THE EFFECT OF MINERAL OIL EXPOSURE ON METAL WORKERS AT A LARGE ENGINEERING PLANT IN BLOEMFONTEIN, SOUTH AFRICA

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THE EFFECT OF MINERAL OIL EXPOSURE ON METAL WORKERS AT A LARGE ENGINEERING PLANT IN BLOEMFONTEIN, SOUTH AFRICA

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Dedicated to –
My father, mother, brothers and Shakila Samay
(त्जवह ँ सलिअ स्ह्यरैल्अइथ्झ)

"And all things, whatsoever ye shall ask in prayer, believing, ye shall receive."
Matthew 21:22 (KJV)

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α	alpha error (or probability error)
δ	means the minimum difference needed to detect a significant change at 95% confidence interval
σ	normal sample deviation
Δ	change
95% CI	95% confidence limit
ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	analysis of variance (one–way)
ATS	American Thoracic Society Medical Section of the American Lung Association
BMRC	British Medical Research Council
/cm	inverse centimetres
CCOSH	Canadian Centre for Occupational Safety and Health
DEA	diethylamine
ES	ex–smokers
FEV_1	forced expired volume in one second
FVC	forced vital capacity
FEV_1/FVC	ratio of forced expired volume in one second to forced vital capacity
$FEV_{1\ post}/FVC_{post}$	ratio of post–shift forced expired volume in one second to post–shift forced vital capacity
IUATLD	International Union Against Tuberculosis and Lung Diseases
L	litres
mg	milligrams
mg/m^3	milligrams per cubic metre
MSDS	Material Safety Data Sheet
MWF	metal working fluid
N	is the size of a calculated statistical population
n	number of workers
NCOH	National Centre for Occupational Health in South Africa
NIOSH	National Institute for Occupational Safety and Health in the United States

List of Abbreviations (continued)

NIOSH REL	1998 NIOSH Recommended Exposure Limit for an 8 hour work day
NS	never smokers
ODP	Ontario Disease Panel in Canada
pH	is the negative logarithm (base 10) of the hydrogen ion concentration
P	probability
PPE	personal protective equipment
PPC	personal protective clothing
PMR	proportional mortality ratio
PSL	permissible safe limit
r^2	Pearson's Correlation Coefficient
%RH	percent relative humidity
RR	relative risk
S	smokers
SD	arithmetic standard deviation
SMR	standard mortality ratio
STEL	1999 ACGIH Short Term Exposure Limit (for 15 minutes)
TEA	triethylamine
TLV	1999 ACGIH Threshold Limit Value for an 8 hour work day (40 hour work week)
Type 1	semisynthetic metal working fluid by Atlas Oils™
Type 2	semisynthetic metal working fluid by Castrol™
Type 3	semisynthetic metal working fluid by Engen™ (GENSOL™ General Purpose)
Type 4	semisynthetic metal working fluid by MarProZap™ (General Purpose)
t-test	Student's *t*-test at a probability level of 95%
TWA	time weighted average
UAW	United Auto Worker's Union
UV–Vis	ultraviolet visible spectroscopy
Z_1	is the z_1–test value at a probability level of 95%
Z_2	is the z_2–test value at a probability level of 95%

Summary

Adverse and chronic pulmonary health effects have been associated with workers exposed to various types of metal working fluids (MWF's). Within South Africa there is a lack of research dealing with specific agents in MWF's which may be the source of pulmonary health problems. This occupational health study deals with the acute pulmonary health effects of MWF's among metal workers employed by an engineering company in South Africa. A cross–sectional population of 341 machine workers was sampled for full shift personal exposures to MWF's according to a modified National Institute for Occupational Safety and Health Method (NIOSH) Number 0500. Forced expiratory volume in one second (FEV_1) tests were completed before and after the worker's shift according to manoeuvers dictated by the American Thoracic Society (ATS). A written health survey comprised from the British Medical Research Council and the International Union Against Tuberculosis and Lung Diseases questionnaire, was utilised to determine the worker's present health condition during the study.

Personal inhalation exposures were lower than the current 1999 American Conference of Governmental Industrial Hygienists Threshold Limit Value (ACGIH TLV) of 5 mg/m^3 (mean = 1.04 mg/m^3, arithmetic standard deviation = 2.0). However, increasing personal exposures to MWF's were positively correlated to decreases in FEV_1 (Plant 1: r^2 = 0.96, Plant 2: r^2 = 0.94, Plant 3: r^2 = 0.97). The change in FEV_1 of nonsmoking workers exposed to MWF's was significantly different in comparison to unexposed nonsmoking workers (ANOVA, P = 0.05, n = 297). Similarly, nonsmoking workers who were exposed to MWF's with higher fractions of triethanolamine (TEA) and diethanolamine (DEA) had greater decreases in FEV_1 (ANOVA, P = 0.02, n = 183). Workers who were current smokers and exposed to MWF's experienced the highest decreases in FEV_1 in comparison to exposed nonsmoking workers (ANOVA, P = 0.05, n = 341). Workers exposed to the four types of MWF's experienced a logarithmic dose–response to the decrease in FEV_1. This dose–response was explained with a mathematical equation for each MWF type.

Permissible safe limits derived from these equations (MWF Type 1: 1.70 mg/m^3, MWF Type 2: 0.41 mg/m^3, MWF Type 3: 0.29 mg/m^3 and MWF Type 4: 0.035 mg/m^3) reflect the validity of NIOSH's recommendation of a safe exposure limit of 0.5 mg/m^3.

It is concluded that workers who are exposed to MWF's, experience acute decreases in FEV_1. Similarly, workers who are smokers and exposed to TEA– and DEA MWF's experience the greatest decrease in FEV_1. Engineering controls, and use of highly refined MWF's containing no DEA and TEA were recommended to the engineering company.

Opsomming

Nadelige en kroniese pulmonêre gesondheidseffekte is met werkers geassosieer wanner hulle aan verkillende tipes olie mis (MWF's) blootgestel word. In Suid Afrika is 'n tekort aan navorsing wat handel oor die spesifieke agense in MWF's wat moontlik die bron van pulmonêre gesondheidsprobleme is. Hierdie beroepsgesondheid studie handel met die akute pulmonêre gesondheidseffekte van MWF's op metaal werkers wat in diens van 'n groot ingenieurs maatskappy in Suid Afrika is. 'n Deursnit populasie van 341 masjien operateurs is vir volskof persoonlike blootstelling aan MWF's, volgens 'n gemodifiseerde "National Institute of Occupational Safety and Health (NIOSH)" metode nommer 0500 gemonster. Geforseerde uitgeasemde volume in een sekonde (FEV_1) spirometrie toetse is voor en na die werker se skof volgens die bewegings voorgeskryf deur die "American Thoracic Society (ATS)" afgeneem. 'n Geskrewe gesondheidsondersoek wat saamgestel is van die "British Medical Research Council" en die "International Union Against Tuberculosis and Lung Diseases" vraelys, is gebruik om die werker se huidige gesondheidstoestand tydens die studie te bepaal.

Persoonlike inasemingsblootstelling was laer as die huidige 1999 "American Conference of Governmental Industrial Hygienists" Drempel Limiet Waarde (ACGIH DPW) van 5 mg/m^3 (gemiddelde = 1.04 mg/m^3, rekenkundige standaard afwyking = 2.0). Desnieteenstaande is verhoogde persoonlike blootstelling aan MWF's positief met die vermindering in geforseerde uitgeasemde volume (FEV_1) gekorrelleer (Aanleg 1: $r^2 = 0.96$, Aanleg 2: $r^2 = 0.94$, Aanleg 3: $r^2 = 0.97$). Die verandering in FEV_1 van die nie-rokers wat aan MWF's blootgestel is, het betekenisvolle verskille in vergelyking met die nie-rokers getoon wat nie blootgestel was nie (ANOVA, $P = 0.05$, $n = 297$). Ooreenkomstig het nie-rokers wat aan MWF's met hoër fraksies van tri-etanolamien (TEA) en di-etanolamien (DEA) blootgestel is, groter afnames in FEV_1 (ANOVA, $P = 0.02$, $n = 183$) getoon. Werkers wat tans rokers is en blootgestel is aan MWF's het die hoogste afname in FEV_1 in vergelyking met blootgestelde nie-rokers getoon (ANOVA, $P = 0.05$, $n = 341$).

Werkers wat aan die vier tipes MWF's blootgestel was, het 'n logaritmiese dosis-reaksie tot die afname in FEV_1 ondervind. Hierdie dosis-reaksie is met 'n wiskundige vergelyking vir elke tipe MWF's verduidelik.

Toelaatbare veiligheidsgrense wat van die vergelykings afgelei is (MWF Tipe 1: 1.70 mg/m^3, MWF Tipe 2: 0.41 mg/m^3, MWF Tipe 3: 0.29 mg/m^3 en MWF Tipe 4: 0.035 mg/m^3) reflekteer die geldigheid van NIOSH se aanbeveling van 'n veilige blootstellingslimiet van 0.5 mg/m^3.

Dit is bewys dat werkers wat aan MWF's blootgestel word, akute afname in FEV_1 toon. Ooreenkomstig ondervind werkers wat rook en aan TEA- en DEA- bevattende MWF's blootgestel word, die grootste afname in FEV_1. Ingenieursbeheer en die gebruik van suiwer geraffineerde MWF's wat nie TEA of DEA bevat nie, is aan die maatskappy aanbeveel.

1. Introduction

Since the 1900's to the present date, metal workers have been using coolants and lubricants to prolong the life of their tools and the machinery that they worked with (NIOSH, 1998). These coolants and lubricating fluids are still in use today among most metal engineering plants in the world. Within the United States of America there is an annual consumption of 71.5 million gallons per annum (NIOSH, 1998). In South Africa the use of these fluids are approximately 69-100 million litres per annum (Somaroo, 1998: Unpublished report). These coolants or oils that are used by metal workers are termed Metal Working Fluids (MWF's) that are used to prolong the life of tools, to carry away metal chips during metal working, to reduce friction and heat production, and to protect or treat the metal surface which is being processed. There are various types of MWF's which are used in the workplace and are distinguished by their chemical composition. *Straight* MWF's are those fluids that are highly refined petroleum, animal, marine, vegetable, or synthetic oils and are not mixed with water. *Soluble* MWF's (emulsifiable oils) contain 30%–85% of highly refined oils but are usually mixed with water. *Semisynthetic* MWF's contain only 5%–30% of highly refined oils and 30%–50% of emulsifiers. These semisynthetic MWF's are dissolved in large quantities of water and are intended for higher stress metal work. *Synthetic* MWF's contain no refined oils and are made up of mainly emulsifiers and no water (Whittaker, 1997: pp.4 – 12). Despite the types of MWF's that are being used, no research into the potential health affects of workers exposed to these occupational agents or their long term health effects was conducted within South Africa (NCOH, 1998).

Studies conducted in the United States and the United Kingdom have shown that MWF's do cause chronic long term health affects such as cancer (Acquavella and Leet, 1991; Eisen, Tolbert, Hallock, Monson and Smith, 1992; McKee, Scala and Chauzy, 1990; Rønneberg and Skyberg, 1988a; Rønneberg, Andersen and Skyberg, 1988b). Acute pulmonary affects have been shown to be caused by occupational exposure to MWF's, but the exact agents that cause these health affects have not yet been proven scientifically (NIOSH, 1998).

Toxicological research and epidemiological studies completed to date have generalised the health affects among workers from occupational exposure to more than one different type of MWF and have not focussed on the specific types of MWF's (NIOSH, 1998; Woskie, Smith, Hammond and Hallock, 1994). Current research into the health affects of MWF's, have not focussed on the agents within the MWF's that may cause the negative health affects.

Although chronic obstructive diseases have been caused by occupational exposure to MWF's a formulation of a dose–response model has not been attempted, due to statistically small population sizes or other confounding factors in research (NIOSH, 1998). This research will add to existing knowledge and answer the question of which elements in semisynthetic MWF's attribute to pulmonary health changes among metal workers and suggest other formulations for a safer MWF.

The dose–response model that is being formulated will assist in determining a permissible occupational exposure limit for semisynthetic MWF's that could be introduced into the South African Occupational Health and Safety Act. The mathematical model will also determine if the current ACGIH TLV and the National Institute of Occupational Safety and Health Recommended Exposure Limit (NIOSH REL) which have been developed for MWF's, are accurate representations of the potential toxicity of semisynthetic MWF's (ACGIH, 1998; NIOSH, 1998).

This cross–sectional occupational health study encompassed 341 employees from three engineering plants in South Africa. Personal monitoring for occupational exposure to MWF's was completed for 247 workers and repeated among selected metal workers.

Spirometry measurements were completed for each employee before and after their respective work shifts. Four different types of semisynthetic MWF's were studied to determine what acute health affects are observed when specific compounds are present in different concentrations.

From this information, the acute pulmonary effects were studied and a dose–response model based on the exposure information gathered from each subject in the study, was composed.

1.1 Occupational epidemiology

Research has shown that metal workers have chronic affects after exposure to MWF's. Early investigations of MWF's for being the source of pulmonary illness was only speculated in case investigations among metal workers. One of these early investigations consisted of a medical case study, where two cases of work related asthmatic illness were reported. One worker was a machinist and the other a tool grinder who were exposed to straight oil MWF's on a daily basis. After a duration of employment an onset of asthmatic symptoms occurred in these previously healthy workers. Unfortunately the researchers had no exposure data to support their claims (Forbes and Markham, 1967).

In a more recent study of 25 workers exposed to various types of MWF's, they found that 75% of these workers had a cross shift decrease in pulmonary function of 25%–45% (Robertson, Weir and Burge, 1988). The workers' pulmonary health problems were also verified with spirometric challenge tests to determine the nature of the pulmonary sickness, and showed that the workers who were sick had definite signs of asthma. Robertson *et al.* (1988) did not have information or did not report any exposure data for these workers and personal monitoring was not carried out.

Gannon and Burge (1991), researched the total incidence of similar pulmonary diseases and occupational asthma among the West Midlands Region of England. The prevalence of 36 per one million metal workers for the development of occupational asthma was calculated. The researchers however, did not provide any exposure information on the cases identified in their study.

Similar medical surveillance programmes in the United States also showed a higher incidence of occupational asthma among metalworkers (250 per one million workers) as documented by Meredith, Taylor and McDonald (1991). Rosenmann, Reilly and Kalinowski (1997) and Rosenmann, Reilly, Watt and Kalinowinski (1995) continued similar studies and calculated a higher prevalence of occupational asthma from being exposed to MWF's at various personal exposure concentrations. Studies into the specific health affects among different types of MWF's have been limited to date but, Oxhøj, Anreasen and Henius (1982) was the first to investigate this idea.

An epidemiological study completed by Oxhøj *et al.* (1982) in Germany studied four types of MWF's and the prevalence of pulmonary symptoms among metal workers. From 27 industries, metal workers were subjected to pulmonary function testing and a health questionnaire. Researchers concluded that the MWF's do attribute to the risk of chronic cough and phlegm suggesting "...a dose–response relationship," but Oxhøj *et al.* (1982) also concluded and found that the types of MWF's did not attribute to drastic changes in the pulmonary health of workers.

Similarly, Ameille, Wild, Choudat, Ohl, Vaucouleur, Chanut and Brochard (1995) studied the bronchial reactivity, ventilatory impairment and respiratory symptoms among 308 French male automobile workers. Multiple types of MWF's were studied and no significant difference between the types of MWF's used and the change in pulmonary function was observed. It was concluded that MWF's do cause a higher prevalence of pulmonary problems among the exposed population and a cross shift decrease in FEV_1 spirometry measurements.

Contrary to this, Zacharisen, Kadambi, Schulueter, Kurup, Shack, Anderson and Fink (1998) recently studied the health of 30 workers and noticed that automobile workers exposed to specific mixtures of MWF's developed specific cases of hypersensitivity pneumonitis and occupational asthma or industrial bronchitis. What was not identified was the type of agents in MWF's that caused the physical symptoms among workers at the automobile plant. Thermophiles and *Legionella* were identified as biological sources for the pulmonary symptoms. Other sources of pulmonary abnormalities could be attributed to "non–specific irritants....[such as] additives, or contaminants..." which were not studied (Zacharisen, *et al.*, 1998).

In studies with larger statistical populations, the analysis of different MWF's was attempted by Greaves, Eisen, Smith, Pothier, Kriebel, Woskie, Kennedy, Shalat and Monson in 1997. In a cohort study of 1 811 automobile workers Greaves *et al.* (1997) studied the prevalence of pulmonary problems and the personal exposures of automobile workers from three General Motors Plants. Full shift exposure monitoring was completed for 475 of the 1 811 workers.

Previous exposure data were included from past industrial hygiene company surveys. From this study it was shown that a prevalence of pulmonary symptoms correlated to the present occupational exposure to MWF's. Unlike the Ameille *et al.* (1995) and Oxhøj *et al.* (1982) studies, the types of MWF's also contributed to the type of symptoms which were being observed. However, the various classes of MWF's studied made it impossible to determine which fluids were more toxic than other formulations (Greaves, *et al.*, 1997). Pulmonary symptoms among workers exposed to synthetic oils consisted of: cough, phlegm, wheeze, chest tightness and chronic bronchitis. A higher prevalence of pulmonary symptoms which were associated with exposure to straight oils were phlegm and wheezing. Greaves *et al.* (1997) calculated the accumulated exposure for developing any type of pulmonary symptom which was 1.02 mg/m^3 per annum. The risk for the development of pulmonary problems was also calculated by Greaves *et al.* (1997) and they found an increase of two fold for a worker who had a working history of more than 40 years and was exposed to MWF's with a thoracic personal exposure concentration of 1 mg/m^3.

Greaves *et al.* (1997) also reported on data in which Eisen, Holcroft, Greaves, Wegman, Woskie and Monson (1997) had studied 25 cases of reported occupational asthma. Based on the occupational personal exposure records of 2 years before reporting the illness, the risk for the development of pulmonary diseases (relative risk, RR) was dependant on the type of MWF (Greaves, *et al.*, 1997).

The relative risk for the development of pulmonary illnesses was calculated by Greaves *et al.* (1997) as: RR = 2.0 (95% CI: 0.9 - 4.6), for straight MWF's; RR = 0.5 (95% CI: 0.2 - 1.1) for soluble MWF's; and RR = 3.2 (95% CI: 1.2 - 8.3) for synthetic MWF's. This calculation of risk is contrary to the Ameille *et al.* (1995) and Oxhøj *et al.* (1982) studies which found no significant change in pulmonary health between different MWF's formulations.

Similarly, Robins, Seixas, Franzblau, Abrams, Minick, Burge and Schork, (1997) studied data from machinists exposed to MWF's and a control population of assemblers not potentially exposed.

Of the machinists that did not have pre–existing asthma, there was a clinically significant decrease of cross shift FEV_1 (of 12%) among 11 of the 83 machinists compared to 3 of the 44 assembly workers.

The odds ratio for the pulmonary function decrease (odds ratios, OR) was OR = 2.1 (95% CI: 0.5–2.3) among the machinists. The personal exposures of the 11 cases ranged from 0.17 mg/m^3 to 0.82 mg/m^3 for all types of MWF's.

Like the Greaves *et al.* (1997) study, Rosenmann *et al.* (1997) completed an occupational medical study of workers exposed to MWF's and followed up 86 metal workers who complained about occupational health problems and MWF's. Through interviews of 37 individual companies and 755 workers, Rosenmann *et al.* (1997) accumulated information on the type of MWF workers was exposed to and, the symptoms that they were experiencing at the time. Of the 755 workers that were studied it was observed that 20% of these workers suffered from pulmonary problems related to the workplace, and felt better during times in which they were away from the workplace. Furthermore the workers exposed to emulsified, semisynthetic or synthetic MWF's were more likely to have chronic bronchitis, visited the doctor for shortness of breath, sinus problems, to be bothered by nasal stiffness, runny nose, or sore throat, and to have a higher prevalence of occupational asthma in comparison to workers exposed to straight MWF's.

Contrastly, Sprince, Thorne, Popendorf, Zwerling, Miller and DeKoster (1997) studied a similar population of workers where automobile transmission workers were exposed to MWF's. The spirometry data collected did not differ from the unexposed assembly workers of the same plant.

The cross shift decreases in FEV_1 were not significantly different from those transmission workers who were exposed to MWF's. Sprince *et al.* (1997) observed workers that had respiratory symptoms below the possible safe limits for MWF's and generated an exposure response relationship to the occupational data accumulated.

A similar study discovered that workers had acute pulmonary health problems at exposure concentrations that were below the current permissible safe limits for MWF's (Hands, Sheenan, Wong and Lick, 1996).

During an international conference in the United States, large organisations along with the United Auto Workers Union (UAW) and the Occupational Health and Safety Administration (OSHA) formed an international symposium on the potential safe limits of MWF's and their relative health affects. It was recommended that the current permissible limit be reduced from 5 mg/m^3 to 0.5 mg/m^3 to ensure that typical respiratory symptoms are avoided.

This conference also introduced other forms of chronic health affects that have been studied by Acquavella and Leet (1991) in a cohort of metal workers from a manufacturing plant. The proportional mortality ratios (PMR's) for lung cancer among all metal workers were significantly higher than the base population. Similarly, Eisen, Tolbert, Hallock, Monson, Smith and Woskie, (1994) studied the incidence of larynx cancer among 108 cases of metal workers. Compounds that were identified as to cause pulmonary problems and the cancer observed were the broad class of polyaromatic hydrocarbons (PAH's), and there was no difference with the type of MWF's that was being used. The odds ratios for the development of the specific cancers or respiratory problems were higher (2.02 times) than the normal control population (Eisen *et al.* 1994).

An earlier study by Eisen *et al.* (1992) had followed up a historic cohort of 45 000 automobile workers exposed to MWF's from three engineering plants in the United States. From the 10 000 deaths that were observed, standard mortality ratios (SMR's) were calculated for lung and larynx cancer. The SMR calculated among metal workers was significantly higher (95% CI: 1.5–2.0) in comparison to the general United States population.

Similarly, in historic cohort studies by Bingham (1988) and Robertson *et al.* (1988), these types of cancers among metal workers were caused by exposure to MWF's consisting of benzo(a)pyrene and PAH's.

Rønneberg *et al.* (1988a, 1998b) studied a historic cohort and found that metal workers exposed to low viscosity MWF's had a higher risk for terminal pulmonary problems when exposed workers were compared to national expected rates for pulmonary disorders and diseases (Hendy, Beattie and Burge, 1985; Hewstone, 1994; Kennedy, Greaves, Kriebel, Eisen, Smith and Woskie, 1989; Sheelan, 1996).

Silverstein, Park, Marmor, Maizlish and Mirer (1988) also studied 1766 metal workers in a historical cohort and found that PMR's for cancer were higher for machinists exposed to straight oils than semisynthetic oils.

Other researchers also observed similar findings (Park, Krebs and Mirer, 1994; Park, Wegman, Silverstein, Maizlish and Mirer, 1988; Robins, *et al.*, 1997; Silverstein, *et al.*, 1988; Skyberg, Rønneberg, Christensen, Næss–Andresen, Borgersen and Refsum, 1992; Tolbert, Eisen, Pothier, Monson, Hallock and Smith, 1992; Vena, Sultz, Fiedler and Barnes, 1985).

All the above mentioned studies reveal the global shortage of research into the specific agents in MWF's that initiate pulmonary problems among metal workers. In a NIOSH criteria document for MWF's, a recommendation for future research to compile dose–response data to the exposure of MWF's and the incidence of pulmonary effects was documented (NIOSH, 1998). NIOSH further stated that research is needed into the toxicity of ethanolamines that are in MWF's, and "to clarify the roles and inherent toxicity of specific MWF's and formulations" (NIOSH, 1998).

1.2 Occupational exposure monitoring

The use of occupational exposure monitoring and epidemiological research in order to determine how much of an agent a worker is exposed to during their work shift, is included in many occupational hygiene studies (NIOSH, 1998). Within this study occupational personal monitoring was completed to determine what personal exposure concentrations of semisynthetic MWF's workers were exposed to.

This type of occupational exposure monitoring attempted to show that the personal inhalation exposures to MWF's correlate through a mathematical model to the pulmonary effects which were being measured. Most occupational health studies do not have completed occupational exposure data or are based on a small proportion of workers' exposure data.

By monitoring all workers who participated in the study, occupational exposure monitoring data assists in the development of dose–response models and the creation of permissible safe limits.

1.3 Spirometry

Spirometry or "lung function testing" is used to determine physiological changes in the lung which may have been caused by exposure to MWF's.

The lung function variables which were utilised to determine the acute effects on the lung, were FEV_1 and FVC. The FEV_1 relates to the volume of air that the worker could exhale in one second and the FVC relates to the total lung capacity in litres. FEV_1 measurements were completed before and after the work shifts of every subject in the study and the pre–shift FEV_1 was compared to the post–shift FEV_1 to determine if any changes in the initial base line reading exist. The FVC data was used in combination with the FEV_1 to determine if any types of acute pulmonary restriction or obstruction may be occurring among the workers. Spirometry is a screening technique which may show acute pulmonary changes within a person, but cannot be used to diagnose an individual with a specific pulmonary disorder (ATS, 1995). Medical records and a standardised health questionnaire were used to determine the previous and present health condition of the worker who participated in the study.

1.4 Metal working

Metal working is a general term which relates to either the drilling, milling, turning, boring or grinding of any type of metal. The metal working which was completed in each plant consisted of either one of the above tasks. Within each task, MWF aerosol generation depended on what task the worker was involved with during that time.

Drilling (Annex I, Figure iv) usually consisted of a task where the tool and the work piece metal underwent high stress conditions, but tool speeds were very slow (60 revolutions per minute). Grinding processes tended to include MWF's that were used to cool the grinding stone and the work piece and to prolong tool life. Aerosol generation during this process tended to be higher due to the higher speeds in which the machinery was operating (120–400 revolutions per minute).

Milling (Annex I, Figure iii) refers to a type of metal working which includes the application of a cutting edge (stationary) to a moving work piece (usually the base metal being cut). The work piece was moving either clockwise or anticlockwise in the plane that is perpendicular to the worker. The potential exposure to MWF's was usually high since there was high stress, high speed and, high amounts of metal filings which need to be flushed away. Higher amounts of MWF's are used during this task which in turn expose the worker to higher concentrations of MWF aerosol.

Boring (Annex I, Figure i) refers to a similar process as milling but, entails larger work pieces, and larger tools. The stationary object is the base metal (or the work piece) and is usually a large turning bit or tool that was moving at high speeds into the work piece. Instruments such as these are usually computer controlled for engineering specifications and design tolerances in the work piece.

Turning (Annex I, Figure ii) is a term that metal workers use to describe the process where the base metal or the work piece is being turned in a clockwise or anticlockwise direction. The turning or rotation which occurs is in a plane that is perpendicular to the worker. The stationary object is the tool, but the speed at which the turning and cutting is being completed is at low speeds and low metal stresses (30 revolutions per minute) (Crow, 1981).

1.5 Metal working fluids (MWF's)

Metal workers tend to use the MWF's to protect the machine or tool that they are working with, and to prolong the life of the tool by reducing the friction or tensile stress of the metal process that is being completed. Anticorrosives within the MWF's also protect the tool and the work piece which is being worked on. Emulsifiers and pH stabilisers are used to prevent any corrosion or damage to the base metal or to the tool/machine which is being used. With the constant use of these fluids, there is the possible contamination of the MWF's with biological flora (bacteria and fungi) and therefore, fungicides and other compounds are used to prevent biological growth.

With the four different types of MWF's (previously introduced) semisynthetic MWF's were studied in this project since there are very few occupational health studies completed in the health hazards associated with compounds in semisynthetic MWF's.

1.6 Hypothesis

Due to the inherent toxicity of semisynthetic MWF's, the hypothesis of this project is the possibility that workers exposed to MWF's concentrations lower than the permissible exposure limits for oil mists, do acquire acute pulmonary health affects that can be predicted by a mathematical function. The null hypothesis which follow is therefore:

H_o: That metal workers exposed to semisynthetic MWF's do not acquire acute pulmonary problems as a result of personal exposures which are below the current permissible limits for MWF's and, that pulmonary health affects cannot be predicted through a mathematical model.

The alternate hypothesis if H_o is proved false by ANOVA at $P = 0.05$, is:

H_a: That metal workers acquire acute pulmonary health problems as a result of personal exposure concentrations below the current permissible limits for MWF's and these health affects can be predicted through a mathematical model.

2. Materials and Methods

2.1 Study population

The study population consisted of male workers from three South African engineering plants within one company. Each engineering plant consists of a study population composed of an exposed and unexposed population. The exposed population was defined as all metal workers (machinists, turners, millwrights and grinders) who had personal exposures to semisynthetic MWF's greater than 0.01 mg/m^3. This exposed population was divided into four major divisions: group S included those workers who were smokers; group ES included workers who were ex–smokers; group NS included those workers who never smoked chronically; group D included those workers who had previous pulmonary health problems. The NS, ES, and S workers were then divided into four groups according to the four different MWF's that were being used. These four groups were further divided into two exposure categories: workers exposed to semisynthetic MWF's containing fractions of TEA and DEA and those workers exposed to semisynthetic fluids not containing TEA or DEA (see Figure 1). A total of 197 out of 297 men cohort were tested.

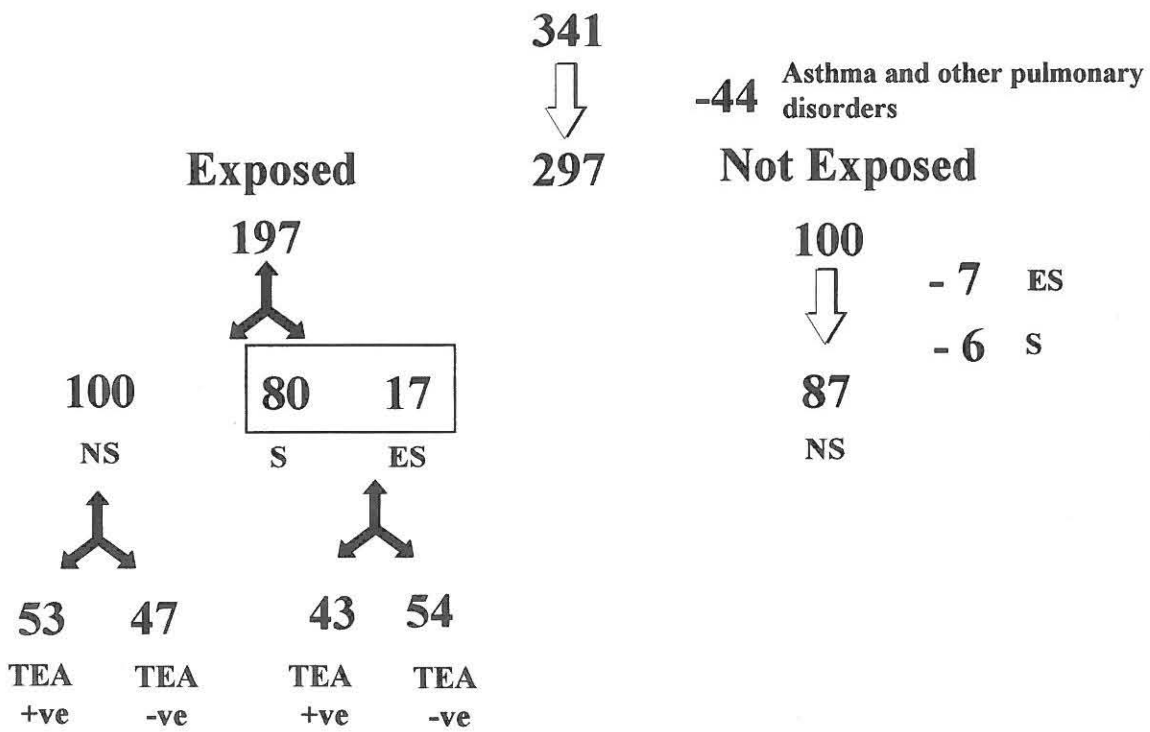


Figure 1: Worker selection of cross–sectional study population.

The unexposed control population (group UE) consisted of nonsmoking office workers selected from other divisions in the engineering plant. These workers performed no machining operations or were not exposed to MWF's for at least 5 years. A total of 100 out of a 297 cohort were tested.

2.2 Metal engineering shops

The metal engineering shops from each of the three locations were similar in design and structure. The equipment which was utilised was also similar in make and design. Each metal engineering shop was located either in a separate building or in an isolated area away from other tasks (such as welding, painting or wood working). Each workshop deals with the machining and fabrication of train or truck parts for the South African railways or other foreign companies.

Metal working specifically deals with either mild steel, brass, iron or nickel material during normal working conditions. The duration of work shifts from Monday to Friday lasted 8 hours per day. During the winter season, work weeks were extended to include Saturdays. Each normal work shift included two 15–25 minute breaks and a 45 minute lunch break. Saturday work shifts lasted 8 hours (5:00 am – 1:00 pm) and included one break for 45 minutes.

2.3 Health questionnaire

A standardised written questionnaire (Annex II) was completed by every worker that participated in the study. This questionnaire was administered (by a nurse or medical doctor) prior to exposure monitoring and the worker's work shift. The written health survey contained questions on individual characteristics such as age, height, weight, race, medical history, work history in the plant, work history before employment in the plant, and tobacco consumption. Never smokers (NS) were defined as persons who never chronically smoked cigarettes or tobacco products, current smokers (CS) as those who smoked at least one cigarette a day and, ex–smokers (ES) were those who smoked at least one cigarette a day and had discontinued smoking for more than 6 months. Questions on respiratory symptoms were adapted from the questionnaire of the British Medical Research Council (BMRC) and from the questionnaire of the

International Union Against Tuberculosis and Lung Diseases (IUATLD) (ATS, 1991, 1995). These questions were translated into English, Afrikaans, Zulu and Sotho and were utilised to determine the worker's present health condition during the study. During repeated visits to each engineering plant, the questionnaire was distributed to obtain the present medical condition of the worker. Personal medical records (maintained by the company's physician) were utilised to determine the past medical histories of each worker.

2.4 Pulmonary function tests

FEV_1 and FVC were completed before and after the work shift of the exposed and unexposed workers. Spirometry was completed according to maneuvers dictated by the American Thoracic Society (ATS, 1995). Measurements of pulmonary functions were achieved at each work site using a portable spirometer (Spiroflow™ 2000, Penta Medical Systems™ South Africa, 1998) which was calibrated before each personal sampling session (Annex II). Acute changes in pulmonary function were determined using the difference in post–shift FEV_1 and pre–shift FEV_1. The degree of pulmonary restriction or obstruction was measured by the ratio of post–shift FEV_1 to post–shift FVC. The change in FEV_1 and the ratio of FEV_1/FVC of each worker was utilised to determine the acute pulmonary effects of MWF exposure. Spirometry data between the exposed and unexposed groups were compared with analysis of variance (ANOVA, $P = 0.05$) to determine any statistical difference. Similarly, significant differences between the pulmonary function of the four major divisions of workers (NS, S, ES and D groups) were determined by ANOVA analysis.

2.5 Exposure monitoring

Personal sampling was completed for all exposed workers during their respective work shifts. All personal sampling was completed according to a modified NIOSH Method Number 5026 (Annex IV). Gilian™ personal sampling pumps were calibrated to 1.5 ± 5% L/min and MWF's aerosols were collected on 37 mm diameter mixed cellulose ester membrane filters (for aerosol concentrations 0.01–5 mg/m^3) or polyvinyl chloride membrane filters (for aerosol concentrations higher than 5 mg/m^3). The samples could not be analysed using infra–red spectroscopy, since the semisynthetic MWF's were not infra–red active at wavelengths between 3200–2700 /cm. An ultraviolet visible (UV–Vis) spectrophotometer, precalibrated with toluene standards from Sigma Chemicals USA, was utilised for MWF analysis. Aliquots of bulk reference MWF samples were scanned from 190–1000 nm and 2 characteristic spectra peaks were identified. Field samples were placed into 4 mL vials with 2 mL of distilled water. The sample was then placed into an ultrasonic bath for 15 minutes. An aliquot was scanned at the characteristic wavelengths identified in the respective bulk sample and the concentration of MWF was calculated.

Field sample concentrations of MWF's were compared to the ACGIH TLV for oil mists (ACGIH, 1999). The arithmetic mean (AM), arithmetic standard deviation (SD), maximum and minimum values of MWF concentrations were calculated for: the four major divisions of workers, for each workplace and, for each type of MWF being used.

2.6 Environmental conditions

Environmental working conditions (temperature and relative humidity) were determined during each survey using a direct reading thermocouple by Airflow Instruments™. Measurement of these variables were completed hourly during each work day starting at 6:40 am and ending at 4:15 pm.

2.7 Statistical analysis

The statistical analyses were performed using Corel Software Quattro Pro™ Version 8.0 (Corel, 1998) and MathCad™ Version 5.0 Software (MathSoft, 1995). The acute effects of semisynthetic MWF's on the pulmonary system was determined by comparing the exposed to not–exposed population's spirometry data.

The significant differences in MWF exposure between the groups (race, smokers, nonsmokers and ex–smokers), or the concentration of MWF's used were assessed by Analysis of Variance (ANOVA) between the groups of workers.

Correlations between personal exposure to MWF's and FEV_1, FVC, temperature and relative humidity, were also completed using a multiple regression package from Sigma Plot™ Version 3.03 (Jandel Scientific, 1995).

2.8 Mathematical modelling

Mathematical modelling was performed between the spirometry and personal exposure data to establish a dose–response function in order to predict pulmonary health affects. Individual exposure and spirometry data of each sampled worker was used in the mathematical modelling.

Four different models were generated for each MWF type. Workers were then categorised into groups according to the magnitude of MWF exposure. An average value of MWF exposure and lung function for each category was plotted on figures 12–15. A series of individual equations for each MWF type was then utilised to describe its respective inherent toxicity. Each model that was derived described the data at $P = 0.05$ (95% of all raw data) (Masse and Cross, 1989).

Modelling and fitting of mathematical functions were completed using Statistica™ Windows Version 5.1 (StatSoft, 1998) and Mathcad™ Version 5.0 (MathSoft, 1995). Prediction values and prediction intervals were derived at the 95% confidence interval for each dose–response equation.

3. Results

3.1 Study population

Within this cross–sectional study there was a total of 341 workers in the total cohort. In this cohort of workers, 197 were exposed to semisynthetic MWF's and 100 were not exposed. Both populations were separated into workers of racial origin that were: Caucasian (white), African (black) and east Indian (Indian). The average age of exposed Caucasian, African and Indian workers was: 39 years (± 12 years), 44 years (± 18 years) and 38 years (± 9 years) respectively. Among the unexposed population of Caucasian, African and Indian workers the average age was: 35 years (± 5 years), 39 years (± 10 years) and 30 years (± 2 years). With respect to the total cohort 32% were Caucasian, 56% were African and 12% were Indian. Of the total cohort 24 workers were ex–smokers, 187 were nonsmokers and 86 were current smokers.

Table 1. Demographics of study population

	Total Cohort	Exposed	Not Exposed
n	341	197	100
Average Age (± years)	37 (15)	38 (19)	33 (13)
White (%)	32	40	58
Black (%)	56	51	32
Indian (%)	12	9	10
Ex–Smokers (n)	24	17	7
Never Smoked (n)	187	100	87
Smokers (n)	86	80	6
Mean Seniority (years)	10 (5)	12 (3)	9 (8)
D (n)	44	16	1

3.2 Spirometry

Among the two major groups of workers (exposed and not exposed to semisynthetic MWF's), pre– and post–shift lung function measurements on FVC and FEV_1 was completed for a total of 297 workers as depicted in Table 2.

Table 2. Change in post–shift pulmonary function tests (corrected for age and height)

	Exposed Group (n = 197)	Not Exposed Group (n = 100)	ANOVA
$FVC_{pre} \pm$ SD (L)	3.94 (1.01)	3.55 (0.97)	P = 0.05
$FVC_{post} \pm$ SD (L)	4.01 (0.50)	3.59 (0.45)	P = 0.05
$FEV_{1\,pre} \pm$ SD (L)	4.99 (0.67)	4.25 (0.98)	P = 0.02
$FEV_{1\,post} \pm$ SD (L)	3.02 (0.55)	4.55 (0.64)	P = 0.02

Similarly, for each cultural group which was studied, the respective changes in the pre– and post–shift lung function measurements were completed. In the following tables the changes in pulmonary function among workers are shown:

Table 3. Change in post–shift pulmonary function tests among Indian metal workers (corrected for age and height)

	Exposed Group (n = 18)	Not Exposed Group (n = 10)	Student's *t*–test
$FVC_{pre} \pm$ SD (L)	3.01 (1.55)	3.12 (0.22)	P = 0.05
$FVC_{post} \pm$ SD (L)	3.11 (1.12)	3.22 (0.13)	P = 0.05
$FEV_{1\,pre} \pm$ SD (L)	4.02 (1.32)	4.03 (0.23)	P = 0.05
$FEV_{1\,post} \pm$ SD (L)	3.14 (0.97)	4.06 (0.29)	P = 0.05

Similar lung function results for those workers who are Black metal workers are as follows in Table 4:

Table 4. Change in post–shift pulmonary function tests among Black metal workers (corrected for age and height)

	Exposed Group (n = 100)	**Not Exposed Group (n = 32)**	**ANOVA**
$FVC_{pre} \pm SD$ (L)	4.04 (1.15)	4.12 (1.02)	P = 0.05
$FVC_{post} \pm SD$ (L)	4.11 (1.33)	4.09 (1.11)	P = 0.05
$FEV_{1\,pre} \pm SD$ (L)	4.46 (1.57)	4.07 (0.87)	P = 0.05
$FEV_{1\,post} \pm SD$ (L)	3.18 (1.55)	4.00 (1.02)	P = 0.05

Workers who were Caucasian and completed similar lung function tests are reflected in Table 5.

Table 5. Change in post–shift pulmonary function tests among Caucasian metal workers (corrected for age and height)

	Exposed Group (n = 79)	**Not Exposed Group (n = 58)**	**ANOVA**
$FVC_{pre} \pm SD$ (L)	3.76 (1.27)	3.98 (1.91)	P = 0.05
$FVC_{post} \pm SD$ (L)	3.81 (1.53)	4.01 (2.00)	P = 0.05
$FEV_{1\,pre} \pm SD$ (L)	3.79 (2.21)	3.45 (2.18)	P = 0.05
$FEV_{1\,post} \pm SD$ (L)	3.11 (0.58)	3.25 (1.76)	P = 0.05

Among all nonsmoking workers exposed to 4 different semisynthetic MWF's, the spirometry data is as follows in Table 6:

Table 6. Change in FEV_1 after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	ΔFEV_1 Exposed NS Group (n = 100)	$FEV_{1\,post}/FVC_{post}$ x 100% Exposed NS Group (n = 100)
1 (5%)	0.05 (0.02)	84 ± 5
2 (33%)	0.33 (0.11)	89 ± 10
3 (45%)	0.32 (0.21)	90 ± 12
4 (85% – 90%)	0.60 (0.30)	95 ± 5

By pooling all the workers who are exposed to MWF Types 1 to 4, changes in the pre– and post–shift measurements of FEV_1 are depicted in Figures 2 to 5.

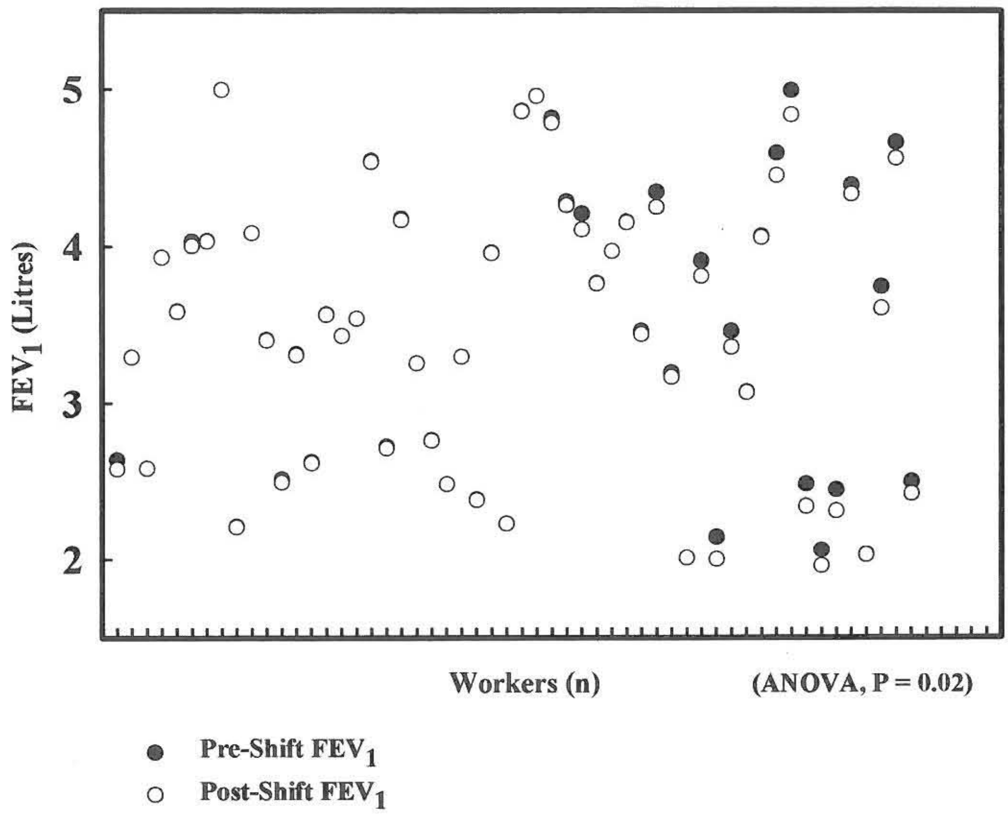


Figure 2: Pre– and post–shift FEV_1 among metal workers exposed to MWF Type 1.

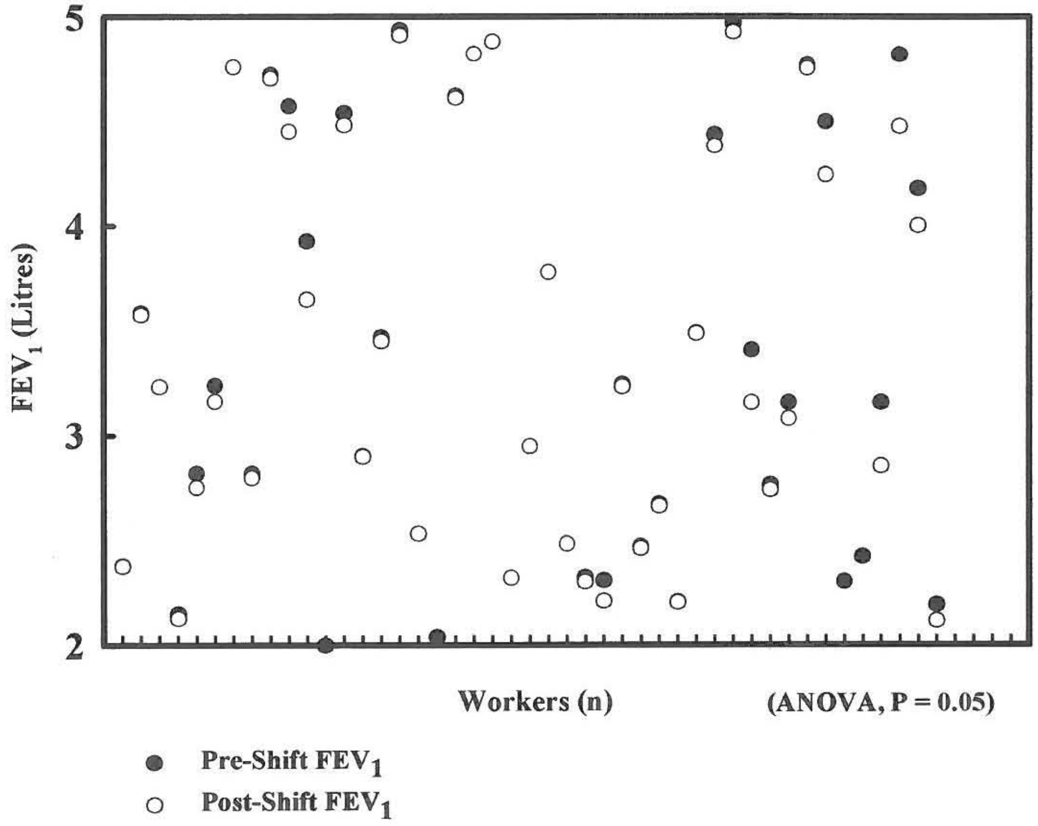


Figure 3: Pre– and post–shift FEV_1 among metal workers exposed to MWF Type 2.

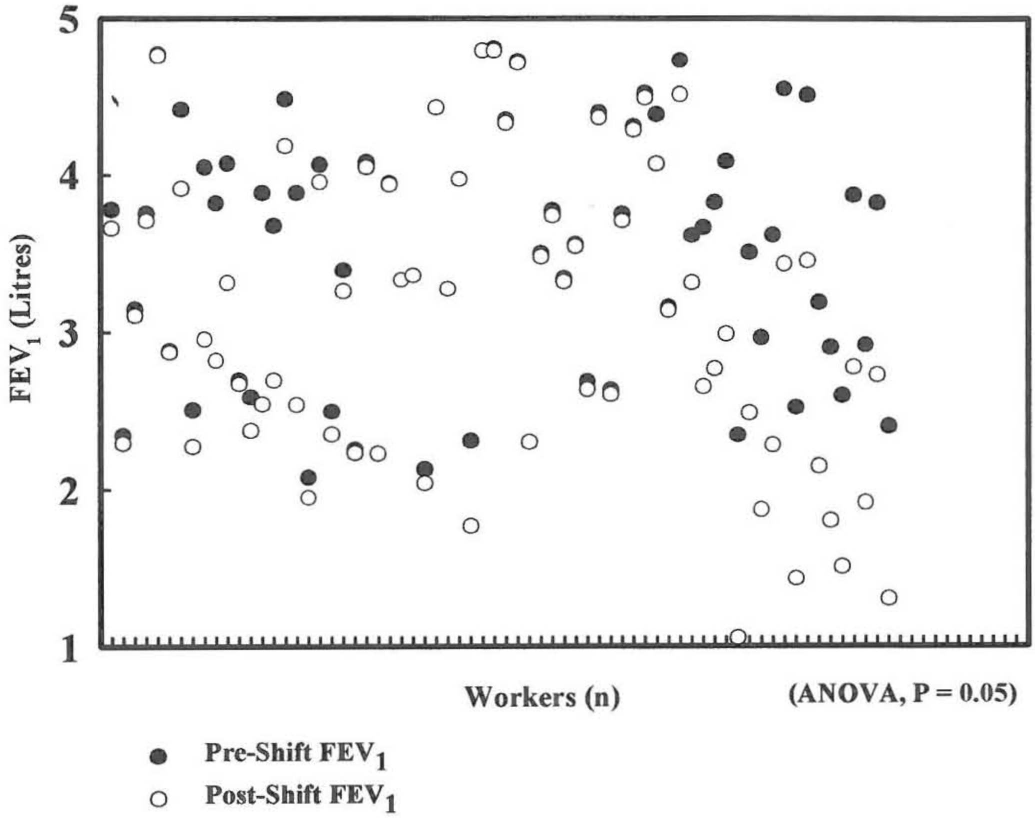


Figure 4: Pre– and post–shift FEV_1 among metal workers exposed to MWF Type 3.

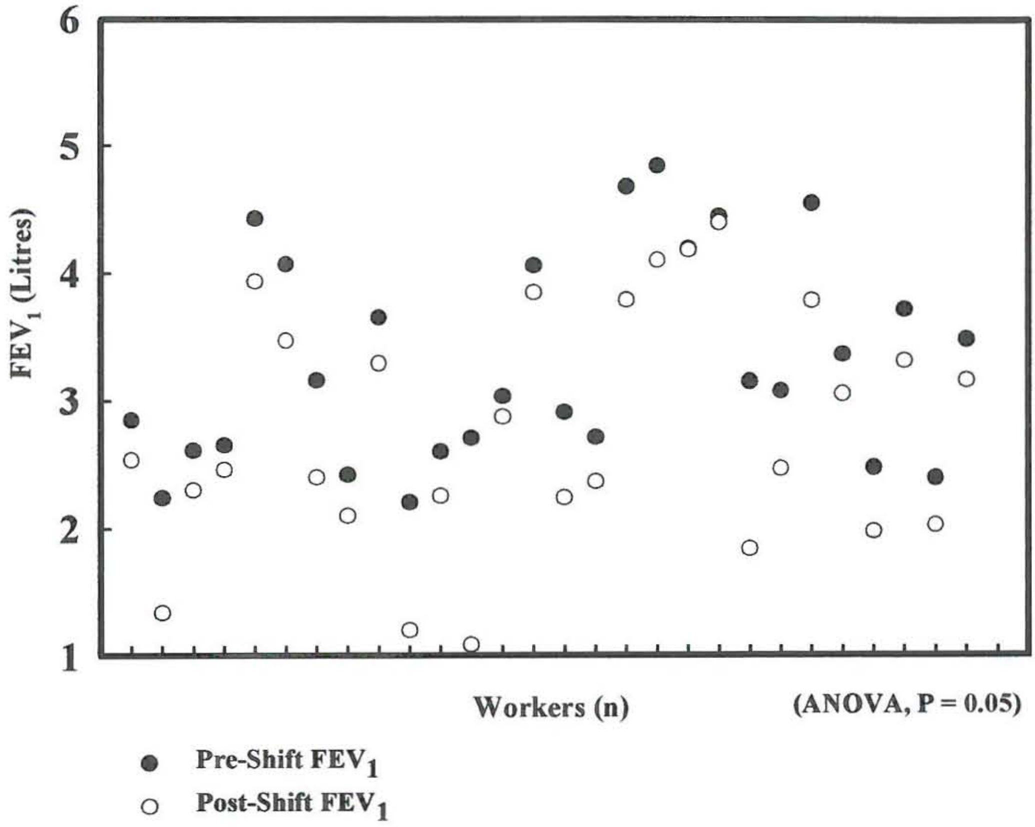


Figure 5: Pre– and post–shift FEV_1 among metal workers exposed to MWF Type 4.

In Table 7, changes in FEV_1 among all exposed workers (NS, ES and S) exposed to 4 different types of MWF's that were observed, are shown.

Table 7. ΔFEV_1 among study population after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 100)	Smokers (S)* (n = 80)	Ex–smokers (ES)* (n = 17)
1 (5%)	0.05 (0.02)	0.09 (0.13)	0.10 (0.09)
2 (33%)	0.33 (0.11)	0.39 (0.25)	0.31 (0.28)
3 (45%)	0.32 (0.21)	0.37 (0.27)	0.30 (0.30)
4 (85% – 90%)	0.60 (0.30)	0.66 (0.31)	0.69 (0.25)

*(Statistically significant: ANOVA, P = 0.05)

Lung function data among specific racial groups using different MWF formulations are reflected in Tables 8, 9, and 10.

Table 8. ΔFEV_1 among Indian metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 12)	Smokers (S)* (n = 4)	Ex–smokers (ES)* (n = 2)
1 (5%)	0.09 (0.08)	0.22 (0.13)	0.31 (0.20)
2 (33%)	0.21 (0.17)	0.43 (0.33)	0.22 (0.17)
3 (45%)	0.27 (0.23)	0.69 (0.54)	0.65 (0.32)
4 (85% – 90%)	0.49 (0.22)	1.06 (1.00)	0.87 (0.81)

*(Statistically significant: ANOVA, P = 0.01)

The post–shift decrease in FEV_1 among Black metal workers exposed to 4 different MWF's is found in Table 9.

Table 9. ΔFEV_1 among Black metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 34)	Smokers (S)* (n = 54)	Ex–smokers (ES)* (n = 12)
1 (5%)	0.19 (0.11)	0.21 (0.09)	0.18 (0.14)
2 (33%)	0.29 (0.04)	0.39 (0.15)	0.31 (0.13)
3 (45%)	0.45 (0.17)	0.66 (0.29)	0.61 (0.20)
4 (85% – 90%)	0.88 (0.21)	0.98 (0.26)	0.89 (0.31)

*(Statistically significant: ANOVA, P = 0.02)

Similarly, the post–shift decrease in FEV_1 of Caucasian workers who were nonsmokers, current smokers and ex–smokers is found in Table 10.

Table 10. ΔFEV_1 among Caucasian metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 54)	Smokers (S)* (n = 22)	Ex–smokers (ES)* (n = 3)
1 (5%)	0.04 (0.02)	0.31 (0.21)	0.29 (0.27)
2 (33%)	0.19 (0.12)	0.38 (0.19)	0.41 (0.21)
3 (45%)	0.29 (0.08)	0.67 (0.09)	0.76 (0.12)
4 (85% – 90%)	0.48 (0.19)	0.81 (0.02)	0.87 (0.19)

*(Statistically significant: ANOVA, P = 0.02)

The degree of pulmonary obstruction or restriction among never smokers, ex–smokers and current smokers is described from the FEV_1/FVC ratio and the results are reflected in Table 11.

Table 11. $FEV_{1\ post}/FVC_{post}$ x 100% among exposed population after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 100)	Smokers (S)* (n = 80)	Ex–Smokers (ES)* (n = 17)
1 (5%)	84 ± 5	77 ± 16	80 ± 23
2 (33%)	89 ± 10	75 ± 28	83 ± 33
3 (45%)	90 ± 12	76 ± 22	84 ± 39
4 (85% – 90%)	95 ± 5	70 ± 15	92 ± 27

*(Statistically significant: ANOVA, P = 0.05)

The degree of pulmonary restriction or obstruction was also observed to be of different severities among racial groups as shown in Table 12. For workers of Indian origin their lung function results are as follows:

Table 12. $FEV_{1\ post}/FVC_{post}$ x 100% among Indian metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 12)	Smokers (S)* (n = 4)	Ex–Smokers (ES)* (n = 2)
1 (5%)	80 ± 2	70 ± 22	81 ± 12
2 (33%)	82 ± 7	85 ± 28	86 ± 23
3 (45%)	86 ± 9	84 ± 12	87 ± 9
4 (85% – 90%)	86 ± 3	89 ± 15	92 ± 6

*(Statistically significant: ANOVA, P = 0.05)

Similarly, the degree of lung function abnormalities among Black metal workers are found in Table 13.

Table 13. $FEV_{1\ post}/FVC_{post}$ x 100% among Black metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 34)	Smokers (S)* (n = 54)	Ex–Smokers (ES)* (n = 12)
1 (5%)	77 ± 14	84 ± 16	83 ± 27
2 (33%)	81 ± 5	85 ± 28	87 ± 13
3 (45%)	89 ± 12	89 ± 12	88 ± 21
4 (85% – 90%)	90 ± 5	92 ± 25	92 ± 7

*(Statistically significant: ANOVA, P = 0.05)

Similarly, workers who are Caucasian, the degree of pulmonary restriction or abnormality can be found in Table 14.

Table 14. $FEV_{1\ post}/FVC_{post}$ x 100% among Caucasian metal workers after exposure to 4 different MWF's (corrected for age and height)

Type of MWF (%TEA/DEA)	Never Smokers (NS)* (n = 54)	Smokers (S)* (n = 22)	Ex–Smokers (ES)* (n = 3)
1 (5%)	74 ± 8	85 ± 19	84 ± 12
2 (33%)	83 ± 15	88 ± 8	82 ± 24
3 (45%)	88 ± 19	89 ± 17	89 ± 31
4 (85% – 90%)	90 ± 2	91 ± 5	90 ± 19

*(Statistically significant: ANOVA, P = 0.05)

Spirometric data consisting of all nonsmoking workers exposed to semisynthetic MWF's which consisted of more than 5% TEA and DEA is as follows in Table 15.

Table 15. Average concentrations and average ΔFEV_1 after exposure to MWF's containing TEA and DEA among nonsmoking workers

[MWF Type 4]* mg/m³ (SD) n = 50	**ΔFEV_1, L (SD)**	**$FEV_{1\,post}/FVC_{post}$ x 100% (SD)**	**[MWF Types 1 + 2 + 3]* (SD) n = 57**	**ΔFEV_1, L (SD)**	**$FEV_{1\,post}/FVC_{post}$ x 100% (SD)**
2.45 (0.62)	0.05 (0.02)	84 (5)	4.24 (1.70)	0.15 (0.02)	80 (9)

*(Statistically significant: ANOVA, P = 0.02)

The combination of current smokers and ex–smokers who are exposed to semisynthetic MWF's which contain greater than 5% TEA and DEA, lung function data is as follows in Table 16.

Table 16. Average concentrations and average ΔFEV_1 after exposure to MWF's containing TEA and DEA among smokers and ex–smoking workers

[MWF Type 4]* mg/m³ (SD) n = 50	**ΔFEV_1, L (SD)**	**$FEV_{1\,post}/FVC_{post}$ x 100% (SD)**	**[MWF Types 1 + 2 + 3]* (SD) n = 57**	**ΔFEV_1, L (SD)**	**$FEV_{1\,post}/FVC_{post}$ x 100% (SD)**
3.03 (1.14)	0.68 (0.29)	76 (11)	2.24 (1.38)	1.05 (0.54)	71 (9)

*(Statistically significant: ANOVA, P = 0.05)

3.3 Personal exposure concentrations of semisynthetic MWF's

Among all workers exposed to semisynthetic MWF's and to the 4 different formulations, the following personal exposures are as follows in Table 17.

Table 17. Average personal exposure concentrations of MWF's in exposed population

	[MWF Type 1] mg/m^3 (SD)	[MWF Type 2] mg/m^3 (SD)	[MWF Type 3] mg/m^3 (SD)	[MWF Type 4] mg/m^3 (SD)
NS	4.34 (1.2)	2.43 (0.5)	2.46 (0.3)	1.11 (0.9)
ES	3.02 (2.50)	1.15 (0.6)	1.09 (0.5)	2.17 (0.5)
S	1.05 (0.5)	1.25 (0.7)	2.32 (0.63)	2.22 (0.41)

Seasonal variations among metal workers exposed to the four MWF's are found in Table 18.

Table 18. Average personal exposure concentrations of MWF's across seasons

	[MWF Type 1]† mg/m^3 (SD)	[MWF Type 2]† mg/m^3 (SD)	[MWF Type 3]† mg/m^3 (SD)	[MWF Type 4]† mg/m^3 (SD)
Summer*	3.68 (0.21)	2.09 (0.43)	2.22 (0.35)	1.96 (0.73)
Winter**	3.77 (0.23)	2.11 (0.61)	2.44 (0.18)	2.04 (0.33)

†(Statistically significant: ANOVA, $P = 0.02$).
*(Summer meaning October to March).
**(Winter meaning April to September).

3.4 Environmental conditions

Current environmental conditions such as temperature (°C) and percent relative humidity (% RH) were recorded during each personal sampling session for each research site and the average values are recorded in Table 19 and Figures 6, 7, and 8.

Table 19. Average environmental conditions at each work plant and total work populations

	Plant 1	**Plant 2**	**Plant 3**
% RH Summer* (SD)	32 % (12%)	15 % (9%)	65 % (24%)
Temperature (°C) Summer* (SD)	25 (5)	22 (14)	35 (11)
% RH Winter (SD)**	17 % (6%)	22 % (18%)	33 % (29%)
Temperature (°C) Winter (SD)**	20 (8)	24 (12)	26 (18)
n workers (NS + ES + S + D)	114	122	105

*(Summer meaning October to March).
**(Winter meaning April to September).

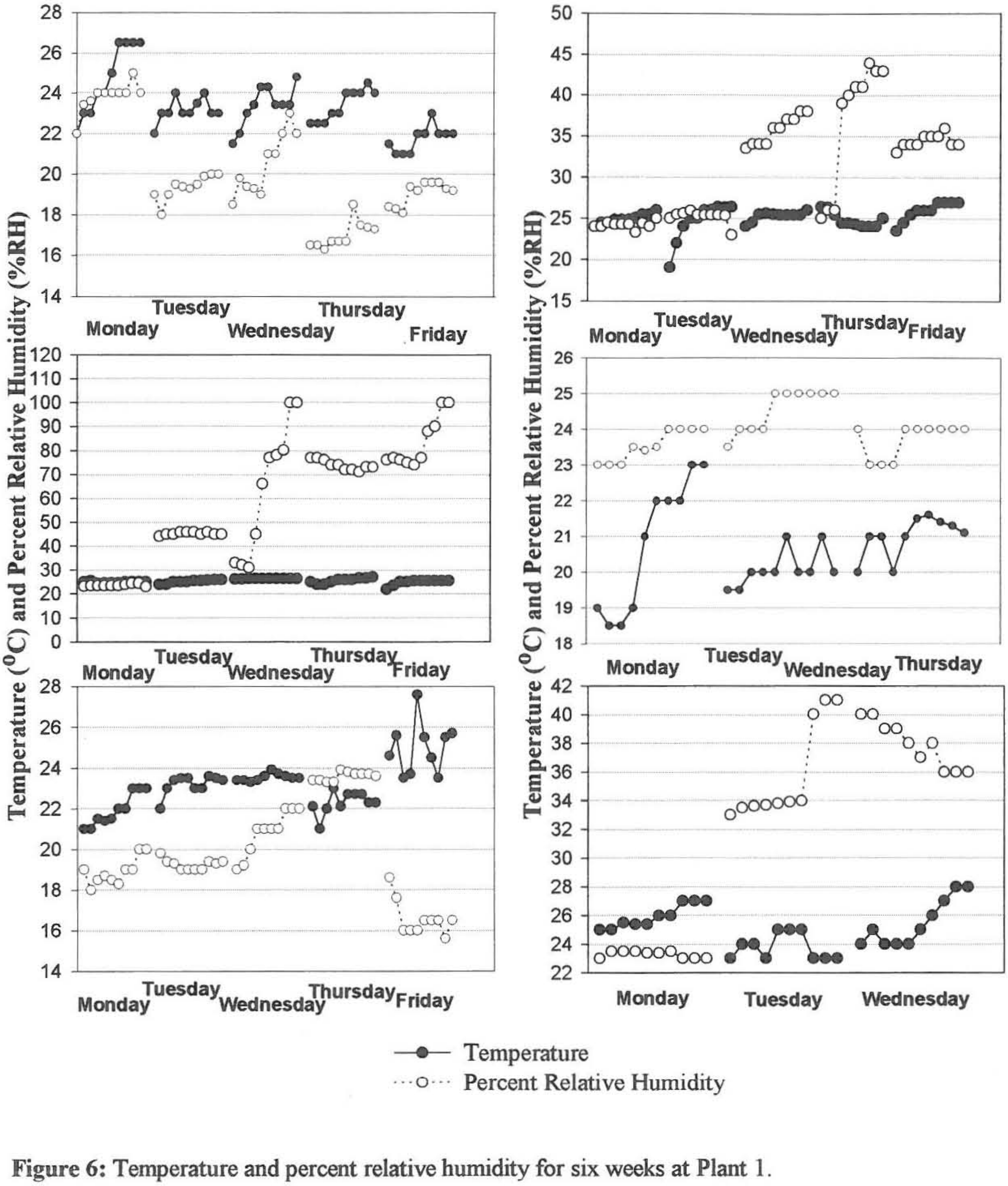


Figure 6: Temperature and percent relative humidity for six weeks at Plant 1.

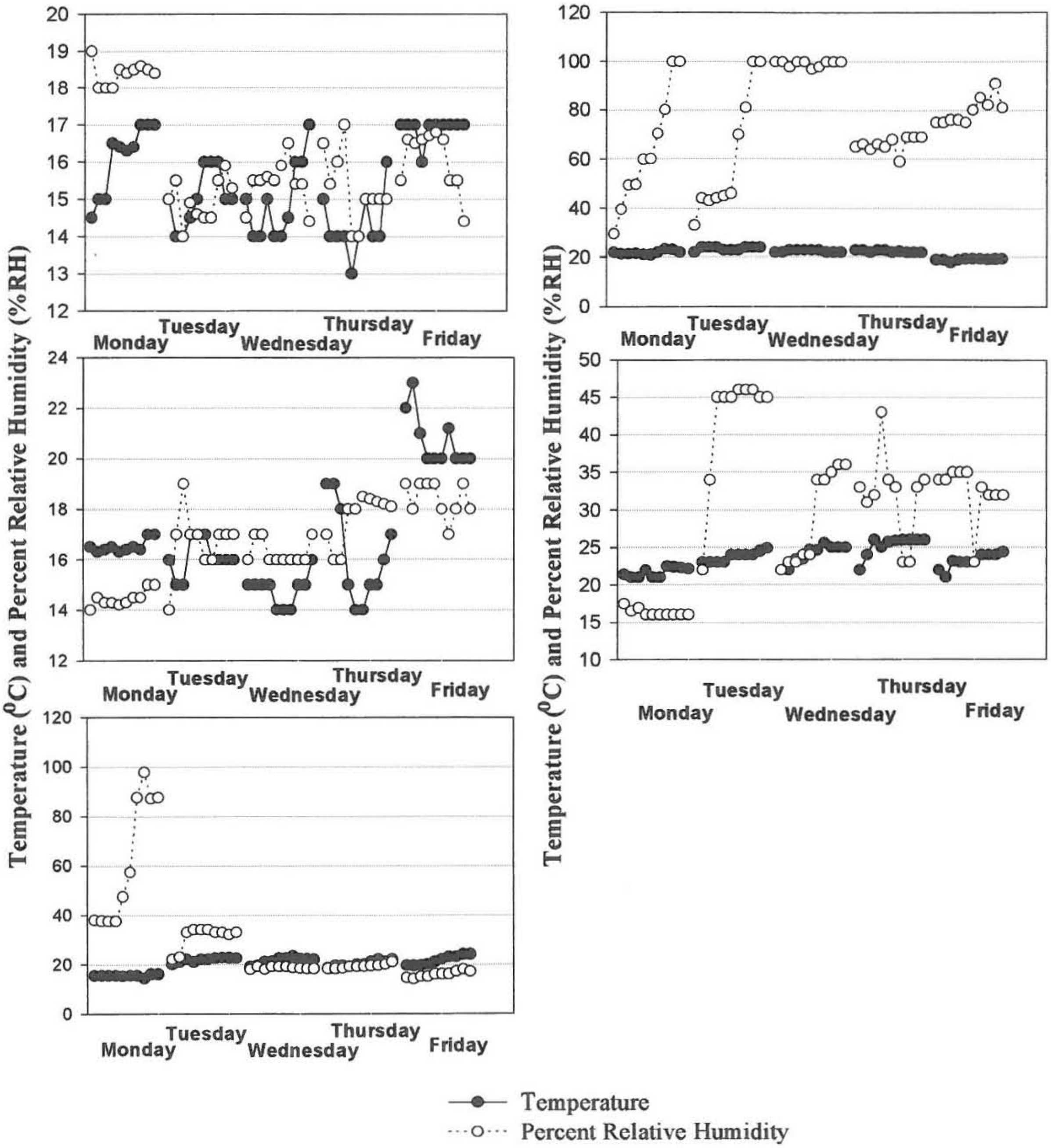


Figure 7: Temperature and percent relative humidity for six weeks at Plant 2.

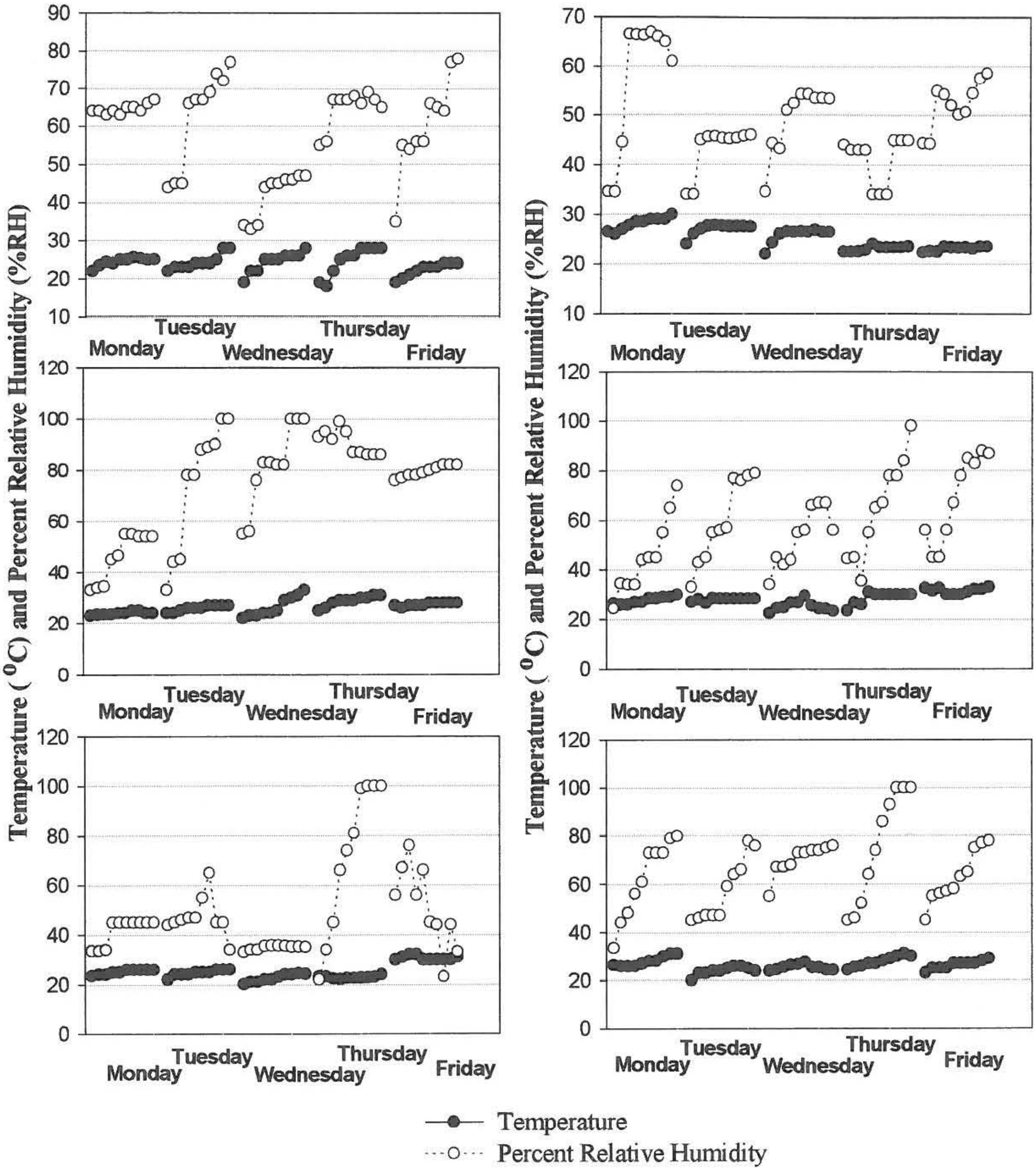


Figure 8: Temperature and percent relative humidity for six weeks at Plant 3.

3.5 Daily work schedules and work routines

Workers at each research plant completed a daily work routine that dictated the length and activities during their work shift. These work routines were repeated Monday to Friday and only changed if workers had to work on a Saturday. The daily work routine for work shifts from Monday to Friday can be found in Table 20 and for Saturday, the work routine is given in Table 21.

Table 20. Daily work day routine (Monday to Friday) of all metal workers

Time	Task Completed
7:45	Daily work day briefing
7:55	Commencement of work
8:00	Metal working commenced
8:45	First work break
9:00	Commencement of metal working
11:45	Lunch Break
12:25	Commencement of metal working
14:45	Second work break
15:00	Commencement of metal working
16:15	End of work shift

Table 21. Daily work day routine (Saturdays) of all metal workers

Time	Task Completed
5:45	Work briefing
6:00	Commencement of metal working
12:00	Lunch break
12:45	Commencement of metal working
15:00	End of work shift

3.6 Correlations between change in FEV_1 and TEA and DEA concentrations

Within the three research sites, 4 similar MWF types were utilised. A corresponding decrease in pulmonary function was plotted as a function of TEA and DEA within the MWF types. The corresponding figures reflects the correlation in the decrease of FEV_1 as a function of the concentration of TEA and DEA.

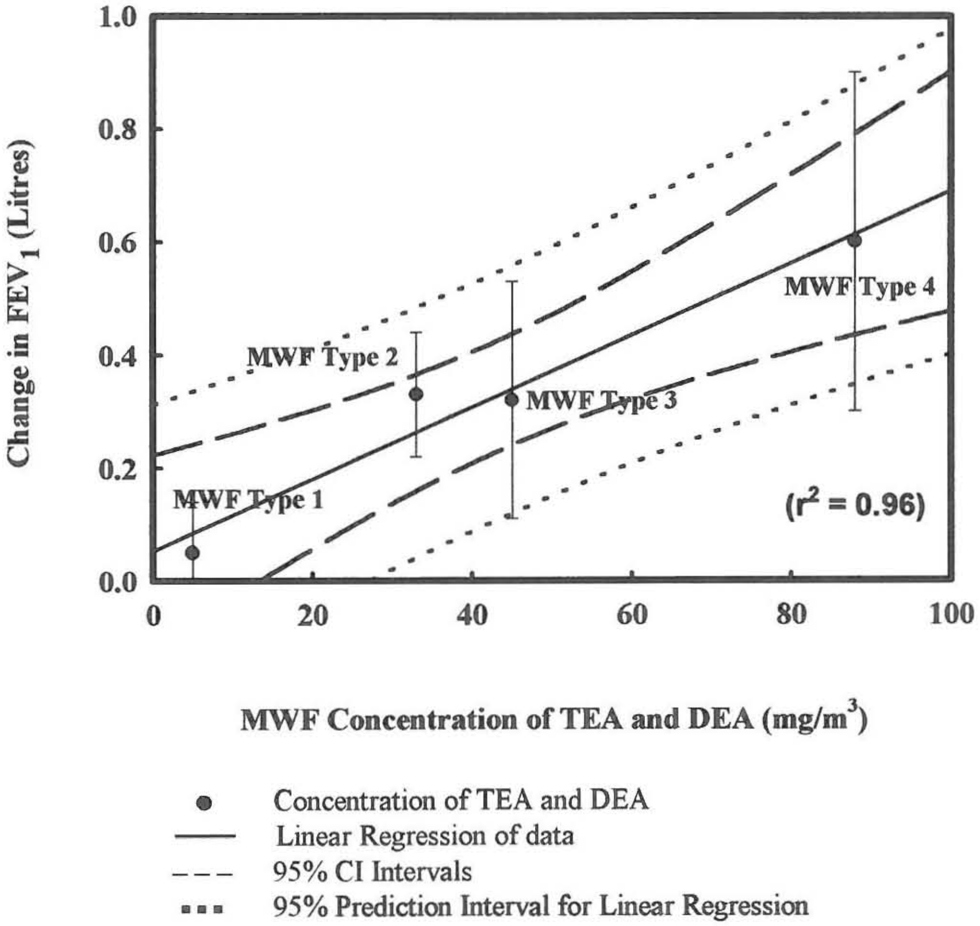


Figure 9: The change in FEV_1 as a function of the concentration of TEA and DEA of 4 MWF Types at Plant 1.

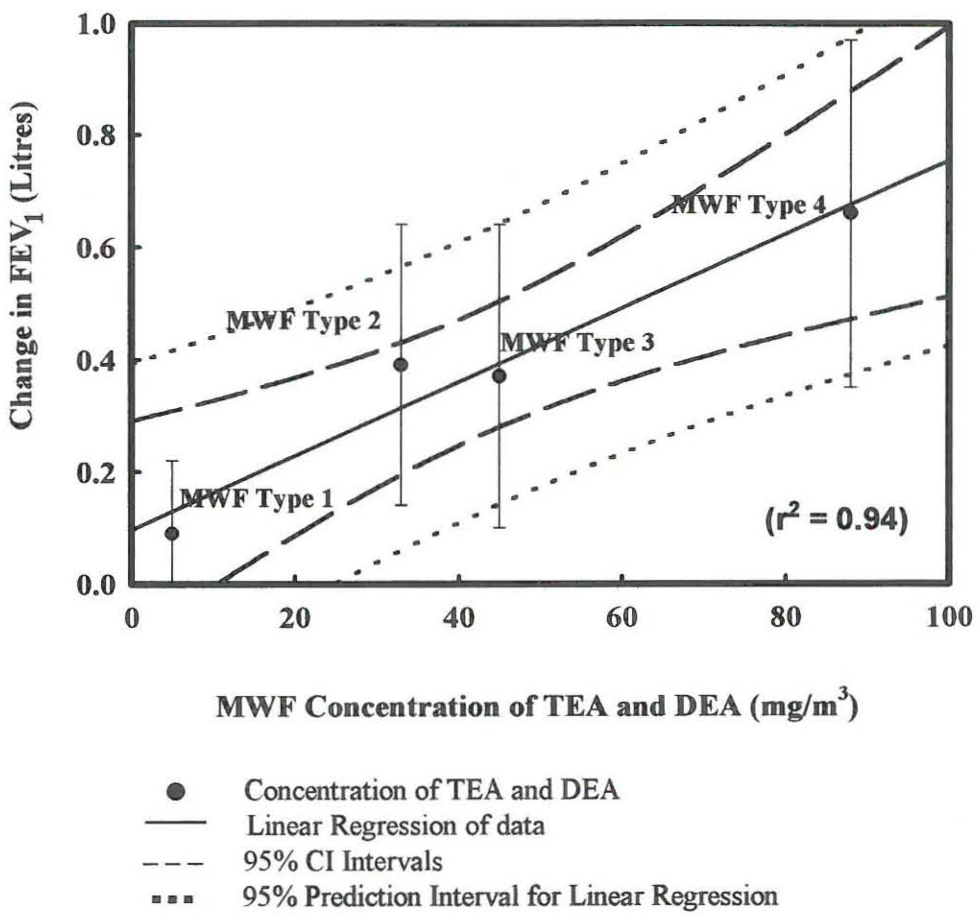


Figure 10: The change in FEV_1 as a function of the concentration of TEA and DEA of 4 MWF Types at Plant 2.

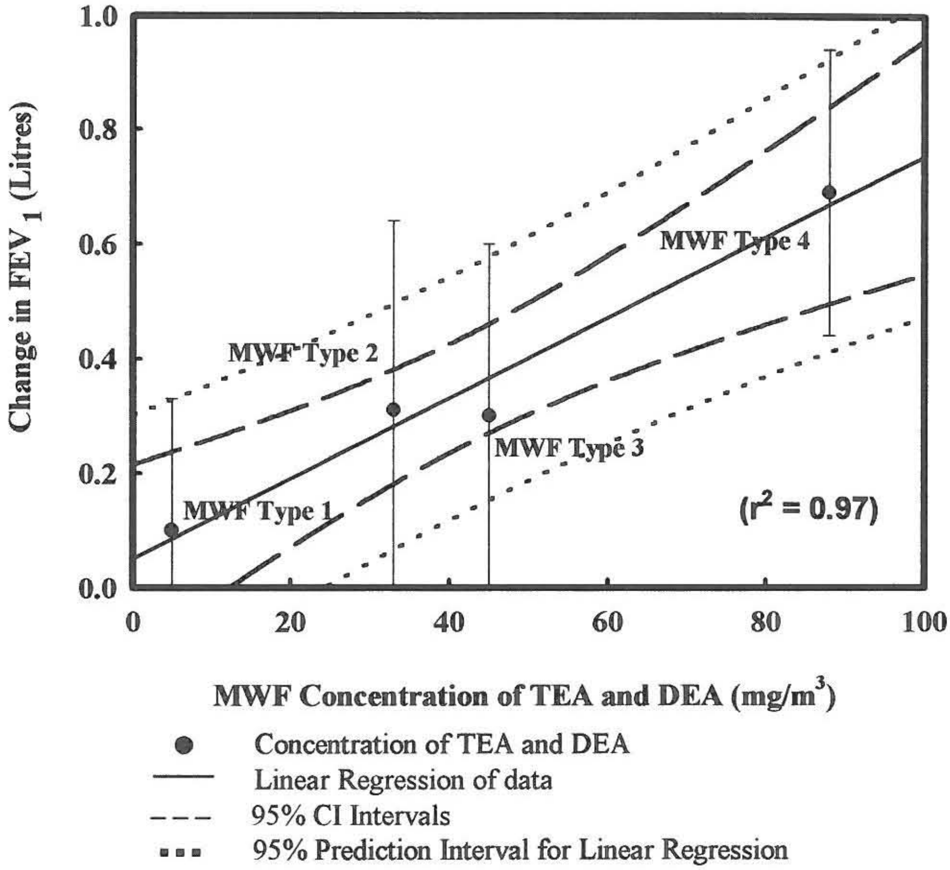


Figure 11: The change in FEV_1 as a function of the concentration of TEA and DEA of 4 MWF Types at Plant 3.

4. Discussion

4.1 Introduction

The study of occupational pulmonary diseases and the incidence thereof, has been a complex and current active research field in occupational health (NIOSH, 1998). With the introduction of new chemical agents into the workplace and the primary route of exposure via the pulmonary system, the development of occupational pulmonary illnesses are increasing.

The incidence of pulmonary illness in the United States and Canada has been increasing at an exponential rate among the general population (Centers for Disease Control and Prevention, 1998; Gannon and Burge, 1991). It has been shown that people are developing pulmonary illnesses at earlier stages in life. Due to the strong environmental factors that can attribute to the development of these illnesses the study of occupational pulmonary diseases are usually confounded by these factors.

Among metal workers the incidence of pulmonary diseases has been observed since the early 1960's, but due to limitations in technology and research techniques, the exact source of pulmonary illness was not attributed to the workplace (NIOSH, 1978, 1998). Metal workers are exposed to a mixture of chemicals that are synthesised to prevent corrosion of machinery and to improve the metal working process.

This research project aims to study those semisynthetic MWF's and the agents within it that are responsible for any type of acute pulmonary condition among machining workers. Generation of a dose–response curve and mathematical models will be used to predict the health affects among metal workers.

4.2 Changes in FVC and FEV_1 among exposed workers

In the comparison of exposed and not exposed groups of workers (depicted in Table 2), a significant difference in lung function was found (ANOVA, P = 0.02). The exposed population of workers had a larger decrease in post–shift FEV_1 in comparison to the not exposed population.

In a study by Eisen *et al.* (1997) a medically significant pulmonary decrease of 20% in the pre–shift FEV_1 was experienced by workers exposed to straight and soluble MWF's. Lung function testing reflected a general decrease of 15%–32% among all exposed workers regardless of the type of semisynthetic MWF being used. These acute decreases in pulmonary function have been shown to attribute to future development of chronic pulmonary problems, such as asthma (Greaves, *et al.*, 1997).

The average decrease of FEV_1 within the exposed population was generally greater than the not exposed population (ANOVA, P = 0.02). According to studies done by the ATS (1991, 1995) forced vital capacity (FVC) did not change significantly (0.5 – 1L) and was found to be within expected normal variations of a healthy worker during the work shift. These variations are described as approximately $\pm 5\%$ of the initial FVC (baseline) reading in comparison to the post–shift FVC reading. The calculation of a 5% error is based on the presence of an instrumental error and physiological fatigue in workers at the end of their work shifts, which result in lower FVC readings.

4.3 Decreases in FEV_1 among nonsmoking workers exposed to different MWF's

Acute decreases in pulmonary function were observed to be directly related to the type of semisynthetic MWF that the worker was using at the time. The average decrease in FEV_1 was greatest (reflected in Table 6, Figures 2–5) when workers were using MWF Type 4 in comparison to MWF Type 1 (ANOVA, P = 0.02). Similarly, workers experienced an approximately equal decrease in pulmonary function when exposed to MWF's Type 2 and Type 3.

Pulmonary restriction or obstruction (FEV_1/FVC) caused by exposure to the four types of MWF's were significantly different (ANOVA, $P = 0.05$). Although it is inaccurate to use a fixed value of 80% to determine whether the FEV_1/FVC ratio is normal, there was a statistical difference in the FEV_1/FVC ratio between worker reaction to different types of MWF's (ATS, 1991, 1995).

Various researchers have speculated that the formulation of an MWF does play an important role in the health affects that the worker experiences (Ameille, *et al.*, 1995; Oxhøj, *et al.*, 1982; Robertson, *et al.*, 1988; Robins, *et al.*, 1997). MWF's of different classes (synthetic and soluble oils) do cause different pulmonary health problems (Ameille, *et al.*, 1995; Bond and Medinsky, 1995; Oxhøj, *et al.*, 1982; Robertson, *et al.*, 1988; Robins, *et al.*, 1997). Unfortunately, alternate mixtures of semisynthetic MWF's have not been investigated to date, and a study by Savonius, Keskinen, Tappurainen and Kanerva (1994) showed that TEA and DEA may attribute to the severity of pulmonary health effects that workers may experience.

The possible presence of biological flora in MWF's could attribute to the decreases in the pulmonary function. Studies by Eisen *et al.* (1994) and Greaves *et al.*(1997) have shown that thoracic exposure to biological flora could result in an additive affect with MWF exposure, attributing to the decrease in pulmonary function.

Among the four formulations of MWF's studied, the ingredients of TEA and DEA varied in concentration. The highest fraction of TEA and DEA was present in MWF Type 4 and the lowest fraction in MWF Type 1.

It was found that workers exposed to those MWF's containing higher fractions of TEA and DEA, experienced the greater average decrease in FEV_1 (depicted in Table 7) in comparison to those workers using MWF Type 1 (ANOVA, $P = 0.05$).

4.4 Decreases in FEV_1 among racial groups of metal workers exposed to different MWF types

The change in post–shift FVC did not differ significantly (Student's *t*–test, $P = 0.05$) among metal workers of Indian origin (reflected in Table 3). However, Indian workers exposed to semisynthetic MWF's had significant decreases in post–shift FEV_1 (Student's *t*–test, $P = 0.05$). As a result of the small population size of this ethnic group, no discrete deductions could be made about the health effects of MWF's and the changes in pulmonary function.

Black metal workers who are exposed to semisynthetic MWF's experienced no significant decrease in post–shift FVC (in Table 4) however, a 10%–30% post–shift decrease in FEV_1 was measured (ANOVA, $P = 0.05$).

Caucasian metal workers (refer to Table 5) showed a similar decrease in pulmonary function after exposure to semisynthetic MWF's. Post–shift FVC measurements did not change significantly, but there was a 5%–15% post–shift decrease in FEV_1 (ANOVA, $P = 0.05$).

Rotimi, Austin, Delzell, Day, Macaluso and Honda (1993) completed a retrospective study of automobile workers exposed to MWF's which included semisynthetic, synthetic, soluble and straight forms, but did not study the individual affects of each formulation. The researchers found a higher incidence of pulmonary diseases among black workers in comparison to white workers. The proportional mortality ratio's (PMR's) for white men (PMR = 132; 95% CI: 111–152) was slightly lower than the PMR's for black men (PMR = 146; 95% CI: 101–191) in the United States who were employed within the same occupation. The difference between racial groups and the quality of health observed suggest a link between the race of an employee and their occupational health. An explanation of this difference however was not given by the researchers.

4.5 Change in FEV_1 among exposed smoking, ex–smoking, and nonsmoking workers

Decreases in pulmonary function among the exposed nonsmoking workers, were also reflected between smoking and ex–smoking workers. Between all four types of MWF's that were used, smokers and ex–smokers generally experienced similar decreases in FEV_1.

It was found that workers who are ex–smokers and exposed to MWF Types 1 and 4, experienced the greatest decrease in pulmonary function in comparison to nonsmokers and smokers (ANOVA, $P = 0.05$). However, smokers (Table 7) in general experienced a greater magnitude of pulmonary decrease in comparison to nonsmoking workers (ANOVA, $P = 0.05$). Contrastly, never smokers exposed to MWF Types 2 and 3, have higher post–shift decreases in FEV_1 when compared to ex–smokers exposed to the same MWF types. This is due to the low population size ($n = 17$) among the ex–smokers in comparison to the large nonsmoking population ($n = 100$). Other studies have found similar paradigms in research as a result of small study populations, which can lead to biassed conclusions (NIOSH, 1998).

Occupational health and medical research to date has shown that workers who smoke have a greater risk of lung cancer and other pulmonary forms of laryngeal cancer (Eisen, *et al.*, 1992, 1994). Hence, workers who smoke and are exposed to any type of semisynthetic MWF are even more prone to develop pulmonary problems.

Other researchers have also found that this was true for many metal workers who are current smokers or ex–smokers and exposed to MWF's (ODP, 1998; Rønneberg, *et al.*, 1988a, 1988b).

4.6 Change in FEV_1 among exposed smoking, ex–smoking, and nonsmoking workers within racial groups

Through the analysis of lung function data among Indian metal workers (Table 8), it was found that workers who are current smokers and exposed to semisynthetic MWF's develop the greatest post–shift decrease in FEV_1 (excluding those ex–smokers exposed to MWF Type 1) (ANOVA, $P = 0.01$).

Workers who were ex–smokers experienced a significant decrease in pulmonary function in comparison to workers who never smoked (ANOVA, P = 0.01). Those workers who experienced the highest post–shift FEV_1 decrease, were exposed to MWF's consisting of high fractions of TEA and DEA (ANOVA, P = 0.05). Similar conclusions were observed for Black and Caucasian metal workers.

Black metal workers who never smoked experienced slightly lower decrease (0.2–0.5 mL) in post–shift FEV_1 (Table 9), in comparison to those Black metal workers who were either smokers or ex–smokers (ANOVA, P = 0.02). Black workers who were either smokers, ex–smokers or never smoked had significant decreases in post–shift FEV_1 when exposed to MWF's that consisted of higher fractions of TEA and DEA (ANOVA, P = 0.02).

Workers who were nonsmokers and exposed to similar MWF's formulations did not experience the same magnitude of post–shift decrease as smoking workers. However, never smokers and ex–smokers had similar decreases in post–shift FEV_1 when exposed to MWF Type 3.

Caucasian workers (Table 10) that were current smokers and exposed to MWF Types 1 and 3, experienced the greatest decrease in post–shift FEV_1 in comparison to ex–smoking and nonsmoking Caucasian workers (ANOVA, P = 0.02). Similarly, those ex–smokers exposed to MWF Types 2 and 4 experienced the highest change in FEV_1 in comparison to Caucasian smokers and nonsmokers (ANOVA, P = 0.02) As seen among the other racial groups, workers who were nonsmokers and exposed to MWF's experienced a decrease in post–shift FEV_1 but, to a smaller magnitude in comparison to ex–smokers and smokers (ANOVA, P = 0.05).

4.7 The degree of pulmonary restriction or obstruction among exposed smoking, ex–smoking and nonsmoking workers

Pulmonary restriction or the development of obstructive pulmonary disorders are indicators for the development of specific diseases (ATS, 1991, 1995). The degree of pulmonary restriction or obstruction was determined by the use of FEV_1 and the FVC of the worker.

A ratio of the FEV_1 to the FVC indicates the pulmonary efficiency of the worker's lung or if there is any form of restriction or obstruction in the lung. Spirometric data gathered from the different groups of exposed workers reflected different degrees of pulmonary abnormalities.

Smoking and ex–smoking workers, experienced greater forms of pulmonary restriction and obstructive disorders (Table 11) in comparison to exposed nonsmoking workers (ANOVA, $P = 0.05$). Similarly, as found by Rotimi *et al.* (1993) workers who were Black, current smokers and exposed to MWF's had a higher probability for the development of pulmonary problems and illnesses.

Traditionally, smokers and workers with smoking histories suffer from a higher form of pulmonary restriction than the nonsmoker (ATS, 1991). The degree of pulmonary obstruction is usually 10%–25% or greater in comparison to the healthy person, and as observed in this study, workers who are smokers and exposed to MWF's do have higher forms of pulmonary disorders (in comparison to the not exposed group).

The type of MWF that was being used also influenced the degree of pulmonary restriction among metal workers. This statistically significant change positively correlated with the amount of TEA and DEA that was within the MWF (Figures 9, 10, 11). Among the four types of MWF's which were studied, there was a positive correlation between the percentage of TEA and DEA, and the post–shift decrease in FEV_1 ($r^2_{Plant\ 1} = 0.96$, $r^2_{Plant\ 2} = 0.94$, $r^2_{Plant\ 3} = 0.97$). This observation was consistent among other populations of workers who were exposed to different types of MWF's (Eisen, *et al.*, 1994; Greaves, *et al.*, 1997; Rønneberg, *et al.*, 1998a; Sommers, 1997). In the comparison of all three categories of exposed workers (S, NS and ES) the degree of pulmonary changes were found to be statistically different (ANOVA, $P = 0.02$).

MWF Type 1 consisted of the least fraction of TEA and DEA in its formulation, and workers exposed to this type of MWF experienced the lowest degree of pulmonary abnormality. However, workers exposed to MWF Type 4, which consists of the highest fractions of TEA and DEA, experienced the highest degree of pulmonary abnormalities (ANOVA, $P = 0.02$).

When combining the spirometry data of those MWF's that contained more than 5% TEA and DEA

(MWF Types 2, 3 and 4) and comparing this data with the spirometry data of workers only exposed to MWF Type 1 (Table 15), the degree of pulmonary abnormalities was more evident (ANOVA, $P = 0.02$). The change in FEV_1 and the degree of obstruction or restriction was statistically higher than the workers exposed to MWF Type 1 with low fractions of TEA and DEA.

By analysing the spirometry data among smoking workers, it was found that these workers had higher decreases in post–shift FEV_1 and significant differences in the FEV_1/FVC ratio, in comparison to nonsmoking workers who were exposed to MWF's of low fractions of TEA and DEA (ANOVA, $P = 0.05$). Similar conclusions could be drawn from the combination of smoking and ex–smoking workers who were exposed to a combination of MWF's containing higher fractions of TEA and DEA (Table 16).

Workers who were exposed to MWF Type 1 experienced a smaller magnitude of post–shift FEV_1 decrease and pulmonary restriction, in comparison to those workers who were exposed to MWF's consisting of higher fractions of TEA and DEA (ANOVA, $P = 0.05$).

ACGIH (1999) has separate TWA–TLV's for TEA and DEA. For TEA the TWA–TLV is 1 ppm and a Short Term Exposure Limit (STEL) of 3 ppm while, DEA has a TWA–TLV of 5 ppm and a STEL of 15 ppm. In other applications in industry ACGIH has observed that ethanolamines have been shown to attribute to acute pulmonary changes among workers (ACGIH, 1998). This could explain the observations among workers who have higher degrees of post–shift FEV_1 changes and pulmonary abnormalities.

ACGIH (1998) and NIOSH (1998) have developed safe permissible limits for a general class of MWF's or oil mists. As found in this study there should be separate TWA's or NIOSH REL's for MWF's of different types. It has been shown that MWF's of different compositions do have different health affects, and may give workers higher risks for cancer development (Eisen, *et al.*, 1994; Greaves, *et al.*, 1997; ODP, 1998; Rønneberg, *et al.*, 1988a, 1988b). Similarly a separate TWA for MWF's consisting of TEA and DEA should be developed.

4.8 The degree of pulmonary restriction or obstruction among exposed smoking, ex–smoking, and nonsmoking workers within specific ethnic groups

Among Indian, Black and Caucasian metal workers the degree of pulmonary restriction depended on the smoking history of the individual (ANOVA, P = 0.05). The degree of pulmonary restriction was significantly different between smokers, nonsmokers and ex–smokers.

Among Indian metal workers (Table 12) the degree of pulmonary abnormality increased as the concentration of TEA and DEA increased.

Similarly, the post–shift FEV_1 decrease was statistically different between workers who were current smokers and nonsmokers (ANOVA, P = 0.05).

Black metal workers exposed to MWF's (Table 13) that consisted of more than 85% DEA and TEA, had the highest degree of pulmonary abnormality and it was more evident among current smokers and ex–smokers.

Caucasian metal workers (Table 14) had significant differences in pulmonary function between the three subgroups of workers (NS, ES, S).

The workers who had the highest degree of pulmonary abnormality were those workers who used MWF's that consisted of high fractions of TEA and DEA and were current smokers or ex–smokers (ANOVA, P = 0.05).

It was observed that between the three racial groups studied, that Black metal workers had the highest post–shift FEV_1 decrease (25%–32%) and levels of pulmonary abnormality (ANOVA, P = 0.02).

The second highest degree of pulmonary abnormality and post–shift decrease (15% – 20%) occurred among the Indian metal workers, which was statistically different from the Caucasian metal workers who had pulmonary decreases and abnormalities of 10%–19%.

An explanation for the pulmonary lung function differences between the racial groups could be based on the fact that many of the Black metal workers completed tasks that involved high forms of manual labour and high exposures to MWF's. Black metal workers tended to complete drilling, lathe work and grinding which are tasks that consist of high exposures to MWF's. Indian metal workers completed similar tasks but, were also using other machinery which was computer controlled and does not emit high concentrations of MWF mists. Caucasian metal workers tended to work only on computerised central bores and very little or no work was completed on the manual labour machines where exposures to MWF's were much higher.

4.9 Concentrations of semisynthetic MWF's

Unlike other industrial hygiene studies which characterised MWF exposure, the concentrations of full shift personal exposure to MWF's was generally: 0.02 – 25.05 mg/m^3, SD = 2.04 mg/m^3 and mean = 1.07 mg/m^3. Personal exposures to all types of MWF's tended to be average (1.07 mg/m^3), but workers using MWF Type 1 had higher personal exposures.

The concentrations which were obtained reflected positive correlations with the type of pulmonary decreases (as mentioned before) and with the decrease in post–shift FEV_1 of the worker.

Among the four types of MWF's, all semisynthetic MWF's reflected a positive correlation between increasing personal exposures to MWF's and decreases in lung function (Figures 9, 10 and 11).

Other studies have shown that workers exposed to concentrations which are lower than those concentrations observed here, various pulmonary dysfunctions and diseases have developed (ACGIH, 1999; Greaves, *et al.*, 1997; Kriebel, 1994; NIOSH, 1998; Pryce, White, English and Rycroft, 1989; Ramos and Lucas, 1974).

As a result of poor construction of machining equipment and the lack of personal respiratory equipment, workers are exposed daily to moderate concentrations of MWF's. It was found that workers' personal concentrations of MWF's increased as a result of poor ventilation during the winter season (Table 18). In contrast, the personal concentrations of MWF's (of all types) decreased during the summer season as a result of natural ventilation in each work shop (Table 18).

Another explanation for the differences in seasonal or weekly personal exposure concentrations could reside in the sampling media used to collect the MWF's. As studied by McAneny, Leith and Boundy (1995), Menichini (1986a, 1986b) and Coenraads, Lee and Pinnagoda (1986), the use of the sampling filter may attribute to the underestimation or the variances in repeated sampling of MWF's. It has been shown that capturing MWF's on a cellulose ester membrane or PVC membrane filter can lead to evaporation during the work day as a result of the high concentration of aqueous parts (Coenraads and Pinnagoda, 1985; Cooper and Leath, 1998; McAneny, *et al.*, 1995; Menichini, 1986a).

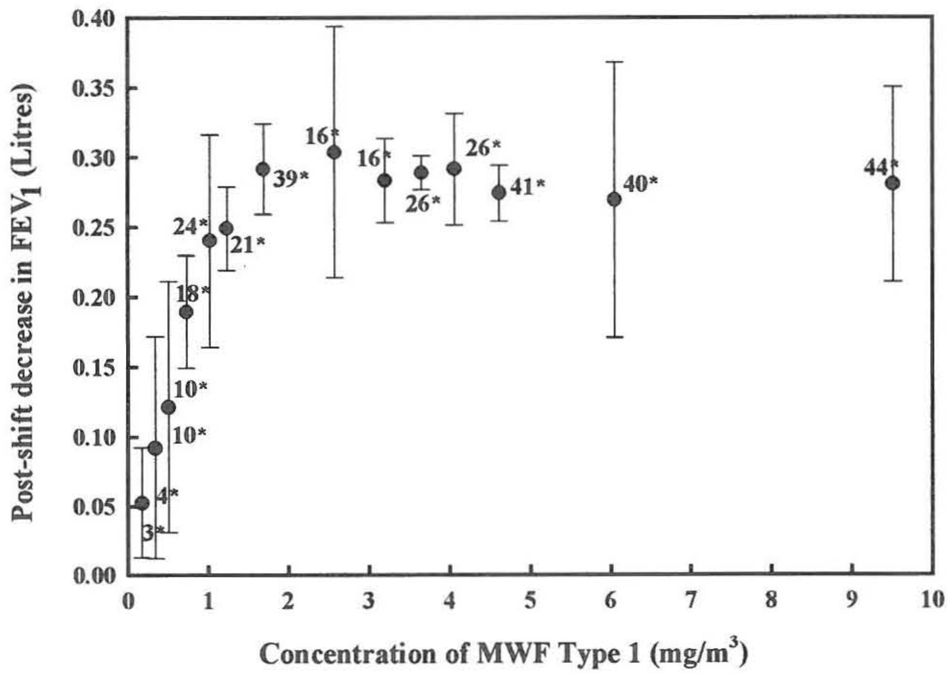
This evaporation will affect the result of personal exposures to semisynthetic MWF's since these MWF's consist of high proportions of water. The final personal exposure results could then be an underestimation of the worker's true exposure.

5. Mathematical Modelling

Mathematical models were based on the exposure and spirometry data of 197 workers who were re–sampled 6 times. The total accumulation of data (1182 data points) from repeated sampling was then further grouped into 4 divisions according to the type of MWF that the worker utilised (Jayjock, 1997: pp.313–326).

Within each MWF division workers were grouped into further groups according to similar personal exposure categories. Personal exposure categories were determined according to the number of workers who were using that specific type of MWF. An average concentration and decrease in pulmonary function (FEV_1) was graphically plotted to depict the decrease in FEV_1 as a function of MWF concentration.

The number of workers selected in each personal exposure group was determined by calculating the minimum sample size in order to detect a statistical difference at P = 0.05 (or α = 0.05) (Bergerova-Fiserova, 1976).



*refers to the number of workers used to generate the data point, where N is: $N = \left[\frac{(Z1 + Z2) \times \sigma}{\delta}\right]^2$

Figure 12: The change in post–shift FEV_1 decrease as a function of the concentration of MWF Type 1.

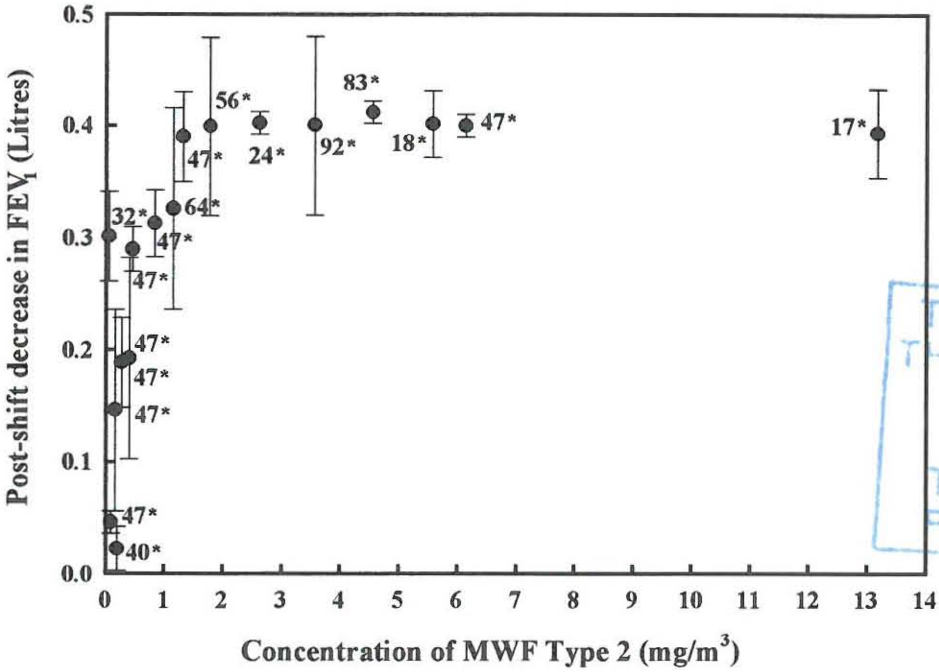
Table 22. Predicted decreases in FEV_1 in comparison to observed results for MWF Type 1.

Concentration of MWF Type 1 (mg/m^3)	ΔFEV_1 (predicted, Litres)	ΔFEV_1 (actual, Litres)	95% CI (α error 0.05)
0.025	0.029	0.059	(0.05 – 0.14)
1.16	0.259	0.250	(0.13 – 0.26)
2.07	0.282	0.261	(0.26 – 0.29)
3.17	0.283	0.30	(0.27 – 0.31)
5.23	0.288	0.27	(0.26 – 0.34)
8.11	0.288	0.27	(0.24 – 0.35)

As shown in Figure 12 and Table 22, workers utilising MWF Type 1 experienced a logarithmic dose–response to the exposure. As workers were exposed to higher concentrations of the MWF Type 1, the post–shift decrease in FEV_1 also increased. According to the equation depicted in Figure 12, a dose–response curve could be derived.

With this equation the permissible safe limits (PSL's) could be predicted for a worker exposed to MWF Type 1. A PSL could only be determined if there is an establishment of what decrease in FEV_1 is tolerable. As studied by Eisen *et al.* (1997) workers who experienced a post–shift decrease of 15%–20% was medically significant. Using the value of a 10% post–shift decrease in FEV_1 before suffering a medically significant affect, the PSL according to the equation (Table 26) will be 1.70 mg/m^3. For this model the calculated 95% confidence interval would place the PSL in a range of 0.99 mg/m^3–1.80 mg/m^3 for 95% of all workers exposed to MWF Type 1.

In comparison to the ACGIH (1999) TWA–TLV, this is drastically different since the limit permits a worker to be exposed to a limit of 5 mg/m^3. Similarly, the calculated PSL in comparison to the NIOSH (1998) REL of 0.5 mg/m^3 is significantly different (Student's *t*-test, P = 0.01).



*refers to the number of workers used to generate the data point, where N is: $N = \left[\frac{(Z_1 + Z_2) \times \sigma}{\delta}\right]^2$

Figure 13: The change in post–shift FEV_1 decrease as a function of the concentration of MWF Type 2.

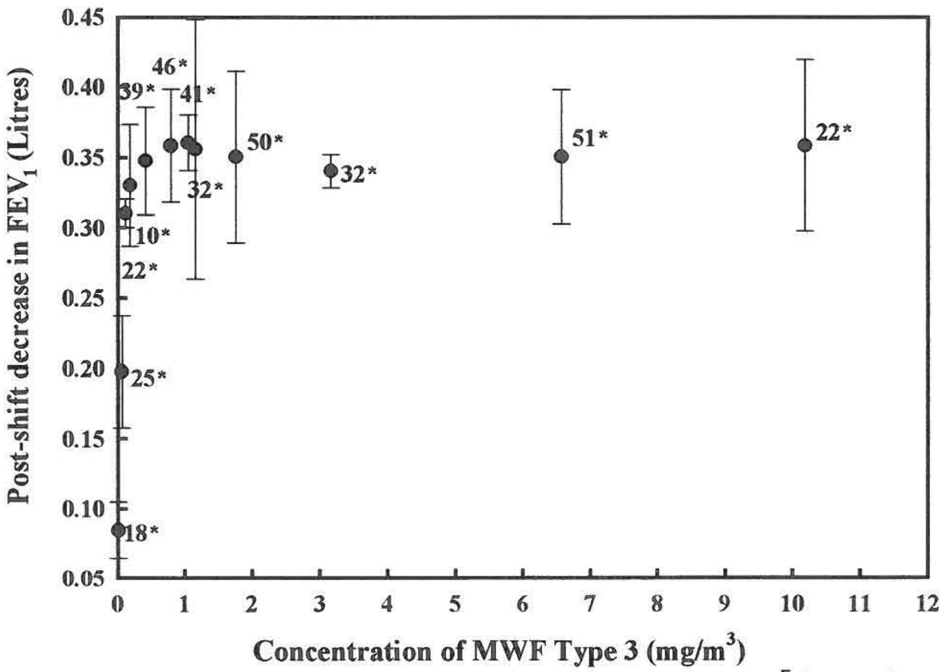
Table 23. Predicted decreases in FEV_1 in comparison to observed results for MWF Type 2.

Concentration of MWF Type 2 (mg/m^3)	ΔFEV_1 (predicted, Litres)	ΔFEV_1 (actual, Litres)	95% CI (α error 0.05)
0.015	0.090	0.04	(0.02 – 0.10)
1.04	0.370	0.28	(0.26 – 0.28)
4.19	0.39	0.32	(0.37 – 0.39)
4.77	0.39	0.37	(0.30 – 0.39)
7.19	0.39	0.43	(0.36 – 0.44)
12.05	0.40	0.38	(0.37 – 0.45)

Similarly, when analysing the data generated when workers were exposed to MWF Type 2 (Figure 13 and Table 23) a dose–response logarithmic function was derived to predict the change in FEV_1 among workers exposed to MWF Type 2.

When workers were exposed to higher personal concentrations of MWF Type 2, each worker had a corresponding decrease in pulmonary function. In comparison to other MWF Types (3 and 4), workers experienced a slightly lower decrease in pulmonary function, due to the fact that this MWF Type consisted of lower fractions of TEA and DEA.

By establishing a tolerable safe limit where the worker experiences a post–shift decrease of only 10%, the workers minimum exposure before any significant health affects could be observed will be 0.41 mg/m^3 (95% CI : 0.20 – 0.42 mg/m^3) according to the mathematical dose–response equation (Table 26). This PSL is different from the PSL calculated for workers exposed to MWF Type 1. The only difference when comparing MWF Types 1 and 2, was that MWF Type 2 consisted of 28% more TEA and DEA, which induced slightly different post–shift decreases among workers exposed to this type of MWF (ANOVA, P = 0.05).



*refers to the number of workers used to generate the data point, where N is: $N = \left[\frac{(Z_1 + Z_2) \times \sigma}{\delta}\right]^2$

Figure 14: The change in post–shift FEV$_1$ decrease as a function of the concentration of MWF Type 3.

Table 24. Predicted decreases in FEV_1 in comparison to observed results for MWF Type 3.

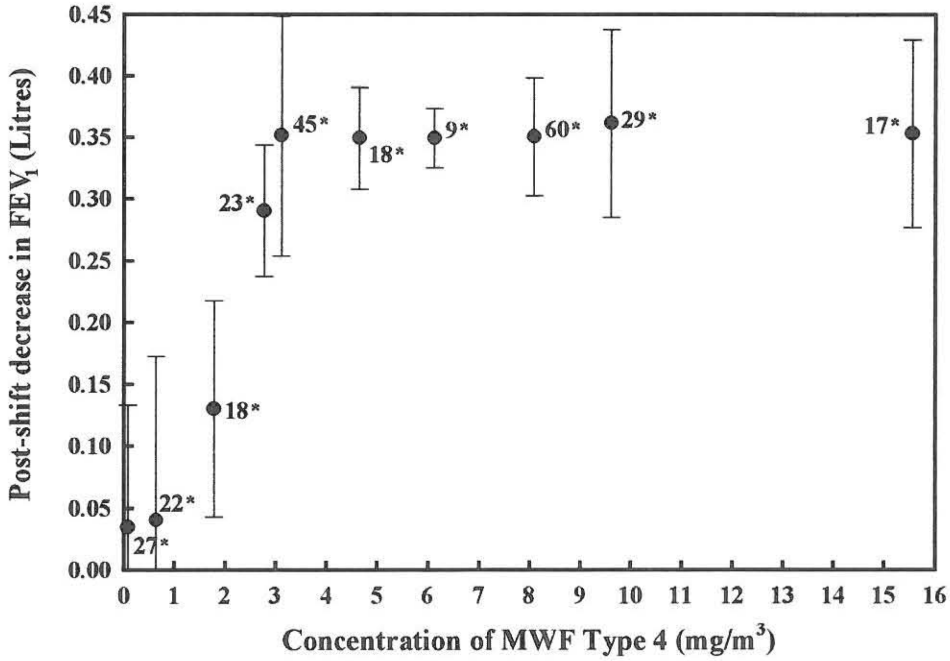
Concentration of MWF Type 3 (mg/m^3)	ΔFEV_1 (predicted, Litres)	ΔFEV_1 (actual, Litres)	95% CI (α error 0.05):
0.06	0.220	0.06	(0.03 – 0.21)
1.02	0.360	0.35	(0.27 – 0.37)
2.01	0.360	0.36	(0.30 – 0.39)
4.33	0.360	0.35	(0.33 – 0.41)
8.14	0.360	0.34	(0.32 – 0.40)
11.07	0.360	0.35	(0.34 – 0.39)

Workers exposed and utilising MWF Type 3 (Figure 14 and Table 24) experienced a closely related logarithmic dose–response. The mathematical model that was derived best fitted the data to predict the health affects in 95% of the worker population (that population using MWF Type 3).

The number of workers using MWF Type 3 was the largest, and there was a higher incidence of complaints indicated on the health questionnaires by workers who used this MWF for lathes or drilling machines. This Type of MWF contained higher fractions of TEA and DEA that was intended for higher stress metal work. As workers were exposed to similar personal exposures the magnitude in the post–shift decrease was statistically different and greater than workers using MWF Types 1 and 2 (ANOVA, P = 0.05).

Using a value of 10% for the change in FEV_1 as being tolerable, then the calculated PSL for workers using MWF Type 3 (according to the equation in Table 26) would be 0.29 mg/m^3 (95% CI: 0.12– 0.89 mg/m^3).

Depicted in Figure 15 and Table 25, are the group of workers who used MWF Type 4, which contained the highest concentration of TEA and DEA. As a result, the post–shift decrease among workers exposed to this Type of MWF was greater and statistically different in comparison to workers using MWF Types 1, 2 and 3. Regardless of the greater toxicity of this MWF, the dose–response that workers experienced was similar to those workers of the other three MWF types.



*refers to the number of workers used to generate the data point, where N is: $N = \left[\frac{(Z1 + Z2) \times \sigma}{\delta} \right]^2$

Figure 15: The change in post–shift FEV_1 decrease as a function of the concentration of MWF Type 4.

Table 25. Predicted decreases in FEV_1 in comparison to observed results for MWF Type 4.

Concentration of MWF Type 4 (mg/m^3)	**ΔFEV_1 (predicted, Litres):**	**ΔFEV_1 (actual, Litres):**	**95% CI (α error 0.05):**
0.51	0.001	0.02	(0.00 – 0.09)
2.71	0.33	0.27	(0.20 – 0.35)
4.02	0.35	0.29	(0.25 – 0.36)
6.77	0.35	0.39	(0.32 – 0.41)
9.12	0.35	0.36	(0.33 – 0.38)
13.07	0.35	0.33	(0.30 – 0.38)

The curve was explained by a logarithmic function and therefore PSL's for this MWF could also be determined by using a 10% decrease in post–shift pulmonary function as acceptable.

Therefore the PSL calculated (according to the equation in Table 26) would be 0.035 mg/m^3, but since the population in this group was very small the 95% CI ranges from 0.02 – 0.09 mg/m^3.

Across all four worker population groups, it was found that the dose–response followed a logarithmic function and that workers experienced significant decreases in pulmonary function only when the concentration MWF was above a specific value (ANOVA, P = 0.05). Spirometry data was adjusted for height, weight, and race and therefore workers' spirometry data could be pooled together and compared. It has been shown by McKay, Levin, Lockey, Lemasters, Medvedovic, Papes, Simpson and Rice (1999) that when studying the trends of pulmonary function among a worker population, the workers' weight can have a significant effect on pulmonary function. McKay *et al.* (1999) states that this is relevant for cohort or long term studies where the affect is much greater. In his study of 361 workers who were studied for changes in pulmonary function after exposure to an agent McKay *et al.* (1999) found that workers not exposed had significant changes in pulmonary function, only as a result of the weight change. This type of bias, is not relevant in the data presented here, since the workers were studied over a short duration of time (cross–sectional study) and workers' weight change was not in significant magnitudes.

In the field of toxicology most agents that a worker is exposed to can be toxic, depending on the dose (Jayjock, 1997: pp.313–326). Among the 4 types of MWF's that were being used, the physiological response among workers was logarithmic in relation to personal exposure. When workers were exposed to a specific range of the MWF (regardless of the type) the worker experienced an associated decrease in pulmonary function. When workers were then exposed to a specific concentration of the MWF, there was a sharp exponential increase in the magnitude of pulmonary function decrease (turning point).

As observed among workers exposed to MWF Type 1 (Figure 12), the turning point for acute pulmonary health affects occurred at an exposure concentration of 1.10 mg/m^3 (SD = 0.05 mg/m^3). For workers that were exposed to MWF Type 2 (Figure 13), the turning point was approximately 0.95 mg/m^3 (SD = 0.03 mg/m^3). Similarly, for workers exposed to MWF Types 3 and 4 (Figures 14 and 15) the turning point is 0.04 mg/m^3 (SD = 0.04 mg/m^3) and 0.35 mg/m^3 (SD = 0.02 mg/m^3).

The analysis of the data as presented in the Figures 12 –15 shows that the turning point at which there is an "all or nothing effect" is important to the degree of toxicity of the substance (Jayjock, 1997: pp.313–326). As seen from the turning points stated above, those MWF's that had lower concentrations of TEA and DEA, had higher turning points in the dose–response curve, and the worker could be exposed to a higher concentrations before adverse pulmonary changes occurred. However, those MWF's that had higher concentrations of TEA and DEA, had lower turning points in the dose–response curve, therefore the worker could be exposed to lower concentrations before adverse pulmonary changes occurred.

Table 26. Logarithmic dose–response equations for each MWF type.

Metal Working Fluid Type	**Mathematical Model**	**Correlation Coefficient***
1	$\Delta FEV_1 = \left[3.531037 + 33.916 \times e^{-4.0 \times (\text{Type 1})}\right]^{-1}$	0.99
2	$\Delta FEV_1 = \left[2.562195 + 8.55207 \times e^{-4.0 \times (\text{Type 2})}\right]^{-1}$	0.89
3	$\Delta FEV_1 = \left[2.75847 + 2.309664 \times e^{-4.0 \times (\text{Type 3})}\right]^{-1}$	0.81
4	$\Delta FEV_1 = \left[2.89528 + 6566.176 \times e^{-4.0 \times (\text{Type 4})}\right]^{-1}$	0.99

* Rosenbrock Correlation Coefficient (at P = 0.05)
ΔFEV_1 = Refers to the predicted change in forced expired volume in one second
Type # = Refers to the concentration of MWF Type (1–4)

6. Conclusions and Recommendations

6.1 Conclusions

Exposure to semisynthetic MWF's has resulted in acute pulmonary changes among South African metal workers who are routinely exposed. Those metal workers who were Black and smokers, had the highest change in pulmonary function in comparison to all other workers. MWF's that contained higher fractions of TEA and DEA attributed to statistically greater decreases in pulmonary function (ANOVA, P = 0.05). Spirometry was completed for each worker to determine the acute pulmonary health affects among workers. The pre– and post–shift measurements of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) was completed to determine the acute pulmonary changes among metal workers.

In the comparison of all exposed workers (S, ES and NS) to not exposed workers, there was a significant difference in pulmonary function between the two groups (ANOVA, P = 0.05). Workers who worked with any type of MWF had a greater decrease in pulmonary function, restriction and obstructive disorders, in comparison to workers who did not work with any type of MWF (ANOVA P = 0.05, ANOVA P = 0.02).

Workers who never smoked and were exposed to different types of MWF's, experienced a medically significant decrease in pulmonary function. There was a positive correlation between the concentration of TEA and DEA in the MWF and the degree of pulmonary function decrease (Pearson's correlations: $r^2_{\text{Plant 1}} = 0.96$, $r^2_{\text{Plant 2}} = 0.94$, $r^2_{\text{Plant 3}} = 0.97$). Among the sub–groups of workers (S, ES and NS) who were using one of the 4 formulations of MWF's, their pulmonary functions were significantly altered (ANOVA, P = 0.05).

Workers using MWF's with higher fractions of TEA and DEA, had greater decreases in pulmonary function or obstruction in comparison to workers who worked with MWF's that had lower fractions of TEA and DEA.

Smokers or ex–smokers who were exposed to one of the 4 MWF's studied had statistically different pulmonary functions in comparison to nonsmoking exposed workers (ANOVA, P = 0.05).

Similarly, smokers or ex–smokers who were exposed to MWF's with higher than 5% TEA and DEA had generally higher decreases in pulmonary function in comparison to nonsmoking workers (ANOVA, P = 0.05). Differences in pulmonary function between current smokers and ex–smokers were not found to be statistically significant (ANOVA, P = 0.01). However, within the group of smokers and ex–smokers, there was a medically significant pulmonary function decrease of 20% that was also found by other researchers (Eisen, *et al.*, 1994; Greaves, *et al.*, 1997).

Current smokers, ex–smokers and nonsmokers experienced a corresponding change in pulmonary obstruction and restriction when exposed to the 4 different types of MWFs. Those workers who were exposed to MWF's and were nonsmokers experienced the least degree of pulmonary restriction and obstruction in comparison to workers who were either smokers or ex–smokers (ANOVA, P = 0.05). Smokers who were exposed to MWF's with higher fractions of TEA and DEA, experienced the greatest degree of pulmonary restriction and obstruction in comparison to nonsmokers and ex–smokers (ANOVA, P = 0.05). Similarly, workers who were exposed to the MWF that had the highest fraction of TEA and DEA and were current smokers, experienced the greatest decrease in pulmonary obstruction and restriction (ANOVA, P = 0.01).

From analysing the post–shift decrease between nonsmoking exposed workers and the degree of pulmonary restriction or obstruction, it was found that these workers had statistically significant decreases in pulmonary function, in comparison to workers who were exposed to MWF's that contained higher than 5% TEA and DEA (ANOVA, P = 0.02). This same conclusion was derived when pooling all exposed ex–smokers and current smokers who were exposed to MWF's that contained higher fractions of TEA and DEA (ANOVA, P = 0.05).

Those workers who were either current smokers or ex–smokers that used MWF's that had higher than 5% TEA and DEA experienced a greater degree of pulmonary dysfunction in comparison to those nonsmoking exposed workers (ANOVA, P = 0.05). Overall, workers in each of the three exposure groups were exposed to a variety of MWF concentrations.

These significant pulmonary dysfunctions were observed to occur when workers were exposed to oil mist concentrations that ranged from 0.02 – 25.05 mg/m^3. Personal exposure concentrations to each MWF type varied depending on what process was occurring that day. Random sampling during the year or season did not effect the conclusion drawn from the workers' spirometry data. Workers' exposure to any type of MWF tended to increase during winter conditions (due to poor ventilation) or decrease during extremely high temperature work days (as a result of evaporation of the MWF samples).

As reflected in each derived model, regardless of the type of MWF the dose–response was similar for all workers. PSL's that were calculated using the mathematical models for each equation has shown that current permissible exposure limits set by ACGIH (1999), may be under estimations of the inherent toxicity of semisynthetic MWF's. The limits that were generated closely resemble those proposed limits by NIOSH (1998), that has shown that all types of MWF's should have a recommended exposure limit of 0.5 mg/m^3. The inherent toxicity of each type of MWF was also demonstrated by its dose–response turning point. The lower the turning point, the more toxic the MWF. As discussed before, the turning points for MWF Types 1–4 were significantly different (ANOVA, $P = 0.02$) and also decreased correspondingly according to the fraction of the TEA and DEA in the mixture.

6.2 Recommendations

The lack of specific safety and health training for workers who were working with MWF's was observed within each workplace. Workers should be provided with the adequate information to deal with the hazards from MWF exposure. Training should encompass the education needed for workers to deal with accidental MWF exposure and the use of personal protective equipment (PPE).

The safety education should entail practices needed for workers' personal hygiene and proper housekeeping to prevent further MWF distribution.

An environmental monitoring programme to assess the effectiveness of PPE, engineering controls and daily work practices should be established in any workplace where semisynthetic MWF's are used. The aim of such an environmental monitoring programme is to determine what workers' personal exposures are to

MWF's and to determine if over–exposure to MWF is occurring. ACGIH (1999) and NIOSH (1998) have separate and different proposed safe limits for MWF. ACGIH has determined that workers should not be exposed to concentrations (full shift exposure) of 5 mg/m^3 and NIOSH (1998) has developed a limit of 0.5 mg/m^3, the latter which is being supported by this research. Based on the modelling and the exposure response data that was established here, the permissible limit for those MWF's which may contain the TEA and DEA fractions should be 1.70 mg/m^3 (MWF Type 1), 0.41 mg/m^3 (MWF Type 2), 0.29 mg/m^3 (MWF Type 3) and 0.035 mg/m^3 (MWF Type 4).

Environmental monitoring should be completed annually with any major changes to work processes in the workplace. All personal sampling should be completed in the breathing zone of the worker to determine his or her exposure to MWF's. The frequency of personal sampling should increase for those workers who are at higher risk of daily MWF over–exposure (such as lathe work). Workers who have personal exposures that are at least one–half of the PSL, should have personal sampling repeated every six months (NIOSH, 1998). Where there are changes in the duration of shift or where workers are utilising different types of machinery to complete the same work task, workers should be monitored to determine if their personal exposure to MWF's have changed.

As seen within South Africa the duration of work shifts tend to be 8–10 hours per day and the potential for over–exposure to MWF's increases with these shifts. It is recommended that workers be routinely monitored for exposure to MWF's during long durations of metal machining and surveillance of the worker's personal work habits must be taken into consideration.

Where the work week is extended to include Saturday or Sunday, workers should be observed to see if there are any changes in personal job tasks. Where shifts exceed 10 hours, the Brief and Scala method for calculating the PSL for this work shift should be used in order to determine if workers are exposed to concentrations of MWF's that are not safe (Cralley and Cralley, 1994: pp.222 – 348).

Further forms of sampling should include area and source sampling, which will determine whether engineering controls or mechanical changes in the process could attribute to any type of unnecessary exposure to MWF's.

6.2.1 Hazard prevention and control

Management of the proper selection, maintenance and application of MWF's for each machine and job task should also be taken into consideration by those workers supervising the tasks being completed. Workers can be contaminated by direct hand contact to MWF's, the splashing, settled mist, dripping, or by handling tools contaminated with MWF's. These sources of contamination can be controlled by the proper application and use of MWF's, MWF maintenance (changing MWF's), isolation of work tasks, use of other materials that may not need MWF's in the job task or with ventilation controls.

Dermal exposure to MWF's can be controlled by the use of appropriate gloves, overalls, masks, face shields and aprons. Workers should be advised to clean exposed skin with clean towels, warm soap and water.

6.2.2 Work practices

In order to determine whether the work practice is safe, the characteristics of the task being completed, fluid type, ventilation, fluid flow speed, machine speed, machine guarding, and mist collection devices must be noted. The MWF mist can be minimised when there is proper application of the MWF. Application of the MWF should be taken into consideration. The degree of pressure and the rate of the MWF being applied will determine the worker's exposure to the MWF mist.

The worker should be educated to apply the MWF to the tool and work piece and not to other rotating parts as this will minimise the amount of MWF mist generated.

Filtration systems on various drills, lathes, central bores or milling machines, should also be maintained. This may include the use of proper chip collection devices, dissolved air–flotation devices, belt skimmers, chillers or plate heat exchanges and decantation devices. When routinely cleaned these systems can prevent the misting and minimise splashing because the MWF that is being applied is cleaner (NIOSH, 1978).

When work is not being performed on the machine, the flow of the MWF should be stopped to prevent any additional workplace exposure to MWF aerosol or mist. In order to work with an MWF it should be: adequate for the job, be the least irritable to the worker and not be a sensitiser.

The MWF collection tanks or trays should be guarded to prevent accidental spills onto the work floor and the location of sump pumps or coolant tanks where in the MWF is decanted should be covered to prevent contamination by other foreign objects or liquids (NIOSH, 1998).

During the successive use of MWF's, the additives will be degraded over a short duration of time. Additives must be maintained at all times in order to obtain maximum MWF efficiency for the tasks that are being completed at the time (NIOSH, 1998). It is important that the MWF pH is monitored and kept within the range that the manufacturer states. Temperature of the MWF must also be maintained in order to prevent the unnecessary loss of water from the MWF, growth of biological flora, and changes in viscosity.

6.2.3 Fluid maintenance

Containers where MWF's are decanted, should be stored away from extreme workplace or environmental conditions. Temperature extremes will cause semisynthetic MWF formulations to become unstable since they are mixed with large portions of water. During increased hot working conditions, the concentrations or formulation of MWF's that are used should be monitored (with a rarefractometer or pH meter).

Replenishment of MWF's into machinery should not be the addition of concentrated MWF to the system or adding large amounts of MWF to fill the system. Rather, the system should be flushed or emptied and the MWF should be mixed with correct proportions of fresh water in a clean drum.

Preparing large quantities of fresh MWF is not advisable since these solutions may stand for unknown periods of time and deteriorate due to workplace or environmental conditions (NIOSH, 1998). While preparing these mixtures it is important that the worker be protected from MWF exposure by using face shields, goggles, gloves, or aprons.

Anaerobic bacterial growth could be prevented by filtering the MWF or cleaning it from machine oils.

During shut down periods the oils will layer and settle. Bacterial growth may occur over weekends during normal shut downs. When the worker starts the machine, he or she is exposed to the biological organisms and the gases that are produced by the biological organisms. In order to prevent this type of acute exposure to gases, fresh air should run through the system to free any blocked openings or to ventilate the build up of these gases. Many semisynthetic MWF's that are used consist of additives that are biocides, which prevent the growth of such bacterial flora. The use of normal disinfectants has proved useful in the cleaning of systems that are contaminated with biological flora (NIOSH, 1978, 1998).

6.2.4 Sanitation and hygiene

Workers should be educated in keeping proper personal hygiene, keeping their work areas clean and separate from eating areas. Workers should be educated to keep their skin clean and wash hands throughly before taking a lunch or tea break.

If the workplace consists of a facility where showers are accessible, workers should be encouraged to keep contaminated work clothing separate from home clothes, and that work clothes be cleaned daily, in order to prevent the build up of MWF residues on the skin (NIOSH, 1998; ODP, 1998).

6.2.5 Engineering controls

6.2.5.1 Isolation

Isolation of the MWF machinery from other processes is usually recommended when the process is producing high concentrations of mist or aerosol (surface grinding). A booth or entire enclosure is used to prevent the worker from any unnecessary exposure to MWF.

These booths consists of their own ventilation systems and supply fresh air. For systems where the amount of work is not completed on a daily basis, simple splash guarding can reduce the amount of aerosol exposure to the worker's hands and face.

6.2.5.2 Ventilation

A ventilation system is used to prevent the accumulation and the recirculation of airborne contaminants in the workplace. A ventilation system consists of a positive means of bringing in at least an equal volume of fresh air from outside, conditioning it, and evenly distributing it throughout the workplace.

Within machining areas in the workplace, the use of natural ventilation is ineffective in controlling the mist generated at the source of the machine. Use of enclosures around the area where the MWF is being applied is usually used in order to control the amount of MWF that the worker is exposed to, as well as how much is being emitted into the workplace environment. If enclosures are not practical it is recommended that local exhaust hoods would be used to ventilate the area around the machine. The amount of airflow should be engineered to the rate and flow of MWF being applied and the speed of the machinery.

A ventilation system of the workplace must be designed to prevent the stagnation of air in the workplace as well as the build up of excess humidity. The system should also be able to supply fresh air in such a manner that the system prevents short circuiting of fresh air and exhaust, and the workers are supplied with a continual flow of fresh air (NIOSH, 1978, 1998; ODP, 1998).

6.2.6 Personal protective clothing

Workers working directly with MWF's are at risk for exposure via inhalation or direct dermal contact with the MWF. Maintenance workers may need to wear PPE to prevent unnecessary exposure to MWF's.

Personal protective clothing (PPC) should be strong enough and resilient to punctures and abrasions when workers are working with tools or large work pieces. Face shields, goggles, and gloves should be worn to prevent workers from any ocular or dermal exposure to MWF's (ODP, 1998).

Respirators that are selected for worker exposure to MWF's should be decided on for the prevention of worker exposure to MWF mist and not just vapour (NIOSH, 1998).

6.2.7 Medical monitoring of workers

Medical monitoring (along with environmental monitoring) represents secondary prevention and should not circumvent primary efforts to prevent worker exposure to MWF aerosol and mist. As completed in this study, simple screening examinations (completed at the same time during environmental monitoring) are reliable indicators for detecting disease and controlling workplace exposures to MWF's. With this type of screening procedure for all workers associated with semisynthetic MWF's, the reduction of acute pulmonary dysfunctions and the development of chronic pulmonary diseases can be avoided (NIOSH, 1998).

Medical monitoring should occur in areas where there has been reports of asthma development, pulmonary illnesses, or where high work production is being completed. Workers therefore need to be educated in the possible health affects and symptoms associated with MWF exposure and what he or she would have to be aware of becoming ill or have developed pulmonary problems (NIOSH, 1998).

Workers should then be referred to specialised medical personnel who are aware of or have training in:

- the elements of a respiratory protection programme.
- the identification and management of occupational asthma, and other work related respiratory illnesses (including pre–existing asthma exacerbated by occupational exposures).

Personnel completing spirometric testing should be competent in completing the testing as well as interpreting the information for other medical personnel. Such procedures should follow a standardised method such as the American Thoracic Society Standard for Spirometry (ATS, 1991, 1995).

Complete job histories, exposure to other hazardous agents, occupational exposures, job task being completed and the PSL's, product material safety data sheets (MSDS) and use of PPC should be accompanied with every medical screening test for each worker.

Workers placed into metal working jobs or in an environment where MWF's are used should have spirometric tests completed to determine their pulmonary health at that time. A medical questionnaire should be completed to determine if the worker has had any type of pulmonary or other related disorders in the past, placing the worker at a higher risk for the development of negative health affects or were previously exposed to MWF's. These results can be utilised as comparison spirometric data to the results of future tests.

The health questionnaire should consist of questions that determine the presence or absence of pulmonary disorders (ie: shortness of breath, wheezing, chest tightness or cough) and their relationship to work. Medical spirometry should only be used if there are specific incidences of pulmonary problems among a worker population, the number of visits to the medical doctor or the number of days of sick leave have increased. In a situation where there are no medical cases of illnesses due to MWF exposure, workers should only have spirometric tests completed on an annual basis (NIOSH, 1998).

Workers' spirometric testing should include FVC and FEV_1 results of each worker before and after his/her work shift. Significant decreases in the post–shift FEV_1 and the increase or decrease of the FEV_1/FVC ratio should be further investigated. Cross shift changes of 10%–20% will indicate strong changes in pulmonary function that may be attributed to some agent within the workplace (NIOSH, 1998). Such testing would indicate the presence of any acute changes that may be occurring as a result of exposure to MWF's.

Detailed pulmonary examinations should include the following physiological testing documents: a) hyper–responsive airways (ie: a comparison of pre– and post–bronchiodialtor methacholine challenge tests) and; b) airway affects as a result of exposure to MWF's (a comparison of pre– and post–spirometric data on the first day of the work week) (ATS, 1995; NIOSH, 1998).

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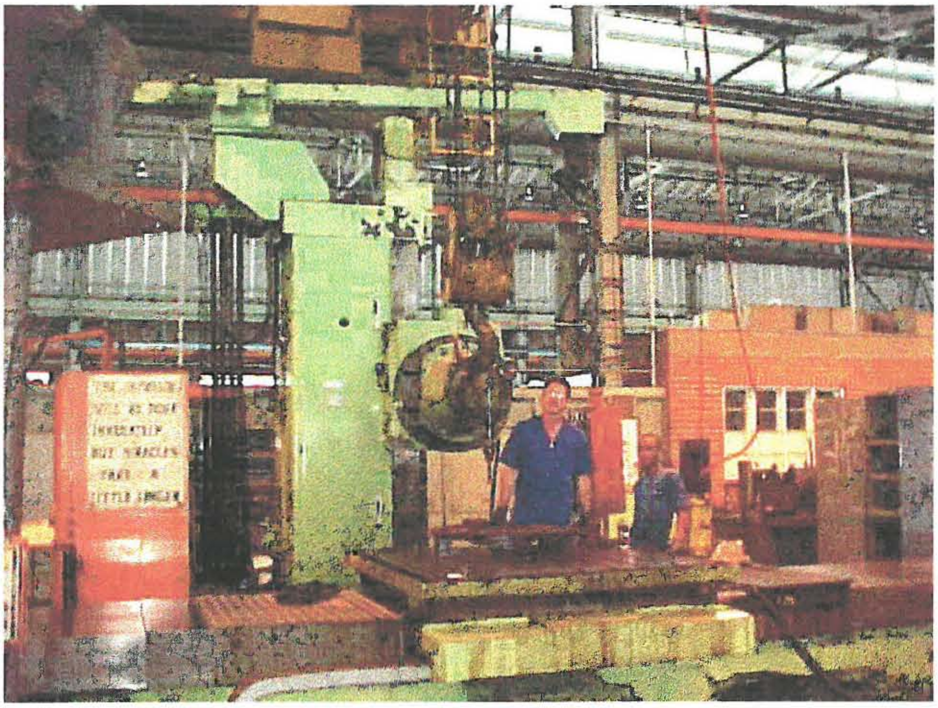

Figure i: A representation of a machinist and a boring machine.

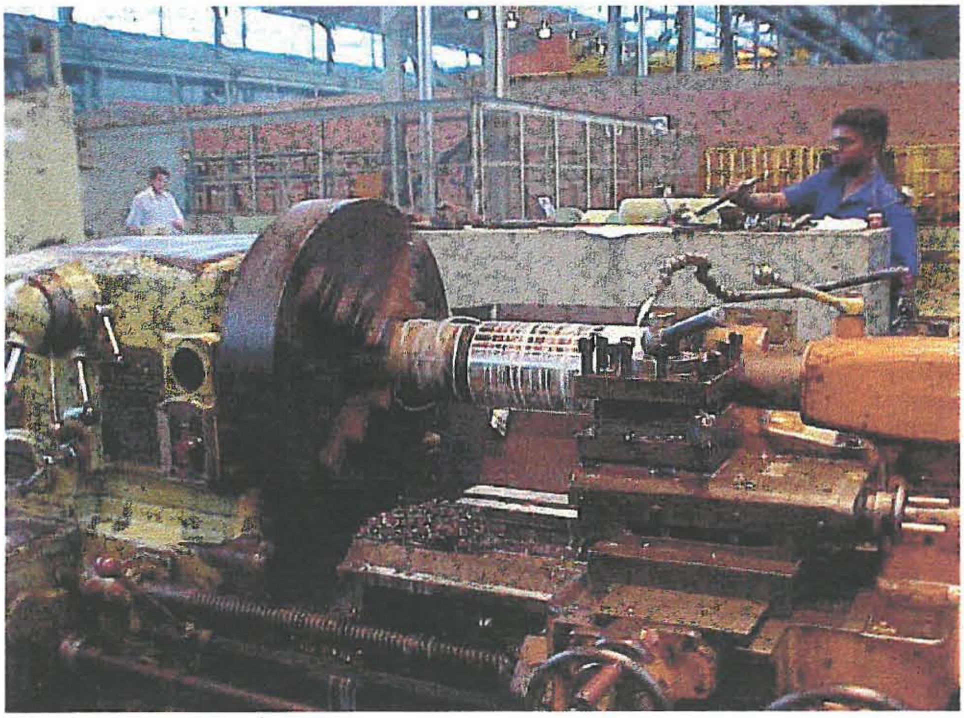

Figure ii: A representation of a machinist and metal turning.

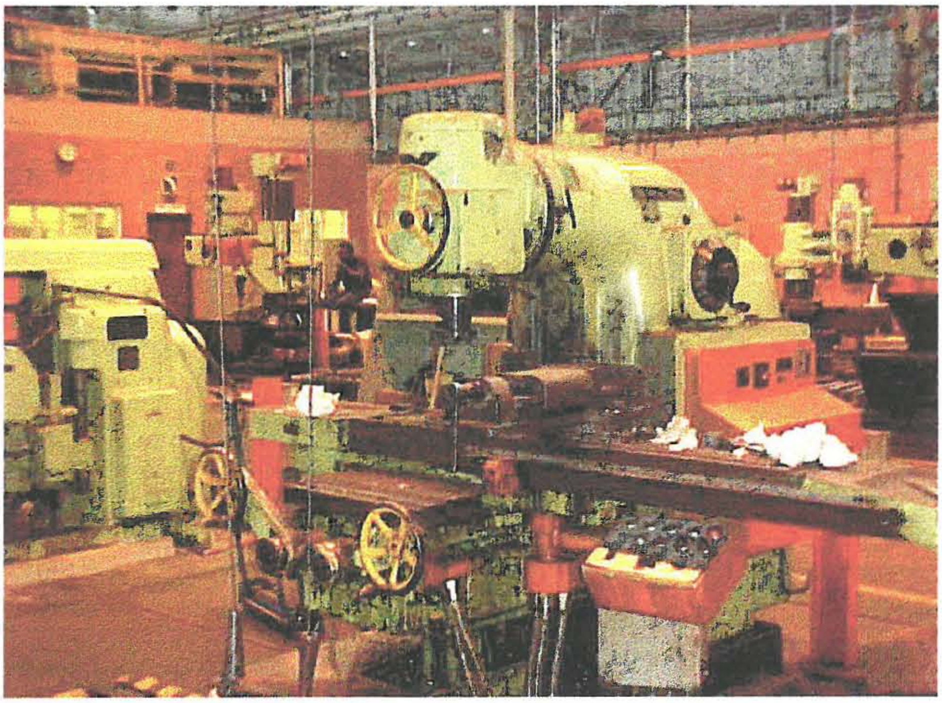

Figure iii: A representation of a milling machine.

Figure iv: A representation of a machinist and a drilling machine.

Health questionnaire

#1) Have you had cough or expectoration for 3 months of the year or more for at least 2 consecutive years?

Yes or No?

#1) Het u gehoes of speeksel afskeiding vir 3 maande van die jaar vir 2 jaar agtereenvolgens gehad?

Ja of Nee?

#1) Anaka nako enngwe o tshwarwa ke sefuba kapa o kgohlela madi kapa mamina kgwedi tse tharo selemo se seng le seseng kapa dilemo tse pedi tse latellanang?

Ee kapa Tjhe?

#2) Have you had a cough and expectoration for 3 months of the year or more for at least 2 consecutive years?

Yes or No?

#2) Het u gehoes en speeksel afskeiding vir 3 maande van die jaar vir 2 jaar agtereenvolgens gehad?

Ja of Nee?

#2) Anaka nako enngwe o tshwarwa ke sefuba ebe o kgohlela madi kapa mamina kgwedi tse tharo selemo se seng le seseng kapa dilemo tse pedi tse latellanang?

Eh kapa Jahe?

#3) Have you had shortness of breath when walking on level ground or walking up slight hills?

Yes or No?

#3) Raak u kortasem wanneer u op gelyk grond of effense opdraande loop?

Ja of Nee?

#3)Ana ka nako enngwe ha o tsamaya kapa o nyoloha leralla, o fella ke moya?

Eh kapa Jahe?

#4) Have you ever had asthma?

Yes or No?

#4) Het u al ooit asma gehad?

Ja of Nee?

#4) Ana o kile was tshwarwa ke asthma (phello ya moya)?

Eh kapa Jahe?

Medical questionnaire for lung function testing

Personal Information:

(A) Male:_____ Female:_____ Age:_____ Weight:_____ kg Height:_____ cm
Race:______

Years employed at the company:_________

Years At Present Job: <1 years___ 1-4 years____ 5-10 years____ >10 years___

Workplace/Occupational Information:

(B) *Job position* :_______________________________________

(C) Shift: (hours, hrs). Fill in the complete hours which you may do in any given workday shift.

1. Day shift :_____ hrs.
2. Night shift:_____ hrs.

(D) Health Information:

1) i) Do you have any type of respiratory (breathing) problems developing when exposed to second hand smoke? (if yes go to question #2, if no go to question #1 ii)).

yes____ no____

ii) Do you have any skin problems (such as dermatitis)?

yes____ no____

2) If so was it gained before working here? yes____ no____

3) *When* did it begin (time after employment)? 1-2 months__ 1 year__ 2 years__ 3+years__

4) *When* did the breathing problems stop (if it did answer the question, if not go to 5)?

a) after work? yes ____ no _____

b) 1-2 months__ 1 year___ 2 years___ 3+years__ after working at the workplace?

5) *When* will symptoms occur?

a) during work? yes____ no____

b) after work? yes___ no____

c) does it get worse over the day? yes___ no____

d) how long does breathing or coughing a problem?

<30 minutes ____ 1-2 hours____ 3+ hours____

6) *Describe* the breathing or skin problems:

chest tightness when breathing? yes___ no ____
red skin rash? yes___ no ____

Describe further (lung or skin problem):

____
____
____

7) Do you smoke (if so answer the question)? 1-5___ 6-10 ___ or 11-13+ pack(s) a day____

8) Have you had a recent medical check up? yes___ no___ (if yes go to 9).

9) Was your breathing and/or skin problem examined by the physician? yes___ no___

a) if so what was the diagnosis?______________________________

(E) Additional Information:

What other allergies do you have (if none go to next question)?

____
____
____

What personal hobbies if any do you have?

____
____
____

What jobs prior to this did you attain?

____
____
____

Do you live near any industrial recycling, water treatment or any other large industrial workplaces?
(if so describe):

____
____
____

Do you have any children? (If yes, did they ever suffer from unusual health problems?):

____
____
____

SpiroFlow™
Lung Function Programme

PentaMedical Systems

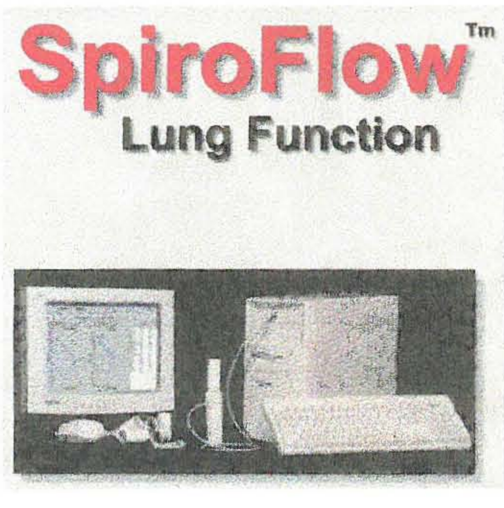

Figure v: Visual representation of Spiroflow™ spirometer.

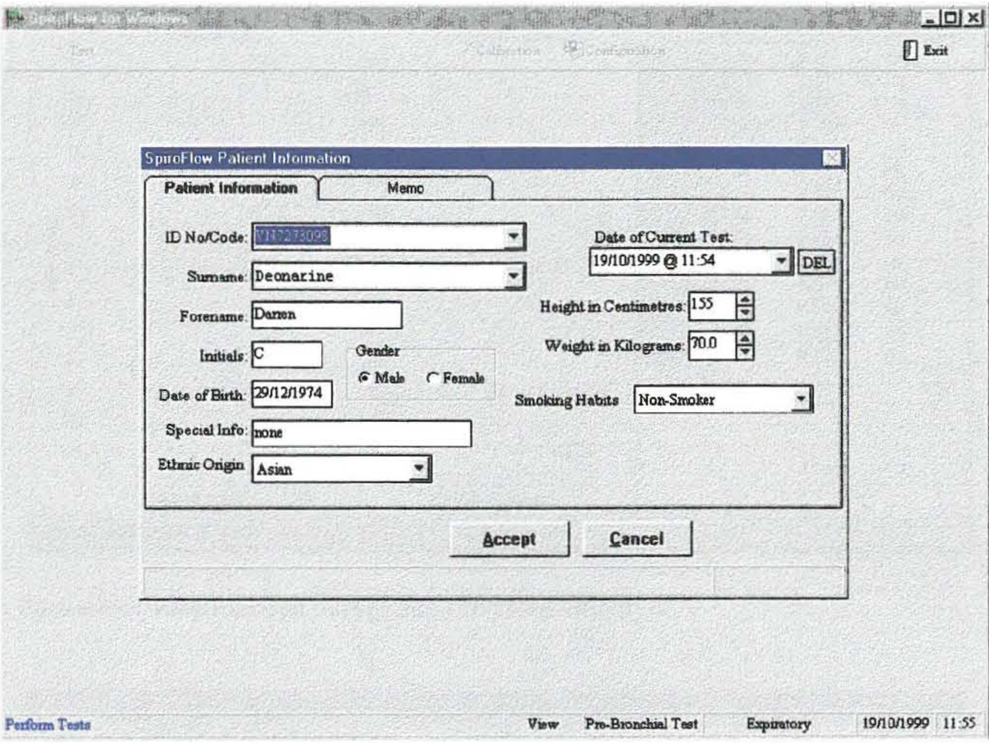

Figure vi: Worker data entry screen within the spirometer programme.

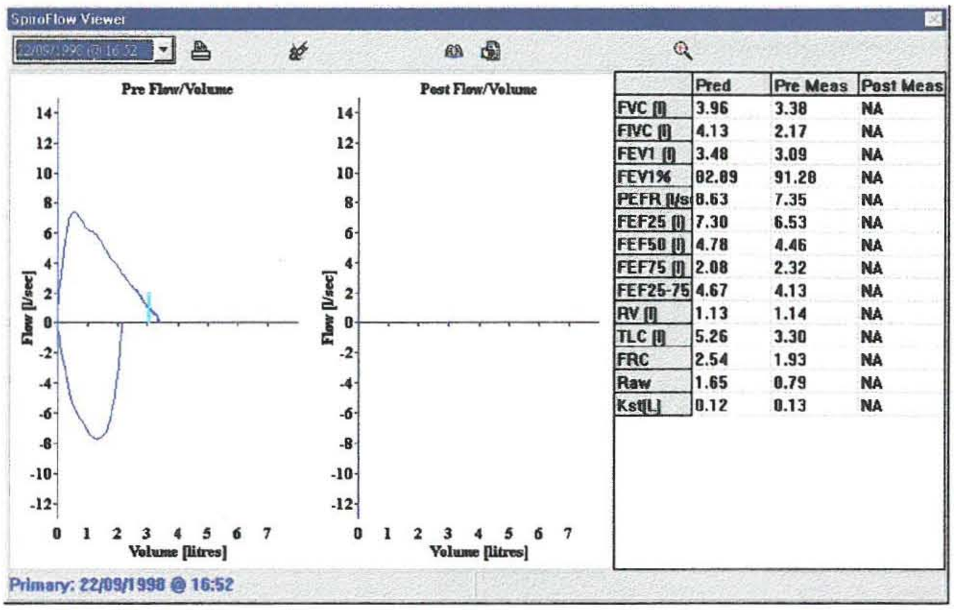

Figure vii: Spirometer lung function curves and predicted values.

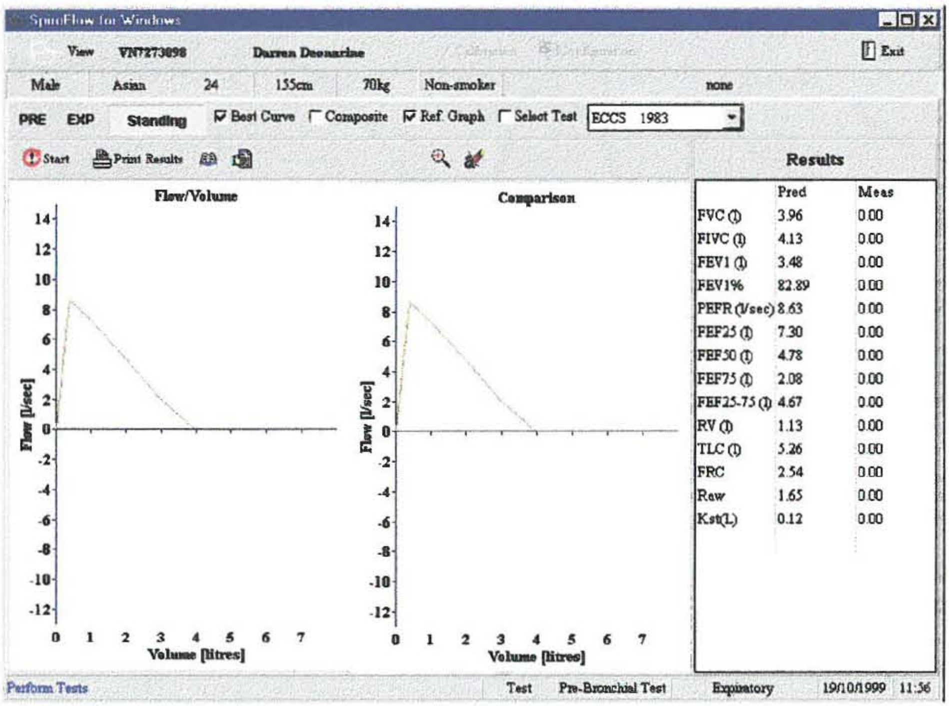

Figure viii: Spirometer lung function testing screen.

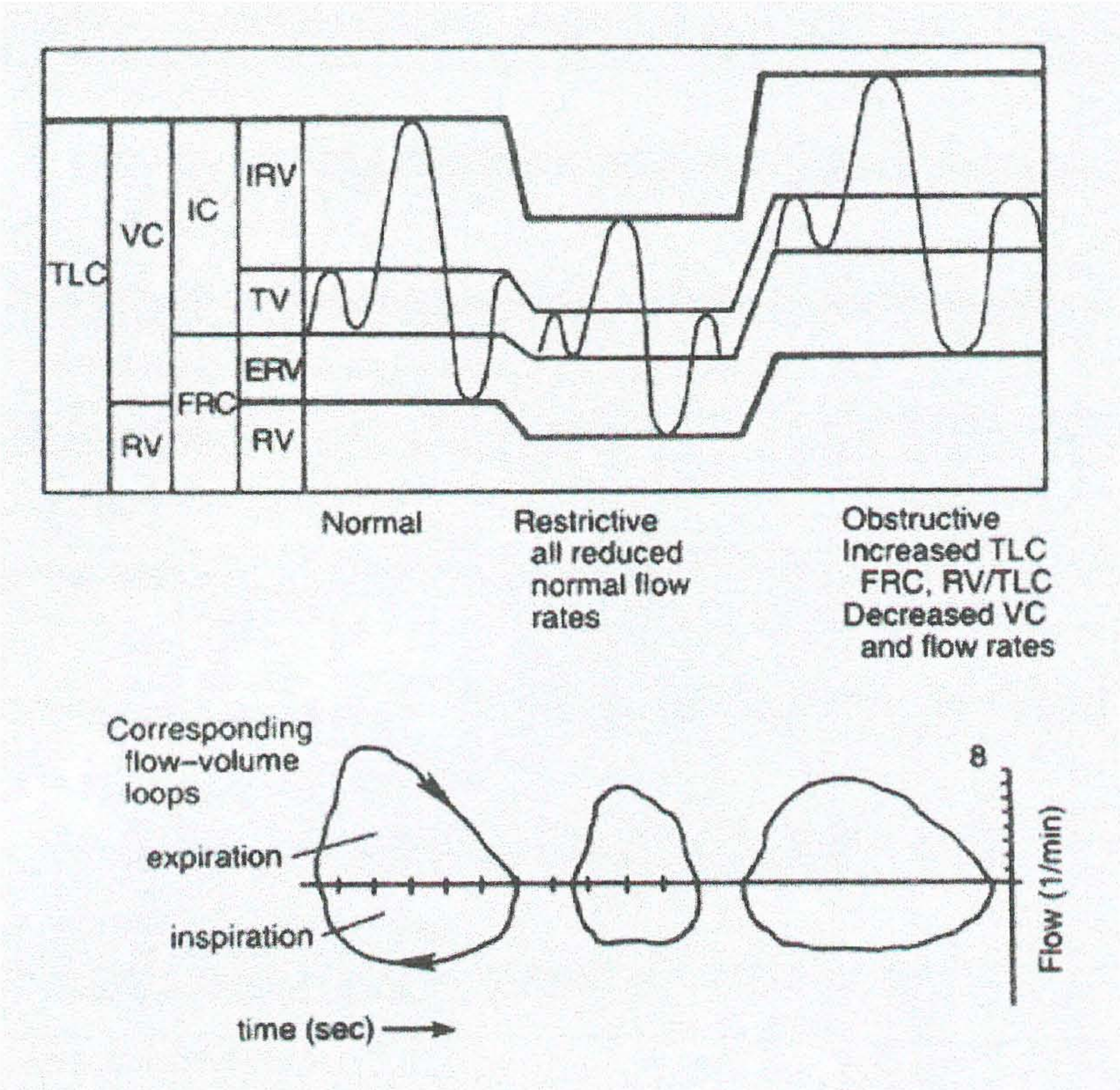

Figure ix: Spirometer calculation of FVC and FEV_1.

MINERAL OIL MIST (Modified NIOSH #5026)

MEASUREMENT

TECHNIQUE : UV / VISIBLE ABSORPTION SPECTROPHOTOMETRY

ANALYTE : Mineral oil

WAVELENGTH : Varies for each oil sample (see step 4 of calibration and quality control).

CALIBRATION : Standard solution of oil sample in deionized water.

PROCEDURE

REAGENTS :

1. Deionized water .

EQUIPMENT :

1. Vials, 4 mL glass , screw cap.
2. Tweezers, metal.
3. Spectophotometer, UV / VISIBLE , with cuvettes , 1-cm path length.
4. Volumetric flasks , 25- to 100 mL.
5. Micropipettes , 100 µL to 1 mL.

SAMPLE PREPARATION :

1. Remove the sample and blank filters from the cassette , fold and place them into a vial using tweezers.
2. Add 3 mL of deionized water to each vial, cap and shake well to wash all the surfaces of the filter.

CALIBRATION AND QUALITY CONTROL :

1. Pipette 100 µL of each of the bulk oil samples into a 100 mL volumetric flask and dilute to the mark with deionised water, to obtain a 100 ppm standard solution. From this solution, pipette 250, 500, 1250 and 2500 µL into a 25 mL volumetric flask and dilute to mark with deionized water to get 10, 20, 50 and 100 ppm standard solution respectively.
2. Scan a 100 ppm standard solution of each oil sample to obtain a wavelength of maximum absorbance for each.

3. Analyse the standards (steps 7 to 9).

4. Prepare a calibration graph (absorbance vs. concentration).

MEASUREMENT :

1. Set wavelength on the spectrophotometer to the desired wavelength.

2. Set to zero using a deionized water reagent blank.

3. Transfer sample solution to a cuvette and record the absorbance.

CALCULATION(S) :

1. From the calibration graph, calculate the concentration, C (ppm), of mineral oil in each sample.