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Artículos

Proposal for the risk analysis for silica exposure based on the respirable fraction dust

Propuesta de análisis de exposición a sílice con base en la fracción respirable

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Abstract: Crystalline silica is a natural chemical compound present in rocks, sand and soil. In industry, it is found in chemical products: cement, bricks, concrete... To measure the amount of silica a worker breathes, a dust sample must be taken from the respirable fraction. Due to the cost of chemical analysis of this fraction against silica, whose proportion is approximately 1:25, it is important to establish a methodology that allows an approximation of the risk calculation related to silica exposure, in order to reduce it. According to this, 63 data (2016-2019) were analysed, corresponding to measurements of the aforementioned dust with emphasis on silica belonging to industrial processes. The data were then analysed, and a statistically acceptable relationship was found for different industrial processes, resulting in a mathematical equation to determine the amount of silica, as a function of the amount of respirable fraction, with a statistical acceptance level.

Keywords: silica, respirable fraction, exposure, similar exposure groups (SEG), TLV.

Resumen: La sílice cristalina es un compuesto químico natural presente en rocas, arena y suelo. En la industria, se halla en productos químicos: cemento, ladrillos, hormigón... Para medir la cantidad de sílice que respira un trabajador, se debe tomar una muestra de polvo de la fracción respirable. Debido al costo del análisis químico de dicha fracción frente a la sílice, cuya proporción aproximada es de 1:25, se entiende la importancia de establecer una metodología que permita realizar una aproximación del cálculo del riesgo relacionado con exposición a sílice, para disminuirlo. Según esto, se analizaron 63 datos (2016-2019), correspondientes a mediciones del citado polvo con énfasis en sílice pertenecientes a procesos industriales. Seguidamente, se analizaron los datos, se encontró una relación para diferentes procesos industriales, aceptable desde el punto de vista estadístico, así resultó una ecuación matemática para determinar la cantidad de sílice, en función de cantidad de fracción respirable, con un nivel de aceptación estadístico.

Palabras clave: sílice, fracción respirable, exposición, grupos de exposición similar (GES), TLV.

1. Introduction

Silica is the name given to a group of minerals composed of silicon and oxygen, in the ratio 1:2, that is, silica is SiO_2. Among the forms of greatest concern, at the occupational level, are the forms of quartz, cristobalite and tridymite. Of the above forms, quartz is the most common in the industry, in processes of mining, construction and manufacturing [1]. The biggest reason for the worldwide interest in silica is undoubtedly the fact that it causes lung cancer obstructs the respiratory tract, and is related to microbial diseases [2]. By the way, as demonstrated by the International Agency for Research on Cancer (IARC) in one of its studies published in 2012, where it concluded that epidemiological findings support an association between lung cancer and crystalline silica inhaled [3].

Silica exists in various forms, where quartz is the most common of them, people can breathe it as respirable crystalline silica, when they are exposed to the aforementioned substances, entering the respiratory system, where their accumulation in the lungs generates serious respiratory diseases, such as silicosis, among others.

In Colombia, in accordance with the provisions of Article 154 of Resolution 2400 of 1979 [4], the permissible limit values of the ACGIH, the TLVs and BEI's® [5] are established, where a TLV-TWA value of 0.025 mg / m^3, for crystalline silica such as quartz and cristobalite. This value explains the toxic characteristic of this substance and accounts for its danger to workers.

To quantify silica at the occupational level, a sample should be taken as established in the NIOSH method 0600 [6], for gravimetric analysis, and NIOSH 7500 [7], for the determination of silica, that is, a sample of respirable dust powder must be taken and then, this sample is subjected to a detailed analysis to determine the silica content as a percentage.

Generally speaking, a breathable fraction dust analysis has an approximate cost of USD 8.2, and if this sample is going to be analyzed to determine silica content, then this cost increases to USD 205. When considering a number of samples representative for the estimation of SEG (similar exposure groups), the minimum number of suggested samples would be six [8], whose study would cost USD 1231, that is, about 25 times more compared with the same amount for the analysis of powder respirable fraction.

In countries such as Colombia, where there are no laboratories accredited by international organizations in the field of industrial hygiene, for example the AIHA (American Industrial Hygiene Association), samples must be sent to other countries for such analysis, raising costs and, therefore, restricting the appropriate number of samples for analysis by SEG or risk analysis by work cycles, since the measurement must be executed for as long as possible, in order to optimize the resource, giving priority to the exposure of the workers, and leaving aside valuable information for the projection of the different control systems applied to dust.

2. Materials and method

The present study has been carried out based on the results obtained from measurements in different processes and places in the metropolitan area of the city of Medellín, including some municipalities in the department of Antioquia in Colombia.

The information from the samples of respirable dust and amount of silica were recovered from the databases of reports made for analysis of exposure to dust, respirable fraction and crystalline silica, according to the professional experience of the authors. In addition, it was possible to relate each measurement to a specific place where the sample was taken.

The measurements executed, during 2016 and 2019, were carried out under NIOSH 0600 [6] and NIOSH 7500 [7] standards (National Institute for Occupational Safety and Health), for exposure to respirable dust powder and silica analysis, respectively.

The silica analysis was done only as quartz, which is the most abundant of the different types of silica available.

The results of gravimetry and silica analysis were carried out by laboratories accredited[1] by the AIHA abroad. In addition, these results were used to produce exposure reports and risk analysis in different organizations.

2.1. Description of the evaluated jobs

2.1.1. The measurements made to the process of tunneling were carried out for the following tasks or activities:

- Supply with Portland cement, accelerant and water in the injection hopper of the BA-03 machine.
- Tunnel operations: 1. remove debris with the objective of locating them in an accessible place for the backhoe arm, 2. inspect the articulated arms of the jumbo with the aim of guiding the machinist in the moments of drilling start, 3. Provide explosives in the holes, previously drilled by the jumbo, for its subsequent detonation.
- Verify the process of unloading material by dump truck on a platform, outside the tunnels.
- Support the process of rock profiling and drilling of this, inside the tunnels.
- Supervise the process of excavation of tunnels
- Carry out work in tunnels, load trucks with sterile material (approximately 60 trips).
- Execute verification tasks and supervision of work fronts, the loading of explosives for blasting must be carried out.

2.1.2. The measurements made to the building process were carried out for the following tasks or activities:

- The operator is in charge of carrying out the polishing of all the facades, using a polisher and hammer drill.
- Store, handle and empty cement.
- Carry out, during the whole day, polishing and resurfacing respectively, the operation is carried out on the screens, skies and

internal walls (concrete), additional and eventually a spatula is used to clean and eliminate burrs.
- Perform support tasks during the preparation of mixtures (sand, concrete, cement, lime), shaking of the mixture and sieve.

2.1.3. Measurements made in the brickwork process were carried out for the following tasks or activities:

- Execute the filling of the stretchers with brick, and alternate tasks in the conveyor belt (brick cut with wire).
- Transport the stretchers by means of electric transfer, feeding the belt (earth) by means of a shovel, carting to the cutter and continuous movement through all the production areas.
- Feed the oven. The movement is made from the plastic area to the oven with tempered (dry) bricks, and these ones are accommodated in rows manually.
- Move the brick to the entrance of the loading area, carry out continuous storage and short displacements along the work area and remove the bricks from the drying area.
- Constantly supply crushed coal in the different hoppers of each of the burners belonging to the furnace.
- Get ready wagons for the baking process. This activity consists of removing the different cracked or fractured bricks found on the platforms.
- Execute tasks in the mix preparation area.
- Remove the bricks after the cooking process.
- Execute brick crushing process.

2.1.4. The measurements made in the boiler process were carried out for the following tasks or activities:

- Inspect pressure pounds of the boiler, coal supply according to production requirements, slag removal or ash from it, in addition, support the material removal process from the sand deposit.
- Boiler supply and slag.

2.1.5. The measurements taken in different cement factory process were carried out for the following tasks or activities:

- Inspect the rock crushing process.
- Verify the loading process of bulk product in vehicles.

2.2. Sampling method

For the purpose of this study, an analysis of the information and results obtained from the measurements executed in the preceeding described processes was made, following the criteria laid down in the sampling method NIOSH 0600 and NIOSH 7500, for the determination of related particles as a respirable fraction and determination of crystalline silica, respectively.

2.3. Sampling conditions

Measurements were made to assess the exposure to respirable fraction and exposure to crystalline silica, during 2016 and 2019.

The measurements were carried out under normal operating conditions, in each of the processes, which is why the circumstances of the data collection can be considered, as a whole, representative of the working conditions.

2.4. Evaluation criteria

The following legal criteria were taken into account as a reference for the analysis made:

Resolution 2400 from May 2, 1979, on housing, hygiene and safety in work places, establishes as legal criteria in Colombia the permissible limit values (TLVs and BEIs®) that the ACGIH periodically publishes.

The TLV-TWA stipulated for silica exposure is 0.025 mg/m^3, represents the weighted average concentration for exposure periods of 8 hours a day and no more than 40 hours a week, to which most of the exposure may be exposed. workers without suffering adverse effects for their health.

3. Results

The results of the statistical analysis, by analysis of the ANOVA variance [8,9], can be found in Table 1.

Table 1
ANOVA statistical analysis.

Origin of variati-on	Sum of squares	Degrees of freedom	Average of squares	F	Value-p	Critical value for F
Betwe- en groups	0.0156	4	0.00390	1.813	0.151	2.668
Within the groups	0.0688	32	0.00215			
Total	0.0844	36				

Source: The Authors.

Performing a data correlation analysis, of RMF vs. SM, you get a graph like the one related to Fig. 1.

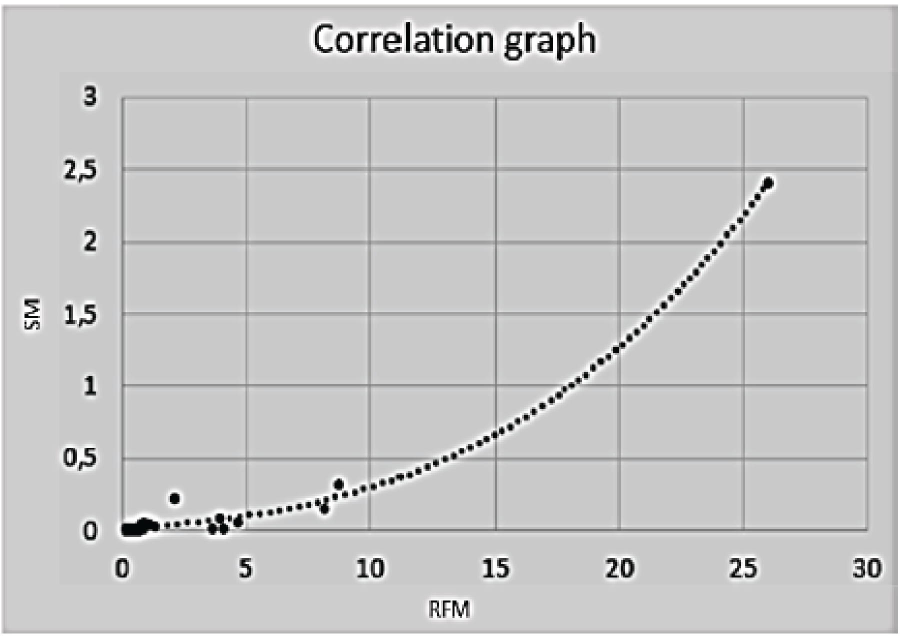

Figure 1
Data correlation RMF vs. SM.
Source: The Authors.

From Fig. 1 we can obtain the related expression in equation (1), where RMF is the mass of the respirable fraction and SM is the mass of silica present in the sample of the respirable fraction. This expression has a data correlation coefficient of $R^2 = 0.9905$.

$$SM = 9 * 10^{-5}(RFM)^3 + 0.0008(RFM)^2 + 0.0124(RFM) + 0.0145. \quad (1)$$

When calculating the mass of silica present in each of the samples, object of study, making use of equation (1), differences that oscillated between 0.05% and 8.3%, with a standard deviation of 1.86% were obtained.

Making a calculation of the geometric standard deviation (GSD) [10,11] of the data (37) a value of 2.21 is obtained and the data is adjusted, applying the Test W, to a normal distribution. If the previous exercise is repeated, this time with 34 data (eliminating the 3 major ones), a value of 1.96 is obtained for the GSD, which allows concluding that the data are related to a similar exposure group due to exposure to silica, in the groups under study.

4. Discussion (or analysis of results)

The study included the analysis of 63 data corresponding to 12 different processes. Of the 63 data, 37 correspond to the related processes in the results obtained, and they are distributed as follows: tunneling (9), building (7), cement factory (2), boilers (5) and bricks (14). A continuation of the study is precisely to obtain more data and project the analysis to other different processes. It should be noted that all data collected have analyzes of laboratories certified with ISO 17025

- The contrast hypothesis, used for the statistical analysis, were the following:
- Ho: The average of the data of the groups are similar, with a 95% reliability.
- Ha: In at least one of the group averages is different, with 95% reliability
- From Table 1 it is observed that the null hypothesis (Ho) is not rejected and, therefore, it can be affirmed, with a 95% reliability, that the means of the data do not have a significant variation. Also, the probability is greater than 0.05.
- From the analysis of the GSD it is observed that the data can be considered as a SEG, once GSD < 2.

5. Conclusions

When studying the relationship between the amounts of silica present in a dust sample respirable fraction, it is possible to establish a mathematical expression, between such quantities. This expression, related in equation (1), allows us to estimate the amount of silica present in a sample of dust, respirable fraction coming from tunnel construction processes, cement works, construction of buildings and brickworks.

With the application of equation (1) and the proposed methodology, in the specific processes of tunneling, buildings, cement and brick factories, a very significant cost reduction can be obtained, taking into account that the processing of samples for silica analysis (NIOSH 7500) is very expensive compared to the processing of samples by gravimetry (NIOSH 0600). This is reflected in the following aspects:

- Lower costs for the analysis of samples, which implies more regularity in the monitoring of the risk agent,
- More information to feed the epidemiological surveillance systems, for an adequate characterization of the process.
- To carry out better risk management, in order to make timely decisions aimed at preventing work-related diseases.

From the results obtained in the present analysis, the use of equation (1) can be recommended for the analysis of exposure to silica based on the results obtained in the measurement of respirable fraction, in the processes of construction of tunnels, construction of buildings, cement and brickwork.

It is proposed to continue the analysis to other economic sectors to find mathematical expressions applicable to these processes.

With the results obtained, a methodology of lower cost can be established for the conformation of SEG, by exposure to silica, in different industrial processes. For example, of the six measurements suggested by the GATISO-NEUMO [9], it could be recommended to make two measurements with emphasis on silica and the rest with respirable fraction, to which the mathematical expression represented by equation (1) would be applied, approaching the exposure calculations. If the substance of interest is not found in the two samples for which the silica analysis is carried out, then the application of equation (1) is not suggested.

This work will be continued by the authors, exploring different industrial processes, to establish a representative equation for these cases.

A noteworthy fact in the data correlation of Fig. 1 is that the endpoint makes the points have a better mathematical fit. Here it is fundamental to understand this data as a safety factor in favor of exposed workers.

Another relevant aspect is that all the measurements exceeded the action level (Risk Index greater than 0.5), the lowest being 0.82, and 66% of the results exceeded the permissible limit (with the TLV-TWA corrected for a period of 48 hours per week). This aspect has a physical meaning: this condition makes that the mathematical expression proposed in equation (1) have an additional safety factor, and it is the fact of having worked with samples that were above the action levels, even above the TLV for silica.

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Notes

1Maxxam. A Bureau Veritas Group Company. Laboratory ID: 100651. Analytics Corporation. AIHA-LAP, LLC Accreditation ID 100531

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