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The simulation of dispersion and distribution of pollutants of flaring operation in refiners of South Pars through AERMOD

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Abstract

One of the most significant environmental problems of oil, gas and petrochemical industries is the disposal of waste hydrocarbon gases in industrial complexes and the most common methods of burning gases is flaring. The flares constitute the main way of wasting energy, loss of economic resources, and emissions of greenhouse gases. It is the underlying factor of global warming and exerts disruptive effects upon the health of humans and other animate entities. Iran is the third country of the world and the first country in the Middle East in regard to emission of flare pollutants. It produces almost 11 percent of the ignited gas in the world. Now, ten refining phases of South Pars region are operating and 28 low-, middle-, and high-pressures flares are burning associated gases. In the present study, the dispersion of air pollutants of flaring operation is simulated through AERMOD Software. The results show that in normal conditions, benzene, H_2S, and SO_2 are produced more than the normal and standard level so that the highest dispersion concentration of benzene is associated with low-pressure flares of phase 2 and 3, highest dispersion concentration of H_2S is associated with medium-pressure flares of phase 4 and 5, and the highest dispersion concentration of SO_2 is associated with high- and low-pressure flares. These gases are dispersed toward downstream of the resources. In the end, some solutions are suggested for reduction of emission of these pollutants.

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Introduction

Flares are one of the most significant elements of operational units, especially chemical industries because through controlling and checking the waste gases in critical and sensitive condition, they prevent damages to the devices and employees (Ghadianloo, GhanbarNejad, and Viraste, 2012). The flares constitute the main way of wasting energy, loss of economic resources, and emissions of greenhouse gases. It is the underlying factor of global warming and exerts disruptive effects upon the health of humans and other animate entities (Farakesh, 2011). The increase in emission of greenhouse gases in the world is due to excessive consumption of fossil fuels and energy carriers that causes negative environmental consequences such as global warming, expansion of deserts, increasing demand for agriculture and increasing rates of some diseases (Ghasemie, Rostami, Mohammadi Rad, PurHamid, and HamleDar, 2012). Based on IPCC[1] report, the share of Iran in emission of greenhouse gases is 1.2 percent which showed that in 2014, Iran had the first position in the Middle East and the seventh position in the word regarding to emission of such gasses (IPCC, 2014). Based on the predictions of World Bank, the emission of ignited gasses will amount to 100 billion cubic meters in 2017 and in this regard, Iran will produce 11.5 percent of total ignited gases in the world.

Accordingly, Iran will be the third country in the world and the first country in the Middle East in regard to emission of ignited gases (IPCC, 2014). In addition, the share of emission of greenhouse gases in oil sector the most significant part of which is flare gases in refineries amount to 35 percent of the emission in the whole country (Public Relations of Oil Ministry, 2004). In the past few years, the campaigns of international and national communities to protect the environment, Kyoto and Montreal protocols have contributed to limitation of emission of greenhouse gases.

In addition, Global Gas Flaring Reduction Partnership (GGFRP) suggested the necessity of a comprehensive study and evaluation of the environment in South Pars region so as to decrease and recovery of flare gases due to environmental concerns and because of the large volume of oil in the region. In the present study, AERMOD

Software is used to simulate distribution, dispersion, and concentration of seven major pollutants in refineries of South Pars Region (Phase 1-10). Flaring Operation: Flare is a defined as an exposed, unchecked and ignited fire sparks but in chimney manufacturing industry it refers to stack or a vertical pipe used for satisfaction of safety of devices and personnel which ignites the waste gases (Farakesh, 2011). The flares act in three different cases of operational conditions and burn input gases: 1- Normal Operating Conditions: The gases accompanying and resulting from some industries are burnt due to lack of collection and transmission mechanism and further applications.2- Turbulence Conditions of Unit: When the gas inside the system is often more than its capacity and when the system is in start-up or shut-down mode. 3- Emergency Conditions of Unit: During an accident, emergence of technical problems in devices, and human error, the non-usable gases are flared (Chavosh Bashi, Derafshi and Radman, 2009).

Flaring Consequences

The first and foremost consequences of flaring, venting or direct disposal of greenhouse gases into the environment are global warming. On the other hand, the flares cause the emission of 207 tons of CO_2 into the environment which in addition to greenhouse effects, the reduction of PH and acidic rain may also result (Andalib Moghadam, 2007).

The second consequence of flaring waste gases is environmental pollution and health impacts. Based on 2000 official papers in Canada, during the burning of flare gases, about 250 toxic materials are released into the air (Shahini, 2011).

In addition, a flare could be the source of soot particles (Pohl and Soelberg, 1985), nitrogen oxides (NO_x), sulfur oxide (So_x), volatile organic compounds (Rahimpour and Jokar, 2012), unignited hydrocarbons (Johnson, Kostiuk, and Spangelo, 2001), and other unfavorable ignition products (Strosher, 2000). Based on the U.S EPA[2] report, the flare gases are the underlying factor behind diseases and respiratory system disorders such as cough, chronic bronchitis, pulmonary function impairment, miscarriage and premature death. The two pollutants of suspended particle (SP) and benzene of the flare cause premature death and leukemia (EPA, 2012).

The third major consequence is loss of resources and energy. World Bank estimates that about 150 billion cubic meters of natural gas is annually flared which is relatively 5 percent of globally produced natural gas per year. This is equivalent with 23 and 30 percent of consumption of natural gas in United States and Europe per year. On the other hand, a significant financial budget is annually assigned for maintenance of flare system (Norozi Hamed, 2012). Based on the official statistics of 2010, about 1518.3 million cubic feet of accompanying gases are burnt in Iran. As noted in the studies of Total Company, 972 million cubic feet of these gases are continually burnt. Therefore, 67 percent of flare gases are continually burnt while 36 percent is temporarily or periodically ignited (Official News Website of Ministry of Oil, 2009).

The fourth major consequence of flaring systems is the flare space and limits. The presence of flare facilities in a site limits its applications and limits. The height of the flare ranges from 4 to 50 meters. Therefore, it influences the industrial applications too. South Pars Gas Field is one of the largest independent reservoirs of gases in the world which is located on the borderline of Iran and Qatar in Persian Gulf. This reservoir is located at the deeps of 300 meters below the sea bed and in a layer the thickness of which is 450 meters.

The stored gas amounts to 464 trillion cubic feet which is equivalent with 8 percent of globally available gas resources and 50 percent of national gas resources. The area of sea territory of Iran is about 300,000 square kilometers. The gas of the reservoir is of sour type in four layers and the content of its sulfurized hydrogen in different layers amount to 500 ppm (South Pars Official Website, 2015).
Characteristics of Flares Installed in South Pars Refineries**,** There are about 45 gas flares burning in South Pars region (Asaluyeh). Almost all of the refineries have all the three types of high-pressure, medium-pressure and low-pressure flares. Therefore, regarding the start-up and utilization of 10 refinery phases about 28 flares are related to gas refinery and the remaining are associated with petrochemical complexes and other sites. On the other hand, it is estimated that the input gas of a high-pressure flare in these refineries amount to 145 kg/h which might sometimes get to maximum level of 531019 kg/h. The gas output velocity of such flares is averagely 220.91 m/s the equivalent amount of which is ignited (SPGC, 2014).

The composition of flare gas is basically similar to that of precedent process. If a part of the system faces problems, the combination of flare gas might radically change. In addition, age and type of materials used in manufacturing of flare might cause the change in combination of the output gas. A major part of natural gas includes methane, ethane, butane, propane, sulfur dioxide, hydrogen sulfide, oxygen, nitrogen, helium and argon (Farakesh, 2011). The aim of this study is show in normal conditions, benzene, H_2S, and SO_2 are produced more than the normal and standard level so that the highest dispersion concentration of benzene is associated with low-pressure flares of phase 2 and 3, highest dispersion concentration of H_2S is associated with medium-pressure flares of phase 4 and 5, and the highest dispersion concentration of SO_2 is associated with high- and low-pressure flares.

Fig. 1. South Pars region in GIS setting.

Table 1. Climatic Conditions of South Pars Region (SPGC, 2014).

Geographic Location	Latitude: 27 degrees, Longitude; 52 degrees
Temperature	5-50 °C
Relative Humidity	59-88%
Precipitation	180 mm annually
Wind Direction	Northwest to Southeast
Vegetation	Moderate and sparse with palm trees and mangrove trees
Slope	10% in beach

Material and methods

Applied-analytical survey

The present study was a applied-analytical survey which was done periodically done. The data-collection method is field-based. The filed-based method includes collection and evaluation of location and descriptive data of South Pars region. The measurement of air pollutants caused by flaring operation, value and flow of input gases of the flare, simulation of distribution of air pollutants in operating phases and different sites of the region was done through AERMOD Software.

Location

Due to location of 22 standard and permanent stations in different places of the region, consistent monitoring of climatic and chemical data in these stations, and as location of monitoring stations shown in table 2 implies, all of these stations have almost covered the whole South Pars region. Therefore, one can use the monitoring data of these stations in these studies.

Table 2. Location of Pollution Monitoring Stations (SPGC, 2014).

Row	Location	Row	Location
1	Shirino	12	Phase 2 and 3- Block A
2	Paye Kooh	13	ENI Storehouse
3	Phase 4 and 5-Gallery	14	Nakhle Taqi
4	Phase4 and 5-Caustic Recovery Unit	15	Asaluyeh
5	Sulfur Storage Unit	16	Phase 9 and 10-Propane Storage
6	Phase 6, 7, and 8-Administrative	17	Phase 9 and 10-Sulfur Graining
7	Phase 6, 7 and 8-Propane Storage Unit	18	Phase 9 and 10-Administrative
8	Phase 1-Industrial Door	19	Bidkhoon- OIEC Camp
9	Phase 1-Guard Post	20	Bidkhoon- SPGC Camp
10	Abgir	21	Bidkhoon- Persian Gulf Camp
11	Phase 2 and 3-Firefighting Exercise Land	22	Control Station

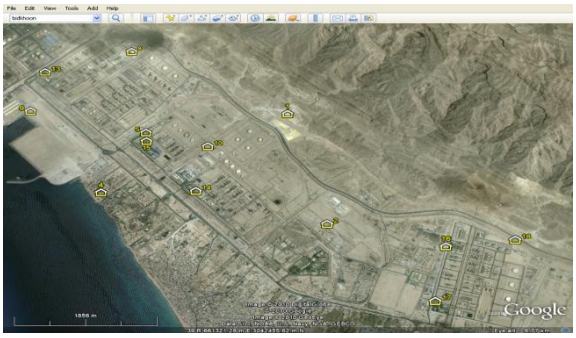

Fig. 2. Twenty Two Pollution Monitoring Stations in GIS.

Meteorological data

The meteorological data for modelling were obtained from metrological station of International Airline of Assaluyeh Port. Because the received synoptic data are related to three hours, one could claim that the data are uniform for the three hours. Therefore, with relative approximation, the data were presumed to be uniform for an interval of three hours.

Measurement Devices

The passive samplers used for measurement are of absorbent and passive one (Dragon ORSA-5) which measures certain air pollutants such as H_2S, BTE_X, NO_2, SO_2 and NH_3. The installation cycle of these samplers and pollutant absorbers can be weakly, two-weekly or monthly. The analyses of samples were done by Passam Company in Switzerland after the end of sampling in the setting and absorption of the pollutants in mean-value format and in ug/m³ unit.

In regard to chromatographic principles, the most common type of analyzer is used for online analysis of gases. Based on separation of different particles, a chemical composition is made due to the principles of physical absorption. The gas chromatography device of the first refinery is SIEMENS PGC 302 which measures mercaptan, hydrogen sulfide, and SO_2. The gas chromatography device of the second refinery is SIEMENS PGC 302 which measures H_2S and SO_2. In the third refinery, the gas chromatography device is MAXUM II which measures H_2S, SO_2, nitrogen and gaseous compounds. In laboratories, the type of gas chromatography device used is VARIAN CP-3800 which measures gaseous compounds in all of the phase.

Table 3. Indicators of Air Pollution Monitored in Stations (SPGC, 2014).

Row	Parameter	Measurement Unit	Annual Mean of Stations
1	Benzene	ug/m³	16.8
2	Toluene	ug/m³	10.4
3	Ethyl benene	ug/m³	4.1
4	P-xylene	ug/m³	2.1
5	M-xylene	ug/m³	5.3
6	O-xylene	ug/m³	3.7
7	VOCs	ug/m³	30.9
8	So₂	ug/m³	241.3
9	No2	ug/m³	38.5
10	H2S	ug/m³	3.1
11	NH3	ug/m³	33.4
12	VOCs	ug/m³	30.9
13	So₂	ug/m³	241.3
14	No2	ug/m³	38.5
15	H2S	ug/m³	3.1

The absorption and measurement of mean concentration in time and weight was done based on MDHS88 guideline through carbon disulfide solvent and gas chromatography system with FID. In monitoring stations, different types of parameters along with other meteorological parameters were measured. As an instance, the 11 parameters were determined as the indicators of air pollutants and the means of annual analysis of the 22 stations were determined as shown in table 3.

Result and discussion

Statistical Population

In the South Pars Gas Complex, the first refinery (phase 1) has two high-pressure and two low-pressure flares. The second refinery (phase 2 and 3) had two high-pressure, two medium-pressure and two low-pressure flares. The third refinery (phase 4 and 5) had two high-pressure, two medium-pressure and two low-pressure flares. The fourth refinery (phase 6, 7 and 8) had two high-pressure, two medium-pressure and two low-pressure flares. The fifth refinery (phase 9 and 10) had two high-pressure, two medium-pressure and two low-pressure flares. The information of each one of the flares such as the amount of flared gas, gas flow rates, inlet gas composition, height of the flares, etc. were obtained from process engineering unit of the refineries. As an instance, the first refinery has two high-pressure and two low-pressure flares with the following characteristics.

Table 4. Characteristics of High-pressure Flares of Phase 1 (SPGC, 2014).

HP Flare	POS (MM)	FGL 3000
Phase 1	NORTH	4645 -3046078(utm)
	EAST	7475 -656857(utm)
	HIGH(m)	93
	DIAMETER	1.016(m)-40/26(In)
	Flue gas flow rate(kg/h)	1004
	Max Flow rate (kg/h)	531019 kg/h
	Outlet Temperature .c	130 .C
	Flue gas flow rate ave(m/s)	220.91 m/s

Table 4. Characteristics of Low-pressure Flares of Phase 1 (SPGC, 2014).

LP Flare	POS (MM)	FGL 3000
Phase 1	NORTH	4645 - 3046283(utm)
	EAST	7725 -656716(utm)
	HIGH(m)	93
	DIAMETER	0.66(m)
	Flue gas flow rate(kg/h)	6781
	Max Flow rate (kg/h)	196625
	Outlet Temperature .c	58.1.C
	Flue gas flow rate ave(m/s)	

Simulation of Distribution of Air Pollution by Flaring Operation

AERMOD is an EPA-approved software which develops a Gaussian model of distribution of smoke in stable conditions for release, distribution and subsidence of pollutants. It is often used for evaluation of the concentration of pollutants of different sources. This model simulates the two parameters of distribution and transmission of pollutants from point, surface, and volume sources as well as sources of flame located in flat areas or areas with highlands and lowlands. It can be used for maximum distribution distance of 50 kilometers and it is often used in the cases of consecutive emission and emission effects of different industrial sources (e.g. refinery flares). The type of release from the source is superficial, near to the ground of highland resources (Abaspur, 2012).

The representative diffusion coefficient denotes the quantity of released pollutant in the environment and associates it to the activity level of its producer. This coefficient is usually determined through division of weight of pollutant by the unit of weight, volume, distance or interval of the activity producing the pollutant. The burn rate is determined through Q=V×H in which Q is the activity or production rate, V is the volume of burnt fuel and H is the heating value (convection) of the fuel. The diffusion coefficients of the pollutants out flowing from the flares are represented in the following table.

Table 5. Diffusion Coefficient of Operating Flare [a].

Compound	Diffusion Coefficient (kg/ 10^6 kj)
Total Hydrogen[b]	0.0602
Monoxide Carbon	0.1591
Nitrogen Oxide	0.0292
Smoke [c]	0-117.8

a. In tests with raw propylene (80% propylene and 20% propane).

b. Measured based on equivalent methane.

c. The smoke based on concentration values: the non-smoking flares 0 ug/L, lightly-smoking flares 17.2 ug/L, average-smoking flares 76.1 ug/L, heavily-smoking flares 117.8 ug/L.

Through mass balance, a proper method for estimation of emission of VOC_s, HAP_s, and CH_4 of venting the gas was obtained which could be applied in processing and emergency devices, active gas pumps, pressure / level control, testing wells, flares, etc. In this simulation, two scenarios are presumed.

Table 6. Clean-air Standards in Iran (2012-2013).

Type of Pollutant	2012-2013	
	ug/m3	Ppm
Carbon Monoxide (CO)		
Maximum (8 Hours)	10000	9
Maximum (1 Hours)	40000	35
Sulfur Dioxide		
Annually	20	0.007
Maximum (24 h)	100	0.037
Nitrogen Dioxide (NO_2)	40	0.021
Suspended Particles (PM_{10})		
Annual	20	
Maximum (24 h)	50	
Suspended Particles ($PM_{2.5}$)		
Annual	10	
Maximum (24 h)	25	
Ozone (O3)		
Maximum (8 Hours)	100	0.05
Maximum (1 Hours)		
Lead	0.5	
Benzene	5	
Benzo(*a*)pyrene	1	
	(ng/m3)	

First Scenario

In the present study, the concentrations of some compounds such as benzene, toluene, xylene and concentration of pollutants, H_2S, NO_x, SO_x, VOC_s out flowing from the flares, their emission and distribution in different operational and normal conditions were simulated through AERMOD Software. To examine the statues of the intended

pollutants in the region, the environmental standards of concentration of pollutants had to be defined and then, the simulated values could be compared with the intended standards. In the case of higher values of modeled values compared with existing standards, the necessity of using control solutions for polluting source is evident and the reduction of emission level is needed. The following table shows the standards of clean air for different types of pollutants. The simulation results showed the following:

Benzene

The variance of mean annual concentration of benzene is shown in fig. 3. The emission of benzene occurred after the flow of input gas into some flares and its values was significantly higher for low-pressure flares of phase 2 and 3 compared with other flares. Based on the wind rose chart of the region (fig. 4), the direction of dominant wind of the region was from northwest to southeast. Therefore, these pollutants are distributed in the same direction in most days of the year. In addition, the highest concentration of benzene was estimated to be 7.85 ug/m^3 which was higher than the environmental standards (i.e. 5 ug/m^3).

Fig. 3. Contour of annual changes of benzene concentration in Assaluyeh.

Sulfate Hydrogen (H_2S)

Due to the fact that the flares had sulfate hydrogen in their input, it was noted that LP flares in phase 2 and 3 as well as MP flares in phase 9 and 10 had significant concentrations of sulfate hydrogen in their input.

Of course, the concentration of input hydrogen for HP and MP flares of phase 4 and 5 is significantly higher than the others. On the other hand, the long height of the flares led to some delays for arrival of H_2S to the ground and be measured by the devices. Based on fig. 5, the concentration contour was obtained at the downstream of the flares. In regard to the dominant wind and the presence of mountains in the upstream, the movement of the pollutants was mostly downward. Based on the results regarding the concentration of H_2S, the value of this pollutant was calculated to be 4.9 ug/m^3 which was higher than the permitted annual mean level of 1.5 ug/m^3.

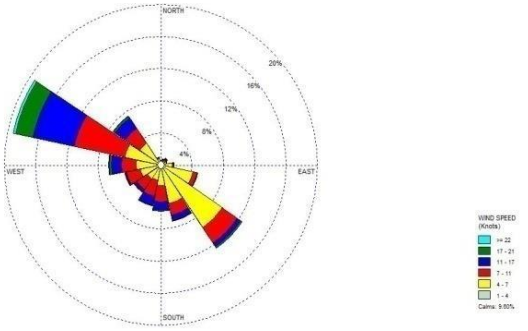

Fig. 4. Annual wind rose chart of Assaluyeh.

Sulfate Hydrogen (H_2S)

Due to the fact that the flares had sulfate hydrogen in their input, it was noted that LP flares in phase 2 and 3 as well as MP flares in phase 9 and 10 had significant concentrations of sulfate hydrogen in their input. Of course, the concentration of input hydrogen for HP and MP flares of phase 4 and 5 is significantly higher than the others.

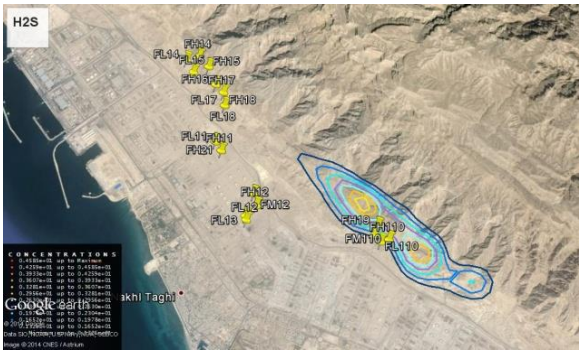

Fig. 5. Contour of annual changes of hydrogen sulfide concentration in Assaluyeh.

On the other hand, the long height of the flares led to some delays for arrival of H_2S to the ground and be measured by the devices. Based on fig. 5, the concentration contour was obtained at the downstream of the flares. In regard to the dominant wind and the presence of mountains in the upstream, the movement of the pollutants was mostly downward. Based on the results regarding the concentration of H_2S, the value of this pollutant was calculated to be 4.9 ug/m^3 which was higher than the permitted annual mean level of 1.5 ug/m^3.

Sulfide Dioxide (SO_2)

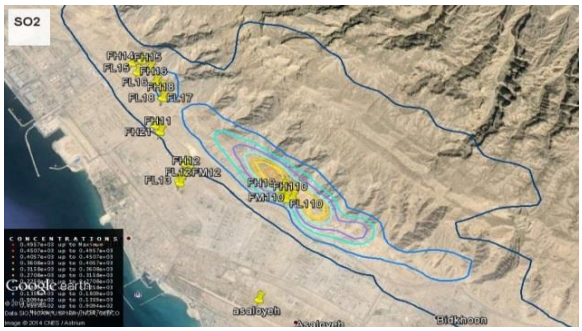

Fig. 6. Contour of annual changes of sulfide dioxide concentration in Asaluyeh.

The above fig. represents the contour of annual mean changes of SO_2. If the input gas of the flares has H_2S, then the emission of SO_2 would be meaningful. Therefore, the flares emitting SO_2 includes the LP flares of phase 2 and 3, HP and MP flares of phase 4 and 5 and MP flares of phase 9 and 10. Based on the geographical condition of the region and presence of mountains and coastal winds, the pollutants are dragged downwards. The comparison of the concentration contour of these two pollutants is similar due to identical sources. The highest concentration of SO_2 was calculated to be 540 ug/m^3 which was significantly higher than its standard and permissible concentration (i.e. 20 ug/m^3).

Nitrogen oxides (NO_x)

Fig. 7 represents the contour of variance of annual mean. This pollutant is produced during ignition process in flare and when nitrogen and oxygen are available in a high temperature. It flows out of the whole flares of the region. Due to existence of mountains in upstream of the flares, the produced pollutant cannot get too far away from the flares and higher concentrations of this pollutant distributes around the flares. Considering the dominant wind of the region, the direction of distribution of pollutants is from northwest to southeast. The highest concentration level for this pollutant was calculated to be 3.7 ug/m^3 which is less than annually permitted value (i.e. 40 ug/m^3).

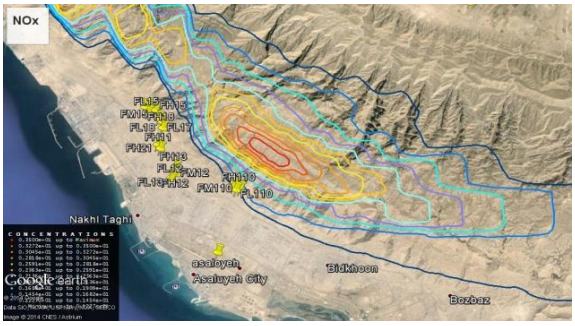

Fig. 7. Contour of annual changes of nitrogen oxides concentration in Assaluyeh.

Toluene

The contour of annual variances of toluene is shown in fig. 8. It is evident that the flares that have toluene in the composition of their input gas lead to its emission. These flares included HP flares of phase 1, LP flares of phase 2 and 3, and LP flares of phase 6, 7, and 8. The flare of phase1 has insignificant diffusion compared with others. The contour of concentration of toluene was obtained in two close points at the downstream of the sources. The reason for this phenomenon was the low height of the flares and quick emission of pollutants in low heights which leads to quick distribution of the pollution in vicinity of the producing sources. Based on higher emission of toluene from LP flares (from 5 to 10 times) in phase 2 and 3, the resultant contour is larger than that of LP flares of phase 6-8. The highest concentration of this pollutant was calculated to be 2 ug/m^3 which is lower than its annually permitted level (i.e. 20 ug/m^3).

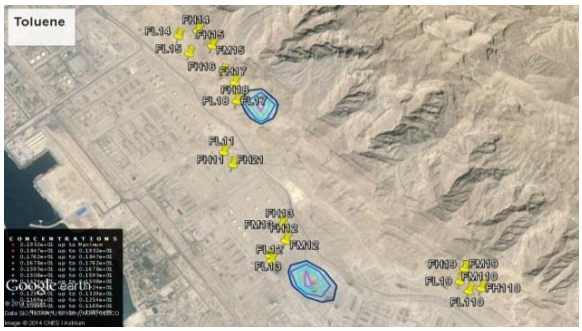

Fig. 8. Contour of annual changes of toluene concentration in Assaluyeh.

Xylene

Just like toluene, the sources of xylene were the LP flares of phase 2 and 3 as well as LP flares of phase 6-8. The concentration contour of xylene is similar to that of toluene. This pollution is distributed in a small distance from and at the upstream of the sources due to low height of the flares. As a result, the distribution of the flares is done in lower heights. In this case, due to the fact that the distribution of xylene from LP flares of phase 2 and 3 is 7 to 12 times more than LP flares of phase 6-8, its contour is bigger and based on the closeness of developed contours in vicinity of the sources, the validity of the simulations is proved (Fig. 7). The highest value of xylene was calculated to be 8.5 ug/m^3 which is less than the standard limit of the pollutant (i.e. 12 ug/m^3, Massachusetts Department of Environmental Protection).

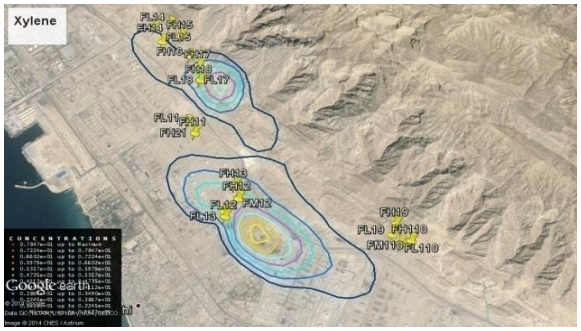

Fig. 9. Contour of annual changes of xylene concentration in Assaluyeh.

Volatile organic compounds (VOCs)

The contour of annual changes of VOCs is shown in fig. 10. Due to production of VOCs from all existing flares, the developed contour covered all of the studied regions and these compounds were distributed along the dominant wind. The highest concentration of this pollutant in Assaluyeh was calculated to be 7.7 ug/m^3 which is significantly less than its standard level (i.e. 100 ug/m^3).

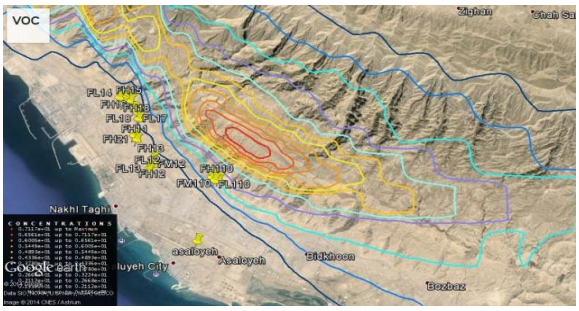

Fig. 10. Contour of annual changes of VOCs in Assaluyeh.

Validation of Software Modeling in Normal Mode

In the following fig., the fig. of comparison of measured and modeled concentration data for different pollutants are represented.

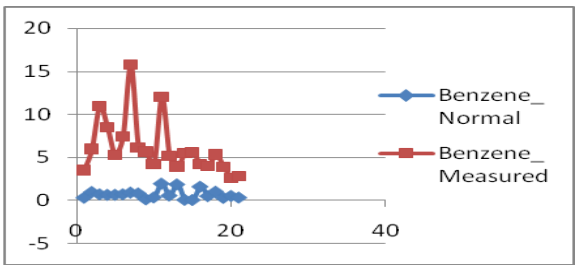

Fig. 1. Comparison of measured and modeled values of benzene.

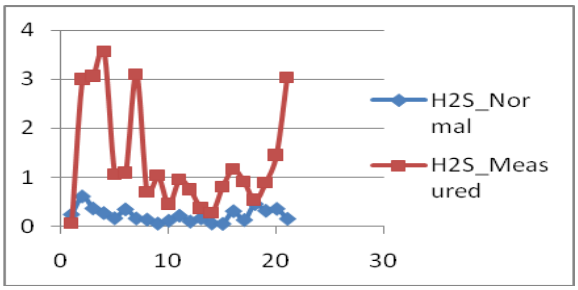

Fig. 2. Comparison of measured and modeled values of hydrogen sulfide.

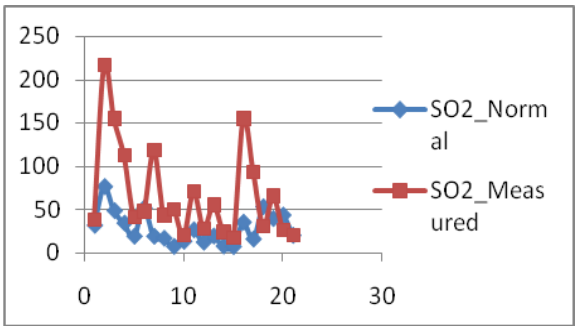

Fig. 3. Comparison of measured and modeled values of sulfide dioxide.

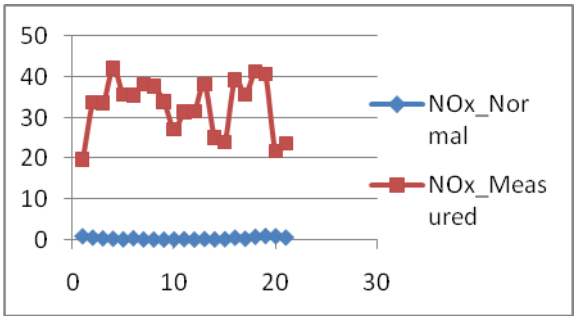

Fig. 4. Comparison of measured and modeled values of nitrogen oxides.

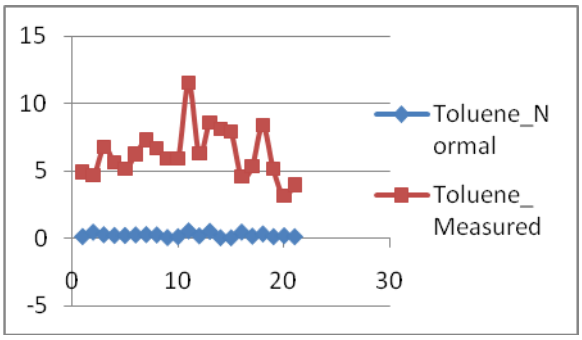

Fig. 5. Comparison of measured and modeled values of toluene.

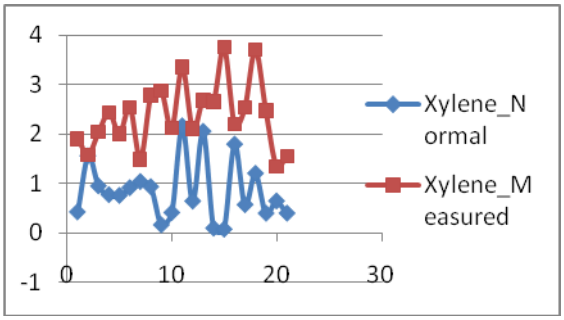

Fig. 6. Comparison of measured and modeled values of xylene.

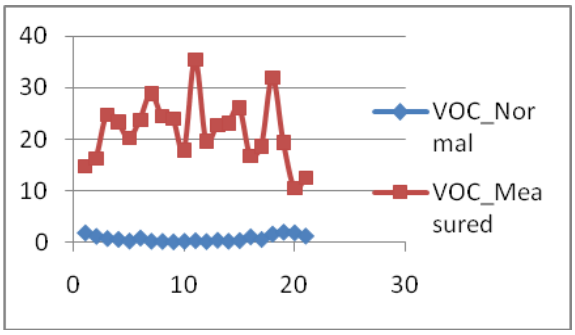

Fig. 7. Comparison of measured and modeled values of VOCs.

Second Scenario

In this case, the function of flares is studied in shut-down mode and the levels of produced pollutants are reviewed. In average, the shut-down mode is presumed to occur 2 times in a year. Now, considering the shot-down mode of all flares, the contour shape didn't change in regard to H_2S, NO_x, SO_2 and VOCs but the concentration of pollutants in the environment increased. For benzene, toluene, and xylene, the resulting contour is not similar to the normal mode the reason of which is pressure rise of this pollutants in LP flares of phase 6-8 compared with normal case of LP flares of phase 2 and 3.

Benzene

In regard to this pollutant, its maximum level in the contour was determined as 59.5 ug/m^3 which is significantly higher than the annually permitted limit (i.e.5 ug/m^3).

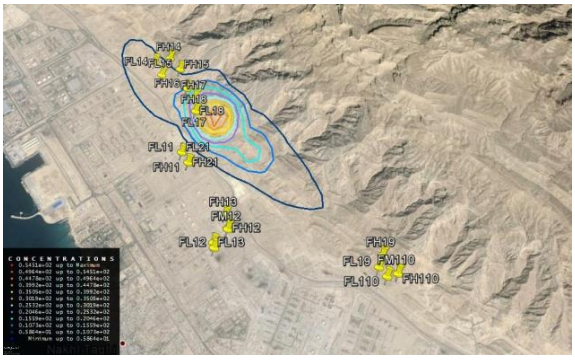

Fig. 11. Contour of annual changes of benzene in Assalouyeh (shot-down case).

Hydrogen sulfide (H_2S)

In regard to this pollutant, its maximum level in the contour was determined as 21 ug/m3 which was higher than the permitted limit (i.e.1.5 ug/m3).

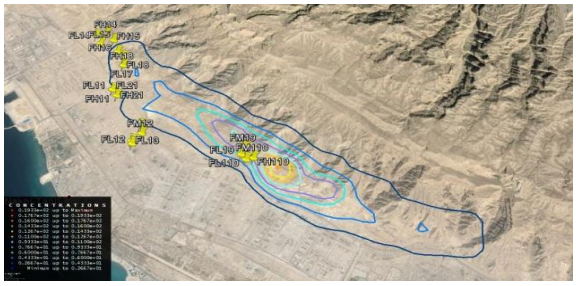

Fig. 12. Contour of annual changes of hydrogen sulfide in Assalouyeh (shot-down case).

Sulfur dioxide (SO_2)

In regard to this pollutant, its maximum level in the contour was determined as 16400 ug/m3 which is significantly higher than the permitted limit (i.e.20 ug/m3).

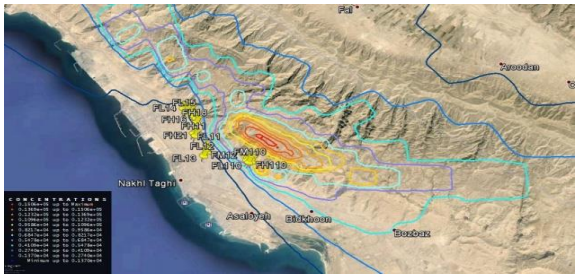

Fig. 13. Contour of annual changes of sulfur dioxide in Assalouyeh (shot-down case).

Nitrogen oxides (NO_X)

In regard to this pollutant, its maximum level in the contour was determined as 1040 ug/m3 which was higher than the permitted limit (i.e.5 ug/m3).

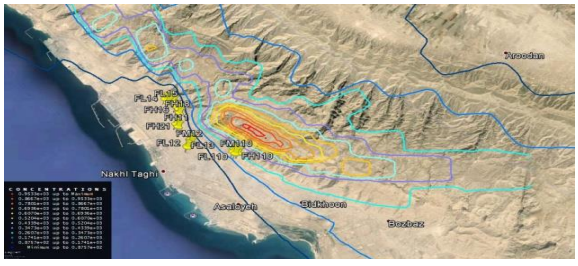

Fig. 14. Contour of annual changes of nitrogen oxide in Assalouyeh (shot-down case).

Toluene

In regard to this pollutant, its maximum level in the contour was determined as 70 ug/m3 which is higher than the permitted limit (i.e.20 ug/m3).

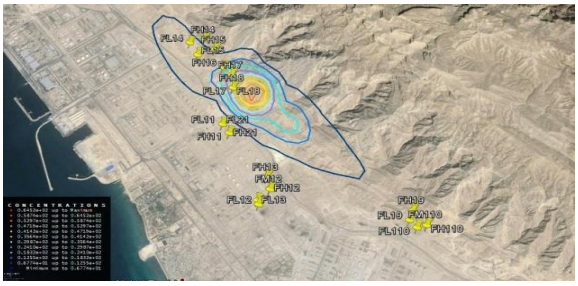

Fig. 15. Contour of annual changes of toluene oxide in Assalouyeh (shot-down case).

Xylene

In regard to this pollutant, its maximum level in the contour was determined as 219 ug/m3 which is higher than the annually permitted limit (i.e.5 ug/m3).

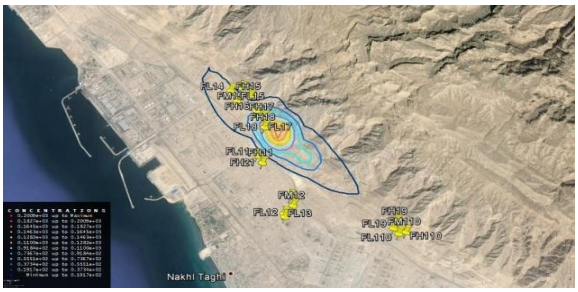

Fig. 16. Contour of annual changes of xylene in Assalouyeh (shot-down case).

Volatile organic compounds (VOC_s)

In regard to this pollutant, its maximum level in the contour was determined as 2140 ug/m3 which is significantly higher than the permitted limit (i.e. 100 ug/m3).

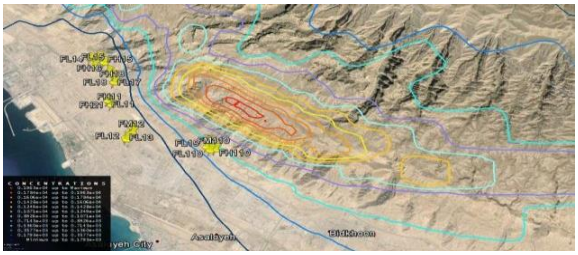

Fig. 17. Contour of annual changes of VOC_s in Assalouyeh (shot-down case).

Modeling Validation in Shut-down Mode

In shut-down mode in which the flow rate of gas was presumed to be equivalent with design values, the velocity of output gases of the flare was unusually and illogically high but in shot-down mode the input flow rate of the flare was presumed to be about fifty percent of designed values. As a result the output velocity was obtained to be close to Mach number or less. As a result, the values were presumed to be 50 percent of design vales for simulation intentions. Considering the received data of the refinery, the flares might go on shot-down mode two times a year. The comparison of measured-on-field values and modeled values through AERMOD Software is represented in the following *Fig*. for each pollutant.

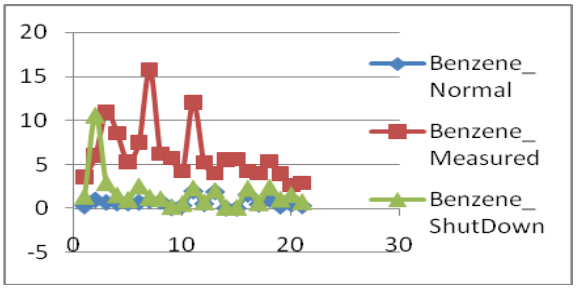

Fig. 8. Comparison of measured and modeled values of benzene in shot-down mode.

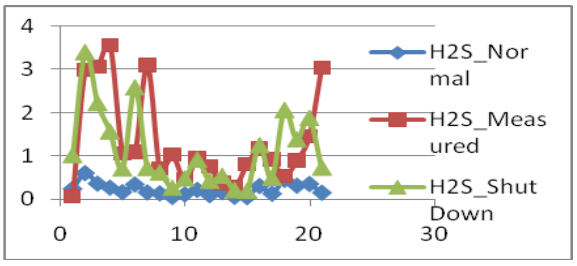

Fig. 9. Comparison of measured and modeled values of hydrogen sulfide in shot-down mode.

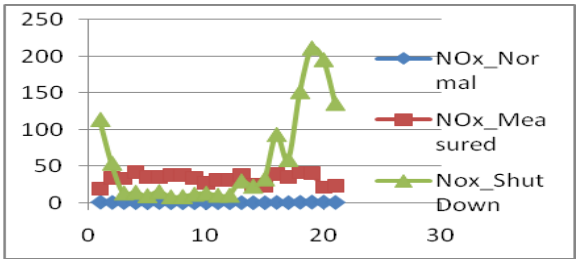

Fig. 10. Comparison of measured and modeled values of nitrogen oxides in shot-down mode.

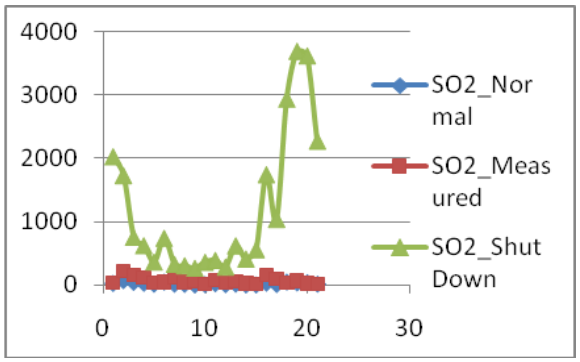

Fig. 11. Comparison of measured and modeled values of sulfide dioxide in shot-down mode.

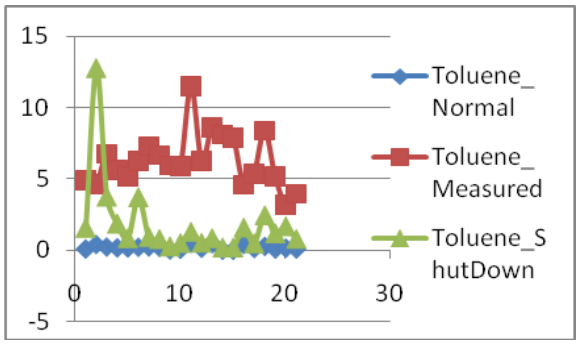

Fig. 12. Comparison of measured and modeled values of toluene in shot-down mode.

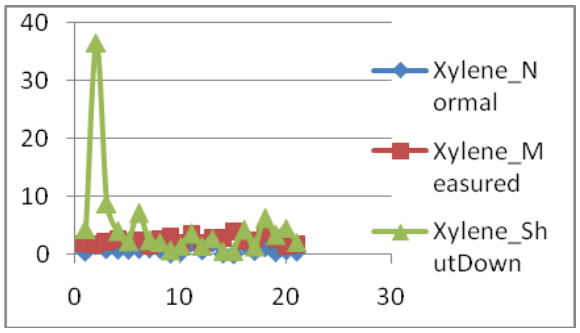

Fig. 13. Comparison of measured and modeled values of xylene in shot-down mode.

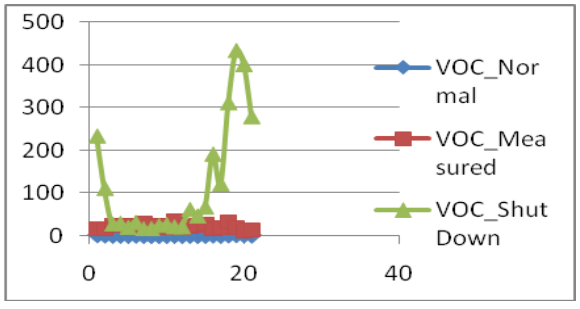

Fig. 14. Comparison of measured and modeled values of VOCs in shot-down mode.

In the present study, the emission and distribution of 7 pollutants produced by flaring operation were simulated and two scenarios were designed. In the first scenario, certain pollutants including benzene, hydrogen sulfide and sulfide dioxide didn't violate the existing standards. The annual mean concentration of benzene was 7.85 ug/m^3 and its highest emission level was in LP flares of phase 2 and 3. The annual mean concentration of H_2S was 4.9 ug/m^3 and its highest emission level was in MP flares of phase 4 and 5. The annual mean concentration of SO_2 was 540 ug/m^3 and its highest emission level was in MP and HP flares due to high level of H_2S in input of flares and logicality of ignition efficiency of 98 percent. In the second scenario, the flow rate of flares was presumed to go on shot-down mode two times a year. The concentration values of modelled pollutants had significantly exceeded the standard and permissible level so that the annual mean concentration of benzene, H_2S, NO_x, SO_2, toluene, xylene and VOC_s were respectively 59.5, 21, 1040, 6400, 70, 219 and 2140 ug/m^3. Considering the results of maximum flow rate, the difference between measured and modelled values increased and in some cases, the modeled values are more than the measured one. In the end, this study is comparable to some previous works such as Holems and Morawska (2006) in industrial region of Thessaloniki (Greece) regarding which 11 small and large polluting factories as well as three mines were simulated in through AERMOD Software in 2006. The other successful models of this software such as distribution modelling (PM_{10}) in Pune of India (Kesarkar, Dalvi, Kaginalkar, and Ojha, 2007), emission modelling of pollutants in Hangzhou of China (Zhang, Wei, Tian, and Yang, 2008) and Mediana Valley located in Italy (Morra, Lisi, Spadoni, and Maschio, 2009), modelling industrial pollutants by Cimorelli et.al (2005), Perry et.al (2005) and Oleson et.al (Olesen, Berkowicz, Ketzel, and Lofstrom, 2009) are noteworthy. In regard to simulation of the function of flares in conversion of H_2S and VOC_s done by Abdollahi, Haqiqi, Fatehi, and Parian Nikoi (2009), the results showed the complete conversion of VOC_s and change of CO into CO_2 while H_2S didn't completely change into SO_x. KhoseGir, Sedaqat and Bodaqapur (2013) modeled the distribution and emission of pollutants of a low-plate flare such as CO, NO_x and SO_2. Ziarati Sadeqju, and Nojomi (2012) calculated the concentration of VOC_s through passive sampling in fifth refinery of South Pars region which revealed that the concentraton of benzene was 5.8 ug/m^3 higher than the standard limit. Goharrukhi and Musavi (2014) simulated the flaring process of phase 4 and 5 of South Pars so as to determine the level of energy waste and environmental pollution. They found out that high-pressure flares and LPG were the most important sources of energy waste while low- and medium-pressure flares were the most significant sources of environmental pollution. The uncertainties of present study might be due to superficial sources of pollution such as chimneys, fuel ditches or evaporation pond, the petrochemical units of the region which produce significant pollutions and occurrence of an unpredictable shut-down mode in the system.

Conclusion

The results of present study show that the distribution of certain pollutants including benzene, hydrogen sulfide, and sulfide dioxide in normal (operating) condition is higher than standard limit and the highest emission concentrations of these materials were related to low- and medium-pressure flares. In shut-down mode, all 7 pollutant examined in South Pars region were higher than standard limit. Therefore, the following suggestions could be contributive in this regard: Obligation of industries to develop green spaces and create a uniform environmental system. Environmental controls such as consistent monitoring of air pollution. Doing environmental evaluation for new industries. Control and optimization of flaring systems and their recovery. Reduction of subsidence of volatile pollutants of the devices. Control of maintenance and transportation of materials and wastewater treatment.

Organization of units of sulfur manufacturing and storage in refinery Promotion of knowledge and technology,increase of efficiency of methods in different industries In this regard, the managerial suggestion include: Reducing the presence hours of personnel in high-risk areas.

Transportation of meeting and gathering places of personnel away from polluted areas. Preparation and supply of personal protection devices for absorption of toxic gases and steams. Therefore, regarding the results of present study and necessity of paying attention to environmental consequences and different effects of industries on health condition of animals, it is recommended that the authorities pay more attention to development of air quality management system in the region.

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