Effectiveness of dust control by atomisation of water sprays on handheld demolition and soil compacting equipment

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Summary

A field study was conducted to investigate the effectiveness of atomisation of water as a method of dust control during the use of jackhammers and plate compactors. The study consisted of two substudies, both designed as intervention studies, where task-based respirable quartz concentrations were assessed. In addition, real-time dust concentrations were monitored

In a first (sub)study, three workers located in a hall used a heavy jackhammer cutting concrete slabs. Each activity was performed four times, twice with and twice without atomisation. Two other workers were involved in scrapping tiles from bathroom walls using a light jackhammer. The activity was performed twice, with and without atomization in identical

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bathrooms. For both types of jackhammers, significant reductions of quartz exposures were shown. On average quartz exposure decreased 86% with use of atomisation during scrapping tiles, whereas the use of atomisation during demolition of concrete slabs reduced quartz exposure with 64%. However, average quartz exposure during the activity still exceeded Dutch OEL (MAC).

In the second (sub)study soil was compacted in an indoor hall using two types of plate compactors: a heavy and a light weight type. For both types of plate compactors 8 datapoints (4 with and 4 without atomisation) were generated. For the light plate compactor, atomisation reduced quartz exposure with approximately 88%, where no significant reduction could be observed for the heavy weight type. During atomisation the average quartz exposure using the light type of plate compactor was below the OEL. During the use of the heavy plate compactor the average exposure level during the work exceeded the OEL.

For both jackhammers and plate compactors it was concluded that a substantial reduction of the quartz exposure could be achieved by atomization using low water volumes, however average levels of exposure were still high compared to the OEL. Optimization of the atomisation and or additional control measures, e.g. exhaust ventilation mounted on the equipment, might be necessary for a further reduction of exposure.

Introduction

Occupational exposure to respirable quartz has been associated with considerable damage of the lungs, e.g. obstruction of the lungs and lung emphysema and silicosis [Hnizdo and Vallyathan, 2003; Castranova *et al.*, 1996; Parkes, 1985]. In a survey in the Dutch construction industry, recess millers, inner wall constructors, and demolition workers showed personal quartz exposures well above the Dutch limit value of 0.075 mg/m^3 (GM 0.5 mg/m^3; GSD 5.6; N=171) [Lumens and Spee, 2001]. In another study, full shift exposure measurements to respirable quartz dust among 34 high exposed workers also revealed exposure concentrations above the Dutch limit value (GM 0.091 mg/m^3; GSD 7.0); N= 67 [Tjoe Nij *et al.*, 2004]. The results of both studies emphasize the need for adequate control measures.

Mody and Jakhete [1988] systematically described different types of dust control mechanisms, e.g. moisture supply to reduce the generation of dust, dust removal by ventilation, and dust removal by spraying water. In general, to capture large dust particles by ventilation a high air speed is required, resulting in heavy load systems and high energy costs. Therefore, non-ventilation types of control, e.g. wet dust suppression techniques, have been explored over the last decade. Water enhances moisture bridges that result in an increase of adhesion forces and the formation of conglomerates. This will reduce the formation of dust. The effectiveness of such an approach has been demonstrated in mining [Volkwein *et al.* 1989]. When dust particles have become aerosols, they may be removed from the air by collision with water droplets and concomitant impaction of the agglomerates. Murfitt and Seymour [1989] demonstrated that preventing particles to become airborne, i.e by wet dust suppression, is more effective than removal of aerosols. The effectiveness of the process of knocking down aerosols can be improved by atomisation of water resulting in droplet sizes similar to the size of the dust particles.

Generally, dust suppression by means of water spraying requires large volumes of water. In a review on engineering controls for exposures in the construction industry Flynn and Susi [2003] reported wet-cutting operations to provide significant reduction of quartz exposures, but they suggested that a flow rate of approx 1.9 L/min would be the indicated minimum. Thorpe *et al.* [1999] showed that supply of pressurized water during cut-off sawing of concrete slab reduced quartz exposure of the operator significantly. However, water flow rates seemed to exceed 1 L/min. Spee *et al.* [1998] demonstrated that the use of high pressure and low flow water sprays reduced respirable dust exposure significantly. Recently, Echt *et al.* [2003] reported a very effective reduction of exposure using a low water flow rate (0.35 l/min) dust control system for a jackhammer during operations with reinforced concrete pavement. All these studies indicate that water atomisation has the potential to reduce quartz dust exposures in the construction industry significantly. To investigate the potential for different types of dust and quartz generating processes in the construction industry an intervention type of study was conducted.

Materials and Methods

Experimental

The study consisted of two sub-studies, both designed as intervention studies. During both sub-studies, a series of measurements was conducted with water atomisation switched off and another with atomisation switched on. One sub-study (sub-study I) consisted of demolition activities, whereas the other (sub-study II) consisted of compacting soil .

Sub-study I

Two types of electrical powered jackhammers were involved in the demolition sub-study. A heavy (high capacity) jackhammer [Wacker EHB 7, beat frequency 1300 - 2100 b/min, weight approximately 9 kg] was used while cutting concrete slabs. The slabs were placed in an open container of approximately 15 m^2, located in a hall of 30 x 25 m and a height of 5.5 m. Doors of the hall were kept close during the experiments. Two hollow cone spray nozzles (BEX Sproei Techniek, Rotterdam, The Netherlands) operating at a 5 bar pressure and a flow rate of approximately 0.085 L/min for each nozzle, *i.e.* in total 0.17 L/min, were mounted to the hammer in the vicinity of the chisel. Water was supplied from a backpack 15 L water tank.

Three workers performed activities during replicates of approx. 34 min (range 32 to 38 min). For each worker two replicates with and without atomisation were taken. Water consumption during the replicates was determined by weighing the water tank prior and following the experiments. A

Table I: Summary of the results of quartz exposure and real-time dust monitoring as time weighted average concentrations during the experiments

Equipment	Atomiser (on/off)	Mean duration (min)	Mean water flow rate (L/min)	Quartz Concentration (mg/m3)		Real-time dust concentration (mg/m3)	
				AM	Range	AM	Range
Jackhammer light HL	Off (n=4)	81	NA	1.63 [B]	1.51 [B] - 1.75 [B]		53.3- 87.6
				0.24 [C]	0.12 [C] - 0.34 [C]	NA [D]	14.3 - 21.1
	On (n=4)	60	0.19	0.24 [B]	0.21 [B] - 0.26 [B]		14.6 – 39
				0.36 [CD]	0.04 [C] - 0.67 [C]	NA	1.6 - 15.1
Jackhammer 'heavy' HH	Off (n=6)	34	NA	0.47	0.08 - 0.66	7.3	3.9 - 18.5
	On (n=6)	35	0.17	0.17	0.02 [E] -0.36	1.1	0.5 - 1.5
Plate compactor light CL	Off (n=4)	30	NA	0.47	0.15 - 0.79	11.1	5.9 - 17.1
	On (n=4)	30	0.93 [A]	0.06	0.02 [E] - 0.169	1.4	1.3 - 1.5
Plate compactor heavy CH	Off (n=4)	30	NA	0.22	0.11 – 0.40	7.8	6.4 – 9.0
	On (n=4)	30	0.93 [A]	0.17	0.08 – 0. 25	3.4	1.7 – 5.4

[NA] Not Applicable
[A] Estimated from theoretical flow rate
[B] Removal of wall tiles (n=2)
[C] Removal of floor tiles (n=2)
[D] Unreliable due to large variation
[E] ½ LOQ based on LOQ quartz and sampling flow

light (low capacity) jackhammer (Hitachi 3/4 " Hex, 21/32" Round Skank, beat frequency 3000 b/min, weight approximately 4.8 kg), provided with a single spray nozzle (operating at a 5 bar pressure and water flow rate approx. 0.19 L/min) was used to remove tiles from bathroom walls and floors. The water supply tank was located in the vicinity of the workplace. Water consumption during the replicates was also determined by weighing the water tank prior and following the experiments The bathrooms (n=4) were located at the first floor of houses that were under reconstruction and had similar dimensions (ground surface area 1.85 m², height 2.4 m). Each bathroom had a door (2.1 x 0.8 m) and a window (0.3 x 0.4 m) that was kept closed during the activities. However, during the removal of wall tiles without atomisation the window had to be opened after approximately 30 min for better view, as this was obscured by high dust levels. Therefore, this procedure was repeated in each experiment. The total surface area of the wall tiles was about 10.5 m². Two workers performed two types of activities. Two replicate samples were taken during removal of all wall tiles (± 10.5 m²) from a single bathroom with and without atomisation and two samples during removal of a part of the floor tiles (± 0.3 m²) from a single bathroom with and without atomisation. During this study, the surface area treated was kept constant for the different experiments instead of a fixed period of time.

Sub-study II

The experiments for compacting soil using plate compactors were conducted in an indoor examination hall of a training centre for pavement workers. The ground surface area of the hall was approx. 100 x 25 m and the height 5 m, whereas the test field for actual soil compaction was 270 m². Doors were kept closed during the experiments. The quartz content of the soil was ± 31 % (w/w). For two types of plate compactors in total 16 replicates of 30 min were collected: 8 for each type consisting of 4 replicates with and 4 replicates without atomisation. The lightweight type soil compactor (Errut PC 400), weighed 81 kg and had a flat plate and a tamping frequency of 6000 b/min. The heavy weight type was a Wacker DPU 6055 type with a tamping frequency of 4140 b/min. It had a V-type of plate and weighed 449 kg. At all four sides flat spray nozzles were mounted with a spraying angle of 90 – 95°, operating at a pressure of 1 bar. Water was supplied directly from the tap by a hose. The water supply flow rate was set at 1 L/min, assuming to result in a flow rate of 0.23 L/min for each spray nozzle.

The study protocol was approved by the Medical Ethics Committee, and all test subjects volunteered to participate in

Table II: Percentage of reduction obtained by atomisation for different equipment

Type of equipment	Reduction based on quartz exposure[A] (%)	Reduction based on 'dust' exposure[A] (%)
Jackhammer light [B] (HL)	86	73
Jackhammer heavy (HH)	64	85
Plate compactor light (CL)	88	87
Plate compactor heavy (CH)	[C]	56

[A] *Reduction (%) = [1 – 1/ (AM atomiser off/ AM atomiser on)] * 100*
[B] *Result based on observations during the removal of wall tiles only*
[C] *No reduction factor could be derived since no statistically different mean exposure could be observed*

the study. Prior to enter the study the test subjects were informed in writing about object and methods of the study and an informed consent form was completed. Prior to each replicate the test subjects were provided with clean work clothing to prevent contamination from previous activities.

Sampling and analysis

Respirable dust samples were collected on Millipore mixed cellulose ester filters (0.8 µm, 25mm) using cyclones (BCIRA-type, SKC, UK) as sampling heads in combination with Gillian Gilair constant flow pumps at a flow rate of 1.9 L/min. The pump flow was checked prior to and following the sampling using a calibrated rotameter. Blank field samples were collected during each sampling period in an uncontaminated room close to the test sites.

The filters were weighed prior and post sampling and sent to an external laboratory (Miljø Kemi, Galten, Denmark) to determine the content of crystalline quartz in the respirable dust. The analysis was performed by IR-photo ionisation detection (wavelength 700-800 cm^{-1}) according to NIOSH method 7602, adjusted by the laboratory. The filters were incinerated during 24 hours at 200 °C followed by a period of 48 hours at 370 °C. After incineration the ash was mixed with potassium bromide in a mortar and pelletised. The limit of quantification was 2 µg (CV 10-20%), resulting in a LOQ for a 30 min sampling period of 0.018 mg/m^3.

Material samples, collected at each test site, were also analysed for quartz. However, the incineration step was skipped during the sample preparation.

In addition, the test subjects were provided with a DataRAM (Type 1000 MIE Personal Dataram, MIE Inc, USA) to assess real-time dust concentrations. This is a direct-reading aerosol monitor based on detection by (IR) light scattering that responds to particles in the range of 0.1-10 _m with a dynamic range of 0.001 to 400 mg/m^3. Sampling intervals of 1 s were chosen. The DataRAM is calibrated with Arizona Road Dust and not with dust from construction sites, so the results cannot be considered representative for respirable construction dust. Therefore the results may be used for mutual comparison only.

After collection the logged data were read into a personal computer using an EXCEL (Microsoft®) spread sheet program. Temperature and relative humidity were monitored over each min during the sampling periods, using a Vaisala HMP 31 UT probe in combination with a Grant Squirrel 1201 datalogger. During the experiments material samples were collected for the determination of the quartz content. Additionally the moisture content of the soil was determined in Sub-study II by comparison of sample weights prior and after period of residence of minimum 5 hours in an exsiccator. Samples were collected by scooping some soil after compaction (up to a depth of 2 cm). All observations, raw data and the results of the chemical analysis were transferred to an EXCEL spreadsheet. Descriptive statistics were performed, analytical results reported as below LOQ were substituted by values $^1/_2$ LOQ. For datasets consisting of results for the same persons with and without atomisation t-tests for paired samples were performed. For all other datasets t-tests for means with unequal variances were used. A significance level of $p < 0.05$ was used. Pearson correlation was calculated between quartz concentration and average dust concentrations as determined by the real-time dust monitoring. Reduction of exposure was calculated using the arithmetic means of either quartz concentrations or real-time dust concentrations.

Reduction (%) = [1 – 1/ (AM atomiser off/ AM atomiser on)] * 100 (1)

Results

Test conditions

The experiments during demolition using the heavy type of jackhammer were conducted on two consecutive days where temperature and RH were 12 °C ± 1 and 66% ± 2.5 respectively. The quartz content of the slabs was approximately 16% (w/w).

The experiments with the light type of hammer were performed within a three weeks period on 4 separate days. The time needed to complete the job differed significantly (p = 0.024) between the experiments with (average 60 min) and without atomisation (average 81 min).

The mean temperature ranged from 14 to 18 °C and the RH from 61 to 76%. During the experiments both wind speed (4 m/s) and direction (SSW) were almost similar for all days. The quartz content of the scrap was approx. 14% (w/w), whereas the quartz content of the floor below the tiles was approx. 15% (w/w).

The experiments during soil compacting were performed during a four weeks period on 6 separate days. Average temperatures during the experiments ranged from 20 to 31 °C and RH varied from 54 to 72%. Prior to the experiment two soil samples were taken. The moisture content of the soil was of 0.60 and 0.53%, respectively. During four days a soil sample was taken at the end of the experiments for the heavy type of compactor (atomisation on). The moisture percentage of the soil ranged from 1.5 to 1.9%. For two occasions this could be compared with the results of samples taken prior to the experiments, yielding an increase of 0.94 and 1.24%.

Exposure

Gravimetrical analysis of the filters revealed many observations below the LOD, therefore no reliable respirable dust concentrations could be obtained. A summary of the results of both the respirable quartz exposure sampling and real-time dust monitoring are presented in Table I. During the activities the TWA exposures to quartz ranged from < LOQ to 1.747 mg/m^3. The highest exposures were observed during the use of the light jackhammer without atomisation, where tiles were removed in (very) small bath rooms, whereas the lowest exposures were observed during the use of the light plate compactor with the atomiser on. Only 5 out of 36 samples showed an average concentration below the Dutch exposure limit (0.075 mg/m^3 TWA 8 hr). Average dust concentrations as determined by real-time air monitoring ranged from 0.5 to 87.6 mg/m^3. The highest concentrations were also observed during the use of the light jackhammer. For all 36 samples the correlation between quartz exposure and average 'dust' concentration as determined by real-time air monitoring was $r^P = 0.78$, but ranged between $r^P = 0.53$ (for the heavy type of soil compactor) and $r^P = 0.86$ (for the light type of soil compactor).

Arithmetic mean quartz concentrations for all types of equipment during atomisation switched on and off are illustrated in Fig. 1. Except for the heavy type of plate compactor (CH) the mean quartz concentration differed significantly between the series with atomisation on and off.

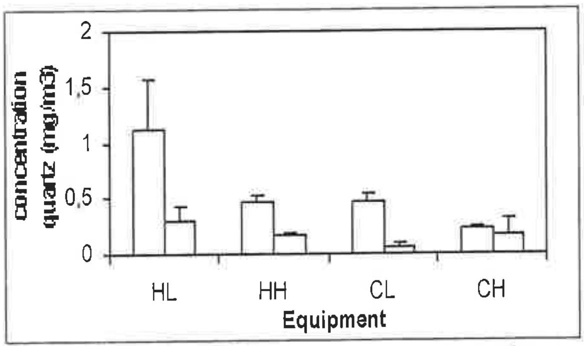

Figure 1 Plot of the arithmetic mean quartz concentrations during the experiments with different types of equipment, i.e. jackhammer light (HL) and heavy (HH), and compactor 'light (CL) and heavy (CH). The solid bars indicate the mean quartz concentrations during the experiments where the atomisation was off, the open bars give the results during atomisation. Differences between atomisation scenarios were all significant (p< 0.05), except for CH (p=0.29).

Table II summarises the effectiveness of atomisation for the different types of equipment. Based on personal exposure sampling for quartz, the average reduction of exposure ranged from 64 to 88%, whereas reduction based on 'real-time' dust concentrations ranged from 73 to 87%. Since no significant differences for concentrations could be observed between atomisation on/off a reduction factor for the heavy type of plate compactor (CH) could be derived only for 'real-time' dust concentrations (56%).

Discussion

All levels of quartz exposure during the (30 min) use of both types of plate compactors with atomisation switched off exceeded the OEL (0.075 mg/m^3 TWA 8 hr). However, the quartz exposures for the light weight type (CL) were much higher than those using the heavy weight type (CH). The higher beat frequency of CL will probably affect the generation of dust and thus the quartz concentration. In addition, the operator is located more close to the device compared to the CH. Switching the atomisation on resulted in a significant reduction of the quartz concentration (mean far below OEL) for the CL, but not for the CH. Visual observations revealed a higher coverage of the spray generated by the nozzles located at the front of the CL compared to that of the CH. Interpretation of the quartz concentrations as observed in the present study to levels of occupational exposure should be done carefully, since in practice plate compactors will be used outdoors. In addition, the equipment is also used to compress brick pavement resulting in other types of dust generation.

The range of respirable quartz exposure in the present study during the use of both types of jackhammer without using atomisation (0.079 – 1.747 mg/m^3) over periods up to 80 min was slightly higher than observed by Tjoe Nij *et al.* [2004]. They reported full shift quartz exposure levels ranging from 0.038 to 1.3 mg/m^3, and reported similar quartz percentages (AM 14%), however, the latter were determined in the respirable dust. Activities performed in small size rooms, *i.e.* removal of tiles in bathrooms, revealed the highest quartz exposure. Significant reductions of quartz concentrations were observed for activities where atomisation was switched on. However, quartz concentrations during actual use of the hammer could only in two cases be reduced to concentrations below the limit value OEL.

The overall effectiveness of the atomisation ranges from about 60% to about 85% reduction of exposure, *i.e.* reduction factors of approximately 2.5 to 8. No significant reduction of exposure was observed for the heavy type of plate compactor (CH), but this could be due to the sub optimum locations of the nozzles.

An indication of the range of reduction could be obtained by comparison pairs of observations of respirable quartz concentration during atomisation off and on. Data sets for three workers with two observations during each scenario for the experiments with the heavy type of jackhammer (HH) were available for such analysis. Based on the average of both observations the reduction for these three workers ranged from 46.5% to 80.7%.

The mean reduction factors observed are quite similar to the reduction factors observed by Thorpe et al. [1999], who observed reduction factors for quartz exposure ranging from 3 to 7 during the use of hand-held equipment (cut-off saws) in the construction industry using a (relatively) high flow pressurised water supply. Since quartz concentrations during the use of water were below LOD the effectiveness may be underestimated. Based on the data for respirable dust higher reduction factors were observed (16 to 24). Echt et al. [2003]

also reported high reduction percentages for an atomisation system mounted on a jackhammer based on personal respirable dust exposure (approx 72%) and based on real-time dust measurements (appr. 90%).
To determine the effectiveness of atomisation two parameters for exposure have been addressed, exposure to crystalline quartz and real-time monitoring of dust. Reduction factors were not similar for both exposure parameters. A lower reduction was observed for the light jackhammer (HL) based on dust concentrations compared to quartz concentrations. The accuracy of the real-time dust monitor results may account for this, since the device expresses numbers of particles detected as mass per volume. Moreover, this type of device has been calibrated for a different type of dust (Arizona road dust) [Willeke and Baron, 1993]. For high dust concentrations, as observed during our measurements, or for very low concentrations, this may result in inaccurate estimates due to scattering. In addition, the dust concentrations registered by the real-time dust concentration device and dust concentration estimated based on respirable quartz concentrations seem to differ substantially, assuming a similar distribution of quartz containing particles over all particle size fractions. When the real-time dust concentrations were recalculated for quartz concentrations, using the quartz content of soil or concrete, respectively, the real-time concentrations still give ten times higher dust concentrations compared to personal air sampling results.
The observed correlation between the respirable quartz exposure and the average real-time 'dust' concentration (r^p=0.78) is low compared to the correlation observed by Taylor and Reynolds [2001]. The authors observed a correlation of r^p=0.95 between inhalable organic dust and average real-time dust concentrations. For the present study, the high dust concentrations indicate an important contribution of the heavy weight non-respirable dust particles. Comparison of such dusts with various diameters and device responses with strictly defined cut-off points of the cyclones for respirable dusts seems to be inappropriate.

For an intervention type of study identical or comparable circumstances prior and following the intervention is critical. For the study on the heavy type of jackhammer the same concrete slab was used for both sessions (with and without atomisation) for the same test subjects, whereas the environmental conditions were very close. For the study on the light type of jackhammers, the test subjects performed activities with and without atomisation in the same bathrooms, so quartz contents of the materials would be similar. Since the activities occurred on different days, (natural) ventilation may have been different. However, all bathrooms had the same orientation and both wind speed (4 to 6 m/s) and wind direction (220 to 240 °) were very similar, and windows were opened after 30 min. Therefore, it is assumed that the air exchange rates during the experiments did not differ much. For the soil compactor study different test subjects were involved during activities with and without atomisation. Compared to hand-held equipment, between-worker variation due to different work habits is considered to be low. It is hypothesised, however, that dust formation will be determined by the moisture content of the soil. All activities were performed in a covered hall, and no additional water had been supplied. Limited data are available to prove that variation of soil moisture contents was low.
For the present situation it should kept in mind that with exception of the light type of jackhammer (HL), all other atomisation devices were prototypes and the location of the spray nozzles need to be optimised. Apart from location of the nozzles the droplet sizes and initial velocity of the droplets generated might also be adjusted to the size and speed of the dust. This may not only increase effectiveness of the atomisation, but may also result in quartz exposure levels below OEL.
In conclusion it can be stated that the results of the present intervention type of study indicate that in semi-experimental/ semi-workplace practice settings, the impact of the use of atomisation of (low flow) water sprays to suppress dust emission and/or for quartz dust control is promising. The low water consumption is an important additional advantage compared to the high water flow techniques or the use of running water.

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