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Measurement of airborne asbestos levels in high traffic areas of Shiraz, Iran, in winter 2014

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ABSTRACT

Aims: Levels of asbestos fibers in ambient air of dense areas of Shiraz, Iran, were monitored in winter 2014.
Materials and Methods: Sampling was carried out by directing air flow to a mixed cellulose ester membrane filter mounted on an open-faced filter holder using a low flow sampling pump. Fiber counting on the filters was conducted using both phase contrast microscopy (PCM) method to determine total fibers and scanning electron microscopy (SEM) method to identify nonasbestos from asbestos fibers.
Results: The average concentration of asbestos fibers in the ambient air of the study in different areas of Shiraz were 1.18 ± 0.28 PCM f/L and 13.64 ± 2.87 SEM f/L, in which a maximum level was measured in Valiasr square (1.89 ± 0.54 PCM f/L [20.37 ± 5.55 SEM f/L]), and that of in Moallem square was in minimum (1.05 ± 0.47 PCM f/L [12.24 ± 3.04 SEM f/L]).
Conclusions: The averages of asbestos fibers in all sampling points were higher than the WHO suggested standards for ambient air (0.05 PCM f/L, 2.2 SEM f/L). This may be attributed to the frequent occurrence of heavy traffic, the existence of relevant industries in and around the city, and the topographic characteristics of the city. Therefore, immediate courses of action such as product substitution, traffic smoothing, and industrial sites relocating should be taken to eliminate asbestos fibers emission.

Key words: Ambient air, asbestos fibers, high traffic, Shiraz

INTRODUCTION

Asbestos is a group of fiber-form silicate minerals with thin microscopic fibers that occurs in rock and soil.[1] Because of its tensile strength, thermal, electrical, and chemical resistance, asbestos has been used in a variety of building construction materials for insulation and as a fire-retardant. Asbestos has also been used widely in friction products heat-resistant fabrics, packaging, gaskets, and coatings.[2] Asbestos fibers may be released into the air by disturbance of asbestos-containing material during product use, demolition work, building or home maintenance, repair, and vehicle braking process. When they are breathed in, they can become trapped in the lungs and stay there for many years.[3] Over time, these fibers can accumulate and lead to serious health problems including asbestosis, mesothelioma, lung cancer, and other lung problems such as pleural plaques, thickening

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of the membranes that surround the lungs, and pleural effusions.[4] A risk assessment study has shown that the excess lifetime cancer risk is associated with the exposure to the exceeded levels of airborne asbestos.[5]

Asbestos fiber is formed from two groups of minerals, namely, amphibole and serpentine. There are six types of asbestos minerals: Chrysotile, a serpentine mineral $(Mg_3(Si_2O_5)(OH_4))_n$, and five types of amphibole minerals including crocidolite $(Na_2Fe_3^{2+}\,Fe_2^{3+}(Si_8O_{22})(OH)_2)_n$, amosite $((Fe, Mg)_7(Si_8O_{22})(OH)_2)_n$, anthophyllite $((Mg, Fe)_7\text{-}(Si_8O_{22})(OH)_2)_n$, tremolite $(Ca_2Mg_5\text{-}(Si_8O_{22})(OH)_2)_n$, and actinolite $(Ca_2(Mg, Fe)_5(Si_8O_{22})(OH)_2)$.[6] Although all commercial forms of asbestos are carcinogen, there are differences in their chemical compositions. Approximately 90% of the asbestos used commercially in the world is chrysotile.[7] Its fibers are curly, thin, flexible, and longer than other asbestos types.[6] Chrysotile has a layer structure mostly made from SiO_4 tetrahydrate and $Mg(OH)_2$ octahydrate.[8] The five other asbestos fibers (amphibole group) have different chemical and physical properties.[6] Amphiboles diagnosis is usually based on their main components, such as magnesium–iron amphibole (amosite), calcium amphibole (tremolite), and alkaline amphibole (crocidolite).[9] Compared to chrysotile, amphibole fibers are resistant to acid and this resistance is different between the fibers of this group.[10] Crocidolite is considered the most harmful type of asbestos which can enter to the bronchi, transmit to lung tissue, and pleural cavity.[11] It is flexible fiber, resistant to acid and thinner than other amphiboles, but less heat resistant than other asbestos fibers.[12]

Amositeis is more toxic than chrysotile, which is mostly used in construction products. It often appears brown in color with fibers shorter and straighter than chrysotile fibers.[13] Tremolite is commonly found alongside deposits of talc, vermiculite, and chrysotile.[14] Anthophyllite deposits are less common than other asbestos deposits, and less of this mineral was used when compared to other forms of asbestos. Actinolite has straight-shaped fibers and is normally dark in color. It was commonly combined with vermiculite to make insulation. The health risk is about 3 times higher for amphiboles as compared to chrysotile.[4] Typically, the diameter of chrysotile is smaller than that of the amphibole fibers group. Thus, amphibole in contrast to chrysotile is stronger and less flexible.[1]

Concentrations of asbestos in ambient air are inherently variable due both to authentic variations over time and space, and also to variations in sampling and analytical methods. Light and heavy automobiles in the braking process emit significant amounts of asbestos fibers into the ambient air, because of severe friction between the brake pads containing asbestos and wheel trays.[15] Acid rain formed by air pollution also causes corrosion of asbestos-cement sheets and releases asbestos, however its apportion is not significant.[16,17] Due to their aerodynamic properties, asbestos fibers travel far away, when they are released into the air. The chemical decomposition of fibers does not occur easily, so washing by rain and snow is the main mechanism of their removal. Only a small portion of total fiber-form aerosols in outdoor air include asbestos fibers.[17,18] Critical fibers, which are biologically very important, have equal or more than 5 μm length and more than 3 μm diameters with a length to diameter ratio of >3:1.[6,9]

In the last two decades, many industrialized countries have decided to eliminate the use of asbestos not only in large industries but also in many small industries.[19] In 1998, the World Health Organization (WHO) proposed a concentration of 0.05 phase contrast microscopy (PCM) f/L (2.2 scanning electron microscopy [SEM] f/L) as a standard of asbestos in the ambient air.[20] In Iran, there is no special criterion directly indicating the health risk of exposure to asbestos.[1] In Iran, studies about the concentration of asbestos fibers in ambient air were a few. For example, study of the concentration of asbestos fibers in nonoccupational environments in Tehran, Iran, was 16 SEM f/L, which was much higher than the WHO standard values.[2] In 2009, mean asbestos concentrations in the outdoor living areas of Italy were 0.56 SEM f/L.[8] SEM is the only way that can detect asbestos fibers among the enormous range of nonfiber particles. This technique in combination with other methods such as selected area electron diffraction and/or energy-dispersive X-ray (EDX) analysis is used to identify the asbestos fibers.[6]

Shiraz is surrounded by mountains from north and south that causes inappropriate air ventilation and conviction of pollutants over the city. The prevailing winds blow from South and Southwest, where the industrial suburban is located, to North and Northeast of the city, directing the emitted pollutants from industry toward the city. This industrial suburban encompasses industries, such as production of fireproofing clothes and brake pads that apply asbestos materials. Furthermore, heavy traffic in different parts of the city leads to enormous and frequent braking action of the drivers that causes asbestos emission. Due to the existence of industrial resources of asbestos around the city, the application of asbestos in car brake pads, inadequate information about the concentration of asbestos fibers in the ambient air of Shiraz, and the health risks of prolonged exposure to exceeded levels of asbestos fibers, monitoring of this harmful pollutant in the ambient air of Shiraz is necessary. The data obtained can give an insight into the exposure level to asbestos fibers and can be applied in traffic management and other control programs.[21,22]

MATERIALS AND METHODS

Sampling

Shiraz, the capital of Fars Province, with a population of more than 1.5 million is the sixth most populous city of Iran located in the Southwest of Iran in an area of 451 km^2. The city is built in a green plain at the foot of the Zagros Mountains 1500 m above the sea level. Sampling points were selected by taking into account the traffic strength, population density, the industrial sources of pollutants, and prevalent winds direction. Thus, eight sampling points were selected which cover the four geographic areas of the city. The air samples were collected between January and March 2014. During this period, we collected two samples from each cites with 45 days interval to evaluate the temporal variations of pollutant concentrations given a total 16 samples. The city map and the sampling points are shown in Figure 1. Numbers from 1 to 8 show the sampling locations as follows: (1) Goldasht-e-Hafez town, (2) Maaliabad bridge, (3) Namazi square, (4) Darvazeh Quran, (5) Moallem square, (6) Darvazeh-Kazeroon, (7) Valiasr square, (8) Forsat-e-Shirazi square, and numbers 9 and 10 indicate industrial zone of Shiraz and electronics industries, respectively. Personal sampling pump (SKC Ltd., MCS Flite, Sweden) was used for sampling. Air samples were collected on mixed cellulose ester (pore size 0.8 μm; diameter 25 mm; lot. no. 12557-7DC-163) membrane filter that was placed on the open-face filter holder. Then, 3.7 l/min airflow was passed through the filter for 3–4 h. Metrological parameters, such as humidity, temperature, visibility, average of wind speed, and wind direction, were obtained from Fars Meteorological Organization.

Sample preparation and analysis

For analysis, the filters were prepared and analyzed according to NIOSH method 7400.[23] One-half of the filter was cleared by acetone vapor apparatus to make it transparent, and then, the filter was examined for counting asbestos fibers by a PCM (model AXIOM; Germany) (magnification of ×400–450) that included Walton–Beckett graticule (type G-22). In this procedure, a particle with length more than 5 μm, diameter <3 μm, and length to diameter ratio of 3:1 is known as asbestos fiber. Although the PCM method is relatively fast and inexpensive, it is not able to distinguish asbestos fibers

Figure 1: Map of Shiraz, showing the sampling points (1–8), industrial zone of Shiraz (9), and Shiraz Electronic Industries (10)

from nonasbestos fibers. Furthermore, this method is unable to detect fibers thinner than 0.25 μm, and the sensitivity of the method is about 0.1 fiber/ml of air.

Afterward, the fibers were counted on the filter, and the number of fibers (fiber per milliliter of air samples) was determined using the following equation:

$$C_{PCM} = \left[\frac{\frac{F}{n_f} - \frac{B}{n_b}}{A_f} \right] \times A_c / 1000V \cdot$$

where

C: Airborne fiber concentration (fibers/ml)

F: Total number of fibers >5 μm counted

n_f: Total number of fields counted on the filter

B: Total number of fibers >5 μm counted in the blank

n_b: Total number of fields counted on the blank

A_f: Microscope counts field area (mm^2). This is 0.00785 mm^2 for a Walton–Beckett graticule

A_c: Effective collecting area of filter (385 mm^2 nominal for a 25-mm filter)

V: Volume of air sampled (liters).

Other half portion of the filter was prepared and analyzed by SEM for identifying asbestos fibers according to BS ISO 14966 method[24] specified by the Asbestos International Association (1984). In this method, the filters were mounted on sample stub with two-sided copper adhesive and were then set in coating apparatus (EMITECH K450X; EM Technologies Ltd., England) for gold coating. After that, using SEM (model WEGA/TESCAN, Czech Republic) with magnifications of 500–2500, the fibers with length more than 5 μm, diameter <3 μm, and length to diameter ratio of 3:1 were counted as asbestos fibers. Besides, EDX system coupled with SEM was utilized for absolute diagnosis of asbestos fibers from nonasbestos fibers and the fiber types. The SEM method can detect smaller fibers than the PCM, but its accuracy for counting fibers is poor due to the small area that can be scanned at high magnification. However, well-skilled operators can get more accurate results. Detection sensitivity of SEM device is estimated in the range of 0.0001 fibers/ml of air.[25,26] Studies have shown that the SEM count gives significantly higher number of fibers compared to PCM.[2] Calculation of SEM results was carried out using the same formula applied for PCM, however, the calibrated screen area was calculated using ImageJ software based on the field magnification. ImageJ is a Java-based application for analyzing images and calculating area and pixel values.

Data analysis

Descriptive statistics were applied for both PCM and SEM measurements of fibers concentrations. The mean fibers concentrations were reported as geometric means. The fibers concentrations in the ambient air of different sites were compared by one-way analysis of variance and *post hoc* tests (multiple comparisons) using the SPSS software for Windows version 20 (SPSS, Chicago, IL, USA).

RESULTS

The air samples were collected from eight designated points of high traffic area throughout January to March 2014 with time intervals of 45 days and analyzed for asbestos fibers. The geometric mean concentrations of airborne asbestos fibers in the sampling points, analyzed by the two different methods (PCM and SEM), are tabulated in Table 1. Variation of the average asbestos fibers concentrations within the sampling points and their comparison with WHO-suggested standard (based on SEM analysis) in the ambient air are presented graphically in Figures 2 and 3.

The morphological analysis and counting of the asbestos fibers was carried out by SEM, and the chemical composition of the fibers was analyzed by EDX coupled to the SEM. As an example, an SEM photograph and EDX spectrum collected from airborne crocidolite fiber, the most harmful fibers, are shown in Figures 4 and 5, respectively. The mean metrological parameters at each sampling time and their average throughout the study period are given in Table 2.

DISCUSSION

Asbestos fibers in the ambient air of Shiraz

Qualitative analysis of the counted fibers performed by SEM-EDX method showed that approximately 25% of the fibers observed by SEM were nonasbestos fibers, which were taken out from the total numbers of counted fibers. The highest concentrations of asbestos fibers were pertained to the Valiasr square (1.89 ± 0.54 PCM f/L and 20.37 ± 5.55 SEM f/L [$P < 0.05$]). Street repairing activities and underway construction, which cause heavy traffic, as well as the release of asbestos fibers from building materials, can be the main reasons for the higher level of airborne asbestos in this region. In addition, it can be largely attributed to the existence of coach and bus station which is located in the vicinity of the Valiasr square.

The second highly contaminated area was Darvazeh-Kazeroon square. This region is densely populated, quite commercial, and marketing place. The streets conduced to the square are narrow which lead to heavy vehicular traffic in the streets converging to the square. Forsat-e-Shiraz sampling point gained the third rank in terms of the asbestos fiber concentrations. This can be due to the location of this site in the direction of the prevailing wind that flows from the industrial zone of Shiraz toward the area. There are lots of industries in the zone which deals with asbestos materials, such as the production of asbestos-cement pipes, asbestos plates, fireproofing clothes, and brake pads. Furthermore, this area is a passageway of heavy vehicles.

Although Maaliabad bridge is an area with low traffic, the high concentration of asbestos fibers in this area can be attributed partially to the high construction activities and largely to the neighboring of the Shiraz electronic industries which use asbestos for production of insulation and electrical materials. Asbestos concentrations in the outdoor air samples taken from Goldasht-e-hafez suburban town, Namazi square, Darvazeh Quran, and Moallem square were lower compared to the four above-mentioned areas (Forsat-e-shirazi square, Valiasr square, Darvazeh-Kazeroon square, and Maaliabad bridge) due to having relatively smooth traffic in these areas.

As an example, an EDX spectrum taken from a fiber [Figure 4] shows an iron to silicon ratio of 4:5, a small peak of sodium, and large peaks of silicon and magnesium which can be matched to the composition of reference crocidolite. The chemical profile of crocidolite asbestos consists of Fe, Mg, and Si that are linked to the oxygen atoms.[27] Crocidolite asbestos is commonly used in asbestos-cement presser pipes, for sprayed coatings and asbestos insulation/lagging.[28] Crocidolite is composed of hydrated silicates of iron, magnesium, and sodium.[29]

Table 1: Averages of airborne asbestos fiber concentrations in different sampling points analyzed by phase contrast microscopy and scanning electron microscopy methods

Station	Number of samples	Asbestos fiber concentrations (f/L)			
		PCM	SD	SEM	SD
Maaliabad bridge	2	0.99	0.38	11.21	2.91
Darvazeh Quran	2	0.82	0.13	11.76	0.79
Namazi square	2	1.12	0.01	14.92	1.32
Forsat-e-shirazi square	2	1.49	0.46	13.58	5.42
Moallem square	2	1.05	0.47	12.24	3.04
Valiasr square	2	1.89	0.54	20.37	5.55
Darvazeh-Kazeroon	2	1.25	0.11	12.78	2.38
Goldasht-e-Hafeztown	2	0.85	0.13	12.28	1.59
Total average		1.18	0.28	13.64	2.87

PCM: Phase contrast microscopy, SEM: Scanning electron microscopy, SD: Standard deviation

Correlation between the airborne asbestos fiber concentrations and meteorological data

Metrological parameters, such as humidity, temperature, average of wind speed, and wind direction, were collected for each sampling days. The mean weather parameters in each sampling time and their averages throughout the study period are given in Table 2. The correlation between

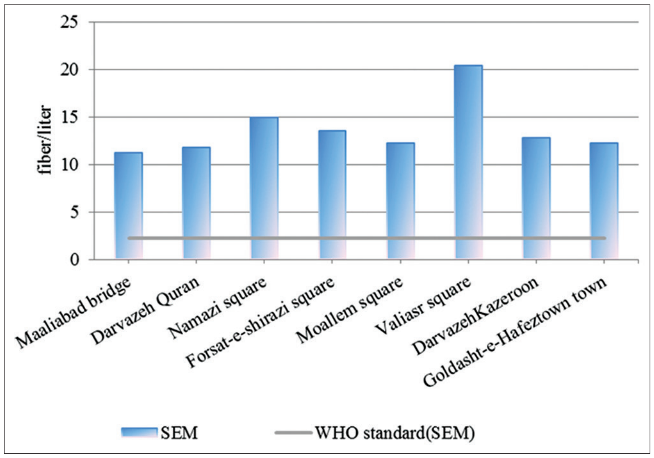

Figure 2: Variation of the asbestos fiber concentrations throughout the sampling points analyzed by scanning electron microscopy and their comparison with the World Health Organization-recommended standard

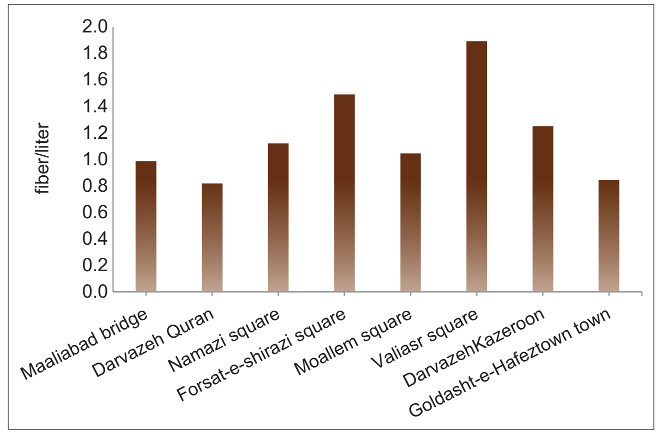

Figure 3: Variation of the asbestos fiber concentrations throughout the sampling points analyzed by phase contrast microscopy

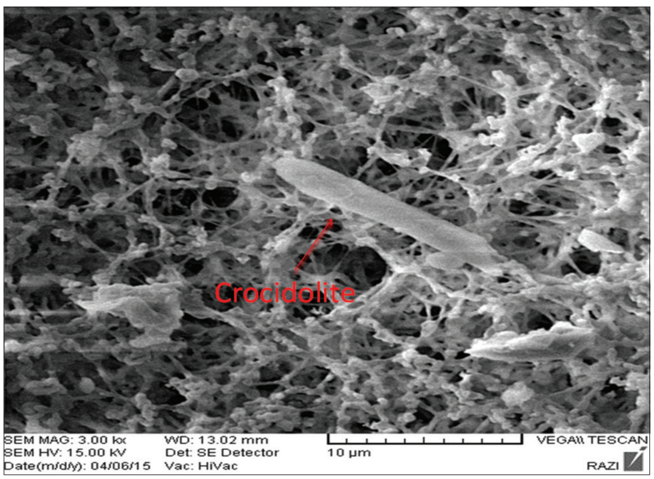

Figure 4: Scanning electron microscope image collected from an airborne crocidolite fiber

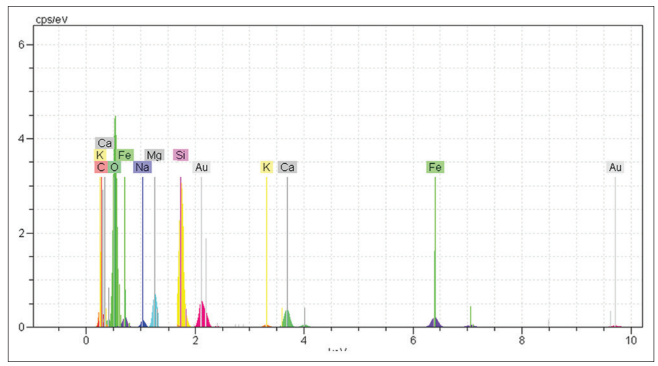

Figure 5: The energy-dispersive X-ray spectrum collected from an airborne crocidolite fiber

Table 2: Mean metrological parameters at each sampling period between January and September 2014

Sampling time	Number of samples	Wind velocity (km/h)	Visibility (km)	Temperature (°C)	Air humidity (%)
Late January	8	5.9	10	13.6	54.3
Early March	8	4.3	4.5	2.6	73.3

changes in weather variables among the study period on the concentration of airborne fibers was statistically analyzed. The results revealed no notable relationship between asbestos fiber concentration and meteorological parameters.

Comparison of the asbestos fiber concentrations with guidelines

According to the results presented in Table 1, the average concentrations of airborne asbestos fibers at each station (13.64 ± 2.87 SEM f/L) were greater than the WHO-suggested standard in the ambient air (2.2 SEM f/L). In addition, the average concentration of asbestos fibers in different parts of Shiraz was lower than that measured in the ambient air of Tehran, Iran (16 SEM f/L).[2] However, those values were much higher compared to the measured concentration in some parts of the world. For instance, Gualtieri *et al.* have reported an average concentration of 0.56 SEM f/L measured in three regions of Italy.[8] This is due to in one hand the emission of asbestos from car brake pads and on the other hand the existence of other sources of asbestos emission such as fireproofing clothes, asbestos plate, and brake pads manufacturing industries located in the upstream of prevailing winds direction of the city, and Shiraz electronic industry complex that is located inside the city. Furthermore, inadequate ventilation of the city's atmosphere because of being surrounded by Zagros Mountains and lower wind speed prevent dispersion and concentrates the pollutants over the city.

CONCLUSION

According to the results of this study, exposure to the airborne asbestos fibers in Shiraz is much higher than the

WHO-recommended standards. Although the asbestos fiber concentrations in the ambient air of Shiraz was lower compared to Iran's capital, Tehran, that was much higher than those reported for the urban environment of Europe. The heavy traffic, the existence of various industrial sources of asbestos inside and around the city, and geographical specification of the city are responsible for the high level of asbestos in Shiraz ambient air. Therefore, the best ways to reduce their emission are replacing asbestos with other materials in products such as brake pads, transferring of manufacturing industries that work with asbestos to downwind direction, and preventing the entrance of heavy vehicles into the city at peak traffic hours.

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Conflicts of interest

There are no conflicts of interest.

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