

Evaluation of surface sampling methods for platinum salts

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20102011
B.Sc. and B.Sc. Hons.

Mini-dissertation submitted in fulfilment of the requirements for the degree
Master of Science at the Potchefstroom Campus of the North-West
University

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November 2010

• Getting it right • Re dira sentle • Ons doen dit reg



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PREFACE

For the purpose of this project it was decided to use article format. For uniformity the whole mini-dissertation is written according to the guidelines of the chosen journal for potential publications which is the Annals of Occupational Hygiene. The journal requires that the references in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones *et al.* (1995) if there are more than two authors and the list of references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation.

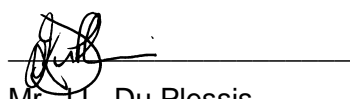
AUTHOR'S CONTRIBUTION

This study was planned and executed by the following team:

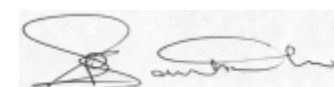
NAME	CONTRIBUTION
Ms. M. Nel	<ul style="list-style-type: none">• Writing of the protocol and proposal.• Responsible for the surface sampling.• Literature research, statistical analysis, writing of the articles.
Mr. J.L. Du Plessis	<ul style="list-style-type: none">• Supervisor• Assisted with designing and planning of the study, approval of protocol, reviewing of the mini-dissertation and documentation of the study and analysis and interpretation of results.
Mr. P.J. Laubscher	<ul style="list-style-type: none">• Co-supervisor• Assisted with the approval of the protocol, interpretation of the results, reviewing of the documentation of the study.

The following is a statement from the supervisors which confirms each individual's role in the study:

I declare that I have approved the article and that my role in the study as indicated above is representative of my actual contribution and that I hereby give my consent that it may be published as part of Minette Nel's M.Sc (Occupational Hygiene) mini-dissertation.



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ACKNOWLEDGEMENTS

With great appreciation, the author would like to thank the following contributors regarding their input to this project and their support:

- **Mr. J. Du Plessis**, my supervisor. Thank you for all your input, help and guidance throughout the year concerning this mini-dissertation. Thank you for all the advice you gave me to improve my mini-dissertation and for always being willing to help.
- **Mr. P.J. Laubscher**, my co-supervisor. I would like to thank you for your insight and recommendations regarding this mini-dissertation.
- **My parents**. Thank you for your love and support. Thank you for all the sacrifices and hard work that made it possible for me to make a success of my studies.
- **My siblings**. Thank you for all your love and support and for always believing in me.
- **My grandparents**. Thank you for all the prayers and positive thoughts which carried me throughout these 5 years of study.
- **Mr. Stephen Engelbrecht**. Thank you for all your insight, advice and guidance throughout this project.

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SUMMARY

TITLE: Evaluation of Surface Sampling Methods for Platinum Salts.

Motivation: The health effects of platinum on the human body are a great concern. It affects the respiratory system as well as the skin. The demands for platinum have seemingly increased over the last few years due to its use in automobile exhaust gas catalysis. Thus there will be an increase in the production and processing of platinum and therefore a greater possibility of exposure to platinum compounds. This is why it is of great importance to evaluate the surface sampling methods, to ensure that they are effective for platinum use. **Objectives:**

1) To evaluate and compare a few different surface sampling methods for removal of platinum salts from contaminated surfaces in order to determine which one of these methods has the best retention and recovery efficiency. 2) To use the most effective method to monitor surface contamination on porous and non-porous surfaces in a platinum refinery. **Methods:**

Two types of filters (mixed cellulose ester and polyvinyl chloride) and Ghostwipes™ were evaluated and compared in this study. Platinum solution (hexachloroplatinic acid) concentrations of 50, 150 and 300 µg Pt/ml solution were used. The retention efficiency of the different sampling mediums was tested by releasing 1 ml of each concentration directly onto the sampling medium. Efficiencies were tested on a non-porous (glass) and porous surface (semi-face bricks). This was done to see how the collection efficiency of the medium will differ on these two surfaces. A total of three wipes were used per surface, however were analyzed individually.

All the samples were analyzed using the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analytical method by an accredited laboratory. **Results:** The results obtained indicated the retention and recovery efficiencies of the three sampling mediums at the three platinum concentrations of 50, 150 and 300 µg Pt/ml solutions. The retention efficiency of the Ghostwipes™ was 93.2% at 50 µg Pt/ml solution, 95.3% at 150 µg Pt/ml solution and 93.6% at 300 µg Pt/ml solution, whilst the mixed cellulose ester (MCE) filters and polyvinyl chloride (PVC) filters were lower than 30% at all three concentrations. The overall recovery efficiencies of all three concentrations of the Ghostwipes™ and MCE filter were the highest: the Ghostwipes™ with levels of 73.9 %, 84.4% and 63.5% and the MCE filters with levels of 71.4%, 84.4% and 80.2%, whilst the PVC filters did not achieve levels above 60%. The wipe materials were also evaluated in terms of the ASTM E1792 standard requirements for wipe materials.

Conclusion: Ghostwipes™ were found to be the most suitable sampling medium based on retention and recovery efficiencies. The Ghostwipes™ also complies with all the requirements listed in the ASTM E1792 standard for wipe materials, which makes it the most suitable wipe sampling material. The MCE and PVC filters however do not comply with all the ASTM E1792 requirements.

Keywords: surface sampling, platinum solution, platinum salts, retention efficiency, recovery efficiency.

OPSOMMING

TITEL: Evaluering van verskillende oppervlakmoniteringsmetodes vir platiniumsoute.

Motivering: Die gesondheidseffekte van platinum op die menslike liggaam is 'n groot probleem. Dit affekteer die respiratoriese stelsel en ook die vel. Aangesien die aanvraag vir platinum baie verhoog het die afgelope paar jaar as gevolg van die gebruik daarvan as voertuiguitlaatgaskatalis, gaan daar meer platinum produksie wees en sodoende 'n hoër blootstelling van werkers aan die platinum komponente. Dus is dit belangrik om die oppervlakmoniteringsmetodes te bestudeer om te verseker dat dit effektief is ten opsigte van platinum. **Doelstellings:** Die doelstellings van hierdie projek is om 'n paar verskillende oppervlakmoniteringsmetodes vir die verwydering van platiniumsoute te vergelyk en te bepaal watter metode die beste gepas is vir platiniumsoute, asook om dan die mees effektiewe metode te gebruik om oppervlaktes in die platinum-werksarea te monitor. **Metodologie:** In hierdie studie is twee tipes filters nl. gemengde sellulose ester en poliviniel chloried en Ghostwipes™ geëvalueer en met mekaar vergelyk. Platinum oplossings van konsentrasies 50, 150 en 300 µg Pt/ml is aangemaak. Die behoudingsvermoë van die drie moniteringsmediums was getoets deur 1 ml van elke konsentrasie direk daarop te laat drup. Die herwinningsvermoë van die mediums is getoets vanaf 'n gladde oppervlakte (glas) sowel as op 'n poreuse oppervlakte (baksteen). Dit is gedoen om te sien of die herwinningsvermoë van die drie mediums verskil op die twee verskillende oppervlaktes. 1 ml van elk van die drie konsentrasies is op 10 cm by 10 cm areas neergedrup en gelos vir 1-3 ure sodat dit droog kan word, waarna dit dan gemoniteer is. Al die monsters is geanaliseer deur die induksie-gekoppelde plasma atoom vrystellingspektroskopie (ICP-AES) analitiese metode deur 'n geakkrediteerde laboratorium. **Resultate en Gevolgtrekking:** Die resultate wat in die studie gekry is, het gedui daarop dat die behoudingsvermoë van die Ghostwipes™ hoër was as 90% by al drie die konsentrasies (93.2%, 95.3% en 93.6% onderskeidelik), terwyl die van die gemengde sellulose ester filters en poliviniel chloried filters beide laer as 30% was. The totale herwinningsvermoë van die Ghostwipes™ en die gemengde sellulose ester filter was die beste. Die Ghostwipes™ met vlakke van 73.9 %, 84.4% en 63.5% en die gemengde sellulose ester filter met vlakke van 71.4%, 84.4% en 80.2%, terwyl die vlakke van die poliviniel chloried filters laer as 60% was. Die moniteringsmediums was ook geëvalueer in terme van die ASTM E1792 standaard vereistes vir oppervlakmoniteringsmediums. Die gevolgtrekking was dat die Ghostwipes™ die beste metode is in terme van die behoudingsvermoë en herwinningsvermoë. Die Ghostwipes™ voldoen ook aan al die vereistes wat genoem word in die ASTM E1792 standaard vir oppervlakmoniteringsmediums, wat bevestig dat dit die mees gepaste metode is. Die gemengde sellulose ester en poliviniel chloried filters het nie aan al die ASTM E1792 vereistes voldoen nie.

Sleutelwoorde: oppervlakmonitering, platinum oplossings, platiniumsoute, behoudingsvermoë, herwinningsvermoë.

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

%:	Percentage
µg/cm³:	Microgram per cubic centimetre
µg/ml:	Microgram per millilitre
µg:	Microgram
cm:	Centimetre
g:	Gram
ml:	Millilitre
mm:	Millimetre
ppm:	parts per million

ABBREVIATIONS

HCN:	Health Council of the Netherlands
ICP-AES:	Inductively coupled plasma atomic emission spectroscopy
MCE:	Mixed cellulose ester
PGE:	Platinum group elements
PGMs:	Platinum group metals
PVC:	Polyvinyl chloride
WHO:	World Health Organization

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CHAPTER 1
GENERAL INTRODUCTION

1. Introduction

Before automobile exhaust gas catalysts were introduced, platinum was mostly used in the jewellery-, glass- and industrial sector and as a catalyst in the chemical- and petroleum industry (Lindell, 1997). The demand for platinum group metals (40-50% is platinum) production has gradually increased worldwide since automobile exhaust gas catalysts were introduced and is expected to increase even further due to the increased use of automobile catalysts and the further advancement of fuel cells (Cristaudo *et al.*, 2005; HCN, 2008). South Africa accounts for 90% of the world's platinum mining and due to the increasing demand for platinum, and consequently an increase in platinum mining and refining, the potential of workers being exposed to platinum will increase (HCN, 2008).

The major concern regarding the exposure to these platinum group metals, is their sensitising potential in particular their salts which contain reactive ligands (Cristaudo and Picardo, 2007; Wiseman and Zereini, 2009). These platinum salts and other compounds may all be present in the workplace, and are all highly reactive elements capable of causing inflammatory and mediated immunological effects among exposed workers (Cristaudo *et al.*, 2005). The mechanism of allergy to platinum salts is a type I allergy with an immediate reaction to inhalation or contact with these complex salts. The number of leaving-halide ions in the platinum complex is correlated to their allergenic potential (Linnett, 2005). Platinum salt sensitivity, with symptoms such as immediate or delayed asthma, rhinitis, urticaria or dermatitis, has been diagnosed in workers in response to platinum salts exposure (Calverley *et al.*, 1999).

In past years the focus has mostly been on the inhalation exposure pathways, as it was considered to be the most important route of exposure. However since then dermal contact with contaminated surfaces has also been found to be an important route of exposure to hazardous chemical substances (Wheeler and Stancliffe, 1998). Dermal contact with contaminated surfaces can lead to contaminants entering the body by either percutaneous absorption and/or by ingestion due to hand to mouth transfer (Wheeler and Stancliffe, 1998; Schneider *et al.*, 2000). Methods for measuring surfaces other than the skin, e.g. clothes and other surfaces that contribute to exposure by contact and transport between such surfaces, have become of great interest (Lundgren *et al.*, 2006).

The manual wipe is the method used most commonly by industries to conduct surface sampling for metals (Wheeler and Stancliffe, 1998). Studies conducted on surface sampling methods used for other metals such as beryllium and lead has been widely published. In a study done by Vincent *et al.* (2009) for the sampling of beryllium on surfaces, the manual wipe method was used by means of Ghostwipes™. In terms of lead sampling on surfaces, standard NIOSH methods 9100 and 9105 have been developed. However, regarding assessment of surface

contamination and the sampling methods used, published literature on platinum is limited to antineoplastic drugs. These drugs include platinum complexes such as cisplatin, oxaliplatin and carboplatin (Brouwers *et al.*, 2007; Schierl *et al.*, 2009). These studies report surface contamination in hospital pharmacies. However, there is no published literature reporting surface contamination in refineries.

The surface sampling medium currently being used by the platinum refinery is the mixed cellulose ester membrane filters with distilled water as the solvent. In this study three different methods will be evaluated to determine the most suitable method for assessing surface contamination by platinum salts in refineries. Hexachloroplatinic acid (salts) will be the platinum salt used to represent platinum contamination in this study.

2. Aims and Hypothesis

The aims of this study are:

1. to evaluate and compare different surface sampling methods to establish the most effective method for assessing platinum surface contamination, and
2. to assess surface contamination in the workplace/refinery by making use of the most efficient method.

The hypothesis of this study is:

- Based on retention and recovery efficiencies, the Ghostwipes™ are more efficient in collecting platinum from surfaces than mixed cellulose ester (MCE) and polyvinyl chloride (PVC) filters.

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CHAPTER 2
LITERATURE STUDY

1. Literature overview

This literature study will focus on exposure to platinum, refining, health effects thereof and the methods used for assessing surface contamination of metals including platinum in the workplace.

1.1 Platinum

Platinum is a silver-grey noble metal which is rarely distributed over the earth's crust (HCN, 2008). Its average concentration in the rocky crust of the earth is approximately 0.001-0.005 mg/kg (WHO, 2000). Platinum is a third- row transition metal and has an atomic number of 78. In platinum compounds its main oxidation states are +2 (most common) and +4 (Giandomenico & Matthey, 1996).

1.2 Commercial uses of platinum

Platinum is used in the glass-, chemical-, electrical-, electronics- and petroleum industries, in medicine, in the manufacturing of jewellery as well as in dentistry as alloys (Matthey, 2009). Platinum has great commercial value due to its high resistance to corrosive agents and its oxidation and reduction catalyst properties. These specific properties have led to highly-developed technical applications in the field of catalysis as part of chemical- and petroleum applications (Cristaudo *et al.*, 2005). Platinum has therefore become a valuable product, being used as automobile exhaust catalyst to convert poisonous gas emissions into more benign forms (Wiseman and Zereini, 2009). The demand for platinum has thus steadily increased over the last three decades to meet its demand for use in this broad range of applications, especially in the automobile exhaust catalyst industry (Wiseman and Zereini, 2009).

1.3 Refining of platinum

Platinum group metals (PGMs) are obtained from mined ore and from recycled metal. Refining is done by a chemical process which initially requires that PGMs are dissolved in concentrated acids before being separated from each other, followed by purification (Linnett, 2005). The following flow diagram (Figure 1) demonstrates the refining process used at one of the South African platinum refineries.

Precious Metals Refinery Metallurgical Flow Sheet

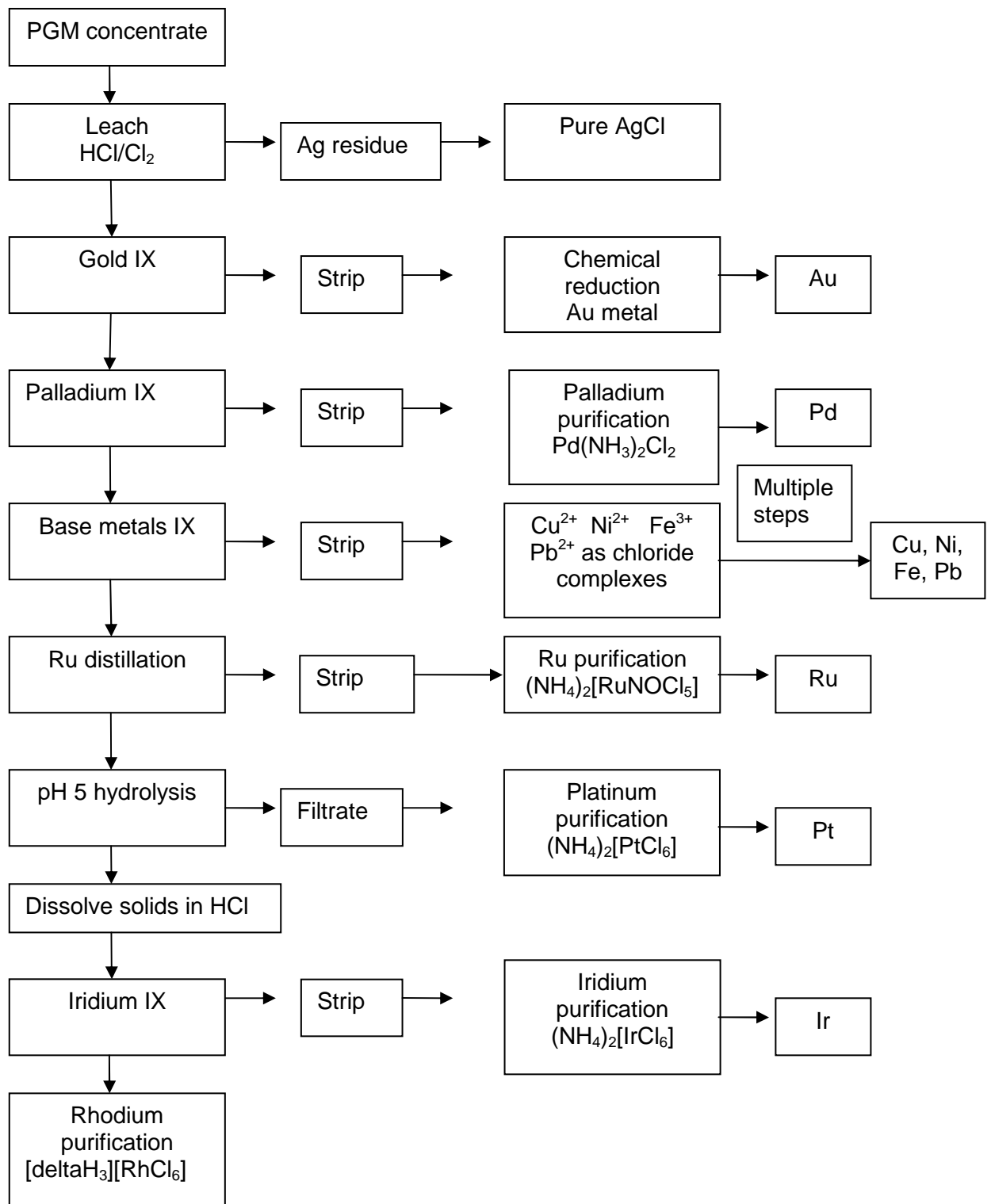


Figure 1: A flow diagram of the refining process used in a South African platinum refinery.

All of the hydrometallurgical processes in the Precious Metals Refinery are performed in hydrochloric acid medium. The first step is to dissolve the PGM concentrate in a mixture of hydrochloric acid and chlorine gas. The solution phase is rich in soluble PGM chloro-complexes and the leach residue consists mainly of silica and insoluble silver chloride. The PGM complexes are selectively removed from the main process stream as shown in Figure 1. Gold (Au), Palladium (Pd), base metals and Iridium (Ir) are selectively removed by using appropriate ion exchange resins. From the IX strip solutions, pure metal salts are precipitated, washed, dried and finally ignited at 1000 °C to decompose the salts to pure metal. Ammonium chloride is used extensively to precipitate the chloro-complexes of Platinum (Pt), Ruthenium (Ru) and Iridium (Ir) as ammonium salts. Palladium ammonium chloride ($\text{Pd}(\text{NH}_3)_2\text{Cl}_2$) is precipitated from an ammonia solution using hydrochloric acid to a target pH of one. Hexachloro-rhodate is precipitated from the solution phase by using protonated diethylenetriamine (Dr. Dirk de Waal, written communication, November 2009).

The different platinum compounds vary in colour from yellow to olive-green, red-brown and black. The solubility of these platinum compounds in water also differs. The platinum metals and platinum oxides are water insoluble, while the complex salts like ammonium hexachloroplatinate (yellow salt) and potassium hexachloroplatinate (red crystal powder) are soluble in water (HCN, 2008).

1.4 Exposure to platinum

1.4.1 Environmental Exposure

Platinum exposure of the general population occurs mainly through mucosal contact with dental restorations and jewellery containing platinum group elements (palladium, rhodium, iridium, ruthenium, osmium and platinum), and most possibly through emissions from automobile catalysts (Forte *et al.*, 2008). Since the use of platinum group metals (PGMs) as exhaust catalysts, the automotive emissions of NO_x , CO and various hydrocarbons have been significantly reduced. The use of catalytic converters has improved the general air quality, but they have also become a primary source of platinum emissions into the environment (Wiseman and Zereini, 2009). The estimated emission of platinum due to exhaust fumes is about 200-300 ng/driven kilometre, although higher estimations have also been made (Herr *et al.*, 2003). The extensive use of platinum as catalytic converters has led to elevated levels of PGE, including platinum, in road dust and soil near busy roads, as well as water and air, which then expand into the urban environments (Hooda *et al.*, 2007).

Studies done by Santucci *et al.* (2000), confirmed that the risk of developing sensitivity to PGM is related to the intensity of the exposure. Positive reactions to PGMs are found in exposed workers but were never observed in people living in the urban areas. Thus the concentrations

found in the living areas are much lower than those found in the occupational setting. In 2003, environmental exposure to platinum was not considered to cause adverse health effects (Herr *et al.*, 2003). However, in a recent study conducted by Wiseman and Zereini (2009) regarding the environmental behaviour of platinum, palladium and rhodium, the authors suggest that these metals are indeed of concern to human health. Firstly, they can easily be mobilised and solubilised by various compounds frequently found in the environment, which increases their bioavailability and exposure potential. Secondly, the PGMs can transform into more toxic compounds upon uptake, for instance the formation of halogenated PGM complexes due to the presence of chloride in the lungs. This complex has greater potential to induce cellular damage by increasing the production of reactive oxygen species (Wiseman *et al.*, 2009).

1.4.2 Occupational Exposure

Occupational exposure to platinum occurs mostly during the mining and refinery processing of platinum (Cristaudo *et al.*, 2005). Platinum in the mining operation, while still in the ore, is usually found in the insoluble form, and its free metal forms are also very insoluble (Lindell, 1997). In refineries, occupational exposure to platinum compounds occurs to a mixture of soluble and insoluble platinum compounds. Depending on their job tasks, the refinery workers are expected to be exposed to a variety of PGM salts and metals as well as other airborne non-PGE respiratory irritants, such as chlorine, ammonia and ozone (Maynard *et al.*, 1997; Lindell, 1997). It is during the production and handling of these complex salts of platinum that health problems may arise (Hughes, 1980).

The major concern regarding PGE exposure, is their sensitising potential, especially their salts (Wiseman and Zereini, 2009). The platinum complex's sensitising potential is constrained to a small group of charged compounds that contains reactive ligands, which are the halogenated compounds, the most potent being the soluble platinum compounds, such as hexachloroplatinic acid and its salts (Cristaudo and Picardo, 2007). These platinum salts and other platinum group elements may all be present in the workplace, and are all highly reactive elements capable of causing inflammatory- and mediated immunological effects among exposed workers (Cristaudo *et al.*, 2005). This capability of causing these previously mentioned effects is due to the fact that platinum is a transitional metal, which belongs to group VIII of the periodic table. This means that it has partly filled d-shells and is thus unable to act as an antigen on its own. In the human body, it forms complexes with donor groups in amino acids thereby forming a complete antigen (Cristaudo *et al.*, 2005).

Merget *et al.* (2000) assessed the exposure to airborne soluble platinum in a catalyst production plant. They found that the personal sampling yielded higher platinum concentrations than the area sampling. The current threshold value for airborne platinum exposure of 2 µg/m³ was

exceeded in measurements all of which were obtained during sampling of the highly exposed operators. The specific South African platinum refinery where this study was conducted uses the ACGIH respirable exposure limits for platinum, which is TLV-TWA: Platinum (metal dust) – 1 mg/m³ and Platinum (soluble salts) – 0,002 mg/m³ or 2 µg/m³. There are however no limits established for surface contamination as of yet.

In the refining processes platinum salts are handled in their dry and wet forms, subsequently these complex salts can get into the atmosphere either in the form of dust or droplets in a fine spray (Hunter *et al.*, 1945). There are various studies done in refineries on the exposure to platinum salts. In studies done by Baker *et al.* (1990) and Calverley *et al.* (1995), the exposure to platinum over 2 µg/m³ were found to be up to 75% and 27% of their measurements taken in platinum refineries.

Exposure to platinum can also occur in other occupational settings such as pharmacological hospitals where platinum is used in treatment as anticancer drugs. Platinum coordination complexes, for instance cisplatin, carboplatin and oxaliplatin, are used in the treatment of various tumours, which results in great amounts of these drugs being produced in hospital pharmacies. Consequently, the hospital personnel are exposed to these cytotoxic drugs via skin contact with drug- contaminated surfaces (Brouwers *et al.*, 2007).

1.5 Routes of exposure

Exposure to metals in the refining of platinum can occur by the following main ways:

1. Inhalation: The most common occupational exposure is through the inhalation of dust by exposed workers (Schneider *et al.*, 2000).
2. Dermal: Platinum salts are considered as low molecular weight agents (Malo and Chan-Yeung, 2009). According to Yunginger (2003) low molecular agents can easily penetrate the stratum corneum of the skin and bind covalently to the keratinocytes in the stratum spinosum below. The mechanism of platinum uptake through the skin however is unknown.
3. Ingestion: This is a relevant route of exposure in the occupational setting due to hand-to-mouth transfer and unintentional ingestion due to deposition of contaminants around the mouth area (Cherrie *et al.*, 2006).
4. Contact with contaminated workplace surfaces contributes to the worker's total exposure to different hazardous substances (Wheeler and Stancliffe, 1998). These surface contaminants can also become airborne again by being dislodged from these surfaces by a number of mechanisms such as washing and abrasion, which means that the potential for these substances to be transferred to the skin are extremely high (Schneider *et al.*, 2000).

1.6 Toxicokinetics of platinum

The uptake of platinum compounds is dependent on the physicochemical properties of the compound and the route of administration (Lindell, 1997). In general, the inhalation and deposits of insoluble metallic compounds in the airways are considered to be very low, however they are likely to be cleared by the mucociliary action, while soluble metallic salts may readily dissociate and be transported as metal ions into the lung tissue and subsequently to the blood (Klaassen & Watkins, 2003). Data for the retention of platinum sulphate, platinum metal and platinum oxide shows that the water-soluble compounds (platinum sulphate), were more rapidly removed from the lungs than the other two compounds (Lindell, 1997). There is limited experimental data regarding studies on humans. These studies showed that after oral uptake of platinum, 42% of the known platinum content was excreted in the urine during the 24 hours measured (Lindell, 1997). Excretion of platinum appears to occur by means of biphasic process, mainly through the urine as well as through feces. The excretion of platinum compounds in humans indicates slow elimination. The half-life of platinum can vary between hours and days. This illustrates that platinum may accumulate in the body, and this is supported by increased urinary platinum levels in individuals who stopped working in platinum industries several years before. The data for toxicokinetics of platinum after dermal exposure is not well documented (HCN, 2008).

As an element, platinum cannot be created or destroyed in the human body. Platinum compounds can, however, play a part in some chemical reactions. These reactions include ligand exchange, hydrolysis and formation of reversible and covalent complexes with amino acids, peptides and nucleic acids (NAS, 1977). The protein binding of ammonium chloroplatinite $(\text{NH}_4)_2 \text{PtCl}_4$ and potassium tetrachloroplatinate $(\text{K}_2\text{PtCl}_4)$ to serum albumin and transferrin was confirmed. In human blood samples, most of the platinum was bound to proteins and 65 to 80% was located in the erythrocytes (HCN, 2008).

1.7 Health effects of platinum

The mechanism of allergy to platinum salts is a type I allergy with an immediate reaction after inhalation or dermal contact with the complex halogeno salts of platinum. Type I hypersensitivity reactions involve IgE-mediated release of histamine and other mediators from degranulation of mast cells and basophils. In patients diagnosed with allergy to platinum salts, increased levels of IgE have been found (Calverly *et al.*, 1999). The reaction is classified as immediate, because the mediators released act rapidly to produce these effects (Pepys, 1984). For the IgE antibodies to be produced and the sensitization effects to occur, an initial exposure to an allergen is required (sensitizing exposure). There is thus a latency period from the first exposure to platinum salts to the occurrence of first symptoms. However only a portion of those

exposed becomes sensitized and this period varies between three months and three years (Schuppe *et al.*, 1997; Kimber and Dearman, 2002).

Symptoms gets worse with increased duration of exposure and do not always disappear when the person is removed from exposure (Santucci *et al.* 2000). Cases of platinum allergy, also referred to as platinum salt sensitivity (PSS), can be diagnosed by the following: (a) one or more of the eye-, skin- and respiratory symptoms, (b) signs consistent with allergy and (c) whether the subject had a positive response to a skin prick test (SPT) with platinum salts. The symptoms and signs include combinations of rhinitis, conjunctivitis, dyspnea, coughing and wheezing, immediate or delayed asthma, urticaria or dermatitis (Calverley *et al.*, 1999; Hughes, 1980). Soluble platinum salts have caused dermatitis, however it more frequently causes occupational asthma and contact urticaria (Schmalz & Arenholt-Bindslev, 2008).

1.7.1 Occupational Asthma

Occupational asthma is a disease commonly found in platinum refineries. Some metals, such as platinum salts, induce asthma through an IgE mechanism (Malo and Chan-Yeung, 2009). Asthma is the spastic contraction of the smooth muscle in the bronchioles, which causes narrowing of the airways (Guyton and Hall, 2006). This occurrence can reverse spontaneously or with treatment over short periods of time. Asthma is also distinguished from other causes of airway narrowing by increased hyper-responsiveness of the airways. This is an exaggerated bronchospasm provoked by non-specific stimuli such as histamine, exertion and inhaled cold air. Agents which can elicit this manifestation of airway inflammation and hyper-responsiveness have been described as inducers. Inducers can induce asthma by direct damage to the epithelium of the airways (irritant inducers) or by a specific hypersensitivity response (hypersensitivity inducers). Irritant-induced asthma does not have a latent period, and develops within hours of exposure. Hypersensitivity inducers include low molecular weight chemicals such as platinum salts (Taylor, 2002). According to the studies done by Calverley *et al.*, (1995), the prevalence of occupational asthma or allergy to platinum salts is 41%, within the platinum refinery workforces.

Smoking is a risk factor for the development of specific IgE antibodies against occupational agents. This thus increases the risk of developing IgE-mediated sensitization when exposed to these charged halogenated platinum salts which causes allergic asthma (Venables *et al.*, 1989; Venables, 1994). This means that smokers are at a higher risk of sensitization by platinum salts.

1.7.2 Contact Urticaria

Contact urticaria is known to have a wheal-and-erythema reaction. This is a response that follows the exposure by an antigen to the skin. It is characterized by swelling and redness of the immediate area due to release of histamine. This reaction occurs in three phases, starting with the appearance of an erythematous (redness of the skin due to congestion of the capillaries) area at the immediate area of exposure. This is followed by the development of a flare surrounding the area and ultimately the formation of a wheal at the area as the fluid leaks under the skin from surrounding capillaries. Contact urticaria can arise from different mechanisms, such as an immunological mechanism and non-immunological response. The immunological mechanism depends on a previous exposure to the substance and the development of an immune reaction, in other words sensitisation. Platinum salts however are a substance proficient in causing non-immunological contact urticaria, which is elicited by direct histamine release which is a Type I or immediate hypersensitivity response (HSE, 2010).

1.8 Surface contamination

Recently there has been a significant interest in contaminated workplace surfaces and the contribution they have on a worker's total exposure to hazardous chemical substances. Dermal contact with these contaminated surfaces has been suggested to be a major pathway for these contaminants to enter the body. The surface contaminants can enter the body either by percutaneous absorption or by ingestion due to hand-to-mouth transfer (Fenske, 1993). The monitoring of surface contamination is thus of great importance and can assist in the identification of the key exposure routes and in evaluating the effectiveness of the current cleaning and working procedures (Brouwers *et al.*, 2007).

Methods for measuring surfaces other than the skin, e.g. clothes that contribute to exposure by contact and transport between such surfaces, are of interest (Lundgren *et al.*, 2006). If these methods used to assess the surface contamination in the workplace are to be developed, it is vital to evaluate and standardize these methods. At present there are a variety of methods available for measuring surface contamination, such as micro vacuuming (suction) and manual surface wipes (Wheeler and Zereini, 1998).

1.8.1 Suction methods

For years wipe sampling methods have been used to assess surface contamination levels and to estimate the possibility for dermal exposure. As an alternative method, vacuum sampling has been used when wipe sampling is considered to be impractical. For instance, the sampling of rough and/or porous surfaces by using wipe sampling may also not be the best option, so the alternative to consider, is sampling by means of a vacuum sampler (suction) (Creek *et al.*, 2006).

Suction methods used to assess surface contamination were first introduced more than three decades ago (Byrne, 2000). Suction techniques have been employed mostly for sampling from surfaces other than skin (Lundgren *et al.*, 2006). When compared with wipe sampling methods, suction methods do have a number of limitations. The physical state of the surface contaminant that can be sampled by suction methods is limited to the solid phase. The apparatus required for suction sampling is significantly more expensive than those used for wipe sampling. The number of sampler components is much greater, and therefore the potential for sampling errors due to malfunction or inadequate cleaning is so much higher. The suction methods do have some advantages over other sampling methods. The surface area from which material is collected, is relatively larger thus allowing a more detailed analysis. The suction samplers are also appropriate for a wider range of surface types and this provides the possibility for greater assessments (Byrne, 2000). However, they have been regarded as poor collectors due to their low removal efficiency (Lundgren *et al.*, 2006).

A micro vacuum consists of a 37mm three-piece air cassette with filter and a backup pad. The cassette has an inlet with a flexible hose extension which is cut at a 45 degree angle. A portable battery-powered personal air sampling pump is used as the suction source. The sampling pump is calibrated to 2.5 L/min and the sampling area (100 cm²) is vacuumed three times in succession. A new inlet hose and sampler are used for each sample to prevent cross-contamination (Creek *et al.*, 2006).



Figure 2: Micro vacuum sampler

1.8.2 Wipe sampling used for metals

The manual wipe is the method used most commonly by industries to conduct surface sampling (Wheeler *et al.*, 1998). In determining surface contamination and the potential risk of skin contact with hazardous substances such as beryllium, the wipe tests are of great value

(Dufresne *et al.*, 2009). Ghostwipes™ were originally used for the sampling of lead contamination. In a study done by Boeniger, the amount of lead recovered by the Ghostwipes™ was better than 75%, which suggested a moderate efficiency (Boeniger, 2006). The ASTM E1792-03 is a standard specification developed for wipe sampling materials used for sampling of lead in surface dust. This specification covers the requirements for wipes that are used to collect settled dusts on surfaces for the subsequent determination of lead. This specification can be employed by users of wipes to compare the performance of different wipes for the sampling of lead in surface dust. The general requirements are discussed in section 6 of the ASTM standard and are as follow:

1. Background Lead – The mean background lead content per un-spiked wipes tested shall be less than 1.0 µg.
2. Lead Recoveries – The mean lead recoveries from wipes spiked with Certified Reference Materials shall be 100% ± 20% of the mean lead recovery from the Certified Reference Materials alone.
3. Collection Efficiency – The minimum of the collection efficiency of at least 95% of the wipes tested shall be 75%.
4. Ruggedness – Wipes shall be sufficiently rugged so as to be used on a smooth surface that a minimum of 95% of wipes tested shall reveal no holes or tears.
5. Moisture Content – Each wipe, when examined, must be wet both visibly and to the touch upon removal from the package. The coefficient of variation of moisture content if wipes tested shall be no greater than 25%.
6. Mass – The coefficient of variation in mass shall not exceed 10%.
7. Sizes – The mean area of wipes shall not be less than 200 cm² and shall not be greater than 625 cm². The mean length of either side shall not be less than 10 cm or larger than 25 cm.
8. Thickness – The mean thickness of wipes shall be at least 0.05 mm but no greater than 0.5 mm.

When evaluated against these requirements, the Ghostwipes™ meet the prerequisites of this standard.

In France, the sampling of industrial establishments for beryllium contamination was conducted using a surface wipe sampling method. Areas of 100 cm² which were bordered by a plastic template were sampled using Ghostwipes™. The Ghostwipes™ are 15 cm x 15 cm individually pre-moistened with deionised water wipes in sealed packets. The surface within the enclosed template was sampled by making concentric squares of decreasing size from the outside edge towards the centre. The average contamination levels recovered by the sampling mediums exceeded the 3 µg/100 cm² (Vincent *et al.*, 2009).

Antineoplastic drugs are commonly used in anti-cancer treatment due to their cytotoxic activity (Schierl *et al.*, 2009). Platinum complexes such as cisplatin, oxaliplatin and carboplatin are used extensively in the treatment of a variety of tumours. Thus large amounts of these agents are processed in hospital pharmacies (Brouwers *et al.*, 2007). Contact with surfaces contaminated with these antineoplastic drugs seems to play a role in dermal exposure to these agents (Schierl *et al.*, 2009).

Several wipe sampling methods for platinum-containing drugs have been published prior to 2000, but in 2000 a validated wipe sampling method for the monitoring of surface contamination by antineoplastic drugs was introduced. The wipe sampling was done with cellulose ester filters that were moistened with eight drops of solvent, 0.03 N HCl. Sampling was carried out by consecutive wiping with three filters, each in a different direction, to cover the entire demarcated area (20cm x 20cm) (Schierl *et al.*, 2009; Brouwers *et al.*, 2007). By sampling of locations where no cytotoxic drugs were handled, they determined that below a threshold of 1.00 ng/g platinum, it was not possible to establish the source of contamination. Thus all surfaces in the preparation areas with platinum levels above this threshold were considered being contaminated by platinum (Brouwers *et al.*, 2007).

From lists provided by Kevin Ashley (PhD, CDC/NIOSH), the following are just some of the methods considered to be the standard methods for surface sampling: NIOSH 9100, 9102 and 9105; along with OSHA ID-125G.

NIOSH method 9100, developed for the determination of surface contamination by lead and its compounds, uses wipes that must be individually wrapped and pre-moistened, for example the Wash 'n Dri™ hand wipes or equivalent such as Ghostwipes™. This method states that Whatman filters should not be used for wipe sampling, because they are not sufficiently durable. The area sampled is the standard 10 cm x 10 cm size. The wiping technique used, is an overlapping S pattern so that the entire area is covered. After the first horizontal wipe it is folded and wiped vertically, folded once more and wiped horizontally again. NIOSH method 9102 is suitable for many elements such as beryllium and lead. Platinum however is not one of the elements listed for this method. This method holds similarity to the NIOSH 9100 method in that this method also uses Wash 'n Dri™ wipes or ASTM equivalent pre-packaged moist wipes. The S pattern sampling technique also corresponds with the NIOSH 9100 method. NIOSH method 9105 also uses an ASTM approved wipe medium, such as Ghostwipes™. For sampling on non-dermal surfaces the sampling technique differs from 9100 and 9102. Wipe across the surface using repeated horizontal motions and then wipe the same surface again using the same side of the wipe for sampling, and wipe at a right angle to the first wiping motion. OSHA method ID-125G was developed for sampling of metal and metalloid particulates in the

workplaces. This method uses Whatman filters moistened with distilled water as well as Ghostwipes™. The size of surface sampled is the standard 10 cm x 10 cm. The sampling technique differs from the NIOSH 9100, 9102 and 9105 due to the fact that surface is wiped from the outside edges toward the centre by making concentric squares of decreasing size.

The recovery efficiencies of the sampling mediums are extremely important. It refers to the ability of the sampling mediums to collect the contaminants from the sampled surfaces. In studies using OSHA and NIOSH methods for the sampling of lead oxide, the wet wipe sampling have been evaluated on smooth and hard surfaces where the recovery efficiencies exceeded 75% (Ashley *et al.*, 2009). In studies conducted by Millson (1994) for the sampling of lead surface dusts using filter papers, gauze pads, Wash 'n Dry™ hand wipes and Wash-A-Bye Baby wipes the percentage recovery overall were 80% and higher. The Wash 'n Dry™ hand wipes had the higher recovery of higher than 90%. The recovery efficiencies of these surface sampling mediums for lead are well above the required minimum as set by ASTM.

There are several standardized procedures for wet and dry sampling which have been produced by various organizations. However, standardized sampling methods are yet to be applied uniformly. This has led to great difficulty in comparing the data gained from different sites. The performance data are frequently absent and as a result many of the collection efficiencies of sampling mediums may be unknown (Ashley, 2006).

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CHAPTER 3
MANUSCRIPT

Title: Evaluation of surface sampling methods for platinum salts.

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Word count: 5236 (For the purpose of examination the prescribed word count is exceeded but will be edited before submission to the journal).

1. Abstract

Objectives: 1) To evaluate and compare a few different surface sampling methods for removal of platinum salts from contaminated surfaces in order to determine which one of these methods has the best retention and collection efficiency. 2) To use the most effective method to monitor surface contamination on porous and non-porous surfaces in a platinum refinery. **Methods:** Two types of filters (mixed cellulose ester and polyvinyl chloride) and Ghostwipes™ were evaluated and compared in this study. Platinum solution (hexachloroplatinic acid) concentrations of 50, 150 and 300 µg Pt/ml solution were used. The retention efficiency of the different sampling mediums was tested by releasing 1 ml of each concentration directly onto the sampling medium. Efficiencies were tested on a non-porous (glass) and porous surface (semi-face bricks). This was done to see how the collection efficiency of the medium will differ on these two surfaces. A total of three wipes were used per surface (each surface wiped three times), however were analyzed individually. All the samples were analyzed using the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analytical method by an accredited laboratory. **Results:** The results obtained indicated the retention and recovery efficiencies of the three sampling mediums at the three platinum concentrations of 50, 150 and 300 µg Pt/ml solutions. The retention efficiency of the Ghostwipes™ was 93.2% at 50 µg Pt/ml solution, 95.3% at 150 µg Pt/ml solution and 93.6% at 300 µg Pt/ml solution, whilst the mixed cellulose ester (MCE) filters and polyvinyl chloride (PVC) filters were lower than 30% at all three concentrations. The overall recovery efficiencies of all three concentrations of the Ghostwipes™ and MCE filter were the highest: the Ghostwipes™ with levels of 73.9 %, 84.4% and 63.5% and the MCE filters with levels of 71.4%, 84.4% and 80.2%, whilst the PVC filters did not achieve levels above 60%. The wipe materials were also evaluated in terms of the ASTM E1792 standard requirements for wipe materials. **Conclusion:** Ghostwipes™ were found to be the most suitable sampling medium based on retention and recovery efficiencies. The Ghostwipes™ also complies with all the requirements listed in the ASTM E1792 standard for wipe materials, which makes it the most suitable wipe sampling material. The MCE and PVC filters however do not comply with all the ASTM E1792 requirements.

Keywords: Platinum, surface sampling, retention efficiency, recovery efficiency.

2. Introduction

Platinum has several toxicological effects on the human body. These toxicological effects are restricted to its complex halide salts. The undesirable health effects of these halide salts complexes are characterized by sensitization. Platinum allergy seems to be provoked by a charged group of compounds with reactive ligand systems, the most intoxicating being hexachloroplatinic acid. The platinum salt allergy mechanism is expected to be a type I immunoglobulin E mediated response. Platinum salts with low relative molecular mass act as haptens which then combine with serum proteins to form the complete antigen. Occupational exposure to complex platinum salts results in a condition termed platinum salt hypersensitivity and the symptoms include watering of the eyes, sneezing, coughing, wheezing, and characteristics of severe asthma, itching, contact dermatitis and urticaria (WHO, 2000).

In past years the focus has mostly been on the inhalation exposure pathways as it was considered to be the most important route of exposure. However since then dermal contact with contaminated surfaces has also been found to be an important route of exposure to hazardous chemical substances (Wheeler and Stancliffe, 1998). Dermal contact with contaminated surfaces can lead to contaminants entering the body by either percutaneous absorption and/or by ingestion due to hand to mouth transfer (Wheeler and Stancliffe, 1998 & Schneider *et al.*, 2000). In the refining process, platinum is precipitated in the form of one of its complex salts, regardless of the method used (Hunter *et al.*, 1945). These salts are sometimes handled in dry form and sometimes in a wet process. If these salts are released into the atmosphere in the dry process it is in the form of dust, and in stages of the wet process are released as droplets (Hunter *et al.*, 1945). Schneider's conceptual model indicates that surfaces which are contaminated by either of the above- mentioned forms can contribute to dermal exposure to these contaminants. Any contaminant which is present on a surface in the form of dust can be released into the atmosphere again if it is disturbed (Schneider *et al.*, 1999). Surface sampling represents an additional approach which provides an estimate of the potential for dermal exposure (Fenske, 1993).

Various surface contamination measurement methods, such as micro-vacuuming and manual wipes, are available (Wheeler *et al.*, 1998). Due to this fact, controversy regarding the different techniques of surface sampling arose; especially which method is the most appropriate for surface sampling in the workplace.

Wipe methods are mostly used for surface sampling. The efficiency of the wipe method however is affected by various factors, which should be considered when using this method:

- i. The concentration and distribution of the contaminant on the surface.

- ii. The roughness and porosity of the surfaces play an important role (Wheeler and Stancliffe, 1998). Wipe sampling is generally used when sampling non-absorbent, smooth surfaces such as metal and glass, as the wiping material could possibly tear apart when rough surfaces are sampled (Hunter, 2007).
- iii. The size of the surface sampled and the pressure applied by the operator conducting the sampling (Wheeler and Stancliffe, 1998). There might be some inconsistency in the pressure applied from sample to sample, which can influence the collection of the samples either by a greater or lesser amount of debris on a number of samples (Sanderson *et al.*, 2008).

Ghostwipes™ according to OSHA method ID-125G are standardized as a surface sampling medium for various metals, although not for platinum. In a study done by Dufay and Archuleta (2006) to compare the collection efficiencies of sampling methods for removal of beryllium surface contamination, it was found that the Ghostwipe™ is the easiest wipe to use, since they are pre-moistened and individually packed. They also have a larger surface area with greater strength compared to the Whatman (MCE) filters. The Whatman filters also performed well in this study, however some weaknesses were identified. The filters need to be moistened to prepare the wet wipes and once they are wet they easily fall apart, and when used on abrasive surfaces can disintegrate (Dufay and Archuleta, 2006). The loss of filter material in such instances will decrease the efficiency of the sampling material (Wheeler and Stancliffe, 1998). The filters are also packaged together and tweezers are necessary to remove them individually, which makes the wetting process more difficult. Separating filter paper between the Whatman filters increases the possibility of contaminating the entire supply when the working areas are filthy. Moreover, the smaller size of the Whatman filters complicates the sampling process once it is folded in half (Dufay and Archuleta, 2006). The retention and recovery efficiencies of these wiping mediums are of great importance in terms of the validation of the method. The retention efficiency refers to the ability of the sampling mediums to retain the contaminant and the recovery efficiency refers to the ability of the sampling mediums to remove the contaminants from the surface when being sampled under firm pressure.

The ASTM Designation E1792 (Standard specification for wipe sampling materials for lead in surface dust), list the requirements that covers wipes that are used for the sampling of lead on surfaces. It is thus important that wipe materials for surface sampling comply with these requirements. The requirements focus on the background levels, recoveries, collection efficiency, ruggedness, moisture content, mass, sizes and thickness of the wipe materials.

Suction methods do have some advantages when compared with wipe sampling methods. Contaminants can be collected from a wider range of surface types as well as from larger areas

(Byrne, 2000). Suction methods are more suitable for the sampling of rough and porous surfaces (Hunter, 2007). The suction methods also have some limitations. The apparatus required for the suction sampling is much more expensive than that necessary for wipe sampling. The surface contaminants which can be sampled are restricted to the solid phase, for example powders and particulates. Lastly, due to the fact that the suction sampler has so many components it is more likely to have sampling errors due to malfunctioning of these parts (Byrne, 2000).

The wipe method using mixed cellulose ester filters as a wipe medium is currently used by the platinum refinery, however only as a qualitative test. Due to the need for a surface sampling method that gives quantitative results, the method currently in use will therefore be compared with Ghostwipes™ and polyvinyl chloride filters to evaluate and determine the most suitable surface sampling method for platinum salts. The most efficient method will then be used for sampling in the refinery.

3. Methods

Sampling mediums

Two types of filters, the MCE (commonly used) and PVC (not commonly used) wipe mediums, and Ghostwipes™ were evaluated in this study.



Figure 1: The materials used in this study.

Pilot study – Recovery efficiency

A pilot study was conducted first, to establish whether the platinum concentrations (hexachloroplatinic acid) used were high enough for the ICP-AES analysis. Two concentrations were used, namely 0.05 µg Pt/ml and 0.5 µg Pt/ml. 1ml of the 0.05 µg Pt/ml and 0.5 µg Pt/ml solution were dripped onto 100 cm² glass areas with a micropipette. The solutions were then left to dry for approximately 3-4 hours, leaving behind the hexachloroplatinic salts.

The three sampling mediums (MCE and PVC filters and the Ghostwipes™) were then used to sample these areas. The S-stroke wipe technique was used for the sampling (Figure 3). Three wipes/filters were used per area with each wipe/filter wiped in a different S-stroke direction. The results obtained from this pilot study were below the detection limit of ICP-AES which is 0.0047 µg Pt/ml. Subsequently, the concentrations were adjusted to 50 µg/ml, 150 µg/ml and 300 µg/ml. During analysis the mediums were dissolved in 20 ml of *aqua regia* (3:1 HCl:HNO₃), bringing the actual concentration to 2.5 µg/ml, 7.5 µg/ml and 15 µg/ml.

Platinum standard solutions:

10 g of pure platinum was dissolved in *aqua regia* (3:1 HCl:HNO₃). The nitric acid was boiled off from the solution. The solution was made up to 1000 g with an acid content of 10% total HCl. The standard was gravimetrically verified to determine the exact platinum content. The solution was diluted to make a range of 50 – 1000 µg/ml platinum solutions.

Retention efficiency:

The retention efficiencies, which refer to the ability of the sampling mediums to retain the platinum, were determined to establish whether the mediums were able to acceptably retain platinum. It was determined by the following procedure: Each Ghostwipe™ was folded up and 1 ml of each of the 50 µg/ml, 150 µg/ml and 300 µg/ml concentrations was dripped onto the sampling medium. The filters can not be folded as they will tear. The samples were placed into separate marked sampling bottles, sealed and sent for analysis. Each filter and Ghostwipe™ were analysed separately. This was repeated six times per sampling medium.

Recovery efficiency

This refers to the ability of the wipe filters or Ghostwipes™ to remove the surface contaminants when the medium is wiped across a surface under firm pressure. The platinum salt solutions (50 µg/ml, 150 µg/ml and 300 µg/ml) were introduced onto these surfaces.

A non-porous surface (glass plate) was divided into several sampling blocks of 10 cm by 10 cm, separated by masking tape. The concentrations used were 50 µg/ml, 150 µg/ml and 300 µg/ml. These concentrations were then placed on each sampling block by a micropipette and left to dry for approximately 4-5 hours. The MCE filters, PVC filters and the Ghostwipes™ were then used to sample these plates as described next.

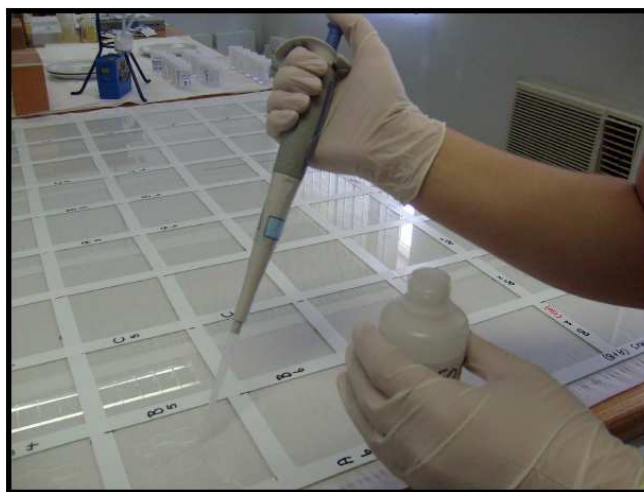


Figure 2: Placement of the platinum concentrations on the sampling surfaces.

Surface sampling with Whatman (Grade 42) quantitative mixed cellulose ester filters and PVC filters:

Hands were washed and non-powdered vinyl gloves were put on. Each filter was moistened by dipping it into double-distilled water and then the entire filter was wiped across the individual sampling area on the glass plate while handling it with tweezers. The surface was wiped while applying firm pressure, using S-strokes to cover the entire surface. The best results are thus achieved by wiping in two directions (vertical and horizontal) to thoroughly clean the surface.

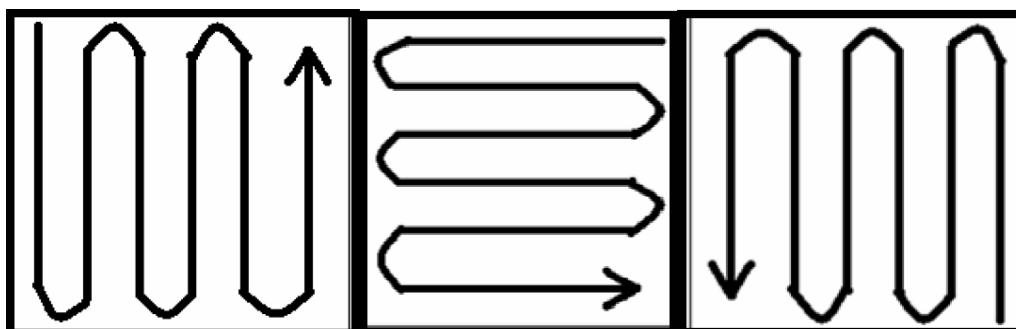


Figure 3: S-strokes used for sampling the surface area.

After the first wipe (vertical), a second and a third filter were used to wipe (horizontally and vertically) across the same area. The filters were then picked up and placed into separate marked sample bottles to be analysed. Eighteen samples were taken on the glass plate per concentration (six blocks with three filters per block). In total, 54 samples were collected for analysis. New gloves were put on after each sample, to prevent contamination.

Surface sampling with Ghostwipes™:

Exactly the same method was used as described above, except for two differences. Firstly, each Ghostwipe™ is manufactured in an individual sealed envelope and secondly, the Ghostwipe™ is already pre-moistened with distilled water, therefore it was used upon opening. The Ghostwipe™ was folded open and wiped across the sampling surface.

Sampling of the porous surface in the form of a semi-face brick:

Characteristics of the various surfaces occurring in the refinery such as porosity, smoothness and roughness will have a major effect on the outcome of the sampling, therefore a porous surface (semi-face brick) was also sampled in an effort to establish the removal efficiencies of the different sampling mediums on the porous surface. Ten samples (5 per medium) of the MCE, PVC and Ghostwipes™ were taken on semi-face bricks. The 300 µg/ml concentration was introduced onto the brick surface (10 cm x 10 cm). It took approximately 1 hour for it to dry. Due to the roughness of the surface the dried platinum solution was dab-sampled with the MCE, PVC and Ghostwipes™. The samples were put into the sampling bottles to be analysed.

Sampling in the refinery:

The method determined to be the most suitable, in terms of retention and recovery efficiency after the first set of results, was used for sampling of various surfaces in different areas of the refinery. The determined surface area sampled was 10 cm x 10 cm, however on certain areas it was impractical to use a template, so it was estimated by the operator.

At each of the sampling stages listed above, field blanks of the filters/wipes were put into sampling bottles for analysis to ensure no background platinum levels were present during sampling. A total of three field blanks (filters/wipes) were analysed for each stage.

Analysis:

The Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analytical method was used by an accredited laboratory. The ICP-AES method is one of the most common techniques used for elemental analysis due to its high specificity and low detection limits (0.0047 µg Pt/ml).

Statistical analyses:

Statistical software v8.0 was used for database management and statistical analyses (Statsoft, Inc., 2008). Graphpad Prism 5 (Graphpad Software Inc., 1992-2010,) was used to illustrate the data. One-way ANOVA tests were used to determine differences in mean values between groups. A p value ≤ 0.05 was considered to be statistically significant.

4. Results

The Ghostwipes™, MCE and PVC filters field blanks analysed for background levels of platinum all indicated that it was below the detection limit of the ICP-AES analytical method. According to the ASTM E1792 requirements the background levels must be less than 1.0 µg, and the detection limit of the ICP-AES is 0.0047 µg Pt/ml.

Figure 1 indicates the retention efficiency of the three sampling mediums. According to the Figure, the Ghostwipes™ have retention efficiencies of $93.2 \pm 0.62\%$, $95.3 \pm 0.68\%$ and $93.6 \pm 2.52\%$ for the 50 µg/ml, 150 µg/ml and 300 µg/ml platinum solution respectively. The retention efficiencies of both the MCE and PVC filters were between $17.1 \pm 4.02\%$ and $24.3 \pm 14.27\%$ which indicates a statistical significant difference ($p \leq 0.05$) between the filters and the Ghostwipes™.

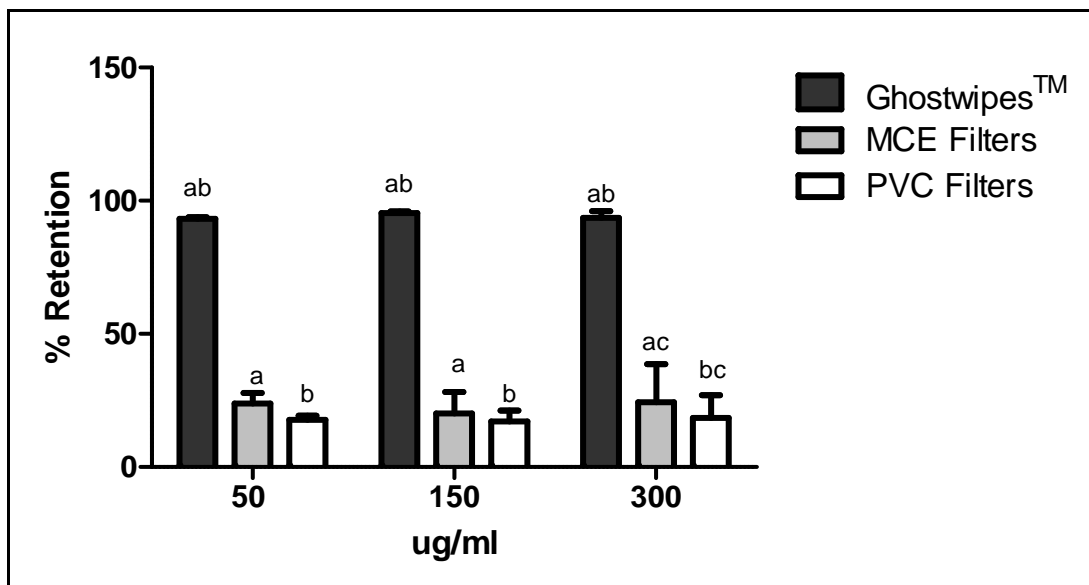


Figure 1: Retention efficiency of Ghostwipes™, MCE and PVC filters at all three concentrations. Statistical differences between the means are denoted with a-c at the respective concentrations.

Figure 2 indicates the recovery efficiency from the glass surfaces of the three mediums (total of three wipes) at all three concentrations (50 µg/ml, 150 µg/ml and 300 µg/ml). The recovery efficiencies at the 50 µg/ml concentration for the Ghostwipes™ were the highest at $73.9 \pm 3.53\%$ in relation to the MCE filters at $71.4 \pm 4.51\%$ and the PVC filters at $52.7 \pm 4.56\%$. The significant difference lied between the PVC filters and the other two mediums. The recovery efficiencies at the 150 µg/ml concentration for the Ghostwipes™ and MCE filters were equal at $84.4 \pm 42.27\%$ and $84.4 \pm 11.06\%$ respectively, with the PVC filters at $52.5 \pm 24.78\%$ which indicates significant difference. At the 300 µg/ml concentration the MCE filters had the highest recovery of $80.2 \pm 49.76\%$, with the Ghostwipes™ at $63.5 \pm 25.73\%$ and the PVC filters at $58 \pm 69.44\%$. There was a significant difference between the MCE and the other two mediums at the 300 µg/ml concentration.

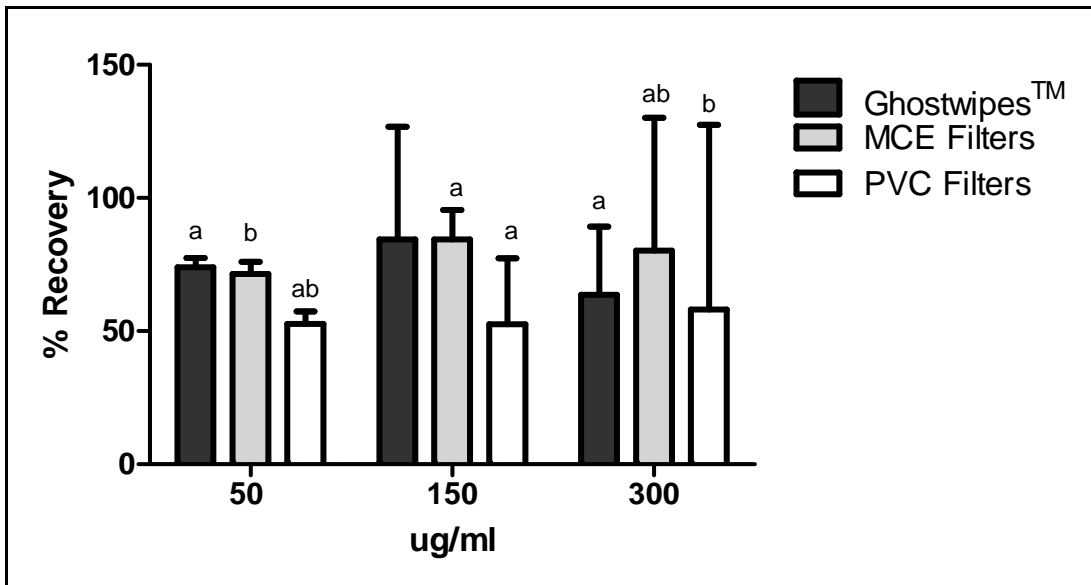


Figure 2: Total recovery (3 wipes) of all the GW, MCE and PVC filters at all three concentrations. The same superscript letter at the respective concentrations denotes statistical significant differences between means, $p \leq 0.05$.

Figure 3 indicates the collection efficiencies of the sampling mediums at the first, second and third wipe at 50 $\mu\text{g/ml}$ concentration. The first wipe of the Ghostwipes™ have the highest recovery at $68.7 \pm 4.14\%$, with the MCE filters at $53.6 \pm 7.56\%$ and the PVC filters at $30.09 \pm 2.79\%$. There was a significant difference between the recovery of the Ghostwipes™ and the other two mediums, as well as between the two filters. Wipe 2 indicates that the PVC filters collected a higher percentage of $15.5 \pm 2.26\%$, with the MCE filters $10.9 \pm 3.27\%$ and the Ghostwipes™ $4.7 \pm 1.75\%$ which differs significantly from that of the PVC filters. The third wipe shows the same pattern as the second wipe, with the PVC filters the highest with $7.1 \pm 0.93\%$, the MCE filters $6.8 \pm 1.92\%$ and Ghostwipes™ $0.48 \pm 3 \times 10^{-9}\%$. The recovery of the MCE and PVC filters differs significantly from that of the Ghostwipes™.

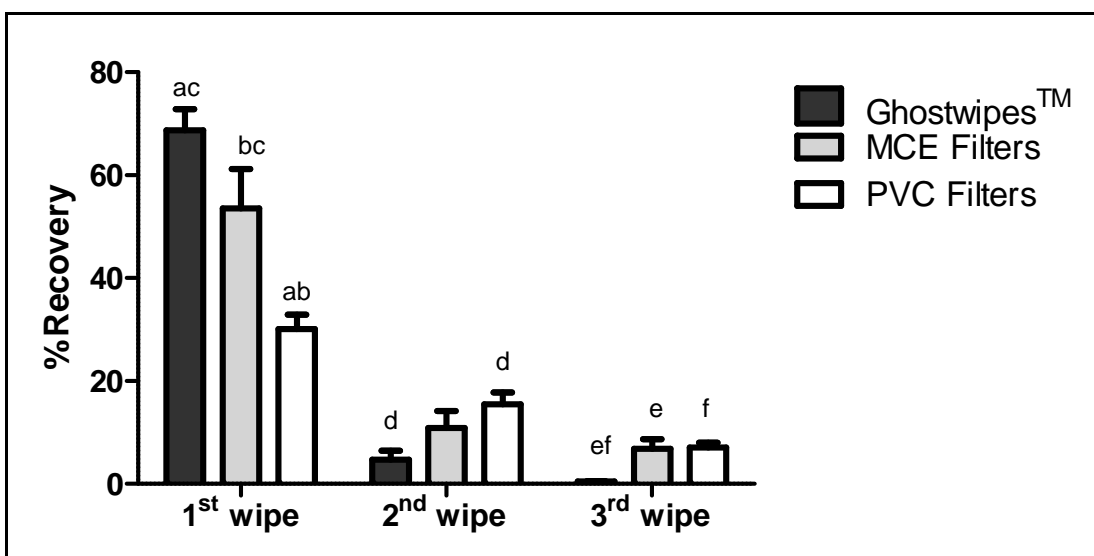


Figure 3: Recovery efficiency per wipe at 50 $\mu\text{g/ml}$. The same superscript letter denotes statistical significant differences between means, $p \leq 0.05$.

Figure 4 indicates the collection efficiencies of the sampling mediums at the first, second and third wipe at 150 µg/ml concentration. This graph indicates that the Ghostwipes™ have the highest recovery with the first wipe at 78.2 ± 40.20%, the MCE filters with recovery of 65.7 ± 11.52% and the PVC filters with 31.54 ± 15.56%. There was a significant difference between the PVC and the other two mediums. The second wipe data indicates that the MCE filters had highest recovery at 13.1 ± 3.11%, the PVC filters 10.78 ± 8.74% and the Ghostwipes™ 4.15 ± 4.44%. The recovery of the two filters with the second wipe differed significantly from that of the Ghostwipes™. The third wipe data indicates that the PVC filters had the highest recovery of 10.19 ± 4.40%, which showed significant difference to that of the MCE filters 5.5 ± 4.69% and the Ghostwipes™ 1.98 ± 2.64%.

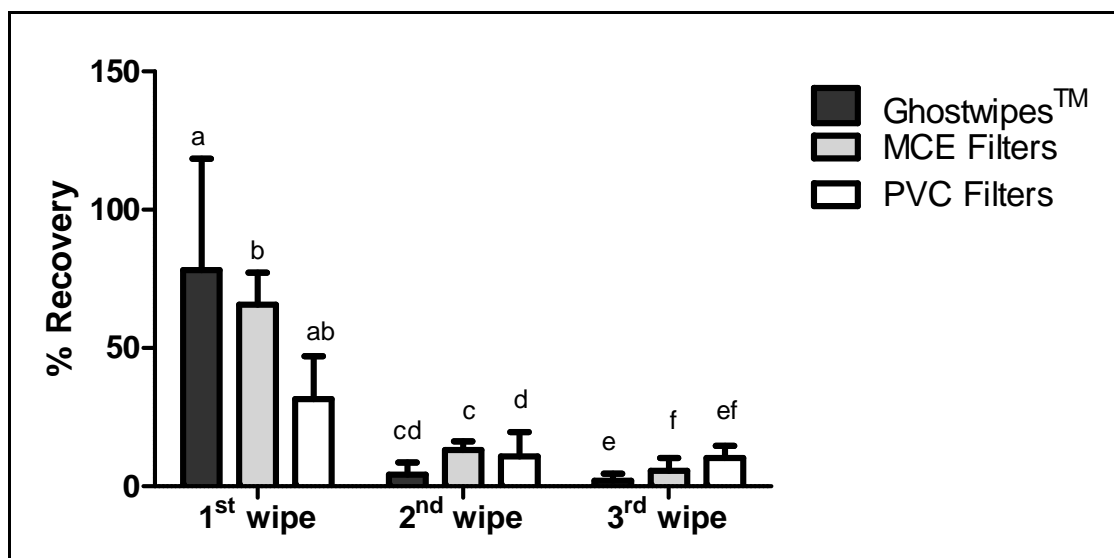


Figure 4: Recovery efficiency per wipe at 150 µg/ml. The same superscript letter denotes statistical significant differences between means, p≤0.05.

Figure 5 indicates the collection efficiencies of the sampling mediums at the first, second and third wipe at 300 µg/ml concentration. This graph indicates that the MCE filters had the highest recovery at 61.77 ± 49.67%. The Ghostwipes™ had recovery of 57.9 ± 34.40% and the PVC filters 39.8 ± 51.49%. The second wipe data indicates that the PVC filters had highest recovery at 11.39 ± 17.28%, the MCE filters 10.5 ± 13.52% and the Ghostwipes™ 4.76 ± 8.07%. The third wipe data indicates that the MCE filters had the highest recovery of 7.94 ± 16.38%, the PVC filters 6.75 ± 9.14% and the Ghostwipes™ 0.75 ± 1.95%. The third wipe indicated a significant difference between the Ghostwipes™ and the two filters.

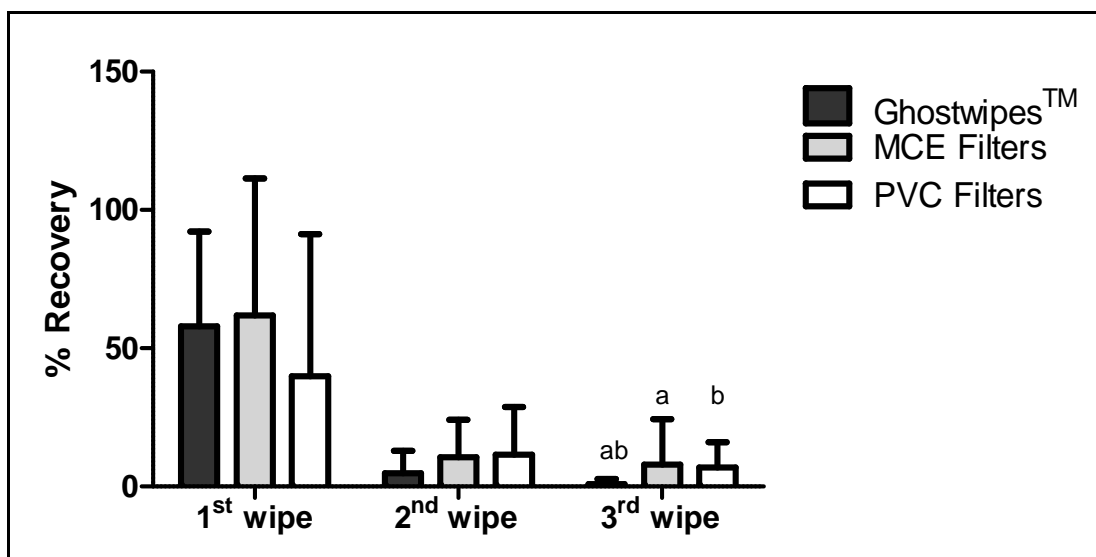


Figure 5: Recovery efficiency per wipe at 300 µg/ml. The same superscript letter denotes statistical significant differences between means, $p \leq 0.05$.

The moisture content of the filters after moistening was approximately 0.2 g for the MCE and 0.06 g for the PVC filters, and it did not vary more than 25% between the various filters (n=4 MCE and PVC filters was used in this measurement). The Ghostwipes™ was wet both visibly and upon touch, which is an ASTM E1792 requirement. The Ghostwipes™ used in this study had a moisture content of approximately 3g/wipe and did not vary more than 25% between the various wipes (n=4 Ghostwipes™ was used in this measurement).

The wipe materials were also evaluated in terms of their sizes. The MCE and PVC filters have a 37 mm diameter (10.75 cm² area) whereas the Ghostwipes™ has a surface area of 15 cm x 15 cm (225 cm²). The thickness of the wipe materials was also determined. A total of three Ghostwipes™, MCE and PVC filters were used in this measurement. The Ghostwipes™ has a thickness of 0.2 – 0.28 mm, whilst the MCE filter is 0.18 – 0.2 mm and the PVC filter is only 0.1 mm.

The batch of Ghostwipes™ used in this study was tested in terms of mass. Five randomly chosen Ghostwipes™ were measured, and the coefficient of variation in mass did not exceed 10%, which is the requirement of the ASTM E1792. This was also the case for the MCE and PVC filters. They both fell within the 10% variation coefficient.

The results obtained from the porous surface samples showed results that were below the detection limit of the ICP-AES. Thus none of the sampling mediums was able to recover analysable levels of platinum salts (n=5 for each of Ghostwipes™, MCE and PVC using two wipes per area sampled).

Based on the retention and recovery efficiencies, Ghostwipes™ were used for surface sampling in the refinery. Platinum salts were detected in all areas where the samples were taken. The only sample which showed BDL was the reference wipe. This is indicated in Table 1.

Table 1: The sample analysis of samples taken on various surfaces in the platinum refinery, using Ghostwipes™ as the sampling medium.

Sample [*]	Platinum detection (µg or µg/cm ²) [**]
Reference wipe	BDL
EPMR Lab, sample receive table	0.02 µg/cm ²
Platinum control area, fan H425F, switch box	252.06 µg
Platinum control area, computer keyboard	265.24 µg
Platinum control area, sample table	50.29 µg/cm ²
New control room, door handle	55.95 µg
H510 tank front floor area	89.09 µg/cm ²
Top floor handrail, Fire exit IPR 745	60.72 µg
Top floor H513 vacuum tank top	360.02 µg
H360 filter press door handle	155.10 µg
Filter press computer 30 keyboard	712.74 µg
Filter press floor, rubber hammer handle	384.94 µg
Filter press top control unit LCPH 320	6017.86 µg
HSS 5 safety shower, main handle	138.14 µg
3032 telephone, hand piece	305.84 µg
Platinum batch area, control H216C	7094.48 µg
Employee 1 – Left shoe sample 1	11.38 µg
Employee 1 – Left shoe sample 2	10.14 µg
Employee 2 – Outer hard hat sample 1	7.49 µg
Employee 2 – Outer hard hat sample 2	9.35 µg
Employee 3 – Fitter, spanner handle sample 1	1.56 µg
Employee 3 – Fitter, spanner handle sample 2	0.83 µg
Employee 4 – Process controller, inner hard hat sample 1	279.68 µg
Employee 4 – Process controller, inner hard hat sample 2	65.14 µg

[*] **Codes used for samples:** These are in terms of certain areas within the refinery, and are only to link the samples to the specific area.

[**] **Platinum detection units:** Not all of the areas were able to be sampled within the template area of 10 cm x 10 cm, because these surfaces were irregular. Thus, these samples are presented in µg. Only the flat surfaces where the template was used are presented in µg/cm².

5. Discussion

All the Ghostwipes™, MCE and PVC filters field blanks analysed for background platinum levels showed results that were below the detection limit of the ICP-AES, which is 0.0047 µg Pt/ml. This indicates that there were no background levels of platinum which could have influenced the sampling results.

The retention efficiencies, which indicate the capability of the sampling mediums to retain the platinum contents of the solution, were compared between the three sampling mediums. The retention efficiency was tested on all three concentrations of platinum salts. Overall, the Ghostwipes™ had the best retention efficiency of higher than 90% at all three concentrations (93.2% at 50 µg/ml; 95.3% at 150 µg/ml; 93.6% at 300 µg/ml). The ASTM E1792 indicates that the retention per sample must be 100% ± 20% of the introduced contaminant alone. As indicated, the Ghostwipes™ had recovery of higher than 90% at all three concentrations, which complies with the requirements set by the ASTM. The data showed a significant difference between the retention efficiencies of the Ghostwipes™ and that of the MCE and PVC filters. The MCE and PVC filters only achieved recoveries between 17.1 and 24.3%, which is much lesser than the required standard. The difference in the size of the three mediums has a great influence on their retention ability. The ASTM E1792 also has a requirement in terms of the size of the wipe material, which states that the mean area of the wipes shall not be less than 200 cm² and not greater than 625 cm². According to this the Ghostwipes™ meet the requirement however the MCE and PVC filters do not. The Ghostwipes™ also consists of a thicker material than the filters (Harper *et al.*, 2002). This is clear when comparing the thickness of the Ghostwipe™ and the filters. According to the ASTM E1792 requirement regarding the thickness of the material, all of them fall within the range of 0.05 and 0.5 mm. Based on this it is clear that the Ghostwipes™ has an advantage in terms of the material available to contain the contaminants, due to its thickness and size. Thus, the MCE and PVC filters can become saturated more rapidly than the Ghostwipes™. In terms of the mass requirement listed in the ASTM E1792, the coefficient of variation in mass should not exceed 10%. The Ghostwipes™ as well as the MCE and PVC filters measured fell within this 10% variation coefficient.

The recovery efficiencies of the sampling mediums over the sequence of three wipes per area on the non-porous surface indicated that the MCE filters had the highest recovery efficiency overall. At the 50 µg/ml solution the Ghostwipes™ had the best recovery with 73.9%. At the 150 µg/ml solution the Ghostwipes™ and MCE filters had equal recovery with 84.4%. At the 300 µg/ml solution the MCE filters showed the highest recovery with 80.2%. In all instances the PVC filters had the lowest recovery of 58% and less. The data showed statistical significance between the PVC filters and the Ghostwipes™ and MCE filters at the 50 and 150 µg/ml solutions. At the 300 µg/ml solution the significance lay between the MCE filters and the other

two mediums. The MCE filters collected the most contaminant over the series of three wipes, which indicates that the MCE filters moistened with distilled water are effective for collecting contaminants in a dry form. Ghostwipes™ were originally used for the sampling of lead on skin and other surfaces. The ASTM standard for wipe sampling for lead on surfaces specifies that the minimum recovery efficiency must be 75% or better, which concurs to a certain extent with the findings in this study (Boeniger, 2006). The recovery efficiencies achieved by the Ghostwipes™ exceeded 70% at the 50 µg/ml solution and exceeded 80% at the 150 µg/ml solution. The MCE filters achieved levels of 80% and higher at the 150 and 300 µg/ml solutions. This indicates that both the Ghostwipes™ and the MCE filters comply with the ASTM standard in terms of recovery (collection). According to sampling conducted by Brouwers *et al.* (2007) in Dutch hospital pharmacies to monitor surface contamination of platinum cytotoxic drugs on stainless steel and linoleum surface by means of Kimtech Science precision wipes, the recoveries were mostly higher than 70%. On the stainless steel the recoveries were 50.4% for cisplatinum, 73.8% for oxaliplatinum and 77.2% for carboplatinum. On the linoleum surface the recoveries were 76.8%, 77.9% and 81.4% for the particular platinum compounds. The results found by Brouwers *et al.* (2007) concur with the results obtained in this study. The data falls within the same recovery range.

The recovery efficiency of the first wipes of the three sampling mediums at the three concentrations signifies the ability of the sampling mediums to collect the majority of the contaminant on the first wipe. This is of great importance, especially when evaluating the ease of using the sampling medium. The recovery efficiency of the first wipe at 50 µg/ml showed that the Ghostwipes™ had the highest recovery efficiency of 68.7%, with the MCE and PVC filters with 53.6% and 30.09% respectively. At the second and third wipe the PVC and MCE had a greater recovery than the Ghostwipes™. This can be attributed to the fact that their first wipes had lower recovery than the Ghostwipes™. At the 150 µg/ml solution the recovery efficiency of the first wipe indicated that the Ghostwipes™ had the highest recovery of 78.2%, with the MCE and PVC filters at 65.7% and 31.54% respectively. The second and third wipes showed similar results as the 50 µg/ml solution, where the PVC and MCE filter had greater collection than the Ghostwipes™. The recovery efficiency of first wipe at the 300 µg/ml solution indicated that the MCE filters had the highest recovery with 61.77%, with the Ghostwipes™ and PVC filters at 57.9% and 39.8% respectively. The fact that the MCE filters had a better first wipe recovery at the 300 µg/ml platinum solution, might be due to the possible difference in pressure applied by the operator between the different areas sampled. Even though all the samples were taken by the same operator and the operator attempted to exert the same amount of pressure during each sample. This was also mentioned as an influencing factor by Sanderson *et al.*, (2008). Once again the data of the second and first wipe is similar to the 50 and 150 µg/ml solutions where the PVC and MCE filters had higher recovery than the Ghostwipes™. It is obvious that

the medium which recovers the highest percentage with the first wipe will have lower recovery with the second and third wipe, since the amount of contaminant still present after the first wipe is less. It is very important to achieve high levels of recovery on the first wipe, since it simplifies the sampling task especially in the refinery itself.

Results obtained from the sampling on the porous surface, indicated that all the samples analysed were found to be below the detection limit. The detection limit is 0.0047 µg/ml. This shows that these three sampling mediums are not suitable for sampling on porous surfaces. Although there were platinum salts present, nothing was detected in the samples. The porous surface absorbed the platinum salt solution, but it does not mean that this cannot later be re-dispersed into the working environment, and should still be considered a possible exposure hazard. Other means of sampling will have to be used when sampling porous surfaces, such as vacuum sampling. The cleaning methods for surfaces are thus very important, because it is one of the first protection methods to ensure that the workers are not exposed to platinum salts due to contaminated surfaces. The cleaning and thus sampling methods must be well studied and adapted to fulfil the obligations. This also highlights the fact that when selecting the building materials for refineries, this should be kept in mind. Porous surfaces are not suitable for refineries, as the platinum dusts and salts can easily be absorbed by these materials. Even though no detectable levels of platinum were obtained from the porous surface by any of the sampling mediums, there were a few observations made during this sampling. Out of the three mediums the Ghostwipes™ showed the best strength, whilst the PVC and MCE filters lost material due to the roughness of the surface. These observations were also mentioned in studies done by Wheeler *et al.* (1998) and Dufay and Archuleta (2006). The ruggedness of the wipe material is also one of the ASTM E1792 requirements listed. When assessing the Ghostwipes™, MCE and PVC filters in terms of this requirement it is clear that the Ghostwipes™ are more rugged than the filters. The filters tend to tear easily during sampling, whereas the Ghostwipes™ showed great strength.

Wipe samples were collected in the refinery after the first initial analyses were received and it was determined that the Ghostwipes™, based on the retention and recovery efficiency, was the most suitable medium. These samples were taken in various parts of the platinum refinery on various surfaces to which the workers have daily contact and thus the possibility of exposure. Platinum salts were detected in all areas of the refinery where samples were taken, only the reference wipe was below detection limit. All of these areas are in immediate contact with platinum due to the handling and processing of platinum in these areas. The employee personal protective equipment sampled, were those of employees working in various divisions of the refinery plant. All of them come in contact with platinum during their daily tasks. The areas found to have the highest levels of platinum salts were the platinum control area, sample

table; H510 tank front floor area; filter press top control unit LCPH 320 and platinum batch area, control H216C. All of these areas have large amounts of platinum being processed and handled every day, which explains the high amounts of platinum recovered from these areas. Wipe sampling of surfaces in the workplace is a useful tool for determining contamination of these surfaces as well as to identify areas where decontamination is required. By ensuring that the surfaces are clean, a potential source of inhalable dust is removed and skin contact with contaminants is prevented (Kerr, 2004).

6. Conclusions

When considering all of the above-mentioned results, the Ghostwipes™ had the best retention efficiency as well as the overall best recovery efficiency with the first wipe. Since the refinery is in pursuit of the easiest as well as the most effective and reliable method, it is concluded that the Ghostwipes™ fit these criteria the best. The Ghostwipes™ also comply with all the requirements of the ASTM E1792 standard for wipe materials. The MCE filters are also considered to be a good surface sampling medium for platinum salts with good recovery efficiencies, especially at the 300 µg/ml solution. The MCE filters also have the best overall recovery over the three wipes, however do not differ statistically from that of the Ghostwipes™. The retention efficiency of the MCE filters was not higher than 24.3% and this lowers the effectiveness of the MCE filters. The reason for this is probably due to the fact that the MCE filters became saturated more rapidly than the Ghostwipes™ and thus struggled to contain the 1 ml of platinum solution. The PVC filters did not fit these criteria at all. The retention as well as recovery efficiencies were very low. Based on the eight requirements listed in the ASTM E1792 standard, the MCE filters only complied with five of them. In terms of the area, retention and ruggedness requirements the MCE filters fell short. The PVC filters also did not meet these requirements with the addition of the recovery efficiency. Thus, the MCE and PVC filters do not comply with all the ASTM E1792 standard requirements and are therefore not recommended as a wipe material for surface sampling.

According to the collection data and the objectives of the study, the conclusion is that the Ghostwipes™ are the better suited sample medium for surface sampling in the platinum refinery, with the highest retention efficiency as well as the highest recovery efficiency using the least amount of wipes.

All the samples taken on the porous surface showed BDL results. Thus none of the three mediums are suitable for sampling on porous surfaces. It is recommended that another means of sampling be used for this purpose. Suction/vacuum methods may be more suitable for this purpose.

7. References

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CHAPTER 4
GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. Summary of the main findings

In this study, the main findings were:

Ghostwipes™ were found to be the most suited sampling medium for sampling platinum on the surfaces in the refinery. This was confirmed by the retention and recovery efficiency data collected. At all three of the platinum solutions of 50, 150 and 300 µg/ml the retention efficiency of the Ghostwipes™ was 93.2%, 95.3% and 93.6% in that order, whilst those of the MCE filters and PVC filters were the highest at 24.5% and 18.4% respectively. The recovery of the Ghostwipes™ was the highest at the first wipe, with levels of 68.7% and 78.2% at 50 and 150 µg/ml. At the 300 µg/ml solution, the recovery was 57.9%, with the MCE filters just higher at 61.77%, however did not differ statistically. This can be explained by some influencing factors which might have had an effect on the sampling and thus the results. The Ghostwipes™ also appeared to be the most robust medium when sampling the porous surface, which indicates that it is more suitable for sampling of various surfaces that are found in refineries. The MCE filters were also concluded to be a good quality sampling medium however the retention efficiency was very poor, which decreases the effectiveness of the filters as sampling medium under the experimental conditions employed in this study. The MCE filters do not comply with all the requirements of the ASTM E1792 standards and are therefore not recommended for surface sampling. The PVC filters were found not suitable for surface sampling, since the retention and recovery efficiencies were very low. It did not comply with all the ASTM E1792 requirements and is not recommended as a good surface sampling medium.

When considering all of the above-mentioned results, the Ghostwipes™ have the best retention efficiency as well as the overall best recovery efficiency with the first wipe. Since the refinery is interested in finding a method that is easy to use, efficient as well as the most time-effective and reliant, it is concluded that the Ghostwipes™ fit these criteria the best. Since the Ghostwipes™ are already pre-moistened and individually packed, it makes the sampling task much easier. Whereas with the MCE and PVC filters, each filter needs to be handled with a tweezer and moistened by dipping in distilled water. This takes a lot of time and the possibility of contamination is much greater (Dufay and Archuleta, 2006). The prices of the Ghostwipes™ when compared to that of the MCE and PVC filters are somewhat more expensive, but the comfort of use and the time saved by this method makes up for the higher cost. Based on all the data as well as practical observations during sampling, the Ghostwipes™ comply with all the ASTM E1792 requirements and are therefore the most suitable surface sampling medium.

The aims in this study was 1) to evaluate and compare a few different surface sampling methods to establish the most effective method for assessing platinum surface contamination, and 2) to assess surface contamination in the workplace/refinery by making use of the most efficient method. Both of the aims set in this study were accomplished.

The hypothesis of this study was, that based on the retention and recovery efficiencies, the Ghostwipes™ would be more efficient in collecting platinum salts from surfaces than the MCE and PVC filters. As concluded from the results, the hypothesis is accepted.

Platinum salts were detected in all areas of the refinery where samples were taken, only the reference wipe was below detection limit. The areas found to have the highest levels of platinum salts were the platinum control area, sample table; H510 tank front floor area; filter press top control unit LCPH 320 and platinum batch area, control H216C. This emphasizes the fact that the workers are constantly being exposed to platinum salts, which can have major health effects.

2. Discussion and findings

2.1 Chance and confounding

The first wipe recovery efficiency of the Ghostwipes™ was well above that of the MCE and PVC filters at the 50 µg Pt/ml and 150 µg Pt/ml solutions. However, at the 300 µg Pt/ml solution the MCE filters had higher recovery efficiency than the Ghostwipes™. It is unclear why this happened, but here are some factors which could have influenced this: the distribution of the platinum solutions on the areas might have been different on the separate areas. The pressure applied during the sampling might have differed between samples even though the operator tried to apply the same pressure during all the samples. It is however possible that the MCE filters are better suitable at higher platinum concentrations in regards to recovery.

2.2 Limitations of the study

There were a few limitations identified during and after the completion of the study. The sampling areas on the non-porous surface (glass plate) were divided into the 10 cm x 10 cm squares by masking tape. Care must be taken when dividing these areas with the masking tape. The masking tape must be secured properly to the surface to ensure that the contaminant solution is contained in the sampling area. During the distribution of the solution onto these areas, the solution must be introduced in the centre of the area so that the distribution is consistent.

Six repetitions per sampling medium were found to be sufficient for the purpose of this study. It might be beneficial to increase the repetitions to nine or ten, when conducting such a study. This might strengthen the data collected in such an evaluating study. This might possibly decrease the standard deviations of the collected data.

The platinum concentrations used in this study were low, since the refinery wanted a sampling method which can detect platinum at these low concentrations. Introducing two higher

concentrations to this study might have shown the ability of these mediums to recover higher platinum concentrations. As shown in a few samples taken in the refinery the platinum recovered were relatively higher than the concentrations used in this study.

The sampling of the porous surfaces highlighted the fact that these sampling mediums are not well-suited for sampling on abrasive surfaces. The Ghostwipes™ were found to be the strongest and did not tear apart, the MCE and PVC filters however did not hold up well. They tear apart easily on these rough surfaces.

3. Recommendations and possible future studies

Based on the results of this study it is recommended that the Ghostwipes™ be used as the sampling medium for platinum in the refinery, as it is also an ASTM approved sampling material.

When sampling abrasive surfaces in the refinery, it must be kept in mind that these sampling mediums are not the best suited. Even though the Ghostwipes™ were the best of the three mediums compared in this study, the samples analysed revealed BDL which indicates that the efficiency of recovery is not what it should be. It is thus recommended that when rough and porous surfaces need to be sampled, other sampling mediums be used, which are more suitable for such surfaces, for example the suction methods.

Possible future studies to be conducted, can focus on the analytical methods used by the laboratories and the recovery rates achieved from the analyses of samples. Developing an analytical method that is more sensitive, accurate and specific to the relevant metal, in this case platinum. The digestion procedure used may not dissolve some compounds, it is thus extremely important to make sure that these methods are applicable to the compound being analysed. The absorption and retention ability of the sampling mediums is very important in retrieving valuable data, it is thus of great importance to develop a medium specifically for platinum sampling.

NIOSH method 9100 describes the use of the Wash 'n Dri™ hand wipes for the sampling of lead on surfaces. The Wash 'n Dri™ hand wipes are also individually packed and pre-moistened. Comparing the Ghostwipes™ and the Wash 'n Dri™ hand wipes for the sampling of platinum on surfaces may also be of interest. The comparison between the manual wipe sampling and vacuum sampling on different surfaces can also be worthwhile. As identified in this study, the manual wipes had difficulty on the porous surface, so it can be beneficial to evaluate the effect of the vacuum sampling on such a surface.

4. References

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