rate	All particulates	200mg/m²/day	Annual mean	Serious nuisance
West Australia Nuisance Standard	All particulates	133mg/m²/day 333mg/m²/day	Monthly mean	First loss of amenity Unacceptable reduction in air quality
West Germany Nuisance Standard	All particulates	350mg/m²/day 650mg/m²/day	Monthly mean	Possible nuisance Very likely nuisance
Malaysia Air Quality Standard	All particulates	133mg/m²/day		Nuisance dust deposit
Israel Air Quality Standard	All particulate	2*105 kg/km²/month		Nuisance deposit

The EU standards have been determined through consultations with due regard to environmental conditions, the economic and social development of various regions and the importance of a phased approach to attaining compliance. The ambient air quality standards of the US-EPA are based on clinical, toxicological and epidemiological evidence. The standards of the US-EPA also reflect the technological feasibility of attainment (US-EPA, 2000).

The US-EPA standard for PM2.5 (particles <2µm is given as

Maximum 24-hour average	65µg/m^3
Annual average	15µg/m^3

The exceedance of maximum daily average limit by the three year average 98th percentile of 24-hour concentrations would constitute a violation of this standard. The PM2.5 three-year annual average needs to be less than the 15 µg/m^3 limit in order to demonstrate compliance with the annual standard (WHO, 2000).

South African ambient air quality quidelines and standards

The South African National Standards (SANS) 1929:2005, Edition 1.1 describes the proposed guideline criteria for dust deposition.

A four-band scale is used to set target, action and alert threshold concentrations for dust depositions, in addition to permissible margins of tolerance and exceptions. The four four-band deposition criteria, extracted from SANS 1929:2005 (Edition 1.1) are shown in Table 2.5. The target, action and alert threshold are shown in Table 2.6.

Table 2.5: Four-band scale evaluation criteria for dust deposition (SANS 1929:2005).

1	2	3	4
Band Number	**Band description label**	**Dust fall rate (D) (mg/m^2/day)**	**Comment**
1	Residential	D<600	Permissible for residential and light commercial
2	Industrial	600<D<1 200	Permissible for heavy commercial and industrial
3	Action	1 200<D<2 400	Requires investigation and remediation if 2 sequential months lie in this band, or more than 3 occur in a year
4	Alert	2 400<D	Immediate action and remediation required following the 1st incidence of dust fall rate being exceeded. Incident report to be submitted to relevant authority

Table 2.6 Dust standards, target, action and alert thresholds for dust deposition (SANS 1929:2005)

Level	**Dustfall Rate (mg/m^2/day)**	**Permitted Frequency of Exceedances**
Target	300	
Action residential	600	Three within any year, no two sequential months.
Action industrial	1 200	Three within any year not sequential months.
Alert threshold	2 400	None. First exceedance requires remediation and compulsory report to authorities.

For heavy commercial and industrial regions, the guidelines state that monthly average dust deposition rates below 1 200mg/m^2/day “are permissible”. Areas recording monthly average dust deposition concentrations between 1 200 mg/m^2/day and 2 400 mg/m^2/day “require further investigation and remediation” Areas recording monthly average dust deposition concentrations that exceed 2 400 mg/m^2/day will “require immediate action and remediation and an incident report to be issued to the relevant authority”.

The largest proportion of dust particles generated from surface mining activities is greater than 30 µm and these will normally deposit within 100m of the source. This does not include the dust emitted from kiln stacks and other heated processes as the dust emitted from these processes can contain a large proportion of particles less than 10 μm. The heat and exit velocity from stacks makes the dust more likely to travel further from the source. The smaller the particles the further they can potentially travel.

CHAPTER THREE

OVERVIEW

This chapter discusses the methodology adopted for the study. The description of the design and principles of operation of the MWDFG and MWAC samplers are given. Details of the sample preparation method and laboratory analysis used to obtain dust data are also explained. Finally microscopy and particle size analysis of dust samples are described.

Methodology

Study site

Dust samples were collected with four samplers Modified Wedge Dust Flux Gauge (MWDFG, Modified Wilson and Cooke normal sized inlet (MWAC N), Modified Wilson and Cooke double sized inlet (MWAC D), and the Single Bucket located at Landau Colliery Schoongezichy Mini – pit, site RAMP 6, over a three month sampling period (March to May 2008). The samplers were located 1.5 meters away from each other, and two meters above the ground. Landau Colliery is located in Mpumalanga province in the Witbank region. Mpumalanga province is situated in the eastern part of South Africa: it is a summer rainfall region with precipitation occurring mainly in the form of thunderstorms. The mean annual rainfall varies from 350 mm in the north east to 1600 mm on the escarpment. The region's proximity to the tropic of Capricorn and warm Mozambique current of the Indian Ocean results in a subtropical, frost-free climate in the low lying areas of the lowveld (Schulze, 1972).

Description of flux gauges

The modified Wedge dust flux gauge and Modified Wilson and Cooke are flux gauges and were used in conjunction throughout this study to determine the most efficient sampler in collecting dust amongst the two against the bucket gauge. Two versions of Modified Wilson and Cooke were used in this study – the normal sized inlet and outlet and the double sized inlet and outlet. Detailed descriptions of the designs of MWDFG and MWAC are presented in the next sections.

Modified wedge dust flux gauge (MWDFG)

The modified Wedge Dust Flux gauge is based on an original design developed by Hall *et al*.. (1994). A picture and technical scheme of the original Wedge Dust Flux Gauge (WDFG) is shown in figure 3.1. The dimensions shown in figure 3.1 refer to half scale version. The WDFG is commercially available in normal and half dimensions. The WDFG consists of a simple, parallel-sided box, wedge shaped in elevation and with extended sides towards the rear holding a baffle plate. The flat, horizontal bottom of the box is 18 cm long and 10 cm wide. The top slopes upwards at an angle of 24.5 degrees. Sediment-laden air enters the instrument via a 1.9 x 10.0 cm rectangle slot. The box contains a particle trap made from 10 pores per inch foam, which is normally sprayed with a thin sticky coating to retain any impacting particles. The layer of the foam is 3 cm deep and is set with its rear face 2 cm from the back face of the box. The WDFG does not respond to changing wind directions. During operation the WDFG is fixed towards the predominant wind direction. The top is a sliding plate for easy access to the foam and the settled dust. Recovery of settled dust without disturbing the original installation position of the sampler is challenging.

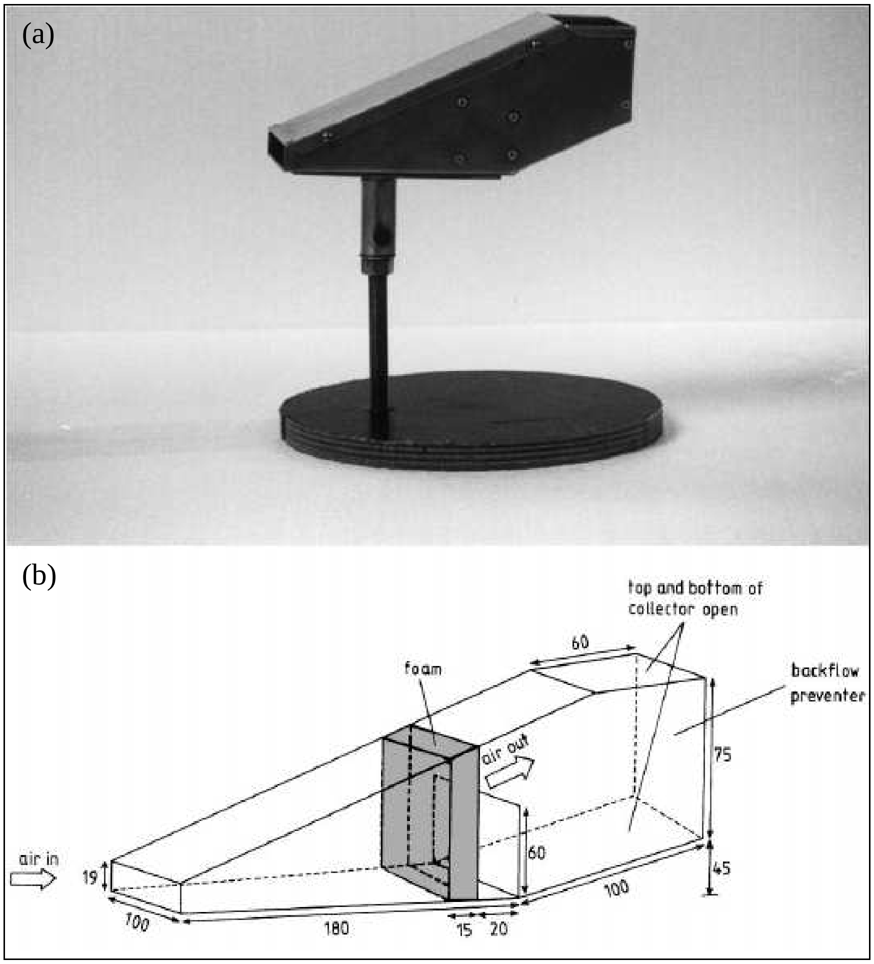


Figure 3.1: (a) Photograph and (b) construction scheme of Wedge Dust Flux Gauge

The Modified Wedge Dust Flux Gauge (MWDFG) is a simple parallel-sided box, wedge-shaped in elevation and with extended sides mounted on a pole through a bearing at the bottom of the instrument (see figure 3.4). The approved drawings of the MWDFG produced by the author is shown in APPENDIX B. The sides of the box extend rearwards by 100 mm to carry the vertical baffle plate, which is of 75 mm depth with its bottom edge set 45 mm above the bottom of the box. The MWDFG contains a dust deposit tray shown in figure 3.2, which is slotted into the gauge through the back by lifting the backflow preventer.

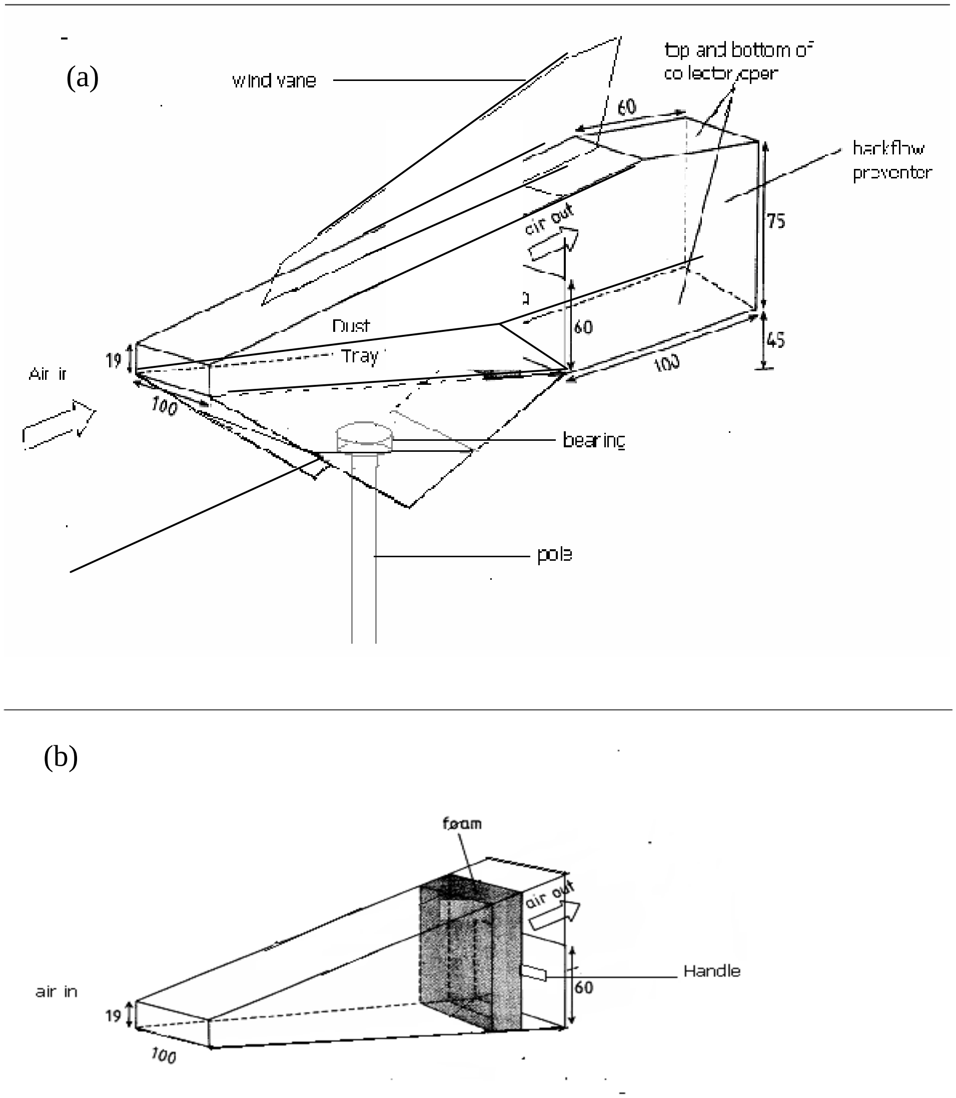


Figure 3.2: Construction scheme of the (a) Modified Wedge Dust Flux Gauge (MWDFG) (b) Dust deposit tray

The horizontal bottom of the dust deposit tray is 180 mm long and 100 mm wide. The top slopes upwards at an angle of 24.5^{o}. The air entry is a slot of 19 mm height over the whole width at the front of the box and the exit a slot of 80 mm height (also over the whole width of the dust deposit tray) set at the top of the flat vertical face which forms the rear of the dust deposit tray. The dust deposit tray contains a particle trap made from 10 pores per inch open-celled foam to retain any impacting particles. The layer of foam is 15 mm deep and set with its rear face 20 mm from the back of the box.

Because of the external shape of the gauge, there is an accelerating flow over its outer surfaces. This produces a low pressure in the base region where the outlet is situated, providing a pressure difference across the front and rear openings sufficient to drive a flow through the gauge and to additionally overcome the pressure drop of an internally fitted particle trap (the layer of porous foam). Because the design is passive, the flow through the gauge is, normally, proportional to the wind speed. The gauge shape is additionally a naturally good particle trap. Particles enter the gauge low down, so are encouraged to deposit on the floor of the dust deposit tray. The internal wedge-shape acts as a diffuser, reducing internal air speeds, which further encourage deposition to the floor. It also reduces the air speed through the foam trap, reducing its pressure losses, so allowing a large flow rate through a relatively efficient trap. The pressure drop across the foam trap additionally improves the effectiveness of the diffuser, which otherwise has a too rapid rate of expansion to retain an attached flow. Besides the foam trap itself, the bottom corner at the rear of the deposit tray is also a natural particle trap. After passing through the foam, the airflow is directed upwards towards the exit, so that this region acts as an impaction collector.

It is important that if wind is reversed over the gauge there should be minimal particle collection. The size and position of the baffle plate, in combination with the overhanging upper surface of the gauge, acts as a back-flow preventer, producing a stalled airflow in the gauge. When the wind direction is reversed, there is no flow through the gauge in either direction. In reverse flow, the baffle plate also produces a strongly rising and accelerating airflow over the exit opening, which is effective in reducing the particle collection performance just as it is with convectional deposit gauge designs (bucket). Also there is only a very limited direct pathway into the exit opening for particles with high inertia. The overhang of the upper surface of the gauge beyond the exit opening also helps to prevent the ingress of rain.

A vane is set above the gauge to respond to different wind directions. The gauge is manufactured of ultra violet resistant polycarbonate and is sufficiently light and well balanced to turn into the wind at all speeds above 1 ms^{-1}. The deposit tray is removable for access to the foam trap and to recover dust from the rest of the deposit tray.

The dimensions given are for the gauge corresponding to a half size. However, the gauge is probably not very size sensitive as long as the shape is maintained. A half-size model was used for this study (see figures 3.3 and 3.4). The model was manufactured at the University of the Witwatersrand Physics Workshop with the assistance of the Physics Technicians. The drawing of the redesigned wedge sampler (APPENDIX B) with templates for each side together with a model made of cardboard were produced by the author and given to the wits Physics Technicians to study. The author monitored and supervised the entire workshop construction of the test device. A dry untreated particle trap made from 10 pores per inch open-celled foam, which was used in this study.

Figure 3.3: Modified WDFG Sampler and the Single Bucket at Schoongezincht Mini pit Site RAMP 6

Figure 3.4: Modified WDFG, MWAC N, MWAC D and the Single Bucket Schoongezincht Mini-pit site RAMP 6

Modified Wilson and Cooke sampler (MWAC) Samplers

The modified Wilson and Cooke (MWAC) sampler is based on an original design developed by S.J. Wilson and R.U. Cooke in 1980 (Hall *et al*., 1994). The sampler consists of a plastic bottle, figuring as settling chamber, to which an inlet tube and an outlet tube have been added (Figure 3.5). The bottle is installed vertically, with the inlet oriented to the wind. Sediment entering the bottle will be deposited due to the pressure drop created by the difference in diameter between the bottle and the inlet and outlet tubes. The clean air then discharges from the bottle via the outlet. The original concept was later slightly modified by Kuntze *et al*., (1990), who attached the bottle in a horizontal (not vertical) position to a mast provided with a wind vane. Attaching several bottles at different levels to the mast, vertical flux profiles can be measured (Sterk, 1993). The inlet and outlet tubes were made of glass 1.25 mm thick, with an inner diameter of 7.5 mm for MWAC N and 15mm for MWAC D. The samplers were made at the University of Witwatersrand, Glassblowing unit in the School of Chemistry under the supervision of the author.

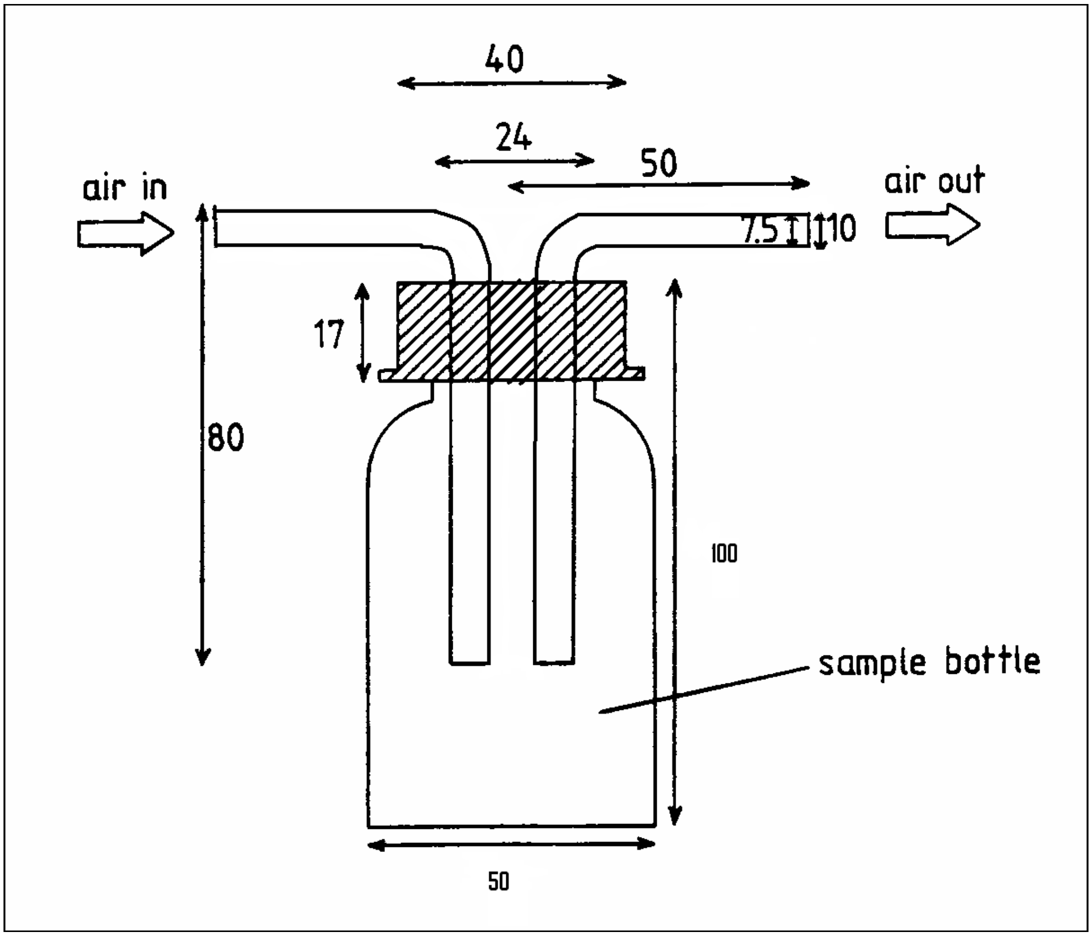


Figure 3.5: Construction Scheme of the MWAC

Single Bucket

Single bucket fallout monitors are deployed following the American Society for Testing and Materials standard method for collection and analysis of dustfall (ASTM D1739) (Egami *et al*., 1989). This method employs a simple device consisting of a cylindrical container half-filled with de-ionised water exposed for one calendar month (see figure 3.6). The water is treated with an inorganic biocide (copper sulphate) to prevent algal growth in the bucket. The bucket stand comprises a ring that is raised above the rim of the bucket to prevent contamination from perching birds. Once returned to the laboratory, the contents of the bucket is filtered and the residue dried before the insoluble dust is weighed. The dustfall rates recorded by the existing single bucket installed at Landau site RAMP 6 by Annegarn Environmental Research (Pty) Ltd were used in this study.

Figure 3.6: Single Bucket monitoring unit, showing sampling bucket with bird ring and Security clamp

Sample preparation method and laboratory analysis

Dust samples were collected by having open buckets, Modified Wedge Dust Flux gauge (MWDFG) and the Modified Wilson and Cooke N (MWAC N) and Modified Wilson and Cooke D (MWAC D) samplers exposed to the atmosphere for 30 days. MWAC D is double the size of inlet and outlet of MWAC N. The sampling period extended over three months. The particulate in the atmosphere fell passively into the samplers and was then weighed to report the results as milligrams per square meter per day ($mg/m^2/day$). Water was maintained in the bucket for the duration of the measurement period to prevent re-entrainment of the dust already collected. Dust results were collected every 30 days within the three months sampling period.

The detailed method used for collecting dust from each sampler is provided in APPENDIX A with a brief description of the method outlined below.

Single bucket – Sample preparation

The bucket was prepared by charging them with de-ionised water, taking into account the expected evaporation that was likely to occur. A small amount of copper sulphate was added to the bucket to prevent algae growth. The buckets were then transported to site and put into the holder of the monitor and left in position for 30 days. After 30 days the bucket was collected and replaced with another bucket. This ensured a continuous monitoring. 47mm filters were pre-weighed in the laboratory. The contents of the bucket were filtered through the pre-weighed filter using a Buchner Funnel. Care was taken to ensure that no dust was left in the buckets. Once the solid contents of the bucket were collected on the filter, it was dried in the oven. When the filter was dry, it was weighed and the mass was recorded with the initial mass of the filter. The initial and final mass of the filter paper was then processed using a spreadsheet to yield a result in $mg/m^2/day$ for each bucket. The height of the polypropylene bucket was 237.0 mm and the inside diameter of the lip was 179.8 mm.

Quality Control

Indeterminate errors are present in most experimental measurements and the potential sources of indeterminate errors for single bucket dust monitoring process as identified by AER are shown in table 3.1.

Table 3.1: Indeterminate errors for single bucket monitoring process

Positive errors	Negative errors
During bucket preparation error would occur if too much copper sulphate was added to the water then the excess copper sulphate would come out of solution and form a solid material that would be collected on the filter.	During emptying of bucket error would occur when the water and dust was put unto the Buchner funnel to be filtered. Any dust that remained in the bucket was not measured.
During bucket cleaning error would occur if residual dust was left in bucket between times that it was used.	During changing of buckets error would occur if old bucket water was spilt accidentally.
During changing of buckets error would occur if dust was allowed to enter either the old or new bucket.	During the filtering process error would occur if spillages from the buckets would result in loss of sample.
If algae grew in bucket either because too little copper sulphate was put into the bucket or because unusual weather conditions, such as excessive rain that diluted the copper suphate to a point where it was not able to prevent the formation of algae an error would occur.	During the filtering process error would occur if the sieves used to keep insects from being added to the dust samples were damaged or bigger than 1mm may allow insects to be added to the mass of the dust collected. If some of the dust adheres to insect and the insect is removed.
During the filtering process error would occur if the sieves used to keep insects from being added to the dust samples were damaged or bigger than 1mm may allow insects to be added to the mass of the dust collected.	

The following procedure was used to limit the error in the dust monitoring results:

The buckets were prepared indoors to prevent dust landing in buckets while open. The lids were put onto the buckets as soon as they had been prepared. The lids remained on the buckets from when they were prepared until they were ready to be put on the stand. The buckets were kept upright during transportation. Care was taken not to kick dust into the buckets or to have open buckets while replacing the old bucket. Buckets were kept closed until they were ready to be processed in the laboratory. The lids were kept loosely on the buckets while they waited in the queue to be processed. The washout water used to wash the buckets out on to the Buchner funnel was also taken from the filtered source. The inside walls of the buckets were cleaned using spatula and a squirt bottle. Rubber gloves were worn to limit the skin contact with the slightly acidic water in the buckets. After buckets were used in the field and the contents filtered, they were cleaned with soap and water and left to drip-dry before being prepared to go into field again.

Modified wedge dust flux gauge – sample preparation

MWDFG with a dust deposition tray was transported to the site. The dust deposition tray contained was fitted with pre-weighed dry foam. During transportation, the dust deposit tray was placed in a clean closed dry bucket to prevent dust contamination. The sampler was then put into a stand and left in position for 30 days. After 30 days the dust deposit tray was collected and replaced with another tray containing pre-weighed foam. Once in the laboratory the foam was weighed and the mass was recorded with the initial mass of the foam. The initial and final mass of the foam was then recorded. 47mm filters were pre-weighed in the laboratory. The contents of the dust deposit tray after removing the foam were transferred into a pre-weighed filter with a clean brush. The pre-weighed filter with the dust was weighed and the mass recorded with the initial mass of the filer. After weighing, the dust in the filter was kept in a Petri dish. The initial and final mass of the filter paper and the initial and final mass of the foam were then processed to yield a result in $mg/m^2/day$ for the MWDFG.

Modified Wilson and Cooke samplers – sample preparation

The samplers were prepared by screwing the plastic container into the inlet and outlet tube holder. The samplers were then transferred to site and put into the stand facing east and left in position for 30 days. After 30 days the plastic container was collected and replaced with another plastic container. This ensured a continuous monitoring. Once in the laboratory the dust sample collected from the dry plastic container was immediately transferred to pre-weighed filter in a Petri dish. The contents of the pre-weighed filter were weighed and the mass was recorded with the initial mass of the filter. The initial and final mass of the filter paper was then processed using a spreadsheet to yield a result in $mg\ m^{-2}$ d-1 for each bucket.

Microscopic analyses

Microscopic analysis was used to identify major components and the morphology of particles in each sample. It was important to do morphologic analyses to obtain a general idea about the composition and the structure of the particles that are produced at a coal mine.

Figure 3.7: Photograph of the Scanning Electron Microscopy used in the study housed at the Wits University in the Biology Department Electron Microscopy unit

The JEOL 840 Scanning Electron Microscope (SEM) used in the study is shown in figure 3.7 located in the School of Animal, Plants and Environmental Sciences, Biology, Department at the University of the Witwatersrand. Specifications of the Wits Scanning Electron Microscope are given in Table 3.2.

Table 3.2: Specifications of the JEOL 840 SEM

Resolution	3µm at 1kV, 1µm at 20kV
Magnification	20 to 900 000X
Accelerating voltage	200V to 30 kV
Probe Current	4 pA to 10nA
Electron Gun	Thermal field emission type
Specimen stage	X=75mm, y=75mm, z=25mm
Detectors	In-Lens annular secondary Electron Detector (SED), Biscattered Electron Detector, (BSED) and Electron Backscatter Diffraction (EBSD)
EDX	Working distance 8.5 mm
Image processing	Pixel averaging, Frame integration continuous averaging
Image resolution	512 x 384 to 3074 x 2304 pixels
Image formation	2D
Working environment (vacuum)	10^{-5} to 10^{-4} torr

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interaction reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data is collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions, crystalline structure, and crystal orientations.

Fundamental principles of scanning electron microscopy (SEM)

Accelerated electrons in an SEM carry significant amounts of kinetic energy, and this energy is dissipated as a variety of signals produced by electron-sample interactions when the incident electrons are decelerated in the solid sample. These signals include secondary electrons (that produce SEM images), backscattered electrons (BSE), diffracted backscattered electrons (ESBD) that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays) that are used for elemental analysis and continuum X-rays), visible light (cathodoluminescence-CL), and heat. Secondary electrons and backscattered electrons are commonly used for imaging samples: secondary electrons are most valuable for showing morphology and topography on samples and backscattered electrons are most valuable for illustrating contrasts in composition in multiphase samples (i.e. for rapid phase discrimination). X-ray generation is produced by inelastic collisions of the incident electrons with electrons in discrete ortitals (shells) of atoms in the sample. As the excited electrons return to lower energy states, they yield X-rays that are of a fixed wavelength (that is related to the difference in energy levels of electrons in different shells for a given element). Thus, characteristic X-rays are produced for each element in a mineral that is "excited" by the electron beam. SEM analysis is considered to be "non-destructive"; that is, X-rays generated by electron interactions do not lead to volume loss of the sample, so it is possible to analyze the same materials repeatedly.

Images were acquired by selectively combining output of the backscattered electron detector (BSED) with an in-lens annular secondary electron detector (SED) using low accelerated voltages of 15 keV. These voltages allowed detection of particles with low energy, narrow beam, and minimum degradation of samples.

Particle size analysis

Four samples for particle size analysis were selected, one from the bucket, MWDFG, normal and double size MWAC samplers. M & L Inspectorate in Johannesburg South Africa, an accredited laboratory, undertook the analysis using a Malvern particle size analyzer. The size range used was from 0.02 to 2000 micron with 102 measurements at different size intervals being taken.

The particle size distribution of a powder, or granular material, or particles dispersed in fluid, is a list of values or mathematical function that defines the relative amounts of particles present, sorted according to size. A representative sample passes through a broadened beam of laser light which scatters the incident light onto a Fourier lens. This lens focuses the scattered light onto a detector array and, using an inversion algorithm, a particle size distribution is inferred from the collected diffracted light data. The method is non-destructive and non-intrusive. Hence samples can be recovered if they are valuable. The method has high resolution up to 100 size classes within the range of system can be calculated on the Marlvern Mastersizer.

Dust data presentation

Results from the Single Bucket dust monitoring carried out at Landau Colliery – Schoongezich Mini-pit for the period January to December 2007 are presented. The dustfall rates obtained by the MWDFG, Single Bucket, and the MWAC samplers for the March to May 2008 are also shown in chapter 4. In the analysis of the dust fallout samples the total gravimetric mass is recorded. Tabular and graphic summaries of the data are given to aid data interpretation. Dustfall rates recorded during the January to December 2007 and March to May 2008 periods are also compared to average dustfall rates measured since the start of the monitoring programme to assess whether changes in such rates have occurred.

Fluctuations in dustfall rates are a function of variations in the meteorological conditions of the site and/or changes in source characteristics. The meteorological characteristics of the site impact on the rate of emissions from fugitive sources and govern dispersion and eventual removal of pollutants from the atmosphere. Fugitive dust emission rates are predominantly a function of wind speed and intensity and duration of the activity generating the dust (e.g. traffic volumes, extent of batch drop operations). Evaporation rates and precipitation rates also influence fugitive emission rates due to their impact on the moisture content of materials being handled or stored, which influences the cohesion of particles. A review of meteorological data, including wind speed and precipitation data is undertaken in the current study in order to assist in the analysis of dustfall rates recorded during the period.

CHAPTER FOUR

Dustfall results for Single Bucket during the January to December 2007 are presented. This is followed by a presentation of dustfall rates, particle size analysis and microscopy analysis for each of the MWDFG, Bucket, MWACN and MWAC D for the period March to May 2008

Results and discussions

2007 Annual Average in Dustfall rates for the Single Bucket recorded at Schoongezicht mini-pit

Annual average dustfall rates observed at each of the Landau Colliery Schoongezicht Mini-pit single bucket sites during the January to December 2007 period are compared to the long-term average dustfall per station recorded since the start of the monitoring programme in November 1992 as shown in Figure 4.1.

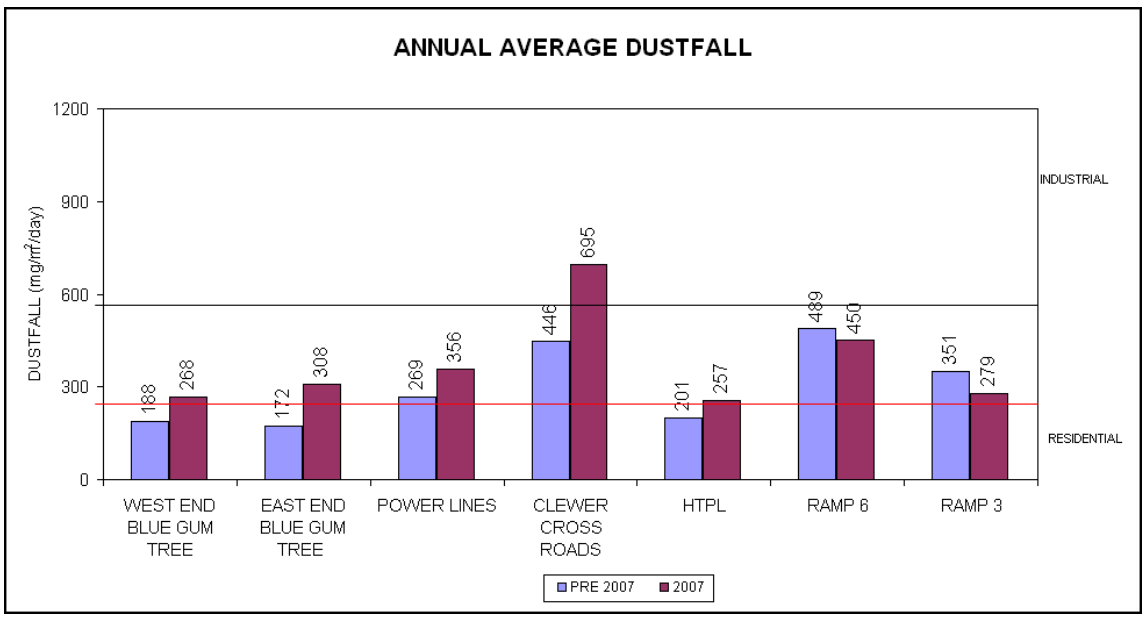


Figure 4.1: Comparison of annual average dust fall rates recorded at each monitoring station in Schoongezincht Mini pit during January to December 2007 with pre-2007 rates

Four sites were above the SANS annual average target of 300 mg/m^2/day, namely, Site 2 (East End Bluegum Trees), Site 3 (Power Lines), Site 4 (Clewer Crossroads) and Site 6 (Ramp 6). Clewer Cross Roads is the only site since commencement of dustfall monitoring in Schoongezicht that has recorded dustfall annual average within the INDUSTRIAL range, all the other sites recorded dustfall rates within the RESIDENTIAL threshold. Site Clewer Cross Roads is located 50 meters from an intersection of unpaved roads within the mine. Haulage trucks use these roads when they are travelling to and from the coal loading zones. Dust suppression using water is carried out regularly within the mining roads. The heavy traffic experienced in the vicinity of site Clewer Cross Roads requires constant dust suppression. The proximity of the Single Bucket to this intersection causes most of the dust particles to be gusted into the gauge. Since the beginning of dust monitoring site RAMP 6 has always recorded annual dustfall rates within the RESIDENTIAL threshold .

*Annual trends of dust fall rates for the Single Bucket recorded at Schoongezicht mini-p*it

A comparative timeplot illustrating mean monthly, temporal averaged dustfall rates for all stations for the January to December 2007 monitoring period and the long-term November 1992 to December 2006 averaging period is presented in Figure 4.2. The averaging of dustfall levels across the entire Schoongezicht mini-pit sampling sites facilitates the analysis of the overall seasonal trends in dustfall levels.

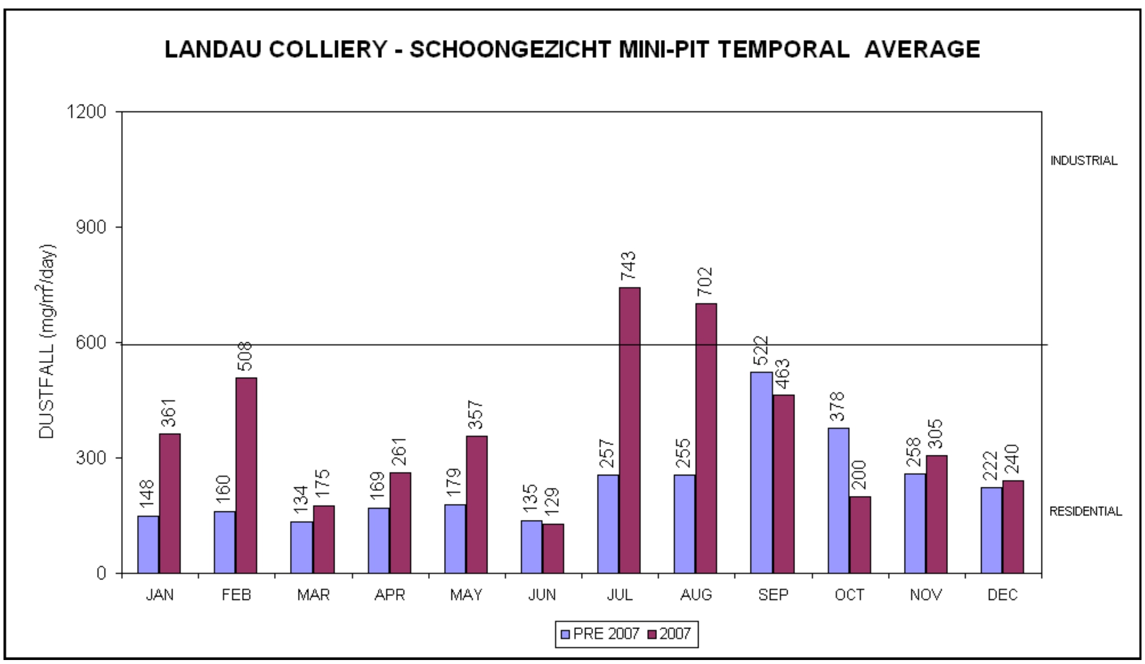


Figure 4.2: Schoongezicht Mini-Pit temporal averaged dustfall recorded during the January to December 2007 period, compared to the long-term mean.

July and August recorded temporal averaged dustfall rate in the INDUSTRIAL range, >600 mg/m2/day. The monthly temporal averaged dustfall rates for January, February, July and August recorded a significant increase compared to previous years results. There was an increase in dustfall rates recorded in 2007 compared to the previous years because Landau Colliery expanded its mining operations in 2007. Two additional dust monitoring sites Mpondozankomo (MPOD) and Schoongezicht (SCOONDW) were a result of the expansion.

The long-term mean shows dustfall rates are generally higher during the dry windy months of August to November; however in the January to December 2007 reporting period the temporal averaged dustfall was higher during July to September and January to February 2007.

The dust monitoring programme creates and maintains awareness with regard to dust generating activities. The information generated from the dust monitoring programme can be used to indicate the dust generating activities on site and provide indication of continuous improvement from a dust generating point of view.

The awareness that a simple passive dust monitoring programme generates is very valuable in another way because the solutions to dust problems are often very simple and sometimes do not require many resources.

Dustfall rates for the Single Bucket recorded at Schoongezicht mini-pit site RAMP 6 over January to December 2007 sampling period

The site was commissioned in September 2006, July recorded ACTION dustfall rates with 1282 mg/m^2/day (figure 4.3). February, August and September recorded INDUSTRIAL dustfall rates with 639 mg/m^2/day, 886 mg/m^2/day and 643 mg/m^2/day, repectively. The remaining monitoring months recorded RESIDENTIAL dustfall rates. October recorded no data as the monitoring equipment was moved to a different location a few meters away. August recorded a significant increase in dustfall rates compared to the 2006 dustfall rates. September and December recorded a significant decrease in dustfall rates compared to 2006 dustfall rates. In July site RAMP 6 recorded dustfall rates that were within the ACTION threshold and August to September recorded dusfall levels that were within the INDUSTRIAL threshold. The main reasons for high dust levels dring the months of July to September 2007 was that the new mining expansions that took place at Landau Colliery in 2007 are closer to site RAMP 6 and the months of July to November are dry windy months and as results more dust was generated and gusted into the Single Bucket.

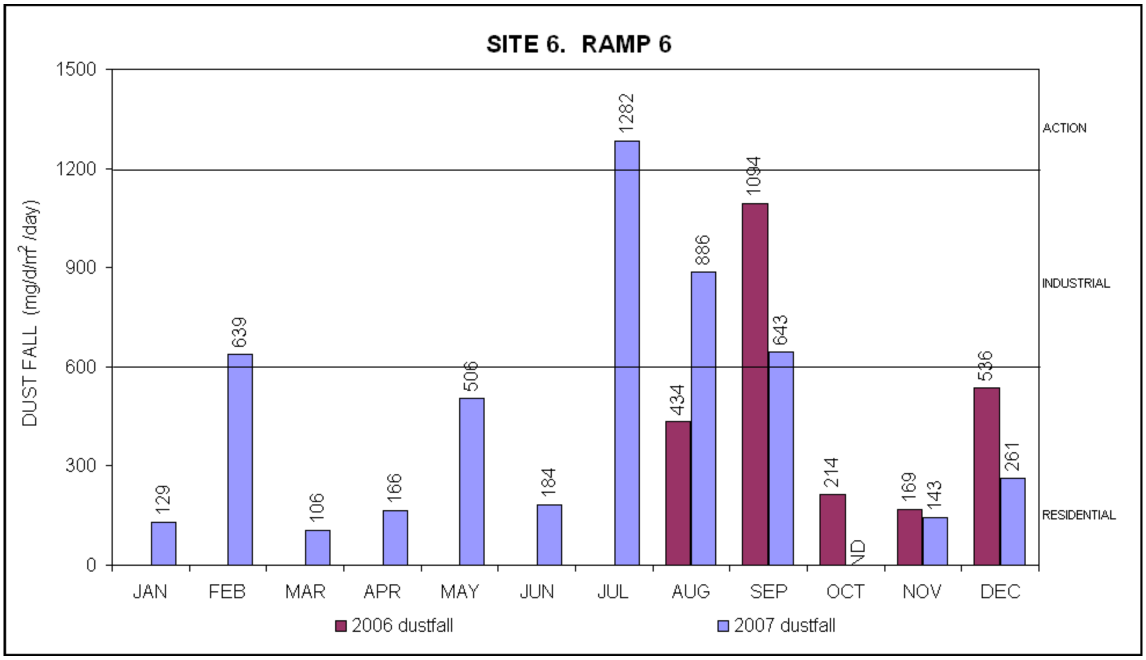


Figure 4.3: Dustfall rates at Site 6 (Ramp 6) during the September to December 2007

Dustfall Rates recorded by the four samplers at Schoongezicht mini-pit site RAMP 6 during the March to April 2008 research period

The dustfall rates obtained by different samplers installed at site RAMP 6 in Schoongezicht for the March to May 2008 dust monitoring period are presented in table 4.1. The dustfall rates on average recorded by the MWDFG fell within the INDUSTRIAL threshold at 647 mg/m^2/day. The averaged dustfall rates recorded by the Single Bucket, MWAC N and MWAC D fell within the RESIDENTIAL threshold with 461 mg/m/day, 312 mg/m^2/day and 317 mg/m^2/day respectively.

Table 4.1: Dustfall rates recorded by four samplers under investigation at Landau Colliery -Schoongezicht Mini-pit site RAMP 6 for the March to May 2008 study period

Sampler	March mg/m^2/day	April mg/m^2/day	May mg/m^2/day	Average mg/m^2/day
MWDFG	648	624	668	647
BUCKET	432	575	377	461
MWACN	338	298	300	312
MWACD	373	372	368	371

The dustfall rates observed at RAMP 6 recorded by the Single Bucket during the March to April 2008 are compared to the dustfall rates for the same period in 2007 (figure 4.4). The dustfall rates for the 2008 sampling period were generally higher than the 2007 sampling period. The dustfall rates obtained by the Single Bucket for the March to April sampling periods of 2007 and 2008 fell within the RESIDENTIAL threshold and are both lower that the dustfall rates recorded by the MWDFG for the same sampling months in 2008 (figure 4.4). The dustfall rates recorded for May 2008 was lower that the same period in 2007, possible due to different weather conditions. The MWDFG recorded higher dustfall at INDUSTRIAL threshold level in March to May 2008 rates compared to the Single Bucket in 2007 and pre-2007 years.

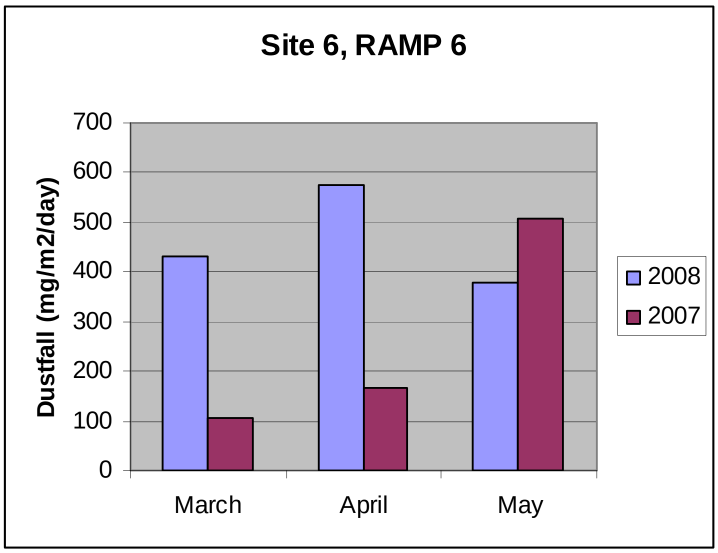


Figure 4.4: Comparison of monthly dustfall rates recorded at Landau Colliery -Schoongezicht Mini-pit site RAMP 6 by Single Bucket during the March to May 2008 with March to May 2007 sampling periods

Dustfall collection efficiencies of the four samplers under investigation

The ratios of the dustfall rates obtained for MWDFG, MWAC N and MWAC D against the Bucket were calculated to determine the collection efficiencies of these samplers against the bucket. The ratio of dustfall rates of MWAC N against MWAC D was also calculated. The ratios obtained are shown in table 4.2. The ratio of MWAC N against MWAC D was calculated to determine which of the two flux gauges was more efficient. The ratios of dustfall rates for MWDFG against MWAC N and MWAC D were calculated to determine how efficient the MWAC flux samplers were against MWDFG

The ratio of MWDFG against the Single Bucket for the month of March 2008 was 1.50:1.00 meaning that for every milligram the Bucket collect MWDFG collects an additional half milligram more. The ratio of MWDFG against the Single Bucket decreased in the month of April but increased in the month of May. The average dustfall ratio for MWDFG against the Single Bucket is 1.50:1.00. The average dustfall ratios indicate that the MWDFG collects double the amount of dust collected by the MWAC N and collects an additional half more quantity that MWAC D collects. The dustfall ratio between MWAC N and MWAC D means that for every 1 milligram that the MWAC D collects MWAC N collects 0.8 milligrams. The Single Bucket collects an additional half quantity more of dust that an MWAC N sampler collects.

Table 4.2: Ratios of dustfall rates and average ratios obtained for the four samplers under investigation

	SAMPLER	DUSTFALL (mg/m^2/d)	RATIO OF DUSTFALL RATES			
			BUCKET	MWDFG	MWACN	MWACD
MARCH	BUCKET	432	1.00	0.67	1.28	1.16
	MWDFG	648	1.50	1.00	1.92	1.74
	MWACN	338	0.78	0.52	1.00	0.91
	MWACD	373	0.86	0.58	1.10	1.00
			BUCKET	MWDFG	MWACN	MWACD
APRIL	BUCKET	575	1.00	0.92	1.93	1.55
	MWDFG	624	1.09	1.00	2.09	1.68
	MWACN	298	0.52	0.48	1.00	0.80
	MWACD	372	0.65	0.60	1.25	1.00
			BUCKET	MWDFG	MWACN	MWACD
MAY	BUCKET	377	1.00	0.56	1.26	1.02
	MWDFG	668	1.77	1.0	2.23	1.82
	MWACN	300	0.80	0.45	1.00	0.82
	MWACD	368	0.98	0.55	1.23	1.00
AVERAGE			BUCKET	MWDFG	MWACN	MWACD
	BUCKET	443	1.00	0.68	1.48	1.20
	MWDFG	653	1.47	1.00	2.18	1.77
	MWACN	299	0.68	0.46	1.00	0.81
	MWACD	369	0.83	0.57	1.23	1.00

The collection efficiency of MWDFG, MWAC N and MWAC D against the Single Bucket is shown in figure 4.3. The Single Bucket is 32 % less efficient in dust collection than the MWDFG, and 48% and 20 % more efficient than the MWAC N and MWAC D respectively.

Table 4.3: Table showing collection efficiency of the MWDFG, MWAC N and MWAC D against the Single Bucket

		DUSTFALL	Excess (Deficiency) in collection relative to reference sampler (%)			
	SAMPLER	(mg/m^2/d)	BUCKET	MWDFG	MWACN	MWACD
MARCH	BUCKET	432	0%	-33%	28%	16%
	MWDFG	648	50%	0%	92%	74%
	MWACN	338	-22%	-48%	0%	-9%
	MWACD	373	-14%	-42%	10%	0%
			BUCKET	MWDFG	MWACN	MWACD
APRIL	BUCKET	575	0%	-8%	93%	55%
	MWDFG	624	9%	0%	109%	68%
	MWACN	298	-48%	-52%	0%	-20%
	MWACD	372	-35%	-40%	25%	0%
			BUCKET	MWDFG	MWACN	MWACD
MAY	BUCKET	377	0%	-44%	26%	2%
	MWDFG	668	77%	0%	123%	82%
	MWACN	300	-20%	-55%	0%	-18%
	MWACD	368	-2%	-45%	23%	0%
AVERAGE			BUCKET	MWDFG	MWACN	MWACD
	BUCKET	443	0%	-32%	48%	20%
	MWDFG	653	47%	0%	118%	77%
	MWACN	299	-32%	-54%	0%	-19%
	MWACD	369	-17%	-43%	23%	0%

Regional climate and analysis of meteorological data

Spatial variations and diurnal and seasonal changes in the wind field and atmospheric stability regime are functions of atmospheric processes operating at various temporal and spatial scales (Goldreich and Tyson, 1988). Atmospheric processes at macro- and meso-scales need therefore to be taken into account in order to accurately parameterise the dust generation potential and atmospheric dispersion potential of a particular area. Local-scale systems are investigated in sections to follow through the analysis of meteorological data observed during the study period, March to May 2008 and previous data of January to October 2007. The precipitation, temperature and humidity data could not be obtained from SAWS for the Witbank Weather Station.

Analysis of local-scale meteorological data

The wind field and the intensity and frequency of occurrence of precipitation represent the most important meteorological parameters influencing emissions, dispersion and deposition of fugitive dust. Hourly average wind data were obtained from the South African Weather Service (SAWS) monitoring station at Witbank for the period under review.

Surface wind field analysis for January to December 2007

The erosion and vertical dispersion of dust is a function of the wind field. The wind speed determines the dust generation potential, the distance of downwind transport, and the rate of dilution of pollutants. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

The monthly average wind speeds are provided in Figure 4.5. Period average and monthly average wind roses for the January to October 2007 interval are given in Figures 4.6 and 4.7, respectively. Wind roses comprise 16 spokes which represent the directions from which winds blew during the period. The colours reflected the different categories of wind speeds; thus light yellow represents wind speeds lower than 1.5 m/s, yellow represents winds of 1.5 to 4.0 m/s, red represents 4.0 to 8.0 m/s and blue represents winds greater than 8 m/s. The dashed circles represent the frequency of occurrence of wind speed and direction categories. Wind speeds higher than 4 m/s will have an influence on dust mobility and are thus the winds of concern with respect to dust concentrations. The threshold wind speed (minimum speed required to transport dust particles) depends on the dust particle size and surface shear.

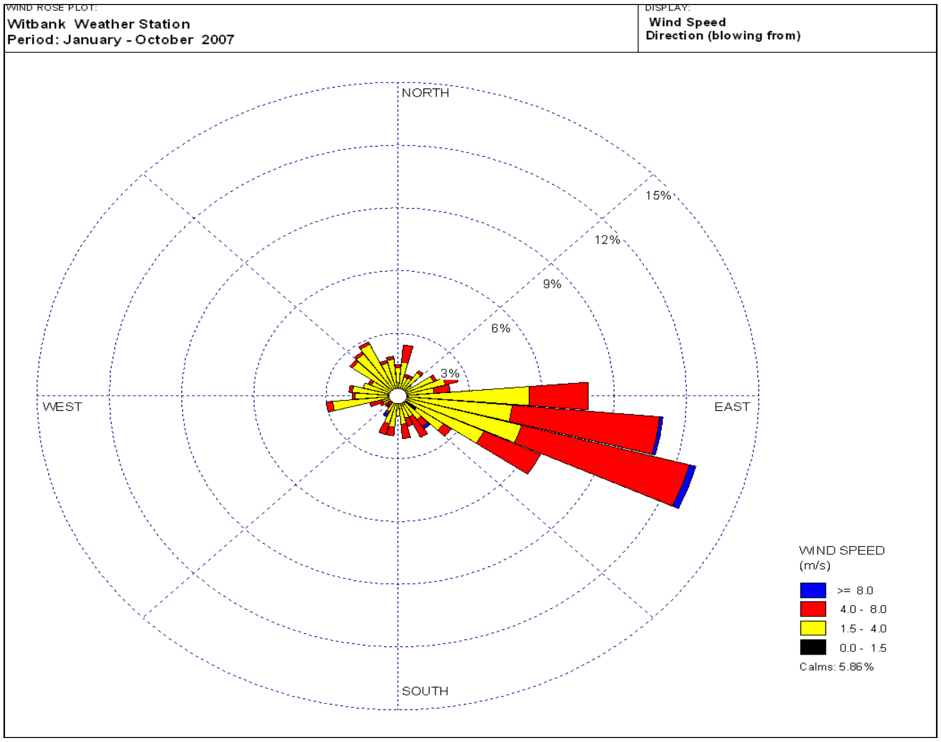


Figure 4.5: Period average wind rose for the January to October 2007 monitoring period based on wind field data from the SAWS station in Witbank

Wind speeds generally decrease during the autumn to winter months and increase again during spring and summer, with maximum gusts during October. Over the annual period, winds in the Witbank region blew predominantly from the easterly to east-south-easterly sector, with winds from the northerly to west of northwest quadrant representing a less frequent secondary flow component. Within the region, the easterly to east of southeast and northern wind components are occasionally associated with gusts.

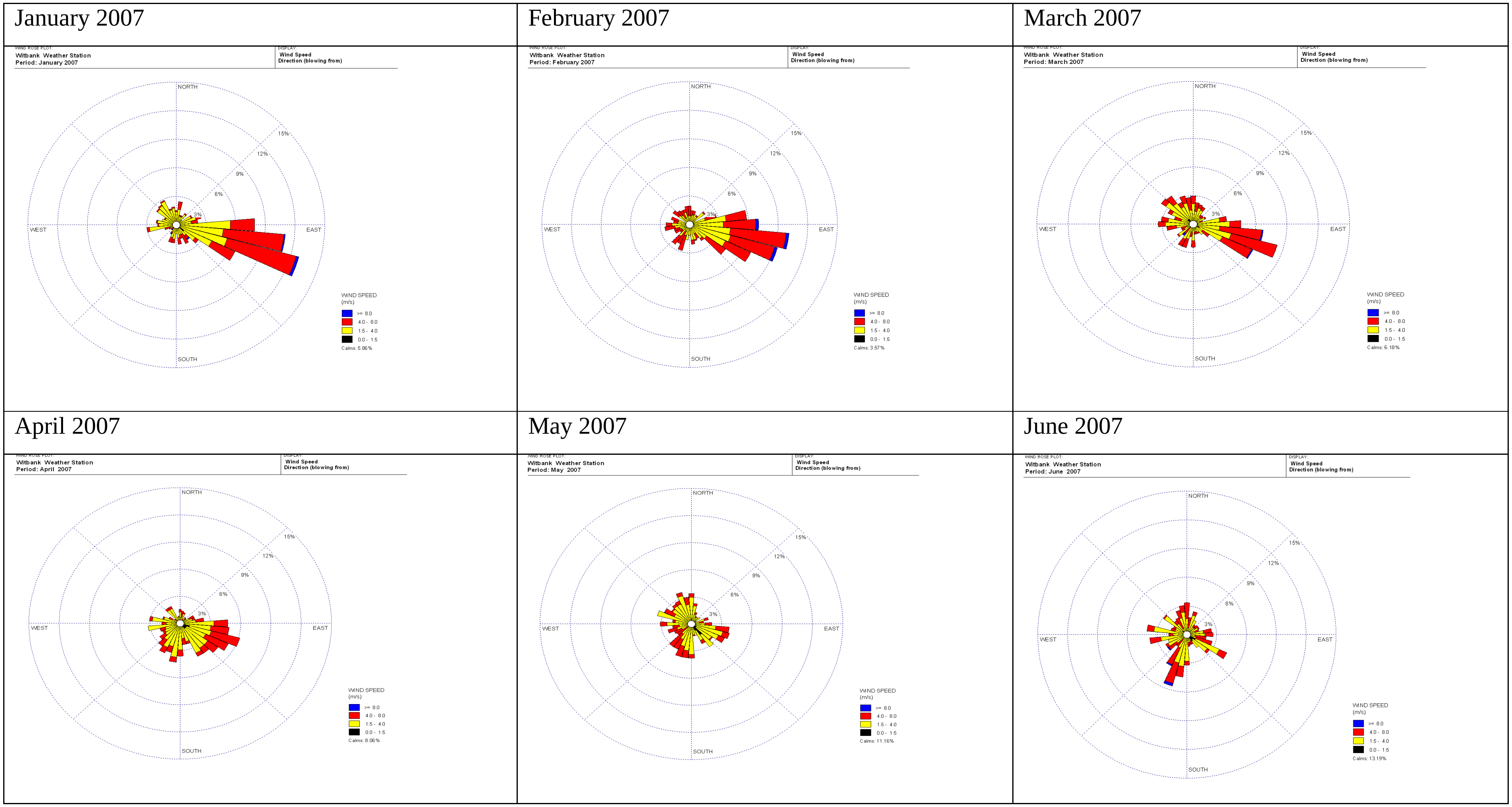
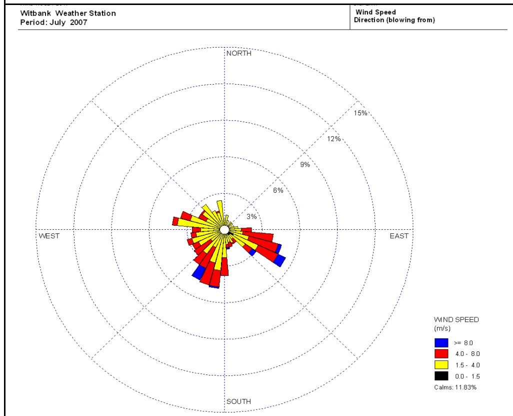
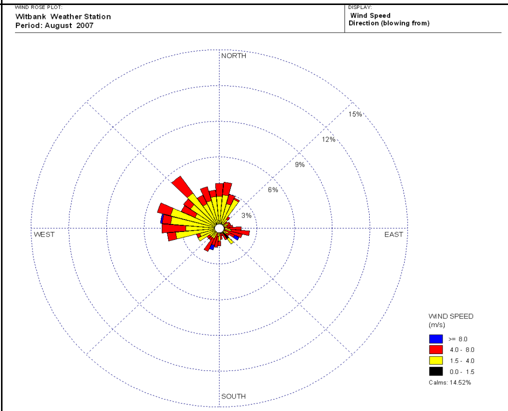


Figure 4.6: Monthly wind rose for Witbank for the period of January to June 2007

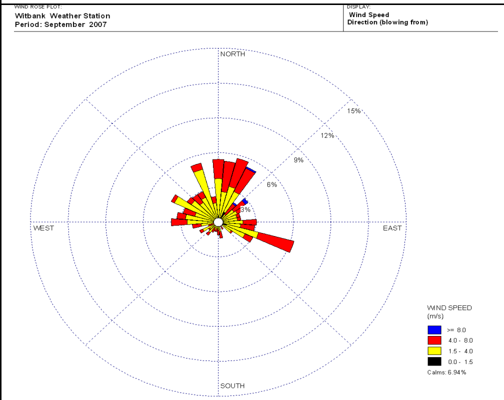
July 2007



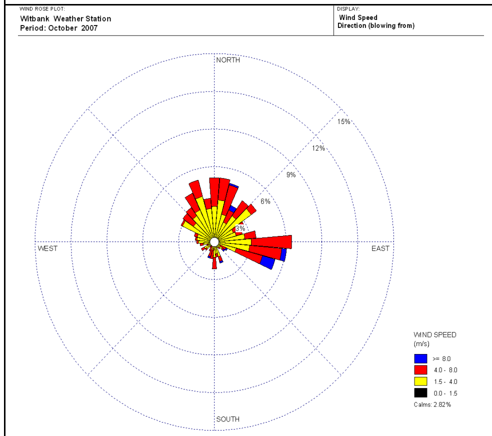
August 2007



September 2007



October 2007



November 2007

December 2007

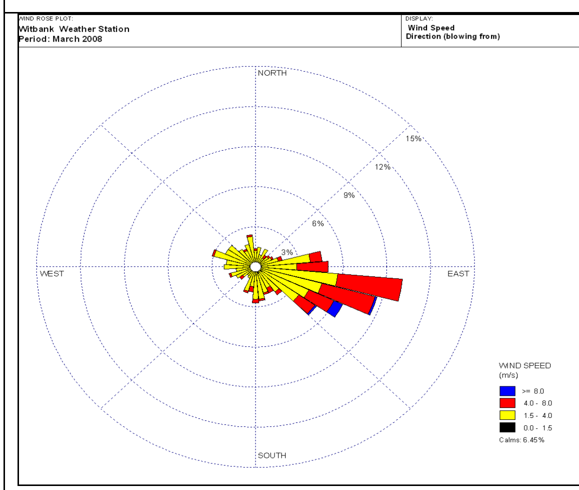
Figure 4.7: Monthly wind rose for Witbank for the period of July to October 2007

The surface wind field largely reflects the synoptic scale circulation. The northerly wind component, associated with the presence of the continental high pressure and the influence of the tropical easterlies persist throughout much of the year. The strengthened influence of the tropical easterlies during spring and summer months is evident by the increase in airflow from the south-easterly sector in October. During winter a decrease in wind speed is evident and, due to the influence of the local terrain, the flow regime is predominantly characterised by westerly and north-westerly winds. However, a more prominent airflow from the southerly component is evident during July, associated with the passage of cold fronts.

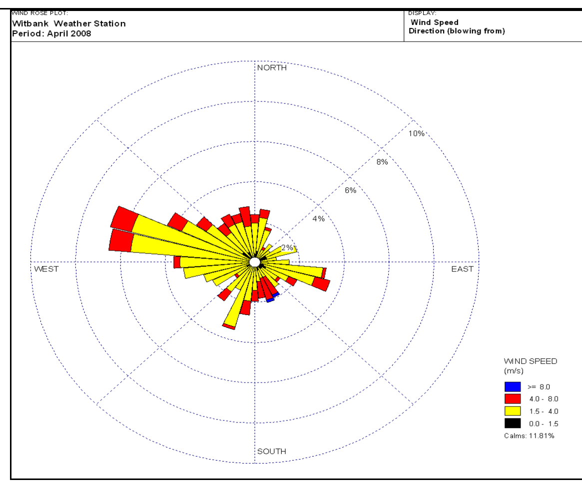
*Surface wind field analysis for Witbank region during March to June 2008 research perio*d

During March 2008, wind in the Witbank region blew predominately from the easterly sector. The wind blew prominently from the westerly quadrant during the month of April 2008. During the month of April wind predominately blew from the east with east representing a less frequent secondary flow component. Monthly average wind roses for the March to April 2008 interval and May to June 2008 interval are given in Figures 4.8 and 4.9, respectively

March 2008



April 2008

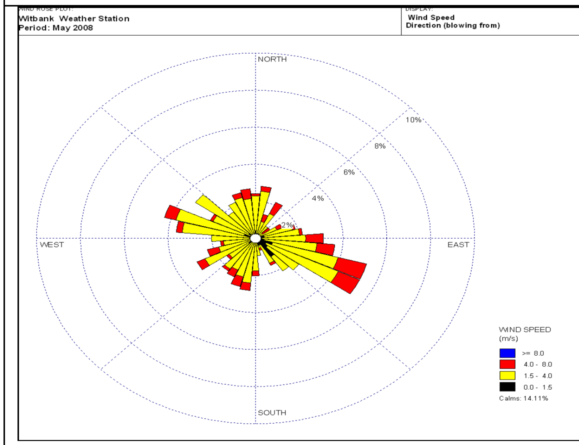


May 2008

June 2008

Figure 4.8: Monthly wind rose for Witbank for the period of March to April 2008

May 2008



June 2008

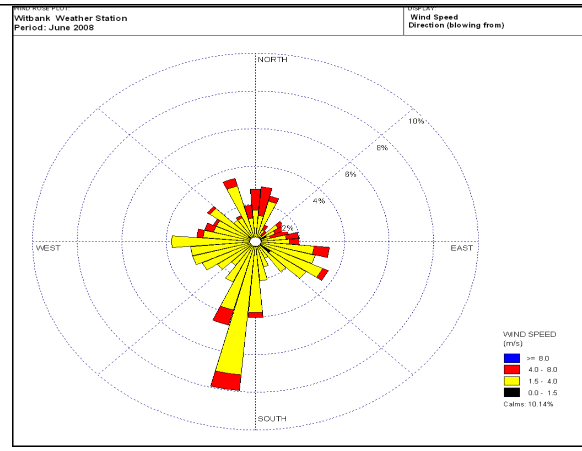


Figure 4.9: Monthly wind rose for Witbank for the period of May to June 2008

Dust morphology

Based on the images of particle surface shape gained by the SEM analysis of dust particles from the four samplers, 6 clusters of particulate morphology have been sorted out; Irregular square, Agglomerate, sphere, floccule and cylindrical.

Irregular square

The Irregular square particles were observed from the dust samples collected by the MWDFG (figure 4.10 a-c), MWAC N (figure 4.12 a and c) and MWAC D (figure 4.13 d). Irregular square grains are the most predominant particle in the samples detected. The surface of these particles is smooth as shown in figure 4.10 b. Some irregular diamonds were observed from the dust samples collected by MWDFG (figure 4.10 e)

Agglomerate

Agglomerate shaped particles are the least predominant than the irregular square in dust particles collected by MWDFG, MWAC N and MWAC D. The Single bucket exhibited a larger quantity of agglomerate compared to the other samplers in the study. Agglomerate particles are little smaller in size than the irregular square particles.

Sphere

Sphere particles were observed from the dust collected by the Single Bucket (figure 4.11 a-e). Sphere particles are generally smaller than all other particle types with average diameter under 3 µm. There are three impressed surface patterns of the sphere particles: smooth, semi-course, and coarse.

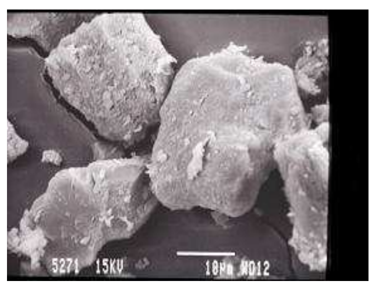
Floccules

These grains are made up of tiny spherical particles normally less than 1 µm. It seems that these floccules particles are structured loosely and have alternative size, but in this research, most floccules shaped grains possess an apparent size of about 10 µm. The floccules particles shown in figure 4.11were observed from dust particles that were collected by the Single Bucket.

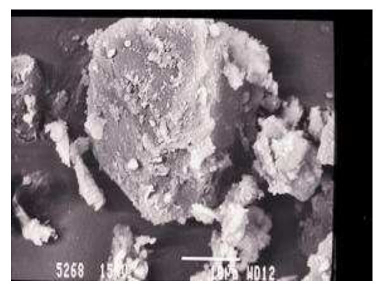
Cylindrical

These particles represent the organic matter possible from grass particles. The morphological analyses of each sample supported the particle size determination results obtained. Cylindrical particles shown in figure 4.12 and figure 4.13 were collected by MWAC N and MWAC D respectively.

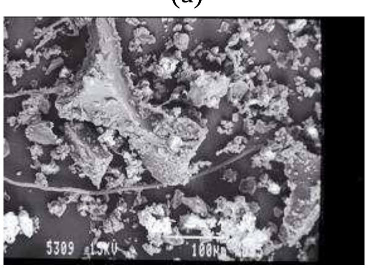
(a)



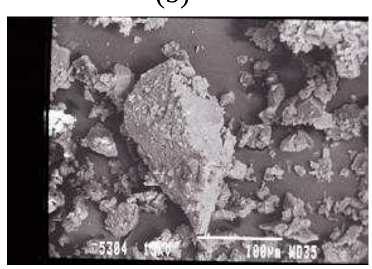
(b)



(c)

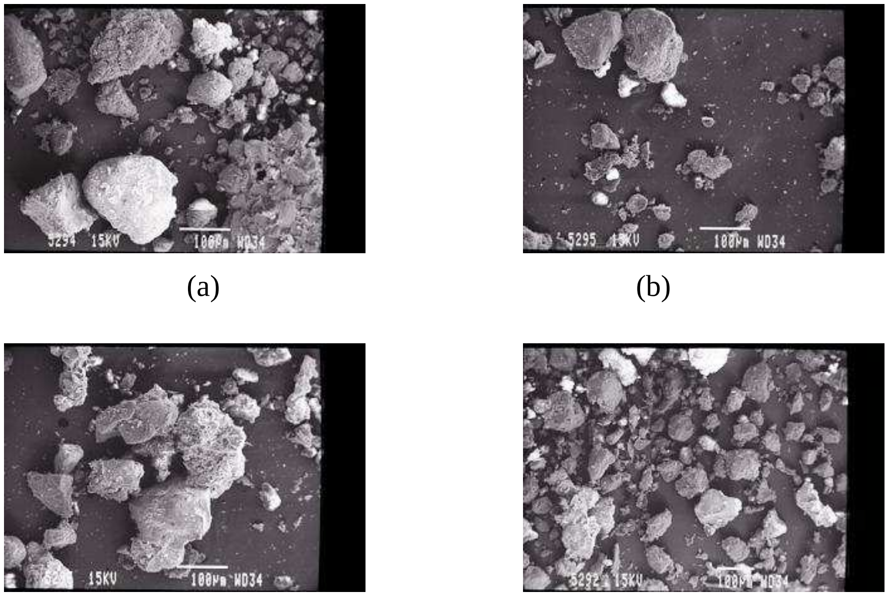


(d)



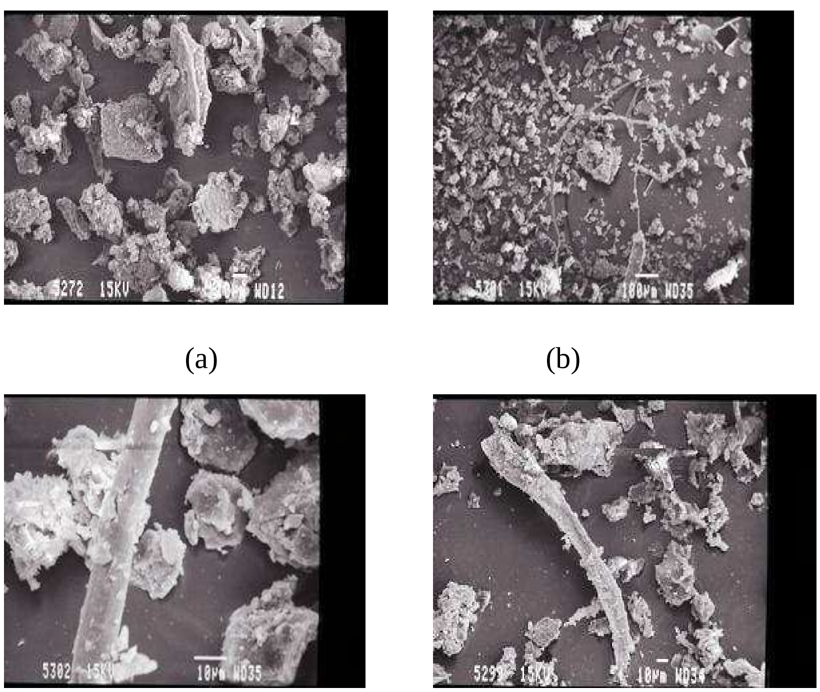
(e)

Figure 4.10: SEM images of dust particles collected by MWDFG (a) irregular square (b) Irregular square and flocule, (c) irregular square and agglomerate, (d) cylindrical (e) irregular diamond



(a) (b) (c) (d)

Figure 4.11: SEM images of dust particles collected by Single Bucket (a) sphere, and agglomerate (b) sphere, floccules and irregular (c) sphere and irregular (d) sphere and irregular



(a) (b) (c) (d)

Figure 4.12: SEM images of dust particles collected by MWAC N (a) Irregular square (b) Column (c) irregular square and column (d) agglomerate and column

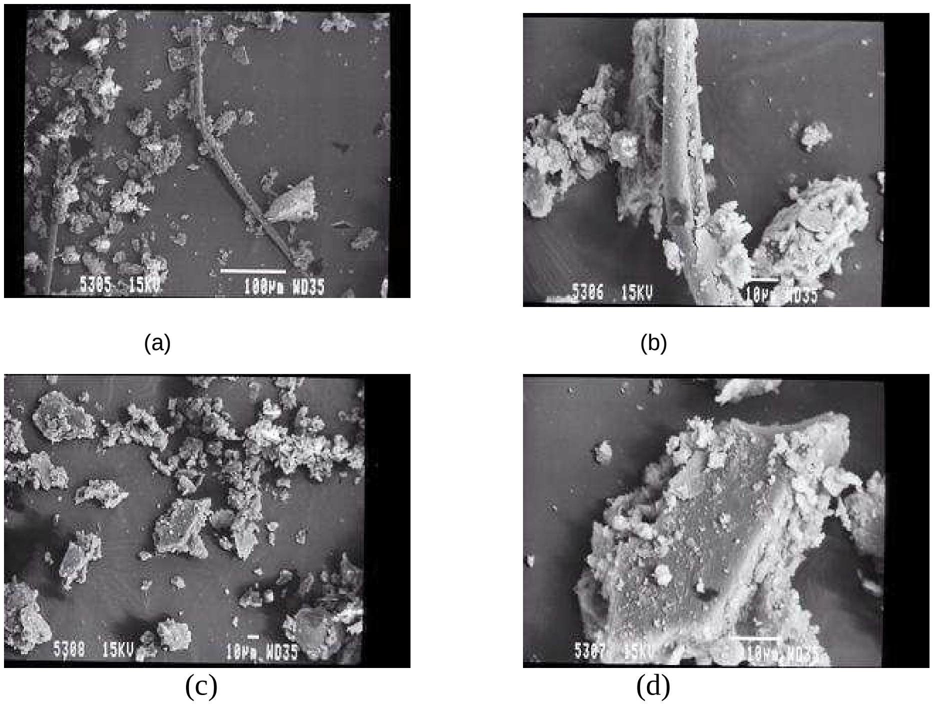


Figure 4.13: SEM images of dust particles collected by MWAC D (a) Column, (b) Column, (c) agglomerate and (d) irregular square.

Particle size analysis for four dust samplers

Four dust samples from Single Bucket, MWAC N, MWAC D and MWDFG were sent for analysis to M & L Inspectorate an accredited laboratory. The particle size analysis graphs are presented in APPENDICES C, D, E and F.

The MWDFG, MWAC N and MWAC D yielded very similar particle analysis results These three are symmetrical around the mode (max value), while the Single Bucket is distinctly asymmetrical. The Single Bucket yielded particle size distribution results that were not log-normally distributed skewed distinctly to the larger sizes (mean diameter 45 micron diameter. The MWDFG yielded particle size analysis results (log – normally distributed) with particles less than 1000 µm. According to Hall *et al.*, (1994), the collection efficiency of the single bucket for wind speeds between 2 and 12 $m.s^{-1}$ and particle sizes between 87 and 400 µm is less than 20%. It is interesting to note that the single bucket during this sampling period recorded more dustfall rate for the 100 µm dust fraction compared to the other samplers under investigation. The MWDFG recorded a higher dustfall rate for the dust fraction above 400 µm compared to the other samplers under investigation. The results obtained suggest that there was another closer source of the dust from a different direction with large dust fractions which were able to be collected by the MWDFG but could not be collected by the single bucket, MWAC N and MWAC D. `

There were particles less than 15 µm that were detected in all particle size analysis results. These particles were within the PM_{10} range and this indicates that all these samplers do collect particles in the PM_{10} size fractionation. The PM_{10} fraction is about 19 percent by volume for MWAC N, 16 percent for MWAC D, 19 percent for Bucket and 23 percent for MWDFG. Particles of 10 microns diameter and less will pass through the nose and throat and reach the lungs. If the sources of PM_{10} are from the same sources as the dust, then measurements of the dust concentrations will be able to indicate if PM_{10} concentrations are being controlled. This excludes sources from high temperature emissions such as combustion and smelting processes.

The diameter of maximum particulate concentration for MWAC N and MWAC D is 27 µm, for the Single Bucket is 50 µm and for the MWDFG is 25 µm for the zero to 100 µm particle size distribution. The MWAC N, MWAC D, Single Bucket and the MWDFG recorded maximum particulate concentration of 450 µm, 500 µm, 450 µm and 320 µm for the 100 to 1000 particle size distribution, figure 4.14.

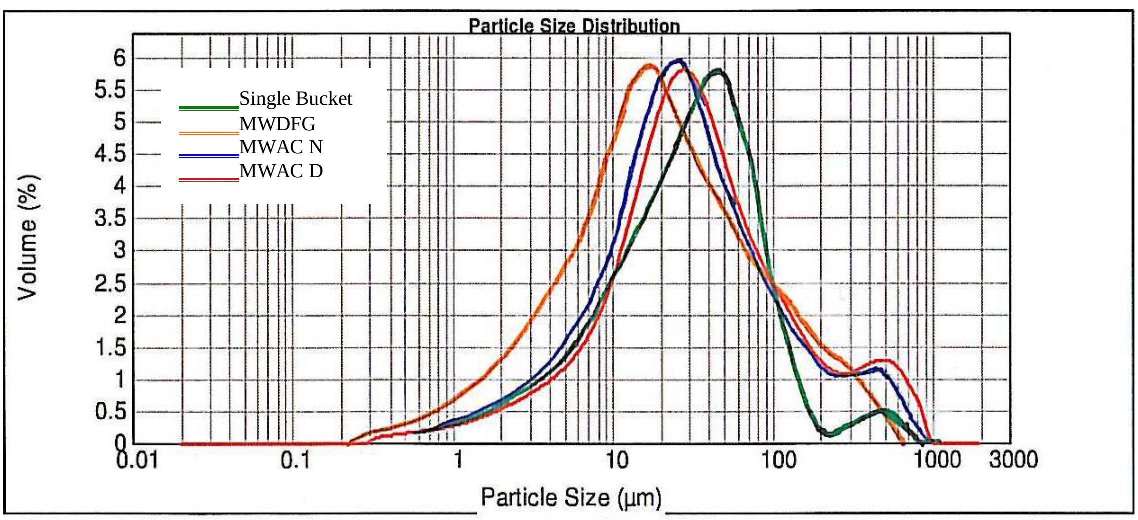


Figure 4.14 Particle Size Distribution plots for the dust collected by the four samplers during the March to May 2008 dust monitoring period at Landau Colliery Schoongezincht mini pit Site RAMP 6

Particles below 40 µm can enter the nasal passage and have been shown to be existent in this size particle analysis. These can contribute to allergies, sensitizations, and asthma. Particles in this size range include pollens, spores, and viruses. The percentage of particles by volume, below 40 µm is just about 63 percent for MWAC N, 59 percent for MWAC D, 59 percent for the Single Bucket and 63 percent for MWDFG particle size distribution.

The percentage of particles by volume of 2.5 µm for MWDFG is 6 percent, 5.3 percent for the Single Bucket, and 3.9 percent for MWAC D and 5 percent for MWAC N. Particles of < 2.5 µm size are repairable and will penetrate into the gas exchange region of the lungs. Many countries including the United States of America do not consider precipitant dust as an indication of atmospheric environmental and health conditions (Grantz *et al*, 2003). These countries use more expensive active atmospheric monitoring equipment to determine the PM_{10} and $PM_{2.5}$ dust concentrations in the atmosphere (Grantz, *et al*, 2003). The fact that the PM10 fraction is collected by the dust monitoring unit under study means that the methods could be used to correlate to the PM_{10} dust concentrations once the appropriate research has been done. While there is currently no method to convert dust depositions to PM_{10} concentrations (Australian Government, 1998), the correlation is mostly going to be specific to the topography and climate of the area and to the sources of PM_{10} particulate matter.
In South Africa and many other countries, the cost of doing PM_{10} and $PM_{2.5}$ atmospheric monitoring is very high and often the monitoring systems do not operate efficiently enough to provide data that can be reliably used to determine environmental and health risk trends. With passive monitoring systems it is often possible to have more monitoring stations and this normally provides more reliable data than active monitoring (Schneider, *et al*, 2002).
With the passive nature of precipitant dust monitoring and the reliability of the monitoring programmes as shown by 2007 and pre 2007 data collected at Landau Colliery discussed in this dissertation, the cost of PM_{10} and $PM_{2.5}$ monitoring programmes could be achievable for third world countries.

Discussion of Results

Dustfall rates recoreded by the four dust samples at Schoongezicht mini-pit site RAMP 6 during March to May 2008

The MWDFG collected more dust than the other samplers during the March to April 2008 sampling period (see table 4.1). There was a decrease in the dustfall rates obtained by MWDFG for the month of April. The dustfall ratio for the MWDFG to the Single Bucket dropped from 1.50:1.00 in March to 1.09:1.00 in April and increased to 1.77:1.00 in May. There were less calms conditions (6.45%) and more high wind speeds (4-8 m.s-1) in March than in April (figure 4.8). These weather conditions were more ideal for the MWDFG function than the Single Bucket hence the extra dustfall collected by the MWDFG. The predominant winds during the month of March were coming from the east.

The ideal weather condition for efficiency of a Single Bucket sampler is weather characterized by calm and low wind speed conditions. The month of April was characterized by more calms and low wind speed weather conditions. These weather conditions resulted in the Single Bucket collecting more dust than in the month of March. The predominant winds during the month of April were coming from the west. The increased dustfall rates recorded by the Single Bucket in April could have been from a source of dust located to the west of Site RAMP 6.

During the month of May the predominant winds were coming from the east with lesser winds coming from the west (figure 4.9). There were more calms conditions (14.11%) and more high wind speeds (4-8 m.s-1). The dominant easterly wind direction and high wind speeds resulted in more dust collected by MWDFG than the Single Bucket. However, the Single Bucket recorded more dustfall rates during May than March because of the westerly wind component and the more calm weather conditions experienced in May. Throughout the investigation period MWDFG did not record significant variations in dustfall rates because it was not affected by changing wind direction as it could orientate itself to any wind direction.

There was no significant variation in dustfall rates recorded by the MWAC N and the MWAC D samplers during the month of March to May 2008.

Particle size analysis of the dust samples

The particle size analysis performed on the dust samples indicate that the dust collected by the samplers is predominantly less than 100 µm. The particle size of less than 100 µm is similar to the size of dust from fugitive dust sources.

The fraction of dust particles above 100 µm recorded by the four samplers indicates that these dust fractions are from within 100 meters of the sampling location. The particles were either gusted into the samplers by wind or mechanically agitated and lifted into the air during calm conditions. The area is next to an unpaved road used by mining trucks to transport coal from the nearby mine pits (figure 1.1).

Significant percentages by volume of particles collected by the four samples are under 15 µm. The PM10 fraction is about 19 percent by volume for MWAC N, 16 percent for MWAC D, 19 percent for the Single Bucket and 23 percent for MWDFG.

Scanning electron microscopy analysis of the dust samples

Based on the morphological features, it can be considered that irregular square and diamond particles are assuredly derived from soil, coal and geological deposit as the product of mechanical abrasion (Kaegi, 2004); the agglomerate and sphere particles are from the combustion of coal (Ramesh and Koziski, 1999:), while the floccules particles are from the discharge of vehicles (Colberk *et al*., 1997), and the cylindrical or stick shaped particles are from bioactivities (Crook and Sherwood-Higham, 1997). In the atmospheric environment, only a few particles possess smooth surface, most of them are fractal. With the enlarged surface area by the cracked and holed process, these fractal particles can provide suitable environment and medium for the secondary atmospheric reactions. The particles observed from the Bucket are rounded possible due to the filtration process. Particles from MWDFG, MWACN and MWAC D could have retained their original sharp edges because they were not subjected to filtration process.

CHAPTER FIVE

CONCLUSION

This chapter has the conclusions and recommendations of the study

Conclusion and Recommendations

During the 3 months sampling period MWDFG recorded dustfall rates that were higher than the Single Bucket with 647 $mg/m^2/day$ on average while Single Bucket recorded dustfall levels with 461 $mg/m^2/day$ on average. The Single Bucket may be measuring inefficiently at higher wind speeds.

The MWDFG and the Single Bucket should be used in combination to assess different aspects of wind-blown dust problems in Landau Colliery. The Single Bucket would give information on local rates of deposition, whereas the MWDFG would indicate dust from various source and direction. The excess dustfall that has been exhibited by the MWDFG during the March to April 2008 dust sampling period is a result of dust from other source directions that could not be recorded by the Single Bucket.

MWAC N and MWAC D are flux gauges, but the results obtained indicated that they were not as efficient as MWDFG in collecting dustfall under high wind conditions. They obtained dustfall level rates of 312 µm and 371 µm on average respectively during the sampling period. Doubling the size of the inlet and out yielded no significant difference as shown by ratios calculated.

MWDFG yielded better dustfall results compared to the Single Bucket and MWAC samplers for the Landau Colliery RAMP 6 sampling site. The results obtained may not be true for other sites, in this and other provinces.

Annegarn Environmental Research and Ecoserve Private Limited recently adopted the MWDFG and thirty units have been produced and installed in Saldanha and Vredenburg and other sites in Durban and Cape Town. The results from these new units will not be included in this study. Results from Ecorseve may only be available towards the end of 2009 and that is out of this study time-frames.

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APPENDIX A. Step by Step Description of the method used to obtain Dust Data

1. Bucket Preparation

Clean the buckets well, making sure that no dust or particulate remains in the buckets.

Rinse out with a little distilled water, discarding this rinse water.

Partially fill with distilled water, allowing for the expected rate of evaporation appropriate to the expected rate of sampling as outlined in Table. These are rough figures and conditions in your area will dictate exact water requirements.

Table 1: Amount of water required for different climatic conditions.

WEATHER CONDITIONS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS OR 1 MONTH
Hot dry warm periods	2.5 liters	3.5 liters	4.0 liters	4.0 liters + check after 3 weeks
Hot wet warm periods	2 liters	2.5 liters	3.0 liters	3.5 liters + check after 3 weeks
Cool dry cold periods	2 liters	2.5 liters	2.5 liters	3.5 liters
Cold dry cold periods	2 liters	2.5 liters	2.5 liters	3.0 liters
Wet cold periods	2 liters	2.0 liters	2.5 liters	3.0 liters + check after 3 weeks

It is not critical to measure the water accurately and the above approximations are good enough. It should be noted that with any longer period of measurement the water should be topped up to prevent total loss of water, which will result in some loss of dust or alternatively failure to catch dust adequately during the period when the bucket is dry.

Add an amount of 5 ml to 10 ml of copper sulphate to each bucket as an algaecide, depending on how full the buckets will be kept. Top-up water does not have to be similarly dosed with bleach

Seal the buckets with the lids, adding labels to the bucket lids

Transport the buckets to site

2. Bucket Collection Procedure

The bucket support cradle must be dropped by unlocking the pad lock

The bucket must be removed and replaced with a pre-prepared bucket, using the labeled lid to seal the removed bucket, taking care to label the sample buckets correctly.

Lift the support assembly back into position and lock.

Any notes should be made in the field book before leaving.

3. Filtering Procedure

The clean Buchner funnel assemblies should be fitted with the pre-weighed and marked filter papers, making sure that the filter paper is located to prevent by-pass leakage around the filter.

The contents of one bucket must be loaded into each funnel after +1mm discard solids are strained out and the vacuum pump started.

Filter numbers must be entered against the designation of the collected bucket on the assessment form.

Enter all the relevant information on the assessment form.

On completion of the filtering process, remove the filters using forceps, place these in the Petri dishes, partially covering the filters and allow these to desiccate in a low temperature oven.

The filter + solids must be weighed once the filters have been desiccated. The stage at which full desiccation has been achieved is defined under “Weighing Procedure”.

The filter mass must be noted on the assessment form.

100 ml of the filtrate solution should be retained if the soluble content of the captured sample is also to be assessed and weighed. The total remaining water must be measured and the quantity added to the assessment sheet to determine the amount of dissolved solids

The above filtrate solution should be boiled off over a low Bunsen or heat source (hot plate) to accelerate the boiling off. The initial operation can be undertaken in a microwave oven and the beaker transferred to a hot plate for final desiccation.

The filtrate solids from the beaker must be collected and weighed, entering the mass on the assessment form as soluble solids.

4. Weighing Procedure – Filter Preparation

Stabilize filters in the laboratory or weighing room for 8 hours or keep stocks in an unsealed partly ventilated container so that they are continuously stable for the laboratory conditions.
Filter papers are individually marked using a ballpoint pen. Ensure that the ink has dried before proceeding with any weighing operations. Should filtrate be required to establish Alpha short or long-lived particles, no marking of the filters must be undertaken.
Each filter must be placed in its own Petri dish: the Petri dishes should also be marked with filter number and bucket number.

5. Weighing Procedure – Filter/Filtrate Weighing
Initial desiccation in a dust free environment for maximum of 24 hours must be allowed or until all sample moisture evaporation has stopped.
Desiccated filters are placed on the balance and permitted to remain on the pan for about 60 seconds. If there is any indication of a continuous fall in mass, it means that the filter/filtrate is not completely desiccated and the sample must be removed for further drying.
If the mass remains stable, remove the filter, allow the balance to zero and reweigh the filter.

6. Calculations

The cross-sectional area of the buckets is a standard constant in all of the calculations representing the area over which precipitant dust collection has been made, 0.02545m2.
The actual mass collected is derived by subtraction of the mass of the filter (mass before) from the combined mass of the filter and filtrate (mass after). Mass after – mass before = collected mass of dust sample.
All units should be expressed in milligrams and the value of milligram/square meter/day derived from the formula:

$$\text{Precipitation rate } (mg/m^2/d) = \frac{\text{collected mass X 1}}{\text{0.02545 X days}}$$

7. Limitations of Sampling and Filter materials

The type of filter paper used and the location of samplers unit in relation to the source of the dust dictate the sample capture restraints

Generally finer suspended dust (2.5µm > 5µm) will remain airborne almost indefinitely due to the dynamic nature of the air currents and thermal activities on any given day, even if there is no wind at all. A rapid increase in humidity together with an absence of wind will result in precipitation of less than 5µ particulate.

Particulate larger than about 5µm will settle on a very still day and this material is collected within the buckets in varying amounts depending on the wind turbulence.

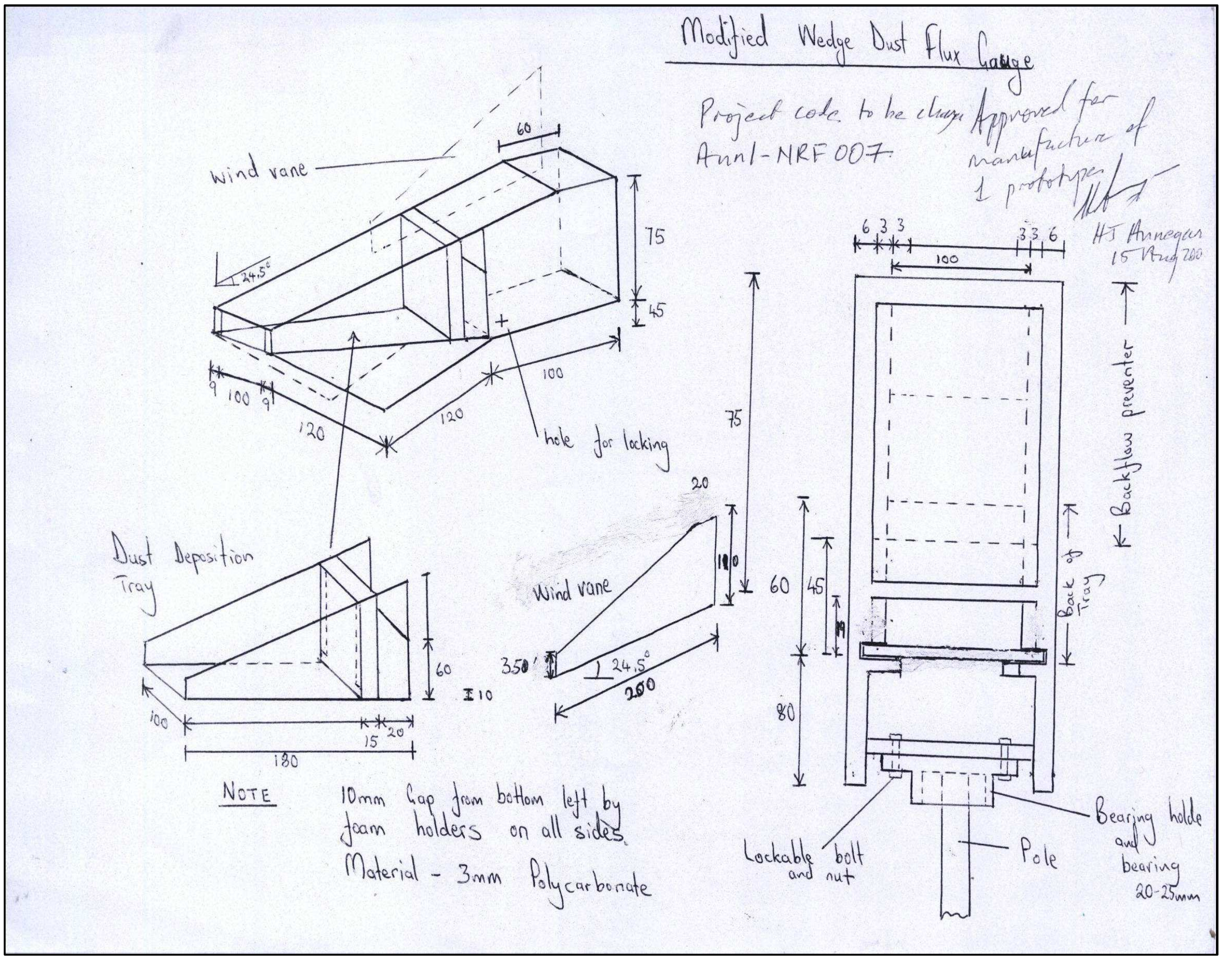
Particulate of large size, 500 µm, carried by high wind velocities will not be collected within the buckets due to the aerodynamic shape. At velocities below 3.0 m/s no particulate of this size is lifted higher than a maximum of about 2.0m.

Once the wind drops to lower levels the particulate starts precipitating and this gets captured in the buckets. We thus note that no dust gets captured during very windy conditions but only when the wind speed drops. Once the wind changes, the maximum precipitation rate is reached when the air mass movement is totally arrested and then starts to move in the opposite direction.

From the above we thus selected filter material with a pore size of about 5µm. The filter papers weave permits capture of 1 -2µm particulate and thus the actual collection guarantee is a lot better than 5µm.

APPENDIX B Schematic Design of modified WDFG

Design drawings of MWDFG by the author



APPENDIX C: Particle size analysis graphs for the Single Bucket dust samples obtained at Schoongezicht mini-pit site RAMP 6 over the month of April 2008

MALVERN INSTRUMENTS

MASTERSIZER 2000

Result Analysis Report

Sample Name:
Lab No.A21808 BUCKET04/08 + after

SOP Name:

Measured:
06 August 2008 11:23:46

Sample Source & type:
Supplier = Inspecorate M&L

Measured by:
Eustace

Analysed:
06 August 2008 11:23:48

Sample bulk lot ref:
SDS3162

Result Source:
Measurement

Particle Name:
Default 1.52 1

Accessory Name:
Hydro 2000G (A)

Analysis model:
General purpose

Sensitivity:
Normal

Particle RI:
1.520

Absorption:
1

Size range:
0.020 to 2000.000 um

Obscuration:
13.35 %

Dispersant Name:
Water

Dispersant RI:
1.330

Weighted Residual:
0.511 %

Result Emulation:
Off

Concentration:
0.0172 %Vol

Span :
2.724

Uniformity:
1.07

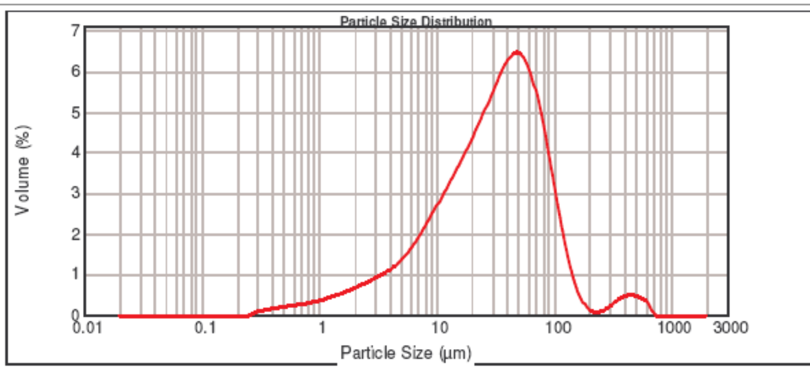
Result units:
Volume

Specific Surface Area:
0.632 m²/g

Surface Weighted Mean D[3,2]:
9.492 um

Vol. Weighted Mean D[4,3]:
48.815 um

d(0.1): 5.057 um   d(0.5): 32.055 um   d(0.9): 92.375 um



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.87	7.096	13.63	50.238	68.24	355.656	98.22
0.022	0.00	0.159	0.00	1.125	2.16	7.962	15.17	56.368	73.05	399.052	98.55
0.025	0.00	0.178	0.00	1.262	2.48	8.934	16.90	63.246	77.69	447.744	98.91
0.028	0.00	0.200	0.00	1.416	2.83	10.024	18.82	70.963	81.99	502.377	99.28
0.032	0.00	0.224	0.00	1.589	3.22	11.247	20.95	79.621	85.85	563.677	99.62
0.036	0.00	0.252	0.00	1.783	3.66	12.619	23.27	89.337	89.15	632.456	99.89
0.040	0.00	0.283	0.03	2.000	4.14	14.159	25.80	100.237	91.85	709.627	100.00
0.045	0.00	0.317	0.10	2.244	4.67	15.887	28.52	112.468	93.94	796.214	100.00
0.050	0.00	0.356	0.19	2.518	5.25	17.825	31.45	126.191	95.46	893.367	100.00
0.056	0.00	0.399	0.31	2.825	5.87	20.000	34.60	141.589	96.48	1002.374	100.00
0.063	0.00	0.448	0.45	3.170	6.55	22.440	37.97	158.866	97.10	1124.683	100.00
0.071	0.00	0.502	0.60	3.557	7.28	25.179	41.58	178.250	97.43	1261.915	100.00
0.080	0.00	0.564	0.77	3.991	8.09	28.251	45.45	200.000	97.58	1415.892	100.00
0.089	0.00	0.632	0.95	4.477	8.97	31.698	49.58	224.404	97.65	1588.656	100.00
0.100	0.00	0.710	1.16	5.024	9.94	35.566	53.97	251.785	97.70	1782.502	100.00
0.112	0.00	0.796	1.37	5.637	11.03	39.905	58.59	282.508	97.80	2000.000	100.00
0.126	0.00	0.893	1.61	6.325	12.25	44.774	63.38	316.979	97.97		

Operator notes:

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Malvern, UK
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Record Number: 918
06 Aug 2008 12:12:31

APPENDIX D: Particle size analysis graphs for the MWDFG dust samples obtained at Schoongezicht mini-pit site RAMP 6 over the month of April 2008

MASTERSIZER 2000

Result Analysis Report

Sample Name:
Lab No.A21804 01WDFG04/08 + after

SOP Name:

Measured:
06 August 2008 10:52:22

Sample Source & type:
Supplier = Inspecorate M&L

Measured by:
Eustace

Analysed:
06 August 2008 11:06:41

Sample bulk lot ref:
SDS3160

Result Source:
Edited

Particle Name:
Default 1.52 1

Accessory Name:
Hydro 2000G (A)

Analysis model:
General purpose

Sensitivity:
Normal

Particle RI:
1.520

Absorption:
1

Size range:
0.020 to 2000.000 um

Obscuration:
21.69 %

Dispersant Name:
Water

Dispersant RI:
1.330

Weighted Residual:
0.410 %

Result Emulation:
Off

Concentration:
0.0263 %Vol

Span :
6.257

Uniformity:
2.04

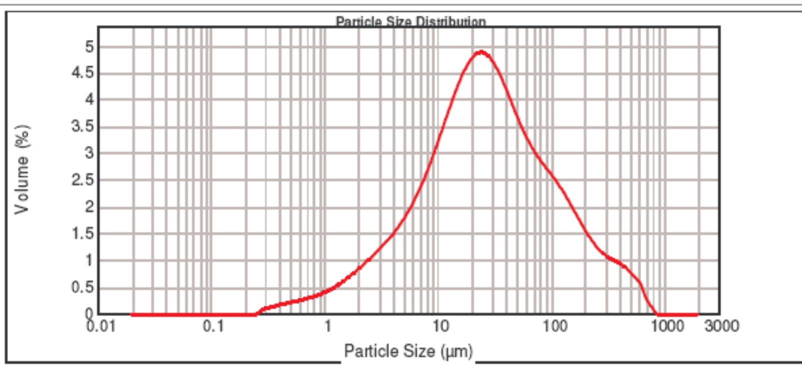
Result units:
Volume

Specific Surface Area:
0.702 m²/g

Surface Weighted Mean D[3,2]:
8.546 um

Vol. Weighted Mean D[4,3]:
64.776 um

d(0.1): 4.067 um **d(0.5): 26.060 um** **d(0.9): 167.129 um**



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.95	7.096	16.92	50.238	68.68	355.656	96.57
0.022	0.00	0.159	0.00	1.125	2.27	7.962	18.81	56.368	71.35	399.052	97.29
0.025	0.00	0.178	0.00	1.262	2.63	8.934	20.89	63.246	73.84	447.744	97.97
0.028	0.00	0.200	0.00	1.416	3.05	10.024	23.20	70.963	76.19	502.377	98.60
0.032	0.00	0.224	0.00	1.589	3.52	11.247	25.73	79.621	78.40	563.677	99.14
0.036	0.00	0.252	0.00	1.783	4.05	12.619	28.50	89.337	80.50	632.456	99.60
0.040	0.00	0.283	0.03	2.000	4.65	14.159	31.49	100.237	82.50	709.627	99.87
0.045	0.00	0.317	0.10	2.244	5.32	15.887	34.69	112.468	84.40	796.214	99.99
0.050	0.00	0.356	0.20	2.518	6.06	17.825	38.08	126.191	86.19	893.367	100.00
0.056	0.00	0.399	0.32	2.825	6.87	20.000	41.62	141.589	87.85	1002.374	100.00
0.063	0.00	0.448	0.45	3.170	7.77	22.440	45.24	158.866	89.37	1124.683	100.00
0.071	0.00	0.502	0.61	3.557	8.75	25.179	48.91	178.250	90.75	1261.915	100.00
0.080	0.00	0.564	0.78	3.991	9.81	28.251	52.54	200.000	91.99	1415.892	100.00
0.089	0.00	0.632	0.97	4.477	10.98	31.698	56.10	224.404	93.10	1588.656	100.00
0.100	0.00	0.710	1.18	5.024	12.26	35.566	59.52	251.785	94.09	1782.502	100.00
0.112	0.00	0.796	1.41	5.637	13.66	39.905	62.77	282.508	94.98	2000.000	100.00
0.126	0.00	0.893	1.66	6.325	15.21	44.774	65.82	316.979	95.80		

Operator notes:

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Serial Number : MAL100574

File name: Inspectorate M&L.mea
Record Number: 894
06 Aug 2008 12:12:31

APPENDIX E: Particle size analysis graphs for the MWAC D dust samples obtained at Schoongezicht mini-pit site RAMP 6 over the month of April 2008

MASTERSIZER 2000

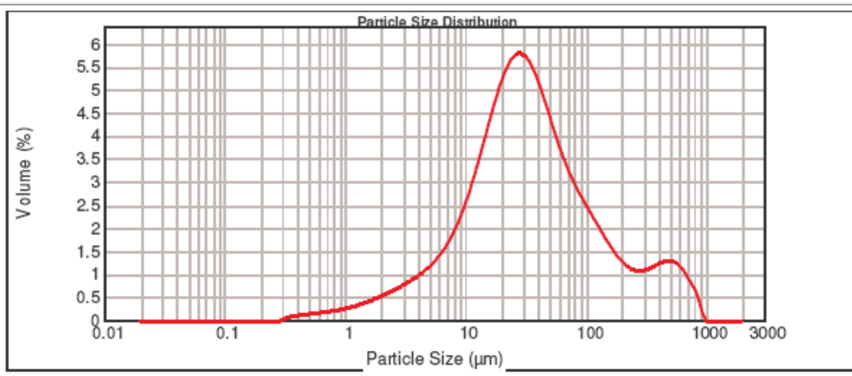
Result Analysis Report

Sample Name:	SOP Name:	Measured:
Lab No.A21806 01MWACD03/08 +		06 August 2008 11:12:52
Sample Source & type:	Measured by:	Analysed:
Supplier = Inspecorate M&L	Eustace	06 August 2008 11:12:53
Sample bulk lot ref:	Result Source:	
SDS3162	Measurement	

Particle Name:	Accessory Name:	Analysis model:	Sensitivity:
Default 1.52 1	Hydro 2000G (A)	General purpose	Normal
Particle RI:	Absorption:	Size range:	Obscuration:
1.520	1	0.020 to 2000.000 um	10.34 %
Dispersant Name:	Dispersant RI:	Weighted Residual:	Result Emulation:
Water	1.330	0.396 %	Off

Concentration:	Span :	Uniformity:	Result units:
0.0163 %Vol	6.771	2.18	Volume
Specific Surface Area:	Surface Weighted Mean D[3,2]:	Vol. Weighted Mean D[4,3]:	
0.512 m²/g	11.723 um	83.391 um	

d(0.1): 6.387 um   d(0.5): 31.277 um   d(0.9): 218.151 um



Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.24	7.096	11.10	50.238	65.98	355.656	93.52
0.022	0.00	0.159	0.00	1.125	1.45	7.962	12.45	56.368	69.13	399.052	94.41
0.025	0.00	0.178	0.00	1.262	1.69	8.934	14.02	63.246	71.98	447.744	95.34
0.028	0.00	0.200	0.00	1.416	1.96	10.024	15.82	70.963	74.55	502.377	96.31
0.032	0.00	0.224	0.00	1.589	2.26	11.247	17.91	79.621	76.90	563.677	97.26
0.036	0.00	0.252	0.00	1.783	2.60	12.619	20.32	89.337	79.04	632.456	98.16
0.040	0.00	0.283	0.00	2.000	2.99	14.159	23.08	100.237	81.00	709.627	98.93
0.045	0.00	0.317	0.01	2.244	3.41	15.887	26.20	112.468	82.79	796.214	99.53
0.050	0.00	0.356	0.07	2.518	3.88	17.825	29.67	126.191	84.41	893.367	99.94
0.056	0.00	0.399	0.15	2.825	4.41	20.000	33.47	141.589	85.87	1002.374	100.00
0.063	0.00	0.448	0.24	3.170	4.98	22.440	37.54	158.866	87.16	1124.683	100.00
0.071	0.00	0.502	0.34	3.557	5.61	25.179	41.80	178.250	88.30	1261.915	100.00
0.080	0.00	0.564	0.46	3.991	6.31	28.251	46.16	200.000	89.31	1415.892	100.00
0.089	0.00	0.632	0.59	4.477	7.07	31.698	50.50	224.404	90.21	1588.656	100.00
0.100	0.00	0.710	0.73	5.024	7.91	35.566	54.73	251.785	91.05	1782.502	100.00
0.112	0.00	0.796	0.88	5.637	8.85	39.905	58.76	282.508	91.86	2000.000	100.00
0.126	0.00	0.893	1.05	6.325	9.90	44.774	62.52	316.979	92.67		

Operator notes:

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Serial Number : MAL100574

File name: Inspectorate M&L.mea
Record Number: 905
06 Aug 2008 12:12:31

APPENDIX F: Particle size analysis graphs for the MWAC N dust samples obtained at Schoongezicht mini-pit site RAMP 6 over the month of April 2008

MALVERN INSTRUMENTS

MASTERSIZER 2000

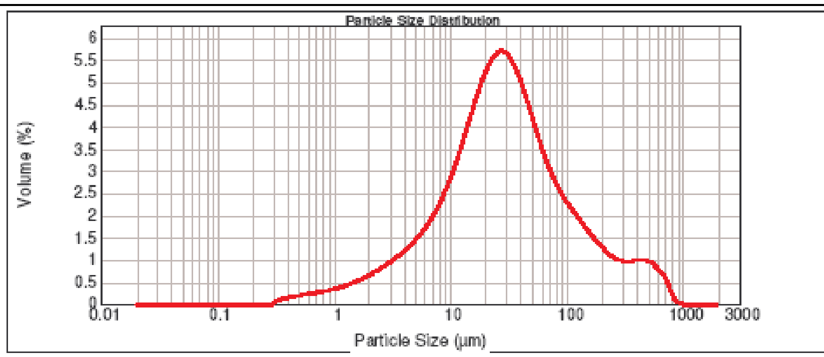
Result Analysis Report

Sample Name: Lab No.A21805 01MWACN03/08 +
SOP Name:
Measured: 06 August 2008 11:04:33
Sample Source & type: Supplier – Inspecorate M&L
Measured by: Eustace
Analysed: 06 August 2008 11:04:34
Sample bulk lot ref: SDS3161
Result Source: Measurement

Particle Name: Default 1.52 1
Accessory Name: Hydro 2000G (A)
Analysis model: General purpose
Sensitivity: Normal
Particle RI: 1.520
Absorption: 1
Size range: 0.020 to 2000.000 um
Obscuration: 3.94 %
Dispersant Name: Water
Dispersant RI: 1.330
Weighted Residual: 0.284 %
Result Emulation: Off

Concentration: 0.0050 %Vol
Span : 5.814
Uniformity: 1.99
Result units: Volume
Specific Surface Area: 0.606 m²/g
Surface Weighted Mean D[3,2]: 9.899 um
Vol. Weighted Mean D[4,3]: 69.138 um

d(0.1): 5.053 um   d(0.5): 28.106 um   d(0.9): 168.456 um



Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %	Size (μm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.65	7.096	13.82	50.238	69.49	355.656	95.51
0.022	0.00	0.159	0.00	1.125	1.92	7.962	15.42	56.368	72.49	399.052	96.25
0.025	0.00	0.178	0.00	1.262	2.23	8.934	17.22	63.246	75.20	447.744	97.00
0.028	0.00	0.200	0.00	1.416	2.57	10.024	19.25	70.963	77.62	502.377	97.74
0.032	0.00	0.224	0.00	1.589	2.95	11.247	21.54	79.621	79.80	563.677	98.45
0.036	0.00	0.252	0.00	1.783	3.37	12.619	24.12	89.337	81.78	632.456	99.06
0.040	0.00	0.283	0.00	2.000	3.84	14.159	27.02	100.237	83.58	709.627	99.56
0.045	0.00	0.317	0.01	2.244	4.37	15.887	30.24	112.468	85.24	796.214	99.91
0.050	0.00	0.356	0.09	2.518	4.95	17.825	33.76	126.191	86.76	893.367	99.99
0.056	0.00	0.399	0.19	2.825	5.59	20.000	37.61	141.589	88.15	1002.374	100.00
0.063	0.00	0.448	0.31	3.170	6.30	22.440	41.67	158.866	89.41	1124.683	100.00
0.071	0.00	0.502	0.45	3.557	7.09	25.179	45.90	178.250	90.54	1261.915	100.00
0.080	0.00	0.564	0.60	3.991	7.95	28.251	50.19	200.000	91.55	1415.892	100.00
0.089	0.00	0.632	0.78	4.477	8.90	31.698	54.45	224.404	92.46	1588.656	100.00
0.100	0.00	0.710	0.97	5.024	9.94	35.566	58.58	251.785	93.29	1782.502	100.00
0.112	0.00	0.796	1.17	5.637	11.10	39.905	62.51	282.508	94.05	2000.000	100.00
0.126	0.00	0.893	1.40	6.325	12.39	44.774	66.15	316.979	94.79		

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