

Evaluation of Misting Controls to Reduce Respirable Silica Exposure for Brick Cutting

BRYAN R. BEAMER^{1*}, STANLEY SHULMAN², ANDREW MAYNARD²,
DENA WILLIAMS³ and DANIEL WATKINS²

¹University of Wisconsin-Stout, PO Box 790, Menomonie, WI 54751, USA; ²Division of Applied Research and Technology, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, 5555 Ridge Avenue, Cincinnati, OH 45213, USA; ³Division of Nutrition and Physical Activity, Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 4770 Buford Highway, NE Atlanta, GA 30341-3717, USA

Received 25 May 2004; in final form 25 January 2005; published online 21 April 2005

It is estimated that more than 1.7 million workers in the United States are potentially exposed to respirable crystalline silica, with a large percentage having been exposed to silica concentrations higher than the limits set by current standards and regulations. The purpose of this study is to characterize the use of water-misting engineering controls to reduce exposure to respirable crystalline silica for construction workers engaged in the task of brick cutting. Since data concerning the efficacy of engineering controls collected at worksites is often confounded by factors such as wind, worker skill level, the experiments were conducted in a laboratory environment. A completely enclosed testing chamber housed the brick-cutting saw. Respirable dust concentrations were measured using the Model 3321 Aerodynamic Particle Sizer[®]. Specifically, the laboratory experiment was designed to compare dust suppression through water misting using conventional freely flowing water techniques. Brass atomizing nozzles with three flow rates were used for making this comparison: low (5.0 ml s⁻¹ or 4.8 gal h⁻¹), medium (9.0 ml s⁻¹ or 8.6 gal h⁻¹) and high (18 ml s⁻¹ or 17.3 gal h⁻¹). The flow rate for freely flowing water, using manufacturer-supplied equipment, was 50 ml s⁻¹ (48 gal h⁻¹). The experiment consisted of five replications of five samples each (low-misting, medium-misting, high-misting, freely flowing water and no control). The order of sampling within each replicate was randomized. Estimates of dust reduction showed that low-misting nozzles reduced the respirable mass fraction of dust by about 63%, medium-misting nozzles by about 67%, high-misting nozzles by about 79% and freely flowing water by about 93%. Based on these results, it may be feasible to use misting to control respirable silica dust instead of freely flowing water. This strategy is of practical interest to the construction industry which must frequently limit the amount of water used on construction sites.

Keywords: construction; dust control; misting; silica; masonry cutting

INTRODUCTION

Silica, the chemical compound silicon dioxide (SiO₂), exists in several forms (NIOSH, 1994). Quartz, the most abundant crystalline form, is the most common mineral in the earth's crust (NIOSH, 1996). Respirable quartz is a particulate capable of reaching deep into the lung and is created by cutting, hammering, crushing, drilling, dumping, loading, chipping or hauling materials containing quartz, such as concrete and masonry brick (NIOSH, 1997; Ringen *et al.*, 1998).

Between 5 and 10% of the world's workforce serves in the construction industry (Ringen *et al.*, 1998). Construction workers are frequently exposed to respirable crystalline silica, which can not only lead to silicosis but also enhance the onset of tuberculosis, lung and stomach cancer, and kidney disease (Landrigan, 1987; Gonzalez *et al.*, 1991). In the United States, it is estimated that >1.7 million workers are potentially exposed to respirable crystalline silica, with a large percentage having been exposed to silica concentrations higher than limits set by current standards and regulations (NIOSH, 1991; Yereb, 2003). Specifically, the number of workers potentially engaged in brick cutting is ~165 000, according to US Bureau of Labor Statistics'

*Author to whom correspondence should be addressed.
Tel: +1 715 232 5178; fax: +1 715 232 5236;
e-mail: beamerb@uwstout.edu

estimates of the number of employed brick masons. The purpose of this study was to characterize the use of water-misting engineering controls to reduce worker exposure to respirable crystalline silica for workers engaged in the task of brick cutting. Specifically, three flow rates of brass atomizing nozzles were used as a control: low (5.0 ml s^{-1} or 4.8 gal h^{-1}), medium (9.0 ml s^{-1} or 8.6 gal h^{-1}) and high (18 ml s^{-1} or 17.3 gal h^{-1}). The flow rate for freely flowing water, using manufacturer-supplied equipment, was 50 ml s^{-1} (48 gal h^{-1}).

To control exposure to respirable crystalline silica, the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) provide recommendations and set limits, respectively, on occupational respirable crystalline silica exposure. NIOSH recommends an exposure limit of 0.05 mg m^{-3} as a time-weighted average (TWA) for up to a 10 h workday during a 40 h week. OSHA enforces a total dust permissible exposure limit (PEL) for respirable dust in mg m^{-3} equal to (OSHA, 2004): $10/[(\% \text{ quartz} + (\% \text{ cristobalite} \times 2) + (\% \text{ tridymite} \times 2) + 2)]$.

Several excellent articles have been published in recent years regarding the control of respirable crystalline silica exposure for construction workers. Much of this literature is summarized in a published literature review (Flynn and Susi, 2003). Specifically, the work in this research complements several articles that have been published in recent years (Thorpe and Ritchie, 1999; Linch, 2002; Rappaport *et al.*, 2003; Yereb, 2003).

The research presented in this article adds to previous research by looking specifically at misting as an engineering control to prevent respirable crystalline silica exposure for a table masonry/concrete saw. Although other research has shown the effective use of water in various situations, to the authors' knowledge no previous study has dealt with misting for masonry/concrete saws—a technology proven to lower dust levels in mining applications. Furthermore, misting was chosen for its potential practicality; misting typically uses less water and dries more

quickly than techniques using freely flowing water. Moreover, the research presented in this article does not attempt to evaluate other viable types of engineering controls such as local exhaust ventilation (LEV). Although LEV can be effective, it is not usually chosen by contractors because: of the high cost of vacuum systems robust enough for construction sites; electricity is not always available in the field; contractors frequently find it burdensome to change collection bags.

METHODS

Equipment

Data concerning the efficacy of engineering controls collected at worksites is often confounded by factors such as wind, differences in worker execution of task which can produce highly variable data. Therefore, testing was conducted in a laboratory environment in order to have more control over these types of variations and to generate more consistent data to optimize engineering control performance before field testing. To accomplish this, the experiment was conducted in a testing chamber with dimensions $1.2 \times 1.2 \times 3.7 \text{ m}$. To protect research personnel, the chamber was completely enclosed; during brick cutting, researchers had access to items inside the chamber only through gloves that were attached to a panel directly in front of the brick saw—a modification of the glove-box concept. A schematic representation and picture of the chamber are displayed in Figs 1 and 2, respectively. Furthermore, the selection of the brick and the blade were made to approximate fairly typical, real-world choices. For instance, the paving bricks chosen can be used in a wide variety of applications; also, the blade chosen was appropriate for both wet and dry cutting and is the same as, or similar to, those used in actual practice. However, the feed rate used in the experiments is slower than those typically used by contractors; this was done to minimize the chance of accidentally binding the brick in

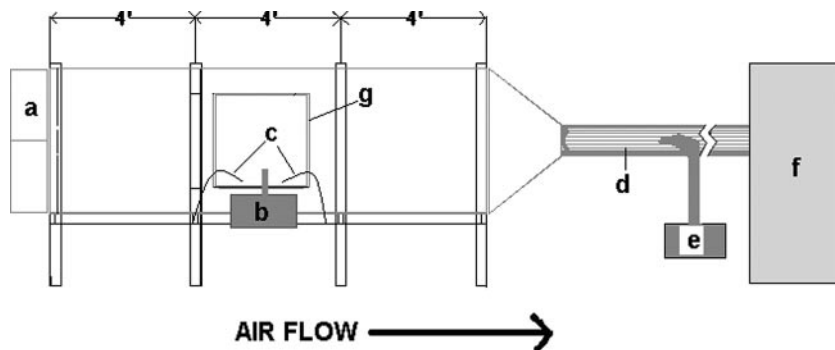


Fig. 1. Schematic representation of the testing chamber. a, HEPA filters; b, 14 inch portable electric masonry saw; c, brass atomizing nozzles; d, duct work; e, Model 3321 Aerodynamic Particle Sizer[®] spectrometer; f, air handling unit; g, location of glove-box type interface.

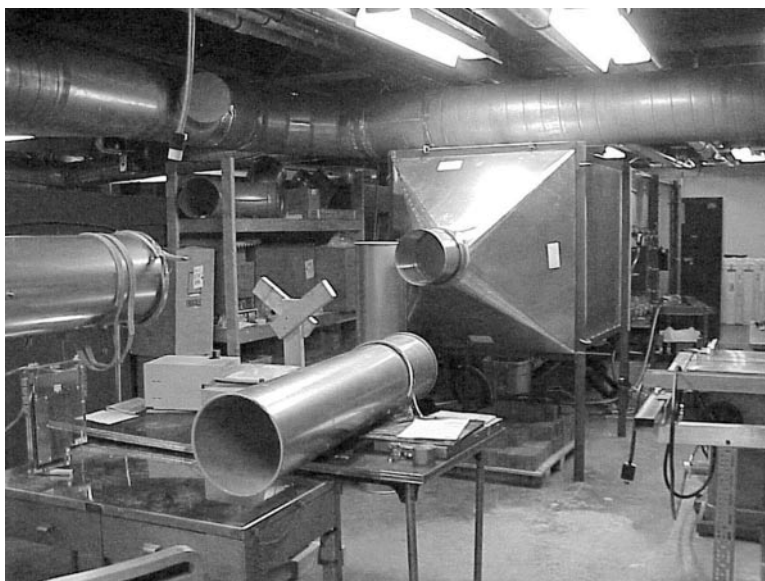


Fig. 2. The testing chamber: in this figure, the main section of the testing chamber is delineated by its structural members. The downstream ductwork has been removed for cleaning.

the saw blade since automatic equipment was used to maintain a constant feed rate.

An air handling unit (model no. PSK-1440, Polaris Industrial Ventilation Inc., Harbor Springs, MI) pulled outside air into the testing chamber through a bank of four high efficiency particle air (HEPA) filters (model no. AEI-251215974, AAF, International, Louisville, KY) at a flow rate of $1.46 \text{ m}^3 \text{ s}^{-1}$. HEPA filters can filter dust particles of $0.3 \text{ }\mu\text{m}$, the most penetrating particle size, in excess of 99.97% efficiency. Air then flowed $\sim 1.8 \text{ m}$ to a portable electric masonry saw, seen in Fig. 3 (model no. GMS-14, EDCO, Inc., Frederick, MD). The saw held a 0.36 m (14-in) diameter, wet/dry, masonry saw blade (model no. LW1412CP, Pearl Abrasive Co., Commerce CA). A 0.5 hp (370 W) motor (model no. 67413A, Dayton Electric Manufacturing Co., Niles, IL) controlled the feed rate of the brick saw to 4.7 mm s^{-1} . The motor was in turn controlled by a variable speed control (model no. 2M171E, Dayton Electric Manufacturing Co.). Solid-red patio brick ($5.7 \text{ cm} \times 9.2 \text{ cm} \times 19 \text{ cm}$, General Shale Brick, Johnson City, TN) from a single batch was used for all experiments. As the saw cut the brick, creating dust, different levels of water mist were sprayed on the brick and saw. The mist was produced by brass atomizing nozzles (Spraying Systems Co., Inc., Wheaton, IL). Three different types of nozzles were used: 2.1 ml s^{-1} nozzles (part no. 1/4M-2); 4.2 ml s^{-1} nozzles (part no. 1/4M-4); 8.4 ml s^{-1} nozzles (part no. 1/4M-8). Water used to supply the nozzles was non-recirculated city water. The city water pressure was regulated to about 6.9 kPa in the laboratory where testing took place.

Air was drawn past the dust-producing brick saw into 4.5 m of 0.3 m diameter ductwork at a velocity of

20 m s^{-1} ; the chamber and the length of ductwork was designed to maximize mixing to obtain an appropriately representative sample. Once the dust-laden air was in the ductwork, a sample was drawn into an isokinetic sampling probe; the nozzle for the isokinetic sampling probe has an inside diameter of 0.31 cm and a wall thickness of 0.076 mm . Over a length of 7.6 cm , the nozzle diameter expanded to 1.9 cm . This nozzle was mounted into the inlet of the 1.9 cm copper elbow that has a turning radius of 1.9 cm . A 0.23 m length of vertical copper tubing connected the elbow to the aerosol measurement system, which was set below the duct. The sample was drawn into a diffusion dryer (model no. 3062, TSI[®], Inc., Shoreview, MN) and subsequently measured by a TSI[®] Model 3321 Aerodynamic Particle Sizer[®] (APS) to determine particle concentration and size distribution. The APS provides particle aerodynamic size distribution by measuring the time-of-flight of individual particles in an accelerating flow field, and provides near-real-time information on size-resolved particle concentration between 0.37 and $20 \text{ }\mu\text{m}$. In this application, the APS provided rapid, high resolution measurements of aerosol size distribution under different test conditions, allowing multiple and repeat measurements to be made within a reasonable time period. Although instrument response is affected by sampling losses and particle detection rates, the use of comparative size distribution measurements minimized the impact of sampling biases on the data analysis. Collecting number concentration-based size distribution data allowed subsequent interpretation of measurements in terms of mass-based versus number-based control effectiveness against the respirable size fraction. The measured size distributions indicated

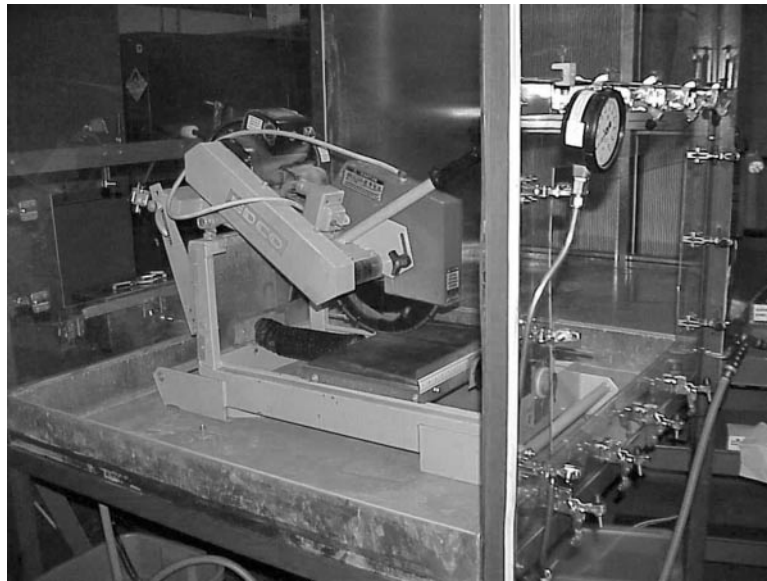


Fig. 3. In this figure, a section of the chamber downstream of the 0.35 m (14 in) electric brick saw was removed for a better view of the internal setup. When in operation, the location directly in front of the saw (to the right in the figure) is fitted with a glove panel to protect the experimenter from incidental exposure to respirable dust during the experiment.

negligible respirable aerosol mass concentration below the lower particle sizing limit of the APS.

Experimental design

First, optimal nozzle placement relative to the brick and blade interface was determined. It has been suggested in the literature that it is usually better to aim sprays at the material/blade interface than at the dust cloud produced by cutting (NIOSH, 2003). During preliminary experiments, this suggestion was confirmed by visually checking dust levels with spray nozzles aimed at (i) the stream of dust generated behind the cut, (ii) the brick/blade interface and (iii) primarily on the blade above the cutting interface. It was clear that blade placement was most effective nearest the brick/blade interface and it was also reasoned that contractors would be more likely to use the control if it aided in preventing tool wear (i.e. aimed at the cutting interface rather than at the dust stream).

To test the effectiveness of misting at three different flow rates versus freely flowing water, a single factor consisting of five different water levels was used in experiments:

- (i) Two 2.1 ml s^{-1} nozzles were positioned on either side of the blade $\sim 3 \text{ cm}$ away from the brick and the saw blade. See Figs 4 and 5 for the approximate position of nozzles for all testing. When both 2.1 ml s^{-1} nozzles were in use, the total flow of water to the brick/saw blade interface was $\sim 5.0 \text{ ml s}^{-1}$ or 4.8 gal h^{-1} .
- (ii) Similarly, two 4.2 ml s^{-1} nozzles were positioned on either side of the blade providing a total flow of about 9.0 ml s^{-1} or 8.6 gal h^{-1} .

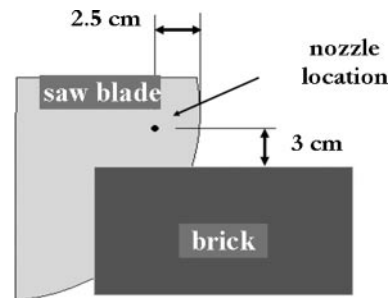


Fig. 4. Side view of nozzle placement relative to the brick and saw blade.

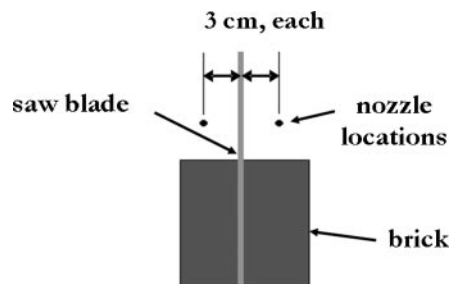


Fig. 5. Front view of nozzle placement relative to the brick and the saw blade.

- (iii) Moreover, two 8.4 ml s^{-1} nozzles were positioned on either side of the blade providing a total flow of $\sim 18 \text{ ml s}^{-1}$ or 17.3 gal h^{-1} .
- (iv) Allowing water to flow freely over the blade was also tested as an engineering control. For freely flowing water controls, the built-in water delivery system of the EDCO brick saw was

used. Specifically, water was delivered to the blade through a water delivery nozzle built by the manufacturer into the top of the shroud surrounding the saw blade—this allowed gravity to deliver the water to flow freely over the blade during use. This scenario required the use of $\sim 50 \text{ ml s}^{-1}$ or 48 gal h^{-1} of water use.

- (v) Dust generation rates using no control (or a water level of zero) were also measured to provide a baseline for the experiments.

Five replicates, each consisting of five tests (one for each water level, above), were completed. Within each replicate, the order of tests was completely randomized. In addition, all cuts for each replicate were made on the same brick to minimize the effects of brick to brick variation.

Each test consisted of (i) a 360 s background sample, during which water was applied to the rotating blade, but no brick cutting was carried out, followed by (ii) a 360 s brick-cutting sample. Since the intent of the experiment was to determine the effect of engineering controls on respirable dust levels, only the respirable fraction of dust was considered. For each 6 min brick-cutting sample, three cuts were made. In order to minimize the effects of background particulate and droplet levels on test results, each 6 min background sample was subtracted from its corresponding 6 min brick-cutting sample. Therefore, results reported for each test (i) represent the particle count for respirable fraction of dust; (ii) have been corrected for background (by subtracting appropriate background particle counts) and (iii) were measured by making three cuts per sample.

Respirable fraction of dust and respirable mass fraction of dust

The respirable fraction of dust and the respirable mass fraction of dust were subsequently computed from this raw data since they represent the data that

are essential for research on engineering controls to reduce exposure to respirable crystalline silica. The respirable fraction was calculated using the appropriate ISO convention (ISO, 1995). Specifically, the respirable fraction data were generated by multiplying particle counts by the respirable-fraction factor for each individual particle size. The respirable mass fraction data were then computed by multiplying the respirable fraction data by particle mass (assuming spherical particles) for each individual particle size. As additional measures of control effectiveness, the percentage reduction and the corresponding 95% lower confidence limit (LCL) for (i) the respirable fraction of dust and (ii) the respirable mass fraction of dust are reported for each treatment. Confidence intervals presented are simultaneous 95% intervals, for the various comparisons of interest: ratio of each control to no control (four comparisons) and ratio of one control to another (two comparisons: freely flowing to mist-high and mist-high to mist-low). Because six comparisons were made, the confidence intervals (computed on the natural log scale) used the value of Student's *t* corresponding to the 100 $(1-0.05/6) = 99.17\%$ confidence level, in order to maintain an overall error rate of 5% for all six comparisons.

RESULTS

No control

The test results from four replicates (excluding replication 2), when using no engineering controls, indicate a range of $1.5\text{--}2.2 \times 10^6$ particles corresponding to the respirable fraction of dust. The mean over four replicates was 1.8×10^6 particles (see Tables 1 and 2, and Figs 6 and 7 for details).

Mist-low

The results from four replicates using two 2.1 ml s^{-1} misting nozzles (5.0 ml s^{-1} or 4.8 gal h^{-1} total flow)

Table 1. Particle counts for the respirable fraction of dust and their natural log

Replication	No control	Mist-low	Mist-medium	Mist-high	Freely flowing water
Particle counts for the respirable fraction of dust					
1	1.5×10^6	6.6×10^5	5.0×10^5	3.0×10^5	1.4×10^5
2	<i>4.1×10^5</i>	<i>2.8×10^5</i>	<i>4.2×10^5</i>	<i>1.6×10^5</i>	<i>8.1×10^4</i>
3	2.0×10^6	5.1×10^5	5.1×10^5	3.1×10^5	1.1×10^5
4	1.8×10^6	7.5×10^5	5.7×10^5	3.5×10^5	1.3×10^5
5	2.2×10^6	6.0×10^5	5.4×10^5	3.2×10^5	7.3×10^4
Natural log—particle counts for the respirable fraction of dust					
1	14.2	13.4	13.1	12.6	11.9
2	<i>12.9</i>	<i>12.5</i>	<i>12.9</i>	<i>12.0</i>	<i>11.3</i>
3	14.5	13.1	13.1	12.6	11.6
4	14.4	13.5	13.2	12.8	11.8
5	14.6	13.3	13.2	12.7	11.2

Italicized data were considered anomalous and were not included in subsequent summary statistics included in this report.

indicate an average particle count of 6.3×10^5 particles for the respirable fraction of dust. These data indicate a 67% (95% LCL 52%) reduction in the background-corrected respirable fraction of dust compared with no control. The reduction in the respirable mass fraction compared with no control is 63% (95% LCL 48%).

Mist-medium

The results from four replicates using two 4.2 ml s^{-1} misting nozzles (9.0 ml s^{-1} or 8.6 gal h^{-1} total flow) show an average particle count of 5.3×10^5 particles for the respirable fraction of dust. These data indicate a 72% (95% LCL 60%) reduction in the background-corrected respirable fraction of dust compared with no control. The reduction in the respirable mass fraction compared with no control is 67% (95% LCL 54%).

Mist-high

When using two 8.4 ml s^{-1} misting nozzles (18 ml s^{-1} or 17.3 gal h^{-1} total flow), an average particle count of 3.2×10^5 particles is generated

Table 2. Percentage reduction in the respirable fraction of dust and the respirable mass fraction of dust and simultaneous 95% lower confidence limits

Water level	Percentage reduction estimate (%)	95% Lower confidence limit (%)
Respirable fraction		
Mist-low	67	52
Mist-medium	72	60
Mist-high	83	76
Freely flowing water	94	92
Respirable mass fraction		
Mist-low	63	48
Mist-medium	67	54
Mist-high	79	71
Freely flowing water	93	90

for the respirable fraction of dust. These data indicate an 83% (95% LCL 76%) reduction in the background-corrected respirable fraction of dust compared with no control. The reduction in the respirable mass fraction compared with no control is 79% (95% LCL 71%).

Freely flowing water

The results from four replicates of freely flowing water show an average particle count of 1.1×10^5 particles for the respirable fraction of dust. These data indicate a 94% (95% LCL 92%) reduction in the background-corrected respirable fraction of dust compared with no control. The reduction in respirable mass fraction compared with no control is 93% (95% LCL 90%).

Other comparisons

The above results do not indicate the results of statistical comparisons between freely flowing water and the different mist levels. For either of the two response variables, the reduction of freely flowing water relative to high mist is at least 50%, at the 95% confidence level. The reduction of high mist to low mist is at least 22% for either of the two response variables. When the no-control data are removed, the relationship between the water flow rate and either response variable is linear in terms of the water flow rate. From the line fitted to these data, it is possible to determine the misting flow rate that would give measurements levels that are statistically indistinguishable (5% level) from the freely flowing water—between 37 and 42 ml s^{-1} (35 and 40 gal h^{-1}) for either response variable (although because of the negative slope in the line the predicted levels for misting at 42 ml s^{-1} still exceed those for freely flowing water).

Notes on statistics

In the measured data for replication 2, results were anomalous compared with other data. To illustrate

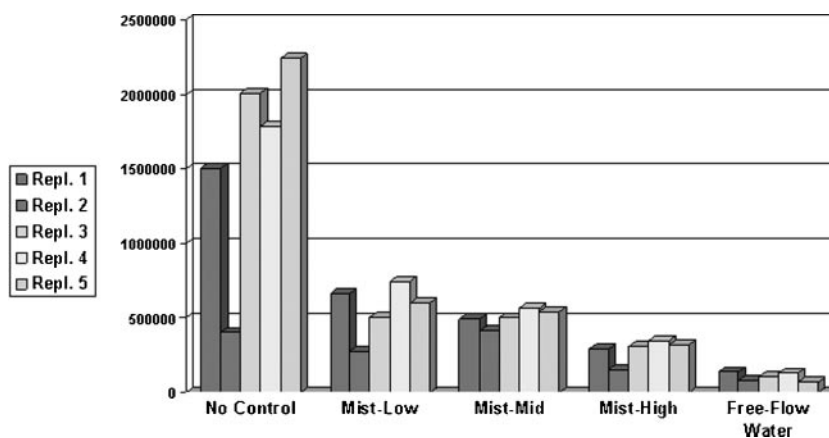


Fig. 6. Particle counts for respirable fraction of dust.

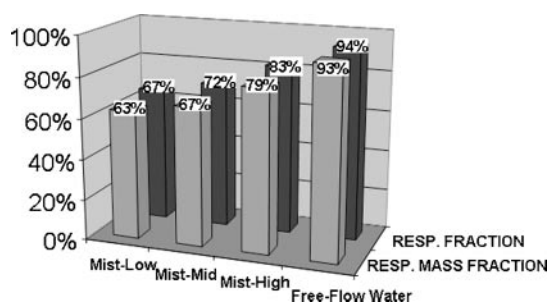


Fig. 7. Percent reduction for respirable fraction of dust and respirable mass fraction of dust.

this irregularity, particle counts of the respirable fraction of dust are given in Table 1. Furthermore, since the differences between the no control and controlled levels are so large, the natural log of these values are included in Table 1. It is apparent that several of the values of replication 2 are exceptional compared with other experimental values. For instance, the 'no control' natural log value for replication 2 is 12.9, while the closest corresponding value is 14.2 from replication 1. Other values for replication 2 indicate a similar trend. Since a specific reason for the irregularities in replication 2 cannot be determined, the authors judged that the most appropriate approach would be to eliminate data from replication 2 in the computation of (i) the particle counts for the respirable fraction of dust, (ii) the percentage reduction in the respirable fraction of dust and (iii) the percentage reduction in the respirable mass fraction of dust. That all data from replication 2 are related and should be eliminated is underscored by the fact that testing within each replication, while randomized, was completed on the same day and on the same brick.

CONCLUSIONS / RECOMMENDATIONS

In summary, the experiments in this research consisted of five replications of five samples each (low-misting, medium-misting, high-misting, freely flowing water and no control). The order of sampling within each replicate was randomized. The estimates of dust reduction showed that low-misting nozzles reduced the respirable mass fraction of dust by ~63%, medium-misting nozzles by ~67%, high-misting nozzles by ~79%, and freely flowing water by ~93%.

It should be noted that freely flowing water reduced the respirable fraction of dust by ~94%, suggesting that properly used freely flowing water is effective in reducing exposure to respirable crystalline silica during brick cutting. A second related issue is—which misting flow rate would produce results similar to freely flowing water? For instance, when aberrant data from replication 2 are not considered,

the data for the respirable mass suggest that the effectiveness of a misting flow rate between 37 and 42 ml s⁻¹ (35 and 40 gal h⁻¹) would be statistically indistinguishable from the effectiveness of freely flowing water; similar results are obtained on examining the data for the respirable fraction of dust. Therefore, if we accept the conclusions that (i) freely flowing water is effective in reducing respirable crystalline silica levels and (ii) misting with water flow rates less than or equal to freely flowing water may be equally effective, the question remains—is misting at a flow rate similar to freely flowing water more practical for use in the field than freely flowing water?

There are several reasons to believe that misting at flow rates similar to freely flowing water is not inherently more practical for field use in the construction industry than freely flowing water techniques. First and foremost, even if less water is needed for misting, the difference in flow rates and the corresponding benefits would be marginal. Moreover, the use of misting as an engineering control on construction sites requires using much the same equipment that freely flowing water uses, and so misting does not make the setup easier for the operator. In addition, architects still call for the use of dry cutting in some instances as it is believed that wet cutting can stain bricks. Although this assumption is debatable, it is not likely that the use of misting as an engineering control will meet the requirements for dry cutting bricks as the bricks are still exposed to moisture.

There is, however, a basis to suppose that misting may be a viable option for brick saw manufacturers and construction contractors as an engineering control to reduce worker exposure to respirable crystalline silica. First, since mist is an aerosol, it tends to dry much more quickly than freely flowing water techniques. This can be of benefit at construction sites where run-off from the brick-cutting process causes problems like increased clean-up time or slips and falls. Furthermore, the research presented in this report is preliminary and it is quite possible that results can be improved with enhancements in technique so that misting at lower flow rates can produce higher reductions. For instance, the position of the misting nozzles used in this research was worked out based on several preliminary trials, but more extensive research dedicated to the best location for a given flow rate could produce better results. Furthermore, modeling of the misting controls using computerized fluid dynamics or some other modeling scheme might demonstrate how to increase the effectiveness of misting as an engineering control.

It is the authors' hope that the research presented in this article can be used to develop misting controls into a viable, desirable control technology that can be incorporated into brick-cutting equipment

by manufacturers. To this end the following suggestions are made for appropriate follow through:

- Further research should be carried out to validate the hypothesis that misting nozzles at sufficiently high water flow rates can provide as much protection as freely flowing water in reducing respirable dust levels to workers engaged in brick cutting.
- Improvements to the misting delivery system should be made to increase control effectiveness while using as little water as possible. It is believed that this optimal level will provide the largest potential benefit to construction contractors. This optimization can take place through modeling of the system or experimental trial and error.
- Once optimal settings for the misting delivery system are attained, it should be verified in field testing that the system adequately reduces worker exposure to respirable crystalline silica.
- Most importantly, however, future research should be coordinated with partners that represent the labor force, contractors and brick saw manufacturers to ensure that there is interest in pursuing misting as a practical option for engineering controls.

REFERENCES

- Flynn MR, Susi P. (2003) Engineering controls for selected silica and dust exposures in the construction industry—a review. *Appl Occup Environ Hyg*; 18: 268–77.
- Gonzalez C, Sanz M, Marcos G *et al.* (1991) Occupation and gastric cancer in Spain. *Scand J Work Environ Health*; 17: 240–7.
- ISO. (1995) Air quality—particle size fraction definitions for health-related sampling. ISO 7708. Geneva. Switzerland: International Organization for Standardization.
- Landrigan P. (1987) Silicosis. *Occup Med: State Art Rev*; 2: 319–26.
- Linch KD. (2002) Respirable concrete dust-silicosis hazard in the construction industry. *Appl Occup Environ Hyg*; 17: 209–21.
- NIOSH. (1991) Work-related lung disease surveillance report. Cincinnati, OH: US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 91–113. p. 38.
- NIOSH. (1994) NIOSH manual of analytical methods (NMAM). 4th edn. Cincinnati, OH: Department of Health and Human Services. Method 7501; issue 2.
- NIOSH. (1996) Preventing silicosis and deaths in construction workers.. Available from: <http://www.cdc.gov/niosh/consilic.html> (accessed 5 December 2004).
- NIOSH. (1997) Construction workers: it's not just dust! Available from: <http://www.cdc.gov/niosh/pdfs/1997-101.pdf> (accessed 14 December 2004).
- NIOSH. (2003) Handbook for dust control in mining; Information Circular 9465. Cincinnati, OH: US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2003–147: pp. 7–8.
- OSHA. (2004) Permissible exposure limits for silica. Available from: http://www.osha.gov/SLTC/etools/silica/compare_to_limit/pel/pel.html (accessed 14 December 2004).
- Rappaport SM, Goldberg M, Susi P, Herrick RF. (2003) Excessive exposure to silica in the US construction industry. *Ann Occup Hyg*; 47: 111–22.
- Ringen K, Seegal JL, Weeks JL. (1998) Chapter 93—Construction. In Stellman JM, editor. *Encyclopedia of occupational health and safety*. 4th edn. Geneva: International Labour Organization.
- Thorpe A, Ritchie AS. (1999) Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. *Ann Occup Hyg*; 43: 433–56.
- Yereb, J. (2003) Evaluation of dry and wet block cutting and recommendation for a masonry company. *Appl Occup Environ Hyg*; 18: 145–50.