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Aerosol Samplers Comparison: IOM Dual Sampler (Inhalable & Respirable) vs Conventional Methods for Assessing Welders Exposure to Manganese

By

Melissa A. Shomody

Submitted to the Graduate Facility as partial fulfillment of the requirements for the

Master of Science Degree in Occupational Health

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An Abstract of

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Occupational exposure to airborne manganese (Mn) is currently determined using National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) analytical methods for particulate not otherwise regulated. The Institute of Occupational Medicine (IOM) dual fraction sampler is capable of providing both inhalable and respirable portions of airborne particles by using only one sampling device. For this study, the IOM dual fraction sampler was compared with OSHA method ID-125G for determining occupational exposure to airborne Mn contaminant during Shielded Metal Arc Welding (SMAW), which was performed in a barge at a marine facility. An aluminum cyclone was used with a 25-mm Mixed Cellulose Ester (MCE) filter to sample respirable Mn contaminants. A 25-mm MCE filter was also used to sample total Mn contaminants. All monitoring was performed by area sampling. The aluminum cyclone readings, except one, were consistently higher than those of the IOM dual sampler (respirable) readings; statistically speaking, the aluminum cyclone showed significantly ($p < 0.01$) more exposure than did the IOM dual sampler (respirable). Therefore, the findings of this study suggest that the IOM dual sampler is not recommended as an alternative to the aluminum cyclone for the sampling of respirable Mn contaminants. However, the readings of conventional total particle sampler were not significantly different from those of the IOM dual sampler (inhalable). Inhalable and total are compared in this study and the results support the conversion factor of 1.0, which is for welding fume. Therefore, the IOM dual sampler can be used as an alternative method to conventional total particle sampler.

Acknowledgments

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Contents

List of Tables

List of Figures

List of Abbreviations

ACGIH……......	American Conference of Governmental Industrial Hygiene
AED……….......	Aerodynamic Equivalent Diameter
AES……...........	Atomic Emission Spectroscopy
ATSDR……......	Agency for Toxic Substances and Disease Registry
CDC……...........	Centers for Disease Control and Prevention
ICAP-AES…….	Inductively Coupled Argon Plasma
IOM……............	The Institute of Occupational Medicine
LOD……...…….	Limit of Detection
MCE……...…….	Mixed Cellulose Ester
Mn……………..	Manganese
NIOSH………...	National Institute of Occupational Safety and Health
OSHA……........	Occupational Safety and Health Administration
PEL……………	Permissible Exposure Limit
PVC……………	Polyvinyl Chloride
REL……………	Recommended Exposure Limit
SMAW………...	Shielded Metal Arc Welding
STEL…………..	Short Term Exposure Limit
SPSS………..….	Statistical Package for the Social Sciences
TLV……............	Threshold Limit Value

Chapter 1

Introduction

1.1 Overview

Occupational exposure to manganese (Mn) fume occurs during welding operations and is a rising concern as reflected by the Notice of Intended Change for Mn in the 2012 American Conference of Governmental Industrial Hygienists Threshold Limit Values (ACGIH TLV's) Handbook. The proposed change is to separate the Mn TLV into respirable and inhalable size fractions with a TLV for an 8 hour Time Weighted Average (TWA) of 0.02 mg/m^3 for respirable Mn and 0.1 mg/m^3 for inhalable Mn (ACGIH, 2012). Current exposure limits are shown in Table 1.1.

Table 1.1: Current Airborne Manganese Exposure Limits

Exposure Limit by Agencies	**Limit Values**
OSHA Permissible Exposure Limit (PEL)	5 mg/m^3 Ceiling
NIOSH REL (Recommended Exposure Limit)	1 mg/m^3 TWA 3 mg/m^3 Short Term Exposure Limit (STEL)
ACGIH TLV	0.2 mg/m^3 TWA
ACGIH Proposed TLV	0.02 mg/m^3 TWA (Respirable) 0.10 mg/m^3 TWA (Inhalable)

If the ACGIH proposed changes are adopted, many industries will need to improve their current exposure control methods to prevent overexposure. Currently, occupational exposure to Mn fume is monitored for both inhalable and respirable particles using the Occupational Safety and Health Administration (OSHA) method OSHA ID-125G for both inhalable and respirable Mn.

According to a publication by Toxic Substances and Disease Registry (ATSDR), respirable fractions travel to the bronchioles and alveoli of the lungs making respirable fractions the most relevant in relation to human health effects (ATSDR, 2012). The OSHA ID-125G require the use of a cyclone when measuring respirable particles (OSHA, 2002). The cyclone needs to be positioned in an upright position to collect the larger particles within the grit pot (red cap). Many welding processes require the welder to sit or stand in awkward positions, which may cause the cyclone to tilt, allowing the larger particles to move onto the filter. The Institute of Occupational Medicine (IOM) dual sampler would eliminate this problem, thus would be more practical for measuring Mn fume during welding operation.

1.2 Purpose

The purpose of this study was to determine whether or not the IOM dual sampler could be used as an alternative method for the sampling of airborne Mn during welding operations. This was done by comparing the IOM dual fraction sampler to the aluminum cyclone used with a 25-mm MCE filter for respirable Mn and also a 25-mm MCE filter for total Mn. In this study, the respirable method using the aluminum cyclone will be referred to as “cyclone” and the total particle method will be referred to as “total.” The

IOM dual fraction sampler has been chosen because it would allow inhalable and respirable fractions to be sampled using one sampling pump and it would be more cost effective than the conventional methods.

1.3 Hypotheses

1. $H_{0:}$ There is no significant statistical difference between the IOM dual sampler (respirable) and the cyclone.

   H_a: There is a significant statistical difference ($p < 0.05$) between the IOM dual sampler (respirable) and the cyclone.
2. H_0: There is no significant statistical difference between the IOM dual sampler (inhalable) and the total.

   H_a: There is a significant statistical difference ($p < 0.05$) between the IOM dual sampler (inhalable) and the total.

1.4 Approach

This study was performed at a marine facility. Area samples were collected inside of a barge during Shielded Metal Arc Welding (SMAW) operation. Area samples were selected, as opposed to personal samples, to prevent the aluminum cyclone from tipping and turning, and to receive a more accurate comparative measurement. The barge was selected because it was a confined space. SMAW was selected because it produces more welding fumes than other common welding methods (Harris, 2013).

Chapter 2

Background

2.1 Welding Fume Particle Size

Particles are separated into three categories based on their size distribution; inhalable, thoracic, and respirable (SKC, 2013b). Inhalable particles range from 10 to 100 microns and are trapped by the nose, throat, and upper respiratory systems when entering the body. Thoracic particles range from 5 to 10 microns and travel past the upper respiratory tract, into the airways of the lungs. Respirable particulates are less than 4 microns and are known to cause the most severe health effects because the particles travel to the deepest portion of the lungs (SKC, 2013b).

The particle size of welding fumes has been studied closely. In one study, 100% of welding fume particles produced during Gas Metal Arc Welding and Flux Cored Arc Welding were smaller than 10 micron aerodynamic equivalent diameter (AED) and 95% of these particles were smaller than one micron AED (Jenkins et al., 2005). In another study, the particle size of the welding fumes produced during Shielded Metal Arc Welding (SMAW) was between 0.59 and 0.46 micron AED (Hewett 1995). The conversion factor for inhalable and total particles for welding fume is 1.0 (Werner et al., 1996).

SMAW is the most common welding process, which is accomplished by creating an arc between the electrode and the base metal (Harris, 2002). Both the electrode and the base metal contain small traces of manganese (Mn) that contributes to the overall exposure (Harris, 2002). A diagram of SMAW is shown in Figure 2-1.

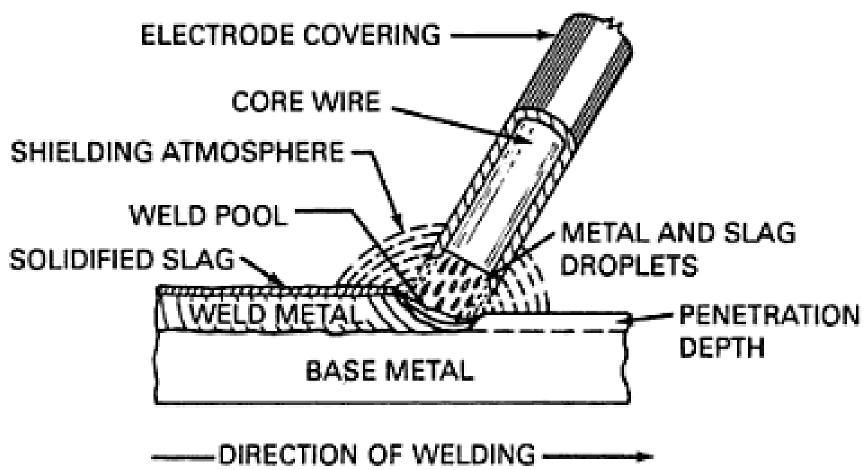

Figure 2-1: Shielded Metal Arc Welding (Harris, 2002)

2.2 Health Effects of Manganese

The health effects from occupational exposure to manganese (Mn) are well documented. Manganese is a neurotoxin and welders with exposure to respirable size particles have shown damage to the central nervous system (Santamaria, 2008). Long term exposure to manganese has caused Manganism, a disease with symptoms similar to Parkinson’s disease (Antonini, 2005).

2.3 Literature Review

There are no current studies that have validated the use of the IOM sampler to measure respirable portions of manganese fumes during welding. Jimenez et al. (2008) compared several sampling methods to develop a standardized method for sampling manganese. However, there was no direct comparison of the IOM dual sampler to the cyclone for the measurement of respirable manganese. Jimenez et al. (2008) recommended that the comparison is needed to validate the use of the IOM dual sampler for measuring respirable manganese (Jimenez et al., 2008).

Although there are no current studies that have validated the use of the IOM dual sampler for manganese, there are a few studies that have measured the validity of the IOM dual sampler for dust. In 2001, the IOM dual sampler was compared to the cyclone by measuring dust levels in several industrial settings. The findings were not statistically significant between the IOM dual sampler (respirable) and the cyclone sampler (Kenny et al., 2001). However, Kenny et al. (2001) suggested validating the findings by testing the specific industry under investigation (Kenny et al., 2001). In this regard, some studies have been performed in South African mines and United Kingdom (UK) brick factories.

As recommended by Kenny et al. (2001), other studies have been performed in United Kingdom (UK) brick factories and South African mines. The IOM dual sampler and the cyclone were statistically different when measuring respirable silica dust in the brick industry (De Vocht et al., 2008). The IOM dual sampler and the cyclone sampler were also statistically different when measuring respirable silica dust in the mining industry (Belle, 2012). In both industries, the IOM dual sampler underestimated the respirable dust levels. Thus, in their studies, the IOM dual sampler was not a satisfactory alternative to the cyclone sampler in the mining and brick industries.

Chapter 3

Methodology

3.1 Samplers

The IOM dual sampler was developed by J.H. Vincent and D. Mark at the IOM in Scotland (SKC, 2013b). The IOM dual sampler is designed to monitor both respirable and inhalable particles by using only one single sampler. The plastic device holds a 25-mm Mixed Cellulose Ester (MCE) filter (plus cassette) and a foam-insert with specific porosity. The foam-insert is used to trap larger particles, allowing respirable size particles to pass through and be collected on a filter (SKC, 2013b).

The filter, cassette bottom and the foam insert are pre-weighed and post-weighed for the analysis of inhalable particles (SKC, 2013b). Only the filter and cassette bottom are pre-weighed and post-weighed for the analysis of respirable particles. A diagram of the IOM dual sampler, with its elements, is shown in Figure 3-1. For Mn, a sampling pump is calibrated to a flow rate of 2.0 Liters/min by using the calibration adaptor shown in Figure 2-2 (SKC, 2013b). The calibration adaptor allows the sampling pump to draw a known volume of air through the MCE filter and foam insert.

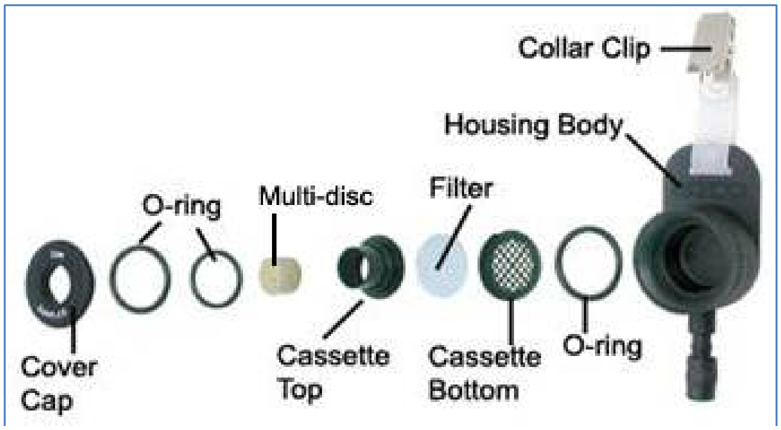

Figure 3-1: Diagram of Plastic IOM Dual Sampler (SKC, 2013b)


Figure 3-2: IOM Dual Sampler Calibration Adaptor

For the collection of total particles, a MCE filter cassette is used. The MCE filter is suitable for welding fume monitoring since it allows the analysis of Mn and thirteen other metals including cobalt, beryllium, molybdenum, cadmium, chromium, copper, iron, Mn, nickel, lead, antimony, vanadium and zinc (OSHA, 2002). In this study, a three-piece MCE filter cassette is shown in Figure 3-3. For Mn, a sampling pump is calibrated to a flow rate of 2.0 L/min. A calibration adaptor is not needed for the collection of total particles (OSHA, 2002).

Figure 3-3: Mixed Cellulous Ester 3-Piece Filter Cassette

The MCE filter cassette is also used to measure respirable particles by attaching an open faced three-piece MCE filter cassette to an aluminum cyclone (SKC, 2013a). The cyclone allows the larger particles to cycle down into the grit pot (red cap). This allows the MCE filter to collect only the respirable particles. The aluminum cyclone is shown in Figure 3-4. For Mn, a sampling pump is calibrated to a flow rate of 2.5 Liters/min by using the calibration adaptor shown in figure 3-5. The calibration adaptor allows the sampling pump to draw a known volume of air through the open face of a 3-piece MCE filter cassette attached to the aluminum cyclone (SKC, 2013a).

Figure 3-4: Aluminum Cyclone (SKC, 2013a)

Figure 3-5: Aluminum Cyclone Calibration Adaptor

3.3 Sampling Procedure

For this study, Mn samples were collected in a barge during Shielded Metal Arc Welding (SMAW) operation at a marine facility. SMAW was performed using a 6010 rod on mild steel. A rod of 6010 is an electrode with 60,000 psi tensile strength with a cellulose sodium coating that can be used in all positions. Area samples were collected simultaneously by positioning the IOM dual sampler, cyclone, and total sampler within 12 inches side-by-side as shown in Figure 3-6. Each sampling train was connected to a calibrated personal sampling pump. A Bios Defender flow pump calibrator was used for calibration. Samples were collected from February 13 to February 23, 2013.

Figure 3-6: Photograph of Cyclone (left), Total (middle), and IOM Dual Sampler Arranged for Sampling

Twenty paired samples were collected for the comparison of the IOM dual sampler (respirable) versus the cyclone and 20 paired samples were collected for the comparison of the IOM dual sampler (inhalable) versus total particle sampler. Of the 20 paired samplers collected for the comparison of the IOM dual sampler (inhalable) versus total particle sampler, only 18 paired samples were valid and were included in the further analysis. Information on the sampling procedures for Mn fume is listed in Table 3.1.

Table 3.1: Information on Sampling Procedures for Manganese Fume during Welding

Sampling Method	Samplers	Flow Rate (L/min)	Particulate Size Selection
OSHA ID-125G (Modified)	IOM Dual Sampler used 25-mm MCE filter (with cassette) and foam insert	2.0	Inhalable/Respirable
OSHA ID-125G	Aluminum Cyclone used 25-mm MCE filter (with cassette)	2.5	Respirable
OSHA ID-125G	25-mm MCE filter (with cassette)	2.0	Total

Sampled filters and the required field blanks were sent to Bureau Veritas North America, Inc (45525 Grand River Avenue Suite 200 Novi MI 48374) for laboratory analysis using OSHA ID-125G method. OSHA-ID 125G is specified for sampling metal and metalloid particles in workplace atmospheres and uses Inductively Coupled Argon Plasma-Atomic Emission Spectroscopy (ICAP-AES) for metal analysis (OSHA, 2002). OSHA ID-125G method is not specific for sampling by the IOM; therefore, but it was modified by the laboratory to suit this analysis. According to the method description, the limit of detection (LOD) for the sampling/analysis of manganese is 1.0μg (OSHA, 2002).

Chapter 4

Results

The summary results for the comparison of samplers, used for the measurement of manganese (Mn) fume, are shown in Table 4.1. The comparisons included the IOM (respirable) versus cyclone (N = 20) and the IOM (inhalable) versus total (N =18). The correlation coefficient value is 0.971 between the IOM dual sampler (respirable) and the cyclone. The correlation coefficient value is 0.960 between the IOM dual sampler (inhalable) and the total as shown in Table 4.2. All blanks were below the LOD (<1.0μg).

Table 4.1: Summary Results for the Comparison of Samplers during Measurement of Manganese Fume (mg/m^3)

Particle Size Selection	**Sampling Method**	**N**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**	**Median**
Respirable	IOM	20	0.132	0.141	0.003	0.410	0.046
	Cyclone	20	0.185	0.183	0.003	0.510	0.123
Inhalable/ Total	IOM	18	0.200	0.190	0.009	0.520	0.148
	Total	18	0.212	0.178	0.009	0.530	0.200

Table 4.2: Pearson Correlation between IOM (Respirable) versus Cyclone and between IOM (Inhalable) versus Total

Particle Size Selection	Samplers	N	Correlation (r)	Sig.
Respirable	IOM vs Cyclone	20	0.971	0.000
Inhalable/Total	IOM vs Total	18	0.960	0.000

The boxplot for comparison of the IOM (respirable) and cyclone in Figure 4-1 show the two devices have different medians and different spreads. The boxplot for comparison of the IOM (inhalable) and the total in Figure 4-2 shows similar medians and spreads. The boxplot graph shows no extreme values or outliers for the both comparison values.

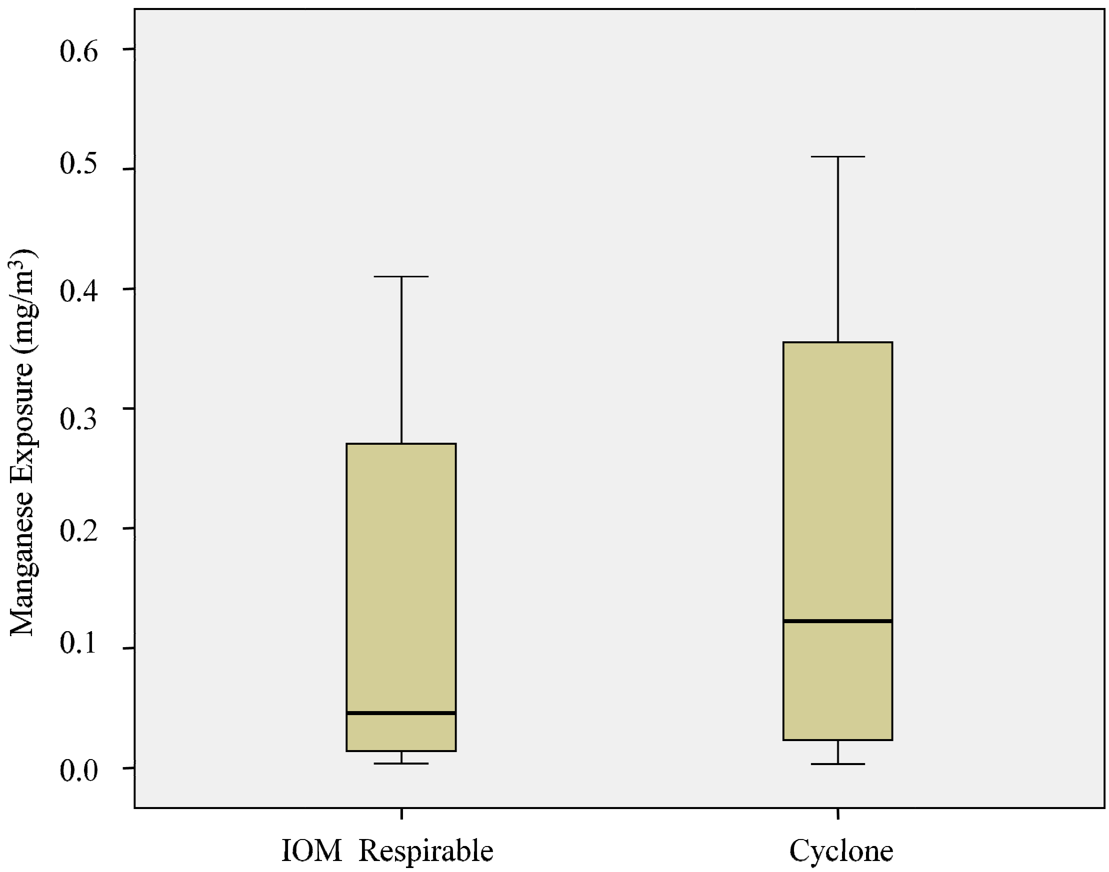

Figure 4-1: Boxplot for the Comparison of IOM (Respirable) and Cyclone during Monitoring Airborne Manganese Contaminants

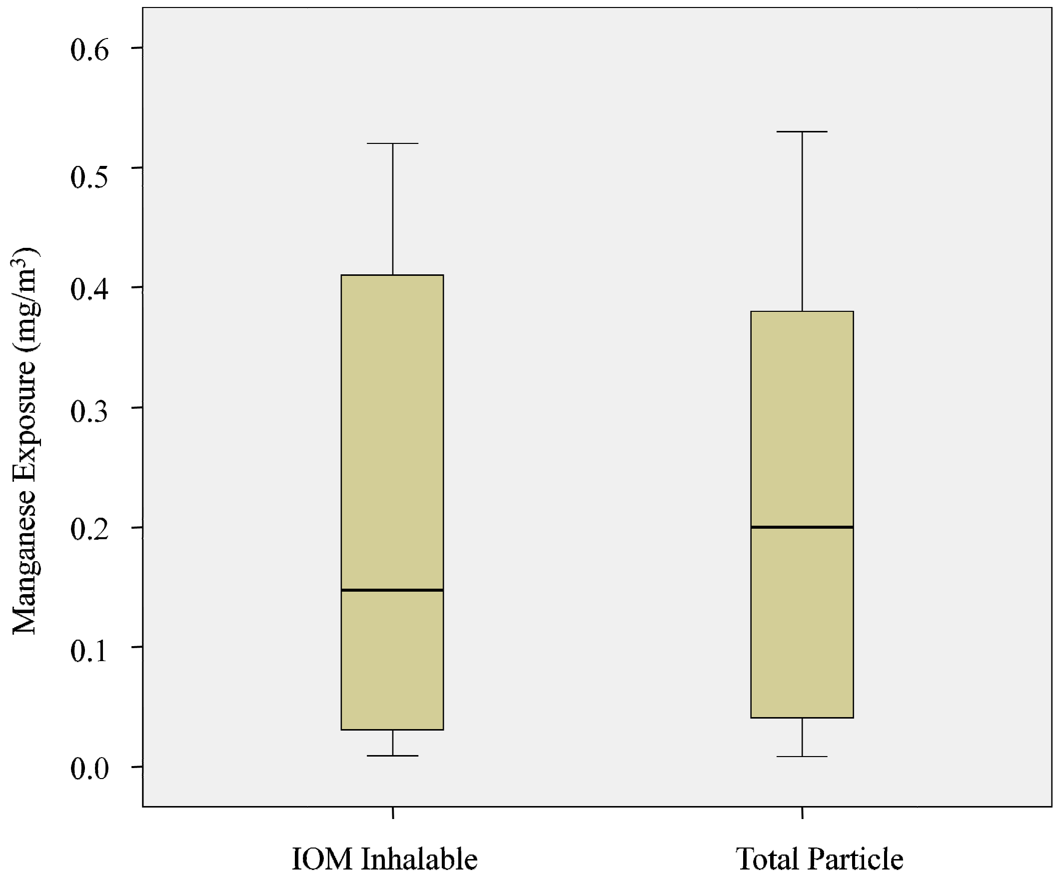

Figure 4-2: Boxplot for the Comparison of IOM (Inhalable) and Total during Monitoring Airborne Mn Contaminants (mg/m^3)

A summary of the paired samples t-Test for the comparison of IOM (respirable) versus cyclone ($p < 0.01$) and IOM (inhalable) versus total ($p = 0.336$) is shown in Table 4.3. Table 4.4 shows the parameter estimates for the sampler comparison of IOM (respirable) versus cyclone (Slope, b = 0.746) and IOM (inhalable) versus total (Slope, b = 1.024).

Table 4.3: Summary of Paired Samples t-Test for Respirable Size Particles and for Inhalable/Total Size Particles (Values are in mg/m^3)

		Respirable	Inhalable/ Total
Particle Size Selection		Respirable	Inhalable/ Total
Media		IOM - Cyclone	IOM - Total
Mean Difference		-0.0531	-0.0118
Standard Deviation of Difference		0.0573	0.0537
Standard Error of Mean difference		0.0128	0.0127
95% Confidence Level of Difference	**Lower**	-0.0800	-0.0385
	Upper	-0.0263	0.0150
t-Value		-4.144	-0.929
Degrees of Freedom		19	17
Sig. (2-tailed)		< 0.01	0.366

Table 4.4: Regression Analysis for IOM (Respirable) versus Cyclone and IOM (Inhalable) versus Total; (The IOM is the Dependent Variable).

Media	**Equation**	**Model Summary**					**Regression Line Parameters**	
		R^2	**F**	**df1**	**df2**	**Sig.**	**Constant**	**b**
IOM-Cyclone	Linear	0.943	299.0	1	18	<0.001	-0.006	0.746
IOM-Total	Linear	0.921	186.0	1	16	<0.001	-0.017	1.02

Regression Lines:

Cyclone-value (mg/m^3) = -0.006 + 0.746* IOM-respirable-value (mg/m^3)[n=20; R^2=0.943]
Total-value (mg/m^3) = -0.017 + 1.02* IOM-inhalable-value (mg/m^3)[n=18; R^2=0.921]

Note: These models can be used to determine IOM readings from conventional methods and vise versa

Figure 4-3 shows the Regression Line of the respirable Mn fume measured by the IOM dual sampler and the cyclone. Figure 4-4 shows the Regression Line of the inhalable and total Mn fume measured by the IOM dual sampler and the total.

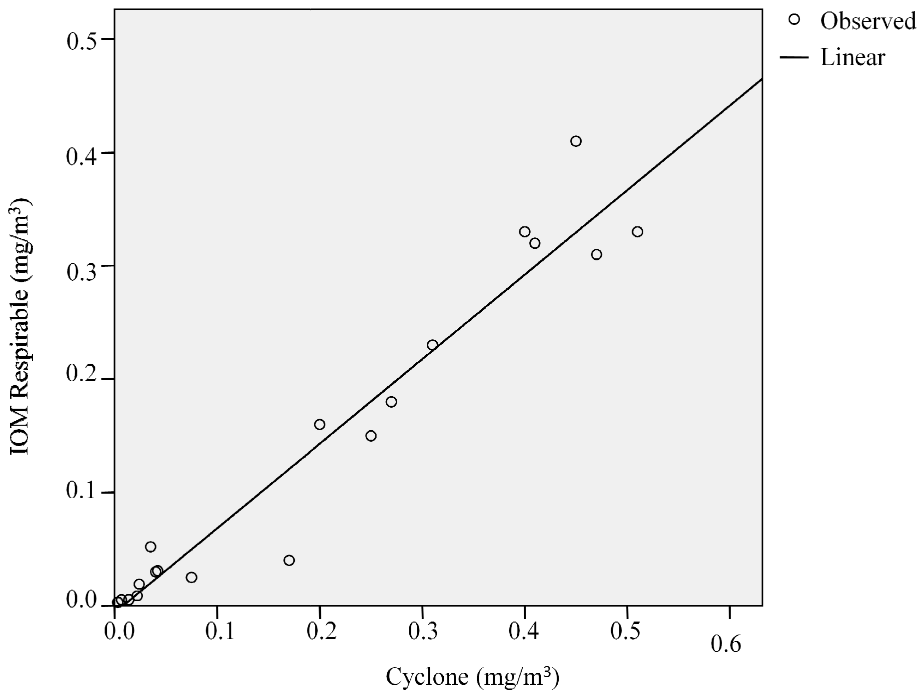

Figure 4-3: Linear Regression of respirable Fume Levels measured by IOM and Cyclone

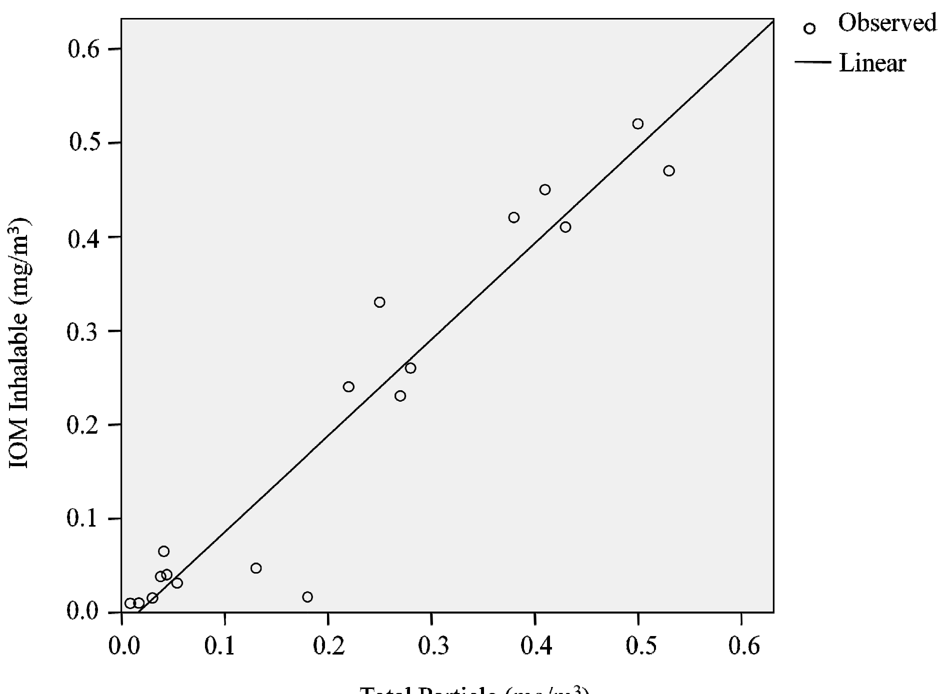

Figure 4-4: Linear Regression of Manganese Fume Levels Measured by IOM Inhalable and Conventional Total

Chapter 5

Discussion

The statistical analysis was performed by using the Statistical Package for the Social Sciences (SPSS). Preliminary analysis showed that the data were (almost) normally distributed. The Pearson Correlation showed a strong linear relationship between the IOM (respirable) versus the cyclone as well as the IOM (inhalable) versus the total. A paired samples t-Test was conducted with α set at 0.05 for both hypotheses to determine the statistical significance of the sampling methods differences. The IOM dual sampler consistently, except for one measurement, was lower than the respirable manganese (Mn) measured by the cyclone. However, the IOM dual sampler accurately measured inhalable portions of Mn levels when compared to the conventional total particle measurement.

Findings of this study are similar to the findings of Belle (2012) and De Vocht et al. (2008) who both compared the cyclone to the IOM dual sampler for the measurement of silica dust. The IOM dual sampler underestimated the amount of silica dust in the two studies, just as did the Mn fume measurement in this study. However, the findings of this study was not in agreement with a study by Kenny et al (2001), who did not find a statistically significant difference between the IOM dual sampler (respirable) and the cyclone.

The current OSHA PEL is a ceiling of 5 mg/m^3, but many industries are more conservative and adopt lower limits set by NIOSH and/or ACGIH. If the ACGIH proposed changes for manganese are adopted, the regression line may be utilized to use the IOM dual sampler for the measurement of respirable manganese. The coefficient of determination (R^2) for the respirable samplers was 0.943, indicating the regression line almost perfectly fits the data. Future comparisons of the IOM dual sampler versus the cyclone for the collection of manganese fume during welding operations are recommended to validate the use of the regression line.

Chapter 6

Conclusion

The first null hypothesis "There is no significant statistical difference between the IOM dual sampler (respirable) and the cyclone" failed to be rejected; the IOM dual sampler (respirable) and the aluminum cyclone, used with 25-mm MCE filter, findings are highly statistically different ($p < 0.01$). Therefore, the IOM dual sampler is not recommended as an alternative to the aluminum cyclone for the sampling of respirable manganese (Mn).

The second null hypothesis "There is no significant statistical difference between the IOM dual sampler (inhalable) and the total" is rejected; the IOM dual sampler and the findings for total were not statistically different ($p = 0.336$). Therefore, the IOM dual sampler can be used as an alternative method to the total particle measurement by 25-mm MCE filter.

According to the findings of this study, the use of the IOM dual sampler for occupational exposure to Mn could lead to compliance issues due to underestimating the Mn levels. Further evaluations are recommended to improve the action of the foam insert for the IOM dual sampler. However, the foam insert may not need improvement if the regression line is validated. Therefore, future comparisons of the IOM dual sampler versus the cyclone for the measurement of manganese fume are recommended to validate the regression line. The IOM dual sampler would be beneficial for the measurement of welding fume in many industries because it only requires one sampling pump for the measurement of inhalable and respirable particles, body position does not affect particle size collected on filter, and furthermore, it is cost efficient.

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Appendix A

Sampling Results

This appendix provides the sampling results for all manganese concentrations measured during this study in mg/m^3 as well as the air volume sampled in Liters. Table A-1 shows the respirable manganese particles collected using the IOM dual sampler and the cyclone. Table A-2 shows the inhalable and total manganese particles collected using the IOM dual sampler and the total particle sampler.

Table A.1: Sampling Results for Respirable Particles using the IOM Dual Sampler and the Cyclone Sampler

IOM Concentration (mg/m^3)	IOM Air Volume Sampled (L)	Cyclone Concentration (mg/m^3)	Cyclone Air Volume Sampled (L)
0.052	593.3	0.035	741.4
0.03	606.7	0.04	755.5
0.0052	809.6	0.0068	1012.8
0.0087	806.1	0.022	990.4
0.0054	791.2	0.014	987.7
0.019	883.6	0.024	1111.8
0.0032	857.3	0.0031	1076.1
0.0032	867.4	0.0032	1076.6
0.18	837.0	0.27	1069.8
0.15	858.6	0.25	1061.2
0.16	852.9	0.2	1065.0
0.33	202.2	0.4	252.1
0.32	207.2	0.41	256.8
0.23	206.0	0.31	257.2
0.33	514.2	0.51	636.0
0.41	501.9	0.45	639.1
0.31	505.5	0.47	642.0
0.031	710.1	0.042	888.1
0.040	706.3	0.17	873.9
0.025	714.1	0.075	887.3

Table A.2: Sampling Results for Inhalable/Total Particles using the IOM Dual Sampler and Total Particle Sampler

IOM Concentration (mg/m^3)	**IOM Air Volume Sampled (L)**	**Total Particle Concentration (mg/m^3)**	**Total Particle Air Volume Sampled (L)**
0.016	590.4	0.18	590.1
0.065	593.3	0.041	595.8
0.04	606.7	0.044	611.24
0.0093	809.6	0.0087	817.0
0.015	806.1	0.03	799.9
0.0095	791.2	0.017	793.9
0.26	837.0	0.28	849.9
0.23	858.6	0.27	854.6
0.24	852.9	0.22	850.1
0.45	202.2	0.41	201.8
0.42	207.2	0.38	206.5
0.33	206.0	0.25	205.8
0.47	514.2	0.53	506.2
0.52	501.9	0.50	507.9
0.41	505.5	0.43	504.5
0.038	710.1	0.038	708.9
0.047	706.3	0.13	712.6
0.031	714.1	0.054	712.5