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Keywords : *silica, stonecutting, dusts, niosh- 7601.*

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Mohammad Hossein Moafi [α], Seyed Mostafa Khezri [σ] & Farideh Atabi [ρ]

Abstract - This research aims at determining amount of dispersion of free silica and inhalant dusts and contents of free silica in the inhalant aerosol of stonecutting factories and offering engineering control strategies to omit or decrease distribution of the aerosol containing silica. Using standard method Niosh- 7601, 40 samples of inhalant dusts were taken from 5 stonecutting factories and concentration of inhalant dusts was calculated by weighting. One sample of each to stonecutting factory was analyzed by method of UV-VIS figure out the amount of free silica. Two volume samples were provided and analyzed by X-ray dispersion to determine type of silica in the inhalant dusts. Concentration of inhalant dusts containing free silica in different worksites is 2.232 mg/m^3 in average. The most amounts were found in grinding and polishing worksite amounted to 3.3293 with criteria deviation of 0.54 and the least amount was related to entrance door station, amounted to 1.1191 with criteria deviation of 0.25. The most amount of free silica in the worksites was related to worksite No.3, amounted to 12.15% and the least amount was related to worksite No.4 which was amounted to 4.25%. The most concentration of inhalant dusts was related to worksite No.2, i.e. 2.745 mg/m^3 in average, and the least concentration of inhalant dusts was related to worksite No.5, i.e. 2.056 mg/m^3 in average. Quartz was the result of analysis of volume samples by XRD method to determine type of silica. Percentage of silica and mean concentration of inhalant dusts for all factories and different worksites showed significant difference, P=0.95, comparing with Standard ACGIH. In all factories, mean concentration of inhalant dusts containing free silica was more than allowed limit. Therefore, considering these amounts and figures, it is necessary to prevent production and dispersion of dusts using different methods like wet system and installation of local air conditioners.

Keywords : *silica, stonecutting, dusts, niosh- 7601.*

I. Introduction

Human has been faced too many problems and dangers in effort to earn a livelihood for centuries. Fortunately in step with the increasing perils, methods of their prevention and control are developing as well. So that in spite of using dangerous chemicals or physical or biological factors, work places could be turned into healthy places in which workers can benefit from health and long life as similar as other people. Certainly the main provision of controlling dangers and preventing them in the places of work is having full knowledge of those dangers and their quality. Nowadays stonecutting industry makes the most important part of civil and construction affairs. It can be assuredly said that civil processes were completed by stonecutting industry. In the stonecutting factories, workers are exposed to several undesirable and detrimental factors and conditions which sometimes endanger their health seriously. Inhalation of free silica dusts is mentioned as one of those factors. Arising career diseases and complications like silicosis and other pulmonary damages are consequences of inhalation of free silica dusts. Importance of stonecutting and increasing need to its products in Iran, explains necessity of paying attention to the health of professionals of this industry.

On the other hand, noticeable number of workers, exposed or will be exposed to detrimental factors of place of work in stonecutting factories, reflects necessity of carrying out research to study on conditions of place of work and especially to precisely find type and amount of free silica dusts in this industry.

Considering the importance of effects resulted from inhalation of free silica dusts, environmental conditions of work in stonecutting industry from aspects of air pollution by this pollutant and the degree of workers' exposure to it were studied in this paper which was performed within fall of 20011 through spring of 2012 at stonecutting factories of Fadaeian Eslam Street of Tehran. We hope that the results can take effective steps toward improvement of the present status and more health of professionals of this industry.

II. Review of Previous Researches

* Banks et.al. figured out concentration of free silica in 2 mills of silica powder in 1981. Concentration of free silica was more than 0.05 mg/m^3 in 85% of inhalant dusts samples and it's silica was variable between 95 to 98% (banks&etal).

* Fulekar's study in stone-grinding factories of Rajasthan State of India indicated that the mean of total particles concentration in the air of these worksites was 22.5 mg/m^3 and the mean of inhalant particles concentration was 2.93 mg/m^3 and considering percentage of free silica in dusts (75%) rate of exposure of the professionals was reported as more than allowed limit of professional exposure: PEL=0.36 mg/m^3 (fulekar,1999).

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* In a research at Kashmar construction mine in 1998, Manouchehr Sakhaei studied on total dusts and free silica (quartz) in which 60 samples of inhalant dusts, 6 samples as control (check sample) and 12 environmental samples were taken from breathing area of the workers in 5 different worksites in order to analyze concentration of free silica and exposure rate of workers in the construction stone mine. Then the concentration was calculated according to Niosh method: the mean concentration of dusts was the highest in the 5th station and the 1st worksite showed the least amount and concentration of free silica in all worksites was less than allowed limit (Sakhaei, Manouchehr, 1998).

* Mr. Sajad Mousavi did study on workers of under construction subway tunnel of Tehran exposed to total dusts and crystal silica (quartz) as M.Sc. thesis of University of Tehran in 2009. In this research, performed by standard method of Niosh-7601, amounts of total dusts and inhalant dusts containing silica exceeded the standards of Iran and ACGIH in all worksites. (Mousavi, Sajad,2009)

III. Stonecutting Factories

In stonecutting factories, there are granite and other construction stones of porcelain type which are cut from larger mineral rocks and brought to stonecutting factories to be prepared for construction. In the stonecutting factories, the stones are cut in different sizes in order to be used in granite stairs and kitchen counter most of which, especially carving granite stairs and kitchen counters, are dry. In the worksites subject of the study, workers cut and carve these stones without using breathing masks and after carving or cutting, these stones are stored in depot or warehouse by the workers and they are finally delivered to the customers.

IV. Silica Forms

* Crystal form (Crysalln) which is seen as 3 forms of quartz, tridimite and crystobalite, depended on temperature of formation time.

* Microcrystal form (micro) including small crystals of quartz attached to each other by amorphous silica.

* Amorphous form (amorph) in which different molecules have dissimilar spatial relation with each other and as a result there is no specific regular pattern between the molecules (lanyer,1978).

V. Free Silica Dispersion Origins

Too many industries like tunnel construction, mining, foundry, buildings stone-working, earthwork, plastic production, glass-working industries, sandblast and ballasting, sand mines, pottery, construction operation, digging, agriculture, hammering, ceramic and brick making, stonecutting, Portland cement production, production of washing materials, etc. are origins of dispersion of free silica in the air.

VI. Materials & Methods

This study has been planned as descriptive-cross-sectional including the following stages:

1. Preliminary investigation and gathering necessary basic information of the research
2. Planning for number of required samples considering number of all worksites and work process in the worksites
3. Sampling according to standard method of Niosh-7601 and transferring samples to the laboratory
4. Weight analysis of the samples
5. Analysis of percentage and concentration of free silica by visible spectrophotometry according to method of Niosh-7601
6. Determination of type of free silica in volume samples for XRD analysis according to method of Niosh-7601

VII. Preliminary Study and Gathering Basic Information Required for the Research

a) Library and data study was performed to get information about process of the work and required instruments and samples analysis

Method of work in the worksites were examined as well which resulted to figuring out type of consuming stones and conditions of work and totally 8 worksites were identified in the stonecutting factories as a result of studying worksites of the factories including: entrance door stations, peak offload, raw stone depot, primary cut (single-cut), secondary cut, grinding and polishing, product depot, loading, locations of sampling were planned, the workers' breathing protection instruments, function of cutting machines, stonecutting factories air conditioners, and number of persons who are exposed to dusts and free silica were examined and it became clear that 8-10 persons were exposed to dusts in average.

b) Applied instruments and materials

Equipment and materials used in this research were as follows:

- Individual sampling pump of SKC LTD type, model EX96 D2120, made in UK with chargeable battery and 5 L/min Debi
- 10 mm Nylon silicon
- Digital calibration system, model 1/08DCL-MRE, made in USA to calibrate individual sampling pump
- Rotameter with 2 L/min flow to calibrate individual sampling pump
- Digital scale, mark sauter and weighting accuracy of 0.0001 gr., made in UK
- Visible Spectrophotometer
- Membranous filter with 37 mm in diameter and 0.8 micron powder

c) Planning for number of required samples considering number of all worksites and work process in the worksites

After inspecting status of the worksites located at the region subject of study, 5 worksites were selected to be studied. Considering the mean and criteria deviation of concentration of aerosol containing free silica in other studies and using statistical relation, 40 samples should be gathered. Therefore 8 samples were taken from each worksite according to process of work in the worksites and one out of each 8 samples was analyzed for percentage of free silica.

d) Sampling according to Standard Method of Niosh-7601

According to aims of the study, sampling of inhalant dusts was performed in 8 regions of each worksite.

At first 37mm filters, with aperture size of 0.8µ, were weighted by a scale, with accuracy of 0.0001 gr. and then they were put in silicon support and sampling pump was fixed on a 1.5 m stand (at the same breathing height of the workers). According to method of Niosh-7601, the pump Debi was set on 1.7L/min and sampling was carried out during 8 hours.

At the beginning and by the end of sampling by the sampling pump, Debi monotony was watched. By the end, the sampling pump was removed from the stand and filters (real and check samples) were put in the support to be transferred to the laboratory and then the filters were weighted in the laboratory. It is worthy to note that to correct sampled air volume to volume in standard conditions, temperature and pressure quota were measured during sampling and the mean was calculated. Controls were treated like the real samples. In this way, the support of the controls was removed in the environment and quickly was placed on it without sampling. Then they were packed and transferred to the laboratory with real samples. Exactly the same stages were passed for real samples and controls. In the laboratory, controls were essentially used to estimate pollutants in the sampling filters. Results of controls should be deducted from results of tests performed on the real samples in order to get more accurate results. (6)

- Weight analysis of the samples

* Weighting filters:

In this research, visible spectrophotometer was used to calculate concentration of crystal silica in the samples. In this method, total weight of dusts should not be more than 2 mg. Sampling filters and control were weighted by digital scale before and after sampling.

VIII. Analysis of Percentage and Concentration of Free Silica by Spectrophotometer in Visible Limit According to Method of Niosh-7601

* Reagents:

1. Silica standard

A: Quartz (1958, 2951, 2950, 1878a SRMs), B: Crystobalite (957, 2960, 1879 SRMs) C: Tridimite

2. 2- Hydrofloricacide 48%
3. Autophosphoricacide 85%
4. Abebdonsilis
5. Hydrocloridricacide 1/10 in Abdionise
6. Solphoricacide 10N
7. Concentrated Nitric Acid
8. Concentrated Percloricacide for PVC filters
9. Boric Acid 5%

IX. Determination of Type of Free Silica in Volume Samples for XRD Analysis According to Method of Niosh-7601

a) Providing volume sample

To find type of free silica in the stones used in the stonecutting factories, volume sample should be prepared from the dusts taken from cutting operation in the stonecutting factories and considering that there are 2 types of granite stones in these factories, 2 volume samples were prepared. After preparation of these samples by 40µ sieve, they were delivered to XRD analysis laboratory in the Research Center of Inorganic Materials Process of Iran to determine type of silica using standard method of Niosh-7500.

b) Analysis by XRD

Generator of X-ray is set on 40 KV and 40 Ma. One standard sample is transferred to the sample support in the system by pincers and the support is placed in the container.

X. Results and Findings

a) The Results of Weight Analysis of Inhalant Dusts

Concentration of inhalant dusts were calculated and presented by weighting method for each sampling station separately. Some parameters used in the calculations are as follows:

V_{mes} : Volume of sampled air in Liter

P_{bar} : Barometric pressure in mmHg.

P_w : Saturated Vapor Pressure in mmHg

$$V_{stp} = V_{measurd} \times \frac{P_{bar} - p_w}{760} \times \frac{298}{273+t}$$

T: Environmental temperature in Centigrade degree

V_{stp} : Air volume in standard conditions in Liter

W_1: Sampling filter's weight before sampling in mg.

W_2 : Sampling filter's weight after sampling in mg.

$\acute{W}_1$: Control filter's weight before sampling in mg.

$\acute{W}_2$: Control filter's weight after sampling in mg.

W: Weight of inhalant dusts on the filter in mg.

C: Concentration of the inhalant dusts in mg/m^3

$$w = (w_2 - w_1) - (w_2' - w_1')$$

Table 1 : Mean, Criteria Deviation, and Calculation of Confidence Limit 95% for Concentration of Inhalant Dusts of Different Worksites of Stonecutting Factories

Worksite	Number of Samples	Mean	Criteria Deviation	Confidence Limit 95%		Amplitude of Changes	
				Lower limit	Upper limit	Min.	Max.
Entrance Door	5	1.1191	0.25	1.12	1.51	0.77	1.64
Peak Offload	5	1.2192	0.27	1.02	1.41	0.87	1.74
Raw Stone Depot	5	2.353	0.41	2.18	2.82	1.91	3.37
Primary Cut	5	2.556	0.45	2.23	2.87	1.96	3.42
Secondary Cut	5	3.2912	0.52	2.91	3.70	2.57	4.02
Grinding & Polishing	5	3.3293	0.54	2.93	3.72	2.59	4.11
Product Depot	5	1.8254	0.42	1.52	2.12	1.10	2.61
Loading	5	1.6204	0.40	1.50	2.10	1.06	2.57

Total average of inhalant dusts concentration in different worksites is 2.232. Maximum average is related to Grinding & Polishing worksite which equals to 3.3293 with Criteria Deviation of 0.54 and the minimum average is related to Entrance Door worksite which equals to 1.1191 with Criteria Deviation of 0.25.

b) The Results of Instrumental Analysis by UV-VIS Spectrophotometry

Table 2-4 shows percentage of free silica in stonecutting factories in microgram. It is worthy to note that silica contents of 2 samples of each worksite were calculated by the following formula using UV-VIS device in Research Center of Inorganic Materials Process of Iran.

Sio2%= Silica Content (mg)/Content of inhalant dusts (mg)×100

Table 2 : Percentage of free silica in inhalant dusts of stonecutting factories

No. of Worksite	Name of Worksite	Content of Dusts (mg)	Contents of Silica (µg)	Percentage of free silica in inhalant dust
1	Product Depot	1	70	7
	Entrance Door	0.7	51	.285
2	Secondary Cut	1.7	124	7.30
	Peak Offload	0.5	21	4.30
3	Raw Stone Depot	1.1	73	6.636
	Grinding & Polishing	1.9	231	12.15
4	Loading	0.7	50	7.14
	Entrance Door	0.4	17	4.25
5	Peak Offload	0.6	40	6.66
	Primary Cut	1.2	76	6.33

Table 3 : Comparison of mean concentration of inhalant dusts with maximum allowed concentration in stonecutting factories

No. of Worksite	Mean concentration	Criteria Deviation	Amplitude of Changes in Concentration		Maximum allowed concentration of inhalant dusts
			Min.	Max.	
1	2.5685	1	1.3	4.05	1.11
2	2.745	0.93	1.526	4.851	1.077
3	2.3	0.84	1.3	3.617	1.075
4	2.193	0.84	1.075	3.2	1.61
5	2.056	0.71	1.1	3.01	1.158

Table 4 : Concentration of free silica in stonecutting factories

No. of Worksite	Name of Worksite	Contents of Silica (µg)	Silica concentration	Silica concentration in professional standard of Iran
1	Product Depot	70	0.151	0.1
	Entrance Door	51	0.111	0.1
2	Secondary Cut	124	0.264	0.1
	Peak Offload	21	0.0451	0.1
3	Raw Stone Depot	73	0.157	0.1
	Grinding & Polishing	231	0.5	0.1
4	Loading	50	0.109	0.1
	Entrance Door	17	0.037	0.1
5	Peak Offload	40	0.0872	0.1
	Primary Cut	76	0.164	0.1

Table 5 : Maximum concentration of inhalant dusts containing free silica in stonecutting factories

No. of Worksite	Name of Worksite	Type of Silica (µg)		Maximum concentration of inhalant dusts (mg/m^3)
1	Product Depot	Quartz	7	1.11
	Entrance Door	Quartz	7.285	1.077
2	Secondary Cut	Quartz	7.3	1.075
	Peak Offload	Quartz	4.2	1.61
3	Raw Stone Depot	Quartz	6.636	1.158
	Grinding & Polishing	Quartz	12.15	0.706
4	Loading	Quartz	7.14	1.093
	Entrance Door	Quartz	4.25	1.60
5	Peak Offload	Quartz	6.66	1.153
	Primary Cut	Quartz	6.33	1.2

Table 6 : Comparison of mean and criteria deviation of concentration of inhalant dusts with maximum allowed concentration in different stonecutting worksites

Name of Worksite	Number of Worksite	Mean concentration	Criteria Deviation	Amplitude of Changes in Concentration		Maximum Allowed Concentration
				Min.	Max.	
Entrance Door	5	1.1191	0.25	0.77	1.64	1.315
Peak Offload	5	1.2192	0.27	0.87	1.74	1.336
Raw Stone Depot	5	2.353	0.41	1.91	3.37	1.178
Primary Cut	5	2.556	0.45	1.96	3.42	1.210
Secondary Cut	5	3.2912	0.52	2.57	4.02	0.8528
Grinding & Polishing	5	3.3293	0.54	2.59	4.11	0.9732
Product Depot	5	1.8254	0.42	1.10	2.61	1.1025
Loading	5	1.6204	0.40	1.06	2.57	1.152

Table 7 : Type, percentage and concentration of free silica in comparison with concentration of silica in professional standard of Iran

Name of Worksite	Contents of Dusts (mg)	Contents of silica (µg)	Type of silica	Percentage of silica%(sio2)	Maximum concentration of inhalant dusts	Concentration of silica (mg/m^3)	Concentration of Silica in professional standard of Iran
Entrance Door	0.7	51	Quartz	7.285	1.077	0.111	0.1
Peak Offload	0.5	21	Quartz	4.30	1.61	0.0451	0.1
Raw Stone Depot	1.1	73	Quartz	6.636	1.158	0.157	0.1

Primary Cut	1.2	76	Quartz	6.33	1.2	0.164	0.1
Secondary Cut	1.7	124	Quartz	7.3	1.075	0.264	0.1
Grinding & Polishing	1.9	231	Quartz	12.15	0.706	0.5	0.1
Product Depot	1	70	Quartz	7	1.11	0.151	0.1
Loading	0.7	50	Quartz	7.14	1.093	0.109	0.1

According to table 7, contents of inhalant dusts and silica in µg, amount, type, percentage and concentration of free silica in µg in comparison with maximum concentration of inhalant dusts and silica are obtained in mg/m^3 in professional standard of Iran.

In this table, concentration of silica in professional standard of Iran in mg/m^3 is showed as 0.1 in all worksites and also maximum concentration of inhalant dusts is showed as fixed amount in mg/m^3 in each worksite of the stonecutting factories.

Figure 1 : Entrance Door Worksite

Figure 2 : Peak Offload Worksite

Figure 3 : Raw Stone Depot Worksite

Figure 4 : Primary Cut Worksite

Figure 5 : Secondary Cut Worksite

Figure 6 : Grinding & Polishing Worksite

Figure 7 : Product Depot Worksite

Figure 8 : Loading Worksite

XI. Discussion

In worksites No.1 to 5, maximum allowed concentration of inhalant dusts were measured as 1.11, 1.077, 1.075, 1.61 and 1.58 mg/m^3 respectively, however concentration of inhalant dusts in 85% of the subject worksites was more than allowed concentration standard and the remaining 15% of the worksites showed the maximum allowed limit of concentration.

The highest concentration measured in this study was 3.910 mg/m^3 and the highest percentage of silica, i.e.12.5%, was related to grinding and polishing worksite No.3 and the least concentration was measured as 1.005 mg/m^3 and the least percentage of silica, i.e.4.25%, was related to entrance door worksite No.4.

According to the results of statistical test, there is significant difference between concentration of free silica in the samples and standard level. Allowed concentration of silica in professional standard of Iran is 0.1 mg/m^3.

In fact, free silica in inhalant dusts of these worksites turns them from ineffective and or annoying dusts to toxic dusts and increases change of suffering pulmonary problems in proportion to percentage of free silica and intensity and duration of exposure to such dusts.

Therefore more polluted worksites must be given priority in taking engineering control measures. Considering the results of tables 1 to 6, concentration of inhalant dusts in sampling worksite of grinding and polishing is more than other worksites. In other words, the most dispersion of aerosol containing free silica happens in grinding and polishing worksite and also secondary cut worksite.

The least concentration of aerosol is related to entrance door and peak offload worksites. Statistical relation shows that concentrations of inhalant aerosol among different worksites of a factory are significantly different from each other and prioritization of management and engineering control actions should be based on these findings. According to XRD analysis, the consumed stone contains free silica of quartz type which pathogenic effects are less than crystobalite. However it's pathogenic effects is emphasized as well because of increase, fashion and more application of crystal form of free silica than other forms. According to table 6, mean concentration of dusts resulted from free silica in all worksites of study is 2-3 times more than maximum allowed limit in stonecutting factories.

XII. Conclusion

Findings of this study indicate that air pollution as inhalant dusts dispersed in stonecutting factories contains free silica of crystal or quartz type and percentage of free silica in dusts of different worksites is measured so that concentration of dispersed dusts is more than allowed concentration. Meanwhile, dispersion of dusts in secondary cut worksites is noticeable from concentration and percentage of free silica aspects and it seems that there is probability of suffering from pulmonary problems among professionals and persons exposed for long term and work conditions of subject worksites are not appropriate from viewpoints of air pollution control and protection of workers' health against inhalation of aerosol containing free silica. Therefore taking appropriate control actions to decrease rate of dusts dispersion and also to decrease their concentration around the worksites seems to be necessary.

XIII. Proposals

According to the results and prioritization of control measurements among worksites of study and factories, preventive control actions should be predicted, planned and taken as management, engineering and individual in proportion to the work conditions in order to omit or decrease health risks resulted from inhalation of free silica dusts in the place of work. Principles of preventions may be summarized as follows:

In general, control methods including: process correction, engineering control, promotion of method of work, and using individual instruments may be used in 3 levels of control in the origin aiming at omission or decrease in producing pollution, control in dispersion path aiming at omission or minimizing pollution area, and finally control in exposure level aiming at omission or minimizing persons' exposure.

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