The influence of hydrochloric acid and chlorine exposure on the skin barrier function of precious metal refinery workers

JANETTA HENDRINA REYNECKE
(Hons. B.Sc)

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

Supervisor: Prof JL du Plessis
Assistant Supervisor: Mr PJ Laubscher

Potchefstroom
2011.10.31

AUTHOR'S CONTRIBUTION

This study was planned and executed by a team of researchers. The contributions of each of the researchers are the following:

NAME	CONTRIBUTION
Ms JH Reynecke	• Responsible for personal and area sampling. • Responsible for literature review and statistical analysis. • Responsible for discussion of results, conclusion and writing of article.
Dr JL du Plessis	• Supervisor. • Assisted with designing and planning of the study, approval of protocol, reviewing of the mini-dissertation and documentation of the study. • Assisted with analysis and interpretation of results.
Mr PJ Laubscher	• Assistant-supervisor. • Assisted with the approval of the protocol and reviewing of the documentation of the study. • Assisted with the interpretation of the results.

The following is a statement from the supervisors that 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 Janetta H Reynecke's M.Sc (Occupational Hygiene) mini-dissertation.

_____ _____

Dr JL du Plessis Mr PJ Laubscher

Supervisor Assistant-Supervisor

ACKNOWLEDGEMENTS

My sincere thanks and appreciation to all those who have supported me during this research. In particular, a special word of thanks to:

- Mart for giving me advice in the right direction and believing in me all these years!

- My family and friends for believing in me, and for continuous support and prayers.

- My supervisor Dr JL du Plessis, and my assistant supervisor Mr PJ Laubscher, for constructive and supportive guidance during the course of this study.

- Mr N van Aarde and Prof J van Rooyen for believing in my potential and for giving me the opportunity to make a difference in my own and others' lives.

- Mr SC Engelbrecht for permission and support during the execution of the project – it was a great learning experience.

- Dr S Ellis for help and support with the statistics.

- Ms L Combrink for the language editing.

I praise God for shining a light when darkness came,
giving rain when earth was dry,
showing the way when doubt overwhelm all sense.
To You all the glory!

LIST OF ABBREVIATIONS

%	Percent
+	Positive
-	Negative
ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
a.u.	Arbitrary units
BC-group	Barrier-cream group
°C	degree Celsius
cAMP	3’5’-Cyclic adenosine monophosphate
Cl_2	Chlorine
cm	centimeter
GAG	Glycosaminoglycans
$g/m^2/h$	gram per square meter per hour
g/mol	gram per mole
H^+	Hydrogen cation
HCl	Hydrochloric acid
IDLH	Immediately dangerous for life and health
IL	Interleukin

IgE	Immunoglobulin-E
l/min	liter per minute
MAGP	Microfibril-associated glycoprotein
m^2	square meter
mg/m^3	milligram per cubic meter
ml	milliliters
mm	millimeters
NADPH	Nicotinamide adenine dinucleotide phosphate
nBC	non-Barrier-cream group
NIOSH	The National Institute for Occupational Safety and Health
NMF	Natural moisturizing factors
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PGM	Platinum Group Metals
PEL	Permissible exposure limit
pH	Hydrogen ion concentration
PPE	Personal protective equipment
ppm	Parts per million
PVC	Polyvinyl chloride
REL	Recommended limit

RHCS	Regulations for Hazardous Chemical Substances
SIMRAC	Safety in Mines Research Advisory Committee
STEL	Short term exposure limit
TEWL	Trans-epidermal water loss
TLV	Threshold limit value
TNF	Tumor necrosis factor
TWA	Time weighted average
µg	microgram

TABLE OF CONTENTS

CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

ANNEXURE

PREFACE

For the purpose of this research project it was decided to use article format. The journal, the Annals of Occupational Hygiene was chosen for potential publication. The journal required that the length of the article do not exceed 5000 words unless justified and that references should be inserted in the text according to Harvard style. Due to the nature of this research, and the amount of data compiled and analysed, the length of this article just exceeds 5000 words. For consistency the reference style used in the mini-dissertation will be according to the guidelines of the Annals of Occupational Hygiene. At the end of each chapter, references are listed in alphabetical order by name of the first author, using the Vancouver style of abbreviation and punctuation.

SUMMARY

Various hazardous chemical substances are used daily in the platinum refineries. This study was conducted in order to determine whether platinum refinery workers' exposure to HCl and Cl_2, two of the hazardous chemical substances, could damage the skin barrier function (i.e. skin hydration, trans-epidermal water loss and skin surface pH) of these workers.

The participants of this study were fourteen workers that were exposed to HCl and Cl_2, constituting the exposed group, and a control group that was made up of ten workers located in another building detached from the plant. Due to the fact that some of the workers in the exposed group used barrier creams, the exposed group was further divided into two groups, namely the barrier cream (BC) and non-barrier cream (nBC) groups. Workers' skin barrier function was measured on six distinct anatomical skin areas, including indirectly exposed skin (i.e. palm, wrist and back of the hand that was covered with protective gloves) and directly exposed skin (i.e. neck, cheek and forehead). These skin measurements were conducted before, during and at the end of shifts, while airborne personal and area HCl and Cl_2 exposure were concurrently assessed.

The results of this study indicated that indirectly exposed skin of the exposed group was dehydrated, and only Cl_2 exposure contributed to a disrupted skin barrier function on the back of the hand. Due to limited correlations with skin hydration, it remained unclear whether HCl and Cl_2 exposure had an influence on skin hydration. The palm of the exposed group had abnormally high TEWL levels, but only HCl contributed to the palm's damaged skin barrier function. Skin surface pH for indirectly and directly exposed skin was found to be within the normal range, but both HCl and Cl_2 exposure contributed towards a decrease in skin surface pH for the directly exposed skin of the exposed group. It also remained unclear whether barrier creams enhanced the exposed group's skin barrier. This lack of certainty can most likely be ascribed to the small participant group.

Additional factors such as the use of latex gloves, continuous washing and scrubbing of hands, and contact with contaminated personal protective equipment and workplace surfaces could also have contributed to an impaired skin barrier.

Workers in the platinum refinery industry are potentially exposed to chlorinated platinum salts, and an impaired skin barrier may result in skin permeation thereof, which could lead to sensitisation and allergy. It is, however, recommended that washing facilities need to be improved; personal hygiene procedures and skin aftercare need to be emphasised during training sessions; and neoprene gloves need to be used to reduce the allergy risk of latex gloves.

OPSOMMING

‘n Verskeidenheid gevaarlike chemiese substanse word daagliks in die platinumraffinaderye gebruik. Hierdie studie is onderneem met die doel om vas te stel of die blootstelling van werkers in die platinumraffinadery aan HCl en Cl_2, twee van die verskeie skadelike chemiese substanse, die velgrensfunksie (d.i velhidrasie, trans-epidermale water verlies en oppervlak-pH van die vel) kan beskadig.

Die deelnemers aan hierdie studie was veertien werkers, wat blootgestel is aan HCl en Cl_2, om die blootgestelde groep te vorm, en die kontrole groep is saamgestel uit tien werkers in 'n ander gebou weg van die aanleg. Aangesien sommige van die werkers in die blootgestelde groep van velgrens-rome gebruik gemaak het, is besluit om die blootgestelde groep te onderverdeel in twee groepe, naamlik die velgrensroom (BC) en die nie-velgrensroom (nBC)-groepe. Die werkers se velgrensfunksie is op ses diskrete anatomiese velareas gemeet, insluitend indirek-blootgestelde vel (d.w.s handpalm, pols en agterkant van die hand wat deur veiligheidshandskoene bedek word), en direk-blootgestelde vel (d.w.s nek, wang en voorkop). Hierdie velmetings is geneem voor, tydens, en teen die einde van werkskofte, terwyl luggedraagde persoonlike en statiese HCl en Cl_2 blootstelling terselfdertyd gemeet is.

Die resultate van hierdie ondersoek toon dat die indirek-blootgestelde velareas van die blootgestelde groep gedehidreer was, en dat slegs blootstelling aan Cl_2 bygedra het tot ‘n versteurde velgrensfunksies op die agterkant van die hand. Aangesien beperkte korrelasies met velhidrasie gevind is, is dit nie duidelik of blootstelling aan HCl en Cl_2 inderdaad velhidrasie beïnvloed het nie. Die handpalm van die blootgestelde groep het abnormaal hoë TEWL-vlakke getoon, maar slegs HCl het bygedra tot die beskadiging van die handpalm se velgrensfunksie. Die veloppervlak-pH van indirekte en direkte blootgestelde vel was binne die normale verspreidingsveld, maar blootstelling aan beide HCl en Cl_2 het bygedra tot ‘n afname in die vel se oppervlak-pH vir die direkte blootgestelde vel van die blootgestelde groep. Dit was ook

steeds nie duidelik of velgrensroom wel die blootgestelde groep se velgrens verbeter het nie. Hierdie onsekerheid kan bes moontlik toegeskryf word aan die klein deelnemersgroep. Verdere faktore soos die gebruik van latekshandskoene, gereelde was en skrop van hande, en kontak met gekontamineerde persoonlike beskermende toerusting en werkoppervlakke kon verder bygedra het tot die verswakking van die velgrens.

Werkers in die platinumraffinaderybedryf word potensieel blootgestel aan gechlorineerde platinumsoute, en ‘n verswakking in die velgrens mag lei tot veldeurdringbaarheid, wat weer tot sensitisering en allergieë aanleiding kan gee. Daar word egter aanbeveel dat die wasgeriewe verbeter moet word; dat persoonlike higiëneprosedures en vel-nasorgstappe tydens opleidingsessies beklemtoon moet word; en dat neoprene-handskoene gebruik moet word met die oog daarop om die allergie-risiko wat met latekshandskoene geassosieer word, te verminder.

CHAPTER 1: GENERAL INTRODUCTION

1.1 INTRODUCTION

In the platinum metal refining industry, processes such as dissolution, ion exchange, molecular recognition and hydrolysis are commonly used in the purification of precious metals. With each of these processes, different hazardous chemical substances are used to obtain rhodium, iridium, platinum, ruthenium, palladium and gold. Employees working in the refining industry as process controllers or operators handle highly toxic and hazardous chemicals on a daily basis. HCl liquid is only one of the substances used to dissolve platinum during metallurgical processes. Added to this, Cl_2 gas is used in the formation of HCl and both these substances are hazardous stressors in a work environment, because both HCl and Cl_2 are toxic to the skin (Nextteq LLC, 2007; Zeliger, 2008). When HCl and Cl_2 dissolve in the skin's water content, they act as corrosives that disturb the skin's barrier function.

The toxic effects of HCl and Cl_2 are local and can lead to severe skin inflammation, skin burns, skin diseases such as irritant- and allergic contact dermatitis, urticaria, ulcers, acne, chloracne and photosensitization (Todd & Carman, 2001; Thorne, 2003; Weber & Pierce, 2003; De Craecker *et al*., 2008). Typical symptoms associated with contact dermatitis are erythema (redness), induration (thickening and firmness of the skin), scaling (flaking) and vesiculation (blistering) on the areas where direct contact with the chemical agent occurred (Cohen & Rice, 2003).

It is interesting to note that inhalation was traditionally considered to be the most important route of exposure to these substances, and priority was given to ensure that effective control measures were in place to prevent inhalation through the provision of chemical detection alarms and the use of respirators (Van Hemmen *et al*., 2003; Van Wendel-de-Joode *et al*., 2003; Ayres, 2005). It was only in the late 1990s that more research was conducted with a view to address the substantial knowledge gap that existed

regarding the route and influence of dermal exposure and consequent reactions of such exposure. Schneider *et al.* (1999) have proposed a conceptual model of dermal exposure that occurs through one or more of the following three pathways: a) deposition of contaminants directly from the air that impact or settle on the skin; b) direct contact through immersion or spillages of contaminants; and c) indirect contact through contaminated surfaces or clothing.

Dermal exposure was initially described in terms of percutaneous uptake of chemicals (Semple, 2004), but according to Proksch *et al.* (2008) is it difficult to measure skin penetration of chemicals. This is because the substance that has penetrated into the skin must be detected by chemical analysis in tape-stripping material, biopsies, tracing of penetrated dyes and radioactive labeling; these types of analysis are not generally allowed to be performed in humans. Currently, dermal exposure can be understood by the three types of chemical-skin interactions. Firstly, the chemicals may enter the body through an intact skin and contribute to the systemic load, or alternatively the chemicals can induce local effects (ranging from irritation to burns or degradation of the barrier properties of the skin), or lastly, the chemicals can cause allergic skin reactions by means of complex immune system responses that can subsequently trigger responses in the skin at both the point of contact or at skin sites remote from the part of contact (Semple, 2004; Badenhorst *et al*., 2007; Zeliger, 2008).

Irrespective of the path followed by dermal exposure or chemical-skin interaction, the human skin's most critical function is to form an effective barrier between the "inside" and the "outside" of the organism through blocking any chemical uptake when there is contact with the skin (Proksch *et al,*. 2008). The main parameters that play important roles in the skin's barrier functions are the "outside-inside barrier" (that includes skin hydration and surface skin pH), as well as the "inside-outside barrier" that includes trans-epidermal water loss (Agache & Humbert, 2004; Serup *et al.,* 2006; Courage & Khazaka electronic GmbH, 2008).

According to current knowledge, no quantitative research has yet been conducted with a view to directly measure HCl and Cl_2 exposure levels on human skin. There are only qualitative methods in use that indicate the presence of HCl on human skin. These methods include detection Surface Swypes™ and Permea-Tec™ sensors (SKC, 2010). In an effort to determine whether HCl and Cl_2 exposure could influence employees' skin barrier function, skin barrier function will be measured concurrently with their airborne personal and area HCl and Cl_2 exposure, which will serve as an indirect means of indicating an acidic working environment. Based on this contextualisation, the aims and objectives of the study are set out below.

1.2 AIM AND OBJECTIVES

The aim of this study is:

- to assess whether HCl and Cl_2 exposure can have an adverse influence on the skin barrier function of precious metal refinery workers.

The objectives of this study are:

- to assess the skin barrier function of workers in a precious metal refinery by assessing their stratum corneum hydration, skin surface pH and TEWL;
- to obtain information regarding refinery workers' personal views of their skin condition and previous experiences of skin diseases;
- to measure workers' airborne exposure to HCl and Cl_2; and
- to establish the possible correlations between skin barrier function and HCl and/or Cl_2 exposure.

1.3 HYPOTHESIS

The hypothesis of this study is that HCl and Cl_2 exposure adversely influence the skin barrier function of exposed precious metal refinery workers.

1.4 REFERENCES

Agache P, Humbert P. (2004) Measuring the skin. New York: Springer. ISBN 3 540 01771 2.

Ayres JG. (2005) The effects of inhaled materials on the lung and other target organs. In Gardiner K, Harrington JM, editors. Occupational hygiene. 3rd ed. USA: Blackwell Publishing. p. 47-58. ISBN 1 4051 0621 2.

Badenhorst CJ, Du Plessis JL, Eloff FC. (2007) Dermal exposure. In Stanton DW, Kielblock J, Schoeman JJ, Johnston JR, editors. Handbook on mine occupational hygiene measurements. Johannesburg: MHSC. p.1 35-142. ISBN 978 1 9198 5324 6.

Cohen DE, Rice RH. (2003) Toxic responses of the skin. In Klaassen CD, Watkins JB, editors. Caserett & Doull's essentials of toxicology. New York: McGraw-Hill. p. 288-300. ISBN 0 07 138914 8.

Courage & Khazaka Electronic GmbH. (2008) Information and operating instructions for Derma Unit SSC3 Sebumeter®/Corneometer®/Skin-pH-Meter® and the software for Windows®. Germany: CK.

De Craecker W, Roskams N, Op de Beeck R. (2008) Occupational skin diseases and dermal exposure in the European Union (EU-25): policy and practice overview. Available at http://www.osha.europa.eu/en/publications/reports/TE7007049ENC_skin_diseases Accessed 10 October 2010.

Nextteq LLC. (2007) MSDS: HCl. Available at http://www.skcinc.com/instructions/MSDSVerifit.pdf Accessed: 23 August 2010.

Proksch E, Brandner JM, Jensen JM. (2008) The skin: an indispensable barrier. Experimental Dermatology; 17: 1063-1072.

Schneider T, Vermeulen R, Brouwer DH, Cherrie JW, Kromhout H, Fogh CL. (1999) Conceptual model for assessment of dermal exposure. Occupational and Environment Medicine; 56: 765-773.

Semple S. (2004) Dermal exposure to chemicals in the workplace: just how important is skin absorption? Occupational and Environment Medicine; 61: 376-382.

Serup J, Jemec GBE, Grove GL. (2006) Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis. ISBN 0 8493 1437 2.

SKC. (2010) Surface/Dermal and decontamination: chemical hazards. Available at http://www.skcinc.com/SurfaceDermalSampling.asp Accessed 23 August 2010.

Thorne PS. (2003) Occupational toxicology. In Klaassen CD, Watkins JB, editors. Caserett & Doull's essentials of toxicology. New York: McGraw-Hill. p. 453-461. ISBN 0 07 138914 8.

Todd G, Carman H. (2001) Occupational skin disorders. In Guild R, Ehrlich RI, Johnston JR, Ross MH, editors. SIMRAC Handbook of occupational health practice in the South African mining industry. Johannesburg: Creda Communications. p. 355-385. ISBN 1 919 85302 2.

Van Hemmen JJ, Auffarth J, Evans PG, Rajan-Sithamparanadarajah B, Marquart H, Oppl R. (2003) RISKOFDERM: Risk assessment of occupational dermal exposure to chemicals: an introduction to a series of papers on the development of a toolkit. Annals of Occupational Hygiene; 47: 595-598.

Van Wendel-de-Joode B, Brouwer DH, Vermeulen R, Van Hemmen JJ, Heederik D, Kromhout H. (2003) DREAM: A method for semi-quantitative dermal exposure assessment. Annals of Occupational Hygiene; 47: 71-87.

Weber LW, Pierce JT. (2003) Development of occupational skin disease. In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 348-360. ISBN 1 931504 43 1.

Zeliger HI. (2008) Human toxicology of chemical mixtures: toxic consequences beyond the impact of one-component product and environmental exposures. New York: William Andrew. ISBN 978 0 8155 1589 0.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

As early as 1775, the first correlation of occupational exposure with skin-related diseases was described by Percival Pott, and in 1899 Herxheimer observed that many industrial workers suffered from skin diseases since the industrial revolution introduced large-scale chemicals manufacturers (Weber & Pierce, 2003). Hydrochloric acid (HCl) as well as chlorine gas (Cl_2) are only some of the hazardous chemical substances to which employees in the metal refinery industry are most frequently exposed to. Even though the respiratory tract is traditionally considered to be the main target organ of these two hazardous chemical substances, the potential impact of these on the skin cannot be ignored.

The skin is a well-studied organ and an extensive body of literature is available that describes the anatomy, organisation and various functions of the skin (Cohen & Rice, 2003; Weber & Pierce, 2003; McGrath & Uitto, 2010; Foulds, 2005; Proksch *et al*., 2008; Rawlings *et al.*, 2008), but up until today no uniform or internationally accepted standards have formulated that stipulate dermal exposure or specify dermal exposure limits in order to prevent occupational skin diseases (De Craecker *et al.,* 2008). In the last decade, Schneider *et al.* (2000) proposed a conceptual model to assess and interpret dermal exposure, but further research regarding occupational dermal exposure is still required.

In this chapter, the properties of HCl and Cl_2 and their influence on human health, specifically on the skin barrier function, will be critically discussed.

2.2 PROPERTIES OF HYDROCHLORIC ACID AND CHLORINE GAS

HCl is a colourless gas with a pungent odour, but can also be in a liquid or mist state. In the following sections, reference to HCl implies exposure to HCl gas and/or mist. HCl has a

molecular mass of 36.5 g/mol and is 1.2 times heavier than air. HCl gas in ambient air would tend to accumulate on floor level. HCl gas is characterised as a poisonous irritant and as corrosive (Stanton, 2007; IVHHN, 2010).

Cl_2 is a Group VIIa (17) element in the periodic table and has a molecular mass of 70 g/mol. It is a greenish-yellow gas with a characteristic pungent suffocating odour and is 2.5 times heavier than air. Cl_2 gas is labelled as a "poisonous gas", but is normally condensed to clear amber liquid and stored in cylinders and tank cars. Cl_2 gas could also form when some chemicals are mixed with other chemicals such as acids, including HCl, or ammonia (SAIF, 2009).

2.2.1 Stability and reactivity

HCl is used in a variety of chemical processes of which burning of PVC products and ignition of platinum salts in the refining process are the most familiar processes in the mining industry (EPA, 2007; Stanton, 2007). It is stable at normal temperatures and pressures, but incompatible with metals, alkalis, oxidising agents, carbides of rubidium and acetylides of rubidium. Although HCl is non-flammable in air, reactions with any of these chemicals is exothermic and violent, and could result in the formation of flammable hazardous decomposition gas products, for example chlorine gas, hydrogen gas, as well as HCl gas (Young, 2001; OXYCHEM, 2010). HCl is also very soluble in water and reacts with moisture in the air to form a mist (IVHHN, 2010).

Cl_2 is an oxidising agent and is used in the purification of water and metals, or as a bleaching agent (Tranter, 2004; SAIF, 2009). When Cl_2 is in a solution, it becomes a very reactive and corrosive material to the extent that it can corrode many metals. Moisture, steam and water increases chlorine's reactivity and hydrochloric acid forms when Cl_2 reacts with hydrogen sulphide and water. Phosgene and sulphuryl chloride is formed when chlorine reacts with carbon monoxide and sulphur dioxide. Cl_2 is also known as a non-combustible gas, but most combustible materials will be able to burn in

Cl_2 (OSHA, 1996a; OSHA, 2007). Therefore, there is a risk of fire and explosion when Cl_2 is in contact with combustible substances such as acetylene, ethylene, hydrogen, ammonia and finely divided metals (ICSC, 2000a).

2.2.2 Respiratory occupational exposure limits

The OEL-STEL for HCl is 5 ppm (7 mg/m^3) according South-Africa's RHCS (1995). The OSHA-PEL (OSHA, 1996b; OSHA, 2005) and NIOSH-REL (NIOSH, 2009) for HCl are the same as South-Africa's RHCS (1995). . NIOSH also proposes a recommended IDLH level of 50 ppm. The ACGIH TLV-STEL for HCl is 2 ppm as a ceiling value (ACGIH, 2010).

South-Africa's OEL-TWA for Cl_2 is 0.5 ppm with a STEL of 1 ppm (RHCS, 1995). The OSHA-PEL for Cl_2 is 1 ppm (3 mg/m^3) as a ceiling limit and, therefore, a worker's exposure may not at any time exceed this ceiling limit (OSHA 1996a; OSHA, 2007). The NIOSH REL-TWA for Cl_2 is 0.5 ppm (1.5 mg/m^3) up to an 8 to 10-hour workday and a 40-hour workweek, and a STEL of 1 ppm (3 mg/m^3). NIOSH proposed an IDLH of 10 ppm for Cl_2 (NIOSH, 2004; NIOSH, 2010). The ACGIH TLV and STEL for Cl_2 is the same as NIOSH's exposure limits with emphasis that the exposure periods should not exceed 15 minutes and that the STEL concentration should not be repeated more than four times a day with a separation interval of at least 1 hour (ACGIH, 2010).

2.2.3 Skin notation

South Africa's RHCS (1995) and organisations such as the ACGIH, AIHA and NIOSH started to recognise the reality of dermal exposure and assigned a "skin notation" attached to the occupational exposure limit (OEL) or threshold limit value (TLV) to some substances. The skin notation alerts the employer and occupational hygienist that, although the airborne exposure is at or even below the OEL or TLV, dermal contact with liquids and aerosols could still result in overexposure through the skin (ACGIH, 2010). This skin notation is only given for substances that could cause systemic effects following dermal exposure and absorption and not for chemicals that may cause dermal

irritation such as HCl and Cl_2. However, even if substances have no skin notation, employers and occupational hygienists should keep it in mind that there are several other factors that may enhance the potential skin absorption of a substance. For example, certain vehicles may act as carriers, thereby enhancing skin penetration or dermatologic conditions that may affect skin barrier function which could further enhance penetration of substance through damaged skin. (Foulds, 2005; Mansdorf & Henry, 2003).

2.2.4 Routes of exposure

Exposure to HCl gas/mist and Cl_2 gas occurs mainly through inhalation (ICSC, 2000a; ICSC, 2000b). The eyes and skin are also exposure routes when in contact with human body tissue water. Ingestion as an exposure route could only occur when these hazardous chemicals are swallowed.

2.2.5 Health effects

The main target organs for HCl and Cl_2 are the upper respiratory system, lungs, eyes, skin, mucous membranes and gastrointestinal tract (Bulls, 2007; NIOSH 2004; NIOSH 2009; NIOSH 2010). Both, HCl and Cl_2, react with human body tissue water to form hydrochloric acid and/or hypochlorous acid that cause severe injuries to the skin. Injury of the targeted organ is proportional to the concentration of the HCl and Cl_2 gas, duration of exposure and/or contact, frequency of exposure and the water content of the exposed tissue (Ruse, 1998; Eaton & Klaassen, 2003). Both HCl and Cl_2 exposure symptoms could at times be delayed (ICSC, 2000a; ICSC, 2000b). In the following section, typical symptoms that could occur after acute or chronic exposure will be discussed.

2.2.5.1 Acute exposure

Acute inhalation of low concentrations HCl over a short period could result in pulmonary irritation, lesions of the upper respiratory tract and laryngeal as well as pulmonary oedema. Inhalation of a higher concentration HCl could result in health effects such as tachypnoea, pulmonary oedema and suffocation (ICSC, 2000b). The eyes, nose and throat become irritated when low concentrations of Cl_2 are acutely inhaled, followed by symptoms such as coughing, wheezing, dyspnoea, excessive saliva production, chest pain, general excitement and restlessness. Inhalation of a higher concentration of Cl_2 could result in symptoms such as difficulty in breathing, violent coughing, nausea, vomiting, cyanosis, dizziness, headache, choking, laryngeal oedema, pulmonary oedema, acute tracheobronchitis, chemical pneumonia and hypoxemia. Hyperchloraemic acidosis and anoxia that may lead to cardiac and/or respiratory arrest could also develop after acute inhalation of Cl_2 gas (Tranter, 2004; Ayres, 2005; Stanton, 2007; NIOSH, 2010).

Acute HCl gas/mist exposure to the skin, eyes and mucous membrane may cause serious skin burns, severe deep burns of the eyes, pain and blurred vision, eye ulceration, conjunctival irritation, cataracts and glaucoma (Cohen & Rice, 2003; Bull, 2007). Acute skin exposure to HCl liquid causes frostbite and severe burns (ICSC, 2000b). Acute dermal contact with Cl_2 gas results in skin irritation, erythema, blisters, burns and pain, while acute skin contact with chlorine liquid causes frostbite and skin burns. Acute eye contact with Cl_2 gas causes eye irritation and conjunctivitis, while acute contact with Cl_2 liquid causes severe deep burns, blurred vision and pain (ICSC, 2000a; OSHA, 2007 Stanton, 2007).

Although acute ingestion is not likely a route of exposure, it is possible that corrosion of the lips, mouth, throat, oesophagus and stomach could occur, as well as dysphagia, nausea and vomiting (Bull, 2007).

2.2.5.2 Chronic exposure

Chronic inhalation of HCl could result in a decrease in pulmonary function, inflammation of the bronchi and nasal ulceration (Bull, 2007). Therefore, typical health effects are chronic bronchitis, hyperplasia of the nasal mucosa, larynx and trachea as well as lesions in the nasal cavity (EPA, 2007; NEXTTEQ LLC, 2007). Chronic inhalation of Cl_2 gas at levels as low as 1 ppm could cause a moderate but permanent reduction in pulmonary function. Other symptoms associated with chronic exposure to Cl_2 gas are coughing, sore throat, severe chest pain, haemoptysis and an increased susceptibility to tuberculosis (Ruse, 1998; Tranter, 2004; Ayres, 2005; Stanton, 2007).

Chronic dermal exposure to HCl causes symptoms such as irritant contact dermatitis, and photosensitisation (Foulds, 2005; EPA, 2007; NEXTTEQ LLC, 2007; De Craecker *et al*., 2008). Chronic dermal exposure to low levels of Cl_2 could result in development of chloracne (ICSC, 2000a; Stanton, 2007; NIOSH, 2010).

Chronic ingestion of HCl could cause discoloration and erosion of dental enamel as well as inflammation of the mouth and mucous membranes (Bull, 2007).

2.3 SKIN ANATOMY AND ORGANISATION

The skin is one of the largest organs in the human body with a surface area of approximately 1.8 m^2 and average thickness of 1.2 mm (Agache, 2004a; Foulds, 2005). It consists of three layers: the epidermis, dermis and subcutis. Each layer has specialised cells and derivatives with particular physiology and function (Agache, 2004a). The skin can be likened to a “door” that provides bi-traffic direction. Substances could enter and/or exit through the skin if the “door is opened”. On the other hand, the skin can also be like a “closed door” and thus prevent penetration of substances through the skin. The skin, therefore, separates the hazardous external environment from the inside of the body.

2.3.1 Epidermis layer

The epidermis layer is also known as the Malpighi's layer and is made up by approximately ten layers of keratinocyte cells (Gentilhomme & Neveus, 2004). Other specialised epidermal cells that are present in this layer are melanocytes, Langerhans's cells and Merkel's cells (McGrath *et al.,* 2004; Tranter, 2004). The epidermis is a thin outer layer of the skin and is composed of five layers: namely the stratum corneum (horny layer), stratum lucidum, stratum granulosum, stratum spinosum and stratum basale. In the lower border of the epidermis, cells are separated from the dermis by a basement membrane, while the upper border of the epidermis cells forms the horizontal plane of the stratum corneum (Gentilhomme & Neveus, 2004).

2.3.1.1 Stratum basale layer

The stratum basale is the bottom layer of the epidermis and contains undifferentiated columnar shaped basal stem cells. These cells have large dark-stained nuclei, dense cytoplasm that contains many ribosomes and dense tonofilaments (McGrath *et al*., 2004). Basal stem cells continually divide of which one half of the cells differentiate and move to the next layer to begin the maturation process, while the other half of the cells stay in the stratum basale layer and divide over and over again to replenish the stratum basale layer (Weber & Pierce, 2003; Bouwstra & Ponec, 2006).

2.3.1.2 Stratum spinosum layer

Cells that differentiate in the stratum basale are pushed into the next layer, the stratum spinosum. Within the stratum spinosum layer, the epibasal keratinocytes enlarge to form spinous or prickle cells (McGrath *et al.,* 2004). These cells change from a columnar shape to more polygonal shapes and start to synthesise keratins. These keratin filaments aggregate to form tonofilaments that could connect keratinocytes via desmosomes in the stratum corneum layer (Weber & Pierce, 2003).

2.3.1.3 Stratum granulosum layer

As differentiated cells move from the stratum spinosum layer to the stratum granulosum layer, they start to lose their nuclei (Foulds, 2005). Enzymes of granular cells within this layer induce degradation of nuclei and organelles. These granular cells are characterised by dark clumps of cytoplasmic material and more keratin proteins. Water-proofing lipids are also produced and organised within this layer (Weber & Pierce, 2003). Organelles known as lamellar bodies or Odland bodies are present in the granular cells of the stratum granulosum layer and are enriched with polar lipids as well as catabolic enzymes. These lipids and enzymes serve as carriers or precursors of stratum corneum barrier lipids that include glycosphingolipids, free sterols and phospholipids (McGrath *et al*., 2004; Bouwstra & Ponec, 2006).

2.3.1.4 Stratum lucidum layer

The stratum lucidum layer is present only in thick skin and reduces shear forces between the stratum granulosum and stratum corneum layers (Foulds, 2005).

2.3.1.5 Stratum corneum layer

The stratum corneum is the top layer of the epidermis and consists of fully matured keratinocytes which contain keratin (Foulds, 2005). These keratinocytes synthesise and express numerous different structural proteins and lipids during their maturation process. Several structural, compositional and functional changes are associated with the final steps of keratinocyte differentiation. The keratins are aligned into highly ordered and condensed arrays through interactions with filaggrin. Filaggrin aggregates keratin filaments into tight bundles and promote the collapse of keratinocyte cells, transforming it in to flat and anucleated corneocytes of the stratum corneum layer (Tranter, 2004; Proksch *et al.,* 2008).

According to Weber and Pierce (2003), the stratum corneum could further be divided into two layers that include the stratum disjunctum and the stratum conjuctum layers.

The stratum disjunctum layer is made up of loosely packed aggregates of dry, dead cell bodies that are daily shed from the surface of the stratum disjunctum layer. This process is described as desquamation (Agache, 2004f). The stratum conjuctum layer can be described as a "brick-and-mortar" structure (Elias, 1983; Elias, 2004). The corneocytes are referred to as the "bricks" and are filled with keratin filaments and water; they are surrounded by a densely cross linked protein layer known as the cell envelope. Cell envelopes are extremely insoluble layered structures and contribute to the stability of corneocytes (Rawlings *et al*., 2008). A lipid monolayer, known as the lipid envelope, is also chemically linked to this densely packed cell envelope and serves as an interface between the hydrophilic corneocytes and the lipophilic extracellular non-polar lipids which surround the corneocytes (Bouwstra & Ponec, 2006). The intercellular spaces between the corneocytes are referred to as the "mortar" and consist of lipid bilayers interspersed with water layers of varying thickness. Intercellular material ("mortar") consists of lipidic layers, mainly spingolipids that lie parallel to the corneocyte cell membranes, and protein enzymes (Agache, 2004b).

Corneocytes are tightly joined by lipidic intercellular glue. This glue contains 50% ceramides, 25% free fatty acids, 20% free cholesterol, 0.5% cholesterol esters, and 3% triacylglycerol. The other 1.5% is unexplained. Proteins of the corneocyte cell membrane connect covalently with this glue to form a proteic link (corneodesmosomes). Across cell membranes, these corneodesmosomes are covalently linked to corneocyte cytokeratin filaments that form the cytoskeleton (Agache, 2004b).

2.3.2 Dermis

The dermis, also known as the cutis, is the middle layer. According to McGrath *et al*. (2004) and Foulds (2005), the dermis contains fibroblasts that synthesise collagen fibres, elastin fibres, reticular fibres and an interstitial ground substance that is rich in proteins and glycosaminoglycans (GAGs). Elastic fibres and fibrillar collagens are embedded in a

viscous gel, a ground substance made of nonfibrillar collagens, proteoglycans and microfibril-associated glycoprotein (MAGP). Due to the high hygroscopic power of the MAGP, the dermis tends to retain a substantial amount of water (Agache, 2004c).

Although the dermis has no clear layers as is the case with the epidermis, two layers can be distinguished: the upper stratum papillare layer and the lower stratum reticular layer (Weber & Pierce, 2003). The stratum papillare layer contains a thin arrangement of collagen fibres and interlacing bundles of fine fibrils. It is highly vascularised and also contains lymphatic vessels, sweat and sebaceous ducts as well as tactile nerves. The stratum reticular layer is thicker and consists of fibroelastic connective tissue, mostly collagen fibres that are arranged parallel to the surface of the skin. Other specialised cells and structures that are located in this layer are: dermal dendrocyctes, mast cells, macrophages, lymphocytes, sebaceous (oil) glands, apocrine (scent) glands that are associated with hair follicles, eccrine (sweat) glands that are not associated with hair follicles, blood vessels, nerve cells, the Meissner's and Vater-Pacini corpuscles (Weber & Pierce, 2003; Foulds, 2005). Chemicals that are able to penetrate the skin to this layer are collected by blood and lymphatic vessels.

2.3.3 Subcutis

The subcutis is the deepest layer of the skin and its thickness varies from 0.1 cm to several centimetres throughout the body. This layer consists mainly of a network of collagen, connective tissue and fat cells. It also houses larger blood vessels, nerves, sebaceous glands, sweat glands and arrector pilli muscles for hairs. The subcutis plays a major role in regulating the skin and body temperature (Agache, 2004d).

2.4 FUNCTIONS OF THE SKIN

The skin is a metabolically active organ with vital functions that include protection and maintenance of homeostasis of the body (Foulds, 2005). Agache (2004a) summarises these general functions of the skin:

- The skin has a self-maintenance and self-repair function, but the repair function of the appendages is not situated within the skin.
- Provision of mechanical protection through resistance to frontal and tangential shocks, attenuation of external pressure and maintaining body external shape through reversible deformations.
- Provision of a chemical barrier through limitation of foreign substance penetration and prevention of water and endogenous fluid loss. This permeable barrier of the skin is primarily located in the stratum corneum (Pirot & Falson, 2004; Proksch *et al.*, 2008; Rawlings *et al.,* 2008; Kezic & Nielsen, 2009). The stratum corneum's permeability can greatly increase if any disease or other condition compromises this barrier, thus, increasing the penetration of foreign substances as well as increasing body water loss (Nielsen *et al.,* 2007).
- Protection against ultraviolet rays through melanocytes that produces the pigment melanin.
- Protection against environmental pathogenic micro-organisms and prevention of entry of bacteria through maintenance of an "acidic mantle" of the epidermis.
- Other functions in cooperation with other organs: sensory function through tactile senses, control of body temperature through vasodilatation and vasoconstriction of blood vessels, immune function through activities of Langerhans's cells and micro-organisms living on the skin, ossification through synthesis of pro-vitamin D that is responsible for intestinal absorption of calcium, and sexual function through conversion of testosterone into more active di-hydrotestosterone.

2.4.1 Specialized functions of enzymes in the epidermis

Keratinocytes in the epidermis contain first-pass-metabolism enzymes that are able to remove cellular and metabolic waste (Agache, 2004c). These enzymes include phase I enzymes such as hydroxylases, dealkylases, deaminases, epoxide hydratases, monoamine oxidases, and NADPH cytochrome C reductases, as well as phase II enzymes such as glucuronidases, sulfatases, esterases and acetylases. Fibroblasts, histiocytes and macrophages in the dermis contain phase I and phase II biotransformation enzymes that are similar to those found in the epidermis (Cohen & Rice, 2003; Weber & Pierce, 2003).

According to Foulds (2005), these enzymes are all able to increase or decrease the systemic bioactivity of a substance and any disruption of enzyme activity could result in changes such as in the organisation of corneodesmosomes, stratum corneum lipid conformation, or changes in skin surface pH. Most of these enzymes are pH-dependent. Penetration of hazardous substances through the skin that contribute to changing skin surface pH will result in the disturbance of dermal enzyme activities, therefore, enhancing the development of poor skin barrier function and manifestation of skin diseases (Rippke *et al*., 2002).

2.4.2 Specialized functions of epidermis lipids

Ceramides, free fatty acids and cholesterol are the three major barrier lipids in the stratum corneum. Ceramide, the most important barrier lipid, is synthesised by serine-palmitoyl transferases. Free fatty acids are synthesised by acid lipase. Cholesterol is mostly synthesised *in situ* from acetate, but can also be reabsorbed from the circulation (Rippke *et al.*, 2002; Proksch *et al.,* 2008).

These lipids are modified and arranged into intercellular lamellae positioned parallel to the cell surface, while lipid envelopes that are covalently bound act as a scaffold for this process (Proksch *et al.,* 2008). The intercellular lamellar lipid layers are composed of alternate hydrophobic and hydrophilic lamellae, thus each sheet consist of two lipid

bilayers (Pirot & Falson, 2004). These intercellular lipid bilayers' tightly packed formation plays an important role in the permeability barrier function of the skin (Proksch *et al.,* 2008; Rawlings *et al.,* 2008).

2.4.3 Specialised functions of signalling

Rawlings *et al.* (2008) refer to the stratum corneum as a biosensor that facilitates other biological protection strategies via signalling between the stratum corneum, epidermis and deeper skin layers. Signalling via cytokines, 3'5'-cyclic adenosine monophosphate (cAMP) and calcium, contributes to the formation and maintenance of the stratum corneum's barrier function (Proksch *et al.,* 2008). Cytokines such as interleukin (IL-1 and IL-6) and tumor necrosis factor (TNF) are potent mitogens and stimulators of lipid synthesis. Chronic barrier disruption causes an increase in cytokine production that could lead to inflammation and epidermal proliferation. Calcium is an important regulator of protein synthesis in the epidermis, but through regulation of transglutaminase-1 activity it also controls the production and synthesis of lipids. The extracellular calcium ions are also important for cell-cell adhesion and epidermal differentiation and disruption of calcium metabolism could lead to an increase in TEWL or influence the skin surface pH. cAMP plays a role in keratinocyte barrier recovery, with an increase in intracellular cAMP delaying barrier recovery, while cAMP antagonists accelerate barrier recovery (Proksch *et al.*, 2008; Rawlings *et al*., 2008).

2.5 SKIN BARRIER FUNCTION PARAMETERS

The skin's major function is to form an effective barrier between the "inside" and the "outside" of an organism (Proksch *et al.*, 2008). Zhai and Mailbach (2002), Feingold (2007) and Foulds (2005) were of the opinion that this barrier function is only situated in the stratum corneum's structure and organisation. It was only recently discovered that the physical, chemical, biochemical barriers and adaptive immunological barriers are also

located in the rest of the epidermis of the skin and not only the stratum corneum (Proksch *et al.*, 2008; Rawlings *et al*., 2008).

The stratum corneum that consists of protein-enriched cells, cornified envelopes, cytoskeletal elements, corneodesmosomes and lipid-enriched intercellular domains form the physical barrier of the skin. The nucleated epidermis also contributes to the physical barrier function by preventing water loss and penetration of harmful substances through tight junctions, gap junctions, adherens junctions, desmosomes and cytoskeletal protein elements. The chemical and biochemical barriers are provided by epidermal lipids that are extruded into the extracellular domains where they form extracellular lipid-enriched layers, acids, hydrolytic enzymes, antimicrobial peptides and macrophages. The immunological barrier is composed of humoral and cellular constituents of the immune system (Proksch *et al.*, 2008; Rawlings *et al*., 2008).

Although various factors could disrupt the integrity of the stratum corneum, there is still no clarity regarding the influence of skin damage and dermal absorption of substances (Kezic & Nielsen, 2009). Penetration of a substance through the skin can be estimated by biological monitoring, which is very difficult and complex, but skin damage can be assessed by measuring TEWL, skin hydration, erythema or visual examination of the skin. An increase in TEWL and a decrease or excessive increase in skin hydration are markers of a disturbed skin barrier function (Kezic & Nielsen, 2009; Proksch *et al.*, 2008). Du Plessis and Eloff (2010) highlight the importance of using different instruments to evaluate the skin barrier. Agache and Humbert (2004) and Serup *et al.* (2006) have compiled handbooks on these measurements and evaluation methods of barrier function. They refer to skin hydration, skin surface pH and TEWL as the three main parameters that could be accurately measured by specialised instruments to determine the magnitude of skin barrier damage.

2.5.1 Skin hydration

The stratum corneum is an effective barrier to water and other substances. Nicander *et al.* (2006) state that skin hydration is a very ill-defined concept. They explain hydration as free water, or more or less bound water, only found in the upper layers of the stratum corneum or in the whole stratum corneum. There is always water supply from the underlying hydrated living tissue which contributes to the stratum corneum's resistance to take up water, and has an ability to lose only small amounts of water from the body (Tagami, 2006). This allows the human skin surface to stay soft, smooth and free for movement without becoming dry, hard, cracked or fissured as long as the water-holding capacity of the stratum corneum remains intact (Barel & Clarys, 2006; Tagami, 2006).

The main components that bind water in the stratum corneum are small water-soluble metabolites, proteinaceous structural components, intercellular ceramides and sebum that cover the skin surface (Tagami, 2006). These components play a role in the stratum corneum's water-holding capacity, preventing easy water passage through the skin as well as prevention of water evaporation. Adequate hydration is, therefore, essential for optimum skin function, but prolonged exposure to water leads to increased hydration of the stratum corneum or pathological skin conditions which reduce the skin barrier function (Warner *et al.,* 2003; Tagami, 2006). Excessive hydration causes large pools of water in the intercellular spaces that result in the disruption of the lipid bilayers and its organisation (Warner *et al.,* 2003). According to Bernengo and De Rigal (2004), water has a greater affinity for polar regions in the skin. Due to water's ion dipole interaction, the insertion of water between these polar regions in the skin causes attractive forces of the aliphatic chains of lipids to decrease, which reduces the stratum corneum's cohesiveness in a similar way as surfactants. This process enhances the absorption of lipophilic chemicals through the stratum corneum (Bernengo & De Rigal, 2004).

An adequate amount of water in the stratum corneum is essential in order to maintain a general appearance of a soft, smooth and well-moisturised skin that is flexible. It contributes to keeping the barrier function intact and allowing slow release of tansepidermal water loss in a dry environment. Water deficiency in the stratum corneum results in a rough, brittle, scaly, cracked, fissured and/or dry appearance of the skin (Barel & Clarys, 2006; Tagami, 2006). There is, however, very little data confirming that a dry skin condition can only be attributed to a diminution of the stratum corneum's water content and there is no universally accepted theory for explaining the exact causes of dry skin. Disorders of corneocyte adhesion and desquamation, modifications in the composition of certain epidermal lipids, disorders in the water-retaining properties of the stratum corneum and/or abnormal presence of NMF in the stratum corneum are all factors that can be related to a dry skin condition (Barel & Clarys, 2006). Abnormally dry skin might also be caused by an increase in blood flow due to an inflammatory mediator release during skin diseases (Rawlings *et al.*, 2008).

The concentration gradient of water within the stratum corneum makes it difficult to measure the absolute amount of water contained in the stratum corneum, but based on the electrical properties of water, the water content of the stratum corneum can be measured with a capacitance method (Barel & Clarys, 2006; Gabard *et al.,* 2006; Zhai & Maibach, 2002). The Corneometer® manufactured by Courage-Kazaka Electonic GmbH (2008) is such an instrument that converts the total capacitance of the skin surface to arbitrary units (a.u.) of skin hydration. The values range from 0 to 110/120 a.u. A value of below 30 a.u. indicates a very dry skin, between 30 and 40 a.u. a dry skin and higher than 40 a.u. normal skin hydration (Gabard *et al.,* 2006).

2.5.2 Transepidermal water loss (TEWL)

Water within the epidermis structure may be strongly or weakly bound, or may exist as free water (Agache & Black, 2004). The superficial layers contain free water, whereas the corneocytes in the deeper layers have strongly bound water. The protein content in the deeper corneocyte layers contribute to this strongly bound water with an

unchanged water concentration and, therefore, remain highly hydrated. NMF such as urea, lactic acids and amino acids, are hygroscopic and are known as moisture collectors that maintain the minimum hydration of the middle and deeper layers of the stratum corneum (Agache, 2004b). NMF help retain weakly bound water in the corneocytes, but filaggrin in disintegrated corneocytes contributes to the release of water and low-molecular weight substances. Water in the intercellular spaces is free or weakly bound to ceramides or other amphiphilic lipids. This water is attracted to the surface of the skin by the lower relative humidity of the atmosphere and passive diffusion thereof occurs through the skin (Agache, 2004b).

Under normal conditions (20°C and relative humidity of 40-60%) approximately 300 to 400 ml water crosses over the stratum corneum per day through passive diffusion (Gabard & Treffel, 2004).

TEWL was initially defined as an indication of the amount of water vapour passing through the stratum corneum by passive diffusion, but nowadays TEWL refers to the total amount of water loss through the skin when there is no sweat gland activity (Tupker & Pinnagoda, 2006; Kezic & Nielsen, 2009). TEWL should not be confused with sweating, which is the active transport of water towards the outside environment and an important mechanism to control body temperature.

TEWL has an inverse relationship with skin hydration (Hon *et al.,* 2008; Proksch *et al.,* 2008). High TEWL values are a marker of disturbed skin that should correlate with low hydration values of the stratum corneum. Such values indicate a poor water holding capacity of the stratum corneum together with visibly dry skin conditions (Proksch *et al.,* 2008). Rippke *et al.* (2004) indicate that high TEWL values and dry skin properties enhance the skin's irritability and permeability to irritants and allergens (Rippke *et al.,* 2004; Kezic & Nielsen, 2009). When the skin barrier function is disrupted, an increase of TEWL will occur.

TEWL can be measured by a VapoMeter instrument manufactured by Delfin Technologies (2010). The probe is a closed, unventilated chamber and measures values in $g/m^2/h$. According to the manufacturer, values between 0 to 25 $g/m^2/h$ indicate healthy to normal skin barrier function, but higher TEWL values indicate impaired barrier function.

2.5.3 Skin surface pH

The skin's pH is a measure of the H^+ concentration in the watery solution present on the surface of the skin and is expressed by the logarithmic reciprocal of the H^+ concentration (Agache, 2004e). The skin surface is often described as the acidic mantle. According to Rippke *et al.* (2002) and Fluhr *et al.* (2006), the skin surface pH is a key parameter of the stratum corneum and is an important regulator of epidermal barrier homeostasis.

Skin surface pH is also known as a buffer system that could bind and release protons as well as hamper changes in protons in order to maintain a stable skin surface pH at different body sites (Ohman, 2006). This acidic skin surface provides a defence mechanism against pathogenic microorganisms, maintains skin barrier homeostasis by affecting stratum corneum desquamation, and controls the post secretory processing of lipid precursors degraded by enzymes (Agache, 2004f; Rippke *et al*., 2004).

The acid mantle of the skin is the result of its interaction with a variety of endogenous and exogenous mechanisms (Fluhr *et al.,* 2006). Exocrine secretions such as fatty acids from sebum, lactic and amino acids from sweat, by-products of keratinisation, free fatty acids from the hydrolysis of epidermal phospholipids, and microbial metabolites all affect the stratum corneum acidification (Rippke *et al*., 2004). Endogenous mechanisms that influence and regulate the skin surface pH are the phospholipid-to-free fatty acid pathway, membrane antiporters that play a role in extruding protons in exchange for sodium, and the histidine-to-urocanic acid pathway that is responsible also for stratum corneum hydration (Rippke *et al*., 2004).

The skin surface pH is not the same on all the skin sites of the human body due to the existence of particular flora on different skin sites. Changes in the skin surface pH can cause ionisation and penetration of chemicals through the skin if the pH on skin site favours that specific hazardous substance which could disrupt epidermal lipids and/or enzymes (Weber & Pierce, 2003; Agache, 2004f; Rippke *et al.*, 2004; Fluhr *et al.*, 2006; Ohman, 2006; Rawlings *et al*., 2008).

Measurement of skin surface pH can be done with an instrument manufactured by Courage-Kazaka Electonic GmbH (2008), a Skin-pH-Meter®. According to Agache (2004f), the skin's surface pH value can vary between 4.2 and 6.1 with a Gaussian distribution between these two values, except for the forehead. Guidelines in Courage-Kazaka's Electonic GmbH manual (2008) indicate a value between 4.5 and 5.5 as normal skin surface pH for women and between 4.3 and 5.5 as normal for men.

2.6 OTHER FACTORS THAT INFLUENCE THE SKIN INTEGUMENT AND SKIN BARRIER FUNCTION

Skin hydration, surface skin-pH and TEWL play an important role in the barrier function of the skin. There is an extensive body of literature available describing other factors that could influence the above-mentioned parameters and disrupt the skin integument and barrier function (Cohen, 1982; Chilcott *et al.,* 2002; Zhai & Maibach, 2002; Agache, 2004f; Farinelli & Berardesca, 2006; Goh, 2006; Nuutinen, 2006; Tupker & Pinnagoda, 2006; Proksch *et al*., 2008; Du Plessis & Eloff, 2010; Packham, 2010). These other factors include:

- Altered genetic factors that are responsible, for example, for the synthesis and development of epidermal enzymes.
- The presence of certain skin diseases that could activate or deactivate intercellular enzyme activities.
- Poor skin condition and enhancement of unbalanced resident bacterial and mycotic flora control on the skin.

- Environmental factors for example seasonal variation, solar radiation, excessive temperatures and high humidity.
- Cultural habits, traditional habits and fauna of a country that could affect the skin's integument and barrier.
- Personal factors such as age, personal hygiene, gender, race, specific body region, drug intake and topical moisturisers. Sweating, emotional or stress conditions, variation in blood perfusion, circadian rhythm or specific washing procedures could also result in skin barrier disruption.
- Occupational and previous on-site exposure to solvents, irritants, wet-work, surfactants, mechanical injury, occlusion due to personal protective clothing, extreme temperatures due to machine operations and repeated exposure to the same substances could all have an inverse effect on the skin.
- Inaccurate handling of skin barrier function measurement instruments.

2.7 CONCLUSION

Employees in the metal refinery industry are exposed to HCl and Cl_2 on a daily basis. Both these substances have respiratory occupational exposure limits, but no skin notation. Furthermore, these two substances are corrosive and could be the primary cause of severe skin injuries and skin diseases. Skin injuries and skin diseases, in turn, can contribute to secondary penetration of other hazardous chemical substances during dermal exposure. Therefore, dermal absorption as an exposure route must not be underestimated. The skin's structure is developed in such a way that it provides a physical and chemical barrier to prevent penetration of substances or excessive body water loss through the skin. This barrier function of the skin can be measured by three main parameters, namely skin hydration, skin surface pH and TEWL. Alteration of these parameters could have an adverse effect on skin barrier functions, resulting in a decrease of skin hydration and/or skin surface pH or an increase in TEWL. Other factors that could also influence the skin integument and skin barrier function need to be considered when assessing skin barrier

function. The following chapter is an article that indicates the effect of HCl and Cl_2 exposure on a number of employees' skin barrier function.

2.8 REFERENCES

ACGIH (AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS). (2010) TLVs® and BEIs® based on documentation of the threshold limit values for chemical substances and physical agents and biological exposure indices. US: Signature Publications. ISBN 978 1 607260 19 6.

Agache P. (2004a) The human skin: an overview. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 3-5. ISBN 3 540 01771 2.

Agache P. (2004b) Stratum corneum histophysiology. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 95-100. ISBN 3 540 01771 2.

Agache P. (2004c) Dermis connective tissue histophysiology. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 199-203. ISBN 3 540 01771 2.

Agache P. (2004d) Subcutis histophysiology. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 402-409. ISBN 3 540 01771 2.

Agache P. (2004e) Measuring the skin surface acidity. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 84-86. ISBN 3 540 01771 2.

Agache P. (2004f) Presentation of the skin surface ecosystem. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 21-32. ISBN 3 540 01771 2.

Agache P, Black D. (2004) Stratum corneum dynamic hydration test. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 153-164. ISBN 3 540 01771 2.

Agache P, Humbert P. (2004) Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. ISBN 3 540 01771 2.

Ayres JG. (2005) The effects of inhaled materials on the lung and other target organs. In Gardiner K, Harrington JM, editors. Occupational hygiene. 3rd ed. USA: Blackwell Publishing. p. 47-58. ISBN 1 4051 0621 2.

Barel AO, Clarys P. (2006) Measurement of epidermal capacitance. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. NY: Taylor & Francis Group. p. 337-344. ISBN 0 8493 1437 2.

Bernengo JC, De Rigal J. (2004) Physical methods of measuring stratum corneum water content in vivo. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 112-152. ISBN 3 540 01771 2.

Bouwstra JA, Ponec M. (2006) The skin barrier in healthy and diseased state. Biochimica et Biophisica Acta; 1758: 2080-2095.

Bull S. (2007) Toxicological overview: hydrogen chloride / hydrochloric acid. Available at http://www. hpa.org.uk/web/HPAwebFile/HPAweb_c/1194947386706 Accessed 29 October 2010.

Chilcott RP, Dalton CH, Emmanuel AJ, Allen CE, Bradley ST. (2002) Transepidermal water loss does not correlate with skin barrier function in vitro. Journal of Investigative Dermatology; 118: 871-875.

Cohen SR. (1982) Risk factors in occupational skin disease. In Maibach HI, Gellin GA editors. Occupational and industrial dermatology. London: Year Book Medical Publishers. p. 15-22. ISBN 0 8151 5727 4.

Cohen DE, Rice RH. (2003) Toxic responses of the skin. In Klaassen CD, Watkins JB, editors. Caserett & Doull's essentials of toxicology. NY: McGraw-Hill. p. 288-300. ISBN 0 07 138914 8.

Courage & Khazaka Electronic GmbH. (2008) Information and operating instructions for Derma Unit SSC3 Sebumeter®/Corneometer®/Skin-pH-Meter® and the software for Windows®. Germany: CK.

De Craecker W, Roskams N, Op de Beeck R. (2008). Occupational skin diseases and dermal exposure in the European Union (EU-25): policy and practical overview. Luxembourg: European Agency for Safety and Health at Work. ISBN 978 92 9191 161 5.

Delfin Technologies LTD. (2008) The VapoMeter: for measurement of evaporation rate. Available at http://www.delfintech.com/prod_vapo_frag.html Accessed 25 June 2010.

Department of Labour, South Africa. (1993) Occupational Health and Safety Act 85 of 1993: Regulations for Hazardous Chemical Substances (GN R1179, 25 Aug 1995 as amended by GN R930, 25 Jun 2003 and GN R683, 27 Jun 2008). Pretoria: Government Printer.

Du Plessis JL, Eloff FC. (2010) Back to basics – the skin barrier and how it is affected in common occupational scenarios. Occupational Health Southern Africa; 16: 24-25.

Eaton DL, Klaassen CD. (2003) Principles of toxicology. In Klaassen CD, Watkins JB, editors. Caserett & Doull's essentials of toxicology. New York: McGraw-Hill. p. 6-20. ISBN 0 07 138914 8.

Elias PM. (1983) Epidermal lipids, barrier functions, and desquamation. Journal of Investigative Dermatology; 80: 44s-49s.

Elias PM. (2004) The epidermal permeability barrier: from the early days at Harvard to emerging concepts. Journal of Investigative Dermatology; 122: xxxvi-xxxix.

EPA (ENVIRONMENTAL PROTECTION AGENCY: UNITES STATES). (2007) Hydrochloric acid (hydrogen chloride). Available at http://www.epa.gov/ttnatw01/hlthef/hydrochl.html Accessed 26 October 2010.

Farinelli N, Berardesca E. (2006) The skin integument: variation relative to sex, age, race, and body region. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 27-31. ISBN 0 8493 1437 2.

Feingold KR. (2007) The role of epidermal lipids in cutaneous permeability barrier homeostasis. Journal of Lipid Research; 48: 2531-2546.

Fluhr J, Bankova L, Dikstein S. (2006) Skin surface pH: mechanism, measurement, importance. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 411-420. ISBN 0 8493 1437 2.

Foulds IS. (2005) Organ structure and function: the skin. In Gardiner KG, Harrington JM, editors. Occupational hygiene. 3rd ed. USA: Blackwell. p. 25-35. ISBN 1 4051 0621 2.

Gabard B, Clarys P, Barel AO. (2006) Comparison of commercial electrical measurement instruments for assessing the hydration state of the stratum corneum. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 351-358. ISBN 0 8493 1437 2.

Gabard B, Treffel P. (2004) Transepidermal water loss. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 553-564. ISBN 3 540 01771 2.

Gentilhomme E, Neveux Y. (2004) Markers of epidermal proliferation and differentiation. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 173-182. ISBN 3 540 01771 2.

Goh CL. (2006) Seasonal variation and environmental influence on the skin. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. NY: Taylor & Francis Group. p. 33-36. ISBN 0 8493 1437 2.

Hon KL, Wong KY, Leungt TF, Chow CM, Ng PC. (2008) Comparison of skin hydration evaluation sites and correlations among skin hydration, transepidermal water loss, SCORAD index, Nottingham eczema severity score, and quality of life in patients with atopic dermatitis. American Journal of Clinical Dermatology; 9: 45-50.

ICSC (INTERNATIONAL OCCUPATIONAL SAFETY AND HEALTH INFORMATION CENTRE) (2000a) Chlorine. Available at http://www.ilo.org/legacy/english/protection/safetwork/cis/products/icsc/dtasht/icsc01/icsc0126.htm Accessed 9 September 2010.

ICSC (INTERNATIONAL OCCUPATIONAL SAFETY AND HEALTH INFORMATION CENTRE). (2000b) Hydrogen chloride. Available at http://www.ilo.org/legacy/english/protection/safetwork/cis/ products/icsc/dtasht/icsc01/icsc0163.htm Accessed 28 August 2010.

IVHHN (THE INTERNATIONAL VOLCANIC HEALTH HAZARD NETWORK). (2010) Hydrogen chloride. Available at http://www.ivhhn.org/index.php?option=com_content&view=article&id=85 Accessed 31 August 2010.

Kezic S, Nielsen JB. (2009) Absorption of chemicals through compromised skin. International Archives Occupational and Environmental Health; 82: 677-688.

Mansdorf SZ, Henry NW. (2003) Personal protective clothing. . In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 913-928. ISBN 1 931504 43 1.

McGrath JA, Eady RAJ, Pope FM. (2004) Anatomy and organization of human skin. In Burns T Breathnach S, Cox N, Griffith C, editors. Rook's textbook of dermatology. 7th ed. Oxford: Blackwell. p. 3.1-3.8. ISBN: 978 1 4051 2974 9.

McGrath JA, Uitto J. (2010) Anatomy and organization of human skin. In Burns T, Breathnach S, Cox N, Griffith C, editors. Rook's textbook of dermatology. 8th ed. Oxford: Blackwell. p. 3.1-3.53. ISBN: 978 1 4051 6169 5.

NEXTTEQ LLC. (2007) MSDS: HCl. Available at http://www.skcinc.com/instruction/MSDSVerifit.pdf Accessed 23 August 2010.

Nicander I, Aberg P, Ollmar S. (2006) Bioimpedance as a noninvasive method for measuring changes in skin. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 345-350. ISBN 0 8493 1437 2.

Nielsen JB, Nielsen F, Sorensen JA. (2007) Defense against dermal exposure is only skin deep: significantly increased penetration through slightly damaged skin. Archives Dermatological Research; 299: 423-431.

NIOSH (NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH). (2004) Chlorine. Available at http://www.cartwright.chem.ox.ac.uk/hsci/chemicals/chlorine.html Accessed 5 January 2011.

NIOSH (NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH). (2009) NIOSH pocket guide to chemical hazards: hydrogen chloride. Available at http://www.cdc.gov/niosh/npg/ npgd0332.html Accessed 28 August 2010.

NIOSH (NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH). (2010) Material safety data sheet: chlorine. Available at http://www.msds.chem.ox.ac.uk/CH/chlorine.html Accessed 5 January 2011.

Nuutinen J. (2006) Measuring of transepidermal water loss by closed-chamber systems. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 393-396. ISBN 0 8493 1437 2.

Ohman H. (2006) The pH gradient in the epidermis evaluated by serial tape stripping. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 421-427. ISBN 0 8493 1437 2.

OSHA (OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION). (1996a) Occupational safety and health guidelines for chlorine. Available at http://www.osha.gov/SLTC/healthguidelines/chlorine/ recognition.html Accessed 9 September 2010.

OSHA (OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION). (1996b) Occupational safety and health guidelines for hydrochloric acid. Available at http://www.osha.gov/SLTC/healthguidelines/ hydrochloric acid/recognition.html Accessed 9 September 2010.

OSHA (OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION). (2005) Material safety data sheet: hydrochloric acid. Available at http://www.sciencelab.com/msds.php?msdsild=9924285 Accessed 5 January 2011.

OSHA (OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION). (2007) Material safety data sheet: chlorine. Available at http://www.mathesongas.com/pdfs/msds/MATH0027.pdf Accessed 5 January 2011.

OXYCHEM. (2010) Material safety data sheet: hydrochloric acid. Available at http://www.oxy.com/ msds/msds.asp?details=M34514 Accessed 29 October 2010.

Packham C. (2010) Is the substance hazardous in contact with the skin: Factors to be considered in assessing risk. Occupational Health Southern Africa; 16: 22-23.

Pirot F, Falson F. (2004) Skin barrier function. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 513-524. ISBN 3 540 01771 2.

Proksch E, Brandner JM, Jensen JM. (2008) The skin: an indispensable barrier. Experimental Dermatology; 17: 1063-1072.

Rawlings AV, Matts PJ, Anderson CD, Roberts MS. (2008) Skin biology, xerosis, barrier repair and measurement. Drug Discovery Today: Disease Mechanisms; 5: e127-e136.

RHCS. (1995) - SEE Department of Labour, South Africa.

Rippke F, Schreiner V, Doering T, Maibach HI. (2004) Stratum corneum pH in atopic dermatitis: impact on skin barrier function and colonization with staphylococcus aureus. American Journal of Clinical Dermatology; 5: 217-223.

Rippke F, Schreiner V, Schwanitz HJ. (2002) The acidic milieu of the horny layer: new findings on the physiology and pathophysiology of the skin pH. American Journal of Clinical Dermatology; 3: 261-272.

Ruse M. (1998) INCHEM IPCS: Chlorine. Available at http://www.inchem.org/documents/pims/ chemicals/pim 947.htm Accessed 9 September 2010.

SAIF CORPORATION. (2009) Industrial hygiene: Chlorine (Cl_2). Available at http://www.saif.com Accessed 9 September 2010.

Schneider T, Cherrie JW, Vermeulen R, Kromhout H. (2000) Dermal exposure assessment. Annals of Occupational Hygiene; 44: 493-499.

Serup J, Jemec GBE, Grove GL. (2006) Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. 1029 p. ISBN 0 8493 1437 2.

Stanton DW. (2007) Gases and vapours. In Stanton DW, Kielblock J, Schoeman JJ, Johnston JR, editors. Handbook on mine occupational hygiene measurements. Johannesburg: MHSC. p. 73-95. ISBN 1 919 853 02 2.

Tagamai H. (2006) Epidermal hydration: measurement of high-frequency electrical conductance. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 329-336. ISBN 0 8493 1437 2.

Tranter M. (2004) Occupational hygiene and risk management. 2nd ed. Crows Nest, NSW: Allen & Unwin. 346 p. ISBN 1 74114 329 2.

Tupker RA, Pinnagoda J. (2006) Measurement of transepidermal water loss by semiopen systems. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. NY: Taylor & Francis Group. p. 383-392. ISBN 0 8493 1437 2.

Warner RR, Stone KJ, Boissy YL. (2003) Hydration disrupts human stratum corneum ultrasounds. Journal Investigative Dermatology; 120: 275-284.

Weber LW, Pierce JT. (2003) Development of occupational skin disease. In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 348-360. ISBN 1 931504 43 1.

Young JA. (2001) Hydrochloric acid. Journal of Chemical Education; 78: 855-984.

Zhai H, Maibach HI. (2002) Occlusion vs. skin barrier function. Skin Research and Technology; 8: 1-6.

GUIDELINES FOR AUTHORS

The Annals of Occupational Hygiene: Guidelines for articles

The language of the manuscript must be in English. British or American styles and spelling may be used. The number of words, excluding the abstract, references, tables and figures, must be stated as a message to the Editor at the time of submission. If this length is more than 5000 words, a statement must be included justifying the extra length. Due to nature of this research and the amount of data compiled and analysed, the length of this article just exceeds 5000 words.

The title should clearly summarise the subject of the paper and the keywords should be a list of words and phrases which an internet searcher might use who is interested in the topic and findings of the paper.

Persons should only be named as authors if they have made significant identifiable intellectual contributions to the work. Other contributions may be recognised by acknowledgement at the end of the submission.

The article should follow the structure of: Introduction, Methods, Results, Discussion, and Conclusions, unless these are clearly inappropriate. The paper must be prefaced by an abstract of the argument and findings, which may also be arranged under the same headings.

Figures that include photographs, diagrams and charts should be incorporated in the text or at the end of the paper. Tables should be numbered consecutively and given suitable caption. Tables should be incorporated in the text or at the end of the paper. In revised version each figure and table should be presented on a separate page. Footnotes to tables should be typed below the table and should be referred to by superscript lowercase letters.

References should be inserted in the text according the Vancouver style. At the end of the paper, references should be listed in alphabetic order by name of first author. ISBNs should be given for books and other publications were appropriate. Internet material can be referred to if it is permanently available. References will not be checked editorially, and their accuracy is the responsibility of authors.

CHAPTER 3: ARTICLE

The influence of HCl and Cl_2 exposure on the skin barrier function of precious metal refinery workers

JANETTA H REYNECKE[1], PETRUS J LAUBSCHER[1], STEPHEN C ENGELBRECHT[1], JOHANNES L DU PLESSIS[1]

[1]*Subject Group Physiology, Faculty of Health Sciences, North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom 2520, South Africa.*

ABSTRACT

Introduction: This article investigates the influence of hazardous chemicals on the skin barrier function of workers in the platinum refinery industry. Workers are exposed to HCl and Cl_2, among other hazardous chemicals substances. The objective of this study is to ascertain whether exposure to HCl and Cl_2 had an adverse influence on workers' skin barrier function (skin hydration, TEWL and skin surface pH).

Methodology: Fourteen workers (exposed group) and ten workers (control group) participated in this study. Some workers used barrier creams and therefore the exposed group was further divided into two groups; the barrier cream (BC) and non-barrier cream (nBC) groups. Personal and area HCl and Cl_2 exposure was concurrently assessed while workers' skin barrier function was measured on six anatomical skin areas, including indirectly exposed skin (i.e. palm, wrist and back of the hand) and directly exposed skin (i.e. neck, cheek and forehead). Skin measurements were conducted before, during and at the end of shifts. Due to the small number of workers participating in this study, HCl and Cl_2 exposure levels and skin barrier functions were measured on two separate days.

Results: The exposed group's indirectly exposed skin was dehydrated, but the directly exposed skin was sufficiently moisturised. HCl exposure showed no correlation with either skin hydration for indirectly or directly exposed skin. Only Cl_2 exposure had a significant negative correlation with hydration on the back of the hand. The exposed group's TEWL for the palm was high, but the remainder of the measured anatomical skin areas had normal TEWL. Both HCl and Cl_2 exposure showed positive correlations with TEWL for indirectly and directly exposed skin. The exposed group's skin surface pH for indirectly and directly exposed skin was normal, but became more acidic as the work shift progressed. HCl and Cl_2 exposure showed negative correlations only with skin surface pH for directly exposed skin. Very few significant differences existed between the nBC- and BC-groups in terms of skin hydration, TEWL and skin surface pH.

Conclusion: Only Cl_2 exposure contributed to a dehydrated and disrupted skin barrier function on the back of the hand. It remained unclear whether HCl and Cl_2 exposure actually influenced skin hydration. The palm had

abnormally high TEWL levels, but only HCl contributed to the palm's damaged skin barrier function. Both, HCl and Cl_2 exposure contributed to a decrease in skin surface pH for the directly exposed skin. No significant proof was found that barrier creams enhanced the skin barrier function. Additional factors such as using latex gloves, continuous washing of hands, and contact with contaminated personal protective equipment or workplace surfaces could also have contributed to an impaired skin barrier. Workers in the platinum refinery industry are potentially exposed to chlorinated platinum salts, and an impaired skin barrier may result in skin permeation thereof, which could lead to sensitisation and allergy. It is recommended that washing facilities need to be improved; that personal hygiene procedures and skin aftercare should be emphasised during training sessions; and that latex gloves be replaced with neoprene gloves to reduce allergy risks.
Keywords: skin hydration, TEWL, skin surface pH, skin barrier function, barrier cream, hydrochloric acid, chlorine

3.1 INTRODUCTION

Inhalation was traditionally considered to be the most important route of exposure to hazardous chemicals in the field of Occupational Hygiene. Serious concern regarding the skin as a route of exposure only occurred during the late 1990s (Weber & Pierce, 2003). Since then, an increase in research has been done regarding dermal exposure, different routes of dermal permeation, measurement of chemical penetration through the skin and measurement of skin barrier function (Schneider *et al.*, 2000; Agache & Humbert, 2004; Semple, 2004; Serup *et al.,* 2006; Kruger *et al.,* 2008; Proksch *et al.,* 2008; Du Plessis & Eloff, 2010).

In the platinum refinery industry, effective inhalation control measures are in place through the provision of ventilation, chemical detection alarms and personal protective respirators in the refinery. Protective gloves are provided as a measure to prevent direct exposure to chemicals. Workers in the platinum refinery work with a variety of dry and liquefied hazardous chemical substances. HCl and Cl_2 gas are two chemicals specifically used in the refining of platinum group metals (PGMs) to dissolve precious metals and to remove base metals from the PGM-solution. Most of these processes are so-called "closed processes", but require high maintenance in order to ensure that no leakages occur. Regular process

samples are collected to ensure the quality of the process solution, and it is during these sampling periods that workers are directly exposed to HCl and/or Cl_2 gas.

HCl, a poisonous irritant and corrosive chemical, is listed 16th, and Cl_2, a poisonous gas, 66th on SIMRAC's list of the 100 most hazardous chemicals used in the mining industry (Stanton & Jeebhay, 2001). Both, HCl and Cl_2 gas are toxic to the skin (Zeliger, 2008), but neither of these have a skin notation attached, because skin notation simply emphasises the possibility that dermal permeation may be a significant contributor to the overall body burden of the chemical and does not denote toxic effects on the skin itself (Klonne, 2003; Schaper & Bisesi, 2003). HCl and Cl_2 gas dissolve in tissue water or sweat on the skin where they may act as a corrosive, leading to severe skin blisters, burns, erythema, pain, irritation, inflammation and skin diseases such as dermatitis (ICSC, 2000a; ICSC, 2000b).

Irrespective of the pathway of dermal exposure or chemical-skin interaction, the human skin's most critical function is to form an effective barrier between the "inside" and the "outside" of an organism by blocking chemical permeation when there is contact with the skin (Proksch *et al*., 2008). The "outside-inside barrier" (that includes both skin hydration and skin surface pH) as well as the "inside-outside barrier" (including trans-epidermal water loss) are the three parameters that play an important role in the barrier function of the skin (Agache & Humbert, 2004; Serup *et al.,* 2006).

To our knowledge, no quantitative research has previously been conducted to measure HCl and Cl_2 exposure levels directly on exposed human skin. Surface Swypes® and Permea-Tec® sensors are colorimetric detectors that are generally used to detect contamination on skin and to determine breakthrough time of personal protective equipment. Therefore, these colorimetric detectors are used to evaluate the effectiveness of protective gloves used and not to determine quantitative exposure levels on the skin (Colormetric Laboratories, Inc., 2009; SKC, 2010). In an effort to determine whether HCl and Cl_2 exposure could indeed influence workers' skin barrier function, their barrier function was measured while

concurrently assessing airborne exposure to HCl and Cl_2. The latter served as an indirect means of indicating an acidic work environment.

3.2 METHODS

Settings at workplace and subjects

Fourteen workers who were potentially exposed to HCl and/or Cl_2 gas on a daily basis participated in this study. These workers were identified as the "exposed group". Ten of these fourteen workers in the exposed group used Reinol® Skincare barrier cream (Reinol Chemicals, South Africa) that contains collagen, allantoin and mahonia-aquifolium hydro extract. This group will be referred to as the "barrier cream exposed group" (BC-group). The other four workers will be referred to as the "non-barrier cream exposed group" (nBC-group). Ten administrative workers who work in offices at a distance from, and off-site from the refinery work area, participated as the "control group".

Measurement of personal and area HCl and Cl_2

In order to characterise the "acidic" working environment, personal and area HCl samples of the exposed group and only area HCl samples of the control group were collected according to NIOSH method 7903, using washed silica gel sorbent tubes with personal sampling pumps calibrated at a flow rate of 0.4 l/min. Two sorbent tubes per day (2 x 4 hours) were used for the exposed group's personal and area HCl exposure measurements, while only one sorbent tube (8 hours) was used for the control group's area HCl exposure measurements. A total of 56 personal HCl samples and 34 area HCl samples were taken. One blank sorbent tube for each 10 sorbent tubes was also analysed. Analysis was done by an accredited analytical laboratory with ion chromatography. The minimum level of detection was 0.6 µg (0.002 ppm).

Cl_2 gas was measured with a direct-reading MiniWarn Dräger (Draeger Safety Inc.) instrument in the exposed group and control group's working areas. Vessels and huge

process-instruments in the refinery form natural passageways in each plant. Cl_2 readings were taken before, during (middle) and at end of the shift on each side as well as in the middle of the passages, following an S-pattern through the sampling area. A total of 147 readings were taken in the refinery and 10 readings were taken in the control group's working areas.

Skin condition questionnaire

All the workers completed a self-assessment questionnaire developed by Dalgard *et al.* (2003) that consists of basic employee information and ten simple questions concerning common skin complaints. Each question was scored on a four-point scale (1: no; 2: yes; 3: yes, quite a lot; 4: yes, very much). A mean score higher than 1.3 indicates a high risk of developing skin diseases (refer to Annexure A).

Measurement of skin barrier function

Skin hydration, skin surface pH and TEWL were measured on the dominant hand (i.e. palm, back of the hand and wrist). These anatomical areas were covered with protective gloves and will be referred to as indirectly exposed skin. Measurements were also taken on the head (forehead, cheek and neck). These anatomical areas were not covered by personal protective equipment and will be referred to as directly exposed skin. Skin hydration and skin surface pH were measured with a Derma Unit SSC3: Corneometer® and Skin-pH-Meter® (Courage+KHAZAKA electronics GmbH, Germany) before, during (middle) and at the end of the shift. TEWL was measured with a VapoMeter (Delfin Technologies, Finland) on the palm, wrist, neck and forehead at the same intervals as described above.

Repetition of measurements

Due to the small number of exposed workers (n=14), exposure measurements and skin barrier function measurements for the exposed group were repeated. Therefore, each worker's exposure and skin barrier function were measured on two separate days (n=28). With the exception of skin hydration for the palm (end of shift), statistical analysis (Mann-

Whitney U Test) indicated no statistically significant differences between different sampling days, and data was subsequently pooled for statistical analysis.

Statistical analysis

All results were statistically analysed using Statistica Version 10 (Statsoft Inc., 2011) and GraphPad Prism Version 5.03 (GraphPad Software, Inc., 2009). Non-parametrical Mann-Whitney U-Tests were used to determine statistically significant differences in measured skin barrier function for the control and exposed groups, and the Friedman ANOVA-Tests were used to determine significant changes in measured skin barrier function during an 8 hour work shift. Spearman correlation tests were used to determine correlations between measured skin parameters of the exposed group, and their levels of HCl and Cl_2 exposure. All results with a $p \leq 0.05$ were considered to be statistically significant.

Ethical aspects

This research was of purely scientific nature for which human subjects volunteer to participate. Participants received no therapeutic or diagnostic benefits. The life, health, privacy, dignity and integrity of all workers were respected and protected during the survey. All the participants were informed about the research's aim, method and potential benefits from research results. The research results provided to the participants' employee can be used to monitor and implement control measures to reduce exposure to hazardous chemicals (North-West University, 2010).

3.3 RESULTS

Participants in the exposed group were process controllers. Their average age was 42.2 years with an average of 14.7 years' experience. The control group's duties comprised administrative work that was performed off-site from the refinery. Their average age was 36.5 years with an average of 9.9 years of experience.

The majority of workers (93%) in the exposed group used one pair of hypoallergenic smooth surfaced latex medical examination gloves each time they entered the plant. On average, this occurred four to six times per shift and they spent three to five hours in the plant. After each entry, 71% of the exposed workers used Reinol barrier cream after initial cleaning of their hands with a liquid soap.

Airborne exposure

In order to assess the possible influence of HCl and Cl_2 in the refinery on skin barrier function, the exposure levels thereof in the workplace environment had to be assessed. To this end, HCl and Cl_2 exposure levels were determined over an 8-hour work shift. Table 1 reflects the workers' mean HCl personal and area exposure levels and Table 2 indicates the workers' mean real-time area Cl_2 exposure levels during an 8-hour shift. The nBC-group experienced higher personal and area HCl exposure levels during the second 4 hours of the shift. The BC-group and exposed group (nBC- and BC-groups) had higher area HCl exposure levels during the second 4 hours of the shift.

Table 1: Mean personal and area HCl exposure levels measured in ppm. Standard deviation is indicated in brackets.

Group	**n**	**Personal HCl exposure levels**			**Area HCl exposure levels**		
		First 4 hours	*Second 4 hours*	*8 hour total*	*First 4 hours*	*Second 4 hours*	*8 hour total*
Control	**10**	-	-	**-**	0.003 (0.004)	0.006 (0.004)	**0.005 (0.004)**
nBC	**4**	0.07 (0.08)	0.24 (0.18)	**0.31 (0.26)**	0.19 (0.144)	4.35 (4.93)	**4.53 (4.90)**
BC	**10**	0.48 (2.02)	0.29 (1.18)	**0.77 (3.2)**	0.25 (0.170)	0.90 (2.71)	**1.15 (2.69)**
Exposed nBC+BC	**14**	0.36 (1.71)	0.27 (1.01)	**0.63 (2.72)**	0.23 (0.16)	1.89 (3.65)	**2.12 (3.61)**

- : indicates not measured

Table 2: Mean area Cl_2 exposure levels measured in ppm. Standard deviation is indicated in brackets.

Group	**n**	**Area Cl_2 exposure levels**		
		First 4 hours	*Second 4 hours*	*8 hour total*
Control	**10**	0	0	**0**
nBC	**4**	0.53 (0.51)	0.01 (0.02)	**0.54 (0.53)**
BC	**10**	0.12 (0.30)	0.01 (0.02)	**0.13 (0.32)**
Exposed: nBC+BC	**14**	0.23 (0.41)	0.01 (0.02)	**0.24 (0.43)**

Hydration

Figure 1 shows that the mean hydration levels for the palm and back of the hand of the control group remained relatively constant throughout the shift, while these levels increased slightly during the middle and end of the shift on the wrist. The mean hydration levels for the palm, wrist and back of hand of the control group were higher than those of the exposed nBC- and BC-groups. Mean hydration levels of the control group's palm were significantly higher than the nBC-group before the shift (p=0.021) and the BC-group during the middle of the shift (p=0.019). Mean hydration levels on the back of the hands of the control group were also significantly higher than the BC-group during the middle of the shift (p=0.029). With exception of the palm before the shift (p=0.029), there were no significant differences in mean hydration levels between the nBC- and BC-groups.

The mean hydration levels of the nBC-group for the palm during the middle of the shift, the wrist during the middle and end of the shift, as well as the back of the hand at the beginning, middle and end of the shift, were slightly higher than those of the BC-group, although not statistically significant. The Friedman ANOVA test indicated a significant change in mean hydration levels for the palm of the BC-group during the work shift (p=0.035), with a 4.07 a.u. decrease by the middle of the shift and a 4.22 a.u increase at the end of the shift, while the wrist and back of the hand's mean hydration levels of the BC-group remained relatively constant throughout the shift.

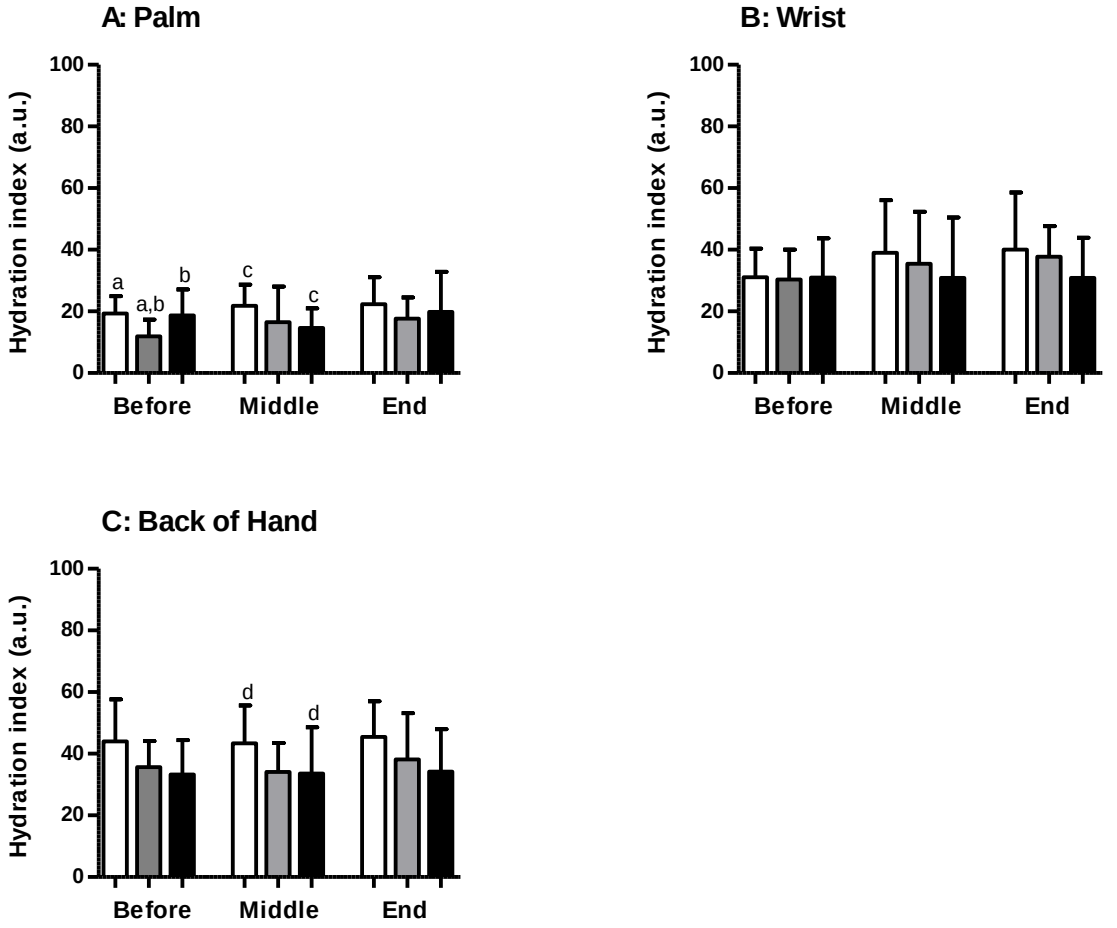

Figure 1: Skin hydration indices on different anatomical areas and intervals during the work shift for a control group (clear bars), nBC-group (grey bars), and BC-group (black bars). Letters a-d indicate statistically significant differences between groups.

Hydration results for the neck, check and forehead were not divided into BC- and nBC-groups, because workers did not apply barrier cream on these areas (Figure 2). Mean hydration levels for the neck, cheek and forehead of the control group increased slightly toward the middle of the shift, with levels on the forehead only increasing further towards the end of the shift. The increase in forehead hydration levels was statistically significant ($p=0.014$). The mean hydration level on the neck of the control group was significantly lower than that of the exposed group before the shift ($p=0.030$). The mean hydration levels

for the forehead of the control group were also significantly lower than that of the exposed group for all intervals (p=0.001 to 0.033).

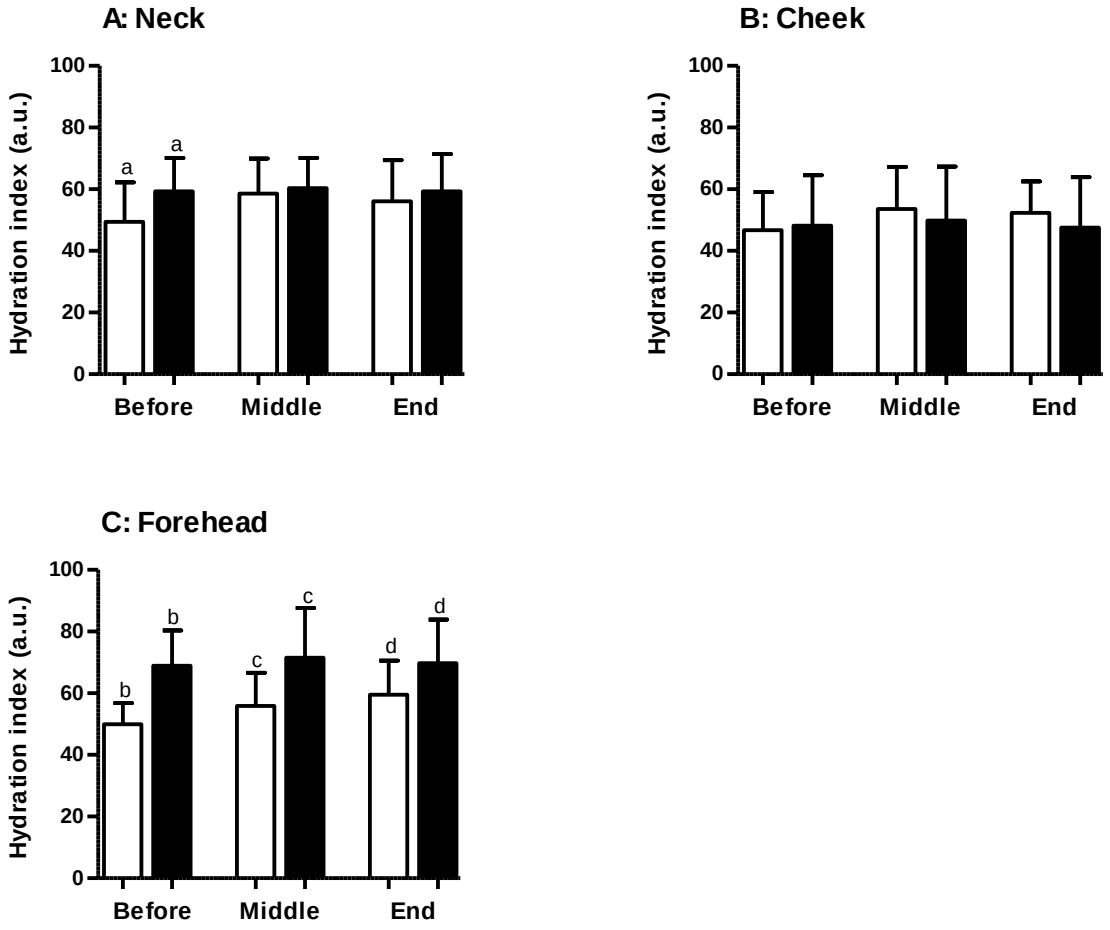

Figure 2: Skin hydration indices on different anatomical areas and intervals during the work shift for a control group (clear bars) and exposed group (black bars). Letters a-d indicate statistically significant differences between groups.

TEWL

Mean TEWL levels for the palm and wrist of the control group (Figure 3) increased towards the middle of the shift, but the levels increased further only on the wrist toward the end of the shift, although not statistically significant. The mean TEWL levels for the palm of the control group remained lower than that of the BC- and nBC-groups throughout the work shift, although not statistically significant. The control group's wrist mean TEWL levels were

significantly lower than those of the nBC-group before the shift (p=0.046). With the exception of the palm measurement taken before the shift, the mean TEWL levels of the nBC-group were higher than that of the BC-group throughout the work shift. The mean TEWL level for the wrist of the nBC-group was significantly higher (p=0.018) than that of the BC-group.

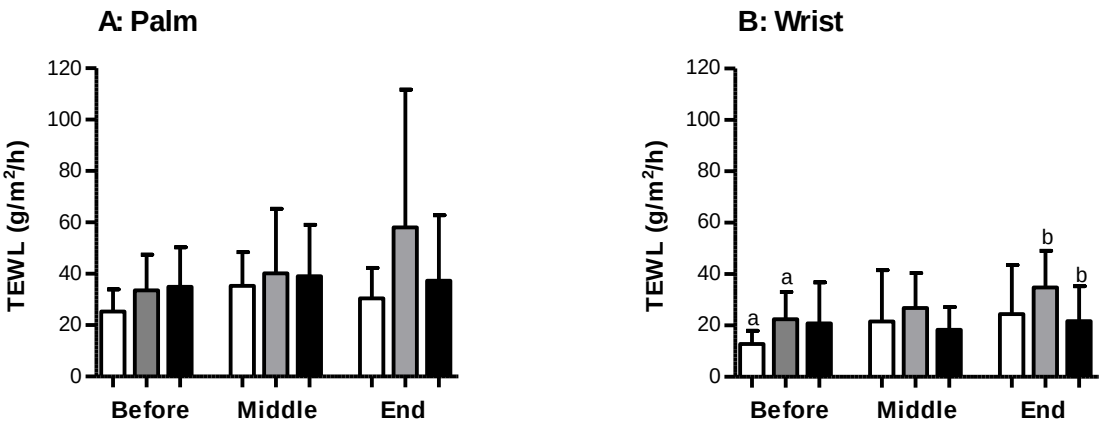

Figure 3: Mean TEWL values on different anatomical areas and intervals during the work shift for a control group (clear bars), nBC-group (grey bars), and BC-group (black bars). Letters a-b indicate statistically significant difference between groups.

The mean TEWL levels (presented in Figure 4) of the neck and forehead of the control group increased towards the middle of the shift, but only the forehead levels increased further towards the end of the shift, although not statistically significant. A significant change (p=0.008) in mean TEWL levels of the neck was indicated for the control group from the beginning of the shift towards the end of the shift. The control group's mean TEWL levels of the forehead remained slightly lower than the exposed group throughout the work shift, although not statistically significant.

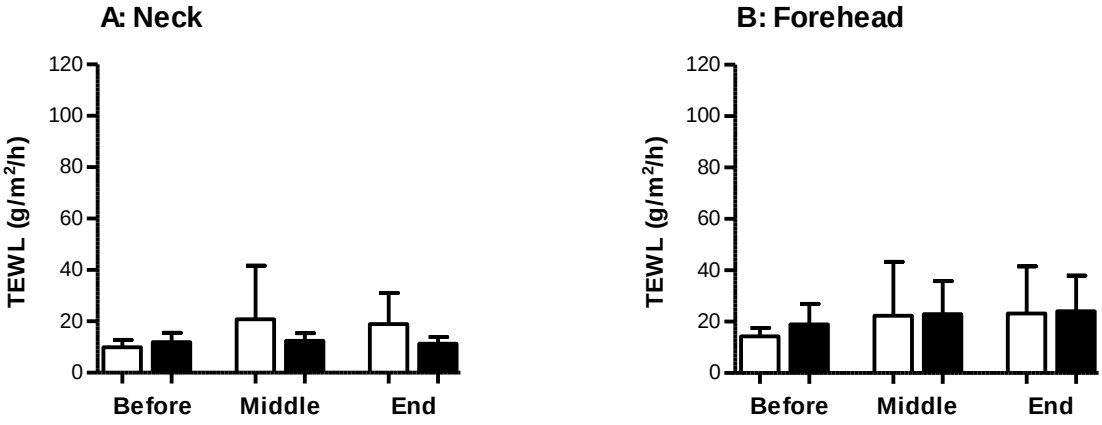

Figure 4: Mean TEWL values on different anatomical areas and intervals during the work shift for a control group (clear bars) and exposed group (black bars).

Skin surface pH

The mean skin surface pH levels for the palm, wrist and back of the hand of the control group were higher than those of the BC- and nBC-groups throughout the work shift (Figure 5). The control group's mean skin surface pH levels of the palm were significantly higher than those of the BC-group before the shift ($p=0.050$) and at the end of the shift ($p=0.004$). The mean skin surface pH levels for the wrist of the control group were significantly higher than those of the BC-group at the end of the shift ($p=0.010$), as well as on the back of the hand of the BC-group at the end of the shift ($p=0.030$). For the palm of the control group, the mean skin surface pH was also significantly higher than that of the nBC-group at the end of the shift ($p=0.009$). The mean skin surface pH of the back of the hand of the control group was also significantly higher than that of the nBC-group before the shift ($p=0.040$). The Friedman ANOVA test indicated significant decreases in mean skin surface pH levels on the palm ($p=0.028$), wrist ($p=0.001$) and back of the hand ($p=0.015$) of the BC-group, as well as for the wrist ($p=0.014$) and back of the hand ($p<0.001$) of the control group throughout the shift. Although there was no significant difference between the BC- and nBC-groups, the mean skin surface pH levels for the palm, wrist and back of the hand of the nBC-group were generally slightly lower than that of the BC-group during the work shift.

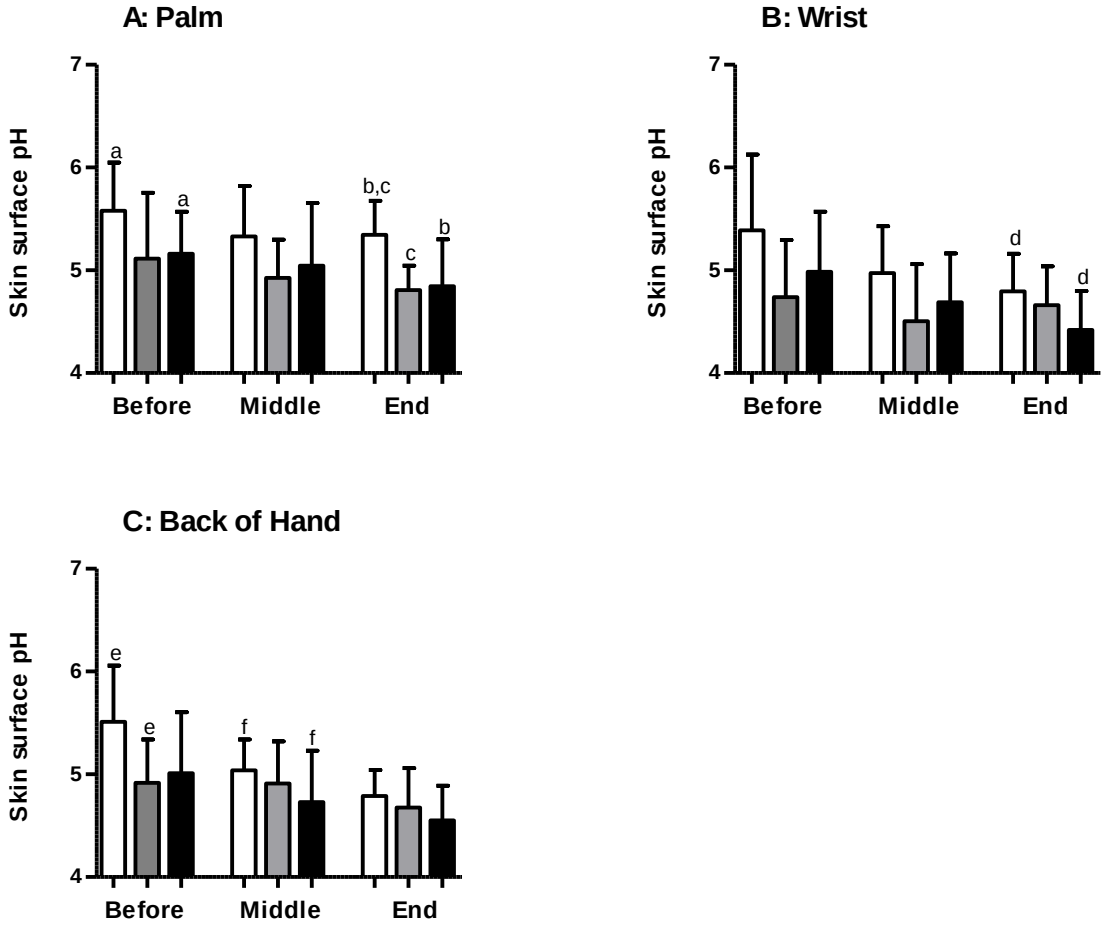

Figure 5: Mean pH values on different anatomical areas and intervals during the work shift for a control group (clear bars), nBC-group (grey bars), and BC-group (black bars). Letters a-f indicate statistically significant difference between groups.

The mean skin surface pH levels for the neck, cheek and forehead of the control group were all significantly higher than those of the exposed group for each of the measured intervals (p-values ranging from 0.003 to 0.010, Figure 6). There were statistically significant decreases in skin surface pH levels on the neck (0.002) and forehead (p=0.020) of the control group as well as for the neck (p<0.001), cheek (p<0.001) and forehead (p=0.001) of the exposed group between the beginning and the end of the shift.

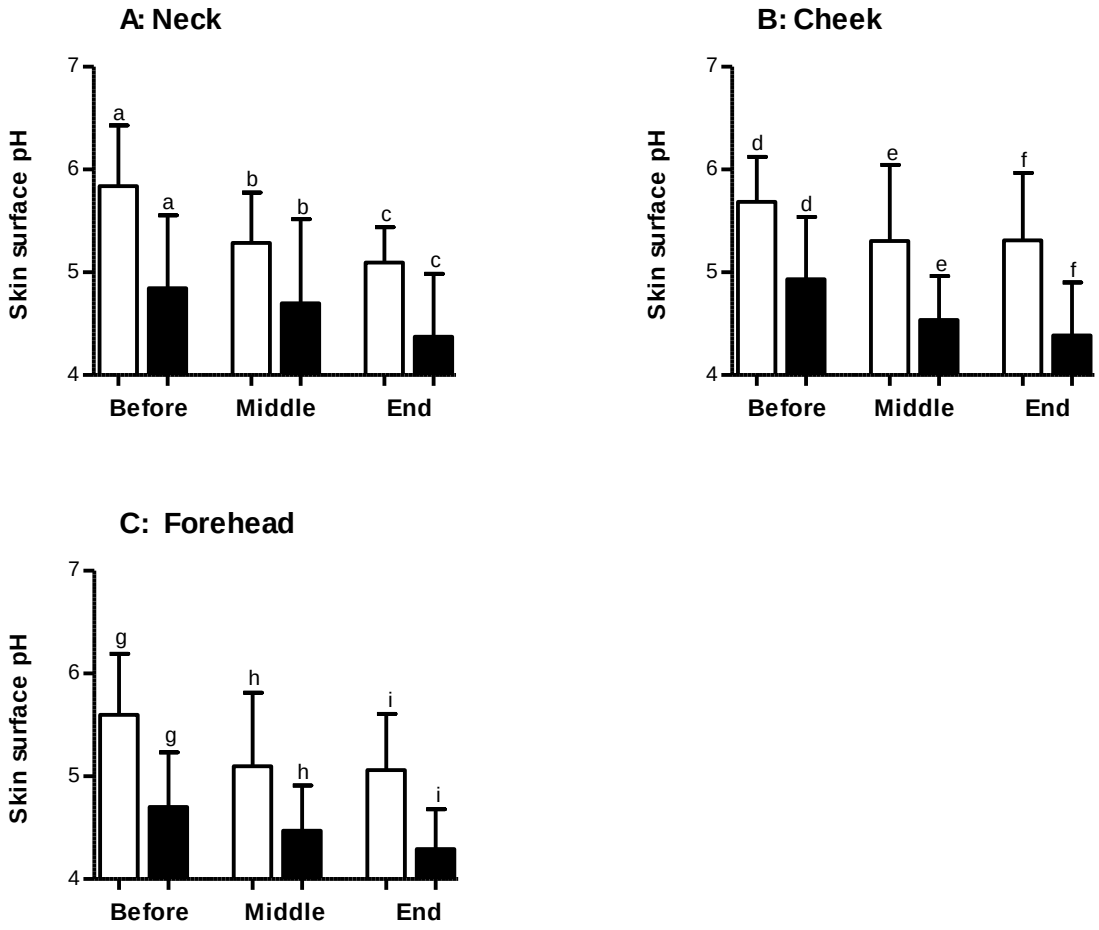

Figure 6: Mean pH values on different anatomical areas and intervals during the work shift for a control group (clear bars) and exposed groups (black bars). Letters a-i indicate statistically significant different difference between groups.

Skin questionnaire

The average Dalgard skin score for both the control and exposed groups was 1.2. Two participants in each group had an average Dalgard skin score higher than 1.3 (1.5 and 1.8 respectively). These four individuals reported very dry, itchy and scaly skin, rashes on the face, forearms and hands, warts on the wrist and feet, as well as troublesome sweating for a period of more than 6 months. Warts were visible on two workers only (on the forearms and hands). The majority of workers were of opinion that they maintained a healthy skin condition.

Correlations

Spearman correlations were drawn for the full work shift of exposed workers to determine whether there were correlations between skin barrier function (i.e. hydration, TEWL and skin surface pH) and working in an acidic environment (HCl and/or Cl_2). The control group's exposure levels to HCl were very low and remained constant throughout the working shift, while their exposure to Cl_2 was measured as zero ppm, therefore, only correlations for the exposed group (nBC- and BC-groups included) could be drawn.

HCl exposure only showed statistically significant positive correlations with TEWL levels for the palm and wrist of the BC group (Table 3). No other significant correlations were established between HCl exposure and the measured skin hydration or skin surface pH levels of both groups.

Table 3: Correlations between HCl exposure and skin hydration, TEWL and skin surface pH of the nBC- and BC-groups.

Skin parameter	**Skin area**	**nBC-group**			**BC-group**		
		Correlation	*r*	*p*	*Correlation*	*r*	*p*
Hydration	**Palm**	+	0.020	0.944	+	0.159	0.327
	Wrist	+	0.161	0.566	+	0.125	0.441
	Back of hand	-	-0.190	0.498	-	-0.051	0.754
TEWL	**Palm**	+	0.480	0.070	+	**0.400**	**0.011**
	Wrist		0.000	1.000	+	**0.333**	**0.036**
Skin surface pH	**Palm**	-	-0.347	0.206	-	-0.236	0.143
	Wrist	-	-0.242	0.385	-	-0.157	0.335
	Back of hand	+	-0.221	0.429	+	0.009	0.956

Statistically significant differences are indicated in bold.

Table 4 indicates positive significant correlations between HCl exposure and TEWL levels of the exposed group's neck and forehead, while negative significant correlations existed for skin surface pH of the exposed group's neck, cheek and forehead.

Table 4: Correlations between HCl exposure and skin hydration, TEWL and skin surface pH of the exposed group.

Skin parameter	Skin area	Exposed group		
		Correlation	*r*	*p*
Hydration	**Neck**	+	0.060	0.666
	Cheek	-	0.081	0.557
	Forehead	+	0.092	0.506
TEWL	**Neck**	**+**	**0.290**	**0.032**
	Forehead	**+**	**0.268**	**0.048**
Skin surface pH	**Neck**	**-**	**-0.323**	**0.016**
	Cheek	**-**	**-0.462**	**<0.001**
	Forehead	**-**	**-0.472**	**<0.001**

Statistically significant correlations are indicated in bold.

Statistically significant correlations were drawn between Cl_2 exposure and skin hydration, TEWL and skin surface pH of the BC-group, as indicated in Table 5. A significant negative correlation existed between Cl_2 exposure and skin hydration on the back of the hand Significant positive correlations were established between Cl_2 exposure and TEWL for the wrist and back of the hand's skin surface pH of the BC-group.

Table 5: Correlations between Cl_2 exposure and skin hydration, TEWL and skin surface pH of the nBC- and BC-groups.

Skin parameter	Skin area	nBC-group			BC-group		
		Correlation	*r*	*p*	*Correlation*	*r*	*p*
Hydration	**Palm**	**-**	-0.061	0.822	-	-0.109	0.503
	Wrist	-	-0.089	0.745	-	-0.286	0.074
	Back of hand	-	-0.046	0.866	**-**	**-0.587**	**<0.001**
TEWL	**Palm**	-	-0.064	0.814	+	0.273	0.088
	Wrist	-	-0.052	0.849	**+**	**0.429**	**0.006**
Skin surface pH	**Palm**	+	0.266	0.319	+	0.108	0.508
	Wrist	-	-0.003	0.991	+	0.148	0.361
	Back of hand	+	0.3087	0.247	**+**	**0.324**	**0.041**

Statistically significant correlations are indicated in bold

Correlations between Cl_2 exposure and the exposed groups' hydration, TEWL and skin surface pH are indicated in Table 6. Statistically significant positive correlations existed

between Cl_2 exposure and skin hydration for the forehead, as well as for TEWL of the neck and forehead. Significant negative correlations existed between Cl_2 exposure and skin surface pH of the neck and cheek.

Table 6: Correlations between Cl_2 exposure and skin hydration, TEWL and skin surface pH of the exposed group.

Skin parameter	**Skin area**	**Exposed group**		
		Correlation	*r*	*p*
Hydration	**Neck**	+	0.209	0.122
	Cheek	-	-0.026	0.851
	Forehead	**+**	**0.425**	**0.001**
TEWL	**Neck**	**+**	**0.435**	**<0.001**
	Forehead	**+**	**0.422**	**0.001**
Skin surface pH	**Neck**	**-**	**-0.293**	**0.029**
	Cheek	**-**	**-0.332**	**0.013**
	Forehead	-	-0.155	0.254

Statistically significant correlations are indicated in bold

3.4 DISCUSSION

The exposure results indicate that workers belonging to the exposed group are working in an "acidic" environment (Table 1 and Table 2). The HCl area exposure of the control group (mean = 0.005 ppm) was 390 times lower than that of the exposed group (mean = 1.950 ppm), and 119 times lower than the personal HCl exposure (mean = 0.593 ppm). The control group's Cl_2 exposure levels remained zero ppm throughout the 8-hour work shift, while the exposed group's Cl_2 exposure was low (mean = 0.230 ppm).

The direct effects of HCl and Cl_2 exposure on skin and how it influenced the skin barrier function of the exposed group were investigated. Skin barrier function results for both the control and exposed groups indicated that skin hydration for the palm was very dry (<30 a.u.), while the wrist and back of the hand were dry (30-40 a.u.). Literature in the field refers to a variety of factors that could influence skin hydration (Baryl & Clarys, 2006; Proksch *et al*., 2008; Rawlings *et al.,* 2008; Kezic & Nielsen, 2009), but none of these

indicates the influence of HCl and/or Cl_2 exposure on skin hydration. The results of this study indicated that HCl exposure (Table 3) showed no correlation with skin hydration for indirectly exposed skin (i.e. palm, wrist and back of the hand). Only Cl_2 exposure (Table 5) had a significant negative correlation with skin hydration on the back of the hand of the exposed group (BC-group). The thinner stratum corneum on the back of the hand is considered to be much more prone to the permeation of hazardous chemical substances (Foulds, 2005). Therefore, Cl_2 exposure may have had a fair influence on skin barrier function on the back of the hand.

The measuring results of the control and the exposed group indicated that the TEWL for the palm was very high (>25 $g/m^2/h$). Low skin hydration and high TEWL levels for the palm indicate that the stratum corneum water content had fallen below a critical level and that the skin barrier function was disrupted (Verdier-Sévrian & Bonté, 2007). HCl and Cl_2 exposure (Table 3 and Table 5) showed significant positive correlations with TEWL on the palm of the exposed group, which indicated that an increase in HCl and Cl_2 exposure led to an increase in TEWL. The wrists are less prone to mechanical stress than the palm during physical work activities. Although the exposed group's TEWL for the wrist was within normal range, it showed a positive correlation with HCl and Cl_2 exposure (Table 3 and Table 5).

Skin hydration (Figure 1) for the indirectly exposed skin of the control group was consistently higher, and TEWL (Figure 3) of the control group was generally lower than that of the exposed group This indicates that the exposed group's skin hydration levels and TEWL were more strained than those of the control group. Only in two instances there were significant differences between the nBC and BC-groups' skin hydration and TEWL (Figure 1 and Figure 3). The barrier creams that the BC-group used seemed to have a positive effect on the TEWL, but not on the skin hydration of the indirectly exposed skin of the BC-group. These limited differences between the nBC- and BC-groups may be ascribed to the small number of participants in the nBC-group as compared to the BC-group. The

purposes of the barrier cream after having cleansed one's hands were to provide a physical barrier between the workers' skin and the contaminated work environment; to restore the skin's natural lipids and moisture components; and also to prevent the development of contact dermatitis (Wöhrl *et al.*, 2001; Reinol®, 2006). It was also suggested in the literature that barrier creams could entrap hazardous chemical substances on the skin, which could actually damage skin barrier function instead of enhancing it. It is, therefore, suggested that barrier creams must be avoided, especially when protective gloves are used (De Craecker *et al.*, 2008). Therefore, further studies with larger nBC- and BC-groups are required to investigate skin barrier cream's effect on skin hydration and TEWL.

Contrary the suggestion regarding barrier creams noted above, the results of skin hydration for directly exposed skin (i.e. neck, cheek and forehead) of the control and exposed groups indicate that both groups' skin was sufficiently moisturised (>45 $g/m^2/h$). Skin hydration of the exposed group's neck and forehead was significantly higher than that of the control group (Figure 2), which gave the impression that the exposed group's skin was better hydrated than that of the control group. This high level of skin hydration in the exposed group could be attributed to personal protective clothing and equipment (PPE, i.e. long-sleeved overalls and hard hats), exposure to high temperatures in the production area, as well as physical hard work. All of these factors could lead to increased sweat secretion (Agache & Canvas, 2004). Apart from the palm, the forehead has the highest density of eccrine sweat glands and thermal sweating is usually more intense on the face (Agache & Canvas, 2004). Although precautions were taken to ensure that skin measurements were conducted under conditions where no sweat production occurred, minimal sweating may still have occurred, which could have accounted for higher hydration levels.

The TEWL results for directly exposed skin of the control and exposed groups were normal (<25 $g/m^2/h$). Both, HCl and Cl_2 exposure (Table 4 and Table 6) showed significant positive correlations with TEWL for the directly exposed skin of the exposed group, indicating that HCl and Cl_2 exposure contributed to an increase in TEWL.

Skin surface pH results indicated that both the control and exposed groups maintained normal skin surface pH (between 4.2 and 6.1) throughout the work shift. The skin surface pH for indirectly exposed skin in the exposed group indicated no correlations with HCl exposure (Table 3), while Cl_2 exposure (Table 5) showed only a significant positive correlation with skin surface pH on the back of the hand of the exposed group (BC-group). This indicated that Cl_2 exposure had a limited influence on indirectly exposed skin's surface pH. In comparison with indirectly exposed skin, both HCl and Cl_2 exposure (Table 4 and Table 6) showed significant negative correlations with skin surface pH for directly exposed skin of the exposed group. This indicated that an increase in HCl and Cl_2 exposure may result in a more acidic skin surface pH for directly exposed skin. The skin surface pH for indirectly and directly exposed skin of the control and exposed groups tended to decrease as the work shift progressed, but the skin surface pH of the exposed group was significantly more acidic than that of the control group (Figure 5 and Figure 6). Therefore, the acidic work environment may have contributed to the exposed group's changing acidic skin surface milieu, irrespective of indirect or direct exposure. The main function of skin surface pH in the stratum corneum is to provide a defence mechanism against pathogenic microorganisms and to maintain skin barrier homeostasis through affecting desquamation and controlling postsecretory processing of lipid precursors degraded by enzymes with an acidic pH optimum (Rippke *et al.,* 2002; Rippke *et al.,* 2004). Therefore, any changes in the skin surface pH may result in skin abnormality and disturbed skin barrier function. It was expected that the exposed group's skin surface pH would become more acidic as the work shift progressed, because Cl_2 is highly reactive with tissue water to form HCl, while HCl dissolves in skin surface fluids or sweat with release of H^+ that had a direct influence on the acidification milieu on the skin surface. Comparing the nBC- and BC-groups' skin surface pH measuring results, the BC-group's skin surface pH was slightly higher for the palm and wrist, but more acidic for the back of the hand than those of the nBC-group (Figure 5). Therefore, the use of skin barrier creams seemed to prevent a decrease in the BC-group's skin surface pH for the palm and wrist in comparison with the nBC-group. Due to the very limited

significant differences between these two groups, no true indication of the barrier creams' influence can be determined.

Since the control and the exposed groups had, at the end of the work shift, lower skin surface pH than what they have started with, the possible influence of circadian rhythm was investigated. Previous studies indicated circadian rhythms of skin surface pH with normal pH values; these values reach a maximum in the afternoon between 14:00 and 16:00, and its minimum value is measured in the morning at 8:00 and evening at 20:00, with a variation of 0.4 units during these two periods (Yosipovitch *et al.*, 1998; Rippke *et al.,* 2002; Agache, 2004; Fluhr *et al.,* 2006). In this study, a maximum skin surface pH on indirectly and directly exposed skin of both groups were observed in the morning before the work shift started, and a minimum skin surface pH in the afternoon when the work shift ended. A variation of more than 0.4 units was also observed at some of the measured anatomical areas. Therefore, it is concluded that the decrease in skin surface pH cannot be attributed to circadian rhythms.

It must be kept in mind that during the period of measuring skin barrier function, a number of other factors were present which have to be considered when the results are analysed. These factors include the following:

- When the exposed group entered the production area, they wore latex gloves for approximately three to five hours. Although prolonged wearing of protective gloves did not cause any occlusion effects, the continuous decrease in skin surface pH may also indicate that permeation of HCl occurred through the gloves. HCl and/or Cl_2 may become trapped between the skin and the glove and contribute to damaging the skin barrier (Zhai & Maibach, 2002; Semple, 2004; Wulfhorst *et al.,* 2004; Pavlides, 2008; Wetzky *et al*., 2009; Du Plessis & Eloff, 2010).
- Wearing latex gloves also creates an allergy risk; it was indicated by earlier research that incidences of latex allergy in workers using latex gloves varied from 17-36% (Edlich *et al.,* 2003; Sawyer & Bennet, 2005). Repeated use of latex gloves, as in the

case of the exposed group, could sensitise the immune system, which can result in the formulation of immunoglobulin E (IgE) antibodies to latex antigens. Once an individual becomes sensitised to latex, an allergic reaction will occur upon re-exposure; this reaction will manifest as an irritation or delayed type hypersensitivity reaction (Type IV allergy) that is known as allergic contact dermatitis (Toraason *et al*., 2000; Abraham & Ramesh, 2002; Hunt *et al*., 2002).

- The exposed group did not only wear protective gloves when entering the production area, but also protective clothes, hard hats and respirators. These PPE may become contaminated in the production area; handling of these contaminated PPE could contribute towards the exposed group's changing skin surface pH and skin barrier function. Direct contact with contaminated work surfaces (i.e. doors, taps, control room work table, computer) could have the same result as the contaminated PPE on the exposed group's skin barrier (Du Plessis *et al.,* 2010).
- The Dalgard *et al.* (2003) skin questionnaire indicated that the majority of workers were of opinion that they have a healthy skin. Workers' perceptions of an intact skin condition may explain why only some of the exposed group's workers used barrier cream after cleansing their hands. However, if contaminated hands are not properly washed before applying barrier cream, the hazardous chemical substances could become trapped on the skin, which will only worsen the skin barrier function instead of enhancing it (De Craecker *et al.*, 2008).

3.5 CONCLUSIONS

The results of this study indicated that HCl and/or Cl_2 exposure may have contributed to the exposed group's deteriorated skin barrier function. It was also found that the exposed group's indirectly exposed skin was dehydrated. Although HCl exposure had no influence on the exposed groups' skin barrier function, Cl_2 exposure contributed to the disrupted skin barrier function on the back of the hand of the exposed group. Due to abnormally high TEWL levels for the palm of the exposed group and its significant positive correlation with

HCl exposure, only HCl contributed to the palm's damaged skin barrier function. Although the skin surface pH for indirectly and directly exposed skin was within the normal range, correlations indicated that HCl and Cl_2 exposure contributed to a decrease in skin surface pH for the directly exposed skin of the exposed group.

Additional factors such the use of latex gloves, continuous washing and scrubbing of hands, contact with contaminated personal protective equipment and workplace surfaces could also have contributed to an impaired skin barrier. Workers in the platinum refinery industry are not only exposed to HCl and Cl_2, but potentially also to chlorinated platinum salts. An impaired skin barrier may contribute towards skin permeation thereof, which could lead to sensitisation and allergy (Herrick *et al.,* 2003; Proksch *et al.,* 2006; Redlich & Herrick, 2008; Redlich, 2010).

Due to very few significant differences found between the nBC and BC-groups, it is unclear whether barrier creams played a role in enhancing the exposed group's skin barrier function. The following measures are, therefore, recommended to improve skin barrier function:

a) improvement of washing facilities for the hands, as well as for the neck and face with warm tap water which should be provided;
b) providing more frequent information and training sessions focusing on:
    - the handling of contaminated overalls, hard hats and workplace surfaces,
    - the permeation risk of protective gloves and allergy risk of latex gloves,
    - the necessity of personal hygiene and aftercare,
    - the correct washing procedures and use of barrier creams during working hours, or moisturising emollient after working hours, and
    - benefits of the use of moisturisers after working hours;
c) improvement of skin aftercare through the provision of emollient skin moisturising cream for each worker after completion of a shift that must be applied to the hands and face areas after cleansing routines at home; and

d) selection of protective gloves (for example neoprene gloves) that could reduce the allergy risk and provide the necessary chemical protection against HCl.

3.6 REFERENCES

Abraham EK, Ramesh P. (2002) Natural rubber latex products: concerns in health care. Journal of Macromolecular Science, Part C: Polymer Reviews; 42: 185-234.

Agache P, Humbert P. (2004) Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. ISBN 3 540 01771 2.

Agache P. (2004) Presentation of the skin surface ecosystem. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 21-32. ISBN 3 540 01771 2.

Agache P, Canvas V. (2004) Eccrine sweat glands. In Agache P, Humbert P, editors. Measuring the skin: non-invasive investigations, physiology, normal constants. Berlin: Springer. p. 302-309. ISBN 3 540 01771 2.

Barel AO, Clarys P. (2006) Measurement of epidermal capacitance. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 337-344. ISBN 0 8493 1437 2.

Colormetric Laboratories, Inc. (2009). The pioneer in reduction of dermal exposure. Available at http://www.clilabs.com/products/skinswypes.html Accessed 23 June 2011.

Dalgard F, Svensson A, Holm JO, Sunby J. (2003) Self-reported skin complaints: validation of a questionnaire for population surveys. British Journal of Dermatology; 149: 794-800.

De Craecker W, Roskams N, Op de Beeck R. (2008). Occupational skin diseases and dermal exposure in the European Union (EU-25): policy and practical overview. Luxembourgh: European Agency for Safety and Health at Work. ISBN 978 92 9191 161 5.

Du Plessis JL, Eloff FC. (2010) Back to basics – the skin barrier and how it is affected in common occupational scenarios. Occupational Health Southern Africa; 16: 24-25.

Du Plessis JL, Eloff FC, Laubscher PJ, Van Aarde MN, Franken A. (2010) Comparison of South Africa skin and sensitisation notations with those of other countries. Occupational Health South Africa; 14: 18-24.

Edlich R, Woodard CR, Hill LC, Heather CL. (2003) Latex allergy: a life-threatening epidemic for scientists, healthcare personnel, and their patients. Journal of Long-Term Effect of Medical Implants; 13: 11-19.

Fluhr J, Bankova L, Dikstein S. (2006) Skin surface pH: mechanism, measurement, importance. In Serup J, Jemec GBE, Grove GL, editors. Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. p. 411-420. ISBN 0 8493 1437 2.

Foulds IS. (2005) Organ structure and function: the skin. In Gardiner K, Harrington JM, editors. Occupational hygiene. 3rd ed. Oxford: Blackwell Publishing. p. 25-35. ISBN 1 4051 0621 2.

GraphPad Software Inc. (2009) Prism 5 for windows, version 5.03. www.graphpad.com <http://www.graphpad.com>.

Herrick CA, Xu L, McKenzie AN, Tigelaar RE, Bottomy K. (2003) IL-13 is necessary, not simply sufficient for epicutaneously induced Th2 responses to soluble protein antigens. Journal of Immunology; 170: 2488-2495.

Hunt L, Kelkar P, Reed CE, Yunginger JW. (2002) Management of occupational allergy to natural rubber latex in a medical center: the importance of quantitative latex allergen measurement and objective follow-up. Journal of Allergy and Clinical Immunology; 110: S96-S106.

ICSC (INTERNATIONAL OCCUPATIONAL SAFETY AND HEALTH INFORMATION CENTRE) (2000a) Chlorine. Available at http://www.ilo.org/legacy/english/protection/ safetwork/ cis/products/icsc/dtasht/icsc01/icsc0126.htm Accessed 9 September 2010.

ICSC (INTERNATIONAL OCCUPATIONAL SAFETY AND HEALTH INFORMATION CENTRE). (2000b) Hydrogen chloride. Available at http://www.ilo.org/legacy/english/ protection/ safetwork/cis/products/icsc/ dtasht/icsc01/icsc0163.htm Accessed 28 August 2010.

Kezic S, Nielsen JB. (2009) Absorption of chemicals through compromised skin. International Archives Occupational and Environmental Health; 82: 677-688.

Klonne DR. (2003) Occupational exposure limits. P. 51-70. In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 51-70. ISBN 1 931504 43 1.

Kruger P, Carman H, Bello B, Page-Shipp L, Phohleli D. (2008) The burden of skin disease in South African mines. Occupational Health Southern Africa; 14: 4-11

North-West University. (2010) Manual for postgraduate studies. Available at http://www.nwu.ac.za/sites/default/files/images/manualpostgrad.pdf Accessed 28 August 2010.

Pavlides AG. (2008) Development in cobalt and nickel electrowinning technology. Anglo American Mining Conference. Johannesburg, South Africa. 1-11.

Proksch E, Fölster-Holst R, Jensen JM. (2006) Skin barrier function, epidermal proliferation and differentiation in eczema. Journal of Dermatological Sciences; 43: 159-169.

Proksch E, Brandner JM, Jensen JM. (2008) The skin: an indispensable barrier. Experimental Dermatology; 17: 1063-1072.

Rawlings AV, Matts PJ, Anderson CD, Roberts MS. (2008) Skin biology, xerosis, barrier repair and measurement. Drug Discovery Today: Disease Mechanisms; 5: e127-e136.

Redlich CA. (2010) Skin exposure and asthma: is there a connection? Proceedings of the American Thoracic Society; 7: 134-137.

Redlich CA, Herrick CA. (2008) Lung/skin connections in occupational lung diseases. Current Opinion in Allergy and Clinical Immunology; 8: 115-119.

Reinol®. (2006). Reinol cares for your hands while it cleans it. Available at http://www.reinol.com/site/reinol_dermasoft_skin_care_cream.php Accessed 11 July 2011.

Rippke F, Schreiner V, Doering T, Maibach HI. (2004) Stratum corneum pH in atopic dermatitis: impact on skin barrier function and colonization with staphylococcus aureus. American Journal of Clinical Dermatology; 5: 217-223.

Rippke F, Schreiner V, Schwanitz HJ. (2002) The acidic milieu of the horny layer: new findings on the physiology and pathophysiology of the skin pH. American Journal of Clinical Dermatology; 3: 261-272.

Sawyer JO, Bennet A. (2005) Comparing the level of dexterity offered by latex and nitrile SafeSkin gloves. Annals of Occupational Hygiene; 50: 289-296

Schaper M, Bisesi M. (2003) Environmental and occupational toxicology. In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 21-50. ISBN 1 931504 43 1.

Schneider T, Cherrie JW, Vermeulen R, Kromhout H. (2000) Dermal exposure assessment. Annals of Occupational Hygiene; 44: 493-499.

Segal E, Tarabar A, Lang ES, De Blieux PMC, Van De Voort JT, Benitez JG, Halamka JD. (2010) Toxicity Chlorine Gas. Available at http://www.emedicine.medscape.com/article/820779-overview Accessed 19 August 2011.

Semple S. (2004) Dermal exposure to chemicals in the workplace: just how important is skin absorption? Occupational Environment Medicine; 61: 378-382.

Serup J, Jemec GBE, Grove GL. (2006) Handbook of non-invasive methods and the skin. 2nd ed. New York: Taylor & Francis Group. 1029 p. ISBN 0 8493 1437 2.

SKC. (2010) Surface/Dermal and decontamination: chemical hazards. Available at http://www.skcinc.com/SurfaceDermalSampling.asp Accessed 23 August 2010.

Stanton DW, Jeebhay MF. (2001) Chemical hazards. In Guild R, Erlich R, Johnston J, Ross M, editors. SIMRAC Handbook of occupational health practice in the South African mining industry. Johannesburg, SA: Creda Communications. p.257-293.) Chapter 9, ISBN 1 919 853 02 2.

StatSoft.Inc. (2011) Statistica: data analysis software system version 10. www.statsoft.com <http://www.statsoft.com>.

Toraason M, Sussman G, Biagini R, Meade J, Beezhold D, Germolec D. (2000) Latex allergy in the workplace. Toxicological Sciences; 58: 5-14.

Verdier-Sévrian S, Bonté F. (2007) Skin hydration: a review on its molecular mechanisms. Journal of Cosmetic Dermatology; 6: 75-82.

Weber LW, Pierce JT. (2003) Development of occupational skin disease. In DiNardi SR, editor. The occupational environment: its evaluation, control and management. 2nd ed. Virginia: AIHA Press. p. 348-360. ISBN 1 931504 43 1.

Wetzky U, Bock M, Wulfhorst B, John SM. (2009) Short-and long-term effects of single and repetitive glove occlusion on the epidermal barrier. Archive Dermatology Research; 301: 595-602.

Wöhrl S, Kriechbaumer N, Hemmer W, Focke M, Brannath W, Götz M, Jarisch R. (2001) A cream containing the chelator DTPA (diethylene triaminepenta-acetic acid) can prevent contact allergic reactions to metals. Contact Dermatitis; 44: 224-228.

Wulfhorst B, Schwanitx HJ, Bock M. (2004) Optimizing skin protections with semipermeable gloves. Dermatitis; 15: 184-191.

Yosipovitch G, Xiong GL, Haus E, Sackett-Lundeen L, Ashkenazi I, Maibach HI. (1998) Time-dependent variations of the skin barrier function in humans: transepidermal water loss, stratum corneum hydration, skin surface pH, and skin temperature. The Journal of Investigative Dermatology; 110: 20-23.

Zhai H, Maibach HI. (2002) Occlusion vs. skin barrier function. Skin Research and Technology; 8: 1-6.

Zeliger HI. (2008) Human toxicology of chemical mixtures: toxic consequences beyond the impact of one-component product and environmental exposures. New York: William Andrew. ISBN 978 0 8155 1589 0.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The objective of this study was to assess the influence of an acidic working environment on workers' skin barrier function (i.e. skin hydration, TEWL and skin surface pH). Personal and area exposure to HCl and Cl_2 was concurrently assessed and skin barrier function measurements were conducted on indirectly exposed skin (i.e. palm, wrist and back of hand that was covered with protective gloves) and directly exposed skin (i.e. neck, cheek and forehead).

HCl and Cl_2 exposure

The HCl and Cl_2 exposure levels confirmed that the work environment of the exposed group was much more acidic than that of the control group.

Skin hydration

Skin hydration of the exposed group was generally lower than that of the control group, which indicated that the exposed group had dryer skin. HCl showed no correlation with the exposed group's skin hydration, neither for indirectly nor directly exposed skin. Although the indirectly exposed skin of the exposed group was dehydrated, only Cl_2 exposure showed an adverse influence on skin barrier function on the back of the hand. Due to the limited correlations of HCl and Cl_2 with skin hydration, it remained unclear whether HCl and Cl_2 exposure actually influenced skin hydration.

TEWL

The exposed group's indirectly exposed skin generally exhibited higher TEWL levels than that of the control group, which indicated that the exposed group's stratum corneum water loss was higher. Although both, HCl and Cl_2 exposure, showed positive correlations with

TEWL on indirectly and directly exposed skin, only HCl exposure contributed to the damaged skin barrier function on the palm of the exposed group.

Skin surface pH

The skin surface pH of indirectly and directly exposed skin in the control group as well as the exposed group was within the normal range. Although both groups' skin surface pH became more acidic as the work shift progressed, the exposed group had a more acidic skin surface pH. HCl and Cl_2 exposure contributed to the decrease in skin surface pH for the directly exposed skin only. It should be noted that changes in the skin surface pH may disturb the skin barrier function.

Other factors impacting on the findings

During measurement of the workers' skin barrier function, a number of other factors were also present that may have influenced the skin barrier of the exposed group.

These factors include:

- *The use of barrier creams*

  Some of the workers used barrier creams, but when their hands were not properly washed (especially when they wore protective gloves in conjunction with the use of barrier creams) the barrier creams may have impeded the skin barrier function instead of protecting or enhancing it (De Craecker *et al.*, 2008). In this study it seemed likely that barrier creams had a positive effect on the BC-group's TEWL, but had no effect on their skin hydration. The BC-group's skin surface pH for the palm and wrist was also higher than that of the nBC-group. The limited significant differences between the nBC- and BC-groups may be ascribed to the fact that a small participant group was involved in this study, and therefore the effect of the barrier creams' influence on skin barrier function could not be established with sufficient certainty.

- *Occupational activities*

  Continuous washing and scrubbing of hands, mechanical injuries, skin friction and abrasion could disrupt the skin barrier function (Kezic & Nielsen, 2009; Du Plessis & Eloff, 2010).

- *The use of latex gloves*

  Latex gloves do not appear to provide the necessary chemical protection against HCl. Hazardous chemical substances can penetrate through these protective gloves and become trapped between the glove and the skin, and can therefore damage the skin barrier (Zhai & Maibach, 2002; Semple, 2004; Wulfhorst *et al.,* 2004; Pavlides, 2008; Wetzky *et al*., 2009; Du Plessis & Eloff, 2010). Latex gloves also pose an allergy risk and repeated use of these could sensitise the immune system which, in turn, could contribute to the development of allergic contact dermatitis (Toraason *et al*., 2000; Abraham & Ramesh, 2002; Hunt *et al*., 2002).

- *Contact with contaminated surfaces*

  Hazardous chemical substances may be deposited on the workers' skin due to direct contact with contaminated protective equipment or workplace surfaces, which could exacerbate damage to the skin barrier function even further (Du Plessis *et al.,* 2010).

Workers in the platinum refinery industry are potentially also exposed to other hazardous chemical substances such as chlorinated platinum salts. An impaired skin barrier may increase skin permeation of these allergens, which could then give rise to sensitisation and allergy (Herrick *et al.,* 2003; Proksch *et al.,* 2006; Redlich & Herrick, 2008; Redlich, 2010).

The hypothesis of this study was that HCl and Cl_2 exposure have an adverse influence on the skin barrier function of exposed precious metal refinery workers.

The results of the study indicated the following:

- Only Cl_2 exposure adversely influenced the skin barrier function of the back of the hand (decreased skin hydration); and
- Only HCl exposure adversely influenced the skin barrier function of the palm (decreased skin hydration and increased TEWL).
- HCl and Cl_2 exposure contributed to the acidification of skin surface pH only for the directly exposed skin.

The hypothesis of this study can therefore be partially accepted.

4.2 RECOMMENDATIONS

Enhancing occupational hygiene practices in the platinum refinery will require adequate management and control measures to ensure the health and safety of workers, with respect to dermal absorption and the maintenance of the skin barrier function. Recommendations in terms of engineering control, administrative and personal protective equipment are as follows:

a) *Improving washing facilities.* At least one basin with tap(s) was present in the control room or near the control room. However, the provision of cold water only may cause a resistance in workers to continue with good personal hygiene practices, which may contribute to the contamination of workplace surfaces. Handling and direct contact with contaminated basin tap(s) could lead to contamination of workers' hands. Therefore, improvement of washing facilities to prevent contamination is recommended.

- Provision of hot and cold water at the washing facilities may motivate workers to engage in sound personal hygiene practices more regularly.
- A further recommendation is the installation of two foot-pedal powered faucets which can supply hot and cold water without touching the taps to open or close (*Horwitz,* 2009).

- Also, the refinery should continue with the provision of liquid cleansing soap, paper towels to dry hands and open-lid bins for discarding used paper towels.

b) *Continue with educational sessions during training or verbal education by the manager.* The following information could be provided during these training sessions:
   - PPE must be treated as a contaminated medium. Workers need to be educated regarding the correct way of removing and handling contaminated PPE to prevent further spreading of hazardous chemical substances to the control room or family members.
   - Workers need to be informed and motivated to engage in sound personal hygiene practices, which include: i) regular washing of hands, face and neck after exposure to hazardous chemical substances, and before each tea or lunch break, ii) correct procedures for washing hands, face and neck before applying any barrier creams or emollients, iii) proper cleansing rituals in the locker/dressing room at the end of the shift, and iv) being informed of the benefits of using emollients after work.

c) *Selection of appropriate protective gloves.* The workers who participated in this study used latex gloves, and these gloves present a high allergy risk and also a high permeation risk for HCl. There is no specific recommended glove that is suitable for protection against all hazardous chemical substance exposures, because different glove materials resist different chemicals (Argonne National Laboratory, 2011; Lab Safety Supply, 2011; Sawyer & Bennett, 2006). Nitrile gloves have a higher resistance to a variety of chemicals, are more puncture resistant and are also safe to use for workers with an allergy to latex, but these gloves do not provide protection against benzene, methylene, chloride, trichloroethylene and ketone. Polyvinyl chloride (PVC) gloves are safe to use against strong acids, bases and salts, but these can be easily stripped. Neoprene gloves seem to be the best protective gloves against oxidizing acids, anilines, phenol and glycol ethers, but are more expensive than other gloves.

4.3 LIMITATIONS OF THIS STUDY

A number of limitations were noted during the study and these may have influenced the measuring or interpretation of the results.

a) Workers who participated in the exposed group were identified by the managers. Because some of the workers in the exposed group used skin barrier creams, the exposure group had to be divided into two groups (nBC- and BC-groups), and this complicated the interpretation of the measured results. The small number of participants in the nBC-group also limited the statistical analysis and conclusions.

b) Workers who participated in the exposed group completed a skin questionnaire which indicated their perceptions of their skin condition, but no verification of these perceptions by means of medical records and/or examinations by a dermatologist took place.

4.4 FUTURE STUDIES

The importance of an intact skin barrier in the platinum refinery was emphasised in this study. Possible future research that can be identified in terms of the analysis of workers' skin barrier function are:

- To repeat the same study, but with a larger homogenous exposed group. A thorough study could be conducted with all the workers in each separate production area, to analyse workers' changing skin barrier function over longer periods while at the same time determining all the hazardous chemical substances to which workers are exposed to during these skin measurements.
- The actual effect of barrier cream on refinery workers' skin barrier function should be investigated, but much larger nBC and BC-groups are required. The influence of protective gloves on the skin barrier function in conjunction with the use of barrier creams could support this investigation.

- It needs to be determined whether there is a correlation between refinery workers' skin barrier function and their exposure levels to contaminated workplace surfaces in the control room, tea/lunch rooms, locker rooms, and with PPE. Workers who are responsible for washing and cleaning of contaminated clothing and PPE of refinery workers could also participate in this study with a view to determine whether handling of contaminated PPE has a negative effect on their skin barrier function. A risk assessment could also be conducted in these washrooms to determine whether decontaminated PPE is safe to be re-used.

4.5 REFERENCES

Abraham EK, Ramesh P. (2002) Natural rubber latex products: concerns in health care. Journal of Macromolecular Science, Part C: Polymer Reviews; 42: 185-234.

Argonne National Laboratory. (2011). Glove selection guideline. US Department of Energy. Available at http://www.aps.anl.gov/Safety_and_Training/User_Safety/glove selection.html Accessed 24 August 2011.

De Craecker W, Roskams N, Op de Beeck R. (2008). Occupational skin diseases and dermal exposure in the European Union (EU-25): policy and practical overview. Luxembourg: European Agency for Safety and Health at Work. ISBN 978 92 9191 161 5.

Du Plessis JL, Eloff FC. (2010) Back to basics – the skin barrier and how it is affected in common occupational scenarios. Occupational Health Southern Africa; 16: 24-25.

Du Plessis JL, Eloff FC, Laubscher PJ, Van Aarde MN, Franken A. (2010) Comparison of South Africa skin and sensitisation notations with those of other countries. Occupational Health South Africa; 14: 18-24.

Herrick CA, Xu L, McKenzie AN, Tigelaar RE, Bottomy K. (2003) IL-13 is necessary, not simply sufficient for epicutaneously induced Th2 responses to soluble protein antigens. Journal of Immunology; 170: 2488-2495.

Horwitz D. (2009) Foot-pedal powered faucet. Fine Homebuildings; 207: 103. Available at http://www.finehomebuilding.com/departments/feedback/foot-pedal-powered-faucet.aspx Accessed 24 August 2011.

Hunt L, Kelkar P, Reed CE, Yunginger JW. (2002) Management of occupational allergy to natural rubber latex in a medical center: the importance of quantitative latex allergen measurement and objective follow-up. Journal of Allergy and Clinical Immunology; 110: S96-S106.

Kezic S, Nielsen JB. (2009) Absorption of chemicals through compromised skin. International Archives Occupational and Environmental Health; 82: 677-688.

Lab Safety Supply. (2011) Chemical protective gloves. GHC Specialty Brands, LLC. Available at http://www.labsafety.com/refinfo/ezfacts/ezf191.htm Accessed 24 August 2011.

Pavlides AG. (2008) Development in cobalt and nickel electrowinning technology. Anglo American Mining Conference. Johannesburg, South Africa. 1-11.

Proksch E, Fölster-Holst R, Jensen JM. (2006) Skin barrier function, epidermal proliferation and differentiation in eczema. Journal of Dermatological Sciences; 43: 159-169.

Redlich CA. (2010) Skin exposure and asthma: is there a connection? Proceedings of the American Thoracic Society; 7: 134-137.

Redlich CA, Herrick CA. (2008) Lung/skin connections in occupational lung diseases. Current Opinion in Allergy and Clinical Immunology; 8: 115-119.

Sawyer JO, Bennett A. (2006) Comparing the level of dexterity offered by latx and nitrile safeskin gloves. Annals of Occupational Hygiene; 50: 289-296.

Semple S. (2004) Dermal exposure to chemicals in the workplace: just how important is skin absorption? Occupational Environment Medicine; 61: 378-382.

Toraason M, Sussman G, Biagini R, Meade J, Beezhold D, Germolec D. (2000) Latex allergy in the workplace. Toxicologcal Sciences; 58: 5-14.

Wetzky U, Bock M, Wulfhorst B, John SM. (2009) Short-and long-term effects of single and repetitive glove occlusion on the epidermal barrier. Archive Dermatology Research; 301: 595-602.

Wulfhorst B, Schwanitx HJ, Bock M. (2004) Optimizing skin protections with semipermeable gloves. Dermatitis; 15: 184-191.

Zhai H, Maibach HI. (2002) Occlusion vs. skin barrier function. Skin Research and Technology; 8: 1-6.

ANNEXURE

SKIN QUESTIONNAIRE - Personal Data Sheet

Name:	**SAP Nr:**	**Subject Nr:**
Age:	**Section:**	**Date:**
Gender: M / F	**Position:**	**Numbers of years:**
Race: B / W / C / I	**Dominant hand:** L / R	**Smoking:** Yes/No

SKIN QUESTIONNAIRE - Result Sheet

During the last week, have you had any of the following complaints?
Mo bekeng e e fetileng, a o kile wa nna le ngwe ya dingongorego tse?

	1 No ***Nnyaa***	**2 Yes, a little** ***Ee, go le gonnye***	**3 Yes, quit a lot** ***Ee, gantsi***	**4 Yes, very much** ***Ee, gantsi thata***
1. Itchy skin (jeuk) *Go babelwa ga letlalo*				
2. Dry/sore rash (droog/seer uitslag) *Boswata bo bo omeletseng/botlhoko*				
3. Scaly skin (afskilfer vel) *Letlalo le le obogang*				
4. Itchy rash on your hands (jeuk uitslag) *Boswata bo bo babelang mo diatleng*				
5. Pimples (puisies) *Dipeise*				
6. Other rashes on your face (uitslag) *Baswata mo sefatlhegong*				
7. Warts (vraatjies) *Diso/dokgoto*				
8. Troublesome sweating (sweet) *Go fufulelwa thata*				
9. Loss of hair (hare) *Go wa ga moriri*				
10. Other skin problems (ander) *Mathata a mangwe a letlalo*				

If yes, when did the skin problems start? Mark one answer.
Fa karabo ya gago ele ee, bothata jwa letlalo bo simolotse leng? Ka kopo, tshwaya karabo e le ngwe.

Questions:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
During the last week/*Beke ee fetileng*										
During the last month/*Kgwedi ee fetileng*										
1-6 months ago/*Kgwedi ele ngwe go tse thataro 1-6*										
More than 6 months ago/*Go feta dikgwedi dile 6 tse di fetileng*										

Do you use any skincare products, what type of products and when?_____
Notes:_____

INTERPRETATION: Total of all ÷ 10

1: None – no medical attention needed	2: Trivial - not justify for medical attention	3: Moderate – justify medical attention	4: Severe sign – need early medical attention