



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

AN EVALUATION OF THE EFFICIENCY OF VARIOUS RESPIRATORY PROTECTIVE EQUIPMENT, USED WITHIN PLATINUM PROCESSING

By

CORNELIA CECILIA VAN ZYL

Hons. B.Sc.

Mini-dissertation submitted in partial fulfillment of the requirements for the degree *Magister Scientiae* Occupational Hygiene at the Potchefstroom Campus of the North-West University

Supervisor:	Prof FC Eloff
Co-supervisor:	Mr PJ Laubscher
Assistant supervisor:	Dr C Badenhorst

DECEMBER 2009

IN LOVING MEMORY OF MY MOM
YOU ALWAYS BELIEVED IN ME

AUTHOR'S CONTRIBUTION

The study was planned and executed by a team of researchers:

NAME	CONTRIBUTION
1. Corlize van Zyl	• Sampling • Literature research, statistical analysis, writing of article.
2. Prof FC Eloff	• Supervisor • Assisting with the design and approval of protocol. • Reviewing of the mini-dissertation and interpretation of data.
3. Mr PJ Laubscher	• Co-supervisor
4. Dr C Badenhorst	• Assisting with the design and approval of protocol

I hereby declare that the mini-dissertation submitted for the Magister Scientiae: Occupational Hygiene at the North-West University is my own original work and has not been previously submitted to any other, and all acknowledgments are done by means of a comprehensive list of references

Author

CC van Zyl

Co-supervisor

Mr PJ Laubscher

Supervisor

Prof FC Eloff

Assistant supervisor

Dr C Badenhorst

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following people who contributed to making this study possible:

- My Father in Heaven for giving me the knowledge, strength, and love I needed to complete my studies. Thank You for carrying me through out the difficult times.
- Prof Fritz Eloff, my project leader, for all the guidance and support.
- Dr Cas Badenhorst, JJ van Staden and Morne de Beer for guidance and help during the sampling stages of the study.
- The platinum processing company that provided funding for the project and the opportunity to gain valuable practical experience.
- Prof Faans Steyn for the statistical advice in the beginning stages of the study.
- Hennie Gerber for the statistical analysis and guidance with the interpretation of the results.
- Hester van der Walt for the technical editing.
- Ettiene, Dad, my sister and my family and friends, for all your patience, encouragement and love. I could not have asked for a better support system.

PREFACE

For this project, it was decided to reflect results and findings in an article format. For uniformity the mini-dissertation was done according the author's guidelines of the Occupational Health Southern Africa journal. The journal requires that all references be inserted in the text as superscript numbers and be reflected in Vancouver style in the list of references.

ABSTRACT

AN EVALUATION OF THE EFFICIENCY OF VARIOUS RESPIRATORY PROTECTIVE EQUIPMENT, USED WITHIN PLATINUM PROCESSING

Workplace performance measurements of respiratory protective equipment (RPE) are fundamental to understanding how well users are protected during work activities. This study evaluated the effectiveness of various respiratory protective devices used within the platinum producing industry and whether facial hair influenced the seal efficiency of the facepiece. Three life-size mannequins, each connected to a personal sampling pump, were used to test the efficiency of respirators within three different work environments. It was found that the 3M 8822, 3M 6000, Moldex 8000 and Dräger air-stream helmet all provided effective respiratory protection against airborne contaminants. Results indicated that the 3M 8822 showed an 18% contaminant concentration on the inside of the facepiece, while the 3M 6000 indicated 15% and the Moldex 8000 only 11%. The air-stream helmet was shown to be the most effective with only 2.5% of exposure concentrations being measured on the inside of the mask. Respiratory devices showed a significant effect in two of the sampling areas, concluding that the sampling area does have an effect on the respiratory efficiency. Conversely the effect of facial hair on the seal efficiency of the respirators only indicated a tendency, but no conclusive data were obtained during this study.

OPSOMMING

EVALUERING VAN DIE EFFEKTIWITEIT VAN VERSKEIE RESPIRATORIESE BESKERMINGSAPPARATE WAT GEBRUIK WORD TYDENS PLATINAPROSESSERING

Die effektiwiteitstoetse in die werkplek is nootsaaklik om werklik die effectiviteit van respiratoriese beskermingsapparate gedurende werksaktiviteite te kan verstaan. Tydens die studie is die effektiwiteit van verskeie respiratoriese beskermingsapparate wat tans gedurende platinumprosessering gebruik word, geëvalueer, tesame met die effek van gesigshare op die seëffektiwiteit van die maskers. Drie lewensgrootte poppe, elkeen gekoppel aan 'n persoonlike moniteringsapparaat, is gebruik om die effektiwiteit van die respirators in drie verskillende werksomgewings te toets. Daar is bevind dat die 3M 8822, 3M 6000, Moldex 8000 en Dräger-lugstroomhelm almal voldoende beskerming bied tydens blootstelling aan verskeie lugverspreide kontaminante. Resultate het getoon dat die konsentrasie aan die binnekant van die maskers soos volg was: 3M 8822 het 'n 18%-konsentrasie getoon, die 3M 6000 15% en die Moldex 8000 11%. Die lugstroomhelm was die effektiwiefste met slegs 'n 2.5%-konsentrasie aan die binnekant van die masker. Daar is bevind dat twee van die areas waar metings geneem is, direk verband hou met die effektiwiteit van die respirators. Die invloed van gesigshare op die seëffektiwiteit kon nie met sekerheid bewys word nie, maar die data dui sterk daarop dat gesigshare wel 'n effek op respiratoriese beskermingstoerusting het.

ABBREVIATIONS

ACGIH	:	American Conference of Governmental Industrial Hygienists
AIHA	:	American Industrial Hygiene Association
ANOVA	:	Analysis of variance
ANSI	:	American National Standard Instituted
APF	:	Approved protection factor
ATSDR	:	Agency for Toxic Substances and Disease Registry
BMR	:	Base Metal Refinery
°C	:	Degrees Celsius
CFR	:	Code of Federal Regulation
CTPV	:	Coal Tar Pitch Volatiles
ESLI	:	End of service life indicator
HCS	:	Hazardous chemical substances
HGG	:	Hot gas generator
IARC	:	International Agency for Research on Cancer
IDLH	:	Immediately Dangerous to Life and Health
DME	:	Department of Minerals and Energy
KG	:	Kilograms
M	:	Meter
MCP	:	Magnetic Concentration Plant
Mg/m ³	:	Milligram per cubic meter
MHSA	:	Mine Heath and Safety Act
MUC	:	Maximum use concentration
MUL	:	Maximum use limit
Ni	:	Nickel
NIOSH	:	National Instituted of Occupational Safety and Health
NPPTL	:	National Personal Protective Technology Laboratory
NRCS	:	National Regulator for Compulsory Specifications
OEL	:	Occupational exposure limit
OEL-STEL	:	Occupational exposure limit - Short term exposure
OHS	:	Occupational Health and Safety
OSHA	:	Occupational Safety and Health Administration
PAH	:	Polycyclic Aromatic Hydrocarbon
PEL	:	Permissible exposure limits

PGM	:	Platinum group metals
PLHCP	:	Physician or Other Licensed Health Care Professional
PMR	:	Precious Metals Refinery
RPE	:	Respiratory protective equipment
PPE	:	Personal protective equipment
PPM	:	Parts per million
QLFT	:	Quality fit test
SABS	:	South African Buro of Standards
SAR	:	Supplied air respirators
SCBA	:	Self contained breathing apparatus
SIMRAC	:	Safety in mining research advisory committee
SO ₂	:	Sulphur Dioxide
TLV	:	Threshold limit value
TWA-OEL	:	Time weighted average occupational exposure limit
TWA	:	Time weighted average
UG2	:	Upper group chromitite layer
WPF	:	Workplace protection factor
µm	:	Micrometer/Micron

TABLE OF CONTENTS

Page Number

Preface	5
Abstract	6
Opsomming	7

CHAPTER 1 – INTRODUCTION

1.1. Background and Justification	13
1.2. Problem Statement	15
1.3. Hypotheses	16
1.4. Aim of the Study	17
1.5. Main Objectives	17
References	18

CHAPTER 2 – LITERATURE OVERVIEW

2.1. Occupational Health Management Programme	21
2.2. Airborne Contaminants	25
2.3. Respiratory Hazards	26
2.4. Exposure Limits	30
2.5. Platinum Processing Industry	31
2.6. Nickel	34
2.7. Sulphur Dioxide	38
2.8. Coal Tar Pitch Volatiles	41
2.9. Respiratory Protection Devices	43
2.10. Assigned Protection Factors (APF)	54
2.11. Service Life	55
2.12. Advantages and Limitations of Air-Purifying Respirators	56
2.13. Advantages and Limitations of Atmosphere-Supplying Respirators	57
2.14. Factors that Influence the Use and Effectiveness of Respiratory Devices	58
2.15. Respiratory Regulations and Approvals	61
References	63

CHAPTER 3 – SCIENCE ARTICLE

3.1. Guidelines for Authors	70
-----------------------------	----

Article: An evaluation of the Efficiency of Various Respiratory Protective Equipment Used Withing Platinum Processing	73
---	----

CHAPTER 4 – CONCLUDING CHAPTER

4.1. Conclusion	92
4.2. Study Limitation	93
4.3. Recommendations	94

CHAPTER 5 – RESPIRATORY MANAGEMENT PROGRAMME

5.1. Respiratory Protection Management Programme	96
5.2. Policy	96
5.3. Responsibilities	96
5.4. Programme	98
5.5. Programme Evaluation	100
5.6. Recommendations	101
References	106

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND AND JUSTIFICATION

Occupational hygiene is defined as: "the art and science devoted to the anticipation, recognition, evaluation, and control of those environmental factors or stressors arising in or from the workplace that may cause sickness, impaired health and well-being, or lead to significant discomfort among workers and/or citizens of the community".^{1, 2}

Assessing and monitoring the risks, and determining whether a health risk exists, form the basis of any occupational hygiene programme. If any health risks are present, control measures should be set in place to eliminate and/or lower exposures below recommended limits to ensure that no health risks pose a threat to the workers and surrounding environment.³

Occupational stressors that may cause sickness, health impairment, or significant discomfort can be classified as chemical (mist, vapours, gases or solids), physical (noise, vibration, ionizing and non-ionizing radiation), biological (living organisms), ergonomic (improper work areas, tools or procedures) or psychosocial. A wide range of adverse health effects ranging from simple irritation to systemic diseases is mostly caused by the inhalation of airborne contaminants.⁴

Airborne contaminants can enter the body through the respiratory tract (inhalation), digestive tract (ingestion) and the skin (dermal absorption). The inhalation of airborne contaminants depends on the nature of the particle, the concentration/intensity, duration of the exposure and the part of the respiratory system in which the contaminant is deposited.⁵

The study described in this mini-dissertation was conducted at a leading primary platinum producer to estimate the effectiveness of respiratory protective equipment (PPE) for lowering exposure to airborne contaminants to below the recommended limits. There is currently insufficient information on occupational respiratory health among platinum miners; therefore, any proposed research within this field may lead to better understanding and assessment of prevailing problems.⁶

CHAPTER 1

INTRODUCTION

Platinum processing is a long and complex procedure consisting of various individual processes each faced with their own specific health risks. Owing to the magnitude of platinum processing, this study only focused on the platinum smelting and refining sections.

Platinum processing starts when the ores from mining operations reach the concentrators where crushing, milling and separation take place. Through the sulphide flotation process, the base metals sulphide and the associated platinum group metals are concentrated. Concentrate containing platinum is transported to the smelters where it is dried, and then melted down in the electric furnace. Granulated or crushed matte from the electric furnace is then sent to the converting section, where excess iron sulphide is removed. The converted matte products are bottom cast, slow cooled, crushed and sent to the magnetic concentration plant at the base metals refinery. Here the magnetic platinum group metal-containing (PGM) fraction is recovered and sent to precious metal refinery (PMR) while the remaining material is treated at the base metal refinery (BMR) to recover nickel, copper and cobalt.⁷

It was estimated during routine sampling conducted at the crusher's, furnace and tank house of a leading platinum producer that soluble and insoluble nickel (Ni), sulphur dioxide (SO₂) and coal tar pitch volatiles (CTPVs) could be identified as possible hazardous airborne contaminants that are released during the crushing, smelting and refining of platinum.

Nickel is an environmental and industrial contaminant that is a well-known human carcinogen.⁸ Nickel dermatitis is a common effect of nickel exposure and leads to itching of the fingers, hands and forearms.⁹

Studies done on nickel workers and animals have indicated that high concentrations of nickel exposure lead to lung damage, which in effect lowers normal lung function. Epidemiological studies have also shown that occupational exposure to nickel is associated with high incidences of lung and nasal cancer among humans.^{10, 11}

CHAPTER 1

INTRODUCTION

The highest exposure to SO₂ occur when they are a by-product, as in the metal smelting industry, and during the processing or combustion of high-sulphur coal or oil.¹² Acute exposure to SO₂ will cause irritation of the eyes, nose, mouth and parts of the respiratory tract.¹³ Chronic exposures to SO₂ may cause a decrease in lung functionality and an increase in lung disease.¹⁴ SO₂ also causes the activation of sensory reflexes that initiate inflammation. The inhalation of SO₂ causes bronchoconstriction in most normal people but can be greatly exacerbated by existing medical conditions such as asthma.¹⁵

CTPVs are formed during the distillation of coal, a process known as carbonization. Studies have shown that exposure to CTPVs may lead to cancer of the kidney, bladder, respiratory tract and skin. The International Agency for Research on Cancer (IARC) has classified CTPVs as a Group 1 carcinogen.¹⁶

Ni, SO₂ and CTPVs are essential by-products during platinum processing that cannot be substituted or effectively eliminated. Respiratory protection devices are provided as the last resort and only for additional control. However PPE can be inadequate when not properly selected and fitted. Factors like specific facial features (facial hair) or poor maintenance programmes may contribute to possible leakages. In most cases, a lack of knowledge also leads to incorrect use.¹⁷

1.2. PROBLEM STATEMENT

Personal exposure to airborne substances is measured by using personal sampling pumps. These techniques have been used for decades. However, personal air sampling methods have limitations in the sense that the concentration of particles being inhaled by the worker on the inside of any respiratory device cannot be measured, because the sampling heads and tubes cause leakage underneath the face mask.¹⁸ Studies have been conducted using mannequins connected to a device that simulates human breathing, but these test are done in a laboratory environment under regulated conditions.^{19, 20} The use of the mannequins connected to breathing simulators has made it possible to measure exposure behind the masks, but true air concentrations in the work environment were absent.

CHAPTER 1

INTRODUCTION

Bearing in mind these two limitations within this study, the effectiveness of four different respiratory devices used within the furnace, crushers and tank house of a platinum processing plant was evaluated. Life-size CPR mannequins were used as test subjects and the airborne contaminant concentrations were measured on the inside of each device by using standard personal sampling techniques. The efficiency of each device was examined within the actual working environment. The concentration on the inside of the face piece was then compared to the environmental concentration to determine the respiratory efficiency.

Standard personal and environmental sampling are conducted on a continuous basis at the processing plant to monitor personal exposure, but the testing of respiratory efficiency using mannequins placed within the work environment has not been carried out before.

1.3. HYPOTHESES

1.3.1. Hypothesis one

Respiratory protection equipment is an efficient control method for reducing airborne contaminant exposure.

1.3.2. Hypothesis two

Although respiratory protective equipment is an effective control method for reducing exposure to airborne contaminants, facial hair may limit the efficiency of respiratory protective equipment.

1.3.3. Hypothesis three

The different sampling areas have an effect on the efficiency of respiratory protective devices.

1.4. AIM OF THE STUDY

The aim of the study was to use personal sampling pumps connected to life-size mannequins under real-time, uncontrolled and random conditions to determine the exposure concentration on the inside of the facepiece for:

- Soluble nickel
- Insoluble nickel
- Sulphur dioxide
- Coal tar pitch volatiles

1.5. MAIN OBJECTIVES

The main objectives of the study are to evaluate respiratory devices that are currently being used, and to identify possible factors that lower the protection efficiency of the respirators. The collected data can then be used to select the most efficient respirator to lower personal exposure and to educate workers on possible factors that may lower the effectiveness of the respirator. The respiratory protective management programme will also be evaluated in order to provide possible recommendation to management to improve and better the current systems. Informing workers of the importance of wearing respiratory protective equipment will promote health and safety among workers.

REFERENCES

1. Gardiner K, Harrington JM. Occupational hygiene. 3rd ed. Massachusetts: Blackwell Publishing Ltd; 2005. p. 3, 30.
2. Plog BA. Fundamentals of industrial hygiene. 5th ed. New York: National Safety Council; 2002. p. 667-725.
3. Tranter M. Hygiene and risk management. 2nd ed. Sydney: Southwood Press; 2004. p. 1.
4. Donoghue AM. Occupational health hazards in mining: an overview. Occup Med. 2004 Apr 20;54(5):283-289.
5. Winder C, Stacey NH. Occupational toxicology. 2nd ed. Florida: CRC Press; 2004. p. 72.
6. Haskins S. Researchers into health effects of platinum mining: [Online]. 2008 [cited 2009 Jan 15]. Available from: <http://www.miningweekly.com/article>
7. Jacobs M. Process description and abbreviated history of the Anglo Platinum's Waterval Smelter. J S Afr Inst Min Metall. 2006 Mar 5-8;7-28.
8. Hu W, Feng Z, Tang M. Nickel (II) enhances benzo[a]pyrene diolepoxide-induced mutagenesis through inhibition of nucleotide repair in human cells: possible mechanism for nickel (II)-induced carcinogenesis. Carcinogenesis. 2003 Nov 6;25(3):455-462.
9. Station I, Ma R, Evans N, Hutchinson RW, Mclead CW, Gawkrödger DJ. Dermal nickel exposure associated with coin handling and various occupational settings: assessment using a newly developed finger immersion method. BJD. 2006 Apr;154(4):658-664.
10. Grimsrud TK, Berger SR, Haldorsen A, Anderson A. Exposure to different forms of nickel and risk of lung cancer. Am J Epidemiol. 2002 Jun 5;156(12):1123-1132.
11. International Agency for Research on Cancer. IARC monograph on the evaluation of the carcinogenic risk of chemical to humans. 1985;7:174.
12. Badenhorst CJ. Occupational health and safety risk associated with sulphur dioxide. J S Afr Inst Min Metall. 2009 May;107:299-303.
13. Vale A. Sulphur dioxide. Medicine. 2007 Dec 12;35(12):656.
14. Agency for Toxic Substance and Disease Registry. Medical management guideline for sulphur dioxide; [Online]. 2007 [cited 2008 Sep 23]. Available from: <http://www.atsdr.cdc.gov/mHml/mmg116.html>

CHAPTER 1
INTRODUCTION

15. Tunnicliffe WS, Hilton RM, Ayres JG. The effect of sulphur exposure on indices of heart rate variability in normal and asthmatic adults. *ERJ*. 2001;17:604-608.
16. Occupational safety and health administration. Coal tar pitch volatiles (CTPV), coke oven emission (COE) and selected polynuclear aromatic hydrocarbons (PAHs); [Online]. 2008 [cited 2008 Sept 10]. Available from:
<http://www.osha.gov/dts/sltc/methods/organic/org058/org058.html#ref51>
17. Environmental, health and safety online. OSHA respiratory protection program; [Online] 2008 [cited 2009 Jan 15]. Available from:
<http://www.ehso.com/RespProtectionSelection.htm>
18. Renstrom A, Karlsson AS, Tovey ER. Nasal air sampling used for the assessment of occupational allergen exposure and the efficiency of respiratory protection. *Clin Exp Allergy*. 2002 Sep;32:1769.
19. Kyungmin JC, Reponen T, Mckay R, Shukla R, Haruta H, Sekar P et al. Large particle penetration through N95 respirator filters and facepiece leaks with cyclic flow. *Ann Occup Hyg*. 2009 Aug 21;21(10):1093.
20. Xu M, Han D, Willeke H, Willeke K. Respiratory fit and protection through determination of air and particle leakages. *BOHS*. 1991;35(1):13-14.

CHAPTER 2

LITERATURE OVERVIEW

2.1. OCCUPATIONAL HEALTH MANAGEMENT PROGRAMME

The main objective of the Mine Health and Safety Act (Act No. 85 of 1993) (MHSA) is to implement a system that creates and maintains a safe and healthy working environment. Section 11(1) (a) (b) and (c) requires that every employer must identify health and safety hazards, record the hazards identified and assess the risks. Section 11(4) states that these assessments must be conducted regularly. The occupational health and safety of each worker are thus the responsibility of the employer.¹

The Safety in Mining Research Advisory Committee (SIMRAC) defines occupational health management as “the improvement in workplace conditions and decrease or elimination of illness and disability, due to actions within the workplace through the implementation of risk prevention and control measures.”² An occupational health management programme is an interactive and continuous process. The management systems form the foundation and are the driving force behind any occupational health risk assessment. Multiple health and safety management standards were identified in the literature review, and the following are the key elements for any occupational health management system.^{2,3,4,5}

2.1.1. Occupational health policies

According to Section 8 of the MHSA the employer must establish a health and safety policy that is prominently displayed for employees to read.¹ The policy should:

- describe the organization’s work activities;
- be appropriate to the nature and scale of occupational health risks;
- contain a commitment from management to improve the health and safety of employees; and
- comply with relevant legislation and standards.

The policy must be implemented and frequently reviewed to ensure that it remains relevant to the work activities.

2.1.2. Planning

The planning phase ensures that action is taken in areas of concern, enough resources are available, responsibilities and authorities are defined, documented and communicated.

There are three key elements that need to be focused on during the planning process:

- Initial reviewing of current management system, hazard identification, baseline risk assessments and risk control or elimination methods suitable for the different operation within the organisation.
- Ensuring legal compliance, communicating information to the personnel and providing training on legal aspects concerning the employer and employee.
- Setting practical and reasonable goals or objectives for continuously improving the health and safety system. Making use of performance feedback systems will help to identify problem areas and measure the effectiveness of the current system.

2.1.3. Implementation and operation

This phase forms the working system of the programme and ideas from the planning phase will now be implemented. The success of this phase depends on the commitment of top management, adequate resources being made available, performance measurements, monitoring and maintenance of a safe workplace and equipment.

The phase is aimed at making use of specialists for advice, information and new processing technologies, controlling risks and ensuring competence through training, recruiting, placements and transfers. Employees should be encouraged to co-operate with the policies and effective communication channels should be set in place by means of visible behaviour, written material or face-to-face discussion.

2.1.4. Monitoring and corrective action

Monitoring consists of two elements, viz. performance measurements and auditing. Performance measurements should not just be in reaction to incidents or failures, but should be predictive indicators that will help to prevent possible accidents or injuries. The results obtained should be measured against standards and appropriate remedial action should be taken.

Based on the risk level, organizations must identify hazards and compile a monitoring schedule to quantify possible exposure. The frequencies of inspections may be defined by law, but schedules based on hazard identification, basic risk assessments, legislation and regulations should be prepared and form part of the occupational health and safety (OHS) management system. The objective is to capture constructive and useful procedures. The following methods can be used to ensure that objectives are fulfilled:

- Auditing of health hazards, risk assessments and control measures on an annual basis or in the event of operational changes that have been made to the working environment.
- Conducting OHS workplace inspections, using checklists, together with conformance evaluations of new plants, equipment, material, chemicals, technologies, process procedures or work patterns.
- Personal and environmental sampling should be done to determine exposures to chemicals, biological or physical agents and comparing them with standards and legislation.
- Identifying personnel with recognized occupational hygiene experience or formal qualifications.
- Behavioural sampling, monitoring the behaviour of workers and identifying unsafe working practices.
- Annual medical surveillance, to be conducted according to regulations and legislation.
- Documentation needs to be analysed and records must be kept of all incidences, sampling or medical reports.

- Conducting surveys determining employee attitudes towards the OHS procedure and management system.

2.1.5. Management review

Top management should appoint a senior accountable person that periodically reviews the OHS management system, based on overall performance and not specific details. The outcomes of the review are utilised to identify action plans, alter and improve the organization's policy and prioritizing areas of concern.

During the review the following aspects need to be addressed:

- Is the current policy is still suitable and relevant?
- Updating or setting new objectives.
- Current risk and effectiveness of control methods that are currently used.
- The sufficiency of current health risk identification methods, assessments and control measures.
- Adequacy of resources.
- Effectiveness of OHS inspection and hazard reporting process.
- Incidences or illnesses that may have occurred, the effectiveness of reporting procedures and outputs of investigation into incidences.
- Results of internal and external audits and the distribution of findings to employees and management.
- Emergency preparedness.
- Assessment of changes to legislation or technical aspects.
- Assessment of employee perceptions of the system and possible improvements that can be made.

Combining these key elements within the workplace will insure that all possible health hazardous be identified and quantified, in order to implement and provide proper controls to lower or eliminate exposures that may cause irreversible health effects.

2.2. AIRBORNE CONTAMINANTS

Airborne contaminants are defined as any substance that can cause harm to humans and/or the environment. They are grouped according to their physical properties and include dust, fumes, mists, gases and vapours.^{5, 6}

2.2.1. Dust

The MHSA defines dust as finely divided solids that may become airborne from the original state without chemical or physical changes other than fracturing.⁷

These solid particles are generated by handling, crushing, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rock, ore, metal, coal, wood and grain.

Air resistance hinders the free fall of the particles. The air resistance is determined by the density and viscosity of the air as well as the aerodynamic size and speed of the falling body. For instance a 1µm particle falling from 2 metres above the ground will take 10 hours to settle onto the floor, while it will take a 100 µm particle five seconds to reach the ground.²

The human eye can detect dust particles as small as 50 µm in diameter. Smaller particles can only be seen when sharp light is deflected from them and respirable dust can only be seen with a microscope. During industrial processing there are usually more invisible than visible particles present in the air.²

Determining the actual exposure to dust is complex. It requires knowledge of the chemical composition and particle size of the dust, the dust concentration in the air, exposure time and how it is dispersed.⁶

It can be concluded that dust that remains in the air long enough to be inhaled should be treated as a health hazard until it has been proven otherwise.

2.2.2. Fumes

Fumes are solid particles generated when a volatile solid such as metal condenses in cool air. This physical phase change is usually accompanied by a chemical reaction such as oxidation. The particles formed are extremely fine with an aerodynamic diameter of less than $1.0\mu\text{m}$. Such fumes, because they are so fine, are readily inhaled during operations such as welding or metallizing and operations involving vapours from molten metals.⁸

2.2.3. Mists

The term mist is applied to a translucently divided liquid suspended in the air. These suspended liquid droplets are generated by the condensation of liquids from the vapour phase back to a liquid state, for example while splashing, foaming or atomizing.⁷

2.2.4. Gases

Gases are formless diffusing fluids that expand to occupy the containers or spaces in which they are confined. Gases can be transformed back to a liquated state only by the combined effect of increased pressure and decreased temperatures.⁹

2.2.5. Vapours

Vapours are gaseous forms of substances that can be transformed to the liquid phase either by increasing the pressure or decreasing the temperature. Vapours can diffuse in the air or into any other gas.⁸

2.3. RESPIRATORY HAZARDS

Respiratory hazards are defined as any concentration of a substance that can lead to damage or lowering of the functionality of the respiratory system.¹⁰ Respiratory hazards can be broken down into two environmental groups, namely oxygen-deficient concentrations and air containing hazardous or toxic contaminants. Each

living cell requires a constant supply of oxygen. Some cells can survive without oxygen for longer periods, but the cells of the brain and heart may die after four to six minutes without oxygen.¹¹

The oxygen deficient concentrations are also known as Immediately Dangerous to Life and Health (IDLH). This results from an oxygen deficient environment (less than 19.5%) or air containing high levels of toxic gases. Air is considered IDLH when a person will not be able to escape unprotected without suffering fatal or serious injury after just a few minutes of exposure.¹²

The air containing high levels of toxins are considered not IDLH, but contain certain airborne contaminants that may cause adverse health effects consisting of irritation, discomfort and irreversible effects. These health effects are a result of repeated exposure to contaminants for a prolonged period. In some cases the hazardous substance cannot be seen, smelled or tasted and causes little or no immediate health effects; however, over time it may cause chronic diseases.¹²

2.3.1. Respiratory systems

Airborne dust and fume particles with an aerodynamic diameter of up to 100 μm can be inhaled and small particles can be deposited into the deeper regions of the respiratory system.¹³ Figure 2.1 shows the basic anatomy of the respiratory system.

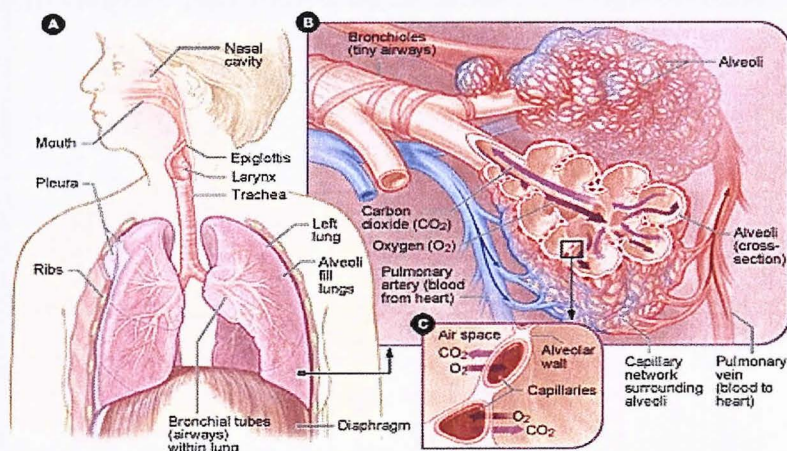


Figure 2.1: Human respiratory system. A shows the location of the structure of the respiratory system. B: Enlarged image of the airways, alveoli and capillaries. C: location of gases exchanged between capillaries and alveoli.¹⁴

CHAPTER 2

LITERATURE OVERVIEW

The respiratory system is divided into an upper and lower respiratory tract. The upper region consists of the nasal cavity, pharynx and larynx. The lower region includes the trachea, bronchi and lungs.¹⁴

Each of these structures contributes to the normal respiration and the breathing process. To survive, the respiratory system has to be reliable, sustained and efficient even when faced with diseases or any unfavourable environment. Structurally and functionally, the respiratory system can only counteract exposure to airborne contaminants to some extent; penetration will depend on the aerodynamic size, shape and solubility of the contaminant.¹⁵

The upper respiratory zone starts with the nose and is functionally designed to counteract the intake of contaminants. However, inhalation sometimes takes place through the mouth, especially during vigorous exercise when more oxygen is needed by the rest of the body. The main function of the nasal passage is to filter, warm and moisten the inhaled air and for resonance during speech. The air enters through the nares or nostril, moving towards the nasopharynx. The nasopharynx opens into the oropharynx. The air entering the oropharynx passes onto the laryngopharynx and empties into the larynx. The air continues past the glottis and down into the trachea.^{14, 16}

The lower respiratory zone starts with the trachea, which divides into the left and right bronchi. The bronchi divide into smaller bronchioles, which lead to the respiratory area of the lungs consisting of the respiratory bronchioles, alveolar ducts and alveoli. Most of the gas exchange occurs in these multi-lobulated sacs.¹⁶

The nasal passage is the first line of defence against particles entering the respiratory system. Some particles are removed through impaction onto the nasal hairs, through bends in the pathway or sedimentation. All the walls of the nose are covered with mucous membranes that secrete a fluid called mucus. The mucus contributes to providing heat and moisture to the incoming air but also serves as a trap for bacteria or dust and dilutes any irritating substance in the air. In addition, the mucous membrane is lined with cilia, which are hair like filaments that propel mucus and trapped particles towards the nostril by wavy movements.¹⁷

The ciliated mucous lining continues to the nasal cavity. Directly beneath the mucosa lies a collection of lymphoid tissue called the adenoids. The adenoids together with the tonsils form an important part of the immune system and are the body's first defence against infection. In some cases, particles are not effectively removed by these mechanisms and a process called phagocytosis ensues, during which particles are taken up by cells called macrophages. The macrophage transports particles out of the respiratory tract. Particles are effectively removed by these mechanisms unless the system is overloaded or the particles have a fibrous shape and cannot be internalized completely, or when factors like smoking limit the clearing process.^{16, 17, 18}

2.3.2. Deposition of particles

Inhaled particulate matter is classified in terms of particle size. Particle size in turn defines the deposition region of the inhaled particulate matter. The respiratory system is divided into three regions where particles are deposited.¹⁹ Table 2.1 indicates the deposition regions of airborne contaminants within the respiratory system according to their aerodynamic diameter.

Table 2.1: Deposition of particles within the respiratory system

Respiratory region	Particle size in μm
Nasopharyngeal (inhalable particles)	Up to 100 μm .
Tracheo-bronchial (thoracic particles)	Up to 30 μm .
Alveolar (respirable particles)	Up to 10 μm .

During inhalation, large particles with an aerodynamic diameter of around 100 μm are mostly deposited into the nasopharyngeal airways. The remaining particles move deeper into the respiratory system towards the tracheo-bronchial region. Smaller particles with a diameter up to 10 μm will enter the alveoli region of the lungs.²⁰

2.4. EXPOSURE LIMITS

Exposure limits are intended to protect workers from excessive exposure to hazardous substances.²¹ Exposure limits set by the health and safety authorities are based on the penetration ability of particles and the effects they may have within the respiratory system. The statistical correlation between high levels of inhalable particulate matter and increased morbidity or mortality has been widely reported. Occupational hygiene monitoring is dependent on these three deposit fractions and sampling methods are designed according to the inhalable, thoracic and respirable dust fractions.

The exposure limits are established by the health and safety authorities in South Africa according to Regulation 22.9(2) (a) of the Mine Health and Safety Act (Act No. 29 of 1996) and the Regulation for Hazardous Chemical Substances (HCS) of the Occupational Health and Safety Act (Act No. 85 of 1993) (OHSA).^{1, 22, 23}

These limits define the concentration to which workers may be exposed to without adverse health effects. The concentrations in the tables are expressed in either parts per million (ppm) or milligram per cubic metre (mg/m³). The exposure limits provided by both the MHSA as well as the HCS regulations are defined in the sections that follow.^{1, 22, 23,}

2.4.1. Occupational exposure limits (OEL-REL)

Each substance has a tolerance level of exposure to which workers can be exposed without causing irreversible health effects. The OEL means the time-weighted average concentrations for an 8-hour workday and 40-hour workweek to which almost all workers can be repeatedly exposed without adverse health effects.

2.4.2. Occupational exposure limits – short-term exposure limit (OEL-STEL)

The OEL-STEL is the maximum concentration to which workers can be exposed continuously for a period of up to 15 minutes without adverse health effects.

2.5. PLATINUM PROCESSING INDUSTRY

Throughout history, humankind has strived to master and improve the utilization of the earth's resources. During mining operations in the Bushveld Complex in 1924, Andries Lombaard found evidence of platinum on the farm Maandagshoek. This led to exploration in 1929 and the famous discoveries by geologist Hans Merensky.²⁴

The Merensky Reef has traditionally been the most important platinum-producing layer in the Bushveld Complex. Today the world's primary producers of platinum still extract PGM from the Merensky and Upper Group (UG2) chromitite layer reef. In 2006, South Africa's known reserve base of PGM represents 87.7% of the world's total and is extracted almost exclusively from the Bushveld Igneous Complex.²⁴

2.5.1. Platinum Processing

The study was conducted at a leading platinum processing plant located within the Rustenburg region. Platinum processing consists of various divisions and for the purpose of the study each sampling area will be discussed briefly to provide a broad overview of work activities and the exposure that may occur within the smelter and BMR.

2.5.1.1. Smelter

The main objective of the smelter is to process wet concentrate to produce crushed, slow-cooled, sulphur-deficient nickel-copper matte rich in PGM, gold and base metals that are then dispatched to the magnetic concentration plant (MCP) at the BMR. At the smelter, moisture is removed from the wet concentrate, producing a dry furnace stock with less than 0.5% H₂O.²⁵ The energy for this process is provided by burning coal in a fluidized bed combustor called a hot gas generator (HGG). The wet concentrate is delivered by road to the concentrate-receiving shed. From the shed, the concentrate is conveyed to the back mixer that breaks up the incoming material while blending it with dry material. The back mixer discharges to the disintegrator, where impeller blades break up lumps and mix them with hot gas. The hot gas evaporates the water and the concentrate is

CHAPTER 2

LITERATURE OVERVIEW

carried up a 40 meter drying column. At the top of the column the dry concentrate is separated from the gas by primary cyclones. The gas passes through many small cyclones and the cleaned gas is vented into the atmosphere. The concentrate is mixed with limestone and the final blend is pneumatically transferred to the feed bins at the electrical furnace.^{26, 27}

The rectangular furnaces have an internal dimension of 8.0 x 25.8 m and accommodate six electrodes each. On a daily basis, 300 kg paste blocks are being loaded into the electrode column of the furnace. Energy is generated in the furnace when an electric current passes through the electrodes and melts the concentrate to form two liquid phases. The lime blended with concentrate acts as flux, causing the formation of slag. The matte contains most of the base metal sulphide and platinum group metals. It is denser than the slag and settles to the bottom of the furnace while the slag layer contains most of the oxides and floats on top.²⁸

Furnace matte is tapped into matte ladles and transported by crane to two granulation stations. The ladle is placed on a hydraulically driven tilter that pours the matte into a granulated launder. The launder discharges above a stream of granulated water that shear-quenches the matte, forming fine particles suitable for dry feeding into the converter. This slurry is pumped to dewatering bins, where it is gravity dewatered before being discharged onto a conveyor with a moist level of less than 10%. The damp matte is then dried by pneumodriers by means of hot air (350 °C) to less than 0.5% H₂O. The material is then discharged into a silo ahead of the converter.^{27, 28}

The converter is a top-blown furnace where granulated matte is continuously fed through the lance that submerges into the slag layer. Air and oxygen are also injected into the slag where it reacts with furnace matte at high temperature. Temperature is controlled at 1300 °C. Oxidation of iron sulphide converts the matte from approximately 40% to 3.5% iron. Silica flux is injected to encourage formation of fayalitic slag.²⁸

The converted matte is tapped into matte ladles and moved to the slow-cooling aisle. The matte then poured in a bottom-cast ladle that cascades into a refractory-lined mould. The mould is covered with an insulating lid, which slows down the cooling process. This slow cooling process allows enough time to elapse in the critical temperature range for fractional crystallization. During this process, metal alloy crystallizes out as a distinct phase. After removing the matte from the moulds it is broken up and crushed for further treatment at the MCP.^{25, 28}

2.5.1.2. Base metal refinery

In the base metal refinery, matte is converted to a precious metal concentrate and quality base metal products. Converted matte from the smelters containing magnetic PGM fractions is removed at the MCP and sent to the PMR while the remaining material is treated at the BMR to recover nickel, copper, cobalt and sodium sulphide crystals. At the tank house high quality nickel metal is plated on cathodes by the reduction of Ni^{2+} ions in the pure nickel feed received from the leach and purification plant.²⁵

2.5.1.3. Tank house

The nickel tank house consists of 168 cells of which 164 are normally in circuit. There are 90 cells on the east bay and 78 on the centre bay, of which 46 are for production and 32 are starters. Each cell contains 41 anodes and 40 cathodes. A common manifold to each cell supplies feed to each cathode bag via bag feed pipes; the flow is regulated by capillary tubes. Labour-intensive operations of starter and production sheets include manual handling of sharp-edged sheets and working with solutions with high sulphuric acid contents.²⁹

- **Nickel starter cell pulling and stripping**

Starter cells are pulled on a two-day cycle. The sheets are stripped, trimmed and treated as starter sheets in the nickel production cells. During the pulling process, a crane is used to lift 10 starter blanks slowly and carefully from bag frames to about 30 cm above the cell. The crane then transports and lowers the blanks into the wash cell

to wash off excess solution and crystals. When the starter blanks are clean, they are moved to the stripping rack where the cell operator loosens the top corners of the sheet using a screwdriver forcing the sheet away from the blank. The sheet are then sorted and stacked neatly. The blank sheets are then washed, cleaned and transported back to the cell, where they are inserted into the bag frames.²⁹

- **Nickel production cell pulling and stripping**

Nickel production cells are pulled on a six-day cycle. Prior to pulling, a fault check is done on each cell. The crane transports the bailer to the cell until about 10 cm above the cathodes to be pulled. The cathodes are lifted from the frame and transported into the wash tank. The starter crane lowers the bailer above holding cell, and then lifts the starter sheet from the cell. The starter sheet is then transported to the cell being pulled and lowered to approximately 20 cm above the cell. Two cell workers insert the starter sheet into the empty bag frames from which the cathodes had been pulled. This process is repeated until all the production cathodes are place in the wash tank. When pulling is completed the crane lifts the cathodes from the wash tank and transports them to the drop-out well onto the receiving bay of the basement. Production cathodes pulled from cells are stacked onto pallets and sent to the packing and transport department to be prepared for marketing.²⁹

In the attempt to unlock the full potential of the earth's abundant resources, people are exposed to occupational health hazards including chemical, physical, ergonomic and biological hazards. Workers in the platinum processing industry are exposed to various airborne contaminants. For the scope of this study the focus is on soluble and insoluble nickel, sulphur dioxide and coal tar pitch volatiles. These are all produced to a greater or lesser extent during the processes that take place in the platinum smelter and base metal refinery. Each of these materials is described briefly in the next sections.

2.6. NICKEL

Nickel was discovered by Axel Fredrik Cronstedt in 1751 in Sweden. The name originated from the German word "kupfernickel" meaning Devil's copper or Old Nick.³⁰

CHAPTER 2

LITERATURE OVERVIEW

The earth's core is composed out of 6-8% nickel and it is the 24th most abundant element. Nickel is classified amongst the transitional metals on the periodic table. Pure nickel is a white, silvery metal with properties that makes it very desirable for combining with other metals such as iron, copper, chromium and zinc to form mixtures called alloys. When nickel binds to other substances such as chloride, sulphur, and oxygen, it is usually water-soluble with a characteristic green colour and no characteristic odour or taste.³¹

In South Africa, most of the nickel and copper deposits were discovered in the Merensky and Upper Group Chromitite layer (UG2) reefs of the Bushveld Igneous Complex in the Rustenburg district. Nickel and copper are removed to produce a high quality platinum concentrate, with nickel and copper being valuable by-products.²⁴

Industrially, nickel is released into the environment from the stacks of furnaces used to make alloys, power plants and trash incinerators. Nickel and its components are used in paint colouring, steel, jewellery, and battery production. Occasionally, nickel is used as a catalyst that increases the rate of chemical reactions. Exposure to nickel occurs during primary and secondary processing.^{31, 32}

Nickel attaches to small particles of dust and either settles to the ground or is taken out of the air by rain. Nickel can remain in the atmosphere for days. If attached to very small particles nickel would take months to be removed from the atmosphere.³¹

Nickel can enter the human body through ingestion, skin contact and inhalation. Organs that can be affected include those of the respiratory system, the immune system and the haematological system.³³ The main negative health effects occur during the inhalation of airborne nickel. Excessive exposure to nickel may lead to certain health effects, such as irritation of the nose, throat, skin, eyes, allergy-related asthma, shortness of breath, and chest tightness.³⁴ Epidemiological studies have shown that occupational exposure to nickel is strongly associated with high incidences of human lung and nasal cancers.³⁵

The toxic effects of nickel depend on its solubility and particle size. Based on water solubility, nickel can be categorized as soluble (nickel sulphate) and insoluble (nickel sulphide). Soluble nickel is more toxic to the respiratory tract than the insoluble compound, because its solubility increases exposure and results in asthma, decreased lung function and bronchitis.³¹

However, studies have also revealed that both insoluble and soluble nickel can be taken up into the cells and enter the nucleus after a long exposure period. Nickel (II) chloride is largely used in industrial processes such as electroplating and steel and battery manufacturing. Studies have shown that even though it is a weak mutagen, nickel (II) is able to significantly enhance the genotoxicity of other mutagens and carcinogens such as polycyclic aromatic hydrocarbon (PAH) and ultraviolet light.³⁶

Skin contact with nickel can cause skin sensations and is one of the most potential skin sensitizers that may develop into allergic dermatitis. Contact dermatitis accounts for 80% of all occupational skin diseases. Penetration through the skin may be enhanced through sweating, the presence of solvents and detergents, occlusion and gloves.³⁷

2.6.1. Short-term exposure

Acute exposure to soluble nickel compounds through the skin may result in an allergic rash or "nickel itch" characterized by eruptions on the skin of the hands and arms. It occurs most frequently when the skin is moist. Sensitized individuals may also experience asthma. Exposure to large amounts results in nausea, vomiting or diarrhea.^{31, 38}

2.6.2 Long-term exposure

Chronic exposure results in severe allergic reactions of the skin, eyes or respiratory tract. Eczema and fungal infections of the skin, loss of smell, difficulty in breathing, reduced lung function, coughing, nasal inflammation, asthma or bronchitis may be evident. Excessive exposure over a long period may even lead to respiratory tract, lung and nasal cancer. Nickel sulphide, nickel oxide and metallic nickel are

carcinogenic to humans and workers heavily exposed to these substances may contract lung and nasal cancers.^{31, 38}

2.6.3. Occupational exposure limits (OEL)

In terms of the Mine Health and Safety Act, No. 29 of 1996, the recommended exposure to soluble and insoluble nickel is an OEL-TWA of 0.1 ppm for soluble nickels and 0.5 ppm for insoluble nickels.¹

2.6.4. Control measures

Because of the carcinogenic effects of nickel, process controls through enclosing methods are mandatory. Refining processes including nickel carbonyl should be completely enclosed, preventing any exposure. Workers handling nickel should be provided with proper protective equipment including respiratory protective devices, gloves, chemical resistant clothing, and chemical safe goggles. Workers should be encouraged to wash their hands before eating or drinking.

NIOSH recommends the following respiratory devices:³⁹

- Concentrations up to 0.25 mg/m³: Any dust and mist respirator with an approved protection factor (APF) of APF=5.
- Concentrations up to 0.5 mg/m³: Any dust, fume and mist respirator or air supply respirators except single-use and quarter mask respirators can be used. An APF=10 is recommended.
- Concentrations up to 1.25 mg/m³: Any supplied air respirator in a continuous flow mode. Any power air-purifying respirator with dust, mist and fume filters with an APF=25.
- Concentrations up to 2.5 mg/m³: Any air-purifying, full face piece respirator with a high particle filter. Any self-contained breathing apparatus with a full facepiece. Any supplied air respirator with a full facepiece. APF=50.
- Concentrations up to 20 mg/m³: APF=2000 is recommended. Any supplied air respirator that has a full facepiece and is operated in a pressure demand or other positive pressure mode.

The IARC has classified most nickel sulphates and the combination of nickel sulphates and oxide compounds found in the refinery industry as carcinogenic to humans.^{41, 42} Therefore all possible controls measures should be set in place ensuring that exposures to nickel are kept minimal.

2.7. SULPHUR DIOXIDE

SO₂ gas is produced as a by-product during the platinum smelting and converting process. Industries that entail exposure to SO₂ include mining, ore smelting, coke ovens, foundries, ore refining and power generators. Sulphur dioxide is a colourless gas with a pungent, irritating odour that forms from the combustion of coal and oil. Oxides of sulphur are corrosive and are produced when sulphur-containing fuels are burned. When released into the air, SO₂ can be converted to sulphuric acid, sulphur trioxide and sulphates.⁴²

Occupational exposure to the human body occurs via inhalation, skin and eye contacts. Target organs are the eyes, skin and respiratory system.⁴⁴ SO₂ is known as an acid gas and is water soluble. When reacting with moisture on the skin or other moist surfaces of the human body, it forms sulphuric acids. Sulphuric acid irritates the respiratory tissue and has the ability to protonate (H⁺) receptor ligands and other biomolecules. This damages membranes directly and activates a sensory reflex that initiates inflammation. Small particles can penetrate the lungs, reaching receptors that stimulate bronchoconstriction and mucus secretion. Sulphuric acids alter the clearance of particles from the lung and thus interfere with the major defence mechanisms of the human body.⁴⁴

2.7.1 Short-term exposure

Acute exposure to SO₂ will cause irritation (burning, stinging and watering) of the eyes, nose, mouth and other parts of the respiratory tract. In the main, SO₂ will only penetrate as far as the nose and throat with minimum amounts reaching the lungs except during heavy breathing. Concentrations of 6–12 ppm cause immediate

irritation to the nose and throat, while 0.3-1 ppm can be detected by the average person, probably by taste rather than smell.⁴³

Exposure to 50 ppm is so objectionable that a person would not be able to inhale a single breath. Acute high concentrations in confined spaces cause severe airway obstruction, hypoxia, pulmonary oedema and death in minutes. Permanent lung damage may occur after severe exposures. The American Industrial Hygiene Association (AIHA) states that the maximum exposure to 50-100 ppm is 0.5 ppm or 1 hour. This atmospheric concentration is immediately hazardous to health. A concentration of 400-500 ppm is dangerous for an even shorter period and evacuation should take place within minutes.⁴³

2.7.2. Long-term exposure

Chronic exposure to SO₂ increases the chance of respiratory infection that may occur within the lungs. After a long period of exposure, the smell receptors become damaged and result in an altered sense of smell, including an increased tolerance of low levels of SO₂. Occupational diseases such as chronic bronchitis, emphysema and asthma are caused by repeated exposure. Adverse health effects like short-term respiratory mobility and mortality can be caused by long-term lower level exposure.⁴⁵

2.7.3. Occupational exposure limits (OEL)

Mine Health and Safety Act, No. 29 of 1996, the OEL-TWA of 2 ppm is prescribed for exposure to airborne sulphur dioxide.¹

2.7.4. Control measures

In areas where the TWA-OEL concentration exceeds 2 ppm, the area should be classified as a respiratory zone and demarcated by appropriate safety symbol signs. Wearing respiratory protective devices is mandatory. Possible engineering control measures should be investigated to prevent exposure and elimination at the

CHAPTER 2

LITERATURE OVERVIEW

source. The use of ventilation extraction systems and at-source extraction hoods with a capture velocity of at least 0.75 m/s is recommended.

If engineering methods have been applied to the full extent and still do not provide the required control, the use of respirators should be considered.

NIOSH recommends the following respiratory devices:³⁹

- Up to 20 ppm – APF=10. Any chemical cartridge respirator providing protection against the compound of concern.
- Up to 50 ppm – APF=25. Any supplied air respirator operating in continuous flow mode. Any power air-purifying respirator with cartridges providing protection against compounds of concern.
- Up to 100 ppm – APF=50. Any chemical cartridge respirator with a full facepiece and cartridges providing protection against compounds of concern. Any air-purifying with cartridge with a chin facepiece with front or back mounted canister providing protection against the compound of concern. Any air-purifying, tight-fitting full facepiece and cartridge respirator providing protection against compounds of concern. Any self-containing breathing apparatus with a full facepiece. Any supplied air respirator with a full facepiece.
- IDLH environments – APF 10 000. Any self-contained breathing apparatus that has a full facepiece and operated by a pressure demand or other positive pressure mode

The IARC has classified SO₂ as a Group 3 substance, in essence stating that it is not classifiable as a human carcinogen. Although SO₂ is not seen as a carcinogenic substance, it can still cause irreversible health effects or even fatal consequences. All possible exposure should be minimized and control measures should be set in place.

2.8. COAL TAR PITCH VOLATILES

Coal tar pitch volatiles (CTPVs) are composed of various chemicals that become airborne during the heating of coal. are the fused polycyclic hydrocarbons that

volatilize from the distillation residue of coal, petroleum and wood. Coal tar pitch is a black or brown soft to hard and brittle substance containing chiefly aromatic resinous compounds along with aromatic and other hydrocarbons and their derivatives; it is used as road tar, in waterproofing roofs and other structures, and to make electrodes.⁴⁶

NIOSH considers coal tar, coal tar pitch, and creosote all to be coal tar products. vary depending upon the specific compounds and include benzene, toluene, phenols, styrene, creosol, naphthalene and numerous aromatic hydrocarbons (PAHs), which can become airborne when heated. These hydrocarbons sublime readily, thereby increasing the amount of carcinogenic compounds in the working area.⁴⁷

Target organs include the respiratory system, skin, bladder and kidneys. Exposure normally occurs through inhalation and skin or eye contact. Epidemiological evidence suggests that workers that are intimately exposed to the products of combustion or distillation of bituminous coal are at risk of cancer. This includes cancers of the respiratory tract, kidney and skin. Both the length of exposure and intensity of exposure lead to mortality from cancer of the lungs, bronchi and trachea. Coke oven emissions have also produced positive results in mutagenicity studies.⁴⁸

2.8.1. Short-term exposure

Acute exposure to CTPVs is irritating to the eyes, the skin and the respiratory tract. Exposure to the sun may enhance the irritating effect of coal tar pitch on the skin and eyes and lead to burns.

2.8.2. Long-term exposure

Chronic exposure to coke oven emissions in humans results in conjunctivitis, severe dermatitis, and lesions of the respiratory and digestive systems. The IARC has classified the coal tar pitch volatiles as a Group 1 carcinogen.^{39, 40}

2.8.3. Occupation Exposure Limits (OEL)

The Mine Health and Safety Act, No. 29 of 1996, prescribe an OEL-TWA of 0,14mg/m³ for exposure to CTPVs.¹

2.8.4. Control methods

It is good industrial hygiene practice to make use of engineering methods to lower exposure limits. These methods include process enclosure, local exhaust ventilation, and general dilution ventilation. If these engineering methods are not technically feasible, respiratory devices should be provide together with personal protective clothing, for example impervious clothing, gloves and face shields. NIOSH recommends the following respiratory devices:³⁹

- Up to 2 mg/m³: APF=10 000. Chemical cartridge respirator with an organic vapour cartridge with a fume or high efficiency filter. Any air supplied respirator. Any self-contained breathing respirator.
- Up to 10 mg/m³: APF=10 000. Chemical cartridge respirator with a full facepiece and organic vapour cartridges with a fume of high efficiency filter. A gas mask with chin style or a front of back mounted organic vapour cartridge with a fume or high efficiency filter. Any air supplied respirator with full facepiece. Any self-contained breathing respirator with full facepiece, helmet or hood.
- Up to 200 mg/m³: APF = 10 000. Type C air supplied respirator with pressure demand, positive pressure or continuous flow.
- Up to 400 mg/m³: APF=10 00. Type C supplied air supplied respirator with a full facepiece operated in pressure demand or other positive pressure or continuous flow.

CTPVs are highly toxic to the humans with fatal consequences; therefore it is critically important that any possible control measure be set in place in an attempt to lower daily exposures.

2.9. RESPIRATORY PROTECTION DEVICES

Functionally, respiratory protection devices are designed to cover the nose, mouth or the entire face and head. They are based on two basic designs: purifying the air by removing contaminants or providing clean air from an uncontaminated source.⁴⁹

The purpose of any respiratory protection device is to ensure that employees are protected from excessive inhalation of hazardous airborne contaminants in work areas where exposure cannot be minimized through engineering and administrative control measures. Respiratory devices are being used throughout the mining and private industries and provide effective and relatively inexpensive protection. However, these devices should be used in conjunction with engineering and administrative control measures and should not be seen as a primary or single solution to lower exposures. The control hierarchies of prevention, control and personal protection should be applied in any situation.²

2.9.1 Historical background

The concept of respirators dates back to the Roman Empire when Pliny discussed the idea of using loose-fitting animal bladders in the mines to protect the workers from inhalation of red oxide of lead.⁵⁰

The earliest, most primitive form of device was nothing more than a bag-like screen placed over the head or a piece of cloth or sponge that covered the nose and mouth. In 1847, Lewis P Haslett invented the first gas mask that allowed breathing through a mouthpiece or nosepiece fitted with two one-way clapper valves. In 1854, John Stenhouse devised the first "active" charcoal filtering respirator, a concept that is still being used today as filtering medium for various vapours.⁵¹

The first fire-fighter's hood was invented in 1871. It consisted of a valve chamber and filter, screwed onto the outside of the respirator. During the late 1800s, the cup-shaped masks came into widespread industrial use. In 1890, Benjamin Lane of Massachusetts received the first known patent for a respirator with a compressed

air supply. These devices allowed the wearer to enter buildings filled with smoke or impure air, sewers, mines and wells, protecting the person from suffocation.⁵⁰

Because of the chemical warfare during World War I the improvement of respirators became essential and in 1930 the first resin-impregnated filter with low breathing resistance and moderate dust-loading characteristics was designed.⁵⁰

Since then scientists have continued to strive to produce respirators that provide adequate protection without imposing unacceptable discomfort on the user.

2.9.2 Modern respiratory devices

Modern respirators are still based on the two basic principles, either lowering or removing the contaminant before it reaches the breathing area, or providing clean air from an uncontaminated source.⁵⁰

Each device has its own design, specifications and applications. Respirators are available in a variety of shapes and sizes to fit various facial structures, ensuring that personal wearer preferences can also be met. Identifying the type of health hazard, toxicity, work activities and the duration of exposure related to the task at hand are all factors that determine the selection of a specific respirator. Therefore, respirator selection must be based on an exposure assessment relevant to the workplace and user factors.⁵²

2.9.3 Respirator classification

Respirators are functionally classified in two categories. The first category consists of air-purifying devices that purify air through mechanical or chemical means by forcing contaminated air through a filtering medium. They can only be used in an environment with sufficient oxygen to support life.⁵³

These devices are grouped into three general types, viz. particulate, vapour and gas removing or a combination. The functional part of the air-purifying portion is the

filters or cartridges. Filters are elements that remove the solid or liquid aerosols, while chemical cartridges or canisters remove vapours and gases.^{50, 53, 54}

Secondly, the atmosphere-supplying respirators receive a limited supply of oxygen from a source independent of the ambient atmosphere. These devices are classified according to the way the air supply is regulated. They range from self-contained breathing apparatus where the air or oxygen is carried on the worker's back, to supplied air respirators where air is supplied through a high-pressure hose from a stationary source to the respirator. A combination of both types is also available.^{50, 53, 54}

Both types of respirators can be sub-classified by a type of inlet covering and mode of operation. The respiratory inlet covers form the framework of the respirator and serves as a barrier element against airborne contaminants.⁵⁴

2.9.3.1. Tight-fitting respirator

Tight-fitting respirators, better known as a facepiece, are mostly made of flexible moulded rubber, silicon, neoprene or similar materials. The head straps are made of incorporated rubber or woven elastic and buckle together at the back of the head or form a continuous loop of material.⁵⁴

The first type is the quarter mask, which covers the nose and mouth forming a seal between the chin and mouth. Quarter masks provide good protection and are commonly used as dust and mist respirators. The only concern is that these masks dislodge easily, with the risk of possible exposure during use. A second type, the half mask, also covers the nose and mouth but seals underneath the chin. These masks form a better seal and are therefore used for more toxic substances.⁵⁰

Lastly, the full-face masks cover the whole face from the hairline to below the chin. The seal is the most reliable, and the mask provides the best protection which includes eye protection. These masks are used during higher concentrations of toxic substances.⁵⁰

2.9.3.2. Loose-fitting respirators

Loose-fitting respirators generally cover the whole face and include hoods, helmets, blouses or full suits. A flexible device covering only the head and neck, or the head, neck and shoulders, is called a hood. When protective headgear is incorporated into the design, it is called a helmet. Blouses extend down to the waist and some have wrist-length sleeves. These types of respirators include an enclosed system through which clean compressed air is distributed around the breathing zone.⁵⁰

2.9.4. AIR-PURIFYING RESPIRATORS

The air-purifying devices cleanse the atmosphere through an air-purifying element. This class includes negative pressure respirators using mechanical filters or positive pressure units with chemical media.⁵⁰

2.9.4.1. Particulate filtering respirator

Particles are drawn in or onto the filter and trapped by the fibres. There are two types of particulate filters, viz. absolute and non-absolute filters. Absolute filters exclude particles that are larger than the pores through screening. These filters have very small pores and therefore have a high breathing resistance. Non-absolute filters are more commonly used throughout the industry. These filters have larger pores and particles are captured and removed by a filtration mechanism.⁵³

During inhalation, the particles collect on the filter, causing a decrease in the openings in the fibre. This causes higher breathing resistance, but the filter also becomes more efficient. This poses as a huge challenge for manufacturers to produce a respirator with the most efficient filter but with the lowest breathing resistance.⁵⁴

CHAPTER 2

LITERATURE OVERVIEW

However, other factors such as particle size to the relative fibre size, velocity, composition, shapes and the electro-charge of both the particle and fibre also determine the probability of the particle being retained within the fibre. These respirators can only be used in an atmosphere where there is sufficient oxygen available to support life.⁵⁵

Aerosol-removing devices provide protection against dust, fibres, mists and fumes, but not against gases, vapours or an oxygen-deficient environment. They are designed for different types of aerosols, and differ in filter efficiency and service life. Disposable respirators are mostly fully composed out of the filtering medium, or the filter forms a permanent part of the respirator, for example the dust mask.⁵⁶

There are five types of filtration mechanisms that works together to form the functional part of the filter, namely interception capture, sedimentation, impaction, diffusion and electrostatic capture. Each mechanism's contribution depends on the flow rate and particle size.^{54, 56, 57}

- **Interception capture**

During interception capture, particles do not deviate from their original airstreams. When the airstreams approach a fibre perpendicular to their pathway, they split and compress in order to go around the obstacle. Particles then are caught when the particle passes the fibre and the centre of a particle comes within a one-particle radius of the fibre's surface. The airstreams rejoin on the other side of the fibre. It is known that when the size of the particle increases, the probability of interception also increases.^{53, 54}

- **Sedimentation capture**

Sedimentation capture consists of capturing particles through gravity. Particles that cannot change direction when the airstreams split, are captured during impact on the surface of the filter. The size, density, speed and shape determine the inertia of the

particle. This mechanism is most effective on particles larger than 3 μm , and with a low flow rate through the filter.⁵⁶

- **Diffusion**

Only the smallest particles are captured through diffusion. Air molecules collide with particles, causing them to move randomly across the airstreams and ultimately come in contact with the fibre. When the flow rate is slower, the particle spends more time in the area of the fibre, increasing the chance of being captured. Smaller particles also have a higher diffusion activity than larger particles.⁵⁶

- **Electrostatic capture**

Electrostatic capture functions as a support system to all other capturing mechanisms. When the particles and fibres have opposite charges, the particles become attracted to the fibre.⁵⁴

It can be concluded that various factors determine the contribution of each filtering mechanism, but some common factors can be identified. Diffusion effectively removes small particles with size below 0.1 μm , while large, heavy particles with sizes above 0.6 μm are mostly trapped by interception, sedimentation or inertia impact. However, impaction and diffusion mechanisms are unable to effectively remove particles with a range of between 0.1 μm and 0.6 μm , which is called the "most penetrating particle size".

Generally, most respirator filters have a most penetrating particle size of 0.2 μm and 0.4 μm . For example, the penetration at the most penetrating particle size is five per cent. However, at 1 μm the penetration is only one per cent. Therefore, the filtration efficiency in the workplace of any particle outside the most penetrating particle range is almost 100 per cent.⁵³

This information is used during the manufacturing process and compromises should be worked out for each filter classification with respect to filter surface area, breathing resistance, filter efficiency to specific particle sizes and service life.⁵²

CHAPTER 2

LITERATURE OVERVIEW

There are three predominantly used types of filter. The most common type is a machine-made flat disk of randomly laid non-woven fibre material. The second type is also a flat disk, made of compressed wool or synthetic fibre felt, or a combination of both. During manufacturing, the material is impregnated with a resin and mechanically beaten, creating an electrostatic charge. This charge increases the filter's efficiency. These filters are readily identified by a slightly sticky feeling on the fingers after rubbing the filter between the fingers and then rubbing the fingers together.⁵³

The third type of dust filter contains a filter medium that is loosely packed in the filtering container, which makes it much thicker than the compressed types. Generally, these filters are made of fibrous glass and sometimes non-felted resin-impregnated natural wood.

Most high-efficiency dust, fume and mist filters consist of a flat sheet of material that is pleated and placed in the filter container. Pleating increases the filter surface, lowers breathing resistance and improves the filter loading.⁵⁴

In 1998, NIOSH introduced a new requirement for particulate filters and the 30 CFR 11 regulations were replaced by the 42 CFR 84 filter classes regulation. This new regulation provides better protection against all particle sizes in the workplace but only applies to non-powered air-purifying particle filter respirators.⁵⁸

The part 84 certification regulations provides for nine classes of filters with three levels of efficiency and three categories of resistance to a filter efficiency degrading. The three levels of efficiency are 95%, 99% and 99.97%. The three categories of resistance to a filter efficiency degrading are labelled N (not resistant to oil), R (resistant to oil) and P (oil proof). Each of these respirators is certified by the NIOSH. Table 2.2 summarises the filter classes certified by 42 CFR 84.^{52,55,58,59}

Table 2.2: Description of filter classes certified by 42 CFR 84

Class of contaminant filter	Efficiency (%)	Test agent	Type of contaminant filter
N-SERIES			
N 100	99.7	0.3 µm NaCl aerosol	Is restricted to solid and waterbased aerosol not containing oil.
N 99	99		
N 95	95		
R-SERIES			
R 100	99.7	0.3 µm DOP aerosol	Can be used for any solid or liquid hazard including oil-based liquids. Can only be used for one eight-hour shift.
R 99	99		
R 95	95		
P-SERIES			
P 100	99.7	0.3 µm DOP aerosol	Have longer use period than R-series (consult manufacturers) Can also be used for any solid or liquid hazard including oil-based liquids.
P 99	99		
P 95	95		

2.9.4.2. Chemical cartridges respirator

In contrast to filters which are effective to some degree no matter what type of hazardous particles is preset, the cartridges and canisters used to remove gases and vapours are designed to provide protection against a specific contaminant. Contaminants are usually removed through interaction of their molecules with a granular, porous material called a sorbent.⁵³

The chemical canisters or cartridges form the filtering element of the respirator. The basic difference between cartridges and canisters is the volume of sorbent contained and not their functional ability. The sorbent volume of cartridges is small, between 5 and 200 cm³ making their service life much shorter, especially in a high-concentration environment. The use of cartridges is therefore restricted to low concentrations of gases and vapours. Cartridges may be used singly or in pairs on quarter and half masks and on full facepieces.⁵⁷

Canisters have a much large sorbent-containing volume and may be chin-, front- or back-mounted. Because of their larger sorbent volumes, about 250-500 cm³ for chin-mounted and 1000-2000 cm³ for front- or back-mounted, canisters can be used in much higher vapour and gas concentrations.⁵⁴

There are three removal mechanisms used in gas and vapour respirators:

- **Adsorption**

Adsorption is the physical attraction between the contaminant molecule and the sorbent surface. This attraction can be chemical or physical. Chemical attraction is a process called chemisorption and produces a much stronger bond than the physical attraction. Active charcoal is mostly used as sorbent material and effectively removes organic vapours and to some extent acids as well. If impregnated with certain substances the active charcoal becomes more selective against specific substances.⁵⁴

56

- **Absorption**

During absorption, molecules penetrate deep into the molecular space of the sorbent and are held there chemically. Absorption sorbents are used for protection against acids and consist of a mixture of sodium/potassium hydroxide with lime and/or caustic silicates.

Absorption largely cannot occur without prior adsorption on the surface of the particles. Absorption differs from adsorption in the sense that it is a much slower process and that the specific interaction surface area, even though it is also porous, is much smaller.⁵⁶

- **Catalysis**

Catalysts are substances that influence the rate of chemical reaction between two or more substances. Hopcalite is used as a catalyst. It is a mixture of porous granules, manganese and copper oxides which speeds up the reaction between toxic carbon monoxide and oxygen to form carbon dioxide.⁵³

In contrast to mechanical filters which become more effective when matter collects onto the filter, chemical respirators' initial exposure is 100% more efficient. However, as soon as the sorbent capacity to adsorb gas and vapour or catalyze them is reached,

their reaction becomes exhausted. Water vapour will decrease the effectiveness of some sorbents, but increase that of others, for example acids, because most acids dissolve in water. Therefore, environmental conditions can influence the effectiveness of the respirator and should be considered during storage.

The American National Standards ANSI K13.1-1973 indicates a colour code for the various types of sorbent cartridges and canisters, which identifies the contaminants against which they are designed to protect. This standard has been included in the OSHA regulation 29 CFR 1910.134 (g) and should be studied before the selection of respirators.⁵⁹

2.9.4.3. Powered air-purifying respirators

Like the non-powered air-purifying respirators, the purifying elements of power respirators are also filters, chemical cartridges or canisters. The difference between these devices is that the power air-purifying respirator uses a power source to operate a blower that passes air across the air-purifying element to provide clean air to the respiratory facepiece. Unlike the non-power air-purifying respirators, air is supplied at a positive pressure, reducing the inward leakage of contaminants. Only high-efficiency filters are used and the filters are approved for all aerosols. They have therefore been assigned higher protection factors.^{49, 50}

2.9.5. ATMOSPHERE-SUPPLYING RESPIRATORS

Atmosphere-supplying respirators are respirators that provide air from a source independent of the surrounding atmosphere. The different types are classified according to the way the air that is supplied is used and regulated. Atmosphere-supplying respirators consist of three groups: air-line respirators, self-contained breathing apparatus and a combination of both.^{49, 50}

2.9.5.1. Self-contained breathing apparatus (SCBA)

SCBA provides respiratory protection against gases, vapours and particles and in oxygen-deficient atmospheres. The distinguishing feature of all SCBA is that the

user does not need to be connected to a stationary breathing gas source; instead, enough oxygen is carried by the wearer. The two types of SCBA are closed circuit and open circuit.⁵³

In a closed-circuit SCBA, all the air is scrubbed and reused. The breathing gas is re-breathed after the exhaled carbon dioxide is removed and the oxygen content restored. Units can be used for periods ranging between 15 minutes and 4 hours and are designed to be stored oxygen systems or oxygen generating systems. Stored oxygen systems supplied oxygen to a breathing bag as either consistent flow or degree of inflation. The wearer inhales and exhales into the bag. Exhaled air is scrubbed from CO₂ through a chemical bed, then reused. Oxygen-generating systems rely on a chemical reaction to supply oxygen. During exhalation the water vapour that is generated reacts with solid chemicals, releasing oxygen.⁵⁴

In open circuits, the exhaled air is released into the environment and not re-breathed. These devices are generally compressed air and designed to provide 30 to 60 minutes of service. The compressed air is supplied to a regulator that reduces the pressure and regulates the airflow to the facepiece. A third type, called an escape SCBA, is designed to be used only during an escape and the use duration is mostly five, seven or ten minutes.^{52, 53}

2.9.5.2. Supplied air respirator

Supplied air respirators supply breathing air to the wearer's facepiece through a hose connected to a static source or compressor. Air-supplied respirators work in three modes: demand, pressure demand and continuous flow. Demand air-line respirators only provide air flow on inhalation and are equipped with either a half or full facepiece. A negative pressure is generated within the facepiece during inhalation causing possible leakage into the facepiece. These devices are not very effective.⁵²

The pressure demand air-line respirator is similar to the demand air-line, but a positive pressure is generated within the facepiece, which means that if a leakage

CHAPTER 2

LITERATURE OVERVIEW

occurs in the facepiece the leakage of air would be outwards. These devices provide a higher level of protection. Continuous flow units have a regulated amount of air delivered to the facepiece. The air supply to air-line respirators is required to meet the requirement of type I gaseous air (Grade D or higher quality).⁵⁴

2.9.5.3. Combination air-purifying and atmosphere-supplying devices

NIOSH has approved various types of air-purifying units or SCBA combination type C supplied air respirators. These types of respirators consist of facepieces, regulator valve, breathing tube, belt or harness, supplied air hose and air-purifying elements. These devices can either be used in air-purifying or air-line mode.⁵³

2.10. ASSIGNED PROTECTION FACTORS (APF)

Cartridge and canister filter media vary in their ability to remove airborne contaminants from breathing air. These cartridges are rated by NIOSH and OSHA and issued with an assigned protection factor. This factor should be used during the selection of respirators for a specific task or environment.^{52, 59}

The assigned protection factors indicate the level of protection which properly functioning respirators would be expected to provide when properly fitted and maintained.

The approved protection factor (APF) is calculated by dividing the measured concentration outside the respirator (CO) by the measured concentration inside the respirator (CI).

$$APF = \frac{CO}{CI}$$

For example, an APF of 10 means that a user could expect to inhale not more than one tenth of the airborne contaminants present. Each respirator is also issued with

CHAPTER 2
LITERATURE OVERVIEW

a maximum use concentration (MUC) or maximum use limit (MUL). The APF is used to calculate the MUC by multiplying the APF with the permissible exposure limits (PEL) of the contaminant. For example if a contaminant has a PEL of 10 ppm according to Table 2.4, the MUL for an air-purifying half-mask respirator will be 100ppm.⁶¹

$$\text{MUC} = \text{APF} \times \text{PEL}$$

In 2006 OSHA re-evaluated the Respiratory Protection Standard 29 CFR 1910.134 and issued the ruling that became final on 22 November 2006, as indicated in Table 2.3.⁵⁹

Table 2.3: OSHA Assigned Protection Factors^{52, 59}

Respirator type	Quarter mask	Half Mask	Full facepiece	Helmet/Hood	Loose-fitting facepiece
Air-purifying respirator	5	10	50	-	-
Power air-purifying respirator	-	50	1000	25/1000	25
Supplied air respirator or air-line respirator					
• Demand mode	-	10	50	-	-
• Continuous flow mode	-	50	100	25/1000	25
• Pressure demand or other pressure mode	-	50	1000	-	-
Self-contained breathing apparatus					
• Demand mode	-	10	50	50	-
• Pressure-demand or other positive pressure mode	-	-	10 000	10 000	-

2.11. SERVICE LIFE

Service life means the period over which a respirator, filter, canister or any other respiratory device will provide adequate protection.⁵⁶ The service life of gas or vapour cartridges depend on various factors including breathing rate, humidity, contaminant concentration and the adsorption or absorption efficiency of the filter.⁵⁴ The higher the breathing rate or concentration of contaminant, the more particles come in contact with the filtering medium. This increases the filter saturation and shortens the service life of the respirator.⁵⁷

Every respirator should be provided with an end-of-service life indicator, or a change-out schedule should be drawn up. This will ensure that cartridges are changed before they reach the end of their service life. The service life can be estimated by conducting experimental tests, making use of manufacturer's recommendations or mathematical equation. Making use of the breakthrough method is not a legal way to determine the service life of the filter. If a user detects an odour or sensation, they have already been exposed. Some hazards do not have an odour, therefore it cannot always be determined when breakthrough occurred.⁵⁹

2.12. ADVANTAGES AND LIMITATIONS OF AIR-PURIFYING RESPIRATORS

2.12.1. Non-powered air-purifying respirators

Air-purifying respirators are usually small and lightweight, with no restriction to the mobility of the user. These devices are simple to use and low in cost. Many combinations of facepieces, mouthpieces, filters, cartridges and canisters allow the user to match the respirator to the particular situation and the user's personal preference.⁵⁵

Air-purifying respirators cannot be used in oxygen-deficient or IDLH atmospheres and many types are limited to environments with low concentrations of contaminants.⁵³ Special care must be taken when selecting the respirator to ensure that the proper protection is provided for a specific contaminant. The negative air pressure on the inside of such a respirator during inhalation may cause inward leakage of airborne contaminants into the mask. Proper fitting tests must be conducted for each user. These respirators cannot be used by workers that have beards and moustaches, because the facial hair causes an incomplete seal that leads to leakage.⁵⁴ Facepieces should be inspected constantly for possible leaks.

During long periods of use or when used in warm and humid environments, the breathing resistance may cause discomfort and fatigue.⁵⁷ The replacement of

disposable masks, including replacing or maintaining elements in reusable masks, has high cost implications.

2.12.2. Powered air-purifying respirators

Powered air-purifying respirators have loose-fitting facepieces, which are usually more comfortable to wear and do not restrict the user's movement.⁵⁶ Because of the loose fit, facepiece fitting tests are not necessary and these respirators can be used by users that have a beard or moustache. Positive pressure is provided inside the hood by the fan forcing air into the facepiece, thus eliminating breathing resistance and providing a cooling effect in hot conditions. These devices can therefore be used for longer periods without discomfort.⁵⁵

Powered air-purifying respirators nevertheless have the same disadvantages as other air-purifying respirators, with a few additional shortcomings. Firstly, the design of these devices is complex, making initial costing, replacement of batteries and purifying elements and general maintenance much more costly.⁵⁴ Battery packs need to be recharged after use and if for some reason the blower fails to operate, the user should leave the contaminated area immediately. When used in cold environments, the cold air supply by fan may result in discomfort to the wearer.⁵⁰

2.13. ADVANTAGES AND LIMITATIONS OF ATMOSPHERE-SUPPLYING RESPIRATORS

2.13.1. Air-line respirators

Air-line respirators can be used in oxygen-deficient environments and may be used for long periods. Because of their static source, the initial installation cost is moderate, along with low operation and maintenance costs.⁴⁹ The devices are relatively lightweight and cause minimal breathing resistance or discomfort. Because the facepieces are loose-fitting, no fitting tests are needed and workers with beards and moustaches are also able to use these devices. The continuous flow and pressure systems provide a high level of protection.⁵⁵

However, air-line respirators can only be used in an IDLH environment if fitted with a full facepiece and combined with an auxiliary self-contained breathing supply system. If there is a sudden loss of air supply from the source due to damage to the hose or the air pump, the user will be left without respirator protection, which may have serious consequences. The trailing hose restricts movement and causes discomfort and fatigue.⁵⁴

2.13.2. Self-contained breathing apparatus

SCBA wearers carry their source of air with them, making them independent from the ambient environment. SCBA provides protection against all particles, gases and vapours and can be used in both oxygen-deficient and IDLH environments. These devices do not restrict movement; however, they are heavy and bulky and should not be used during strenuous work or in confined spaces.

Other disadvantages of SCBA are that they are complex systems and have to conform to stringent requirements. Proper fitting tests and extensive training should be conducted before they are taken into use. The initial, operating and maintenance costs are high and time-consuming. The devices can only be used for short periods and negative pressure inside the facepiece may result in hazardous substance leakage during inhalation.⁵⁴

2.14. FACTORS THAT INFLUENCE THE USE AND EFFECTIVENESS OF RESPIRATORY DEVICES

2.14.1. Facial hair

Facial hair like beards, moustaches, sideburns, low hairlines and bangs can cause leakage of airborne contaminants into the interior of the respiratory inlet covering.⁵⁹ Leakages may occur with tight fitting and loose fitting facepieces of powered air-purifying respirators and atmosphere supplying respirators. The facial hair limits air flow to the wearer, wasting air and shortening the service life of the respirator. Facial hair also interferes with respirators that have a valve located in the respiratory inlet covering.⁶² Wearers with beards should not be allowed to wear

such respirators in a hazardous, IDLH or oxygen-deficient environment. They should rather use loose-fitting respiratory inlets that enclose the whole facial area.⁵⁰

2.14.2. Head coverings

Additional PPE like head coverings and glasses or goggles may cause the same problems as facial hair. Wearing a head covering that passes between the sealing surface of the respiratory device and the face should not be allowed under any circumstances, especially not in a hazardous environment.⁵⁴

2.14.3. Facial deformities

Standardized facial dimensions are used for developing and designing respiratory facepieces. A nose with an unusual shape, structure or size may prevent the mouthpiece of a nose-clamp type of respirator from closing properly over the nose.⁵⁴ Facial deformities like scars, severe acne, deep skin creases, hollow cheeks, protruding cheekbones, and unusual facial configurations may prevent a proper seal between the respirator and the wearer's face. Missing teeth or dentures may prevent an adequate seal of a respiratory mouthpiece over a person's mouth. Therefore, persons with these types of deformities should not be allowed to wear respiratory devices.⁵⁰

2.14.4. Vision

Spectacles that have temple bars or straps that pass between the sealing surface of a respiratory device and the wearer's face prevent a good seal, with possible leakage of contaminants into the facepiece. Spectacles and safety glasses may also interfere with the seal of quarter and half masks. Special corrective lenses should rather be fitted within the facepiece, or soft gas-permeable contact lenses can also be used.

2.14.5. Communication

The wearing of respiratory devices makes it difficult to communicate properly. This poses a problem and possible health hazards in areas where hazardous substances or equipment are present. Trying to speak while wearing a respirator may break the seal and cause possible exposure to contaminants. Wearers often take their masks off to communicate and then put them back on without ensuring that they fit properly. Wearers should be encouraged to communicate by using hand signs, signal lines or any other form of communication. Specialized communication equipment incorporated into respiratory devices is available from certain manufacturers.⁵⁴

2.14.6. Low and high temperatures

Low temperatures may fog the lenses of respirators and the exhalation valve may freeze. Antifogging components can be used, or full facepiece nose cups that direct the warm, moist exhaled air through the exhalation valve without touching the lens. Dry oxygen supplies should also be used.

Hot environments are very stressful for workers. Providing a person with a respiratory device causes even more stress. The weight and breathing resistance of the respiratory device should be kept at a minimum. When working in IDLH environments, air-line devices should rather be used, for their cooling function and light weight.⁵³

2.14.7. Physiological stress on wearers

Wearing respiratory protective equipment in conjunction with other types of protective equipment causes some physiological stress on the wearer. The weight of the equipment, for example, increases the energy requirements for a given task.⁶³

The human response and endurance are greatly affected and normally in a hot environment or during hard work, the body relies on a great deal of heat loss

through evaporation and sweat. With impermeable clothes, the body is not able to lose heat. In addition, the weight of the respirator and possible breathing resistance add to the metabolic rate and even more heat is produced by the body. All these factors together causes heat stress.⁵⁵

Tight-fitting respirators raise facial temperatures, causing the face to perspire, leading to discomfort, possible shifting of the facepiece and a less effective face seal. Therefore, the selection of the respirator should be based on breathing resistance, weight, type and amount of protection needed and an individual's tolerance and personal preference in respect of a device.⁶²

2.15 RESPIRATORY REGULATIONS AND APPROVALS

The Mine Health and Safety Act (MHSA) (Act 29 of 1996) and the subsequent Mine Health and Safety Amendment Act (Act 1997) have been the legal basis for regulating occupational health and safety in South Africa.^{1,23} The MSHA is a modern approach to the Occupational Health and Safety Act (Act 85 of 1993) which regulates health and safety in other sectors in South Africa.²²

Every employer in the mining industry is required by the MHSA to ensure and establish a work environment that is safe and without risk to the health of employees (section 6). They are required to investigate and identify hazards through effective monitoring and investigating, provide possible control measures and safety training, provide each worker with adequate personal protective equipment at no cost and ensure that the workers are properly informed about the correct use or limitations during use. Every employee is obligated by section 22(c) of MHSA to take proper care of the health and safety equipment provided by the employer.

Technical requirements in accordance with the General Safety Regulation of the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) as published by Government Notice No R. 736 (Government Gazette No. 22565) of 1 September 2001, and the Regulation under the MHSA, 1996 (Act No 29 of 1996) published by Government Notice No. R 904 (Government Gazette No. 23583) of 2 July 2002,

CHAPTER 2

LITERATURE OVERVIEW

state that all respiratory protective equipment must be submitted to the National Regulation for Compulsory Specifications (NRCS) for homologation in accordance with SANS 10338:2009: "Homologation of respiratory equipment"^{22,23,64,65}

The use of respiratory protective devices within the mining industry should be accompanied by proof of homologation in the form of a NRCS Homologation granted or NRCS Homologation extended certificate. This certificate states that the product was homologated by the NRCS and was approved for use within the mining industry. These certificates then serve as proof of compliance with the relevant legislation during inspection by the Department of Minerals and Energy (DME). The NRCS has compiled a list of all approved respiratory protective devices, which is available on their website.⁶⁴

REFERENCES

1. The Mine Health and Safety Act of 1996, Pub. L. No. 29 (Jun 14 1996).
2. Guild R, Ehrlich R, Johnston JR, Ross MH. SIMRAC: Handbook of occupational health practice in the South African mining industry. Johannesburg: Cedra Communications; 2001. p. 21.
3. British Standard Institute. Occupational health and safety management systems: BS OHSAS 18001; 2007.
4. American National Standard Institute. Occupational health and safety management systems: ANSI; 2005.
5. Department of minerals and energy: Mine Health and Safety Inspectorate. Guideline for the compilation of mandatory code of practice for an occupational health program on personal exposure to airborne pollutants. [Online]. 2001 [cited 2008 Jun 30]; Available from:
http://www.dme.gov.za/pdfs/mhs/guidlines/occ_health_prog_airborne_pollutants.pdf
6. Plog BA. Fundamentals of industrial hygiene. 5th ed. New York: National Safety Council; 2002. p. 123.
7. Reese C, Eidson J. Handbook of OSHA construction safety and health. Florida: Taylor & Francis Group; 2006. p. 461-3.
8. Cash D. Introduction to operator air sampling. [Online]. 2008 [cited 2008 Jun 21]; Available from: <http://www.msha.gov/s&hinfo/oprsamp/oprsamp.htm>
9. Winder C, Stacey NH. Occupational toxicology. 2nd ed. Florida: CRC Press; 2004. p. 91.
10. Occupational Safety and Health Administration. Hazard recognition. [Online]. 2009 [cited 2009 May 21]; Available from:
<http://www.osha.gov/SLTC/respiratoryprotection/recognition.html>
11. Pollak AN, Cupton C. Emergency care and transportation of the sick and injured. New York: Jones & Bartlett; 2002. p. 189.
12. American Lung Association. Respiratory protection for breathing hazards. [Online]. 2008 [cited 2009 April 3]; Available from:
<http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=23035>
13. Canada's National Occupational Health and Safety Resource. How do particles enter the respiratory system. [Online]. 1999 [cited 2008 Jun 23]; Available from:
http://www.ccohs.ca/oshanswers/chemicals/how_do.html?print

CHAPTER 2
LITERATURE OVERVIEW

14. U.S. Department of Health & Human Science. The respiratory system. [Online]. [cited 2009 Feb 3]; Available from:
http://www.nhlbi.nih.gov/health/dci/Diseases/hlw/hlw_respsys.html
15. Roberts F. Respiratory physiology. [Online]. 2000 [cited 2009 Feb 25]; Available from: <http://www.nda.ox.ac.uk>
16. New World Encyclopaedia. Respiratory systems. [Online]. 2008 [cited 2009 April 3]; Available from: http://www.newworldencyclopedia.org/entry/respiratory_systems
17. Francis C. Respiratory care. Oxford: Blackwell; 2006. p. 4-6.
18. Agius R. Occupational and environmental lung deceases. [Online]. 2007 [cited 2009 Jul 5]; Available from: <http://www.agius.com/hew/resource/lung.htm>
19. Chong N, Sivaramakrishnan K, Well M, Jones K. Characterization of inhalable particulate matter in ambient air by scanning electron microscopy and energy dispersive X ray analysis. EJEAFChe. 2002;1(3):145-164.
20. Belle BK, Stanton DW. Inhalable and respirable dust. In: Stanton DW, Kielblock J, Schoeman JJ, Johnston JR, editors. MHSC Handbook on mine occupational hygiene measurements. Braamfontein: Mine Health and Safety Council; 2001. p. 19-21.
21. Regulation of Hazardous Chemical Substances. Annexure 1: Applying occupational exposure limits. [Online]. 1995 [cited 2009 Aug 3]; Available from: http://www.acts.co.za/ohs/hcsr_ann_1_applying_occupational_exposure_limits.htm
22. Occupational Health and Safety Act of 1993, No. 85 (June 23 1993).
23. Regulation of hazardous chemical substances. r 5, 6, 10, 11. (Aug 25 1995)
24. Conradie A. Platinum group metal mines in South Africa. [Online]. 2007 [cited 2008 Sep 10]; Available from: URL:<http://www.dme.gov.za/pdfs/minerals/D6%202007.pdf>
25. Jacobs M. Process description and abbreviated history of the Anglo Platinum's Waterval Smelter. JS Afr Inst Min Metall. 2006 Mar 5-8;17-28.
26. Cawthorn RG. The platinum and palladium resources of the Bushveld Complex. S Afr J Sci. 1999 Dec;95:481-489.
27. Mostert JC, Roberts PN. Electrical smelting of nickel-copper concentrates containing platinum group metals at Rustenburg Platinum Mines Limited. JS Afr Inst Min Metall. 1973 Apr;73(9):290-299.
28. Jones RT. Platinum smelting in South Africa. S Afr J Sci. 1999;95:525-534.

CHAPTER 2
LITERATURE OVERVIEW

29. Anglo Platinum Management Services: Technical Service Division. Process division review; 2003.
30. Encyclopaedia Britannica. Nickel processing. [Online]. 2009 [cited Oct 2009] Available from: <http://www.britannica.com/EBchecked/topic/414313/nickel-processing>
31. American National Standard Instituted. Toxicological profile for Nickel. [Online]. 2005 [cited Mrt 2007]; Available from: <http://www.atsdr.cdc.gov/toxprofiles/tp15.html>
32. U.S. Environmental protection agency. Nickel compounds. [Online]. 2007 [cited Aug 2007 5]; Available from: <http://www.epa.gov/ttn/atw/hlthef/nickel.html>
33. OEHHA/ARB. Approved acute reference exposure levels and target organs. [Online]. 2009 [cited 2009 Mar 14]; Available from: <http://www.arb.ca.gov/toxics/healthval/acute.pdf>
34. Ecobichon DJ. Toxic effect of pesticides. In: Klaassen D, Watkins III JB, editors. Casarett and Doull's essentials of toxicology. New York: McGraw-Hill; 2003. p. 356-357.
35. Sorahan T, Burger DC, Hamilton L, Harrington JM. Lung cancer mortality in nickel/chromium platers. [Online]. 1998 [cited 2008 Nov 15]; Available from: <http://oem.bmj.com/cgi/content/abstract/55/4/236>
36. Hu W, Feng Z, Tang M. Nickel (II) enhances benzo[a]pyrene diolepoxide-induced mutagenesis through inhibition of nucleotide repair in human cells: possible mechanism for nickel (II)-induced carcinogenesis. Carcinogenesis 2004;25(3):455-462.
37. Burns DA, Breathnach SM, Cox N, Griffiths CE. Rook's textbook of dermatology. 7th ed. USA: Blackwell; 2004.
38. National Instituted of Occupational Safety and Health. Occupational safety and health guidelines for nickel soluble compounds. [Online]. 2008 [cited 2008 Nov 23]; Available from: URL: <http://www.osha.gov/SLTC/healthguidelines/nickelsolublecompounds/recognition.html>
39. National Institute for Occupational Safety and Health. NIOSH pocket guide to chemical hazards. [Online]. 2005 [cited 2008 Jun 23]; Available from: URL: <http://www.cdc.gov/niosh/npg/npgname-a.html>

CHAPTER 2
LITERATURE OVERVIEW

40. National Institute for Occupational Safety and Health. Occupational cancers. [Online]. 2008 [cited 2009 Mar 14]; Available from:
URL:www.cdc.gov/niosh/topics/cancer/npotocca.html
41. IARC. International Agency for Research on Cancer. IARC monographs on the evaluation for carcinogenic risk to humans of chromium, nickel and welding. Geneva Health Organization. 1990:257-446.
42. Agency for Toxic Substances and Disease Registry. Public health statement for sulphur dioxide [Online]. 1998 Dec [cited Apr 2008]; Available from:
URL:<http://www.atsdr.cdc.gov/toxprofiles/phs116.html>
43. Badenhorst CJ. Occupational health and safety risk associated with sulphur dioxide. JS Afr Inst Min Metall. 2009;107:299-303.
44. Costa DL. Air pollution. In: Klaassen D, Watkins III JB, editors. Casarett and Doull's essentials of toxicology. New York (NY): McGraw-Hill; 2003. p 411-412.
45. Tunnicliff WS, Harrison RM, Kelly FJ, Dunster C, Ayres JH. The effect of sulphurous air pollutant exposure on symptoms, lung function, exhaled nitric oxide, and nasal epithelial lining fluid antioxidant concentrations in normal and asthmatic adults. [Online]. 2003 [cited 2007 May 23]. Available from:
URL:<http://oem.bmj.com/cgi/content/full/60/11/e15>
46. Occupational Safety and Health Administration. Safety and health topics coal tar pitch volatiles. [Online]. 2007 Mar 27. [cited 2008 Apr 3]. Available from:
URL:<http://www.osha.gov/SLTC/coaltarpitchvolatiles/index.html>
47. National Institute for Occupational Safety and Health. Pocket guideline to chemical hazards: Coal tar pitch volatiles. [Online]. 2005 [cited 2008 Apr 3]. Available from:
URL:<http://www.cdc.gov/niosh/npg/npgd0145.html>
48. Agency for Toxic Substances and Disease Registry. Toxicological profile for wood creosote, coal tar creosote, coal tar, coal tar pitch, and coal tar pitch volatiles. [Online]. 2002 [cited 2008 Apr 23]. Available from:
URL:<http://www.atsdr.cdc.gov/toxprofiles/tp85.pdf>
49. Occupational Safety and Health Administration. Respiratory protection. [Online]. 2002 [cited 2008 Jan 23]. Available from:
URL:<http://www.osha.gov/Publications/osh3079.pdf>

CHAPTER 2
LITERATURE OVERVIEW

50. Occupational Safety and Health Administration. Technical manual. Section VIII:Chapter 2. Respiratory protection. [Online] 2008 [cited 2007 Oct 10]. Available from: URL:http://www.osha.gov/dts/osta/otm/otm_viii/otm_viii_2.html
51. Harris WP. How regulation and innovation have shaped respiratory protection. [Online]. 2009 [cited 2009 May 4]. Available from: URL:http://ehstoday.com/ppe/respirators/regulation_innovation_shaped/
52. Bollinger N. NIOSH respiratory selection log. [Online] 2004 [cited 2007 Sep 23] Available from: URL:<http://www.cdc.gov/niosh/docs/2005-100/>
53. Colton CG. Respiratory protection. In Plog BA, editor. Fundamentals of industrial hygiene. 4th ed. Chicago: National safety council; 1996. p. 619-656.
54. Occupational Safety and Health Administration. Respiratory protection advisor. [Online]. 2002 [cited 2009 Feb 13] Available from: URL:http://www.trustcrm.com/ectny/respiratory_advisor/contents.html
55. Harvard University Environmental Health and Safety. Types of respirators. [Online]. 2009 [cited 2009 Mar 13] Available from: URL:http://www.uos.harvard.edu/ehs/ih/rpp_types.shtml#uos
56. Rajhans GS, Pathak BP. Practical guide to respiratory usage in industry. 2nd ed. Woburn (MA). Elsevier Science; 2002.
57. Revoir WH, Bien C. Respiratory protection handbook. Florida: CRC Press; 1997.
58. Approval of respiratory protection handbook, 42 C.F.R Part 84 (2003).
59. Occupational Safety and Health Administration. Regulations (Standard-29 CFR) Respiratory protection standard – 1910.134. [Online]. 2006 [cited 2007 Jun 27]. Available from: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=12716&p_table=standards
60. 3M Occupational Health and Environmental Safety Division. Technical data bulletin # 175 – Assigned protection factors for 3MTM hoods and helmets. [Online]. 2009 [cited 2009 Jun 23]. Available from: URL:<http://multimedia.3m.com/mws/mediawebserver>
61. Occupational Health and Safety Administration. Assigned protection factors for the revised respiratory protective standard. [Online]. 2009 [cited 2009 Sep 10]. Available from: URL:<http://www.osha.gov/Publications/3352-APF-respirators.pdf>

CHAPTER 2
LITERATURE OVERVIEW

62. Harber P. Respirators. In Rom WN, editor. Environmental and occupational medicine. 4th ed. Philadelphia: Lippincott. Williams & Wilkins; 2007. p. 1777-1779.
63. Gardiner K, Harrington JM. Occupational hygiene. 3rd ed.: Wiley-Blackwell; 2005. p. 3, 30.
64. National Regulator for Compulsory Specifications. Minimum safety regulations for respiratory protective devices in South Africa. [Online]. 2009 [cited 2009 Jun 23]. Available from: URL:<http://www.nrccs.org.za/content.asp?subID=45>
65. National Regulator for Compulsory Specifications Act, 2008 (Act No. 5 of 2008)

CHAPTER 3
SCIENCE ARTICLE

3.1. GUIDELINES FOR AUTHORS

Occupational Health Southern Africa

3.1.1. Article

Original and review

Articles reporting original and relevant research are welcomed. Review article must contribute to the body of knowledge, and not just repeat previous documented findings. The article should not exceed 2 500 words, and use the following format.

Title

This should reflect the content of the manuscript, without being too long.

Abstract

Include an abstract of less than 150 words.

Introduction

This should clearly indicate the nature of the data gathering, the main issue to be covered, definition and delimitation of the problem, the importance of the paper and the purpose of the research or review. The date when the research was conducted must be provided. The cited literature (which may be part of the introduction or a separate section) must be relevant and correctly acknowledged.

Methodology

The research methodology employed must be clearly subscribed and justified. For quantitative analyses the statistical tests must be relevant and appropriately interpreted. Where appropriate, evidence of ethical clearance must be provided (the name of the organisation and an ethics clearance number). Review articles must describe the literature search strategy

Results

These must be accurate, comprehensive and relate to the purpose of the research or review.

Discussion

The findings should be discussed in the light of the literature and indicate how the paper has contributed to the body of knowledge.

Conclusion and recommendations

Conclusions must relate to the findings, whilst recommendations should be logical and feasible.

3.1.2. References

All articles should be appropriately referenced. References should be set out in the Vancouver style according to the International Committee of Medical Journal Editors. Only approved abbreviations of our journal titles should be used. References should be inserted in the text as subscripted numbers and listed at the end of the article in numerical order. The accuracy of references is the author's responsibility. Personal communication and unpublished observations may be cited in the text, but not in the reference list.

3.1.3. Authorship, Factual Accuracy And Copyright

Authors are solely responsible for the factual accuracy of their work and must ensure that their work does not infringe copyright. Submission of the complete "Statement of acceptance of conditions and responsibilities pertaining to the publication of the manuscript by all authors is required prior to the review of the manuscript.

3.1.4. Manuscript

Manuscript should be typed in 1.5 spacing, using only one side of the paper. The font used for the body of the article should be Arial 11pt. All captions should be in Times New Romans 12pt. Pages should be numbered consecutively and leave wide margins (3,17 cm left and 2,54 cm top and bottom). Scientific measurements should be expressed in S.I units. Abbreviations and acronyms should only be defined on first use. Illustrations, tables and graphs should be submitted separately to text, in electronic format. Photographs must be submitted as images of at least 300dpi. These photographs should not be imbedded in MS word document. All these accompanying materials should be clearly identified by means of captions that are also indicated in the text of the manuscript. Tables should use

Arabic numerals, 1, 2, 3 etc, and illustrations Figure 1, 2, 3, etc. Additional data will form part of the electronic journal.

3.1.5. Author's Details

A separate title page should contain the title, the authors full name, contact details relevant to correspondence and the author's position in a public sector department and/or affiliation to an academic institution. Authors who are members of MMOA, SAIOH, SASOHN or SASOM must indicate this membership. A word count should be included on this page.

3.1.6. Conflict Of Interest And Affiliation

Any a commercial organizations or conflict of interest should be declared.

3.1.7. Review Process

All manuscripts will be submitted to referee as confidential without naming the author and all referees shall remain anonymous. Authors will be informed of the outcome of the review process.

3.1.8. Proofs

Corrected manuscripts, once approved for publication by the authors and editor will be submitted to the publisher. Thereafter, the publisher will complete the layout of the material, and will provide the authors with an electronic proof of the final pages in Adobe portable document format (PDF). Alterations to proof must be limited to misprint or factual errors. Major alterations or new material cannot be accepted. Proof not returned within the time limit specified will be regarded as approved.

3.1.9. Submission

Manuscripts should be e-mailed to the editor

Linda Grainger,

Tel: (021) 851-1790,

Fax: (021) 851-1790

E-mail: occhealthsa@technews.co.za

**AN EVALUATION OF THE EFFICIENCY OF VARIOUS
RESPIRATORY PROTECTIVE DEVICES USED WITHIN PLATINUM
PROCESSING**

Cornelia Cecilia van Zyl

North-West University, Potchefstroom Campus
School of Physiology, Nutrition and Consumer Sciences
Member of SAIOH

Tel: (011) 972-6575
Fax: 086 684 5932
Cell: 083 45 47 829
E-mail: corlizev@mweb.co.za

Prof Fritz Eloff

North-West University, Potchefstroom Campus
School of Physiology, Nutrition and Consumer Sciences
Member of SAIOH

Tel: (018) 299 2442
Fax: (018) 299 2433
E-mail: fritz.eloff@nwu.ac.za

Dr Cas Badenhorst

Group Occupational Hygiene Specialist
Member of SAIOH

Tel: (011) 373 6726
Fax: (011) 373 5103
Cell: 083 455 0155

Mr Petrus Laubscher

North-West University, Potchefstroom Campus
School of Physiology, Nutrition and Consumer Sciences
Member of SAIOH

Tel: (018) 299 2441

Fax: (018) 299 2433

E-mail: petrus.laubscher@nwu.ac.za

Total word count: 3842

DECEMBER 2009

AN EVALUATION OF THE EFFICIENCY OF VARIOUS RESPIRATORY PROTECTIVE EQUIPMENT USED WITHIN PLATINUM PROCESSING

ABSTRACT

Workplace performance measurements of respiratory protective equipment (RPE) are essential for understanding how well the users are protected during work activities. This study evaluated the effectiveness of various respiratory protective devices used within the platinum producing industry and whether facial hair influences the seal efficiency of the facepiece. Three life-size mannequins connected to a personal sampling pump were used to test the efficiency of respirators within three different work environments. It was found that the 3M 8822, 3M 6000, Moldex 8000 and Dräger air-stream helmet all provided effective respiratory protection against airborne contaminants. Results indicated that the average concentration of the 3M 8822 device showed a 17.6% contaminant concentration on the inside of the facepiece, while the 3M 6000 indicated 15.4% and the Moldex 8000 only 11.0%. The air-stream helmet proved to be the most effective with only 2.2% of exposure concentrations being measured on the inside of the mask. Conversely, the effect of facial hair on the seal efficiency of the respirators indicated a tendency, but no conclusive data were obtained during this study.

Keyword: Respirators, efficiency, facial hair, mannequins, platinum processing.

INTRODUCTION

Respirators used in the mining industry are all approved by the National Regulator for Compulsory Specifications (NRCS) as specified by the Mine Health and Safety Act, 1996 (Act No. 29 of 1996). The South African Bureau of Standards (SANS) standard SANS 10338: 2009 are used for efficiency tests, which comply with internationally approved methods.^{1,2}

However, the performance of respiratory protective equipment (RPE), and in particular the level of protection it provides when worn within the working environment, is a complex subject. The interaction of many factors such as correct usage, the adequacy of a device for a specific type of airborne contaminant, task performed, degree of training, proper fitting, and facial features all contribute to the difficulty of determining the actual efficiency of the respirator.³

Most respirator efficiency research is conducted using mannequins or human test subjects within test chambers as prescribed by certification regulation 42 CFR 84,181.⁴⁻⁷ According to the National Personal Protective Technology Laboratory (NPPTL) total inward leakage testing, performed under laboratory conditions, does not necessarily reflect actual field-level personal protective equipment (PPE) performance, but only represents a criterion for performance that influences the PPE.⁸

Each work environment is different and since respirators are often used under stressful working conditions such as high temperatures, high humidity and a heavy work rate, the test conditions should reflect real use situations. For this reason workplace protection factors (WPF) are more commonly used than the assigned protection factors (APF) provided by the manufacturers, and are calculated by dividing the workplace contaminant concentration the user would inhale if they were not wearing the respirator by the concentration inside the facepiece taken at the same time.⁹⁻¹²

WPF studies have been conducted using employees performing normal working activities within the actual working environment.¹³ However; these field studies are quite expensive and require specialized sampling techniques and equipment, making it difficult for occupational hygienists within the private and mining sector to conduct RPE efficiency tests within their required work environment.

The purpose of the study was to use life-size mannequins to test the performance characteristics of respirators used during platinum processing within the actual work environment. Different respirator suppliers are used due to cost implications, personal preferences and task-specific requirements. Therefore, the difference in efficiency of the various brands was also examined for the purpose of respirator selection in specific areas.

The study furthermore looked at the effect of facial hair on the seal efficiency of the masks. Scientific laboratory studies have shown that facial hair increases the leakage through the respirator face seal and therefore manufacturers stipulate that respirators be used on a clean-shaven skin.¹⁴⁻¹⁵ However, users do not always adhere to these criteria owing to their lack of understanding and knowledge of possible effects on their health that may be caused by incorrect usage.

Using the mannequins as test subject with basic personal sampling methods, field studies were conducted under optimal production activities over a selected period of time. The study posed no direct danger or discomfort to employees and was also more cost-effective than other field studies found in current literature.

The aim of the study was to evaluate the performance efficiency of the different types of respirators used during platinum processing in order to select the most effective respiratory protective equipment for each work environment. The workers could then be educated on the importance of wearing respiratory protective devices and the possible effect of facial hair on the seal efficiency of the facepiece using data gained from their actual working environment.

Respiratory field performance testing is still very limited and the developing and investigation of field data is therefore essential.

METHODOLOGY

Study design

Portable life-size mannequins connected to air monitoring devices were used to determine the effectiveness of RPE as well as the effect of facial hair on the sealing efficiency of the facepiece. The airborne contaminant concentrations were measured on the inside of the facepiece within the actual work environment by using standard sampling techniques. Sampling was conducted at the smelter and base metal refinery (BMR) of a leading platinum producer where employees were exposed to different airborne contaminants on a daily basis. The study focused on the prescribed respiratory equipment provided to workers in each sampling area.

Sampling was conducted in three different areas of the platinum processing cycle and areas with high exposure levels were identified according to routine sampling that was conducted in each area. Four problematic airborne contaminants were identified, namely soluble and insoluble nickel (Ni), sulphur dioxide (SO₂) and coal tar pitch volatiles (CTPV), which were then used to quantify

possible exposure. The following respirators were used during the study: 3M 8822 dust mask, 3M 6000 respirator, Moldex 8000 respirator and the Dräger air-stream helmet.

Preparation

A hole was made in the back of three CPR mannequins' heads through which tubing was extended to one of the nasal openings. Each mannequin was connected to a Gilian personal sampling pump with filters, to determine the concentration of nickel, sulphur dioxide and coal tar pitch volatiles on the inside of the facepiece. The environmental concentrations were also measured and represented. Costume beards and moustaches were used to test the effect of facial hair on the seal efficiency of the respirators. Each mannequin was fitted with a beard/moustache before sampling on day 6 and 7. After used each beard/moustache was cleaned and placed within a plastic bag to prevent contamination. Filter preparation and pump calibration were conducted daily at the sampling laboratory of the platinum producer before and after sampling.

Air monitoring

Sampling Area 1: Smelter

Sampling was conducted at the crushers and furnace areas of the smelter. A total of 28 insoluble nickel samples were taken at the crushing plant, while 28 sulphur dioxide and 28 coal tar pitch volatile samples were taken on paste the floor of the furnace.

The 3M 8822, 3M 6000 and Moldex 8000 are prescribed respirators used in these areas and were therefore used during sampling at the crushers and furnace. The sampling layout for both areas were the same and sampling was conducted according to NIOSH 7300, NIOSH 6004 and OSHA 58 methods for nickel, sulphur dioxide and coal tar pitch volatiles respectively.¹⁶⁻¹⁸

The three mannequins were each properly fitted with a respiratory device and precautions were taken to ensure that no leakage occurred. Respirators were tested simultaneously to ensure that they were exposed to the same exposure concentration on the day of sampling. Each mannequin was connected to a personal sampling pump and filters and positioned on a chair within the working environment at a height of approximately 1 metre as shown in Figure 1.1.

Sampling was conducted during the day shift due to higher production and exposure levels during the day. Positioning of the mannequins were rotated daily to ensure equal exposure to contaminants and also for statistical analysis. Sampling was conducted over a seven-day period during which the efficiency of the respirators was tested for five consecutive days as indicated in

figure 1. On day 6 and day 7 each mannequin was fitted with a beard and moustache to determine the seal efficiency of the tight- and loose-fitting respirators, as indicated in Figure 2. Environmental samples were also taken to calculate the concentrations on the outside of the mask as indicated in Figure 2.

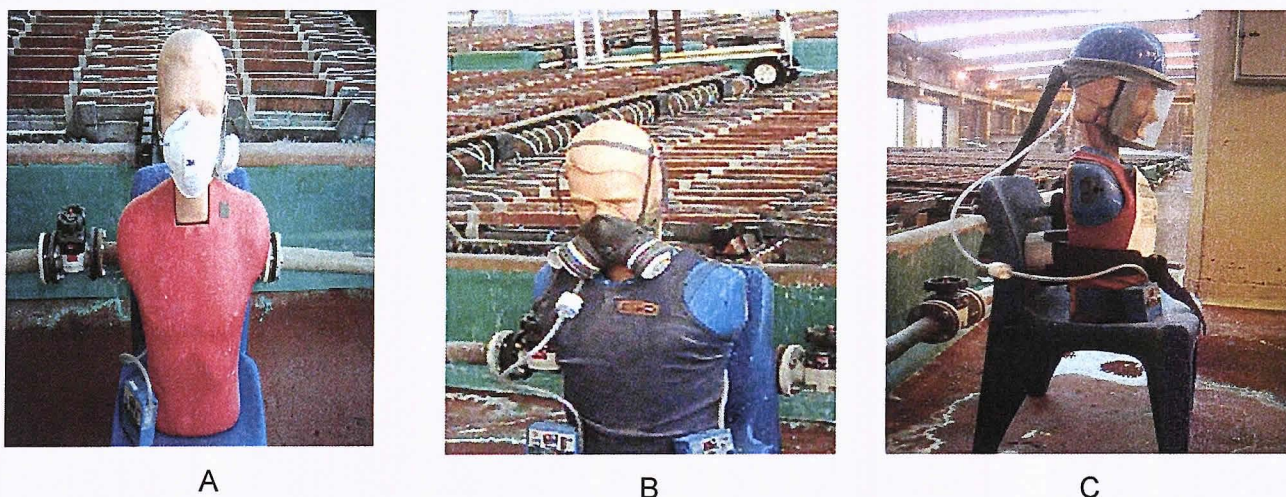


Figure 1: Example of mannequin sampling setup for testing the efficiency of the respirator using various respiratory devices: (A) 3M 8822, (B): Moldex 8000 and (C): Dräger air-stream helmet.

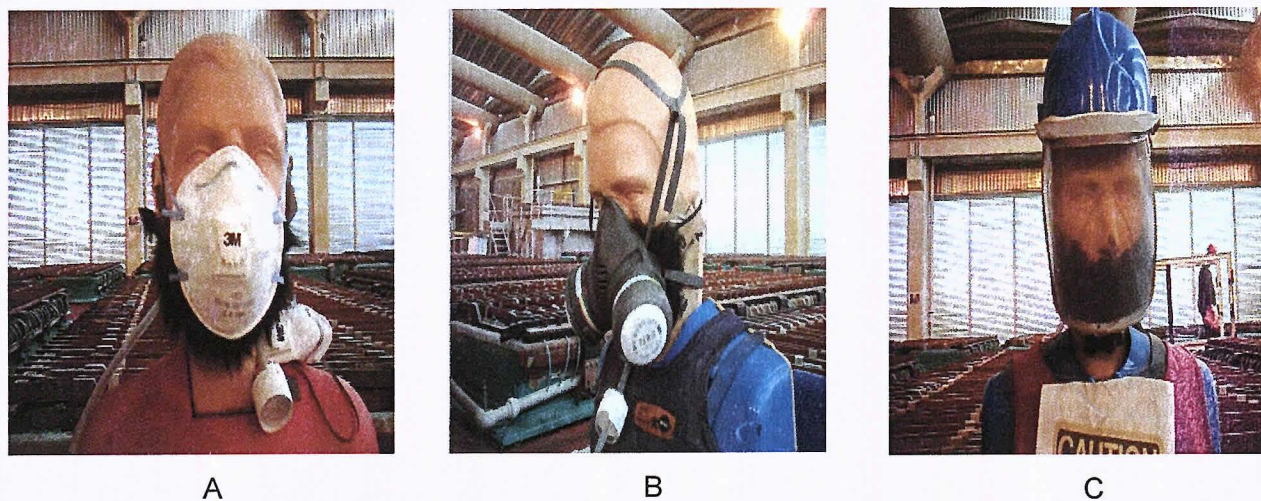


Figure 2: Example of mannequins fitted with beard and moustache, sampling systems (A) 3M 8822, (B): Moldex 8000; and (C): Dräger air-stream helmet.

Sampling Area 2: BMR

Sampling was conducted at the tank house of the BMR during which 28 soluble nickel samples were taken. The 3M 8822, Moldex 8000 and the air-stream helmet are prescribed respirators used in this area and were therefore used for sampling purposes. The sampling layout and strategy were the same as during the sampling at the smelter.

Statistic analysis

Filters were analysed for total soluble and insoluble nickel, sulphur dioxide and coal tar pitch volatiles by a SANAS accredited laboratory. The time-weighted average (TWA) for an eight-hour reference period of each filter was calculated and is represented mathematically by:

$$\frac{C_1T_1 + C_2T_2 + \dots + C_nT_n}{8}$$

Where C_1 is the occupational exposure value (concentration) and T_1 is the associated exposure time in hours in any 24-hour period.

The TWA concentrations were statistically analysed by the Statistical Consultation Services, North-West University, Potchefstroom Campus, using the SPSS statistical program. A three-sided analysis was conducted as follows:

- (1) All the TWA concentrations for each respiratory device were used together to determine the differences in effectiveness of the various respirators independent of the sampling areas, by using descriptive statistics (mean, standard deviation, variation), two-way analysis of variance (ANOVA), Tukey multiple comparison tests and Dunnett's one-sided tests.
- (2) The samples were analysed to determine the variance between respirators according to their sampling areas;
- (3) The effect of facial hair on the seal efficiency of the respirator.

The ANOVA was used to observe variance partitioned into components due to different explanatory variables. All differences were analysed at a significance of $p < 0.05$.

RESULTS

Table 1: The overall effectiveness of respiratory devices used throughout the study independent from the sampling area. The overall % of airborne concentrations on the inside of the facepiece was used to indicate where there was a difference in protection efficiency between the various devices

Device	Total number of samples taken	Mean Mg/m^3	Std Error	p-value	Airborne contaminants % on the inside of RPE
3M 8822	20	0.0024	0.0022	0.0025*	17.6%
3M 6000	15	0.0021	0.0026	0.0045*	15.4%
Moldex 8000	20	0.0015	0.0022	0.0010*	11.0%
Dräger air-stream helmet	5	0.0003	0.0044	0.0336*	2.2%
Environmental	20	0.0136	0.0022	1.0000	

Note:

* : P-value < 0.05

mg/m^3 : Milligram per cubic meter

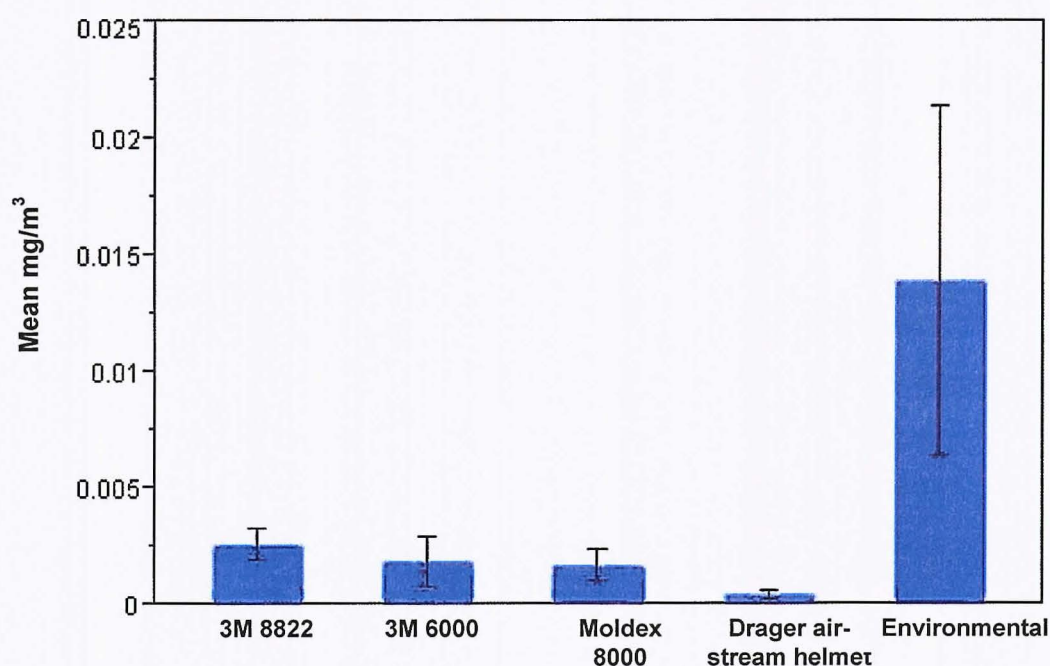


Figure 1: The graph show the overall effectiveness of respiratory devices used throughout the study independent from the sampling area, to determine where there was a difference in respiratory protection between the various devices

Table 1 indicated basic descriptive statistics using mean and standard deviations to determine the overall effectiveness of the various respirators without referring to the specific sampling area. The environmental concentrations were clearly much higher than the concentrations on the inside of the masks with a mean of 0.0136. All four devices showed a significant effect on a 95% level of confidence with p-values < 0.05. The 3M 8822, 3M 6000 and Moldex 8000 devices showed little difference between their concentration on the inside of the mask. The 3M 8822 showed a 17.6% concentration on the inside of the facepiece, while the 3M 6000 indicated 15.4% and the Moldex 8000 only 11.0%. The air-stream helmet proved to be the most effective with only 2.2% of exposure concentrations being measured on the inside of the mask.

Table 2: Effectiveness of respiratory devices tested within the different sampling areas to determine whether the sampling area had an effect on the respiratory efficiency and possibly which respiratory device are more effective within the certain sampling area

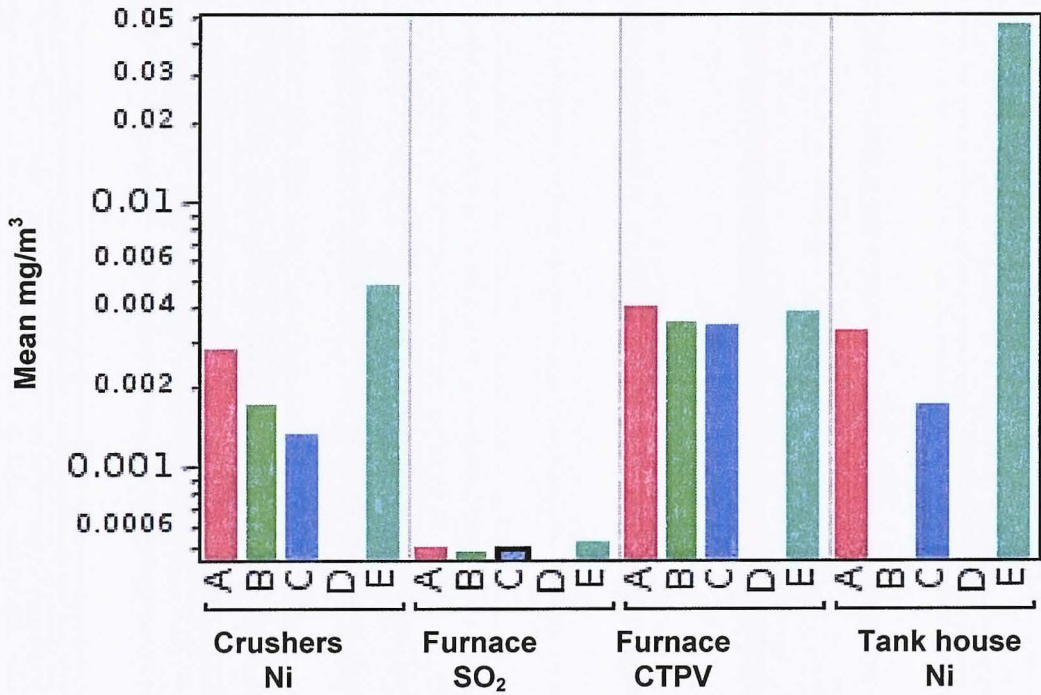
Device	Total number of samples taken	Mean mg/m ³	Std error	p-value	Airborne contaminants % on the inside of RPE
AREA 1 (CRUSHERS – Ni)					
3M 8822	5	0.0028	0.0008	0.1578	56.0%
3M 6000	5	0.0019	0.0008	0.0336*	38.0%
Moldex 8000	5	0.0013	0.0008	0.0121*	26.0%
Environmental	5	0.0050	0.0008	1.0000	
AREA 2 (FURNACE – SO₂)					
3M 8822	5	0.0005	0.0001	0.9939	96.0%
3M 6000	5	0.0004	0.0001	0.9563	86.5%
Moldex 8000	5	0.0005	0.0001	0.9939	100%
Environmental	5	0.0005	0.0001	1.0000	
AREA 3 (FURNACE – CTPV)					
3M 8822	5	0.0032	0.0013	0.9917	88.8%
3M 6000	5	0.0041	0.0013	0.9878	113.8%
Moldex 8000	5	0.0026	0.0013	0.9078	72.2%
Environmental	5	0.0036	0.0013	1.0000	

Device	Total number of samples taken	Mean mg/m ³	Std error	p-value	Airborne contaminants % on the inside of RPE
AREA 4 (TANK HOUSE – NI)					
3M 8822	5	0.0031	0.0022	0.0001*	6.8%
Moldex 8000	5	0.0017	0.0022	0.0001*	3.7%
Dräger air-stream helmet	5	0.0003	0.0022	0.0001*	0.8%
Environmental	5	0.0451	0.0022	1.0000	

Note:

* : P-value < 0.05

mg/m³ : Milligram per cubic meter



A: 3M 8822; B: 3M 6000; C: Moldex 8000; D: Air-stream helmet; E: Environmental

Figure 2: Indicates the effectiveness of respiratory devices within the each sampling areas to indicate which device is more effective within a certain working environment

In Table 2 the effectiveness of each respirator used within the different sampling areas was tested to determine whether the sampling area had a significant effect on the various respirators. Areas 1 and 4 indicated a significant effect with $p=0.0225$ and $p<0.0001$ respectively. Areas 2 and 3, however, showed no significant effect with $\{(F_{3,19}=0.1375, p=0.9362)$ and $(F_{3,19}=0.2293, p=0.8746)\}$ respectively.

Each device was individually tested against the environmental concentrations within the specific areas to determine which device was more effective within the specific area. At the crushers the 3M 6000 and Moldex 8000 devices showed a significant effect towards the environmental concentrations with p-values of $p=0.0472$ and $p=0.018$ respectively. In the furnace area, none of the devices showed a significant effect. Most of the devices indicated that the concentrations on the inside of the respirator were higher than the environmental concentration. All the devices in the tank house indicated a significant effect on a 95% confidence level. Figure 2 indicates the correlations between the various devices and the environmental concentrations within the different areas. The average TWA concentrations for the 3M 6000 and Moldex 8000 devices in the crushers and tank house indicated concentrations that were much lower than the average environmental concentrations. Only a small difference between the average TWA concentrations on the inside of the masks in relation with the environmental concentrations was noted in the furnace area.

Table 3: The possible effect of a beard/moustache on the seal efficiency of the different respiratory devices

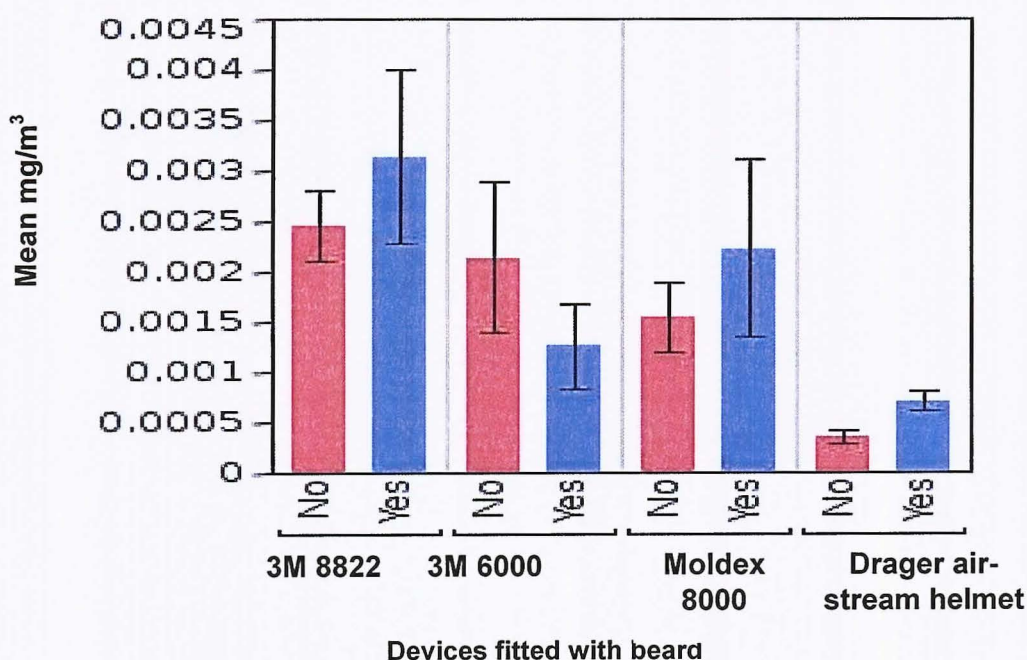
Device	Total number of samples taken	Mean mg/m ³	Std error	p-value	Airborne contaminants % on the inside of RPE
3M 8822					
With no beard/moustache	20	0.0025	0.0004	0.3927	17.9%
With beard/moustache	8	0.0031	0.0007		22.1%
3M 6000					
With no beard/moustache	15	0.0021	0.0007	0.4741	15.0%
With beard/moustache	6	0.0013	0.0010		9.3%
MOLDEX 8000					
With no beard/moustache	20	0.0015	0.0004	0.3837	10.7%
With beard/moustache	8	0.0022	0.0007		15.7%

Device	Total number of samples taken	Mean mg/m ³	Std error	p-value	Airborne contaminants % on the inside of RPE
AIR-STREAM HELMET					
With no beard/moustache	5	0.0003	0.0001	0.0348*	2.1%
With beard/moustache	2	0.0007	0.0001		5.0%

Note:

* : P-value < 0.05

mg/m³ : Milligram per cubic meter



No: Without a beard/moustache,

Yes: With a beard/moustache

Figure 3: The possible effect of a beard/moustache on the seal efficiency of the different respiratory devices

The average environmental concentration during sampling was 0.0136 mg/m³. In Table 3 the effect of facial hair on the seal efficiency of the mask was individually tested for each device when compared with the environmental concentrations. The 3M 8822, 3M 8000 and Moldex 6000 devices showed no significant effect between the TWA concentrations with a beard/moustache in correlation with the concentration without the beard/moustache, with p-values of p=0.3927, p=0.4741 and p=0.3837 respectively. The air-stream helmet, however, revealed a significant effect

on a 95% confidence level with $p=0.0348$. All devices, except for the 3M 6000, indicated higher concentrations when tested with the beard/moustache. The exposure concentration percentages on the inside of the facepiece for the 3M 8822, Moldex 8000 and air-stream helmet also showed increased levels of 22.1%, 15.7% and 5.0% respectively.

Figure 3 illustrates the effect of facial hair on the seal efficiency of the mask. In Table 3 no correlation was found between concentrations with a beard/moustache and concentrations without, for the 3M 8822, 3M 6000 and Moldex 8000. However, the graph indicates a tendency to elevated average concentrations when the beard/moustache was placed on the mannequins. The only exception was the 3M 6000

DISCUSSION

Using life-size mannequins for test subjects made it possible to test the efficiency of various respirators within the actual work environment, providing exposure concentrations on the inside of the facepiece without posing any risk to employees.

The results in Table 1 and figure 1 indicate that the overall averages of the respiratory devices that was tested during the study effectively lowered exposure concentration. The Dräger air-stream helmet proved to be the most effective with only 2.5% of the overall TWA concentration measured on the inside of the facepiece. The 3M 8822, 3M 6000 and Moldex 8000 devices showed minor differences in efficiency with 17.6%, 15.4% and 11.0% of contaminants measured on the inside of the facepiece respectively.

Because of the difference in airborne contaminant exposure in each area, the study focused on determining the effectiveness of each respirator within the different sampling area and whether it was possible that some respirators could be more effective than others. However the 3M 8822 only provides 92 % protection against dust particles, water based and non volatile liquid aerosols.¹⁹ Table 2 indicated that in the crushers area, the 3M 6000 and Moldex 8000 device showed a significant effect towards the environmental concentrations $p=0.033$ and $p=0.012$ respectively. The 3M 8822 provided the least protection, lowering exposure by 44%, while the 3M 6000 provided 62% protection and the Moldex 8000 74%. The Moldex 8000 was shown to be 30% more effective than the 3M 8822 and 18% more effective than the 3M 6000 device within the crushing area.

In the furnace, none of the devices had a significant effect with the environmental concentrations. The 3M 6000 indicated higher exposure concentrations than the environmental concentrations, thus providing no effective protection against sulphuric acids and coal tar pitch volatiles. According to NIOSH when fitted with a multi functional gas and vapour cartridge the 3M 6000 should provide

sufficient protection against SO₂ and CTPV.²⁰ On the paste floor of the furnace, paste blocks with high concentrations of are placed within the six electrodes of the furnace. When the electrodes are opened, a high concentration of CTPV compounds released. This causes fluctuation in exposure concentrations from quite high to very low because of the release of gases during the opening of the electrodes. The devices situated close to the source, therefore, are exposed to higher concentrations, especially during the reloading of paste blocks. During the sampling process, the environmental sample was not always taken close to the source because of rotation, also contributing to lower concentrations. The concentration differences were minimal and limited samples being taken made is impossible for correlations to be made.

In the tank house all three the devices that were tested had a significant effect with the environmental concentrations on a 95% confidence level. These data stated that the air-stream helmet was shown to be 99% effective in lowering exposure concentrations. The Moldex 8000 device proved to be 96.0% effective, with the 3M 8822 being 86.5% effective. The fresh air supplied to the breathing zone effectively lowered the exposure concentration before it could be inhaled. These devices provide minimal breathing resistance and do not restrict mobility. Because the loose-fitting hood does not form a seal with the face, it is ideal for persons with facial scars or facial hair. Because of relative high levels of humidity within the tank house the air stream helmet can provide a cooling effect. Nevertheless, employees working in the tank house were hesitant to wear these devices because they are heavy and bulky and the batteries need to be charged after use. However all three these devices provide sufficient protection within the tank house.

The effectiveness of various respiratory devices and the correlations between the different devices are of great importance to selectors; and because of the small difference in effectiveness between the 3M 6000 and Moldex 8000, economic or personal preference factors can be taken into consideration during selection. The 3M 8822 dust mask was the least effective throughout the study and proved to provide a little less protection than the re-usable devices. However the dust mask is not equipped to provide protection against gases and vapours and therefore is not recommend to be used within the furnace.¹⁹ The dust mask is also a disposable device with a service life of up to eight hours, which is a much shorter usage period than that of the 3M 6000 and Moldex 8000, which can be used for 40 hours depending on exposure and work activity. The filter capacity of the disposable devices is therefore much lower than the re-usable respiratory devices.

The effect of the facial hair on the efficiency of respirators was also investigated and it was found that the beard/moustache factor indicated a tendency toward higher TWA concentrations than those without the beard, as indicated in Figure 3. The 3M 8822, Moldex 8000 and air-stream helmet showed increased concentrations during the beard test. These results are consistent with current literature that shows that facial hair does have a significant effect on the seal efficiency of

the tight-fitting respirators. Hence, manufacturers recommend that tight-fitting respirators only be used on a clean-shaven skin. However, some institutions recommend that people with facial hair should rather use powered purifying devices with loose-fitting helmets and hoods, as long as the facial hair does not interfere with the valve or function of the respirator. During this study, a significant effect on a 95% level of confidence was found with the air-stream helmet. Because of the limited number of samples taken with the air-stream helmet, it cannot be stated with assurance that facial hair has an effect on the effectiveness of the air-stream helmet. From this study there was no conclusive evidence on a 95% confidence level that facial hair had a limiting effect on the seal efficiency of any of the respiratory devices tested.

CONCLUSIONS

In this study it was found that respiratory protection equipment has proven to be an efficient control method for reducing airborne contaminant exposure during the platinum crushing and refining processes. However the respiratory devices used provide insufficient protection within the furnace during the exposure to SO₂ and CTPV. Therefore the different sampling areas and airborne contaminants showed to have had a significant effect on respirators efficiency. Nevertheless, the effect of facial hair on respirator efficiency is inconclusive, because insufficient data that were obtained during the study due to high costs and time limitations. The lowering in respiratory efficiency by facial hair, however, cannot be ruled out completely and the data indicated a tendency towards less protection by respiratory devices if facial hair is present.

RECOMMENDATIONS

During the survey the effectiveness of respirators was indicated. It is recommended that further studies be done that focus on one specific sampling area and airborne contaminant. Studies should distinguish between different respirators concerning their service life and capacity specification. Devices from different supplies within the same functioning category should be tested against each other and compared with current laboratory results that incorporate factors like breathing and respiration. Tests concerning the air-stream helmets should also look at the air flow rate in comparison with filter efficiency.

Factors like facial hair should be tested independently, using tight-fitting respirators and a variety of artificial beards and moustaches. Using mannequins as test subjects seemed to be an effective test method within the actual work environment, but should also be integrated with data from laboratory tests.

REFERENCES

1. National Regulator for Compulsory Specifications. Minimum safety regulations for respiratory protective devices in South Africa. [Online]. 2009 [cited 2009 Jun 23]. Available from: URL:<http://www.nrccs.org.za/content.asp?subID=45>
2. Mine Health and Safety Act of 1996. Act 22.9. (Sep 2002).
3. Clayton MP, Bancroft B, Rajan B. A review of assigned protection factors of various type and class of respiratory protective equipment with reference to their measured breathing resistance. *Ann. Occup Hygien* 2002; 46(6): 573-547.
4. Approval of respiratory protection devices, 42 C.F.R. Part 84 (2003)
5. Johnson AT, Frank CK, Jamshidi S. Human subject testing of leakage in loose fitting PARP. *J. Occup Environ Hygien* 2008;5:325-329.
6. Lawrence RB, Dulling MG, Calvert CA, Coffey CC. Comparison of performance of three different types of respiratory protection devices. *Occup. Environ. Hygien.* 2006;3:465-474.
7. Balazy A, Toivola M, Reponen T, Podgorski A, Zimmer A, Grinshpun SE. Manikin-based performance evaluation of N95 filtering face-piece respirators challenged with nanoparticles. *Ann Occup Hyg* 2006;50(3):259-269.
8. The National Personal Protective Technology Laboratory. Program concept for total inward leakage performance requirements and test methods. [Online]. 2004 [cited 2008 Apr 20]. Available from: URL:<http://www.cdc.gov/niosh/npptl/standardsdev/til/>
9. Respiratory Protection Code, 29 C.F.R. Sect. 1910.134. (2006)
10. Vaughan N, Rajan-Sithamparanadarajah B. Meaningful workplace protection factor measurements: Experimental protocols and data treatment. *Ann Occup Hyg* 2005;49(7):549-561.
11. Janssen L, Bidwell J, Cuta K, Nelson T. Workplace performance of hood style supplied air respirators. *J Occup Environ Hygien* 2008;5:438-443.
12. Janssen L, Cuta K, Nelson T. Workplace performance factors for N95 filtering facepiece respirators. *J Occup Environ Hygien* 2007;4:698-707.
13. Renstrom A, Karlsson AS, Tovey E. Nasal air sampling used for the assessment of occupational allergen exposure and the efficiency of respiratory protection. *Clin Exp Allergy* 2002;32:1769-1775.
14. National Personal Protective Technology Laboratory. Letter to all respirator manufacturers. [Online]. 2006 [cited 2008 Sept 21]. Available from: URL:<http://www.cdc.gov/niosh/npptl/resources/pressrel/letters/ltr-100206.html>

15. Occupational Safety and Health Administration. Regulations (Standards-29 CFR) Respiratory protection standard – 1910.134. [Online]. 2006 [cited 2007 Jun 27]. Available from:
URL:http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=12716&p_table=standards
16. National Institute for Occupational Safety and Health. NIOSH manual of analytic methods: [Online]. 2003 [cited 2007 Mrt 21]. Available from: URL:<http://www.cdc.gov/niosh/docs/2003-154/pdfs/7300.pdf>
17. National Institute for Occupational Safety and Health. NIOSH manual of analytic methods. [Online]. 2003 [cited 2007 Mrt 21]. Available from: URL:<http://www.cdc.gov/niosh/docs/2003-154/pdfs/6004.pdf>
18. Occupational Safety and Health Administration. Sampling and analytic methods for coal tar pitch volatile. [Online]. 2007 [cited 2007 Mrt 21]. Available from:
URL:<http://www.osha.gov/dts/sltc/methods/organic/org058/org058.html>.
19. 3M Occupational Health Group. 8822 Respirator. [Online]. 2002 [cited 2009 Sep 21]. Available from:
URL:http://www.afrox.co.za/downloads/products_services/safety/head_face/8822%20Respirator.pdf
20. 3M. Respiratory protection. [Online] 2006 [cited 2009 Oct 20]. Available from:
URL:<http://www.safetyfirstind.com/products/ppe/RespiratorProtection.pdf>

CHAPTER 4
CONCLUDING CHAPTER

4.1. CONCLUSION

In this study the effectiveness of respiratory protection currently being used during platinum processing was quantified to provide information on the efficiency of the different devices.

During platinum processing, employees are exposed to various health hazards which consist mostly of hazardous chemical substance exposures. For this reason employees are provided with respiratory protection which is used in conjunction with other engineering and administrative control measures. However, determining the effectiveness of respiratory devices is very complex. Various factors such as correct usage, its adequacy for different types of airborne contaminants, task performed, degree of training, breathing resistance, proper fitting, vapour accumulation and facial features all contribute to the difficulty of determining the actual efficiency of a particular respirator. Sampling equipment and methods for determining exposure concentration that incorporate all of these factors are very expensive and require specialized training.

The study therefore focused only on measuring the exposure concentration on the inside of the face piece, using mannequins fitted with various respiratory devices and standard personal sampling methods. From this, hypotheses one and three can be accepted, which state that (1) respiratory protection is an effective control measure to reduce exposure concentration; and (2) the sampling areas do have an effect on the efficiency of respiratory devices. Different respirators are supplied for each area, such as dust masks, cartridge/canister respirators and air-stream helmets. Comparing the efficiency of the different devices within selected work environments provided valuable information that can be used when selecting respirators. The air-stream respirator proved to be the most efficient device. However, because of its weight and bulk, employees at the tank house prefer not to use this device. The exposure concentration from this study can be used to inform employees of the effectiveness of this device, possibly making them more eager to make use of it. The 3M 6000 and Moldex 8000 are used in all areas of platinum processing. They are functionally identical and proved to provide more or less the same protection. Information gained during the study will come in useful during the selection process and provide the opportunity for employers to select respirators

CHAPTER 4
CONCLUDING CHAPTER

according to personal preference or financial ability. Even more important, proper fit tests can be done to determine which of these devices provide a proper fit, especially for workers with facial deformities. Area testing is also critical. Determining the efficiency of respirators in respect of specific airborne contaminants can also help during the selection process, ensuring that the devices that are selected provide sufficient protection as stated by the manufacturer. Further testing within the furnace should be conducted to determine conclusively whether the respiratory devices that are currently being used within this area provide sufficient protection.

In comparison, hypothesis two cannot be accepted. The effect of facial hair on the respiratory efficiency of the test devices could not be determined and the results were inconclusive. Most of the exposure concentrations indicated an increase in concentration during the beard test, but were not significant on a 95% level of confidence. The only device that showed a significant effect was the air-stream helmet. These results contradict most literature. However, only two samples were taken using this device and therefore, it cannot be stated with statistical certainty that facial hair has an effect on the respiratory efficiency of a device.

During the study it was observed that employees were reluctant to wear their respiratory protection. It was found in numerous instances that respirator cartridges had expired or filters exceeded their service life. The employees showed much interest during the study; showing them samples that were taken on the inside of the devices in comparison to the environmental concentrations, created an awareness on the importance of respiratory protection. However most employees are unwilling to wear there RPE and from observation minimal efforts are made by management and supervisors to ensure that employees do comply and wear there RPE. It is therefore clear that a well planned respiratory protective management program could go a long way to educate the employees on the benefits of wearing their RPE.

4.2. STUDY LIMITATION

The two major shortcomings of the study were limited finances and time. To cover most of the areas that pose a health concern, only limited numbers of samples

CHAPTER 4
CONCLUDING CHAPTER

could be taken within each area. Making use of life-size mannequins placed within the work environment provided actual workplace exposure concentrations. Nonetheless, human factors like breathing resistance, inspiration and expiration could not be accounted for. Another limitation was the difference in service life, functionality and capacity factors of the different devices.

4.3. RECOMMENDATIONS

It is recommended that more studies be conducted, testing respiratory device efficiency using mannequins and standard sampling techniques. These studies should focus on one specific sampling area and repeated sampling should be conducted over a period of time. It is also recommended that respiratory devices from different suppliers, but with the same service life and characteristics, be compared with each other to provide information on which device is best for a specific sampling area. The beard/moustache test should be conducted separately from standard sampling, with more repeats. Feedback should be given to employees concerning results. This will create awareness on how effective respiratory devices are, the effect of facial hair and how important it is for employees to wear the respiratory protection. During the study the respiratory protective management program was evaluated through basic observation during daily activities to determine the effectiveness thereof. It is therefore recommended that a further investigation be done to determine the overall effectiveness of the current respiratory protective management program currently implemented at the platinum producer.

CHAPTER 5
RESPIRATORY PROTECTION MANAGEMENT PROGRAMME

5.1. RESPIRATORY PROTECTION MANAGEMENT PROGRAMME

The respiratory protection management programme from the basis of effective and correct usage of RPE. More importantly forms a fundamental part of managements attempt to lower airborne contaminant exposures within the workplace. It was therefore seen fit to observe the respiratory protective management program currently implement by the platinum producer. The current implemented respiratory protective management programme will firstly be discussed and thereafter possible limitations that were observed are noted under the recommendation section of this chapter. The following general observation was noted according to visual observation and written respiratory protective management programmes implemented by the platinum producer:

5.2. POLICY

The platinum producer has developed and implemented respiratory protective programmes according to the international OSHA respiratory standards 29 CFR 1910.134. These MHSA and SABS/SANS standards were used as guidelines during the development of the programme.^{1,2,3,4,5} Each respiratory protective programme was developed for a specific area and information relevant to the particular facility is added and adjustments to each programme are specific to the different departments/sections.

The aim of the respiratory protection programme is to establish minimum requirements for the use of respiratory protective equipment. It is intended to ensure that workers are protected against excessive inhalation of hazardous airborne pollutants by providing respiratory protection in areas where the implementation of engineering and administrative controls was not effective.

5.3. RESPONSIBILITIES

Any respiratory protection programme need to managed and designated persons should be assigned to implement, maintain and review the program. The platinum

CHAPTER 5
RESPIRATORY PROTECTION MANAGEMENT PROGRAM

producer assigned the following persons each form a distinctive role in the respiratory protective management program.

5.3.1. Employer

The organization's management is responsible for providing respirators to employees when it is necessary for health protection. The organisation provides respirators that are applicable and suitable for the intended purpose to affected employees, at no charge. Any expenses associated with training, medical evaluations and respiratory protection equipment are borne by the company.

5.3.2. Programme administrator

The programme administrator is the person responsible for developing and administering the respiratory programme. The office of OHS is responsible for establishing and maintaining the respiratory protective programme. This administrator is a qualified individual and has relevant experience in the training, proper selection, correct use, maintenance and continuous evaluation of the programme. The occupational hygienist is appointed as the programme administrator and even though the respiratory protective programme is the responsibility of the hygienist, he/she can delegate some of the responsibilities to other qualified individuals within the health and safety committee. The main duties of the administrator are to keep up with respiratory regulations, identify and evaluate hazardous areas, select respirators, conduct fit tests, provide proper training, update the programme as needed and conduct employee compliance evaluation.

5.3.3. Supervisors

The supervisor in each section is responsible for ensuring that the respiratory protective programme is implemented in their area. They are informed and familiar with the respiratory protection programme and specific regulations regarding the use of respiratory protection. Supervisors promote and enforce compliance amongst employees to wear the correct respiratory protection in demarcated areas and

assist the administrator in identifying hazardous areas. The supervisor should support the occupational hygienist in hazard identification.

5.3.4. Employees

Each employee is responsible for wearing their respiratory protection in areas when and where required. Employees are informed of the legal aspects and are required to obey and comply with aspects of the respiratory programme. Employees are responsible for taking care of their respiratory protection and ensuring that it is stored in a bag that fits comfortably around the waist or in a sanitized place. Employees are advised to report any defects of the device to the supervisor.

5.4. PROGRAMME

The following section briefly describes the respiratory protection management program of the platinum producer.

5.4.1. Risk assessment

Before the selection of respiratory protective equipment was done, a competent person under the supervision of the occupational hygienist conducted a hazard evaluation that included occupational hygiene monitoring of the specific task and area. The nature of the task, work period and physical and psychological stress were noted. Concentrations obtained from monitoring the task area were then compared with occupational exposure limits. Respirator selection was then conducted according to manufacturers' instructions. The respiratory zones are demarcated with symbolic signs for either disposable or cartridge respirators.

5.4.2. Medical

Using a respirator places a physiological burden on the employees depending on the work task, environment and the type of respirator. A medical evaluation programme is implemented to determine each employee's state of health and whether the employee is fit for physical work. The medical evaluation is conducted

before the employee is fit tested for a respirator or required to work. Medical eligibility is determined by the physician or occupational nurse at the medical centre.

5.4.3. Selection

All respirators are selected specifically for each work environment, and are appropriate for the specific contaminant's physical and chemical properties and the conditions under which employees must work. All respirators have a homologation certificate certified by the SABS as required by the MHSA. The selection is based on an exposure assessment and relevant workplace and user factors which are done annually. A group PPE matrix is used for the selection of respiratory devices according to risk assessments conducted within each area. Respiratory protection is distributed from the general storeroom. The store foreman makes use of an electronic database which indicates which personal protective equipment is approved for which area. The employee's access card is then swiped and data regarding issuing dates, type of respirators and work areas are all displayed electronically.

5.4.4. Training

The human resources department of each plant provides training to all supervisors and employees, informing them of the respiratory protection programme, legislation and standards. Training is normally done during induction, before employees commence with the work activities. During the platinum-specific induction, occupational hazards encountered in the area and its health effects are also discussed.

5.4.5. Fit tests

Because of the large numbers of employees and contractors on site, the effective fit test is not always conducted on each employee that is provided with a tight-fitting face piece respirator. Different suppliers are used, offering a choice of selection of

devices. However, all devices are not always kept in stock; this is dependent on cost and availability from suppliers.

5.4.6. Maintenance, inspection and storage

The employer provides each employee with a respirator that is clean, sanitary and in good working condition. If a respirator is used by more than one user, the device is cleaned after every use. Employees are advised to clean respirators and inspect the respirator before use. However, this is not common practice. Employees store respirators in a material bag that can fit around the waist and the bag is kept in the employee's locker.

5.4.7. Record-keeping

A copy of the respiratory protection programme is kept at the office of the programme administrator or health and safety department and is available to employees that would like to review it. All information on the issuing of respirators is electronically captured and can be evaluated on request. However, because of the large numbers of employees working on the plants, individual checks are not always feasible.

5.5. PROGRAMME EVALUATION

The programme administrator periodically re-evaluates the work environment or when a change in the process or work activities has taken place. During the re-evaluation it will be determined if the current respiratory programme is still effective and being implemented as intended.

The evaluations will include regular consultations with employees who use respirators and their supervisors, site inspections, air monitoring, review of records and cost efficiency. Identified problems are addressed to the programme administrator. These findings are then reported to management, and the report will list plans to correct deficiencies in the respirator programme and target dates for the implementation of those corrections.

5.6. RECOMMENDATIONS

The following recommendations are provided to assist management with the management of the current respiratory protection system and encourage further investigation within certain aspects of the programs.

5.6.1. Medical evaluations

Medical evaluations include the completion of a medical questionnaire or a medical examination that provides the same information. Factors such as burden imposed by respirator, including weight and breathing resistance, duration and frequency used, musculoskeletal stress temperatures and humidity extremes that may be encountered are evaluated. The occupational practitioner should prepare a written report regarding the employee's physical ability to use the respirator. The medical evaluation should be reviewed annually and all records must be kept.

5.6.2. General respirator use

A respirator should not impair a worker's movement, vision, hearing and communication needed to perform the task. Assigned protection factors according to the new OSHA regulation should be used during selection. When using air-purifying respirators they should be awarded an indicator of the end of service life, or a cartridge/canister schedule should be set in place and the cartridge/canister must be changed before the respirator reaches its end of service.

Facial features and personal preference should also be taken into account. A respirator is only effective if it is properly fitted; if it is not comfortable, the employee will be hesitant to wear it. If the exact exposure cannot be determined, the employer should apply the more protective APF rule.

Implementation procedures for the proper use of respiratory devices should be established. Employees should use their respirators under conditions specified in the respiratory protective programme and in accordance to training that they were

given on the specific device. All employees should conduct either a negative or positive pressure seal test before the respirator is used.

The positive seal test is performed by closing off the exhalation valve by hand. Air is then breathed into the mask. The face fit is satisfactory if some pressure can be built up inside the mask without any air leaking out between the mask and the face of the wearer.

The negative pressure test is performed by closing off the inlet openings of the cartridge with the palm of the hand. Some masks may require that the filter holder be removed to seal off the intake valve. The user then gently inhales to form a vacuum within the face piece. The breath should be held for ten seconds. If the vacuum remains, and no inward leakage is detected, the respirator is fitted properly.

Employees with deformed facial features and facial hair should not be allowed to wear tight-fitting respirators. If corrective glasses/goggles or any other form of respiratory protection is used, it must be ensured that when worn it should not interfere with the seal of the respirator.

5.6.3. Training

From observations it was clear that employees are reluctant in wearing their RPE indicating the ineffectiveness of the current training program. Training before the usage of respirators needs to be conducted and should include the following:

- Use data from this study or related studies to illustrate the effectiveness of RPE currently being used (especially the air stream helmet used in the tank house).
- Proper selection and use of respirators
- Possible limitations
- Respirator seal checks
- Fitting tests
- Procedures for inspection
- Maintenance and storage procedures
- Medical symptoms and effects of ineffective respirator usage.

Training should be given annually by the supplier representative and should be done according to the educational level of employees. The trainer should ensure that employees fully understand all aspects of the respiratory programme and will be able to use the respirators effectively.

5.6.4. Fit testing

It has long been recognized that respirators must fit properly to provide protection. If a respirator seals properly around the face, it only creates the illusion of protection. Facial characteristics vary among individuals. A number of manufacturers offer facepieces in several sizes and models. All employees wearing tight-fitting air-purifying respirators and atmosphere-supplying respirators should be fit tested to ensure that the respirator selection fits the employees well enough to provide adequate protection.

The fit test should be conducted according to international standards and recommendations. These fit tests may be either qualitative fit tests (QLFT) or quantitative fit tests (QNFT). The respirator should be worn for at least five minutes before the test is conducted. The worker should be fitted with the same make, model, style and size that will be used in the workplace.

Qualitative testing (QLFT) involves the introduction of a gas, vapour or aerosol test agent into an area around the head of the respirator user. Before the test the user must undergo a sensitivity test to determine how they react to the testing agent. It is then determined whether or not the user detects the presence of the agent through odour, taste or nasal irritation. If any sensation occurs, the respirator fit is considered inadequate. The four OSHA approved tests are (1) isoamyl acetate, which produces a predominant smell; (2) saccharin and (3) BitrexTM – these substances have a distinctive taste – and (4) a smoke test that elicits an involuntary irritation.

In a qualitative fit test the adequacies of the respirator fit is assessed by numerically measuring the amount of leakage into the respirator. Test aerosols, ambient aerosols or controlled negative pressure can be used to measure the volumetric

leak. Appropriate instruments are needed to quantify the respirators' fit and provide a qualitative fit factor. This factor is the ratio of the outside concentration to the concentration inside the respirator facepiece.

5.6.5. Maintenance, inspection and storage

Respirators need to be regularly cleaned and disinfected to prevent skin irritations or dermatitis and encourage worker acceptance. The accumulation of contaminants on the respirator face seal or within the respirator can reduce the protection, compromise the seal and even lead to deterioration of the respirator material. Therefore, respirators should be cleaned and disinfected as often as necessary.

Employees should inspect the respirator before and after use. This inspection should include a check of the respirator function, tightness of connections, the condition of the various sections, any limitations to the facepiece, head straps, valves, connecting tube, cartridges, canisters or filters. The electrometric parts must be evaluated for pliability or deterioration. All respirators that fail to pass the inspection shall be removed from the service inspection and arranged to be repaired or disposed of.

After inspection, cleaning, and necessary repairs, respirators shall be stored appropriately to protect them against dust, sunlight, heat, extreme cold, excessive moisture, or damaging chemicals. Respirators must be stored in a clean, dry area, and in accordance with the manufacturer's recommendations. Each employee cleans and inspects their own air-purifying respirator in accordance with the provisions of this programme, and stores their respirator in a plastic bag in the designated area.

Each employee must have his/her name on the bag and that bag will only be used to store that employee's respirator. Respirators must be packed or stored so that the face piece and exhalation valve rest in a near normal position. Respirators must not be placed in places such as lockers or toolboxes, unless they are in carrying cartons.

CHAPTER 5
RESPIRATORY PROTECTION MANAGEMENT PROGRAM

Respirators maintained at stations and work areas for emergency use have to be stored in compartments built specifically for that purpose, be quickly accessible at all times, and be clearly marked.

The record of medical evaluations for each employee must be retained and must include a medical questionnaire and written report and recommendation of the PLHCP.

5.6.7. Records

A fit test record must be kept until the next fit test is administered and should include: name, type of fit test, make, model and size of respiratory fit, date of issue and pass or fail results when QLFT tests were done.

The key element of an effective respiratory protective management program is based on the relationship between management and the employees. A good relationship between management and employees can have a wealth of benefits which include⁶:

- The effective use, maintenance of respirators lowering replacement and repair cost
- Better morale cuts down on absenteeism and can spill over to other areas where trust and communication improve performance;
- Workers are more likely to wear the respirators, reducing the risk of illness and lost workdays;
- The risk of perceived illness declines, potentially reducing the number of respiratory disease allegations against the company.

The implementation and execution of the respiratory protection management system should be a team effort and management, supervisors and employees should work together and encourage each other to wear and maintain the respiratory protection, which in the end can lower costs and, more important, save lives.

REFERENCES

1. Regulation of Hazardous Chemical Substances. r 11. (Aug 25 1995)
2. Mine Health and Safety Act of 1996. r 22.9 (Sep 2002).
3. South African Buro of Standards. Homologation of respiratory equipment; SABS 0338:1999/SANS 10338;1999
4. South African Buro of Standards. The selection, use and maintenance of respiratory protective equipment. SABS 0220/SANS 10220;1988
5. South African Buro of Standards. Respiratory equipment for protection against harmful particulates and gas. SABS 1455/SANS 1455-1;1988.
6. Nash, J. Working together for respiratory protection. [Online]. 2003 [cited 2008 Nov 20]. Available from: URL:http://ehstoday.com/ppe/respirators/ehs_imp_36373/