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"Gheorghe Asachi" Technical University of Iasi, Romania

AIR POLLUTION BY HEAVY METALS FROM PETROCHEMICAL INCINERATORS: MEASUREMENT AND DISPERSION MODELLING

Akbar Pirbadali-Somarin, Seyed Mohsen Peyghambarzadeh*

Department of Chemical Engineering, Mahshahr branch, Islamic Azad University, Mahshahr, Iran

Abstract

Distribution of solid particles in the atmosphere around the pollution sources has an important role in decision making to oppose with air pollutants. This study reports the concentration and distribution of 11 heavy metals including Cu, Co, Ni, Cd, V, Ti, Mo, Cr, Pb, As, and Hg emitted from 6 incinerators (A to F) with various feeds and operating conditions to determine the extent of exposure for industrial and residential areas. These incinerators located at Petrochemical Special Economic Zone (PSEZ), Mahshahr, south-west of Iran. The concentration of pollutants for two periods of year (July 2015 and January 2016) was measured experimentally using Vapor Generation Accessory 77 (VGA77) tool according to Iso 9096 no Central Point (EPA m-29&VDI 3868). AERMOD modelling software was then implemented using some information from incinerations, five years-averaged metrological data (2010-2014), and 50×50 km topographical information. Results on the modeling for the hot and the cold seasons showed that none of the residential and urban areas are affected by the release of the heavy metals, and only a part of the PSEZ is influenced. Also, Arsenic metal is not observed in the measurement, and Chromium is the most abundant among all the emitted metals. Finally, incinerators F represents the worst condition according to its flow rate and other parameters

Key words: AERMOD, air pollutants modeling, environment protection, incinerator; solid waste

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1. Introduction

Heavy metals are natural elements that have a density at least 5 times more than water density and a high atomic weight (Ferguson, 1990). Their several industrial applications such as petrochemical industry have led to their extensive distribution in the environment and raising worries on their potential influences on the health of human and the environment (He et al., 2005). The greatest significant harm created by contact with solid particles is the environmental contamination, mostly owing to the discharge of nutrient salts, heavy metals and organic substance with the resulting growth of these materials in species of plant and soil (Moustakas et al., 2019). Metallic elements are known systemic toxicants that include several organ damages, even at lower exposure levels. Also, they are categorized as human carcinogens based on the U.S. Environmental Protection Agency, and International Agency for Research on Cancer (Tchounwou et al., 2012). As a result, monitoring and assessment of air quality and measurement of emission rate of heavy metals pollutants are a fundamental and prominent portion of air pollution study and control.

Following the scientific and practical importance of the topic, there is a significant amount of work in the literature dealing with measurement of concentrations of air pollutants (Hua et al., 2016; Hua et al., 2016; Manu et al., 2018; Mousavian et al., 2017; Sadovska, 2012; Wang et al., 2016). Mousavian et al. (2017) investigated the estimation of heavy metal (Ni, Cr, Pb and Cd) exposure in workplace and health exposure risk evaluation among factory workers of

* Author to whom all correspondence should be addressed: e-mail: peyghambarzadeh@gmail.com; Phone: +98 9123241450; Fax: +98 1133325861

alloy steel company in Iran. In order to analyze heavy metals. Their results indicated that maximum and minimum values of concentration is recorded for Pb and Cd, respectively. However, the heavy metals average concentrations are lower than the mentioned occupational exposure levels, their occupational carcinogenic risks are dissimilar. Sadovska (2012) measured the concentrations of particular heavy metals (Ni, As, Pb, and Cd) in chosen localities with various types and characterizations in region Moravia, the Czech Republic, from 2007 to 2009. Based on the results, the values of air pollution were not exceeded, and health risk evaluation was acceptable, except for the augmented cancer risk probability from long-term exposure to As. Hua et al. (2016) measured the emission factors of some hazardous air pollutants (HAPs) (PM, Hg, Cd, Cr, Pb, Zn, SO_2, NOx, CO, As, Ni, and Cu) from cement industry in China from 1980 to 2012. Their results showed that the total emissions of HAPs have quickly augmented by about 1-21 times at an annual average increasing rate of 1-10 % over the past three decades. Wang et al. (2016) investigated different heavy metals (Hg, Cd, Cr, Ni, As, Mn, Zn, Cu, Pb, and V) emission from iron and steel industry of China in the time period of 1978-2011. Odabasi et al. (2010) performed experimental analysis to determine the heavy metals (As, Cd, Cr, Cu, Ni, Pb, Sn, Zn) emission in iron and steel industries in Hatay-Iskenderun region in Turkey. Eslami and Sekhavatjou (2018) studied the emission rates of different heavy metals from Incinerator of Purified Terephthalic Acid (PTA) unit, Shahid Tondgooyan Petrochemical Complex, Iran. They reported the value of 8022 mg/min for Cr and 3073 mg/min for Co. Nzihou et al. (2012) studied 124 MSW incinerators in France that most of them generated electricity or heat. They indicated that MSWI dioxin emissions in French reduced from 435 g in 1997 which to only 1.2 g in 2008. The study indicated that all incinerators are operated properly lower than the standard of EU and French. Rovira et al. (2018) investigated the concentrations of trace components and PCDD/Fs around a municipal solid waste incinerator in Girona (Catalonia, Spain) to evaluate health risks for the people in the neighborhood. The levels of Co, Cr, Cu, Hg, Mn, As, Cd, Sb, Sn, Pb, Ni, Tl and V, and PCDD/Fs were analyzed at different distances and wind directions around the MSWI. They found that in air, significant higher levels of Co, Mn, Ni, Pb, As, Cd, Tl and V were detected in 2016.

It is significant to investigate air quality in industrial area since significant release of metals to environment can lead to problematic issues for humans. Due to the great potential of petrochemical industries in the creation of metal solid wastes, its environmental impact assessment is very important (Ghobadi et al., 2015). One of the main sources of generation of air pollutants (especially solid metals) in the petrochemical industry is incinerators, but there has been no detailed study to determine the pollutant emissions from incinerators of petrochemical industry.

In this paper, the dispersion of heavy metals emission is studied from incinerators with various feeds and operating conditions in the Petrochemical Special Economic Zone, Mahshahr, Iran, specifically V, Ti, Mo, Cu, Co, Ni, Cd, Cr, Pb and Hg, in order to show exposure areas, where solids concentrations may cause damage or discomfort to workers or residents. These petrochemical incinerators work with different types of waste including solid, liquid, and gaseous wastes. Their capacity of waste processing is between 500-3000 kg/h. Data from nearby climatological stations, the topography of the terrain and heavy metal concentrations are used in the process of air modelling.

2. Material and methods

2.1. Sites of study

The industrial complex considered in the present study is located (30° 29′ N, 49° 5′ E) at Mahshahr, Khuzestan province, Iran. It is one of major industrial centers and is referred as Petrochemical Special Economic Zone (PSEZ). PESZ is situated at a distance of 20 km in the southwest direction from Mahshahr city and spread over an area of 17 km^2 consisting of five sites. The average height of PESZ is 3 m from sea level. There are several small, medium and large scale units of different type petrochemical companies in operation, feed and production in this area. Fig. 1(a) shows a typical incinerator which is used in this industry.

These companies release different pollutants into the air environment. The emissions from them cause major worry in deteriorating the quality of ambient air. One of the main sources of the pollutants is incinerators of these companies. Thus, it is necessary to measure the emission rate of pollutants form the incinerators. In this study, six active incinerators are selected and their locations are shown in Fig. 1(b).

2.2. Measuring instrument

In this study, Vapor Generation Accessory 77 (VGA77) tool was used to measure the pollutants concentration in flue gas. The VGA 77 is a vapor generation system for Atomic Absorption (AA), Inductively Couple Plasma Optical Emission Spectrometry (ICP-OES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) applications.

Vapor generation is a complex method used for determining the level of heavy metals. The sample capillary is located in the solution to be measured and the VGA77 pumps the sample through a reaction coil where it is acidified and mixed automatically with an appropriate reductant. The resulting vapor is conveyed to an atomization cell for determination by the spectrometer. The VGA77 is provided in a modular form, with separate reagent module and a pump unit. Since ICP and AA applications utilize dissimilar gas or liquid separators, using separate plumbing

assemblies for different regents enables. In addition to the concentration of the pollutants, we used the process data of incinerators to calculate the emission rates of pollutants. Therefore, the characteristics (mechanical and process data) of the incinerators and flue gas are given in Tables 1 and 2.

2.3. Methodology

Methodology of this study was summarized in three steps, which are investigation of process information, measurement and analyzing the concentration of pollutants, and calculation of emission rate (ER). In the first step, data and process information were collected (as reported in Tables 1 and 2). In the second step, the concentration of pollutants in flue gas of incinerators were measured by VGA77 (the results will be shown in the next section). The third step was calculation of emission rates (ER) of pollutants by using the Eq. (1) (Walker and Cooper, 1992):

$$ER = f.C_{mass}.F_{actual} \quad (1)$$

where: C_{mass} is pollutants concentration (g/m^3), F_{actual} is actual stack gas flow rate (m^3/h), and f is conversion factor to convert from micrograms to nanograms or milligrams, as desired.

(a) (b)

Fig. 1. (a) An illustration of incinerator, (b) Geographical location of PSEZ and incinerators

Table 1. The characteristics of the incinerators

Incinerator	*Internal diameter of stack (m)*	*Length of stack (m)*	*Capacity (kg/h)*	*Type of waste*	*Combustion temperature (ºC)*
A	1.10	20	3000	Solid	950
B	0.95	30	833	Solid	700
C	1.60	20	588	Liquid	1200
D	0.70	45	1000	Solid	1100
			240	Liquid	
E	0.80	30	1200	Liquid	1100
			1900	Gas	
F	0.75	17	570	Liquid	1020

Table 2. The characteristics of the flue gas

Incinerator	*A*	*B*	*C*	*D*	*E*	*F*
Temperature (℃) - hot season	67.13	143.38	333.55	53.42	52.33	67.12
Actual flow rate (m^3/h) - hot season	26052	26038	42444	8271	11533	12962
Temperature (℃) - cold season	24.21	26.95	31.90	25.36	22.88	29.10
Actual flow rate (m^3/h) - cold season	7971	10603	51463	6552	11273	6091

For the calculation of C_{mass} the following procedure was performed according to standard method of Iso 9096 no Central Point (EPA m-29&VDI 3868). As previously stated all the procedures of sampling and chemical analysis and also calculations of the heavy metals concentration were performed according to Iso 9096 no Central Point (EPA m-29&VDI 3868). In this method, the sample volume of the wet gas at real operating condition and also the sample volume of the dry gas at the standard operating condition was obtained directly from TCR TECORA. These data were then used to calculate the sample volume of wet gas at standard operating condition and dry gas at real operating condition.

In order to update the sample gas volume for a given temperature and pressure, Eq. (2) is implemented:

$$V_s = V_e \times \frac{P_e}{P_s} \times \frac{T_s}{T_e} \quad (2)$$

where: V_s is standard air volume, V_e is sampled air volume (from TCR TECORA), P_e is ambient pressure, P_s is standard air pressure (= 1 atm), T_s is standard air temperature (= 273.15 K), and T_e is stack temperature.

Then, wet gas flow rate at the real operating condition was obtained using Eq. (3):

$$Q_{we} = V \times A \quad (3)$$

where: V is sampled gas velocity (m/s), Q_{we} is wet gas flow rate at the real condition (m^3/s), and A is stack cross sectional area (m^2). Then, wet gas flow rate at the standard operating condition, Q_{ws} is calculated as Eq. (4):

$$Q_{ws} = Q_{we} \times \frac{P_e}{P_s} \times \frac{T_s}{T_e} \quad (4)$$

Dry gas flow rate, Q_{DS} at the standard operating condition is calculated as Eq. (5):

$$Q_{DS} = Q_{WS} \times \frac{1}{1 + \frac{x_s \times \rho_{crcy}}{\rho_{BRH}}} \quad (5)$$

where: Q_{DS} is dry gas flow rate at the standard operating condition, Q_{ws} is wet gas flow rate at the standard operating condition, ρ_{crcy} is dry gas density at the standard condition, and x_s is mass relation between the water and the dry gas.

Dry gas density at the standard condition, ρ_{crcy} is calculated as Eq. (6):

$$\rho_{crcy} = r_{co_2} \times \frac{M_{co_2}}{V_{co_{2n}}} + r_{o_2} \times \frac{M_{o_2}}{V_{o_{2n}}} + r_{N_2} \times \frac{M_{N_2}}{V_{N_{2n}}} \quad (6)$$

where: Vi is molar volume of the sampled gas at the standard condition (m^3/kmol), M_i is molecular weight of species i (kg/kmol), and r_i is the volume fraction of species i in the sampled gas (read from the gas analysis Table).

Mass relation between the water and the dry gas, x_s is calculated as Eq. (7):

$$X_s = \frac{m_{KB}}{V_{rp} \times \frac{P_e}{P_s} \times \frac{T_s}{T_e} \times \rho_{crcy}} \quad (7)$$

where V_{rp} is gas volume at gas meter condition, m_{KB} is the amount of condensed water (kg) which is obtained from KIMO apparatus for each stack.

Dry gas density at the real condition ρ_{BRH} can be calculated as Eq. (8):

$$\rho_{BRH} = \rho_{crcy} \times \frac{1 + X_s}{1 + \frac{X_s \times \rho_{crcy}}{\rho_{BII}}} \quad (8)$$

where ρ_{BII} is water vapor density.

Then, dry gas flow rate at the real condition, Q_{De} is calculated as Eq. (9):

$$Q_{DS} = Q_{De} \times \frac{P_e}{P_s} \times \frac{T_s}{T_e} \text{ n} \quad (9)$$

At the end, the heavy metal concentration (mg/m^3) can be calculated from Eq. (10):

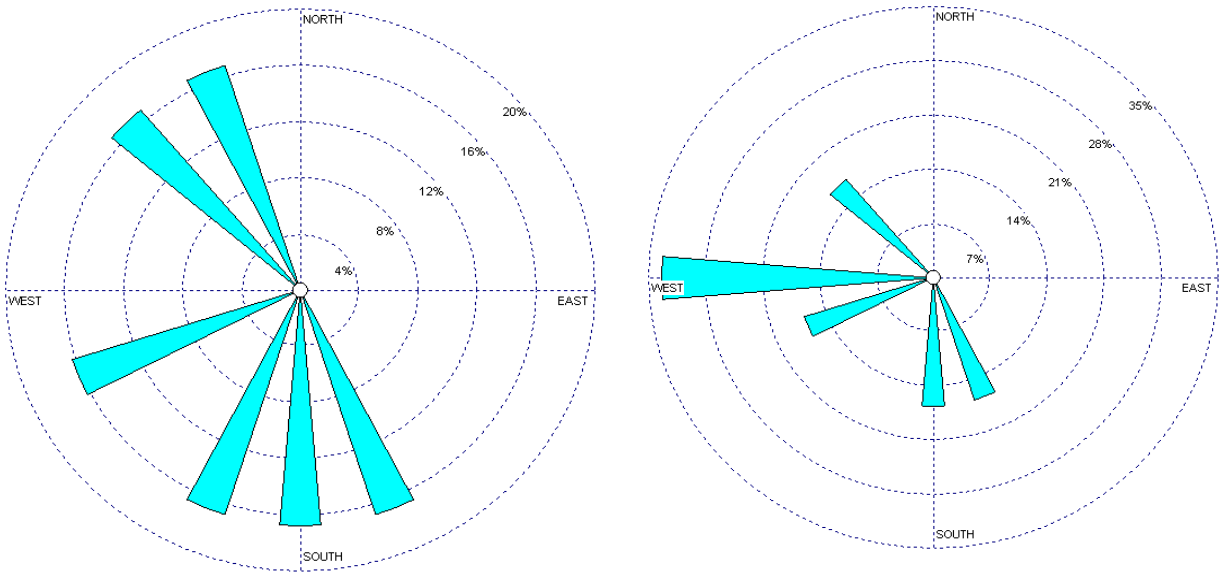
$$\frac{measured\ analyte\ concentration\left(\frac{mg}{l}\right)}{x} = \frac{Sampled\ gas\ volume(m^3)}{Solvent\ volume(l)} \quad (10)$$

3. Modelling

3.1. Method of modelling

The AERMOD model was used in order to illustrate dispersion and transport of pollutants which are essential for calculating the quality of air spreading from the incineration plants. The AERMOD is a plume model using steady-state condition. It considers the distribution of concentration to be Gaussian in both the horizontal and vertical dimensions in the stable boundary layer. The horizontal and vertical distributions of pollutants are presumed to be Gaussian and bi-Gaussian probability density functions in the convective boundary layer, respectively.

It is one of the well-known software packages for modelling of dispersion of air pollutants which was suggested by the United States Environmental Protection Agency (USEPA) for the environmental evaluation in order to study the air quality (Matacchiera et al., 2018; Seangkiatiyuth et al., 2011). The AERMOD software consists of two modules: AERMET and AERMAP. The AERMET is utilized to analyze the meteorological data that will be used by AERMOD later.



(a) (b)

Fig. 2. Direction of wind, (a) hot season, (b) cold season

The AERMAP is a terrain data pre-processor, which makes topographic data for advanced usage. Eventually, the AERMOD is a post-processor tool that incorporate information of topographical and meteorological data, also information of reception and emission, to model the concentrations of a specified pollutant around and far from the emission source.

3.2. Variables of climate

The meteorological data used in this research consists of wind direction, wind velocity, temperature of air, atmospheric pressure, and relative humidity. This data was measured through the meteorological locations, which are nearby to the sites of the area under study.

The data from the meteorological stations was evaluated by means of the AERMET and WRPlot tools of the AERMOD software. The AERMAP was utilized to handle a Digital Elevation Model (DEM). It provided the treatment of meteorological data to model the spreading of particles in all directions.

4. Results and discussion

Results of the measurement tools and modelling strategies are discussed in the following sections.

4.1. Meteorological results

Wind roses can be seen in Fig. 2, in two six months of the year. Fig. 2 shows the five years-average data (2010-2014) of PSEZ in different months of the year. It is clear that the direction of the winds is changing to the north-east, north, northwest, east and also south-east of the PSEZ. Sampling was carried out in two seasons of the year, which is hot and cold seasons. Therefore, in modeling, distribution coefficients from hot season are considered for both autumn and summer, and the distribution coefficients derived from cold season are considered for both spring and winter seasons.

4.2. Results of field measurement

The concentration of pollutants in flue gas of incinerators for two seasons, hot season (July 2015) and cold season (January 2016) are presented in Tables 3 and 4. The results showed that Arsenic (As) metal was not produced in these incinerators, and Mercury (Hg) was generated in incinerator C only. Also, Chromium (Cr) was the most common metal in all incinerators in both seasons. Fig. 5 shows the comparison between metals concentration clearly.

The values of emission rate of different pollutants are reported in Tables 5 and 6. It is clear that in all incinerators, Cr has more emission rate in comparison with other metals in both seasons. Fig. 3 shows the solid waste particle percentage of each incinerator in hot and cold seasons without consideration of Hg and As concentration. In both seasons, the abundant of Cr is greater than other components (incinerator C in the hot season and B in the cold season) and the least is Hg which is emitted just from incinerator C.

Precipitation of particles on neighboring area depends on several factors, especially height of stack, outlet flow rate, particle characteristics, and wind direction (Charalampos et al., 2003; Harrington and Shishu, 1973; Menrad and Haselhorst, 1981). Fig. 4 demonstrated the effect of height of each stack on the emission flow rate in both seasons. Obviously, high flow rate and long stack height will eventuate settlement of particles in far area and longer times.

Table 3. The concentration of pollutants for hot season (ambient temperature: 42 ℃)

Component	***Unit***	***Incinerator***					
		A	***B***	***C***	***D***	***E***	***F***
Cu	ppm	0.149	0.182	0.325	0.066	0.065	0.091
Co	ppm	0.641	0.871	0.123	0.181	0.091	0.002
Ni	ppm	0.764	0.961	0.847	0.523	0.242	1.945
Cd	ppm	0.000	0.018	0.000	0.000	0.000	0.012
V	ppm	0.000	0.000	0.000	0.531	0.081	0.000
Ti	ppm	0.511	0.681	0.928	0.033	0.011	0.021
Mo	ppm	0.613	0.782	0.473	0.000	0.112	0.741
Cr	ppm	2.178	2.830	6.012	2.393	1.304	1.537
Pb	ppm	0.011	0.151	0.000	0.192	0.291	0.000
Hg	ppm	0.000	0.000	0.011	0.000	0.000	0.000
As	ppm	0.000	0.000	0.000	0.000	0.000	0.000

Table 4. The concentration of pollutants for cold season (ambient temperature: 16 ℃)

Component	***Unit***	***Incinerator***					
		A	***B***	***C***	***D***	***E***	***F***
Cu	ppm	1.741	0.577	0.649	0.635	0.722	0.874
Co	ppm	0.397	2.927	0.231	0.110	0.039	0.123
Ni	ppm	3.231	1.402	1.567	2.566	1.688	3.247
Cd	ppm	0.018	0.011	0.000	0.021	0.011	0.014
V	ppm	0.000	0.000	0.000	0.620	0.000	0.000
Ti	ppm	1.152	1.431	1.403	1.101	1.320	0.880
Mo	ppm	0.331	0.591	0.403	0.392	0.861	1.201
Cr	ppm	7.614	7.635	3.605	1.472	2.399	1.664
Pb	ppm	0.352	0.111	0.000	0.160	0.000	0.130
Hg	ppm	0.000	0.000	0.012	0.000	0.000	0.000
As	ppm	0.000	0.000	0.000	0.000	0.000	0.000

Table 5. The emission rate of pollutants for hot season (ambient temperature: 42 ℃)

Component	***Unit***	***Incinerator***					
		A	***B***	***C***	***D***	***E***	***F***
Cu	g/h	2.6	1.2	9.4	0.3	0.7	1.0
Co	g/h	11.1	5.7	3.6	0.8	1.0	0.0
Ni	g/h	13.3	6.2	24.5	0.4	2.7	22.2
Cd	g/h	0.0	0.1	0.0	0.0	0.0	0.1
V	g/h	0.0	0.0	0.0	2.5	0.9	0.0
Ti	g/h	8.7	4.4	26.9	0.1	0.2	0.2
Mo	g/h	10.4	5.1	13.6	0.0	8.4	8.4
Cr	g/h	37.9	18.4	174.2	2.9	17.5	17.5
Pb	g/h	0.1	1.0	0.0	0.9	0.0	0.0
Hg	g/h	0.0	0.0	0.3	0.0	0.0	0.0
As	g/h	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. The emission rate of pollutants for cold season (ambient temperature: 16 ℃)

Component	***Unit***	***Incinerator***					
		A	***B***	***C***	***D***	***E***	***F***
Cu	g/h	2.8	0.6	1.7	0.2	0.6	3.2
Co	g/h	0.6	3.1	0.6	0.0	0.0	0.4
Ni	g/h	4.7	1.5	4.1	1.0	1.4	12.1
Cd	g/h	0.0	0.0	0.0	5.7	0.0	0.1
V	g/h	0.0	0.0	0.0	0.2	0.0	0.0
Ti	g/h	1.7	1.5	3.6	0.4	1.1	3.3
Mo	g/h	0.5	0.6	1.0	0.1	0.7	4.4
Cr	g/h	11.0	8.0	9.4	0.6	2.0	6.2
Pb	g/h	0.5	0.1	0.0	0.1	0.0	0.5
Hg	g/h	0.0	0.0	0.0	0.0	0.0	0.0
As	g/h	0.0	0.0	0.0	0.0	0.0	0.0

Considering these factors, the incinerator F in the hot and cold seasons has worst condition among the other incinerators because of low flow rate and short height.

Analysis of pollutants shows that Ni had more percentage among the emission rate of the components in the whole of year (without considering Cr which had the most emission rare). The comparison between the components is shown in Fig. 5(a). As illustrated in Fig. 5(a), the total emission rate of components in the first half of the year is more than the second half of the year. Fig. 5(b) demonstrated that incinerator C had the most emission rate in hot season while emission rate of incinerator F was the most in cold season. It is an important result to be considered for environmental protection near these incinerators.

4.3. Modeling results

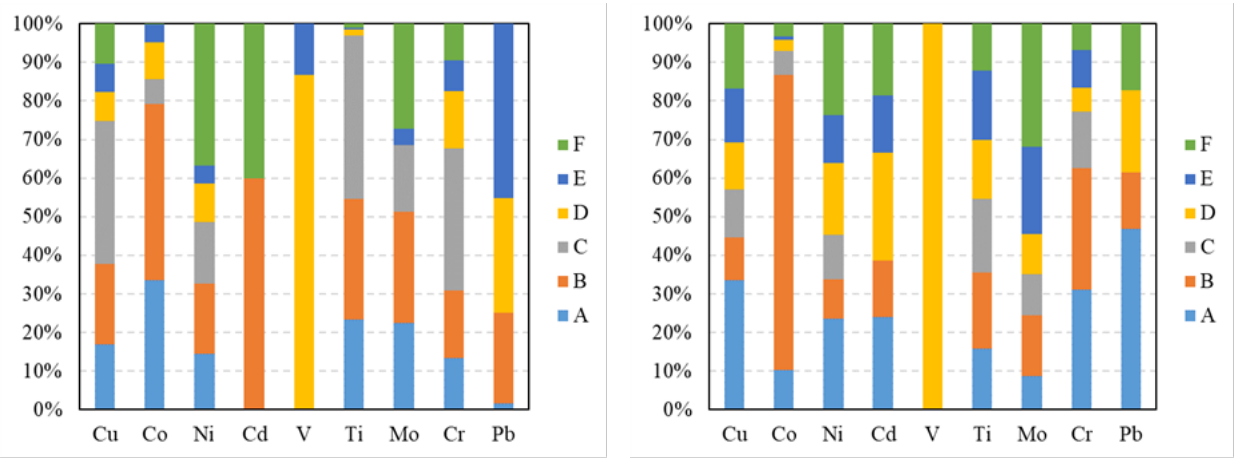
At first, for the sake of model verification, it is important to say that the emission measurements were performed in six stacks but the region contains several petrochemical companies with different types of emission sources, and there aren't any data about those. We also have concentration data measured in several receptor points. If this simulation run and compare its results with the concentration data measured in the receptors, the model results will not be in good agreement with the measured data (usually were lower than the measured values) since there is a significant amount of emissions related to other sources. In this complex situation, another innovative technique can be suggested for model verification.

There are some periods of time when one or more stacks do not operate. This situation would be a good time to measure the pollutants at the receptors because this would provide a "background" concentration of these pollutants in the absence of that or those stack emissions. For measurements at receptors made during operation of the stacks, this background could be subtracted from the measurement result. If Aermod modeling performed considering out of operation stack(s), the "background" concentration of these pollutants were obtained for modeling. Once again, if the "background" concentration of modeling is subtracted from the concentrations obtained from full working stacks in modeling, these differences should be similar in the absence and presence of out of operation stacks. This method was implemented several times in this research, the differences were in good agreement with the average deviation of less than 20%.

In this section, the results of modeling of distributed heavy metals from different incinerators are presented. Due to the importance of these types of pollutants and their destructive effects on the environment, air quality of the region, and the health of the residence, the modeling has been carried out for all heavy metals found in the output of each incinerator. The modeling has separately been done in the first and the second half of year, and also over a year for some metals.

Figs. 6 and 7 show the distribution pattern of different heavy metals contaminants in the first and the second six months of the year, taking into account all the selected waste incinerators. As demonstrated in Figs. 6(a) and 7(a), the common point in both seasons is the release of Cu in the PSEZ, and the urban areas is not affected by this pollutant at either time. Comparison of Fig. 6(a) and 7(a) shows that the distribution range of this pollutant in the second six months of the year is more extensive due to increase in the production of this pollutant in this period of time in the incinerators C and E. Also, this is the reason for occurring the maximum concentration in these area.

Figs. 6(b) and 7(b) depict the distribution pattern of Co pollutant in the first and the second half of the year, taking into account all incinerators. The results of both periods indicate that the spread zoon of this pollution is located around the PSEZ. This range in the first six months of the year is lower than that in the second half of the year, due to the decrease in the production of this pollution in the second period of year by incinerators A, B, C, and D. The reason for the reduction of maximum concentration in the second six months is the same.



(a) (b)

Fig. 3. Solid waste particle percentage of each incinerator in (a) hot season, and (b) cold season

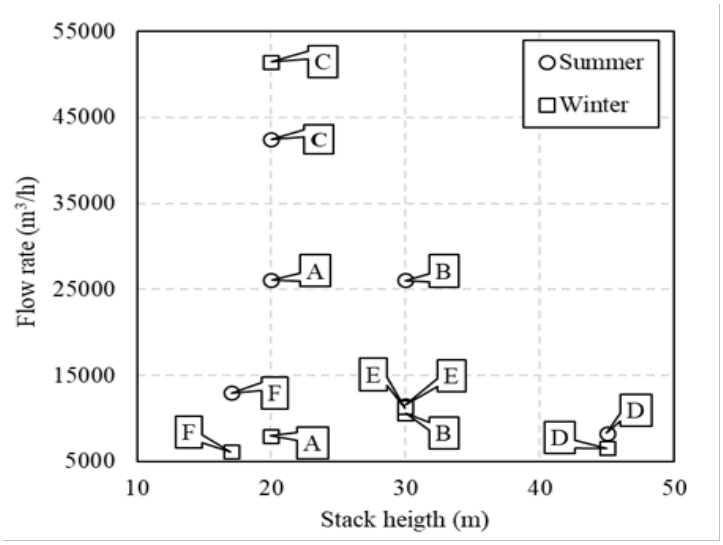
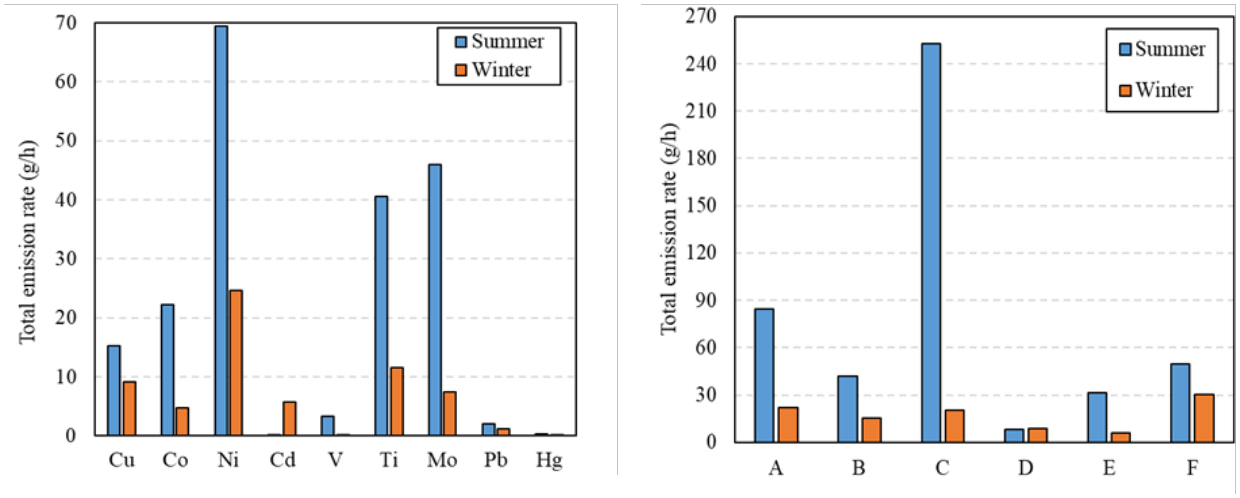


Fig. 4. Total flow rate of incinerators in two seasons with respect to stack height



(a) (b)

Fig. 5. Total emission rate in two seasons (a) for each particles (b) for each incinerator

Distribution of V over one year in two sections (the first and the second half of a year) is depicted in Figs. 6(c) and 7(c). According to the results, only the incinerator D produces this pollutant and based on its geographical location, in the first half of a year, a small area between PSEZ and salt lakes is affected by the release of this pollutant. Also, in the second six months of the year, the range of its distribution increases due to the more production of this pollutant by incinerators D and F of petrochemical companies.

Figs. 6(d) and 7(d) shows dispersion of Ti in the two periods of time. Ti affected the PSEZ partially and did not influence on urban and residential areas. Ti emissions have affected the eastern part of the PSEZ. The modeling of Cr distribution over one year in two section (six months) is shown in Figs. 6 (e) and 7(e) for all incinerators located in PSEZ. According to the results presented at both time intervals, some parts of the PSEZ were affected by the release of this pollutant without any effect on the residential and urban areas, also the release of this pollutant in the first six months of the year is more than the second one.

Figs. 6(f) and 7(f) illustrate the results of Pb modeling dispersion in the first and the second six months of the year, respectively. According to the results presented in both parts of a year, it is clear that the PSEZ has been affected by the release of this pollutant over both periods. Considering that the amount of this pollutant in the first six months of the year is slightly more than the second six months, the area is influenced by the release of this pollutant and the maximum concentration in the first six months of the year is more than the second six months.

Although not shown here, the influenced area by the release of Mo and its maximum concentration in the first half of the year is more than the second half of the year, which is due to the decrease in the production of this pollutant in the second half of the year by the incinerators A, B, E, and F of petrochemical companies.

Figs. 8 (a)-(c) depicts the area affected by the release of Ni, Cd, and Hg in one year. The results of Ni dispersion modeling over one year is illustrated in Fig. 8(a). According to these results, PSEZ was

affected partially by releasing the Ni especially near salt lakes and the dispersion of this metal pollutant does not cover the residential and urban areas. Fig. 8(b) depicts the area affected by the release of Cd in one year. According to the results, the release of this pollutant throughout the year did not affect a wide range and only influenced a small fraction of the PSEZ. Fig. 8(c) shows the results of the modeling of Hg dispersion over one-year period. It should be noted that the only producer of this pollutant was incinerator C. According to the modeling results, the release of this pollutant only affected the areas surrounding the incinerator, and much of the PSEZ was not affected by the release of this pollutant.

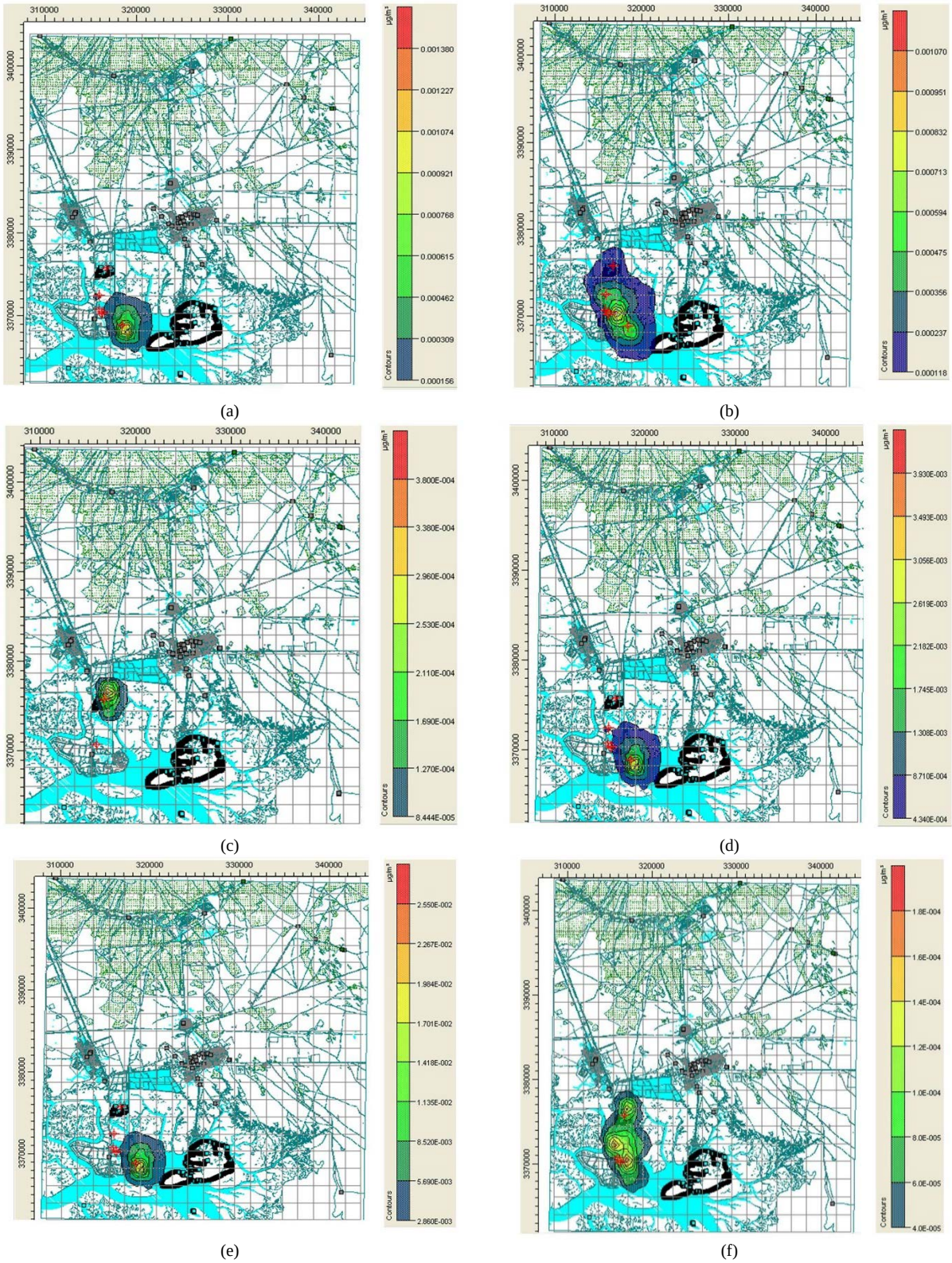


Fig. 6. Distribution of different heavy metals in hot season (a) Cu, (b) Co, (c) V, (d) Ti, (e) Cr, (f) Pb

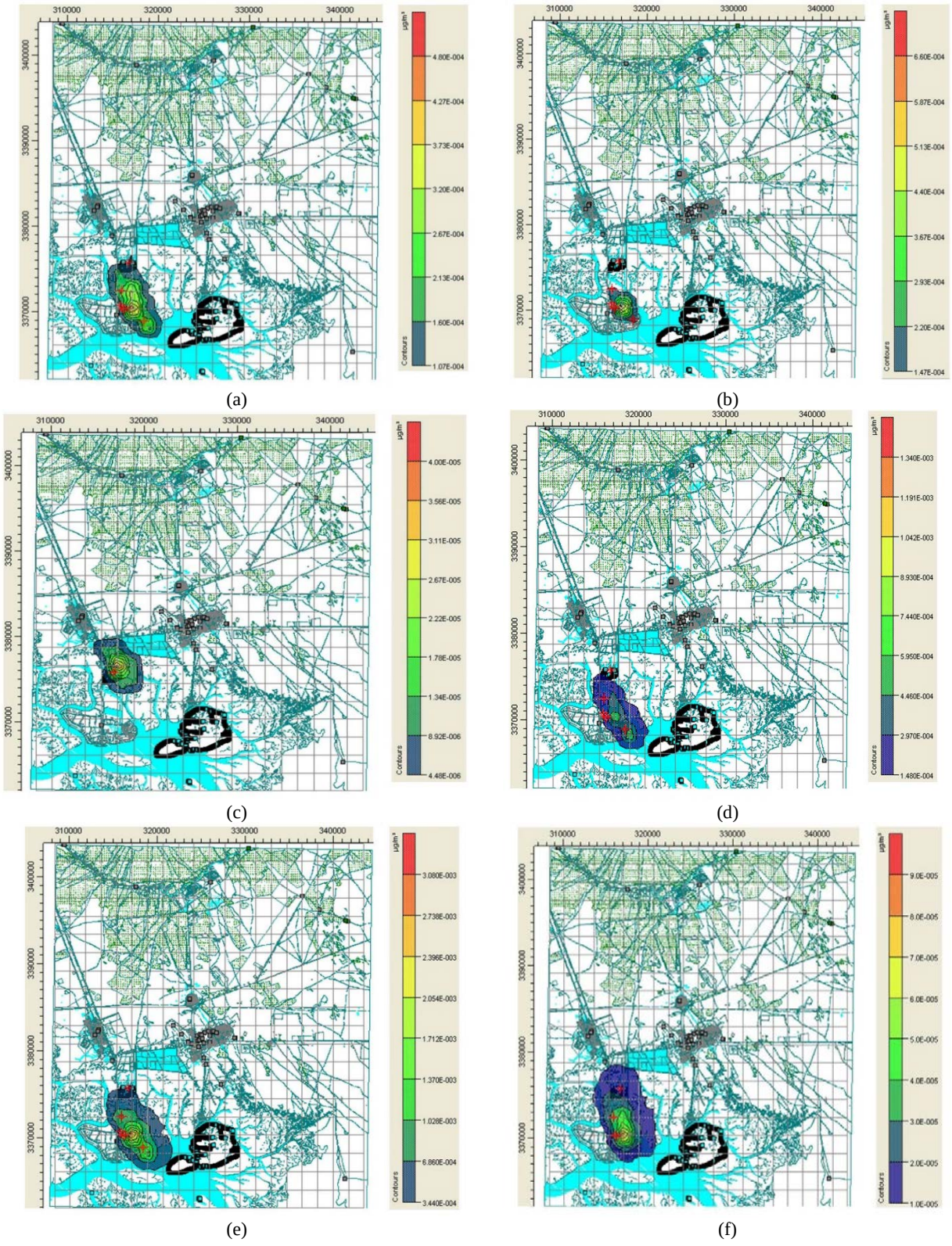


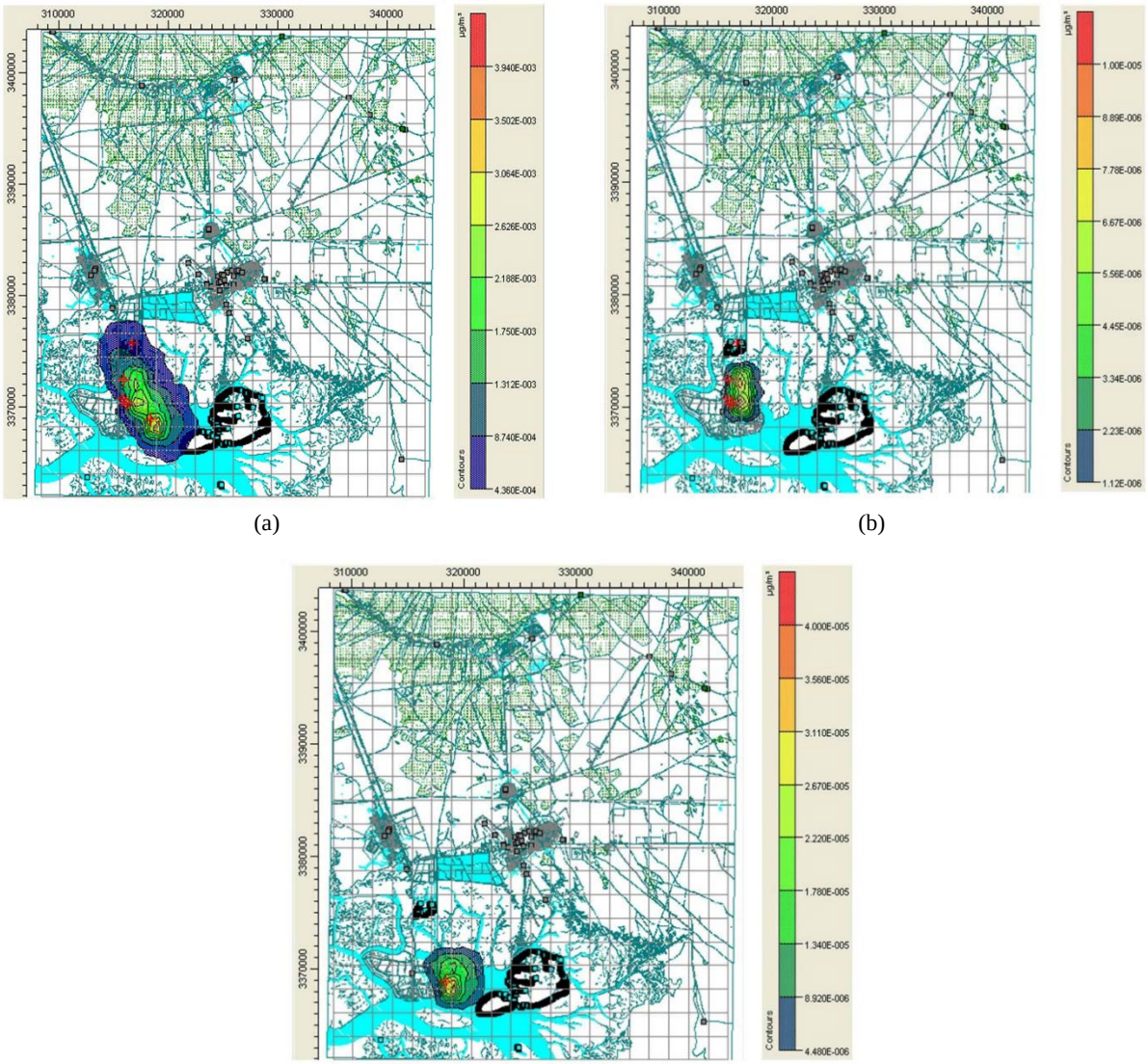
Fig. 7. Distribution of different heavy metals in cold season (a) Cu, (b) Co, (c) V, (d) Ti, (e) Cr, (f) Pb

5. Conclusions

Knowledge on the pollutants dispersion around an industrial area is of critical importance in the development of new residential area and also in estimating the health influences of the existing residential area. In this study, the emission and dispersion of heavy metal particles (including Mo, Cr, Cu, Co, Ni, Cd, V, Ti, Pb, and Hg) from six petrochemical incinerators located at Petrochemical Special Economic Zone (PSEZ), Mahshahr, south-west of Iran was investigated.

The following important results were concluded:

- Arsenic (As) metal was not produced in these incinerators.



(a) (b)

(c)

Fig. 8. Distribution of (a) Ni, (b) Cd, (c) Hg over a year

- Mercury (Hg) was generated in incinerator C only.
- Chromium (Cr) was the most emitted metal from the incinerators and had more emission rate in comparison with other metals in both seasons.
- Cu, Ni, Co, Cr, and Ti were detected in the flue gas of all the incinerators.
- The emission rate as high as 174.2 g/h was obtained for Cr from incinerator C in hot season.
- Incinerator F is the shortest incinerator that emits gas with low flow rate near the surface of the ground, and it can create serious environmental issues.
- Total emission rate in the summer is more than that in the winter for almost all the incinerators.
- Results of distribution and direction of particles dispersion showed that none of the residential and urban areas were affected by the release of heavy metals and only a part of PSEZ was influenced.

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