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Country Report

Determination of crystalline silica in respirable dust upon occupational exposure for Egyptian workers

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Abstract: Crystalline free silica is considered as a lung carcinogen and the occupational exposure to its dust is a health hazard to workers employed in industries that involve ores of mineral dust. In Egypt, thousands of people work under conditions of silica dust exposure exceeding the occupational exposure limit, as a result the monitoring of this occupational exposure to crystalline silica dust is required by government legislation. The assessment of the later is a multi-phase process, depend on workplace measurements, quantitative analyses of samples, and comparison of results with the permissible limits. This study aims to investigate occupational exposure to crystalline silica dust at 22 factories in Egypt with different industrial activities like stone cutting, glass making, ceramic, and sand blasting. Dust samples were collected from work sites at the breathing zone using a personal sampling pump and a size-selective cyclone and analyzed using FTIR. The sampling period was 60–120 min. The results show that the exposure at each of the industrial sectors is very much higher than the current national and international limits, and that lead to a great risk of lung cancer and mortality to workers.

Key words: Crystalline silica, Mineral dust, FTIR, Quantitative analyses, Egyptian workers

Introduction

Our body possesses an efficient filtration system manifested in the respiratory system, which capture and remove particles of varying sizes entering with the breathing air. Large particles are removed first in the nose and throat. Intermediate particles are removed in the upper airways. Small particles are removed in the area of the lung in which the exchange of gases happens. Particles, known as the respirable fraction, are the cause of silica-related diseases. These are so small that they cannot be seen and are capable of penetrating to the area of the lung in which gas exchange occurs[1)].

Silica or silicon dioxide (SiO_2) exists in nature in amorphous and crystalline forms. Crystalline silica is the most widely occurring of all minerals, found in most rocks, and it occurs naturally as quartz, cristobalite and tridymite. Of those α-quartz is the most common mineral of commercial and medical importance. The inhalation of airborne dust of silica gives rise to silicosis (the most important form of pneumoconiosis) and also lung emphysema[2)]. Unfortunately, silicosis is not curable, but it can be prevented by reduction and control of exposure to silica compounds[3)].

The presence of crystalline free silica in workplace air can be detected and measured following fully considered procedures. The procedures for monitoring, sampling and determining the concentrations of airborne silica in the workplace and a worker's exposure to airborne silica must be in accordance with standard methods for workplace air

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sampling and analysis[1, 4)].

The NIOSH (National Institute of Occupational Safety and Health) recommended exposure limit (REL) for respirable crystalline silica is 0.05 milligrams of respirable silica per cubic meter of air (mg/m^3) as a time-weighted average (TWA) which is similar to the permissible limit of free silica according to the Egyptian labor law No. 12, 2003[5)]. The ACGIH (American Conference of Governmental Industrial Hygienists) threshold limit value (TLV) for respirable silica (as α quartz) is 0.025 mg/m^3 TWA for up to an 8-h workday[6)]. The Egyptian labor law 12/2003 devotes a specific section (Book V) to occupational safety and health (OSH) and assurance of the adequacy of the working environment. It is supplemented by ministerial decrees which elaborate more specific technical provisions, the most important ones being decree No. 211 (2003) specifying conditions and precautions essential for the provision of OSH measures at the workplace. It is important to indicate that the TLV list at decree No. 211/2003 takes as a basis the ACGIH values of 2002, and now there are efforts from the authority to update it[7)].

There is a strong epidemiological evidence for the association between occupational crystalline silica exposure and several diseases such as silicosis, lung cancer, and pulmonary tuberculosis. There are other diseases that may be associated with occupational crystalline silica exposure including autoimmune (rheumatoid arthritis) and renal diseases (glomerulonephritis)[8)].

In Egypt, there are thousands of factories employing millions of temporary or permanent workers with different industrial activities from which we are interested in those involving mineral dusts in the manufacturing, which lead to silica dust exposure, as a result, more than hundreds of workers are subjected to problems in the breathing efficiency because of silicosis and bronchitis. Occupational safety and health administration (OSHA) estimated that 2.8 million workers are in contact with silica in America[9)]. Nevertheless, in Egypt the exact number of workers exposed to dust does not exist. The health hazards among Egyptian ceramics workers exposed to different environmental risk factors including silica and radon dusts were determined and also exposure response relationship between intensity of exposure and the degree of health impairment was assessed[10)]. Hepatic functions in silica-exposed workers in the clay brick industry in Egypt and the possible role of matrix remodeling and immunological factors were evaluated[11)].

Materials and Methods

In this study, we measured personal exposure of 47 randomly selected workers from ten industrial sectors in 22 Egyptian factories. These samples were collected using portable dust samplers. Each sampler consists of a cyclone (Higgins-Dewell, SKC) loaded with 25 mm cellulose membrane filters, pore size 0.8 µm (SKC) where the respirable dust precipitated and a pump (Gilian GilAir5) which is calibrated with Dry Cal Defender 530 calibrators (Bios International, Butler Park, N.J.). The flow rates were 2.2 l/min and sampling periods were about 60–120 min. The cyclones were fixed on the worker's clothes attached to the belt and collars at the breathing zone (PZ). Filters were weighed before and after sampling using an electronic balance (model HA-202M, A&D Co., Ltd., Japan) to give the weight of dust collected. The volume of air was calculated from the sampling flow rate and the sampling time. The dust concentration was then derived as equation 1:

$$\text{Dust Concentration}\,(mg/m^3) = \frac{\text{Weight of dust collected}\,(mg)}{\text{Volume of air sampled}\,(m^3)} \quad (1)$$

During sampling a minimum of three unused loaded cassettes with weighed filters were kept as a blank and treated as far as possible in the same manner as those actually used for sampling but without drawing air through them. The method used for the determination of respirable dust is MDHS14/3. This MDHS aims to guide those who wish to measure the concentrations of respirable and/or inhalable dust in air, for the purpose of monitoring workplace exposure. It updates and replaces MDHS 14/2[12)].

In this study, infrared spectra were acquired by means of a Nicolet is 10 FTIR (Thermo scientific, USA) data resolution of 4 cm^{-1}. The number of scans was set at 16–64. Filters loaded with samples for investigation has been ashed in a muffle furnace at 600°C for 2 h. It was then homogenized with 300 mg dried spectroscopic grade potassium bromide (KBr) in an agate mortar. The later was pressed into 3 mm diameter pellets with a hand press.

α-quartz as a standard reference material; from national institute of standards and technology NIST-SRM 1878, was used to prepare the crystalline silica calibration curve. Although crystalline silica has several polymorphs such as cristobalite and tridymite, it is reasonable to use quartz as the standard because the other forms of silica are usually not present in a significant amount in industrial hygiene samples[13)].

The absorbance at 800 cm^{-1}, which is due to the symmetrical stretching vibration of Si-O-Si, was used to find the weight of quartz, W_q (μg), from the calibration graph. The concentration of silica, C (mg/m^3) was calculated using equation 2:

$$\text{Silica concentration} = \frac{W_q}{V}\,\text{mg}/\text{m}^3$$ (Where V is the volume of air sampled in liter (2)

To calculate the percent of quartz,% Q, we used the equation 3:

$$\%\ \text{silica} = \frac{W_q}{W_s} \times 100$$ (Where W_s is the total sample weight) (3)

In decree No. 211/2003 (Egyptian labour law 12/2003), there is only a TLV for respirable dust with free silica content <1% (3 mg/m^3) where the TLV for respirable dust containing silica in general industry is determined by the equation 4[5]:

$$TLV\ (mg/m^3) = \frac{10}{(\%\text{Respirable } SiO_2 + 2)} \quad (4)$$

For comparisons to the law, a TLV is calculated for each sample as an 8-h TWA.

This is also the case to calculate TWA concentration for the OSHA PEL as an 8hr TWA, but now OSHA has dropped the TLV calculations and has moved like NIOSH and ACGIH to use just the measured concentration of silica as a limit value.

Dust samples measurement and free silica analysis were made in the national institute for occupational safety and health, Heliopolis, Cairo, Egypt. All samples were analyzed according to MDHS 14/3; a general method for sampling and gravimetric analysis of respirable and inhalable dust[12] and NIOSH manual of analytical methods (NMAM), method 7602 (Silica, Crystalline by IR)[13].

Results

In order to obtain calibration curves for crystalline silica, quartz samples of respirable range were used as the standard. The absorption at 800 cm^{-1} is generally accepted as the most suitable band for analytical peak measurement[13]. Therefore, an ordinary calibration curve is expressed as the graph of absorbance at 800 cm^{-1} *vs*. mass of quartz in a sample pellet, Fig. 1.

In this study, we monitored the levels of respirable dust and free crystalline silica in the work environment of 22 factories categorized into 10 industrial activities in and near Cairo industrial zones. 47 samples were collected from these places with mean sampling time of 60–120 min at the personal breathing zone of the workers during a normal work shift.

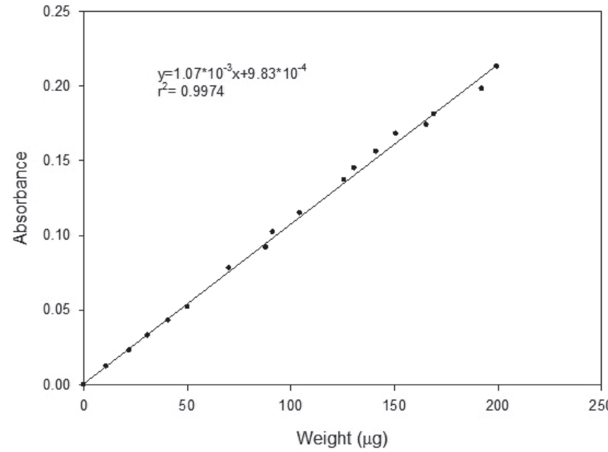

Fig. 1. Infrared calibration curve for the standard quartz (NIST standard) samples.

Table 1 lists the detailed job titles, number of samples for each job title, respirable dust concentration in mg/m^3, and the statistical calculations for industries with a number of samples greater than 6.

Considerate to Egyptian standard for respirable dust concentration (3 mg/m^3) and regarding to Fig. 2, the respirable dust concentration mean exceeds the permissible limit in all of the industrial sectors except at fertilizers industry during mixing the components of the fertilizers mixture.

The crystalline silica percent with the statistical calculations are listed in Table 2. It was found that silica% exceeds the 50% in the sectors of glass making (during discharging of the sand in the mixture), ceramic (at the worker responsible for the mills), and stone cutting (at drilling machine worker). Figure 3 present the percentage mean of silica with a max mean silica% found in stone cutting at 48.65% and the min mean silica% in painting at 2%.

Table 3 lists the calculated TLV as 8-h TWA for respirable dust concentration containing >1.0% silica in mg/m^3 and the statistical calculations for each of the job titles. Figure 4 shows the silica concentration mean with the maximum silica concentration mean at painting industry (2.5) as a result of a minimum silica percent. The minimum silica concentrations mean was at stone cutting industry (0.2) as a result of maximum silica percent.

Discussion

This study has some limitations. First, samples measure the workers' personal breathing work environment exposure

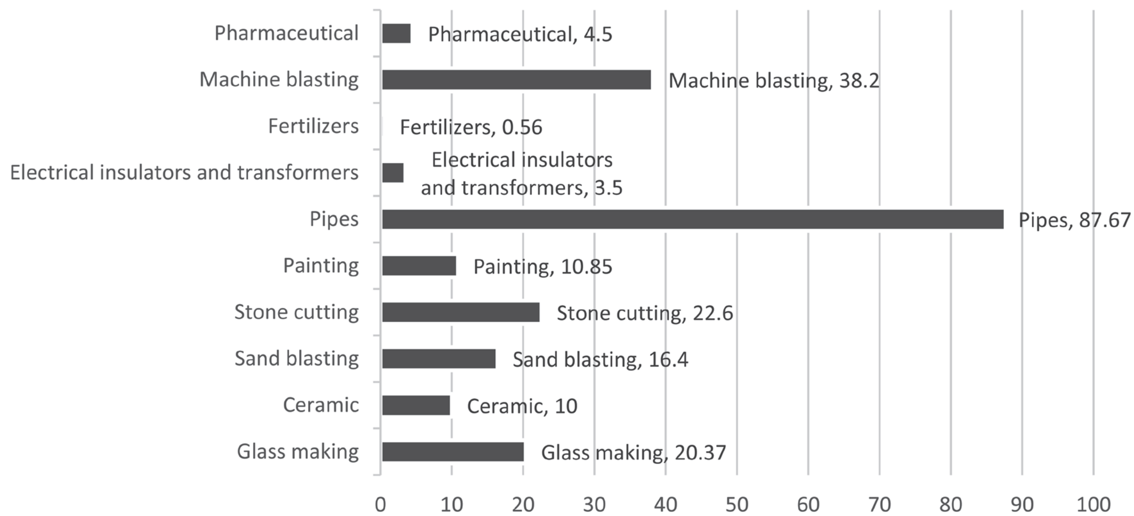

Fig. 2. Mean concentration of respirable dust (mg/m^3) of sampled sectors at different industrial regions.

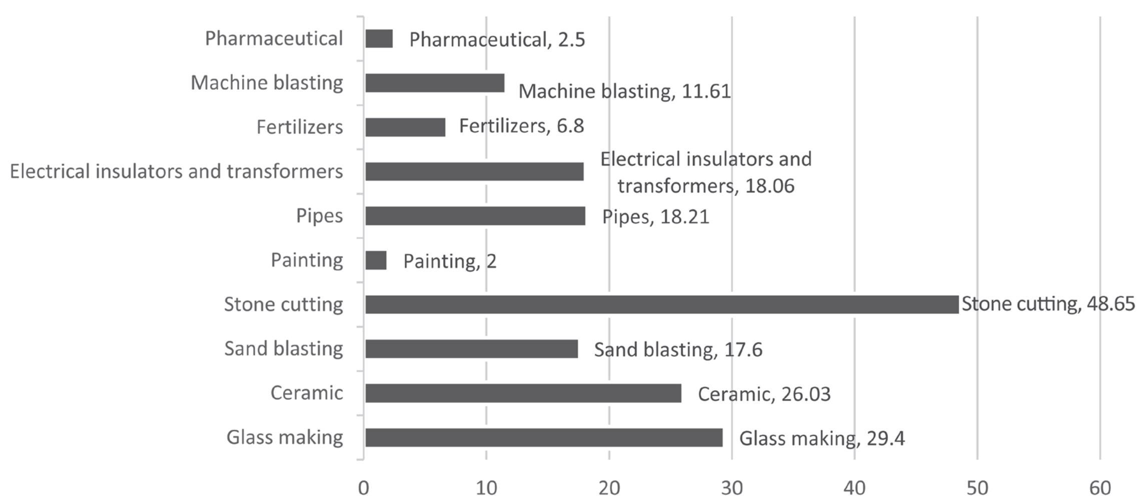

Fig. 3. Mean percentage of silica in respirable dust of sampled sectors at different industrial regions.

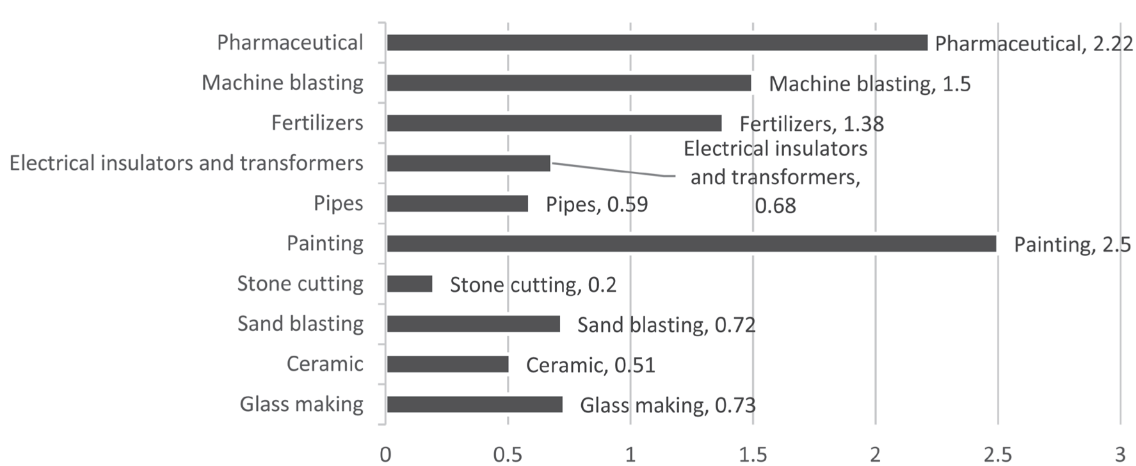

Fig. 4. Silica mean concentration (mg/m^3) in respirable dust of sampled sectors.

Table 1. Respirable dust TWA (mg/m^3) by job title at different industrial regions

Job title	No. of samples	Dust TWA	Statistical* calculations
Glass making			
Sand charging	1	56.50	
Weighing raw materials	1	2.56	
Mixture discharging	1	2.05	
Ceramic			
Pistons operators	3	13.70, 2.44, 6.80	
Quarry observer	1	0.60	Max=54.80
Mills observers	3	54.80, 0.26, 33.60	Min=0.26
Glaze mills observers	3	11.60, 0.45, 1.50	Mean=10.00
Furnaces observer	1	2.70	Median=2.44
Clark driver	1	0.50	95% confidenceinterval=9.89
Mixer operator	1	1.02	
Sand blasting			
Blasting workers	4	10.40, 53.70, 0.50, 0.90	
Stone cutting			
Drilling machine	1	32.00	
Chopping machine	1	13.20	
Painting			
Plastic mixture discharging	1	2.00	
Putty mixture discharging	1	19.70	
Pipes			
Ores mixing	1	7.30	
Glaze mills observers	2	7.90, 0.78	
Crusher operator	1	0.72	Max=338.00
Blasting	1	259.80	Min=0.72
Mixers charging	1	57.50	Mean=87.67
Small parts casting	1	6.90	Median=14.90
Manual mixer operator	1	41.50	95%confidence
Automatic mixer operator	1	14.90	interval=83.69
Pipe finishing	1	228.60	
Cleaning	1	338.50	
Electrical insulators and transformers			Max=5.80
Sand charging	3	2.80, 5.80, 2.80	Min=2.40
Feldspar charging	1	2.40	Mean=3.50
Clay charging	1	4.70	Median=2.80
Mixture discharging	1	2.50	95% cofidence interval=1.47
Fertilizers			
Mixing raw materials	1	0.52	
Mill observer	1	0.60	
Machine blasting			
Blasting in assembly workshop	3	98.00, 4.70, 11.90	
Pharmaceutical			
Weighing of aerosol powder	1	4.50	

*Statistical calculations were carried out for N>6.

without taking into account the use of a respirator. Actual exposure levels for some workers may be much less than the workers' ambient readings of exposure. As a result, this sampling measurement may overestimate the workers' exposure levels. Second, a potential limitation is the inability to identify the duration of employment of the individual

Table 2. Crystalline silica percent (%) by job title at different industrial regions

Job title	No. of samples	Silica %	Statistical* calculations
Glass making			
Sand charging	1	67.80	
Weighing raw materials	1	4.60	
Mixture discharging	1	15.80	
Ceramic			
Pistons operators	3	50, 23.70, 32	
Quarry observer	1	16.50	Max=72.60
Mills observers	3	18.80, 72.60, 4.50	Min=4.50
Glaze mills observers	3	15.20, 21.40, 15	Mean=26.03
Furnaces observer	1	41.80	Median=18.80
Clark driver	1	16.50	95%confidence interval=11.35
Mixer operator	1	10.40	
Sand blasting			
Blasting workers	4	33, 23.30, 7.60, 6.40	
Stone cutting			
Drilling machine	1	56.40	
Chopping machine	1	40.90	
Painting			
Plastic mixture discharging	1	2	
Putty mixture discharging	1	2	
Pipes			
Ores mixing	1	16.60	
Glaze mills observers	2	26.40, 11.40	
Crusher operator	1	6.90	Max=31.70
Blasting	1	15	Min=6.70
Mixers charging	1	20	Mean=18.20
Small parts casting	1	19.50	Median=18
Manual mixer operator	1	18	95%confidence interval=5.49
Automatic mixer operator	1	31.70	
Pipe finishing	1	28	
Cleaning	1	6.7	
Electrical insulators and transformers			Max=34.50
Sand charging	3	17, 18.70, 34.50	Min=4.50
Feldspar charging	1	4.50	Mean=18.06
Clay charging	1	8.90	Median=17.85
Mixture discharging	1	24.80	95% cofidence interval=11.35
Fertilizers			
Mixing raw materials	1	10.50	
Mill observer	1	3.1	
Machine blasting			
Blasting in assembly workshop	3	2.13, 29, 3.7	
Pharmaceutical			
Weighing of aerosol powder	1	2.50	

*Statistical calculations were carried out for N>6.

worker and the duration of exposure to silica dust.

During sites visiting, it is noticed that sand blasting was performed in the open and dust is visibly present during blasting especially when sand movers are refilled and actively operating. Direction and wind speed, as well as the configuration of the sand handling and other equipment

Table 3. Silica TLV as 8-hr TWA (mg/m^3) by job title at different industrial regions

Job title	No. of Samples	Silica TWA	Statistical* calculations
Glass making			
Sand charging	1	0.14	
Weighing raw materials	1	1.51	
Mixture discharging	1	0.56	
Ceramic			
Pistons operators	3	0.19, 0.39, 0.29	
Quarry observer	1	0.54	Max=1.54
Mills observers	3	0.48, 0.13, 1.54	Min=0.13
Glaze mills observers	3	0.58, 0.43, 0.59	Mean=0.51
Furnaces observer	1	0.23	Median=0.48
Clark driver	1	0.54	95% confiidence interval=0.21
Mixer operator	1	0.80	
Sand blasting			
Blasting workers	4	0.28, 0.39, 1.04, 1.19	
Stone cutting			
Drilling machine	1	0.17	
Chopping machine	1	0.23	
Painting			
Plastic mixture discharging	1	2.50	
Putty mixture discharging	1	2.50	
Pipes			
Ores mixing	1	0.54	
Glaze mills observers	2	0.35, 0.74	
Crusher operator	1	1.12	Max=1.15
Blasting	1	0.59	Min=0.29
Mixers charging	1	0.45	Mean=0.59
Small parts casting	1	0.46	Median=0.50
Manual mixer operator	1	0.50	95% confidence
Automatic mixer operator	1	0.29	interval=0.19
Pipe finishing	1	0.33	
Cleaning	1	1.15	
Electrical insulators and transformers			Max=1.54
Sand charging	3	0.52, 0.48, 0.27	Min=0.27
Feldspar charging	1	1.54	Mean=0.68
Clay charging	1	0.92	Median=0.50
Mixture discharging	1	0.37	95% confidence interval=0.49
Fertilizers			
Mixing raw materials	1	0.80	
Mill observer	1	1.96	
Machine blasting			
Blasting in assembly workshop	3	2.42, 0.32, 1.75	
Pharmaceutical			
Weighing of aerosol powder	1	2.22	

*Statistical calculations were carried out for N>6.

on site, appear to influence the concentration, direction, and migration of airborne sand dusts. Predictably, when workers were near or downwind from point sources of dust generation they had greater risks for exposures than if farther away or upwind.

Stone cutting was performed in the open under the shade. Only few of the stone cutting equipment used water jets to control silica dust.

At the pipes industry, no dust control system was in place and a disposable cellulose filter was the only personal protective equipment used by workers in most of the operations. Blenders and mills operators worked in both closed and open cabs on their machinery, and these job titles had exposures that exceeded TLVs even when operators reported or were observed to spend most of the day in a cab. Blender trucks typically had enclosed cabs, but none had high-efficiency particulate filtration or positive pressurization. Blasting, pipe finishing, and cleaning workers were the worst exposed to silica containing dust (Fig. 2).

In the studied glass making industry, glass was produced traditionally in a hall ventilated by a few fans and most of the workers did not use any protective equipment. Ceramic production was also run traditionally in a hall ventilated by several wall fixed fans that did not reduce workers'' exposure because they were working near emission sources. Workers in this factory did not use any personal protection equipment. Poor dust control, ventilation, and personal protection are therefore the major issues in these work environments. However, in some cases, these job titles had exposures >TLV, Table 2, indicating that personal exposures exceeding these concentrations can occur even when workers were not in proximity to the primary source of dust generation. This could be due to silica-containing environmental dust carried onto the site or dusts generated from on-site vehicular traffic.

Workers less commonly observed in the immediate area of dust generation included those in pharmaceutical, fertilizers, painting, and electrical insulators industries (Fig. 2). However, these workers exposed to respirable dust and silica exceeded the TLV except for workers in fertilizers industry were the only within the permissible limit.

Overexposures to silica have been demonstrated in many countries. As an example of areas did similar studies, in Iran, where conditions similar to those found in Egypt might be anticipated, several studies have demonstrated high concentrations in various industries. An exposure assessment to dust and free silica for workers of Sangan iron ore mine in Khaf, Iran was conducted. Comparison to Iranian standard for respirable dust concentrations (0.11 mg/m^3) and international standards (ACGIH=0.1 mg/m^3 and NIOSH=0.05 mg/m^3), it was found that dust and free silica amounts were much higher than national and international standard levels in this mine[14]. The dust concentration and its silica percentage in an ironstone ore in southern Khorasan province were determined, founded that the average percentage of silica in the mine was 15.5% and the measured respirable and total dust concentration was several times higher than standard concentration[9]. The occupational exposure to silica dust of 48 workers in stone cutting, glass making, ceramic, and sand blasting plants in the north of Iran was investigated. The results showed that exposure at each of the workplaces is three to 12 times higher than the current national and international thresholds, which make these workers, run a greater risk of lung cancer and mortality[15].

In Egypt, the safety and health of workers has been a legal matter of concern since the beginning of the last century. The earliest legislation concerning occupational health in Egypt dates back to July 1909. It concerned the employment of children in cotton ginning factories. A number of Acts including sections dealing with health of factory workers followed. The first comprehensive Labour Law was adopted on 5 April 1959 then regulations developed and expanded gradually in order to cover all hazards and economic sectors[7].

Finally, to reduce the adverse effects of industrial silica exposure, it is important to evaluate the degree, type, and source of exposure. Optimally, silica-containing materials should be replaced; work processes should be isolated and enclosed; adequate ventilation should be provided; and personal protective equipment used at all times during possible silica exposure. Even with such measures, some settings may witness rates of exposure that exceed guidelines. Consequently, it is clear that continued efforts are needed to train and supervise workers to promote worker safety with regard to silica exposure. Plants in Egypt are mostly owned privately and policy makers should impose and enforce stricter regulations to control silica dust exposure. Our findings call for a specific ventilation design and personal protection improvements in the studied plants as well as stricter enforcement of the existing regulations by authorities.

Conclusions

Investigation of occupational exposure to crystalline silica dust at 22 factories in Egypt with different industrial activities like stone cutting, glass making, ceramic, and sand blasting were carried out and the samples were analyzed using FTIR. The sampling period was 60–120 min. It was found that the exposure at each of the industrial sectors is very much higher than the current national and international limits, and that lead to a great risk of lung cancer and mortality to workers.

Acknowledgments

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