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Mist Characterization in Drilling 1018 Steel

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Abstract

Limited studies have been performed to determine the characteristics of mist produced while machining with minimum quantity lubrication (MQL).This study investigates the resulting mist concentration levels produced while drilling ASI 1018 steel using a vegetable based cutting fluid. ANOVA was performed to determine whether tool feeds and speed levels or their interactions have significant effects on mist concentration and particle diameter. The results show that all the independent variables levels studied and their combinations had a significant effect on the resulting concentrations. Moreover the study showed that all levels of concentrations obtained exceeded those currently permissible by OSHA and NIOSH.

Keywords: *Minimum Quantity Lubrication, Mist Characterization, Green Machining, aerosol mass concentration, aerosol particle size.*

1. Introduction

Cutting fluids provide reduced friction between the tool and part, corrosion prevention of metal, the transportation of chips during machining and cooling for the workpiece. Furthermore, the coolant also provides a reduction in the dimensional variations between machined parts Tasdelen et al.,(2008). Research has shown that the cost, filtering and waste removal of the coolant can be higher than the coolant itself. As environmental regulations increase with the disposal of cutting fluids, the cost will inherently increase. Reducing the quantity of fluids used will have a positive impact on the environment and provide a reduction in the manufacturing cost Dhar et al., (2006) and 2007). To achieve these goals, an alternative to flood cooling is minimum quantity lubrication (MQL).

Minimum quantity lubrication, also referred to as near-dry lubrication or micro-lubrication .Khan et al. (2006), replaces the traditional method of flood cooling with small amounts of high-efficient lubrication . The flow rate at which MQL operates is between 50-500 ml/h. This is approximately three to four times lower than the amount used in traditional flood cooling . This decreased amount of lubricant utilized by MQL yields reduced cycle time in cleaning the workpiece/tool/machine and decreased occupational hazards

The National Institute for Occupational Safety and Health (NIOSH) recommends that the exposure level that workers encounter from metalworking fluids should be limited to 0.5 mg/m³ during a 10 hour day for a 40 hour workweek ("Workplace Safety and"). The U.S. Occupational Safety and Health Administration (OSHA) states the permissible exposure level is 5 mg/m³ based on an 8 hour workday . However, it has been found in the past that the oil mist produced by traditional flood cooling methods in U.S. automotive parts manufacturing facilities range from levels of 20-90 mg/m³ (Bennett et al. 1985). Workers are exposed to these fluids by direct skin contact from splashes or mist during the machining process or handling the tools, parts and equipment. Workers also inhale the mist by means of the fluid circulation system and the exhaust system in the room . This contact can result in a number of health issues. Such concerns are dermatitis, acute and chronic respiratory diseases, skin cancer and other cancers .

Flood cooling constitutes 600 million gallons of usage in the metal working industry. Of that number, the United States alone accounts for 175 million gallons. The use of the coolant is 10% to 17% of the total manufacturing cost .Bandyopadhyay et al. (2009). Another economic issue is the recycling of the machined chips. Flood cooling requires the chips to be cleaned before reuse. With MQL, the chips are virtually dry and there will not be a large cleaning expense for recycling as reported by Fratila et al. (2007).

A number of experimental tests have been performed in order to determine the effects that minimum quantity lubrication has on numerous variables when machining. These include the wear of the cutting tool as reported by Bhowmick et al.,(2010),Shaikh et al (2014), the cutting forces and the consumption of energy Vadim et al.(2006) ,quality of workpiece and tool Shaikh et al (2013), Boelkins, Chuck (2012),safety during machining Boubekri and Shaikh ,(2010) and (2012), pollutants produced and the vibrations associated the machine .Fratila et al. (2007), Rahim et al. (2010). However, limited studies have been performed to characterize the mist produced under MQL.

2. Objective of Study

The objective of this study is to evaluate the concentration levels and particle diameters of mist during the drilling of AISI 1018 steel. Acculube 6000 is the chosen minimum quantity lubricant. A total of four treatments is conducted, and the results are compared to OSHA and NIOSH metalworking mist standards.

3. Design of Experiment

The experiment as shown in table 1 is a randomized factorial design for mist characterization.

Table 1: Experimental Design for the Speed and Feed Rate Combinations.

Drilling Parameters		Cutting Speeds (SFM)	
		120	100
Feed Rates (IPR)	0.004	120, 0.004	100, 0.004
	0.003	120, 0.003	100, 0.003

4. Equipment Specifications

The tool used is a high-speed steel drill with TiN/TiAlN multilayer coating . The drill has a 118 degree point angle, a diameter of 0.5 inches, a straight flank, bright oxide finish and a maximum drilling depth between 1 - 1.5 inches. Guhring Inc manufactured the drills.

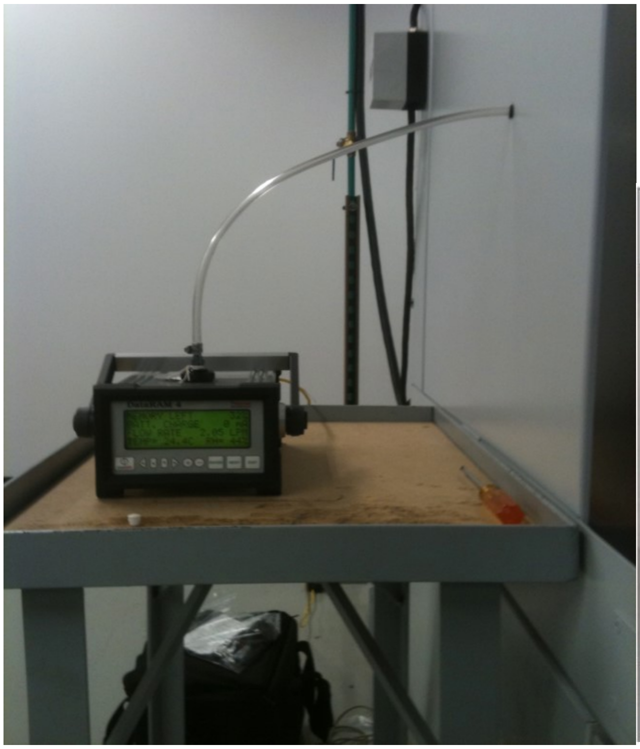
Mori Seiki DuraVertival CNC machining center was used to perform the drilling operations under MQL. This machining center has a maximum RPM of 10,000 and 15 horsepower. The filtration system is a LOSMA, Inc Darwin 2000M model. This model is a single-centrifuge filtration system used for air containing small quantities of particulate produced by the mist of soluble coolant or neat oils. The CNC's workspace is fully enclosed when in operation.

The machining center is equipped with an ECOSAVER KEB3 micro-lubrication system. This system was fitted to the CNC so that the lubricant was supplied externally through a nozzle. MQL supply air pressure can operate between 0.3 - 0.7 MPa and airflow ranging from 30 - 200 L/min. For this experiment, Accu-lube 6000 vegetable based lubricant was supplied under a flow rate of 11 ml/h. Its attributes are listed in Table 2.

Table 2: Properties of Accu-lube 6000 (vegetable based).

Characteristics	Values
Density	7.74 lbs/gallon
Appearance	Medium blue viscous
Specific Gravity	0.92
Viscosity at 40°C	8.9 cSt
Flash Point	418°F (214°C
Pour Point	. -40°F (-40°C
Sulfur	None
Chlorine	None
Silicone	None
VOC	Nil
Mineral Oil	0%
Water Solubility	Insoluble

The mist produced during drilling is measured with a Thermodynamic DataRAM 4 as shown in figure 1.Ambient mist concentrations are regulated by a Millipore filter. The filter is 37 mm in diameter and has a 0.8 micrometer cellulose ester membrane. During operation, the DataRAM 4 processes the airborne particulate matter by a light scattering sensing configuration. The instrument has a measurement range from 0.0001 to 400 mg/m³. The DR-4000 model is capable of storing 50,000 data points which include individual point averages and the median particle size (µm).



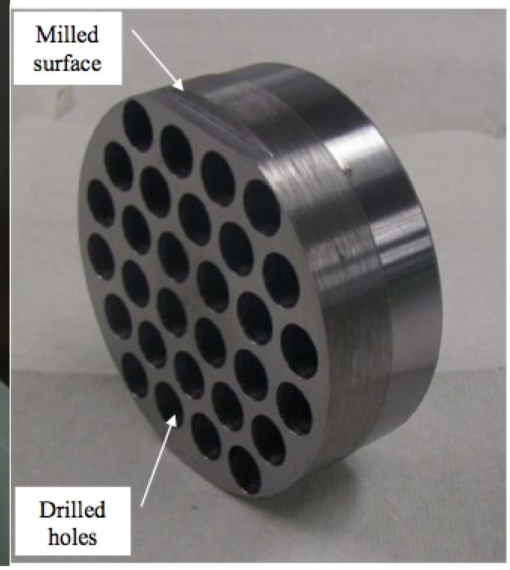


Figure 1: DataRam 4 Installation

Figure 2.workpiece

5. Data Collection

The DataRam 4 was configured so that a data point was recorded every second. After 30 holes were drilled into a workpiece as shown in figure 2, the DataRam 4 was stopped and the data was saved internally to the machine. The DataRam 4 was then connected to a computer to access the saved files. The resulting files produced were in Excel format. A tag number was assigned to each file, and each tag represented 30 holes. The last workpiece varied in hole number depending on when the tool failed. The concentration levels and particle diameter were then averaged for each individual workpiece. These values were then inputted into Design Expert in order to perform the analysis of the data

6. Analysis and Results

Design Expert was used to produce the ANOVA results and normal probability plots.

6.1 Normal Plot of Residuals

The normal probability plot as shown in figure 3, indicates a reasonable linear pattern for the center of data for mist concentration levels.

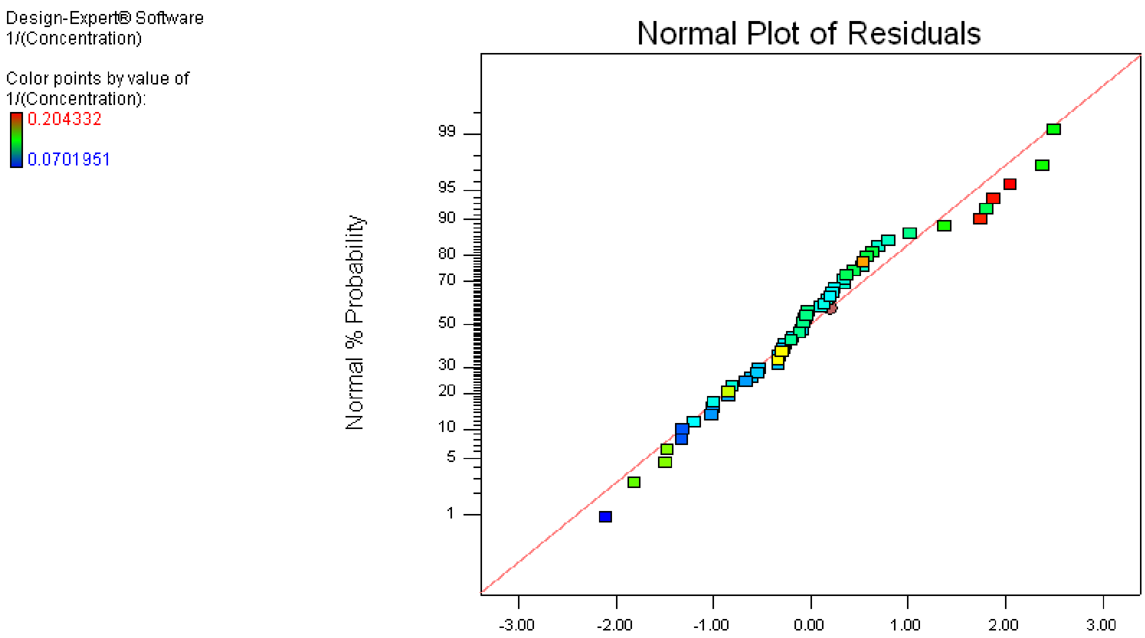


Figure 3: Normal Plot of Residuals for Concentration Levels of Mist

The normal probability plot as shown in figure 4, indicates a reasonable linear pattern for the center of data for the particle diameter

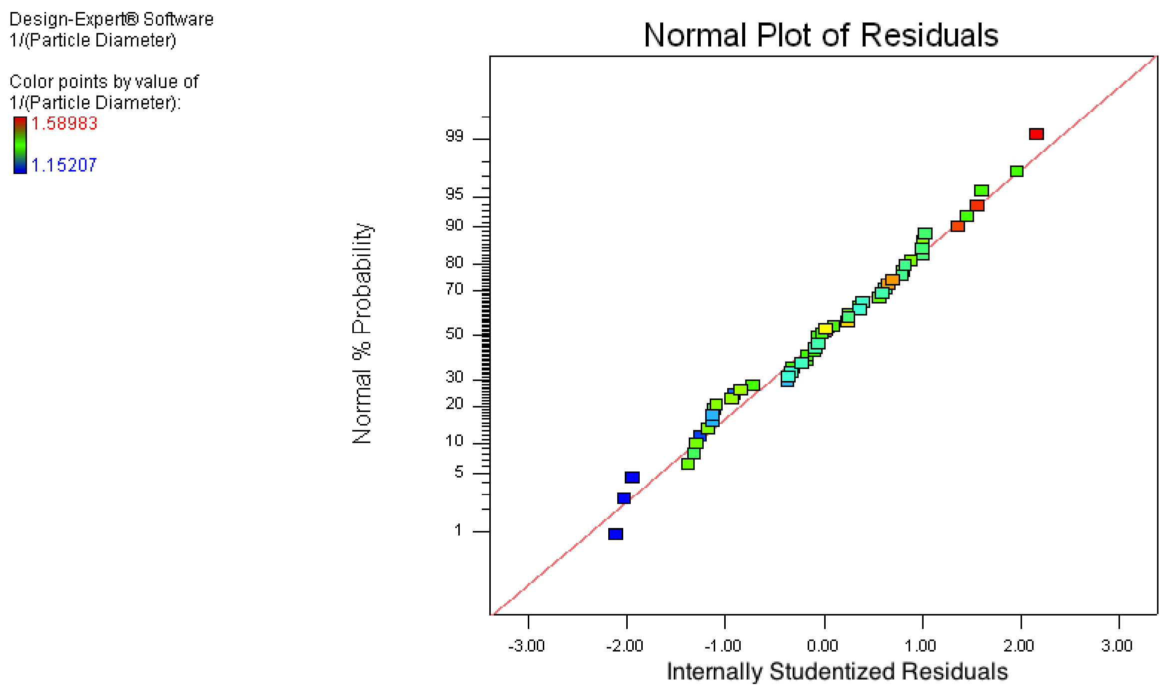


Figure 4: Normal Plot of Residuals for Particle Diameter of Mist

6.2 ANOVA Results for Mist Concentration

Table 3 shows the analysis of variance for the concentration levels of mist produced while drilling.

Table 3: Analysis of Variance for Concentration Level

ANOVA for selected factorial model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.041	3	0.014	62.01	< 0.0001	Significant
A-Speed	8.53E-03	1	8.53E-03	38.83	< 0.0001	
B-Feed	0.028	1	0.028	126.15	< 0.0001	
AB-Interaction	0.012	1	53.63	53.63	< 0.0001	
Pure Error	0.011	52	2.20E-04			
Cor Total	0.052	55				

Std. Dev.	0.015	**R-Squared**	0.7815
Mean	0.12	**Adj R-Squared**	0.7689
C.V %	12.37	**Pred R-Squared**	0.7438
PRESS	0.013	**Adeq Precision**	18.957

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.13	1	2.024E-03	0.12	0.13	
A-Speed	0.013	1	2.024E-03	8.55E-03	0.017	1.04
B-Feed	0.023	1	2.024E-03	0.019	0.027	1.01
AB-Interaction	0.015	1	2.024E-03	0.019	1.04	1.04

Final Equation in Terms of Coded Factors

1/Concentration = +0.13 + (0.013 * Speed) + (0.023 * Feed) + (0.015 * Speed * Feed)

The R-Squared for the resulting model is 78.15% indicating that the model is a good predictor.The “Pred R-Squared” of 0.7438 is in reasonable agreement with the “Adj R-Squared” of 0.7689. Finally, the “Adeq Precision” measures the signal to noise to ratio. A ratio greater than 4 is desirable. The ratio of 18.957 indicates a strong signal.

6.3 ANOVA Results for Particle Diameter

Table 4 shows the analysis of variance for the particle diameters of mist produced while drilling.

Table 4: Analysis of Variance for Particle Diameter.

Transformed: Inverse

ANOVA for selected factorial model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.42	3	0.14	52.07	< 0.0001	Significant
A-Speed	0.33	1	0.33	124.29	< 0.0001	
B-Feed	0.063	1	0.063	23.57	< 0.0001	
AB-Interaction	0.016	1	0.016	0.0184	0.0184	
Pure Error	0.14	52	2.66E-03			
Cor Total	0.55	55				

Std. Dev.	0.052	**R-Squared**	0.7503
Mean	1.35	**Adj R-Squared**	0.7358
C.V %	3.81	**Pred R-Squared**	0.71101
PRESS	0.16	**Adeq Precision**	16.351

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	1.35	1	7.04E-03	1.34	1.37	
A-Speed	-0.079	1	7.04E-03	-0.093	-0.064	1.04
B-Feed	0.034	1	7.04E-03	0.020	0.048	1.01
AB-Interaction	-0.017	1	7.04E-03	-3.02E-03	1.04	1.04

Final Equation in Terms of Coded Factors

1/diameter = +1.40 - (0.038 * Speed) + (0.036 * Feed) - (0.020 * Speed * Feed)

The R-Squared for the resulting model is 75.03% indicating that model is a good predictor. The "Pred R-Squared" of .7110 is in reasonable agreement with the "Adj R-Squared" of 0.7358. Finally, the "Adeq Precision" measures the signal to noise to ratio. A ratio greater than 4 is desirable. The ratio of 16.35 indicates a strong signal.

6.4 Frequency Distributions

Figure 5 shows the frequency distribution for the concentration levels.

Figure 6 shows the frequency distribution for the mist particle diameter

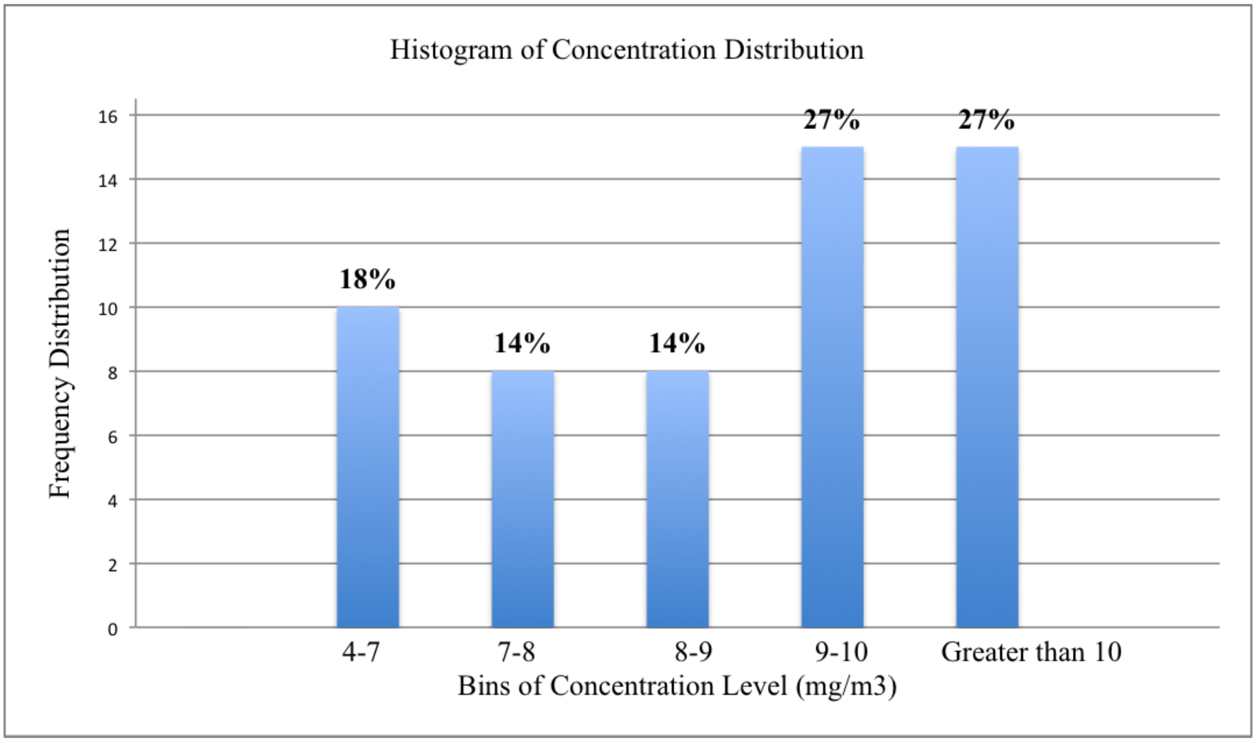


Figure 5: Frequency Distribution of Concentration Levels.

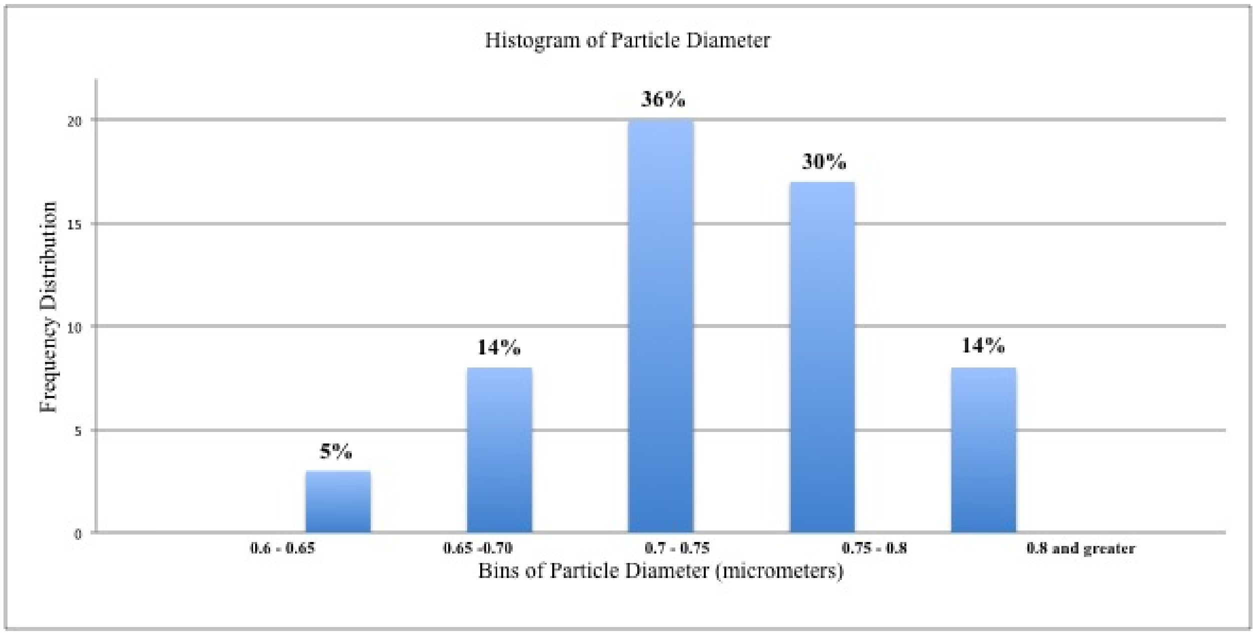


Figure 6: Frequency Distribution of Particle Diameter.

7. Conclusions and recommendations

As stated ealier,the National Institute for Occupational Safety and Health (NIOSH) recommends that the exposure level that workers encounter from metalworking fluids should be limited to 0.5 mg/m³ during a 10 hour day for a 40 hour workweek.The U.S. Occupational Safety and Health Administration (OSHA) states the permissible exposure level is 5 mg/m³ based on an 8 hour workday. All treatment combinations analysed in this study produced concentration levels greater than the rabove recommended levels. Moreover 82% of the resulting produced concentrations were greater than 7 mg/m³ indicating a definite high concentration if people are exposed. Though no guidlines exist for the resulting particles size,the results indicate that at least 86% of the resulting particle diameters were smaller than 0.8 µm which increases the likelihood of potential skin or respiratory problems if a person is exposed. While using MQL has its economic benefits,designing machine with high efficient mist collector systems and reliable enclosures to ensures worker safety is a paramount objective.

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