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# Evaluation of the NIOSH MWF Total Particulate Matter: Thoracic Particulate Matter Conversion Factor in a Machining Environment

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Worker exposures to metalworking fluids were characterized at a plant that produced air compressors. Full-shift, side-by-side air samples ( $n = 147$ ) were collected and analyzed for total particulate matter, extractable total particulate matter, thoracic particulate matter, and extractable thoracic particulate matter. The thoracic particulate matter geometric mean of  $0.32 \text{ mg/m}^3$  was below the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) of  $0.4 \text{ mg/m}^3$ . The total particulate matter geometric mean of  $0.52 \text{ mg/m}^3$ , however, was above  $0.5 \text{ mg/m}^3$ , the total particulate matter concentration offered as a surrogate REL in the NIOSH Criteria for a Recommended Standard for Occupational Exposure to Metalworking Fluids.<sup>(1)</sup> Of the 83 total particulate matter results that were at or above  $0.5 \text{ mg/m}^3$ , only 50 (60%) of the corresponding thoracic particulate matter results were at or above  $0.4 \text{ mg/m}^3$ . These data indicated a conversion factor of 1.65 between thoracic particulate matter and total particulate matter concentrations and 1.40 between thoracic extractable particulate matter and total extractable concentrations. These factors were significantly different from the 1.25 used to compare total particulate matter with thoracic particulate matter concentrations in the NIOSH Criteria Document<sup>(1)</sup> ( $p < 0.01$ ) and call into question the validity of a universal conversion factor. The authors conclude that thoracic particulate matter exposure assessment should be done directly. In terms of protecting the worker, however, the 1.25 conversion factor appeared to be conservative since each time a total particulate matter result was below  $0.5 \text{ mg/m}^3$ , its paired thoracic particulate matter measurement was below  $0.4 \text{ mg/m}^3$ .

**Keywords** SIC 3563 air and gas compressors, coolants, extractable MWF, machining, metalworking fluids, MWFs, thoracic particulate matter, total particulate matter

In 1998, the National Institute for Occupational Safety and Health (NIOSH) published the *Criteria for a Recommended Standard for Occupational Exposure to Metalworking Fluids*,<sup>(1)</sup> which established a recommended exposure limit (REL) for metalworking fluids (MWF) of 0.4 milligrams per cubic meter of air thoracic particulate matter mass as a time-weighted average (TWA) concentration for up to 10 hours per day during a 40-hour workweek. Since devices to measure thoracic particulate matter mass were not yet widely available, NIOSH offered total particulate matter sampling as an acceptable substitute.

Based on data from one study,<sup>(1)</sup> a conversion factor of 1.25 was recommended unless another conversion factor had been experimentally measured for a given operation. This resulted in the thoracic particulate matter REL of  $0.4 \text{ mg/m}^3$  corresponding to a total particulate matter result of  $0.5 \text{ mg/m}^3$  ( $0.5 \text{ mg/m}^3 = 1.25 \times 0.4 \text{ mg/m}^3$ ). Results of MWF health hazard evaluations (HHEs) conducted subsequent to the REL suggested that the universal applicability of this conversion factor be explored.

In addition to these HHE results, a 2001 publication<sup>(2)</sup> presented an overview of industrial hygiene surveys from 79 machine shops that represented multiple MWF classes and types of machining. The data from that study indicated a ratio of 1.82 for total to thoracic particulate matter concentration and 1.92 for extractable total to extractable thoracic particulate matter concentration. In this study, worker exposures to MWFs were characterized in the machining area and the adjacent assembly area test the validity of the 1.25 conversion factor proposed by NIOSH.

In this plant, aluminum and cast iron parts were machined in two areas of the plant, sent through a washer, and assembled into either a single- or dual-stage pump. All of these areas were contained in one large, open room, and dilution ventilation was the primary means of exposure reduction. The sampling was

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conducted in midwinter when all the overhead doors remained closed. About half the machines were at least 75% enclosed when running, but these had no local exhaust ventilation so mist did escape from the open areas or each time the door was opened to change parts. Two grinders had new mist collectors added, and several machines had plastic curtain barriers between the operator station and machine's action. Five different MWFs were used in the plant—one straight oil, one water-soluble oil, two semisynthetic fluids, and one synthetic fluid. The machines each contained their own MWF sump, and the fluids were well maintained by a coolant technician.

## METHODS

### Air Sampling Analysis

Personal-breathing zone (PBZ) and general area (GA) side-by-side total and thoracic particulate matter air samples were collected on 5 consecutive days throughout the machining and assembly area (121 PBZ samples and 26 GA samples). Sampling time lasted 7 to 8 hours, which was the full time when employees were working in their assigned locations. Of the approximately 50 operating machines and work locations throughout the machining and assembly areas, about 30 samples were collected each day—at least one sample pair from each group of similar machines or locations. Samples were collected according to *NIOSH Manual of Analytical Method (NMAM) #5524* (draft) for all categories of MWFs.<sup>(2)</sup>

The total particulate matter samples were collected on two-piece, 37-mm closed-face cassettes with tared 2  $\mu$ m pore size polytetrafluoroethylene (PTFE) filters at a flow rate of 2 L/min. The thoracic particulate matter samples were collected next to the total particulate matter samples on three-piece, 37-mm closed-face cassettes with tared 2  $\mu$ m pore size PTFE filters attached to a thoracic cyclone at a flow rate of 1.6 L/min. The PBZ samplers were clipped to the employees' lapel or apron tie in their breathing zone and connected via Tygon<sup>®</sup> tubing to the sampling pumps attached to the employees' belt. GA samples were collected in work stations where employees did not want to wear a personal sampler; they were placed either on a table in the area or on the machine, whichever location was closer to where the employee spent the most time.

**TABLE I. Summary of Particulate Matter Sampling Results (n = 147)**

Type of Sample	Geometric Mean (mg/m <sup>3</sup> )	Geometric Standard Deviation	Range (mg/m <sup>3</sup> )
Total particulate	0.52	1.77	0.07 to 2.60
Extractable total particulate	0.31	1.87	0.03 to 1.39
Thoracic particulate	0.32	1.62	0.11 to 0.90
Extractable thoracic particulate	0.22	1.83	0.03 to 0.78

For both total and thoracic particulate matter, the weight of the collected particulate matter was determined by measuring the gross weight of each filter on an electrobalance and subtracting the previously determined tare weight of the filter. The collected material on the filters was then extracted using a 1:1:1 blend (by volume) of dichloromethane, methanol, and toluene. After drying in a vacuum oven for at least 2 hours, the filters were allowed to re-equilibrate to balance room conditions for at least 2 hours. The filters were then reweighed on the same electrobalance, and the liquid aerosol weight was calculated by subtracting the postextraction filter weight from the pre-extraction filter weight (extractable total and extractable thoracic particulate).

Prior to the extraction, solubility tests were performed on bulk MWF samples to ensure that the MWFs were soluble in the extraction solvent mixture. None of the field blanks had detectable particulate or extractable particulate mass; therefore, no adjustments were made to the raw sample filter weights before concentrations were calculated. The limit of detection (LOD) for the total particulate and thoracic particulate sample filters ranged from 0.01 mg to 0.02 mg, and the limit of quantitation (LOQ) ranged from 0.02 mg to 0.06 mg. The LOD for the extractable total particulate and extractable thoracic particulate sample filters ranged from 0.01 mg to 0.03 mg, and the LOQ ranged from 0.02 mg to 0.1 mg.

### Data Analysis

A 2  $\times$  2 table approach was used to determine false positive rates and predictive values when using total particulate concentrations as a predictor of thoracic particulate concentration. Then the raw total and thoracic particulate results were compared using linear regression models with no intercept term (the REL established the relationship: total particulate concentration = 1.25  $\times$  thoracic particulate concentration). The resulting regression coefficient (conversion factor) was then tested for equality with the NIOSH 1.25 conversion factor. These analyses were done on the whole data set and then individually for each MWF type.

## RESULTS AND DISCUSSION

Table I presents a summary of the particulate sampling results. The thoracic particulate geometric mean (GM) of 0.32 mg/m<sup>3</sup> was below the REL of 0.4 mg/m<sup>3</sup>, but the total particulate GM of 0.52 mg/m<sup>3</sup> was above 0.5 mg/m<sup>3</sup>, the total particulate concentration said to be equivalent to 0.4 mg/m<sup>3</sup> thoracic particulate.

Table II demonstrates the predictive values of using the total particulate concentration and a conversion factor as a test for thoracic particulate overexposure. Of the 83 total particulate results that were greater than or equal to 0.5 mg/m<sup>3</sup>, only 50 (60%) of the corresponding thoracic particulate results were greater than or equal to 0.4 mg/m<sup>3</sup>. Therefore, using the total particulate matter result as a test for thoracic overexposure only had a positive predictive value of 60%. During this study, the prevalence of overexposure (thoracic particulate

**TABLE II. Number of Thoracic Particulate Matter Results Above and Below the NIOSH REL of 0.4 mg/m<sup>3</sup> Relative to the Number of Total Particulate Results Above and Below 0.5 mg/m<sup>3</sup>**

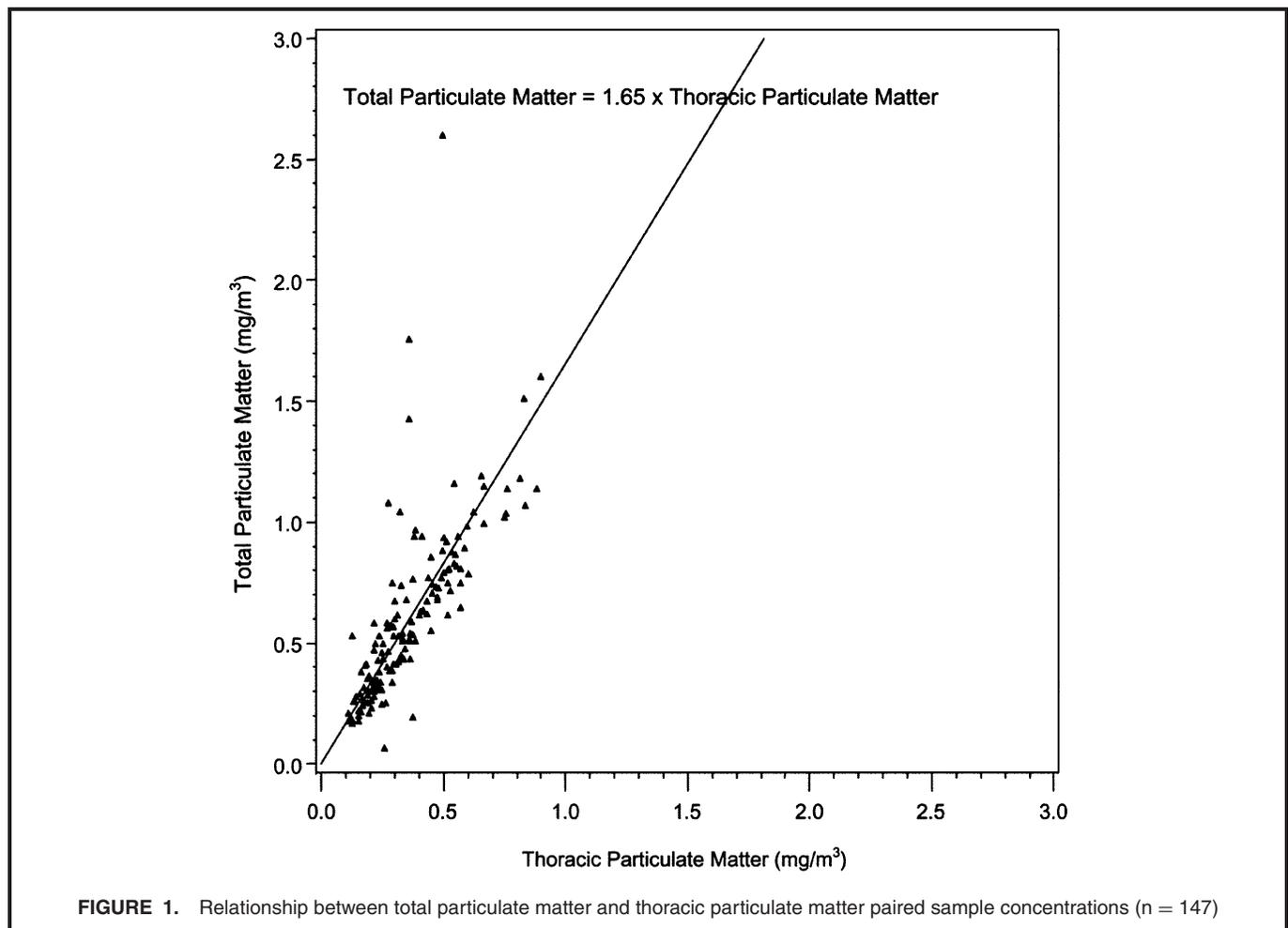
	Thoracic Particulate Results $\geq 0.4$ mg/m <sup>3</sup>	Thoracic Particulate Results $< 0.4$ mg/m <sup>3</sup>	Total
Total particulate results $\geq 0.5$ mg/m <sup>3</sup>	50	33	83
Total particulate results $< 0.5$ mg/m <sup>3</sup>	0	64	64
Total	50	97	147

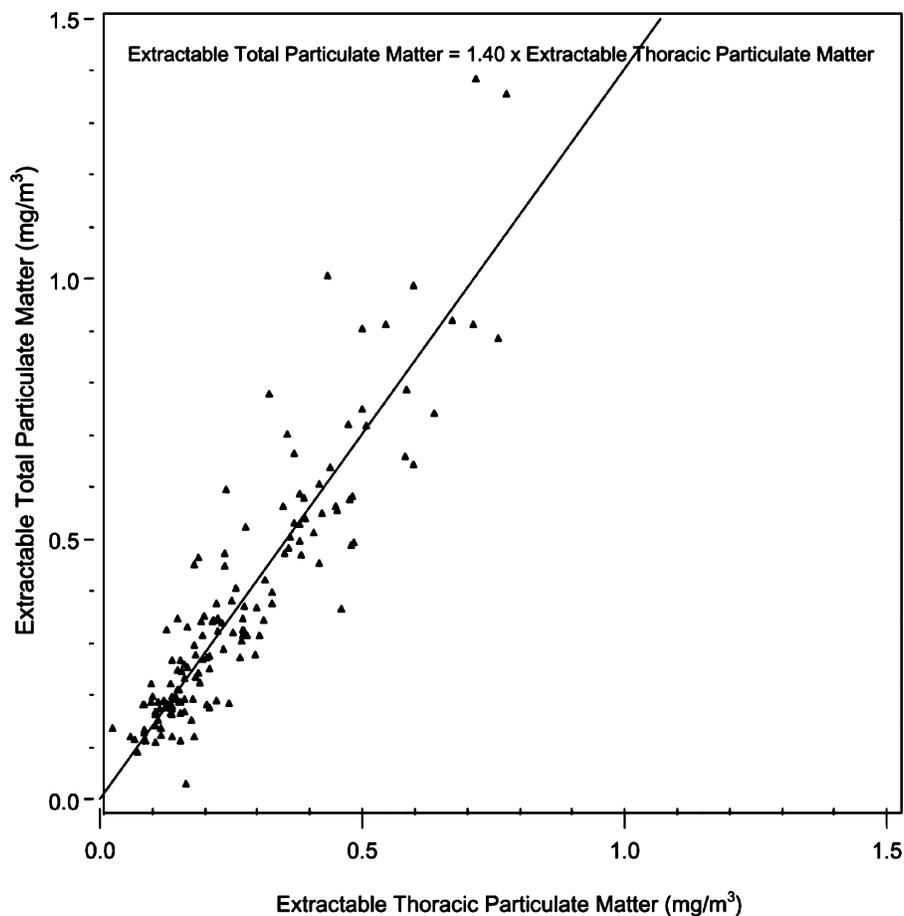
*Note:* Using the total particulate concentration as a test of thoracic particulate concentration in this environment had positive predictive value of 60%, a negative predictive value of 100%, a sensitivity of 100%, and a specificity of 66%.

concentrations greater than the REL) was 34%. In plants with lower prevalence of overexposure, assuming the same specificity (66%) and sensitivity (100%) of the test, the positive predictive value of the test would be even lower than 60%.

However, Table II also shows that of the 64 total particulate results that were less than 0.5 mg/m<sup>3</sup>, 64 of the corresponding thoracic particulate results were less than 0.4 mg/m<sup>3</sup>—a 100% negative predictive value. Thus, the test is conservative because it can be safely used to maintain worker exposures below the REL; but since many companies make capital expenditure decisions (purchasing new machines, installing new engineering controls on existing machinery, etc.) based in part on the prevalence of overexposure in the workplace, it is important not to have false indications of overexposure.

Figures 1 and 2 display the relationship between each pair of the total particulate matter and thoracic particulate matter sample concentrations. The data suggest conversion factors significantly different from 1.25 ( $p < 0.01$ ) – 1.65 (SE = 0.05) between thoracic particulate matter and total particulate matter concentrations (Figure 1) and 1.40 (SE = 0.03) between thoracic extractable particulate matter and total extractable concentrations (Figure 2). When the MWF types are considered separately, the conversion factors are not consistent. The conversion factors between total and thoracic particulate matter varied from 1.5 to 1.67 and were all significantly different than 1.25 (Table III).





**FIGURE 2.** Relationship between extractable total particulate matter and extractable thoracic particulate matter paired sample concentrations (n = 147)

Although the extractable measurements do not correspond to any exposure criteria, nor have previous studies addressed extractable concentrations, they do help to determine how much of the total mass can be attributed to liquid aerosol. The

results are presented here merely in anticipation of the NIOSH MWF sampling method that will include extraction. The extractable total particulate matter and the extractable thoracic particulate matter GMs were 0.31 mg/m<sup>3</sup> and 0.22 mg/m<sup>3</sup>,

**TABLE III. Conversion Factors Between Total and Thoracic Particulate MWF Concentrations by Type of MWF**

MWF Type	Thoracic to Total Particulate			Extractable Thoracic to Extractable Total Particulate			Proportion of Falsely Indicated Overexposures <sup>C,D</sup>
	Conversion Factor <sup>A</sup>	Standard Error	Significantly Different from 1.25 <sup>B</sup>	Conversion Factor <sup>A</sup>	Standard Error	Significantly Different From 1.25 <sup>B</sup>	
Synthetic (n = 37)	1.61	0.09	Yes (p < 0.01)	1.29	0.04	No (p = 0.34)	38%
Water-soluble oil (n = 25)	1.67	0.05	Yes (p < 0.01)	1.61	0.07	Yes (p < 0.01)	11%
Straight oil (n = 6)	1.50	0.09	Yes (p = 0.04)	1.51	0.11	No (p = 0.07)	0%
Semisynthetic (n = 15)	1.51	0.07	Yes (p < 0.01)	1.26	0.05	No (p = 0.79)	54%

<sup>A</sup>Estimated slope in linear regression model with no intercept term.

<sup>B</sup>Testing slope = 1.25 in linear regression model with no intercept term.

<sup>C</sup>Proportion of samples, among those with total particulate ≥ 0.5 mg/m<sup>3</sup>, that have thoracic particulate < 0.4 mg/m<sup>3</sup>.

<sup>D</sup>Based on total particulate results.

respectively. In cases where the extractable concentration was much lower than the total concentration, we had to consider that other particulate matter, such as metal fines or nuisance dust, were the major contributor to particle exposure. This was the case for some of our samples collected near dry milling and drilling operations.

## CONCLUSIONS

The results of this study demonstrate that the 1.25 conversion factor is not universal; it may hold true in some instances, but it cannot be assumed without comparison sampling in each MWF environment. Measuring total particulate matter and using the 1.25 conversion factor to estimate thoracic exposure is not an accurate thoracic particulate matter exposure assessment method, and the authors recommend directly measuring worker exposure to thoracic MWF aerosol. Using a conversion factor to estimate thoracic particulate matter results based on total particulate matter measurements may only be appropriate once a particular worksite's unique conversion factor has been determined for a given set of operational and environmental conditions. However, in terms of protecting the worker, the 1.25 conversion factor appears to be conservative since when the total particulate matter result was below  $0.5 \text{ mg/m}^3$ , all the thoracic particulate matter measurements were below  $0.4 \text{ mg/m}^3$  (Table II). Therefore, if exposures are maintained at or below  $0.5 \text{ mg/m}^3$  total particulate matter, then

the REL of  $0.4 \text{ mg/m}^3$  thoracic particulate matter is probably being met but the actual thoracic exposure cannot be known from the total particulate matter data.

## ACKNOWLEDGMENTS

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