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Exposure Assessment to Dust and Free Silica for Workers of Sangan Iron Ore Mine in Khaf, Iran

Ali Naghizadeh · Amir Hossein Mahvi · Hossein Jabbari · Elham Derakhshani · Hassan Amini

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Abstract We aimed to conduct an exposure assessment to dust and free silica for workers of Sangan iron ore mine in Khaf, Iran. The maximum concentrations of total dust and free silica were measured in crusher machine station at 801 ± 155 and 26 ± 7 mg/m^3, respectively. Meanwhile, the minimum concentrations were measured in official and safeguarding station at 8.3 ± 2 and 0.012 ± 0.002 mg/m^3, respectively. Also, the maximum concentrations of respirable dust and free silica were measured in Tappeh Ghermez drilling no. 1 at 66 ± 13 and 1.5 ± 0.4 mg/m^3, respectively, while the minimum concentrations were measured in pneumatic hammer at 5.26 ± 3 and 0.01 ± 0.005 mg/m^3, respectively. Considerate to Iranian standard for respirable dust concentrations (0.11 mg/m^3) and international standards (ACGIH = 0.1 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.

Keywords Crystalline silica · Iron ore mine

A. Naghizadeh · H. Amini
Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Qods Street, Tehran, Iran
e-mail: al.naghizadeh@yahoo.com

H. Amini
e-mail: amini_h@razi.tums.ac.ir

A. H. Mahvi (✉)
Department of Environmental Health Engineering, School of Public Health; and Institute for Environmental Research, Tehran University of Medical Sciences, Qods Street, P.O. Box 14155-6446, Tehran, Iran
e-mail: ahmahvi@yahoo.com

H. Jabbari
National Institute of Health Research, Tehran University of Medical Sciences, Qods Street, Tehran, Iran
e-mail: jabbari@sina.tums.ac.ir

E. Derakhshani
Department of Environmental Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran
e-mail: el.derakhshani@yahoo.com

Silica (SiO_2) is one of the most abundant minerals on earth, extremely toxic, and also, can cause fibrosis. Exposure to silica compounds more than permissible limits is known as a hazardous potential in pulmonary disease (Iler 1979; Banks and Parker 1998). Also, silica contributes in silicosis and sclerosis (Banks and Parker 1998; Englert et al. 2000). One of the most important mines in Iran is iron ore mines. However, the high quantities of dust and particles are produced during the digging, stonecutting, and rock drilling processes. Meanwhile, different particles can cause different lung injuries (Banks and Parker 1998).

Quartz is a term that often refers to free silica dusts (Yassin et al. 2005). Silicosis is a lung disease and decreases the ability of the lungs in oxygen up taking. Overexposure to crystalline silica in either respirable or irrespirable forms can cause adverse health effects. In case of respirable silica health effects, silicosis is one of the most important reported diseases. As a result, more than 250 workers die each year in United States of America because of silicosis, and more than hundreds of workers are disabled because of silicosis and bronchitis. Unfortunately, silicosis is not curable, but it can be prevented by reduction and control of exposure to silica compounds (Kane 1997). In a study that conducted by Samadi (2002) in Emarat Lead mine of Iran, the concentration of respirable free silica dust was a few times higher than standard level. Moreover, in another study in ferrosilica mine of Semnan, exposure level to respirable silica dusts was evaluated and reported to be higher than National Institute of Occupational Safety and Health (NIOSH) standard level (Dehdashti and Malek 2000). Also, in another report, 8-h occupational exposure level in the United States during 1998–2003 was reported higher than American Conference of Governmental Industrial Hygienists (ACGIH) standard level. However, during the years 1998–2003, exposure trend was declining, but still it was higher than Occupational Safety and Health Administration (OSHA) standard levels (Yassin et al. 2005). Exposures in occupational fields are in very wide ranges. For example, occupational exposures occur by working in ore, coal, nonmetallic mineral and stone mines, coarse and fine sand and clay digging, shingle making, ceramic manufacture, non-iron melting, and so on (Clayton et al. 1993). Pulmonary disorders due to dust particles are one of the oldest occupational diseases. This kind of pneumoconiosis appear in exposure to free silica from ore digging or crusher station and is a difficult and costly work-related disease (West 1982; Estellita et al. 2010).

The International Agency for Research on Cancer (IARC) was classified crystalline silica as a “group 1 human lung carcinogen” at 1997 (Brun and European Agency for Safety and Health at Work 2009; Steenland et al. 2001). Also, current evidence implies that free silica is an effective potential in lung cancer occurrence (Flynn and Susi 2003). Considerate to improved work conditions and dust control in developed countries, incidence rate of silicosis is declining (De-Vuyst and Camus 2000). While in developing countries, exposure to dust is an important health problem (Samadi 2002). Hence, dust concentration cognizance in workplace air, particularly free silica, has been practiced to minimize the adverse health effects.

Khaf is a county in Razavi Khorasan Province in Iran in neighboring with Afghanistan. It is a small border town about 250 km from Mashhad. The historical city of Nashtifan with centuries-old windmills is located close to Khaf.

Sangan iron ore mine in Khaf is one of the richest mines in the Middle East region. It has been estimated that discovered iron ore deposit be about 1,200 billion tons that some 500,000 tons exploit each year. Production is foreseen to reach 40.2 million metric tons in 2013 and 42 million metric tons in 2014. Figure 1 presents the location of Razavi Khorasan Province and Khaf.

According to the data gathered from this mine, there is a high silica concentration in extracted stones of this region. Therefore, it is obvious that silica can spread out in the air during excavation or mining the ground and can cause various dangers for workers, such as silicosis. Thus, this survey was conducted in 2010 in order to evaluate the dust and free silica concentrations in different indoor air of Sangan iron ore mine in Khaf.

Materials and Methods

Typically, respirable silica has been analyzed via two methods including X-ray diffraction (XRD) and infra-red spectrometry. Of these, XRD is the more accurate and less susceptible to interferences from other minerals that will be found in respirable dust (as defined as less than 10 μm in aerodynamic diameter or PM_{10}).

XRD can also distinguish the three main types of silica, namely as crystabolite, tridymite, and alpha quartz on single 25 mm personal air sampling filter. This is important in foundries and other high temperature environments were quartz can denature to tridymite and crystabolite at high temperatures, both of which are hazardous chemical substances.

Free silica concentration in total, respirable, and control samples were collected from workplace environment and analyzed based on XRD technique (Allen et al. 1974). The total and respirable sampling were accomplished based on 7500 NIOSH method (NIOSH 2003). In order to remove humidity from filters, before weighing, they were maintained and dried for at least 24 h in desiccators, before sampling. Filter weighing was performed by digital balance with precision of 0.001 g. Selected membrane filters had 25 mm diameter and were provided from Sartorius Company (Germany). Sampling pump (MCS-10 model) was provided from SKC Company (United States). As calibration is required for sampling train, we calibrated the pump using a flow meter before sampling and after each repair or abuse in the field. For calibration of the sampling pump, the suction tube of sampling pump was connected to the inlet of the flow meter. Then, by adjusting the flow rate of the pump on a specific rate, the flow rate was read on the flow meter and was considered as true flow rate of the sampling pump.

Sampling was based on environmental and personal sampling methods. In environmental sampling method, sampling apparatus including filter and filter holder, environmental sampling pump, and flexible pipe were prepared and fixed in sampling stations. Environmental sampling period was 2 h and flow rate was 8 L/min. In personal sampling method, the flow rate of the personal samplers was 1.7 L/min and the pumps stopped automatically at 4 h. Personal sampling apparatus was included cyclone and holder (clung on worker collar), sampling pump (clung on worker waist) and flexible pipe. At the end of the sampling periods, filters were transferred to the laboratory and, after drying in desiccator, weighted with digital balance, thereby

Fig. 1 Map of the study area in southeast of Razavi Khorasan province of Iran

total and respirable dust concentration were computed based on the following equation at milligrams per cubic meter (mg/m^3):

$$C = \frac{(W_2 - W_1) \times 10^3}{\Delta t \times Q}$$

where C is dust concentration of air in workplace; W_1 = filter weigh before sampling, mg; W_2 = filter weigh after sampling, mg; Δt = sampling period, min; Q = sampling pump flow rate, L/min (with correction of sampled air volume to volume in standard condition).

Finally, 96 workers in the mine were examined medically. Environmental samples, control samples, and also 26 standard silica samples were analyzed with XRD technique.

Based on the NIOSH instruction, XRD technique was used for free silica (quartz) determination in dust samples. Considerate to the fact that XRD quantitative analysis technique need standard curve to determine unknown sample concentrations, standard samples should be prepared. Filtration method was used to achieve this purpose. Thus, pure and standard respirable quartz powder samples in 10 and 50 mg prepared. Then, each sample was transferred to a 1 L capacity beaker and filled to the mark with 2-propanol solution. Thereafter, the mixture agitated for 20 min until a suspension was reached. Simultaneously, a silver filter with 25 mm in diameter and 0.8 μm in pore size diameter was fixed on the holder and a pump with 1.7 L/min was turned on. Based on the simple mathematical computations, appropriate amount of suspension was picked up by a pipette and poured on the silver filter. Eventually, on the several standard filters of 10, 20, 30, 50, 100, 200, 500, and 800 μm, standard silica was existed. After standard sample preparation, they were set into diffract meter in turns and intensity was read. Then, their standard regression curve was drawn. In order to analyze the total and respirable dusts in samples, membrane filters were set into specific area of diffract meter and quartz peak intensity was obtained based on cycle per second (CPS) and each filter peak intensity was read. These results were reported as geometric mean and were compared with ACGIH, NIOSH, and Iranian Standards.

Results and Discussion

In this study we monitored the levels of silica in air of Sangan iron ore mine for distinguishing that the workplace is dangerous for workers or not. Because of the obvious dangers involved with inhaling silica dust, it is important for a monitoring system to be in place to ensure levels of respirable crystalline silica are within 0.1 mg/m^3 for mining and 0.4 mg/m^3 for general industry. These levels are prescribed in the Hazardous Chemical Substances Regulations Act of 1995 and the Occupational Health and Safety Act 85 of 1993. In Tables 1 and 2 the sex and ages of miners in each category and sampling station have been presented.

In this study, In order to identify whether silica exists in zoisite or not, eight stone and powder samples were collected from different parts of the mine and analyzed by XRD technique (Chen et al. 2010). As a result, high percentage of free silica (mean quartz concentration = 10.8%) was found. Altogether, 48 environmental samples were collected and analyzed by eight work stations including crusher machine, crusher machine loaders, site loading, Tappeh Ghermez drilling no. 1, Tappeh Ghermez drilling no.2 , rest room of Tappeh Ghermez workers, rest room of crusher machine workers, and official and safeguard stations. Volume selections of the environmental samples were based on sampling from outset to the end of the mine, and whole mine stations were sampled. As shown in Figs. 2, 3, and 4, the total dust maximum mean concentration was measured in crusher machine station at 801 mg/m^3 (SD = 155) and the minimum concentration was measured in official and safeguard station at 8.3 mg/m^3 (SD = 2).

The total quartz maximum mean concentration was measured in crusher machine station at 26 mg/m^3 (SD = 7) and the minimum concentration was measured in official and safeguard station at 0.012 mg/m^3 (SD = 0.002). Also, the total quartz maximum mean percentage was measured in crusher machine station and the minimum was measured in official & safeguard station, respectively.

Altogether, 48 personal samples were collected and analyzed from eight work stations including crusher machine operators (inside the building), crusher loading terminal, crusher loading machine, separator machine controller, Tappeh Ghermez drilling no. 1, Tappeh Ghermez drilling no. 2, pneumatic hammer, and site loading (loader driver) stations.

As shown in Figs. 5, 6, and 7, the mean of maximum concentration of respirable dust was measured in Tappeh Ghermez drilling no.1 at 66 mg/m^3 (SD = 13), and its minimum was measured in pneumatic hammer station at 5.3 mg/m^3 (SD = 3). The respirable quartz maximum mean concentration was measured in Tappeh Ghermez drilling no. 1 at 1.5 mg/m^3 (SD = 0.4), and its minimum was measured in pneumatic hammer station at 0.01 mg/m^3 (SD = 0.005). Also, the respirable quartz maximum mean percentage was measured in the separator machine controller station and its minimum was measured in the pneumatic hammer station.

Considerate to Iranian standard for total dust concentration (10 mg/m^3) and regarding to Fig. 2, only the total dust concentration in official and safeguard station was lower than Iranian standard level, and in other stations, particularly in crusher station, was about eighty times higher than Iranian standards. Also, by considering Iranian respirable dust standard (3 mg/m^3) and regarding to Fig. 5, respirable dust concentration in all sampled stations were higher than Iranian standard and the dust concentration in Tappeh Ghermez drilling no. 1 was twenty two times higher than Iranian standard.

Figures 3 and 4 present the total dust free silica analysis and also total mean percentage of quartz in different parts of the mine. By considering Mine Safety and Health Administration (MSHA) and OSHA Standards which are 0.27 and 0.26 mg/m^3, respectively, it was found that the total dust free silica concentration in three stations including pneumatic hammer; rest room of crusher machine workers; and rest room of Tappeh Ghermez workers are lower than above standards. In other stations, such as crusher machine station, crusher machine loaders

Table 1 Number, sex and age of miners and sampling time in personal sampling station

Location	Number of worker	Sex	Average age	Number of samples	Sampling time (h)
Crusher machine operators	12	Male	25	6	4
Crusher loading terminal (drivers)	6	Male	35	6	4
Crusher loading machine (drivers)	12	Male	30	6	4
Separator machine controller	20	Male	35	6	4
Tappeh Ghermez drilling No. 1 (workers)	5	Male	30	6	4
Tappeh Ghermez drilling No. 2 (workers)	5	Male	30	6	4
Pneumatic hammer (drivers)	8	Male	30	6	4
Site loading (loader drivers)	6	Male	35	6	4

Table 2 Number, sex and age of miners and sampling time in environmental sampling station

Location	Number of worker	Sex	Average age	Number of samples	Sampling time (h)
Crusher machine	18	Male	25	6	2
Crusher machine loaders	9	Male	33	6	2
Official and safeguard	16	Male	28	6	2
Tappeh Ghermez drilling No. 1	5	Male	30	6	2
Tappeh Ghermez drilling No. 2	5	Male	30	6	2
Rest room of Tappeh Ghermez workers	–	Male	–	6	2
Rest room of crusher machine workers	–	Male	–	6	2
Site loading	28	Male	35	6	2

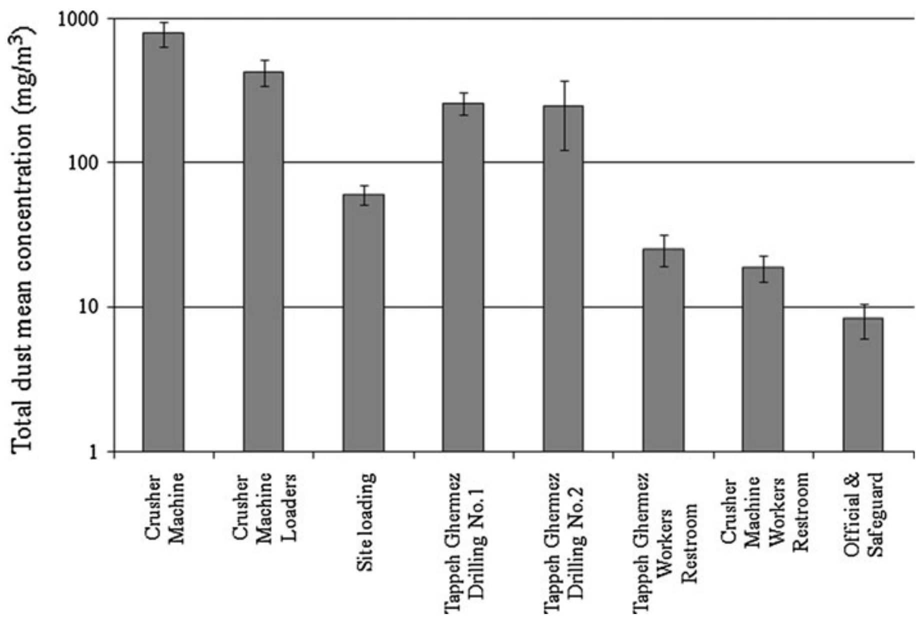

Fig. 2 Concentration mean of total dust and standard deviation of sampled stations

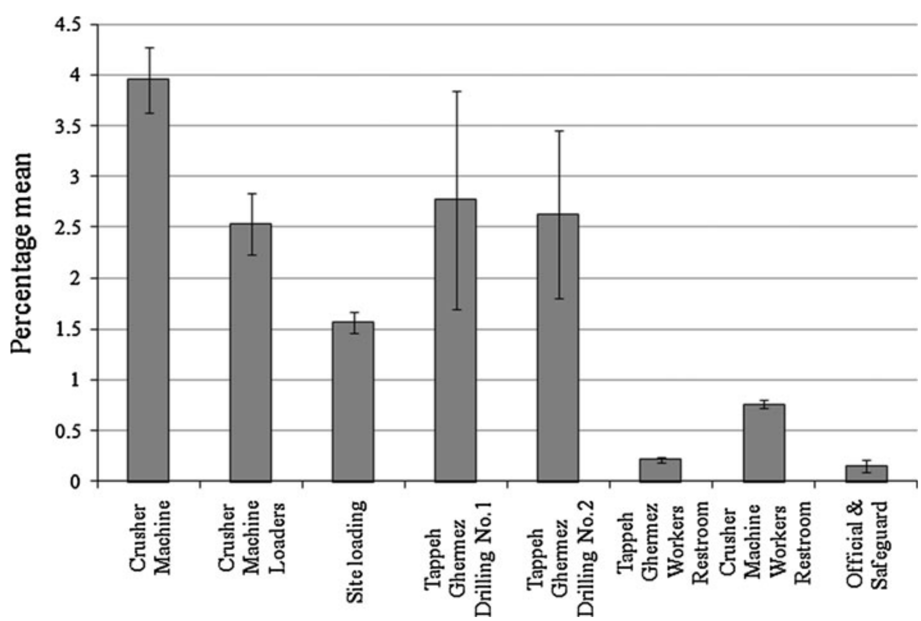

Fig. 3 Percentage mean of quartz in total dust of sampled stations

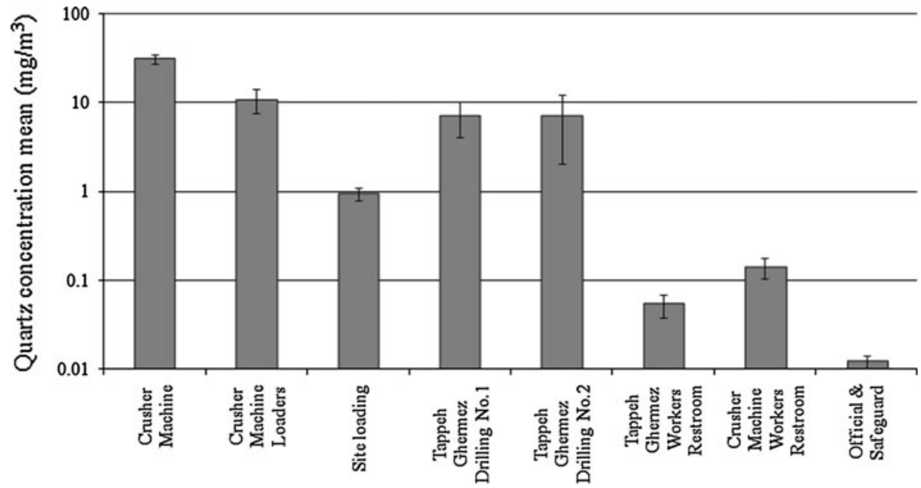

Fig. 4 Quartz concentration mean and standard deviation in total dust of sampled stations

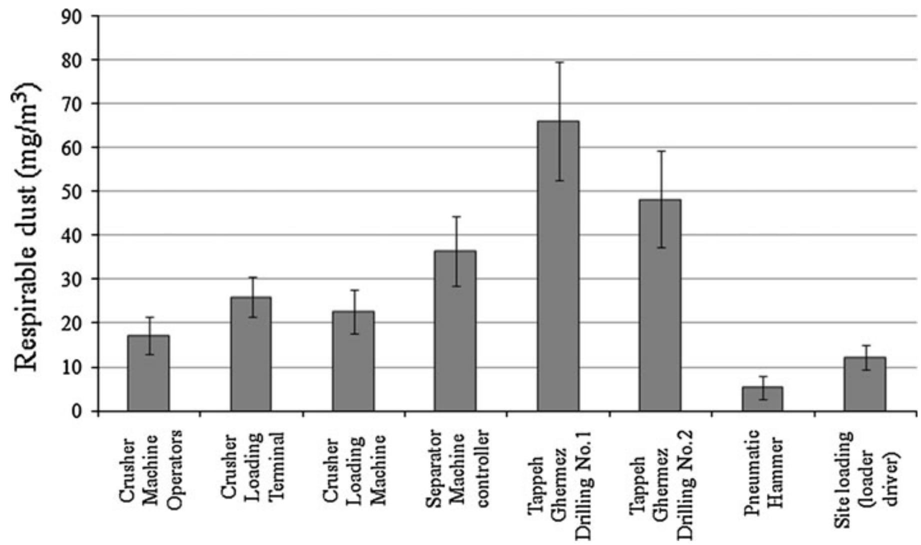

Fig. 5 Respirable dust (as defined as less than 10 µm in aerodynamic diameter or PM_{10}) concentration mean and standard deviation in personal sampling stations

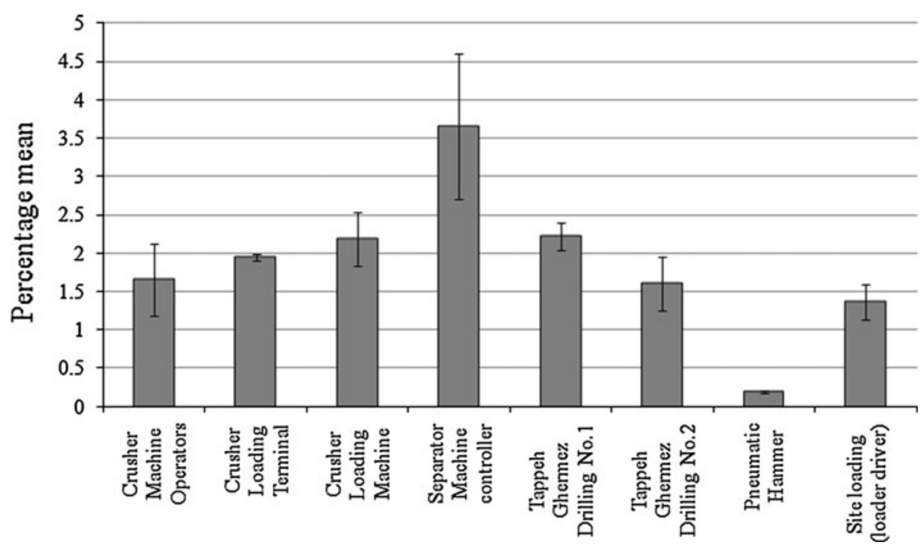

Fig. 6 Percentage mean of quartz (defined as a hard mineral consisting of silicon dioxide) in respirable dust of personal sampling stations

station, and Tappeh Ghermez drilling nos. 1 and 2 stations, these concentrations are by 100, 42, and 28 times higher than above standards (NIOSH 2003; Schatzel 2009).

Figures 6 and 7 present the results of free and respirable silica measurements, and also, mean percentages of respirable quartz in different parts of the mine. By considering

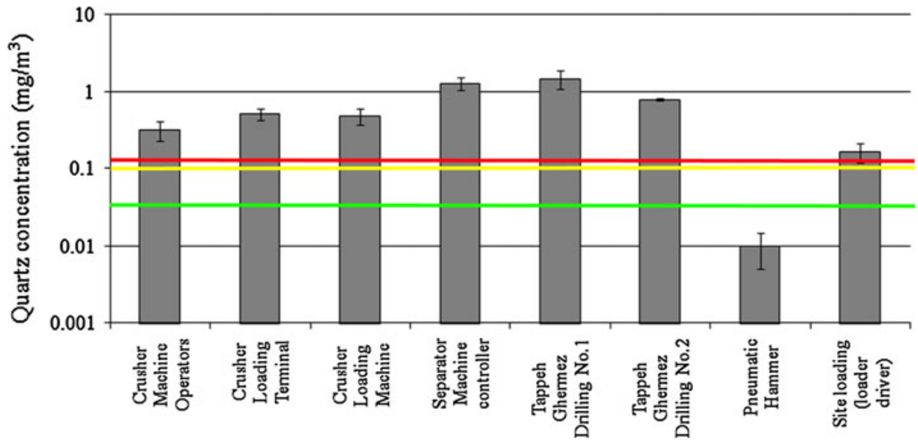

Fig. 7 Mean of respirable dust concentration as well as standard deviation of personal sampling stations and Iranian (*red line* = (0.11 mg/m^3)) and international standards (*yellow line* = ACGIH standard (0.1 mg/m^3), *green line* = NIOSH standard (0.05 mg/m^3))

Iranian standard about free respirable silica (0.11 mg/m^3) it was found that only in pneumatic hammer station the concentration was lower than Iranian standard. Moreover, it should be noted that the respirable free silica in site loading station was close to Iranian standard. In other stations, these amounts are very higher than Iranian standard. For example, in Tappeh Ghermez drilling no. 1 station, respirable free silica was about 15 times higher than Iranian standard. By comparing respirable silica concentrations with ACGIH and NIOSH permissible standards, it was obtained that respirable silica in crusher machine operators (inside the building), crusher loading terminal, separator machine controller, Tappeh Ghermez drilling no. 1, Tappeh Ghermez drilling no. 2, and site loading stations were higher than ACGIG and NIOSH Standards and only in pneumatic hammer station it was less than the standards. In conclusion, the obtained results demonstrated that dust and free silica amounts in workplace air of this mine were very higher than mentioned standards. Eventually, there are many specific and general recommendations to reduce exposure to respirable crystalline silica at the workplace. Workers can limit their exposure by being aware of and practicing the following tips:

- Identify through measurements in the workplace where silica dust may be generated.
- Use containment and/or controls methods, such as wetting dust producing areas. Thereby limiting exposure of workers to hazardous dusts.
- Regularly maintain dust control systems to ensure they are working as well as possible.
- Conduct air monitoring to measure exposure of workers.
- Install dust extraction equipment preferably with bag filtration.
- The use of respirators or personal filtration masks should be enforced where dust levels are high.
- Warning signs should be placed at entrance of any area where high levels of dusts are going to be encountered.
- Inform staff about hazards of respirable crystalline silica dust and any other hazardous dust they may encounter in the workplace
- Issue protective masks and respirators at areas where high dust exposure is going to be encountered.

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