Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

Experimental approaches and analytical technique for determining heavy metals in fallen dust at ferrosilicon production factory in Edfu, Aswan, Egypt

SOLTAN M.E.[†1], RAGEH H.M.[2], RAGEH N.M.[2], AHMED M.E.[3]
([1]*Department of Chemistry, Faculty of Science at Aswan, South Valley University, Egypt*)
([2]*Department of Chemistry, Faculty of Science at Qena, South Valley University, Egypt*)
([3]*Department of Environment, Egyptian Ferroalloy, Edfu, Aswan, Egypt*)
[†]E-mail: mesoltan@hotmail.com
Received May 6, 2005; revision accepted June 16, 2005

Abstract: In this study aimed to evaluate the pollution extent of metals and nonmetals inside and outside the ferrosilicon production factory in Edfu, Aswan, Egypt, raw materials (quartz, cokes, iron oxides), ferrosilicon alloy, silica fume, dust and suspended dust (at different sites) samples were collected from the factory, and fallen dust samples were collected from outside the factory, horizontally (at different sites and different distance and directions) and vertically (at different floors in the selected buildings). Gravimetric methods, X-ray fluorescence (XRF), flame photometer, wide range carbon determinator and atomic absorption spectroscopy tools were used for elements determination. The results indicating that the fallen dust and its element contents on southern factory walls being higher than those on eastern factory walls may be due to the nature of the dusts and effects of wind force and wind direction. Fallen dust levels in different regions outside the factory were found to be affected by the distance, direction and floors. The nature of dust samples was affected by gravity and the suspended dust in different factory units depended on the work capacity and method of handling materials by personnel in different production units. Silica fume was a complicated problem, had dangerous effect against the workers' health, and was characterized by high concentrations of SiO_2 (90.6%~93.6%) and heavy metals (Mn, 420.6×10^{-6}~520.3×10^{-6}; Fe, 2354×10^{-6}~2685×10^{-6}; Co, 80.7×10^{-6}~101.6×10^{-6} and Ni, 5.3×10^{-6}~6.05×10^{-6}). The TSP (Total Suspended Particulate) levels in all factory units were higher than the recommended air quality value (70 μg/m^3) under Egyptian law. The effect of ferrosilicon factory fallen dust on the surrounding regions decreased with increasing distance between the factory and these regions. The suspended dust samples in the factory units and their components greatly exceeded national and international standards, so health and environmental criteria must be enforced on these units.

Key words: Air pollution, Dust, Heavy metals, Fallen dust
doi:10.1631/jzus.2005.B0708 **Document code:** A **CLC number:** X13

INTRODUCTION

Car exhaust fumes, fuel gases, mining dust, and aerosols are atmospheric pollutants considered to be hazardous to the health of humans, soil, animals and water (Stern *et al*., 1984).

The main inputs of trace metals to the atmospheric cycle are strongly correlated to particle emission processes. For most toxic trace metals, anthropogenic inputs are more important than natural sources such as continental dust, volcanic dust and gas, sea spray, and biogenic particles (Bertine and Goldberg, 1971; Nriagu, 1989). Man-induced mobilization of trace metals into the biosphere has become an important process (Nriagu and Pacyna, 1988). Some sources have been reported to have emission highly enriched in toxic metals without a significant increase in PM10 levels (Stwart, 1993). It is well recognized that many heavy metals have chronic effects on humans and as such, they are potential environmental health hazards, particularly to young children (Body *et al*., 1991). Dust metals may travel from the roads, through the windows and balconies into the houses. Homes that do not have their windows opened often had a lower level of contaminants in their house dust. Occupants, who sweep their floors or dust their furniture on daily bases and use vacuum cleaners, have a lower level of metals inside their houses. Another finding of interest is that the color (red indicating presence of Cd) of the wall paint used in the house may be another factor influencing the contamination levels (Susanna and Kin, 2000). Cadmium is a potentially toxic heavy metal with no known benefit to humans; plant foods are the predominant sources of Cd in human diets (Norvell *et al.*, 2000). Lead and arsenic concentrations in topsoil adjacent to a battery plant decreased rapidly with distance from the plant (Linzon *et al.*, 1976). Occupational exposure in battery factories can be highly due to the use and handling of lead oxide powder and to high levels of air borne Pb in the workplace (Bishop and Hill, 1983; Ibiebele, 1979). Mean air Pb concentrations is 92 $\mu g/m^3$ in the casting and pasting area of a battery plant compared to 4.2 $\mu g/m^3$ in the administration area of the factory. Such occupational exposure can lead to contamination of the home environment via the transport of Pb dust on the work clothes of employees (Ibiebele, 1979). The rapid growth of population and industry, and the increased use of automobiles and other modes of transportation, have made air pollution a serious problem. The air has become so filled with pollutants that can cause health problems. The damage caused by air pollution costs governments billions of dollars each year, this includes money spent for health care and increased maintenance of buildings. Air pollution also causes damage to the environment that cannot, unfortunately, be remedied (Sharaf *et al.*, 1999). Cobalt has both beneficial and harmful effects on human health. Cobalt is beneficial because it is part of vitamin B_{12}, and has also been used as a treatment for anemia, because it causes red blood cells to be produced. Exposure to high levels of cobalt can harm your health. Effects on the lungs, including asthma, pneumonia, and wheezing, have been found in workers who breathed high levels of cobalt in the air (ATSDR, 1992). The effects of exposure to any substance depend on the type of exposure, concentration of the substance, and the length of exposure time. Additional factors that must be considered are age, gender, diet, family traits, life style, and health status. In the general population, most people are not affected adversely by nickel at the typical levels encountered. Studies showed that nickel in small amounts is essential for maintaining proper health in animals and probably important in human nutrition as well (Egyptian Environmental Affair Agency, 1996).

EXPERIMENTAL DETAILS

Study area

The ferrosilicon production factory (24°84′ N and 32°81′ E) north of Edfu City (110 km north of Aswan City) is situated on the eastern bank of the Nile Valley. Environmental studies have been done to assess the effect of fallen and suspended dust and its elements distribution on around the factory.

Samples collection

The raw materials (quartz, cokes, iron oxides), ferrosilicon alloy, silica fume and dust samples were collected from different sites (production units, on factory walls, in addition to El Atwany, Elmamlaha and El Nosel regions) during the study period. Samples (except ferrosilicon alloy) were dried at 105 °C, and powdered in an agate mortar, sieved to size<0.063 mm with the aid of stainless steel sieve and kept in polyethylene bottle.

DIGESTION OF SAMPLES

Known weight of each sample and USGS-G2 geological standard (Flanagan, 1973) were digested with various concentrations of HF, $HClO_4$ and HNO_3 acids in a Teflon beaker. The extraction residue was dissolved in 25 ml of 20% HNO_3 and rewarmed at 80 °C for 20 min. The solution was made up to 50 ml with deionized water.

MEASUREMENTS

SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO were measured by gravimetric methods, K_2O and Na_2O were measured by flame photometers, carbon was measured by a wide range carbon determinator (Leco WR 112); Cd, Pb, Co, Mn, Fe and Ni were measured by SP1900 Pye Unicam Recording Flame Atomic Absorption Spectrophotometer at their respective wave lengths using hallow cathode lamps (Air-Acetylene burner was used). Ferrosilicon alloy samples were measured by X-ray fluorescence (XRF) using standard ferrosilicon samples.

RESULTS AND DISCUSSION

Characterization of raw materials (quartz, iron oxide and ash coke)

Raw materials for ferrosilicon alloy manufacture are considered the main sources of pollutant components. Quartz is one of the main constituents in this manufacture and consists mainly of SiO_2 (98%), in addition to traces of Fe_2O_3 (0.3%), Al_2O_3 (0.12%), CaO (0.06%), MgO (0.03%), Na_2O (0.03%) and K_2O (0.15%). The second constituent is iron oxide that consists of Fe_2O_3 (41.9%) as a major content, Al_2O_3 (2.06%), SiO_2 (1.35%), CaO (0.61%), MgO (0.50%), Na_2O (0.3%) and K_2O (0.25%) as minor contents. The last constituent (ash coke) is characterized by high contents of SiO_2 (49.5%), Al_2O_3 (25.4%) and Fe_2O_3 (17.8%) and minor concentrations of CaO (2.9%) MgO (0.6%), Na_2O (0.6%) K_2O (0.5%). The investigated metals (Cd, Co, Mn, Ni and Pb) in the raw materials showed depletion of Cd and Pb in all samples, while high concentrations of manganese were detected in iron oxide (350.9×10^{-6}), quartz (207.8×10^{-6}) and ash coke (103.6×10^{-6}). Moderate concentrations of Co were measured in quartz (125×10^{-6}), ash coke (80×10^{-6}) and iron oxide (70×10^{-6}). Low concentration of Ni was determined in iron oxide (7.6×10^{-6}), quartz (5.9×10^{-6}) and ash coke (5.2×10^{-6}). The results are listed in Table 1. The data above were provided by JSA (1990) and Popov (1989).

Characterization of the ferrosilicon alloy and silica fume

Ferrosilicon (FeSi) is an alloy of silicon (73.5%), and iron (25.1%), in addition to minor amounts of Ca, Al, Cr, P, S, C and other trace elements (Co, 70.1×10^{-6}; Mn, 4.2×10^{-6} and Ni, 16×10^{-6}). The results are listed in Table 2. Ferrosilicon alloy is one of the basic raw materials in the steel industry (Hauksdottir *et al.*, 1998). Silica fume is very fine noncrystalline silica produced by electric arc furnaces as a by-product in the production of ferrosilicon alloy. It is a powder with particles size of 0.1 μm to 0.2 μm. The components of silica fume are SiO_2 (95.1%), Fe_2O_3 (0.63%), CaO (0.19%), MgO (0.53%), K_2O (0.90%), Na_2O (0.5%), Mn (315.4×10^{-6}), Co (77.9×10^{-6}) and Ni (4.5×10^{-6}). The results are listed in Table 3. The data above were provided by Drivdal (1990). Silica fume used as an admixture in concrete mix has significant effects on the properties of the resulting materials. These effects pertain to the strength, modulus, ductility, vibration damping capacity, sound absorption, abrasion resistance, air void content permeability resistance to chemical attack ...etc. (Chung, 2002).

Evaluation of the fallen dust and its contents on factory walls (southern and eastern directions)

The quantity of fallen dust on the southern factory wall (13.9~15.2 $g/(m^2\cdot month)$) being slightly higher than that on eastern wall (11.2~13 $g/(m^2\cdot month)$) (Tables 4 and 5) could be due to the effect of wind force and wind direction (Xiongdong, 1997) or to the effect of atmospheric transport (Falatah, 1974; Modaihsh, 1997). The above quantities of fallen dust of the factory walls were still lower than the permissible limit of Egyptian law (ECS, 1994). The major constituent in fallen dust samples was SiO_2, which ranged from 92%~93.6%, in addition to minor constituents as such K_2O; the contents of fallen dust as mean values on eastern and southern walls ranged from 92.2% to 93.6% for SiO_2 as a major constituent and 0.34%~0.37%, 0.88%~1.48%, 0.20%~0.23%, 0.48%~0.49%, 0.24%~1.11%, 0.64%~0.81% and 0.31%~0.43% for Al_2O_3, Fe_2O_3, CaO, MgO, C, K_2O and Na_2O, respectively, as minor constituents. Trace metals exhibited high values for Mn (455×10^{-6}~497.8×10^{-6}) resulting from the presence of Mn in the iron ores as Fe-Mn oxides (Wong *et al.*, 2002). Moderate values are detected for Co (57.3×10^{-6}~63.4×10^{-6}) and Pb (16.4×10^{-6}~30.3×10^{-6}) vs low values for Ni (9.1×10^{-6}~9.3×10^{-6}) in the fallen dust samples on eastern and southern walls of the factory. Obvious increase of Fe_2O_3 (1.48%), Mn (497.8×10^{-6}), Pb (30.3×10^{-6}) and Na_2O (0.43%) in the fallen dust at the eastern side of factory walls, was due to the nearness of the iron oxide storehouse to this wall. Also, the

Table 1 Concentrations of raw material components (major, minor and trace elements) in the ferrosilicon factory in Edfu, Aswan, Egypt

Samples	Concentration										
	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Pb ($\times10^{-6}$)
Quartz	98.00	0.30	0.12	0.06	0.03	0.15	0.03	207.8	125	5.9	BD
Ash coke	49.50	17.80	25.40	2.90	0.60	0.50	0.60	103.6	80	5.2	BD
Iron oxide	1.35	41.93	2.06	0.61	0.50	0.25	0.30	350.9	70	7.6	BD

BD: Below detection limit

Table 2 Analysis of ferrosilicon sample

Item	Concentration											
	Si (%)	Fe (%)	Ca (%)	Cr (%)	P (%)	S (%)	Ti (%)	Al (%)	C (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)
FeSi	73.5	25.1	0.3	0.03	0.023	0.002	0.0005	0.3	0.2	4.2	70.1	16

Table 3 Concentration of silica fume components (major, minor and trace elements) in the ferrosilicon factory in Edfu, Aswan, Egypt

Item	Concentration										
	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Pb ($\times10^{-6}$)
Silica fume	95.1	0.63	0.39	0.19	0.53	0.90	0.50	315.4	77.9	4.5	BD

BD: Below detection limit

Table 4 Concentration of fallen dust components (major, minor and trace elements) on southern wall of ferrosilicon factory from May 2000 to August 2001

Date	Fallen dust (g/(m^2·month))	Concentration											
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	C (%)	K_2O (%)	Na_2O (%)	Pb ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Mn ($\times10^{-6}$)
May 2000	14.40	95.20	0.45	0.67	0.21	0.45	0.26	0.98	0.22	15.0	60.0	9.35	510
Aug. 2000	13.90	94.80	0.41	0.60	0.24	0.50	0.33	1.00	0.55	13.5	36.3	9.30	470
Nov. 2000	14.20	92.30	0.37	0.70	0.30	0.60	0.25	1.20	0.30	17.6	51.3	−10.35	465
Feb. 2001	15.20	93.85	0.34	1.43	0.18	0.48	0.20	0.60	0.25	17.7	63.3	8.70	480
May 2001	14.20	92.30	0.30	0.85	0.24	0.40	0.18	0.50	0.26	18.0	66.7	8.90	395
Aug. 2001	14.00	93.00	0.36	1.00	0.20	0.50	0.20	0.55	0.29	16.3	66.0	9.40	410
Mean	14.32	93.60	0.37	0.88	0.23	0.49	0.24	0.81	0.31	16.4	57.3	9.30	455

Table 5 Concentration of fallen dust components (major, manor and trace elements) on eastern wall of the ferrosilicon factory from May 2000 to August 2001

Date	Fallen dust (g/(m^2·month))	Concentration											
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	C (%)	K_2O (%)	Na_2O (%)	Pb ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Mn ($\times10^{-6}$)
May 2000	12.9	93.0	0.36	1.34	0.25	0.48	0.84	0.85	0.50	64.2	62.1	10.85	515.0
Aug. 2000	11.2	91.3	0.36	1.01	0.22	0.45	1.20	0.80	0.44	17.7	26.6	9.86	500.0
Nov. 2000	12.6	92.3	0.30	2.01	0.16	0.70	1.30	0.60	0.45	27.6	51.3	8.88	412.0
Feb. 2001	12.0	92.7	0.33	1.80	0.17	0.40	1.20	0.54	0.45	17.0	63.3	7.90	540.0
May 2001	12.7	92.8	0.32	0.80	0.24	0.50	0.94	0.45	0.30	28.9	95.6	7.98	560.0
Aug. 2001	13.0	91.3	0.34	1.43	0.18	0.35	1.19	0.60	0.45	26.2	81.4	9.40	460.0
Mean	12.4	92.2	0.34	1.48	0.20	0.48	1.11	0.64	0.43	30.3	63.4	9.10	497.8

slight increase in SiO_2 (93.6%), Al_2O_3 (0.37%), CaO (0.23%) and K_2O (0.81%) in the fallen dust at the southern wall could be due to the effect of the raw materials (quartz and coke) constituents on the fallen dust contents, or the raw material storehouse near the southern wall of the factory. Generally, there was no obvious relationship between the fallen dust and study time compared with the other factors (factory operating).

Fallen dust in El Atwany Village

1. Effect of the distance from factory (horizontal variation)

The load of fallen dust samples and their horizontal variations of major, minor, and trace elements in El Atwany Village (Table 6, Fig.1 and Fig.2). Generally, the load of fallen dust increasing from the wall of the factory (14 g/(m^2·month)) until the third station (1.5 km away from the factory), and reaching 16.5 g/(m^2·month) as a result of traffic along this distance; but gradually decreasing at 3 km (the sixth station) from the village center could be due to the effect of fallen dust from the factory. Also, results showing values (7.2 g/(m^2·month)) were indicative of the factory's slight effect on this village, as the values lie within the safety baseline levels of Law No. 4/94 (ECS, 1994). The effect of traffic on the composition of fallen dust was clear in the region between the factory and the third station, was characterized by the richness of the agricultural soil, as indicated by the relatively high concentration of SiO_2 (91.3%), Al_2O_3

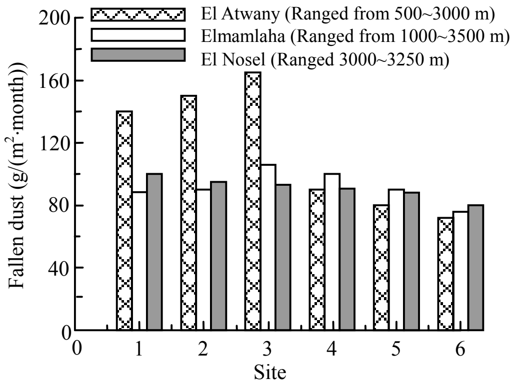

Fig.1 The relationship between fallen dusts in different regions

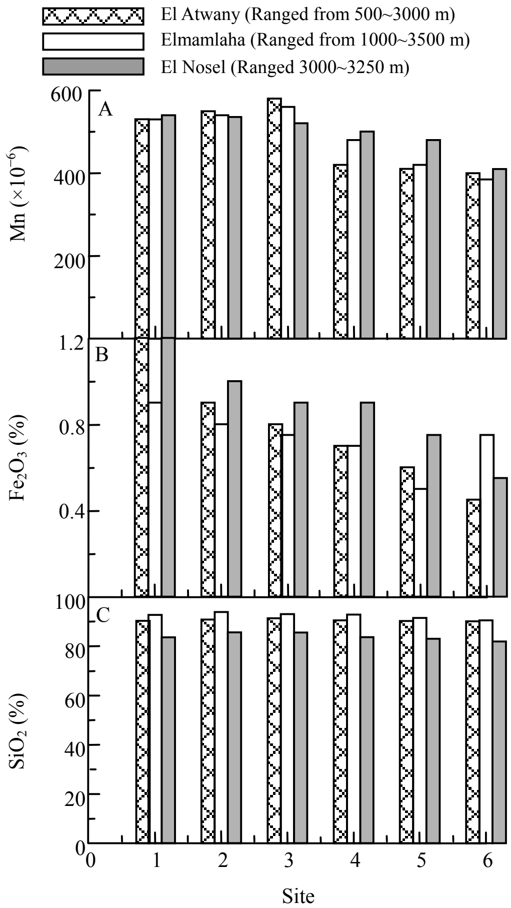

Fig.2 The relationship between elements (A: Mn, B: Fe_2O_3 and C: SiO_2) in different regions

Table 6 Horizontal variations of major, minor and trace elements in fallen dust in El Atwany Village in May 2000

Distance (m)	Fallen dust (g/(m^2·month))	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Pb ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Co ($\times10^{-6}$)
500	14.0	90.30	0.80	1.20	0.50	0.90	0.60	0.45	530	BD	27.3	BD
1000	15.0	90.80	0.90	0.90	0.43	0.83	0.55	0.38	550	BD	26.6	BD
1500	16.5	91.30	0.90	0.80	0.50	0.63	0.50	0.35	580	BD	20.3	BD
2000	9.0	90.50	0.90	0.70	0.48	0.55	0.45	0.30	420	BD	16.2	BD
2500	8.0	90.20	0.80	0.60	0.43	0.45	0.38	0.25	410	BD	18.3	BD
3000	7.2	90.10	0.75	0.45	0.40	0.33	0.35	0.27	400	BD	16.3	BD
Mean	11.6	90.50	0.84	0.80	0.46	0.62	0.47	0.33	481	BD	20.8	BD

BD: Below detection limit

(0.9%), CaO (0.9%), Mg (0.9%), Fe (41835×10^{-6}), Ni (27.3×10^{-6}) and Mn (530×10^{-6}) determined in the samples at the third station (at 1.5 km) compared with the lower concentrations in the samples on the factory wall (Table 6). The concentrations of these elements gradually decreased after this station (1.5 km) until the sixth station (3 km, center of the village), which indicated that the obvious effect of factory exhausts loaded with dust not more than 1.5 km away from the factory in the normal conditions as a result of the negative correlation between the distance from the factory and the concentration of the component in fallen dust sample.

2. Effect of vertical variations on the fallen dust and its components in El Atwany Village

The vertical variations of fallen dust samples and their components are listed in Table 7 and represented graphically in Fig.3 and Fig.4.

The load of fallen dust samples showing obvious decrease toward the highest floor (6th floor, 13 g/(m^2·month)) in comparison with the middle floor (3rd floor, 18 g/(m^2·month)) could be due to the nature of the fallen dust or external parameters such as temperature and relative humidity. The element concentrations in the fallen dust at different floors showed normal trend vs the load of fallen dust samples, whereas the element concentrations of dust increased from 1st to 3rd floor and decreased again until the 6th floor. The concentrations of these elements

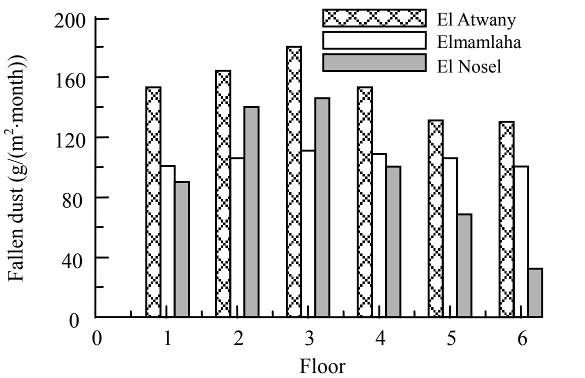

Fig.3 The relationship between fallen dust against floors in different regions

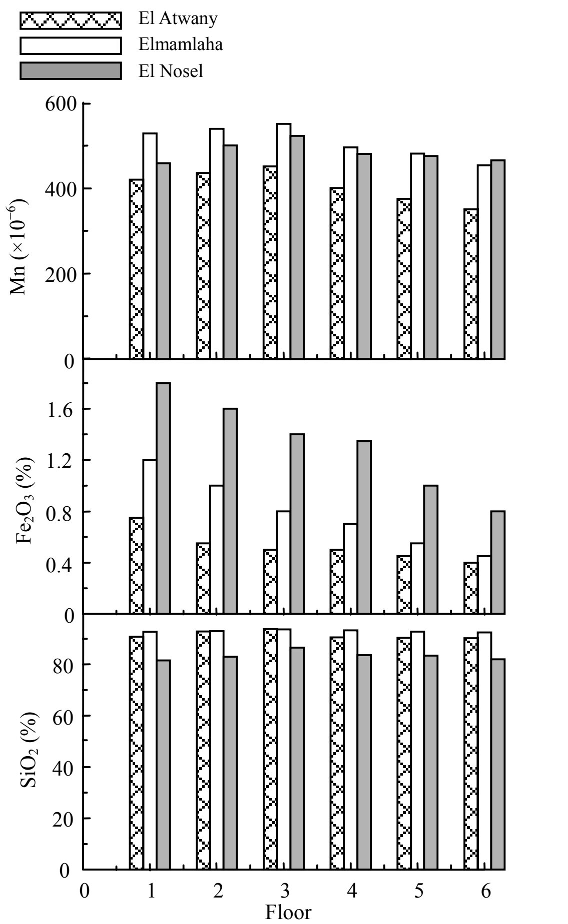

Fig.4 The relationship between elements [A: Mn, B: Fe_2O_3 and C: SiO_2] in different floors

Table 7 Vertical variations of major, minor and trace elements concentrations in fallen dust in El Atwany Village in May 2000

Floors	Fallen dust g/(m^2·month)	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Pb ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Co ($\times10^{-6}$)
1	15.3	90.8	0.80	0.75	0.48	0.50	0.60	0.40	419.64	BD	20.4	BD
2	16.4	92.8	0.70	0.55	0.50	0.63	0.60	0.35	435.51	BD	21.6	BD
3	18.0	93.8	0.73	0.50	0.63	0.80	0.80	0.55	450.60	BD	21.3	BD
4	15.3	90.5	0.55	0.50	0.70	0.85	0.90	0.60	400.30	BD	20.2	BD
5	13.1	90.4	0.66	0.45	0.60	0.50	0.43	0.30	374.40	BD	19.9	BD
6	13.0	90.2	0.70	0.40	0.65	0.63	0.50	0.35	350.30	BD	19.9	BD
Mean	15.2	91.5	0.70	0.44	0.60	0.60	3.80	0.43	338.40	BD	20.6	BD

BD: Below detection limit

(Table 7) were not close to their concentrations in the fallen dust samples on the ferrosilicon factory walls, as a result of the effect of surrounding agricultural soil characterized by high concentrations of Al_2O_3, CaO, MgO and Na. Also, the increase of fallen dust density and therefore the concentration of some elements showed that these elements came from factory dust.

Fallen dust in Elmamlaha region

1. Effect of the distance from factory (horizontal variations)

The results listed in the Table 8, and represented graphically in Fig.1 showed that the distribution of fallen dust samples along the route from the factory to the center of Elmamlaha Village (3.5 km) obviously increased (18.83 g/(m^2·month)) at the first station (1 km) followed by another increase (19 g/(m^2·month)) at the second station (1.5 km), but at the third station (2 km), a decrease of fallen dust load (10.5 g/(m^2·month)) occurred. Continuous decreasing of the fallen dust load at the fourth station (2.5 km) reached to 10 g/(m^2·month). Sudden increase of fallen dust load at the fifth station (11.5 g/(m^2·month)) was followed by another obvious increase (17.58 g/(m^2·month)) at the final station (3.5 km). We can conclude that the effect of the ferrosilicon factory is limited at the village centre and that the effect of the surrounding area (mountain region) is very clear. The distribution of elements along the route from the factory to the village showed little variations that were within the normal values.

2. Effect of floor difference on fallen dust in Elmamlaha regions

The results listed in Table 9, and represented graphically in Fig.3 showed that fallen dust increased from (10.6 g/(m^2·month)) at the 1st floor to (11.1 g/(m^2·month)) at the 3rd floor. The high floor levels up to 6th floor showed decrease of fallen dust. The levels of heavy metals in the fallen dust samples resembled the trend of fallen dust along the floor levels. The observed little variations of element concentrations at all floor levels indicated that the fallen dust at different floor levels was due to the linear relationship between factory dust and element (SiO_2, MgO, Mn, Fe, Ni) distribution. Also, the variation of fallen dust from one floor to another could be due to the nature of the dust and the effect of wind force and gravity.

Fallen dust in El Nosel region

1. Effect of distance on the fallen dust in the El Nosel region

The results listed in Table 10, and represented graphically in Fig.1 showed that with increasing distance between village and factory, the fallen dust decreases. From zero level (village wall, 3000 m from the factory) until Site 2 (250 m inside the village), the fallen dust decreased from 10 g/(m^2·month) to 8.5 g/(m^2·month). The concentration of SiO_2 decreased from 83.6% to 81.9%, the concentration of MgO decreased from 0.9% to 0.43%, Mn deceased from 540.9×10^{-6} to 410.6×10^{-6}, Fe deceased from 3736×10^{-6} to 2630×10^{-6}, Ni deceased from 108×10^{-6} to 100×10^{-6}, with increases of distance between village and factory. Also, results on fallen dust in the El Nosel region lower than Elmamlaha and El Atwany region, were due to position difference of these regions from the factory. And values of fallen dust in the El Nosel region were lower than the base line range of Egyptian Environmental Law No. 4/94 (ECS, 1994).

2. Effect of floor difference on fallen dust in El Nosel region

The results listed in Table 11 and represented graphically in Fig.3 showed that with increases in floor level the fallen dust increased AD_1 (9 g/(m^2·month)), AD_2 (14 g/(m^2·month)), AD_3 (14.57 g/(m^2·month)), after which the fallen dust underwent decreases in AD_4 (10 g/(m^2·month)), AD_5 (6.849 g/(m^2·month)) AD_6 (3.23 g/(m^2·month)) which could be due to the nature of the fallen dust, or external parameters such as temperature and relative humidity. And elements SiO_2 AD_1 (81.6%), AD_2 (83%), AD_3 (86.5%) underwent increases with increases of fallen dust. After that at AD_4 SiO_2 (83.6%), AD_5 (83%), AD_6 (82%), i.e. SiO_2 percent decreased with decreased percent of fallen dust, which indicated that SiO_2 came from factory dust containing a certain percentage of SiO_2. Also, Al_2O_3 showed behavior similar to that of SiO_2, as the concentration of Al_2O_3 increased when fallen dust increased, and also Al_2O_3 distribution at different floor, Al_2O_3 at AD_1 (0.5%), AD_2 (0.65%), AD_3 (0.71%), AD_4 (0.6%), AD_5 (0.5%) and AD_6 (0.5%). These may be due to the fact that the aluminum in fallen dust was in aluminum silicate form in accordance with the relationship between silica and aluminum in fallen dust. Manganese increased from Ad_1 to AD_3 (458.3×10^{-6} to 522×10^{-6}).

Table 8 Horizontal variations of major, minor and trace element concentrations in Elmamlaha Village in May 2000

Distance (m)	Fallen dust (g/(m^2·month))	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn (×10^{-6})	Pb (×10^{-6})	Ni (×10^{-6})	Co (×10^{-6})
1000	18.83	92.7	0.80	0.90	0.45	0.73	0.60	0.43	530.0	BD	27.14	BD
1500	19.00	93.9	0.95	0.80	0.50	0.75	0.60	0.40	540.0	BD	39.30	BD
2000	10.50	93.0	0.89	0.75	0.50	0.80	0.60	0.50	560.0	BD	35.60	BD
2500	10.00	92.8	0.75	0.70	0.53	0.75	0.60	0.43	480.0	BD	37.13	BD
3000	11.50	91.5	0.70	0.50	0.40	0.70	0.63	0.43	420.0	BD	26.40	BD
3500	17.58	90.5	0.85	0.75	0.45	0.65	0.63	0.45	385.0	BD	25.40	BD
Mean	14.60	92.4	0.82	0.86	0.47	0.73	0.61	0.44	485.8	BD	31.80	BD

BD: Below detection limit

Table 9 Vertical variations of major, minor and trace elements concentrations in fallen dust samples in Elmamlaha Village in May 2000

Floors	Fallen dust (g/(m^2·month))	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn (×10^{-6})	Pb (×10^{-6})	Ni (×10^{-6})	Co (×10^{-6})
1	10.60	92.7	0.80	1.20	0.48	0.85	0.55	0.35	527.70	BD	28.7	BD
2	10.59	93.0	0.80	1.00	0.50	0.90	0.60	0.48	538.80	BD	25.6	BD
3	11.10	93.6	0.80	0.80	0.48	0.95	0.50	0.45	550.20	BD	35.7	BD
4	10.86	93.3	0.85	0.70	0.43	0.85	0.63	0.43	495.20	BD	21.7	BD
5	10.59	92.8	0.73	0.55	0.40	0.70	0.55	0.40	480.66	BD	22.1	BD
6	10.30	92.5	0.75	0.45	0.38	0.65	0.50	0.43	453.40	BD	18.9	BD
Mean	10.70	93.0	0.80	0.78	0.45	0.81	0.55	0.42	506.70	BD	25.5	BD

BD: Below detection limit

Table 10 Horizontal variations of major, minor and trace element concentrations in El Nosel Village in May 2000

Distance (m)*	Fallen dust (g/(m^2·month))	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn (×10^{-6})	Co (×10^{-6})	Ni (×10^{-6})	Pb (×10^{-6})
0	10.05	83.6	0.60	1.20	0.50	0.90	0.63	0.48	540.0	190.0	108.5	BD
50	9.50	85.6	0.70	1.00	0.45	0.60	0.40	0.20	535.3	213.0	110.6	BD
100	9.30	85.5	0.70	0.90	0.50	0.50	0.50	0.35	520.6	220.0	108.6	BD
150	9.07	83.7	0.85	0.90	0.40	0.43	0.60	0.40	500.7	180.0	105.3	BD
200	8.80	83.0	0.80	0.75	0.38	0.50	0.70	0.40	480.3	176.0	103.8	BD
250	8.50	81.9	0.73	0.55	0.40	0.43	0.65	0.35	410.0	180.0	100.9	BD
Mean	9.20	83.9	0.70	0.88	0.43	0.48	0.60	0.36	497.8	193.2	106.3	BD

* At 3000 meters from factory; BD: Below detection limit

Table 11 Vertical variations of major, minor and trace elements concentrations in fallen dust samples in El Nosel Village in May 2000

Floors	Fallen dust (g/(m^2·month))	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	K_2O (%)	Na_2O (%)	Mn (×10^{-6})	Co (×10^{-6})	Pb (×10^{-6})	Ni (×10^{-6})
1	9.00	81.6	0.50	1.80	0.88	0.40	0.50	0.30	458.3	157.0	BD	91.3
2	14.00	83.0	0.65	1.60	0.60	0.35	0.60	0.25	500.0	94.6	BD	72.0
3	14.57	86.5	0.71	1.40	0.48	0.30	0.60	0.18	522.1	223.0	BD	102.0
4	10.05	83.6	0.68	1.35	0.45	0.30	0.40	0.20	480.0	213.0	BD	110.6
5	6.84	83.4	0.53	1.00	0.40	0.25	0.35	0.30	475.0	198.0	BD	.53
6	3.23	82.0	0.50	0.80	0.43	0.30	0.30	0.33	465.0	56.2	BD	151.0
Mean	9.62	83.6	0.60	1.30	0.60	0.31	0.46	0.26	483.4	156.9	BD	96.7

BD: Below detection limit

After that by increases highest i.e. at AD_4 manganese decreases AD_4 (Mn 480×10^{-6}), AD_5 (Mn 475×10^{-6}), AD_6 (Mn 465×10^{-6}). The elements distribution at different floors and its values indicated that the elements came from factory fallen dust.

Results of suspended dust measurement at different factory units

Evaluations of the total suspended dust levels are listed in Tables 12~14. The values ranged from 17~65 mg/m^3 for ferrosilicon production unit, 17~50 mg/m^3 for coke preparation unit and 17~55 mg/m^3 for silica fume unit in May and Nov., 2000, respectively. The metal concentrations in these samples reflected the chemical composition of unit components. The ferrosilicon ferrosilicon production unit showed high concentrations of SiO_2 (89.5%~90.6%) as a result of the presence of quartz as a main component in this unit. High concentrations of Al_2O_3 (12.8%~21.03%), CaO (9.8%~18.3%), MgO (0.9%~1.14%) and Na_2O (0.95%~0.96%) were detected at the coke preparation unit resulting from the ash-coke components as main materials in this unit. The silica fume unit had the complicated problem of endangering the workers' health, as this unit was characterized high concentrations of SiO_2 (90.6%~93.6%) and heavy metals (Mn, 420.6×10^{-6}~520.3×10^{-6}; Fe, 2354×10^{-6}~2685×10^{-6}; Co, 80.7×10^{-6}~101.6×10^{-6} and Ni, 5.3×10^{-6}~6.05×10^{-6}). The TSP levels in all factory units were lower than the recommended air quality value (100 mg/m^3) of the Egyptian Law No. 4/1994 (ECS, 1994) on Air Quality Protection. The metal concentrations in the suspended dust exceeded the permissible limits under Egyptian law and the WHO Air Quality Guidelines for Europe (van Leeuwen, 1997). Occupational exposure to respirable quartz may cause obstruction of the lungs and lung emphysema (Castranova, 1996) and may lead to silicosis (Lumens and Spee, 2001). Heavy metals have several toxic effects on human beings (Jabeen *et al*., 2001).

Table 12 Evaluation of suspended dust samples and their components (major, minor and trace elements) in ferrosilicon production unit from May 2000 to Aug. 2001

Date	FeSi (mg/m^3)	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Pb ($\times10^{-6}$)	Fe ($\times10^{-6}$)
May 2000	65.0	90.6	0.43	0.35	0.50	0.60	0.40	315.50	78.95	4.70	BD	285.3
Aug. 2000	40.0	91.7	0.47	0.30	0.48	0.57	0.38	420.60	70.90	5.40	BD	130.5
Nov. 2000	17.0	89.5	0.30	0.19	0.40	0.53	0.30	310.30	60.30	3.50	BD	100.0
Feb. 2001	26.0	91.7	0.37	0.23	0.37	0.48	0.28	370.60	85.40	7.40	BD	100.3
May 2001	38.0	92.0	0.40	0.27	0.55	0.40	0.33	410.70	90.30	4.70	BD	989.5
Aug. 2001	53.0	93.6	0.35	0.25	0.60	0.50	0.25	530.60	88.70	8.00	BD	981.0
Mean	35.8	91.5	0.45	0.27	0.50	0.51	0.32	393.05	80.40	5.60	BD	431.0

BD: Below detection limit

Table 13 Evaluation of suspended dust samples and their components (major, minor and trace elements) in coke unit from May 2000 to Aug. 2001

Date	Ash coke (mg/m^3)	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	MgO (%)	CaO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Ni ($\times10^{-6}$)	Pb ($\times10^{-6}$)	Fe ($\times10^{-6}$)
May 2000	30.0	51.8	24.90	3.20	20.40	1.00	0.95	127.3	35.70	3.05	BD	1853.0
Aug. 2000	38.0	49.5	24.40	1.60	3.90	1.30	0.98	130.6	40.70	1.70	BD	1650.0
Nov. 2000	17.0	47.7	12.80	0.90	18.30	0.75	0.96	210.0	43.50	0.95	BD	1750.0
Feb. 2001	43.0	51.2	24.90	1.60	2.95	0.90	1.30	98.5	40.60	2.20	BD	1350.0
May 2001	50.0	62.1	21.03	1.14	9.80	0.80	0.95	113.8	38.00	2.10	BD	950.0
Aug. 2001	28.0	51.3	19.90	1.50	10.60	0.85	1.00	120.9	28.50	2.20	BD	850.0
Mean	34.3	52.3	21.30	1.40	15.70	0.65	0.86	133.5	37.80	2.03	BD	1400.5

BD: Below detection limit

Table 14 Evaluation of suspended dust samples and their components (major, minor and trace elements) in silica fume collection unit from May 2000 to Aug. 2001

Date	Silica fume (mg/m^3)	Concentration										
		SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	Mn ($\times10^{-6}$)	Co ($\times10^{-6}$)	Fe ($\times10^{-6}$)	Pb ($\times10^{-6}$)	Ni ($\times10^{-6}$)
May 2000	55.0	93.6	0.36	0.25	0.48	0.85	0.50	420.6	101.6	2685.0	BD	6.05
Aug. 2000	30.0	92.3	0.28	0.16	0.70	0.60	0.45	370.6	95.9	1959.0	BD	7.40
Nov. 2000	17.0	90.6	0.25	0.20	0.95	0.60	0.35	520.3	80.7	2354.0	BD	5.30
Feb. 2001	49.0	93.5	0.37	0.18	0.43	0.40	0.35	475.3	83.7	1950.0	BD	6.15
May 2001	28.0	93.7	0.30	0.32	0.50	0.60	0.42	470.3	70.3	2350.0	BD	6.00
Aug. 2001	33.0	91.3	0.27	0.35	0.60	0.70	0.45	518.3	73.2	1065.0	BD	5.90
Mean	53.3	92.5	0.31	0.42	0.60	0.63	0.42	462.6	84.2	2060.5	BD	6.13

BD: Below detection limit

CONCLUSION

The results of major, minor and trace elements analysis of fallen dust samples during the study period showed that the main elements of fallen dust samples came from the used raw materials in the factory and that the fallen dust on factory walls were affected by the directions, so that the load of fallen dust samples on factory wall in southern direction was more than that in eastern direction, this may be due to the effect of wind force and wind speed. The distribution of fallen dust samples and their components had horizontal and vertical variations in all study locations. These variations depended on the effect of wind direction and wind velocity, in addition to the grain size of particles, humidity and gravity. The effect of ferrosilicon factory fallen dust on the surrounding regions decreases with increasing distance between the factory and these regions. The quantity of suspended dust and its components in some factory units greatly exceeded the national and international standards, so Health and Environmental Criteria must be applied on these units.

References

ATSDR (Agency for Toxic Substance and Disease Registry), 1992. Impact of Lead-contaminated Soil on Public Health. Atlanta, Georgia, p.30333.

Bertine, K.K., Goldberg, E.D., 1971. Fossil fuel combustion and the major sedimentary cycle. *Science*, **173**:233-235.

Bishop, L., Hill, W.J., 1983. A study of the relationship between blood lead levels and accupational air-lead levels. *Amer. Stat.*, **37**:471-475

Body, P., Inglis, G., Dolan, P., Mulcahy, D., 1991. Environmental lead: A review. *Crit. Rev. Environ. Control*, **20:**299-310.

Castranova, V., 1996. Silica and Silica Induced Lung Diseases. CRC Press, Boca Raton (FI).

Chung, D.D.L., 2002. Improving cement-based materials by using silica fume. *Journal of Materials Science*, **37**:673-682.

Drivdal, G.A., 1990. Specification of Ores and Alloys Kristiansand Silica Laboratory. Elkem Materials, NORWAY.

ECS (Egyptian Chemical Standards), 1994. Law No. 4, Protection of the Nile River and Water Stream from Pollution. Ministry of Irrigation, Cairo, Egypt.

Egyptian Environmental Affair Agency, 1996. Lead Smelting in Egypt−Baseline Study (Private Lead Smelters in Greater Cairo). Technical Cooperation Office for the Environment.

Falatah, A.M., 1974. Fractionation of micronutrient cations in a selected Saudi Arabia subjected to different tillage practices. *Arid Soil Research and Rehabilitation*, **7**:63.

Flanagan, F.J., 1973. Values for international geochemical reference samples. *Geochim. Cosmochi. Acta*, **37**:1189-1194.

Hauksdottir, A.S., Gestsson, A., Vesteinsson, A., 1998. Submerged arc ferrosilicon furnace simulator: Validation for different furnaces and operating ranges. *Control Engineering Practice*, **6**:1035-1042.

Ibiebele, D.D., 1979. Air and blood levels in a battery factory. *Sci. Tot. Enviro.*, **152(3)**:269-273.

Jabeen, N., Ahmed, S., Hassan, S.T., Alam, N.M., 2001. Levels and sources of heavy metals in house dust. *J. Radio Analytical and Nuclear Chemistry*, **247**(1):145-149.

JSA (Japanese Standards Association), 1990. Ferrous Materials and Metallurgy. TOKYO, JAPAN.

Linzon, S.N., Chai, B.L., Temple, P.J., Pearson, R.G., Smith, M.L., 1976. Lead contamination of urban soils and vegetation by emission from secondary lead industries. *J. Air Pollute Contr. Assoc.*, **26**:650-654.

Lumens, M.E., Spee, T., 2001. Determination of exposure to respirable quartz dust in the construction industry. *Ann. Occup. Hyg.*, **45**(7):585-595.

Modaihsh, A.S., 1997. Characteristics and composition of the fallen dust sediments on Riyadh city, Asudi. *Journal of*

Arabia Arid Environments, **36**(2):211-223.
Norvell, W.A., Wu, J., Hopkins, D.G., Welch, R.M., 2000. Association of cadmium in Durum Wheat Grain with soil chloride and chelate–extractable soil cadmium. *Soil Science Society of America Journal*, **64**:2162-2168.
Nriagu, J.O., 1989. A global assessment of nature sources of atmospheric trace metals. *Nature*, **338**:47-49.
Nriagu, J.O., Pacyna, J.M., 1988. Quantitative assessment of world wide contamination of air, water and soils by trace metals. *Nature*, **333**:134-139.
Popov, Y., 1989. Buligarium Specification of Ore and Alloys. SOFIA.
Sharaf, E.A., Garib, A.M., Khaled, N., 1999. Impact of high way maintenance decisions on air quality. *Environmental Conference, Cairo*, **1**:453-463.
Stern, A.C., Bouble, R.W., Turner, D.B., Fox, D.L., 1984. Fundamentals of Air Pollution. 2nd Ed., Academic Press, London.
Stwart, E.A., 1993. Chemical Analysis of Ecological Materials. 2nd Ed., Black Well Scientific Publications, Boston.
Susanna, T.T., Kin, C.L., 2000. Home sweet home. A case study of household dust contamination in Hong Kong. *The Science of The Total Environment*, **256**(2-3):115-123.
van Leeuwen, F.X.R., 1997. Update and revision of WHO air quality guidelines for Europe. *Environmental Research Forum*, **7-8:**22-25.
Wong, S.C., Li, X.D., Zhang, G., Qi, S.H., Min, Y.S., 2002. Heavy metals in agricultural soils of the pearl river delta, south China. *Environmental Pollution*, **119**:33-44.
Xiandong, P., Chi, S., Chan, R.C., Barry, J., 1997. Concentration and Chemical Partitioning of Heavy Metals in Road Dust and Urban Soils in Hong Kong. 4th International Symposium on Environ. Geochem. Vail, USA.