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Review Article

Evaluation of Exposure to Silica and Silicosis Incidence at High-Risk Industries in Iran

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Abstract

Silica is a major pollutant which releases into the workplace air of many industries, and it causes silicosis and pulmonary diseases. Control of silica in high-risk factories such as silica-crushing, sandblasting, glass manufacturing, glassware, and silica-granulation is considered one of the main objectives of the Environmental and Occupational Health Center (EOHC) in Iran. During the past 20 years, various studies have focused on the exposure of inhaled silica in workplace air, controlling silica, and examining the incidence rate of related pulmonary diseases. The present work reviews all the studies concerning assessing silica in the workplace, installing industrial ventilation, and case-finding. Also, the existing problems in Iranian industries in which silica is produced or consumed are specified; further, several methods have been proposed to improve workers' health, control silica in the workplace, and prevent its dispersion in the outside air.

The present study result that the highest risk of silicosis in Iran is associated with workers in the silica powder industries who have suffered silicosis for even one year of work experience. This study represents that the workers of silica granulation, glass manufacturing, glassware, and silica-crushing industries are at high risk of developing silicosis. The duration of silicosis among workers depends on the type of job, and exposure to free silica is usually 1 to 15 years, and in the silica powder industries is 1 to 3 years.

Keywords: Silica; Air; Silicosis; Control

Introduction

Silica (SiO_2) is a mineral consisting of one silicon atom and two oxygen atoms, which melts at 1600°C. It is a colorless, odorless, and noncombustible solid. The crystals are generated when their molecules are placed linearly [1-3]. The mineral is found in crystalline and amorphous forms; the first types include quartz, tridymite, and cristobalite, depending on the formation temperature. However, different molecules have different spatial relationships in the amorphous form. The types of crystalline silica are transformed into each other under a specific temperature and pressure. Thus, quartz, tridymite, and cristobalite can be observed in various processes by considering temperature and pressure [1,2,4].

Iran is one of the significant silica manufacturers, with around 85 silica mines and 80 silica production/granulation and glass manufacturing factories; most are located in the west of Iran. Local Exhaust Ventilation (LEV) systems have been utilized in 60 high-risk granulation and glass manufacturing factories in Iran since 2007. However, 20 factories have not had LEV systems or have used them incompletely. The systems for dust control are based on baghouse and cyclone-spray scrubber. The silica powder is mainly applied in glass manufacturing, glassware, foundry factories, sandblasting, preparing laundry powders and detergents, and producing glaze and paint chemical compounds. Due to the operations such as crushing, milling, grinding, cutting, screening and abrasion in all the factories, silica particles are dispersed in the air, leading to workers' exposure to an extended range of free silica. Occupational exposure to the inhalation of crystalline silica cause diseases, including immune system damage, chronic bronchitis, emphysema, silicosis, and lung cancer [4,5].

The most important disease caused by exposure to free crystalline silica is silicosis, the progression of which increases a person's vulnerability and the risk of tuberculosis [2,5].

The International Agency for Research on Cancer (IARC) has classified crystalline silica as a human carcinogen (group I), necessitating the examination of the pollutants of silica particles in workplaces [6]. According to the Iranian Environmental and Occupational Health Center (EOHC), the Occupational Exposure Limit (OEL) to respirable free silica is equal to 0.025 mg/m [7]. Based on several studies in the various industries of Iran, many workers have encountered silica, and silicosis has been detected among workers in most sectors [8-11]. Over the last 15 years, different by-laws and laws have been approved and announced by the EOHC of Iran's Ministry of Health and Medical Education. In this regard, the silica in ambient air should be thoroughly evaluated at high-risk factories to maintain its concentration less than the OEL. Considering the objectives of the Ministry of Health and Medical Education of Iran, the dispersion of free silica particles should be controlled entirely in all relevant industries and the environment by 2020. Thus, studies have

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highlighted silica measurement, control, and silicosis patients in high-risk sectors [12-15]. In this respect, the studies on silica measurement have been conducted by assessing the individual exposure of workers in factories. The Local Exhaust Ventilation (LEV) system has been examined in various workshops. In addition, different dust collectors, such as cyclone-baghouse and cyclone-scrubber, have been utilized to clean exhaust air. Also, some studies have focused on individuals with an occupational disease using spirometry and chest radiography.

The following goals can be achieved by studying silica emission in the workplace air and evaluating workers suffering from silicosis:

- The effects of Ministry of Health regulations on silica control in the workplace in high-risk industries are identified.
- The concentrations of silica emission in high-risk factories are determined according to the type of process, industries, and apparatuses.
- The silica control methods in industries are reviewed, and the disadvantages of silica dust collectors are identified.
- The disease control process and silicosis patients are specified.

In the present investigation, the inhaled silica concentration in workplaces and the silicosis patients were assessed in several studies in high-risk industries in Iran during the last 20 years (2001-2021). Furthermore, the best methods to control the silica dust in enterprises were suggested. Finally, the success of the Ministry of Health and Medical Education in controlling silica and reducing the incidence rate of silicosis was assessed.

Materials and Methods

In the present study, the data were collected from the studies concerning the emission of inhaled silica particles and silicosis patients in high-risk workplaces in Iran. Furthermore, the studies on the efficiency of LEV systems and dust collectors were reviewed. Additionally, this study focused on all research determining silica concentration by considering the average 8h exposure to respirable particles. Reviewing studies conducted since 2005 in Iran, it was found that sampling and analyzing inhaled silica in the workplace, evaluating air pollution collectors, and determining patients with silicosis have been performed by the following methods.

Sampling and analyzing of respirable free silica

Researchers have assessed silica by applying the following methods.

National Institute for Occupational Safety and Health (NIOSH) 7500 technique: In this method, a personal sampling pump, a 10 mm nylon cyclone, and 27 mm Polyvinyl Chloride (PVC) filters are used for sampling in ambient air. The sampling pump is calibrated with a rotameter at a flow rate of 1.7 l/min, and dust is sampled using a nylon cyclone in the workers' respiratory zone. Further, silica particles are washed with tetrahydrofuran solution and passed through silver membrane filters using a filtration device and Büchner funnel. After preparation, the diffraction intensity of standard and original samples is recorded by the X-ray Diffraction (XRD), followed by calculating the level of samples in the air [16].

NIOSH 7601: In this technique, respirable silica particles are sampled similar to the NIOSH 7500 one. However, free silica concentration in standard and original samples is obtained through visible spectroscopy at 820 nm. Furthermore, quartz level in unknown samples is computed by comparing the absorbance of samples with the standard curve [16].

The collection efficiency in dust collectors

The efficiency of collectors was calculated based on the total collected mass shown in the following equation [17]:

$$EF=[C1-C2]/C1 \times 100$$

Where:

EF=overall collection efficiency

C2=total outlet concentration (mg/m^3)

C1=total inlet loading concentration (mg/m^3)

Assessment of patients with occupation-caused diseases

The workers of factories with high-risk workplaces were evaluated using spirometry and radiograph and examined the silicosis patients detected in the workplace by occupational medicine specialists and pulmonologists [18-24].

Results

Table 1 provides the results of silica measurement in the individual exposure to silica dust in different industries. The highest exposure of workers to silica is related to silica-crushing, glass manufacturing, and foundry workshops, while the least occurs in the cement industry. In the silica-crushing workshops, silica stones (>99% of silica) are used in the glass manufacturing industry after producing silica powder. However, the rocks have silica below 90% applied in sandblasting, furnace linings, ceramics, refractories, and porcelain articles.

Since 2005, the EOHC of the Ministry of Health and Medical Education of Iran has forced all industries to install pollutant purification and LEV systems in silica-crushing and glass manufacturing workshops. The results of the studies on silica evaluation in enterprises indicated a 99% decline in dust following the installation of an LEV (Table 2). In addition, baghouse and cyclone-scrubber systems have been applied to control pollutants in factories, environmental standards being better in baghouse (efficiency: >99%) than cyclone-scrubber (efficiency: 95%) (Table 2). Moreover, the prevalence of silicosis in the industries related to glass manufacturing, mines, and silica-crushing is more than in other enterprises. The disease has been reported among those employed with below three years of experience in some silica-crushing industries. Further, suspected cases of silicosis are observed among individuals working in the pottery-related industries for above 30 years. All the workers are men in the silica-related sectors of Iran (Table 3).

Discussion

Based on the studies conducted in the factories with a high risk of silica exposure, the inhaled silica concentration over the 8-hour exposure is more than the OEL recommended by the EOHC [7], the Ministry of Health, and Medical Education of Iran. Additionally, the maximum silica release rate is observed in silica-crushing enterprises and the silica mill of glass manufacturing factories and foundries. Over the different processes of silica-crushing and glass factories, quartz stone is broken during the grinding operation and then transferred to a crushing machine through a conveyor belt to produce silica powder. The powder produced in the glass factories moves to the furnace, and in the silica smelters, it is used for various purposes such as foundries and sandblasting. During these processes, large amounts of silica dust are produced, so the risk of silicosis increases. The shortest silicosis

Table 1: Exposure to inhaled silica in different industries of Iran.

Industry	Total number of samples	Process and jobs	Number of samples	Exposure level (mg/m^3)	Ref
Stone Quarry	60	Horizontal rock drill	12	0.02 ± 0.01	[25]
		Vertical Rock drill	12	0.02 ± 0.01	
		Hammer drill	24	0.06 ± 0.02	
		Bulldozer	6	0.01 ± 0.01	
Stone Silica Crushing	40	Process workers	12	0.21	[26]
		hopper	8	0.45	
		Drivers	11	0.2	
		Office Employees	9	0.04	
Stone Quarry	48	Crushing machine operators	6	0.4 ± 0.2	[27]
		Crusher loading terminal	6	0.85 ± 0.15	
		Crusher loading machine	6	0.75 ± 0.16	
		Separator machine controller	6	1.1 ± 0.2	
		drilling No.1	6	1.5 ± 0.4	
		drilling No.2	6	0.9 ± 0.01	
		Pneumatic hammer	6	0.01 ± 0.01	
		Site loading	6	0.2 ± 0.15	
East zone of Tehran	94	Stone cutting & milling	20	0.28	[28]
		Foundry work	20	0.34	
		Glass manufacturing	20	0.13	
		Sandblast operation	14	0.27	
		Cement manufacturing	20	0.22	
Cement factory	44	Raw mill	11	0.05 ± 0.04	[29]
		Furnace	14	0.04 ± 0.02	
		Cement mill	7	0.02 ± 0.01	
		Loading	12	0.04 ± 0.02	
Tehran subway tunnel	100	Excavation	20	0.41 ± 0.07	[30]
		Reinforcement	20	0.11 ± 0.09	
		Cementing	20	0.26 ± 0.06	
		Soil transportation	20	0.32 ± 0.10	
		Evacuation and depot	20	0.37 ± 0.03	
Small foundries of Pakdasht	62	Molding	24	0.03 ± 0.03	[31]
		Core Making	23	0.06 ± 0.07	
		Sandblasting	15	0.05 ± 0.06	
Factories of Mazandaran province	48	Glassmaking	12	0.13 ± 0.13	[32]
		Ceramic	12	0.17 ± 0.06	
		Sandblasting	12	0.31 ± 0.18	
		Stone cutting	12	0.32 ± 0.12	
Construction workers	34	Stone worker	17	0.07 ± 0.02	[33]
		Building cleaner	17	0.10 ± 0.02	
Small foundriesof Pakdasht	80	Iron casting	46	0.03	[34]
		Brass casting	12	0.03	
		Aluminum casting	3	0.01	
		Alloys casting	19	0.04	
Insulator	60	Body preparation	12	0.33 ± 0.15	[35]
		Glaze line	12	0.30 ± 0.21	
		Furnace	12	0.02 ± 0.01	
Foundry	55	Machine Operator	23	0.31 ± 0.10	[36]
		Color operator	9	0.17 ± 0.02	
		Furnace	6	0.23 ± 0.07	
		Cleaning and arrangement	17	0.20 ± 0.02	
Cement factory	29	Loading	6	0.05 ± 0.11	[37]
		Raw mill	6	0.03 ± 0.05	
		Preheater	5	0.08 ± 0.11	
		Stone crushing	6	0.54 ± 0.60	
		Soil transportation	6	0.04 ± 0.05	
Silica Powder	8	dustmen	8	3.05 ± 0.8	[15]

duration is among the silica powder industry workers (1 to 3 years). The concentrations of inhaled silica in these industries are between 5 mg/m^{3}to 100 mg/m^3.

The workers performing high-risk activities in silica-screening factories, silica open-pit mines, and many foundries are among periodic and seasonal workers. Employers replace them with new workers for a maximum period of six months. Silicosis has been observed in some sandblasting and glass manufacturing industries where workers are employed permanently. The rate of silicosis has been reported in various studies over the past two decades. Despite the declaration of health regulations by the Ministry of Health, there are no signs of disease control in Iran. The rules relate to executing a comprehensive silica control plan in Iran [7]. All factories must apply LEV upon the program, and silica should be less than the OEL [7].

Despite implementing silica control programs in industries and applying LEV in some factories, the silica level dispersed in the sectors

Table 2: Assessing the efficiency of dust collection systems in the industrial ventilation used in controlling silica.

Industry	System type	Measurement type	The average sum of the particles before installing LEV (mg/m³)	The average sum of the particles after installing LEV (mg/m³)	Efficiency (%)	Ref
Silica-crushing factory	Cyclone and scrubber	Before and after collectors in channels	700	18.18	94.2	[14]
Stone-crushing factory	Cyclone and scrubber	Before and after collectors in channels	5393 ± 986.2	131.0 ± 30.5	97.5	[12]
Mining	Cyclone and scrubber	Before and after collectors in channels	1131.39	105.49	90.63	[13]
Mineral processing	Bag filter	Before and after collectors in channels	995.7	3.2	99.67	[38]

Table 3: The incidence of silicosis in workers in various industries of Iran.

Industry	Test	Number of workers	Silicosis	working experience (years)	year	Ref
Silica powder production	Spirometry, Chest radiography	100	10	3	2006	[18]
Silica powder production	Spirometry, Chest radiography	300	80	44621	2007	[39]
Turquoise mines	Spirometry, Chest radiography	72	8	11.5	2009	[40]
Stone carving	Spirometry, Chest radiography	70	7	43952	2013	[41]
Agate grinding	Spirometry, Chest radiography	170	22	10	2014	[42]
Glass manufacturing	Spirometry, Chest radiography	3121	218	16.1 ± 7.2	2015	[43]

is 1.2-20 times more than the occupational exposure limit. In these enterprises, the equipment with old technology is utilized for milling, crushing, and granulating silica; thus, silica dust is dispersed in the numerous cracks and holes existing in apparatus, emitting in the air around the workplaces. Further, using some vehicles, such as loader and lorry, for carrying silica powder leads to the dispersion of the pollutants in the air of workshops. Different silicosis cases have been reported in factories where workers were employed permanently [18]. The comparison between the silica level dispersed in Iran and other Asian countries' factories indicates that it is less spread in high-risk factories of Iran than in India but is more compared to the USA.

The present study results show the utilization of the control systems of cyclone-scrubber, cyclone-baghouse, and baghouse in industries with a high risk of silica in Iran [12-15]. The minimum dispersed silica level is obtained in cyclone-baghouse and baghouse. Due to the regulations on the non-release of particles into the outside air by the Department of Environment, all new factories must use baghouse or cyclone-baghouse. The baghouse system exhibits an efficiency of >99% in removing particles below 5 μm. However, cyclone-scrubbers systems cannot effectively control the particles and are dispersed in the outside air.

Many industries in Iran still are devoid of LEV systems and dust collectors. Thus, the dispersal of the particles inside the factory affects workers' health. Furthermore, milling and granulation machines with old technology disperse particles in workplaces. The machines should be replaced with closed system machinery, and those with advanced technology should be applied in silica crushing, glass manufacturing, and foundry. The Ministry of Health and Medical Education of Iran should prevent the operation of factories without dust collectors and LEV systems. Periodic examinations should be performed for all of the occupancies. The workers suffering from primary silicosis should be identified, and their jobs should be changed so they do not expose to silica during their daily work. All workers should be trained to protect themselves, reducing their exposure to silica. Workers are provided with personal protective equipment, and workers are trained to use them. Other engineering methods, such as wetting methods during grinding, lead to dust reduction.

The limitations of the present study include the lack of silica measurement in construction projects. In addition, limited studies and silica measurements have been performed in the silica open-pit mines and other stone production mines of Iran. Finally, silica is used as an interstitial material in many heavy industries in Iran, which researchers have not highlighted.

Conclusion

The present study results represent that the workers of silica granulation, glass manufacturing, glassware, and silica-crushing industries are at high risk of developing silicosis. The results of studies on silicosis in Iran show that the duration of silicosis among workers depends on the type of job and exposure to free silica. It is usually 1 to 15 years, and in the silica powder industries, it is 1 to 3 years.

We recommend immediate actions must be taken to install LEV systems and dust collectors in enterprises. The seasonal workers should be examined periodically, and their life processes should be assessed. Further, an electronic system should be set up to record silica dust concentration in Iran's industries to identify those producing the silica dust level above the standard limit. Finally, clinical tests, radiography, and spirometry should be performed to detect the workers prone to silicosis and prevent their exposure to silica.

Highlights

- The silicosis has been observed in workers of silica powder and glass factories with work experience of one to three years.
- The workers in silica powder, glass manufacturing, glassware, and silica-crushing industries are at high risk of developing silicosis.
- Bag filter systems are the best way to control silica particles with the highest efficiency.

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