POLLUTANTS EMISSION AND DISPERSION FROM FLARES: A GAUSSIAN CASE – STUDY IN IRAQ

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Abstract

The aim of this research is to study the emission and dispersion of pollutants (HC, CO, NO_x, SPM) from the elevated flares in three situations of South Gas Company for Liquefied Petroleum Gas (LPG) production in Al-Basrah Governorate in Iraq. These three situations are Khor Al-Zubair plant, North Al-Rumaila Plant, and Storage Complex. The number of flares in the situations are 5, 3, and 2 flares respectively.

A mathematical model formulated in a computer program written in visual basic language was utilized in finding the ground level concentrations of pollutants HC, CO, NO_x, and SPM emitted from the elevated flares of the three situations; the concentrations were found at selected sites inside and outside of each situation at different distances.

The programmed model takes into consideration all the meteorological conditions (wind speed, wind direction, ambient temperature, and atmospheric stability) which may take place at the study region.

The emission rates of the pollutants which are emitted from the elevated flares are found depending on the laboratory analysis of gas compositions send to the flares , also by utilizing the modern EPA methods for determination the emission rates.

The results of research illustrate the meteorological cases which are more effect in causing the maximum ground level concentrations of pollutants especially the unstable atmospheric conditions and wind speed.

On the other hand, the programmed model is utilized to find the concentrations of hydrocarbons (HC), propane (C_3H_8) , and butane (C_4H_{10}) which are released from flare column to the atmosphere in case of combustion failure of these gases, at areas adjacent to the situations of flares.

Keywords: Elevated flares, combustion, emissions, dispersion, modeling.

Introduction

Air pollution is a dangerous problem facing human in the daily life, and it is caused great harmful which may cause death especially when it is higher than the critical environmental limits of pollutants [(1)].

The industrial activities contribute largely in air pollution; one of these activities is the petroleum industries including the manufacture of liquefied petroleum gas (LPG).[(2, 3, 4)]

The flares system is safety equipment necessary in petroleum plants. Flares are designed to avoid the uncontrolled emissions. It is used for two cases related strongly with safety, one of them is during the unstable operations such as start-up, shut-down of unit operations; the second case is to management the waste gases discharged from routine production operations. Elevated flare is a one type of flares, it is a vertical pipe opened from its top supplied with igniters. The waste or discharged gases are burned with atmospheric air at the tip of flare stack. The sending of these gases and burning them in flares lead to emitting the pollutants and discharging them to atmosphere, the concentrations level of these pollutants depending on the type of burned gases and flare efficiency[(2, 3, 5)]. There are some factors effects in the efficiency of combustion process in flares such as heating value, velocity of gases entering to flare, meteorological conditions and its effects on the flame size [(6, 7, 8)]. In order to increase the combustion efficiency, the steam or air is used as assistant in flares, which create a turbulent mixing, and better contact between carbon and oxygen.[2, 3,9]

EPA studies conducted in the early 1980's do not take into account environmental factors that may affect flares efficiency. There is no suggestion (in the EPA studies) that combustion efficiencies may depend on parameters that influence flame size, and consequently heat released, such as stack velocities and wind speeds.[10] A recent study conducted by research scientists in Canada and published in the Journal of the Air and Waste Management Association (JAWMA), noted that these factors can greatly influence the ability of flares to destroy pollutants sent through vapor streams. Specifically, researchers found that wind speed played a significant role in determining combustion efficiency. According to study, wind speed greatly impacts the size of the flame "decreased in flame size occur in a significant manner with increasing stoichiometric mixing ration, wind speed, and stack exit velocity".[11,12]

elevated flares. Table (1) shows the design data of flares in the three situations of South Gas Company. The main air pollutants which are produced from burning of hydrocarbonic gases in flares are: Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Suspended Particulate Matter (SPM).[13,14] The emission rates of these pollutants depend on two main factors: the waste gas composition sent to the flare and the combustion efficiency.[5]

The programmed mathematical model which applied in the present paper was developed by Al-Rubai [15] for prediction of SO_2 , NO_2, CO, and suspended particulate matter (SPM) ground level concentration and its dispersion from the stacks of Al-Daura oil refinery in Iraq. This model gives good agreement with the measured concentrations. The model overpredict SO_2 concentrations within a factor of 1.4, while the model underpredict NO_2 within a factor of 1.5 , CO within a factor of 2.2 and SPM within a factor of 1.3.

Table (1)
The design data of elevated flares in the three situations (Khor Al-Zubair Plant, North Al-Rumaila Plant , and Storage Complex) of the South Gas Company.

Situation	Type of flare	Number of Flares	Height of Flare Stack (m)	Diameter of Flare Stack (m)	Flow Rate of Gases which burned in flare (ton/hr)	Molecular Weight	Temperature of Gases entering to flare stack (^oC)
Khor Al-Zubair Plant	Dry Flares	2	70	0.92	360	25	-80 to +80
	Wet Flares	3	70	1.07	700	60	110
North Al-Rumaila Plant	Dry Flares	1	70	1.07	456	25	-48
	Wet Flares	2	70	1.07	450	44	65.5
Storage Complex	Low Pressure Flares (LPF)	1	70	0.76	42	43-57	38
	High Pressure Flares (HPF)	1	70	0.66	146	43	43

The flares in South Gas Company at the three situations are classified as unassisted

In the present paper, some modification making for the model developed by

Al-Rubai[15] and the modified model utilized to find the concentrations of HC, CO, NO_x, and SPM in ambient air, and the pollutants dispersion from the elevated flares of three situations of South Gas Company in the south of Iraq. The paper will take into account the factors that more effect in the predicted concentration, especially the atmospheric stability and wind speed.

Determination of Emission Rate

The study of flare emissions requires determination of emission rate of each pollutant resulting from the combustion process before dispersing it in atmosphere. The two main problems being in determination of flare emissions are: [6, 13, 14]

1- Difficulty of determination exactly the composition of gases, which send to flares because the flares are not routine process. Also the type and amount of gases are changed from time to other.

2- Difficulty of measuring the composition of gases or pollutants which are resulted at the end of flare or flame, this is mean that flares are not submitted to traditional test methods of emissions.

There are few attempts achieved to determination the flare emission. The recent tests of EPA determined the emission factors of pollutants emitted from flares as shown in Table (2).[13, 14]

Table (2)
The Emission factors of pollutants emitted from flares.

Pollutant	Emission Factor ($kg/10^6$ kJ)
Hydrocarbons (HC)*	0.060
Carbon Monoxide (CO)	0.159
Nitrogen Oxides (NO_x)	0.029
Suspended Particulate Matter (SPM)**	0 – 274

**** Total hydrocarbons measured as equivalent to methane.***
***** Suspended particulate matter measured in units of mg/m^3.***

Tables (3), (4), and (5) show the results of laboratory analysis of gases sent to the flares. The analysis achieved by using Gas chromatography device. This analysis achieved for all types of gases sent to the flares of the three situations (Khor Al-Zubair plant, North Al-Rumaila plant, Storage Complex) The volume percentage of each type of gases is the average of four samples analysis. The results of analysis adapted in calculations of density, volumetric flow rate, and heating value of gases. The emission rate is calculated for each pollutant (HC, CO, NOx, SPM) in units of kilogram per hour (kg / hr) by using the following equation:[6, 10]

$$E_x = EF_x * Q \quad ....(1)$$

where:
Ex: emission rate of pollutant x, (kg/hr).
EFx: emission factor of pollutant x, ($kg/10^6$ kJ)
Q: average heating value of fuel (gases), (kJ/hr),
calculated from the following equation:

$$Q = V * H \quad .... (2)$$

, where :
V : volumetric flow rate of gases in flare stack (m^3/hr).
H : heating value of gases, (kJ/m^3 of fuel).

Table (6) shows the emission rates of pollutants HC, CO, NOx, and SPM.

Table (3)
The average volume percentage of gases sent to the flares of Khor Al-Zubair Plant.

Type of hydrocarbonic gases					
(Dry Gas)		**(Broad-cut)**		**(Feed Gas)**	
Components	average **(% Volume)**	**components**	average **(% Volume)**	**Components**	average **(% Volume)**
C_1	80.65	C_2	0.40	C_1	70.00
CO_2	1.51	C_3	39.42	CO_2	1.45
C_2	16.82	n-C_4	6.07	C_2	14.59
C_3	1.02	Iso-C_4	20.87	C_3	8.22
		n-C_5	8.98	n-C_4	1.06
		Iso-C_5	12.54	Iso-C_4	2.56
		C_6	11.72	n-C_5	0.43
				Iso-C_5	0.65
				C_6	1.00

Table (4)
The average volume percentage of gases sent to the flares of North Al-Rumaila Plant.

Type of hydrocarbonic gases			
(Dry Gas)		**(Feed Gas)**	
Components	**average (% Volume)**	**Components**	**average(% Volume)**
C_1	78.59	C_1	69.68
CO_2	2.24	CO_2	2.02
C_2	17.16	C_2	16.16
C_3	1.75	C_3	7.98
n-C_4	0.15	n-C_4	2.04
Iso-C_4	0.08	Iso-C_4	0.91
		n-C_5	0.40
		Iso-C_5	0.40
		C_6^+	0.30

Table (5)
The average volume percentage of gases sent to the flares in Storage Complex.

Type of hydrocarbonic gases			
Propane		Butane	
Components	average (% Volume)	Components	average(% Volume)
C_2	1.25	C_3	1
C_3	96.25	n-C_4	52.4
n-C_4	1.71	Iso-C_4	44.6
Iso-C_4	0.79	n-C_5	1
		Iso-C_5	1

Table (6)
The emission rates of pollutants emitted from the flares of Khor Al-Zubair Plant , North Al-Rumaila Plant , and Storage Complex, of the South Gas Company.

Situation	Type of Flares	Number of Flares	Type of burned Gases	Mass Flow Rate of Gases which Burned in one Flare (ton/hr)	Rate of Heating Value of Gases Entering to Flares * 10^{10} (kJ/hr)	Emission Rate of one Flare* 10^8 µg /sec			
						HC	CO	NO_X	SPM
Khor Al-Zubair Plant	Dry Flare	2	Dry Gas	360	1.47	2.46	6.49	1.19	0.26
	Wet Flare	3	Broad cut	700	4.59	7.67	20.30	3.73	0.29
			Feed Gas		4.78	7.10	21.14	3.88	0.64
North Al-Rumaila Plant	Dry Flare	1	Dry Gas	456	1.37	2.30	6.07	1.12	0.18
	Wet Flare	2	Feed Gas	450	2.71	4.54	11.99	2.20	0.42
Storage Complex	High Pressure Flare (HPF)	1	Propane	42	0.23	0.94	1.01	0.19	0.02
			Butane		0.22	0.37	0.98	0.18	0.02
	Low Pressure Flare (LPF)	1	Propane	146	0.80	1.33	3.52	0.07	
			Butane		0.77	1.29	3.40	0.63	0.05

Modeling of dispersion air pollutants emitted from flares:

a mathematical model formulating in a computer program written in visual basic language using Gaussian equation is utilized to investigate the dispersion process and distribution of pollutants (HC, CO, NO_x, SPM) emitted from the elevated flares of the three situations. The programmed model finds the concentration of pollutants at selected sites inside and outside of the three situations.

Gaussian equation (equation 3) is used in the programmed mathematical model to find the ground level concentrations of gaseous pollutants HC, CO, NOx. [11, 12, 16]

$$C(x,y,0,H)=\frac{Q}{\pi u\sigma_y\sigma_z}\exp\left\{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2+\left(\frac{H}{\sigma_z}\right)^2\right]\right\} \qquad \text{..............................(3)}$$

where:

C: concentration of pollutant emitted from flare, (µg /m^3).
Q: emission rate of pollutant emitted from flare, (µg /sec).
u: average wind speed (m/sec).
σy, σz : horizontal and vertical dispersion coefficient (m).
x: down wind distance (m).
y: cross wind distance (m).
H: effective height (m), where H = hs + Δh
hs: height of flare stack (m).
Δh: plume rise (The height from the end of flare stack to the midline of the emitted smoke), (m).

The units of calculated concentration (C) from equation 3 convert from (µg /m^3) to ppm by dividing the concentration value by conversion factor of the pollutants.

The suspended particulate matter (SPM) emitted from flare differs than the gaseous pollutant, the SPM follows down to ground under the effect of gravity; it is reach ground surface and can not return to the atmosphere by wind. The following equation is used in a programmed mathematical model to find the concentration of SPM in ambient air: [11, 12, 16]

$$C = \frac{Q_p}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left\{\left(\frac{y}{\sigma_y}\right)^2 + \left[\frac{Z-(H-V_t x/u)}{\sigma_Z}\right]^2\right\}\right] \qquad \text{.................................(4)}$$

where :

Q_p: emission rate of SPM from flare (µg /sec).
Vt: settling velocity of SPM (m/sec).
Z: height above ground surface (m).

Application of the Model:

The value of each pollutant concentration at each site is calculated as hourly average (hourly average ground level concentration) and the total concentration is the sum of the concentrations from all sources (flares). These concentrations found at selected sites at areas around the flares. Selection of the sites (sites which the concentrations are calculated) was according to the prevailing wind direction at the study area (north-west), and some sites are selected inside the plant to find the pollutants concentrations which are arrived to the workers in plant. The selected sites are at different distances from flares in order to determine the distribution of pollutants in areas around the flares or plant. The concentration is calculated supposing that all flares in the plant are operated with larger amount of burning gases.

Program Input Data:

Emission rate of pollutants:

The emission rate of pollutant (*Q*) from each point source (flare) required to the model. Table (6) shows the emission rates of the pollutants HC, CO, NOx, and SPM.

Meteorological Data:

The programmed model finds the pollutant concentrations at all weather conditions that may take place at the study region. These conditions imply submitting carefully selected meteorological data and adapted the actual meteorological conditions at the study region recorded by Al-Basrah Meteorological Station, to be defined in terms of PGT (Passquill-Gifford-Turner) and ASME (American Society for Mechanical Engineers) stability categories. [15, 17, 18]

Wind speed and direction:

At each site, the pollutant concentration is calculated at upper and lower limit of wind speed defining each stability category. Such a technique provides a way to obtain a range defined by a maximum and minimum limit concentration values that may take place for each expected weather condition.

As mentioned previously the selection of sites depends on the prevailing wind direction which is north-west, Therefore, the selected sites will be at downwind (south-east) of flares.

On the other hand, some sites are selected at the direction where the pollutants arrive to the workers in plant, also at the direction of residential area of workers (site number 11). Each site is selected in a way that the pollutant can be reach by wind to this site from concentration of all flares by wind. As shown in Figs. (1), (2), and (3).

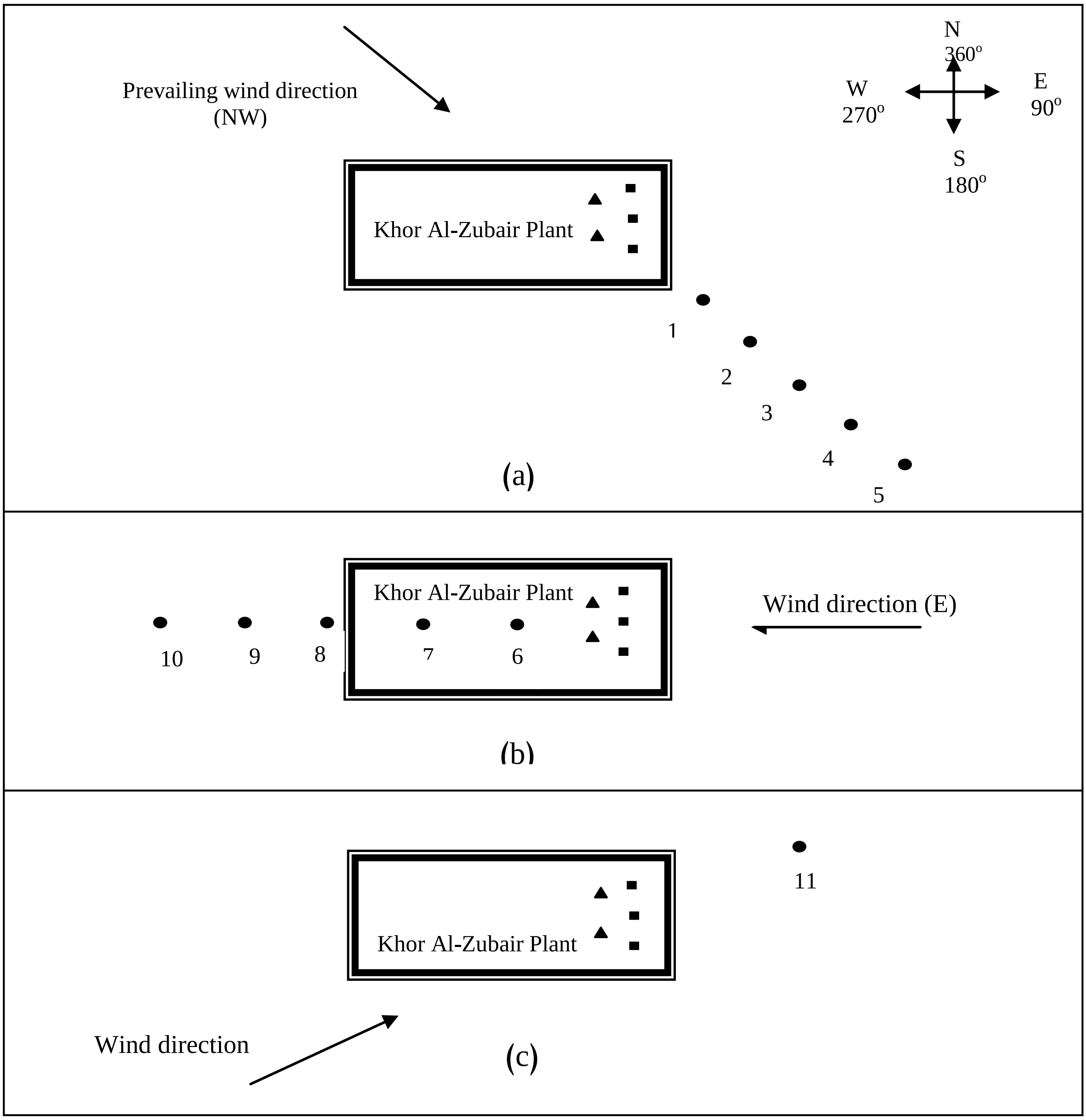


Fig. (1) : Sketch illustrates the selected sites which the ground level concentration are calculated, when the pollutants are emitted from flares of Khor Al-Zubair Plant. Wind directions are: (a) North-West (prevailing wind direction) , (b) East, (c) South –West (for calculating the pollutants concentrations at site residential area of the workers).

- ■ **wet flare**
- ▲ **dry flare**
- ● **site which the ground level concentration is calculated.**

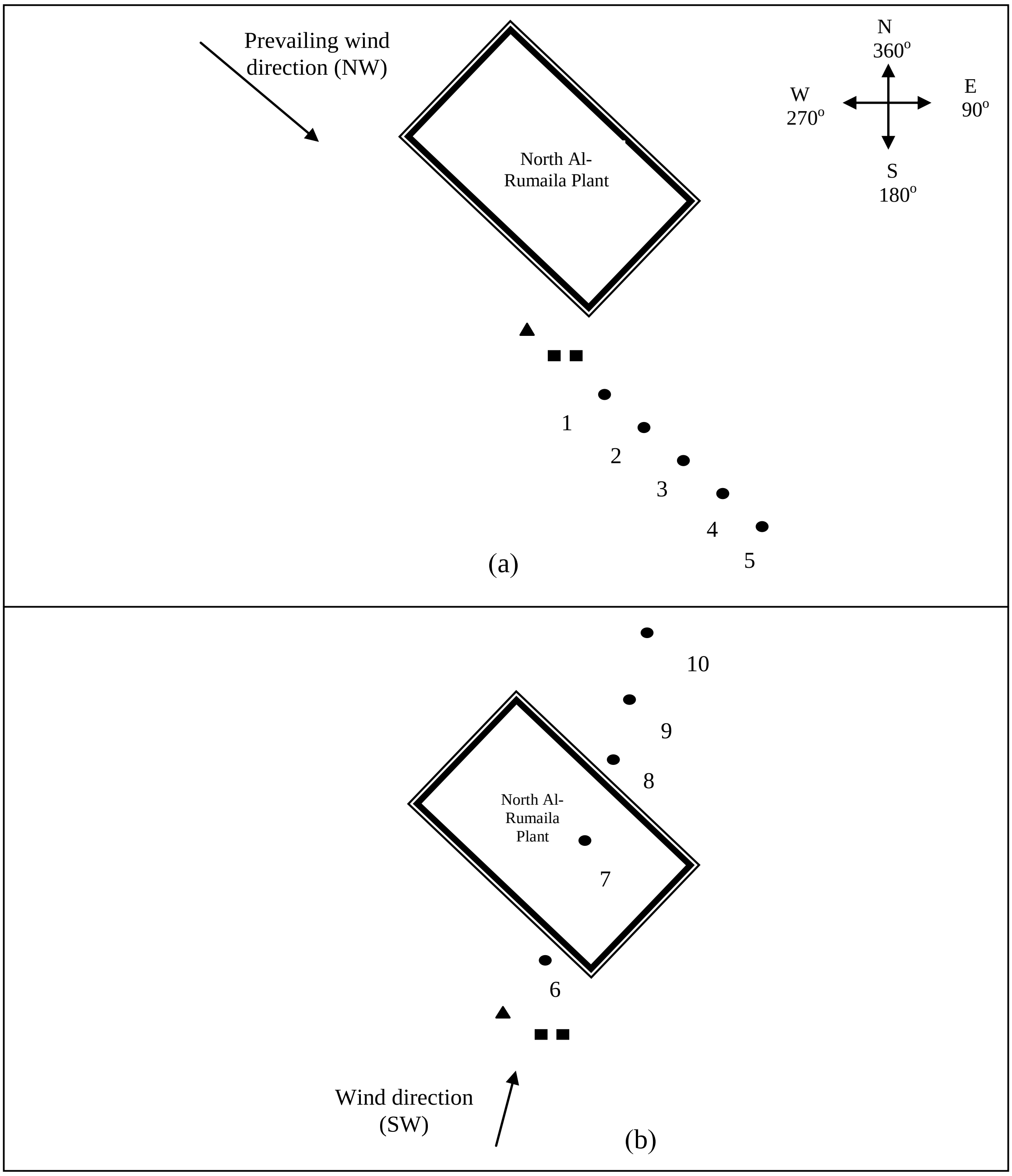


Fig.(2) : Sketch illustrates the selected sites which the ground level concentration are calculated, when the pollutants are emitted from flares of North Al-Rumaila Plant. Wind directions are: (a) North-West (prevailing wind direction) , (b) South –West.

- ■ **wet flare**
- ▲ **dry flare**
- ● **site which the ground level concentration is calculated.**

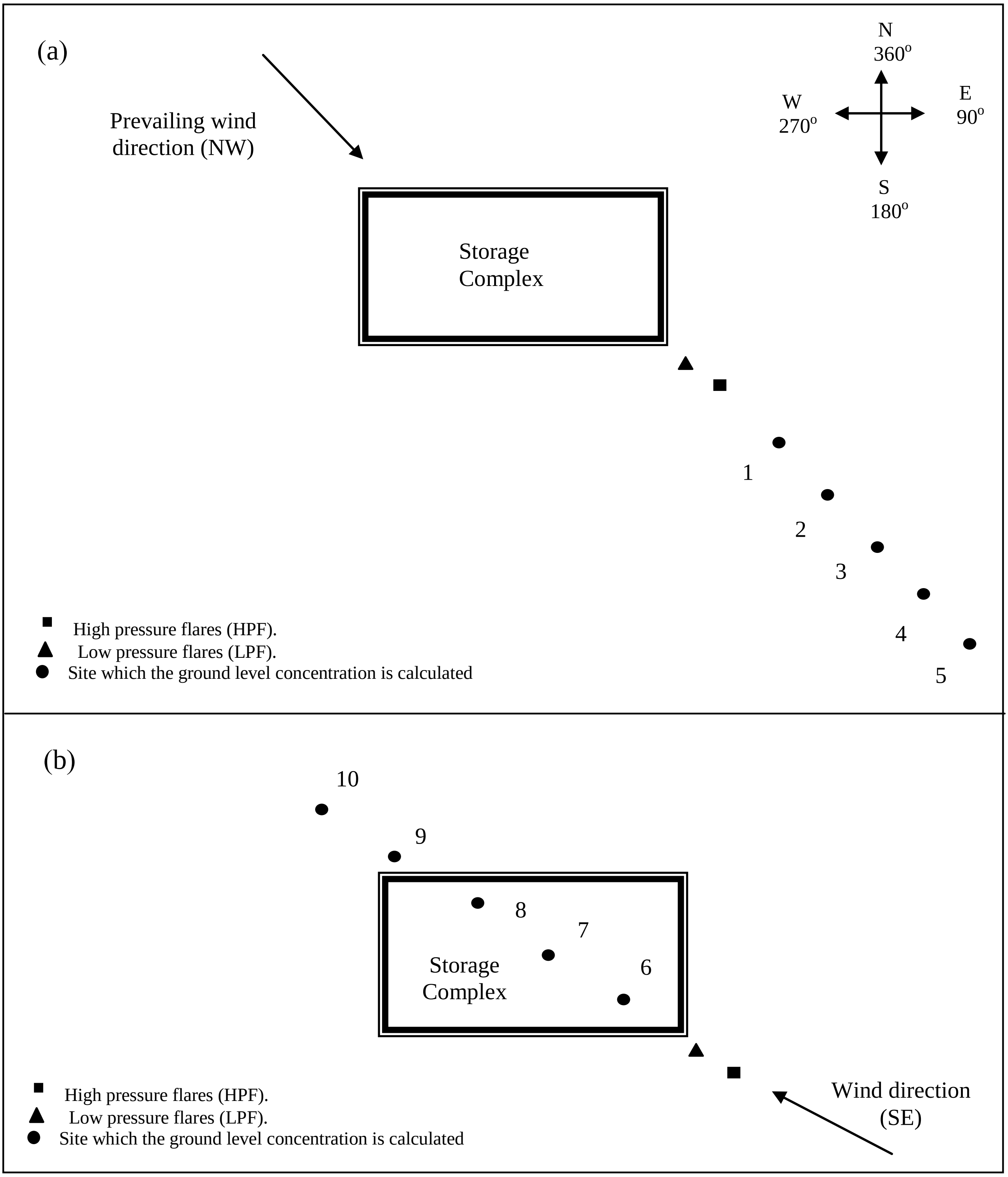


Fig. (3): Sketch illustrates the selected sites which the ground level concentration are calculated, when the pollutants are emitted from flares of Storage Complex, Wind directions are: (a) North-West (prevailing wind direction) , (b) South –East.

Atmospherics Stability:

In order to take into account all expected meteorological conditions Table (7), the concentrations are calculated at 24 meteorological cases defined in 12 stability classes, six of them (A, B, C, D, E, F) occur in summer and the other six. Occur in winter.

Also the concentrations are calculated at the upper and lower wind speed at each stability class. The ASME classification for the stability; defined to what is represented in PGT system [15, 19]; is used to find the concentrations at all selected sites.

Table (7)
The meteorological conditions defined in 24 cases.

Meteorological Case No.	PGT stability	ASME stability	Wind speed at 10 m $\frac{\text{upper}}{\text{lower}}$ limit (m/sec)	Season	Ambient temperature (^oC)
1	A	Very unstable	0.10 / 1.99	S	48.9
2					
3	A		0.10 / 1.99	W	4.9
4					
5	B		3.00 / 4.99	S	48.9
6					
7	B		3.00 / 4.99	W	4.9
8					
9	C	Unstable	5.00 / 6.00	S	48.9
10					
11	C		5.00 / 6.00	W	4.9
12					
13	D	Neutral	0.10 / 6.00	S	48.9
14					
15	D		0.10 / 6.00	W	4.9
16					
17	E	Stable	3.00 / 4.99	S	30
18					
19	E		3.00 / 4.99	W	4.9
20					
21	F		0.10 / 2.99	S	30
22					
23	F		0.10 / 2.99	W	4.9
24					

Dispersion coefficients (σy, σz):

The ASME system is used for calculating the dispersion coefficients (σy, σz) for plume emitted from each flare. A grid system for each plant (situation) map is designed to determine the distances in geographic coordinate and then to be used in finding the down wind distance (x) and cross wind distance (y) between each pollution source (flare) and the site which the ground level concentrations are calculated. The equation of ASME system for calculating the dispersion coefficients (σy, σz) are: [15, 19]

$$\sigma_y = A\, x^p \quad (5)$$

$$\sigma_z = B\, x^p \quad (6)$$

where *A*, *B*, and *p* are constants.

Effective Height (H):

As mentioned previously the effective height (*H*) is the sum of flare stack height and plume rise (Δh).

Briggs (1975) formula is used for calculating plume rise (Δh). [16, 20] The reasons which are led to the selection of Briggs (1975) formula for calculating the plume rise in the mathematical model are:

- Suitable and recommended for calculating plume rise of multiple adjacent stacks or flares (multiple point sources).
- Takes into consideration the flare temperature and ambient temperature.
- Takes into consideration the down wind distance (*x*).
- The Briggs formula can be applied for all meteorological conditions.

Results and Discussion

The pollutants concentrations are found at different distances from the flares of Khor Al-Zubair plant, North Al-Rumaila plant, and Storage Complex separately, at 24 cases of meteorological conditions.

The results illustrate that the meteoro-logical cases which the maximum concentrations of pollutants occurred at most sites are cases number 2, 6, 9, and 10 (the cases of meteorological conditions are defined in Table (7)). Also some maximum concentrations at some sites are happened at case number 14. The most maximum concentrations are occurred at unstable atmospheric conditions because of the resulted mathematical effects of interaction factors which are wind speed, effective height, and horizontal and vertical dispersion coefficients. Figs. from (4) to (7) illustrate the change and distribution of pollutants (HC, CO, NOx, SPM) concentrations with distance at the meteorological cases which the maximum pollutants concentrations are occurred.

The greatest dispersion of plume which resulted from the flare occurs when the atmosphere is most unstable, while the lowest dispersion of plume occurs when the atmosphere is most stable. The greatest dispersion causes more dilution of pollutant and this will happened at certain down wind distances which may bring the pollutant concentrations to be detected at ground surface. While the lowest dispersion which occurs at stable conditions causes low dilution of pollutant and the ground level concentrations may be detected at farther distances.

Recent studies indicates that flares achieve high combustion efficiency only under optimal conditions such as low wind speed, and only if they are properly maintained and large enough to handle high waste volume. Companies assume the flare combustion process will destroy 98-99 % of the hazardous air pollutants entrapped in the waste gas stream. But the 98-99 % destruction efficiency rate assumes that certain meteorological conditions are also being met. Most important of these for flame destruction efficiency is the wind speed surrounding the flare, which influences the flares flame size. When the flame size is less than optimal, flare do not burn as efficiently and therefore destroy less of the pollutant than would be destroyed using standard a 98-99 % destruction efficiency rate. Also the high wind speed produces smaller flame size therefore less efficient combustion by flare occurs.

The ground level concentrations are calculated at all atmospheric stability classes which are considered to be happened at both dominated seasons through the year summer and winter. Relatively, no distinguished difference between the concentration.

In case of combustion failure, the gases which are sent to flare stack will be emitted from the top of stack to atmosphere without combustion, these Gases (or pollutants) are:

-The mixture of hydrocarbons (HC) is emitted from flare stacks of Khor Al-Zubair plant and North Al-Rumaila plant.

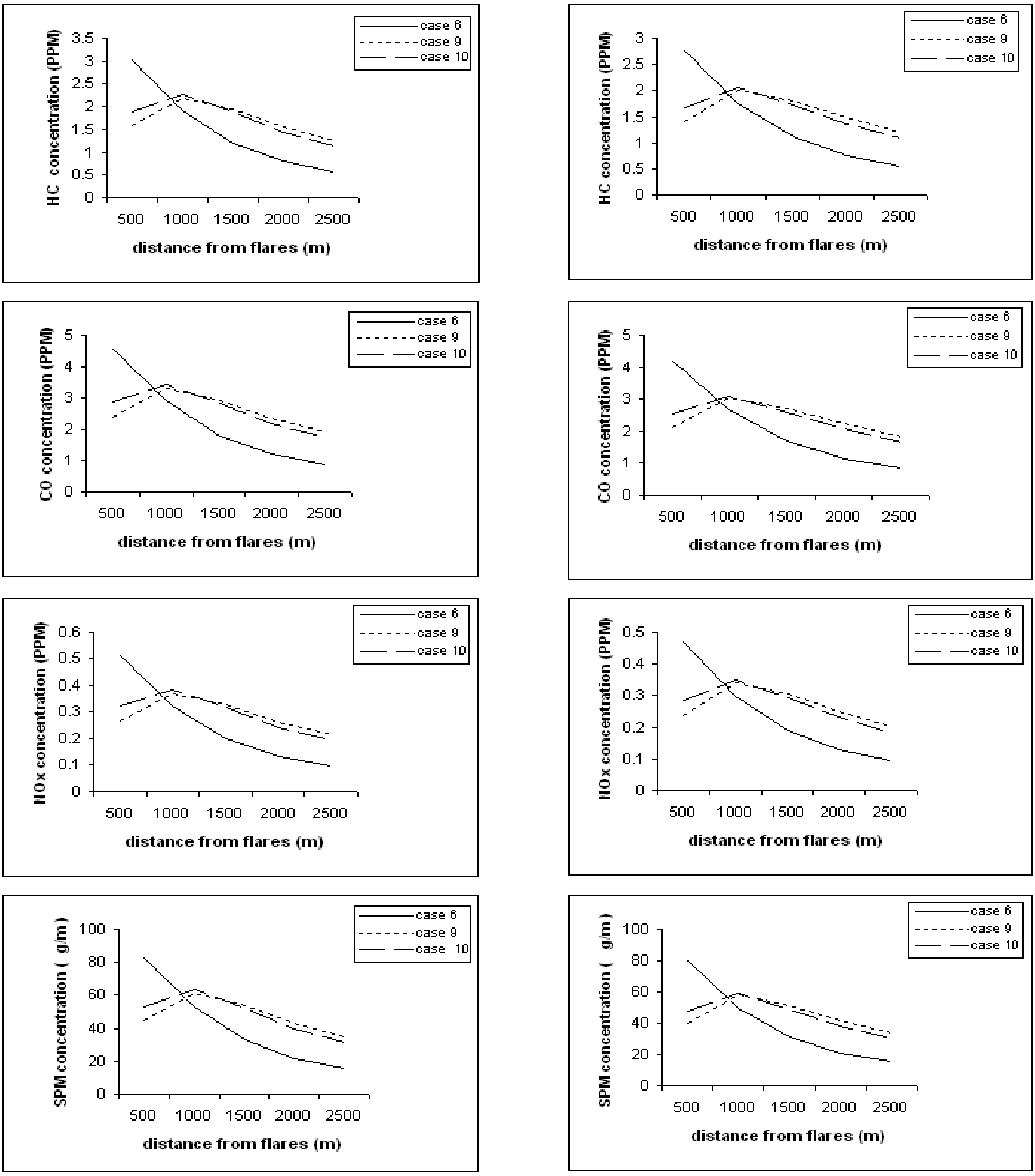
-Propane (C_3H_8) and butane (C_4H_{10}) are emitted from flare stacks of the Storage Complex.

To determine and study the ground level concentrations of the gaseous pollutants in ambient air, the programmed mathematical model is used to find these concentrations in areas around the flare stacks at different distances at 24 cases of meteorological conditions. The results show that the maximum concentrations of HC, C_3H_8, and C_4H_{10} in most sites occur at unstable atmospheric conditions (case number 1, 2, 9). Also some of the maximum concentrations at some sites occur in neutral atmospheric conditions (case number 14). The Figs. from (8) to (11) illustrate the change and distribution of pollutants concentrations with distance at the meteorological cases which the maximum concentrations are occurred.

Conclusion

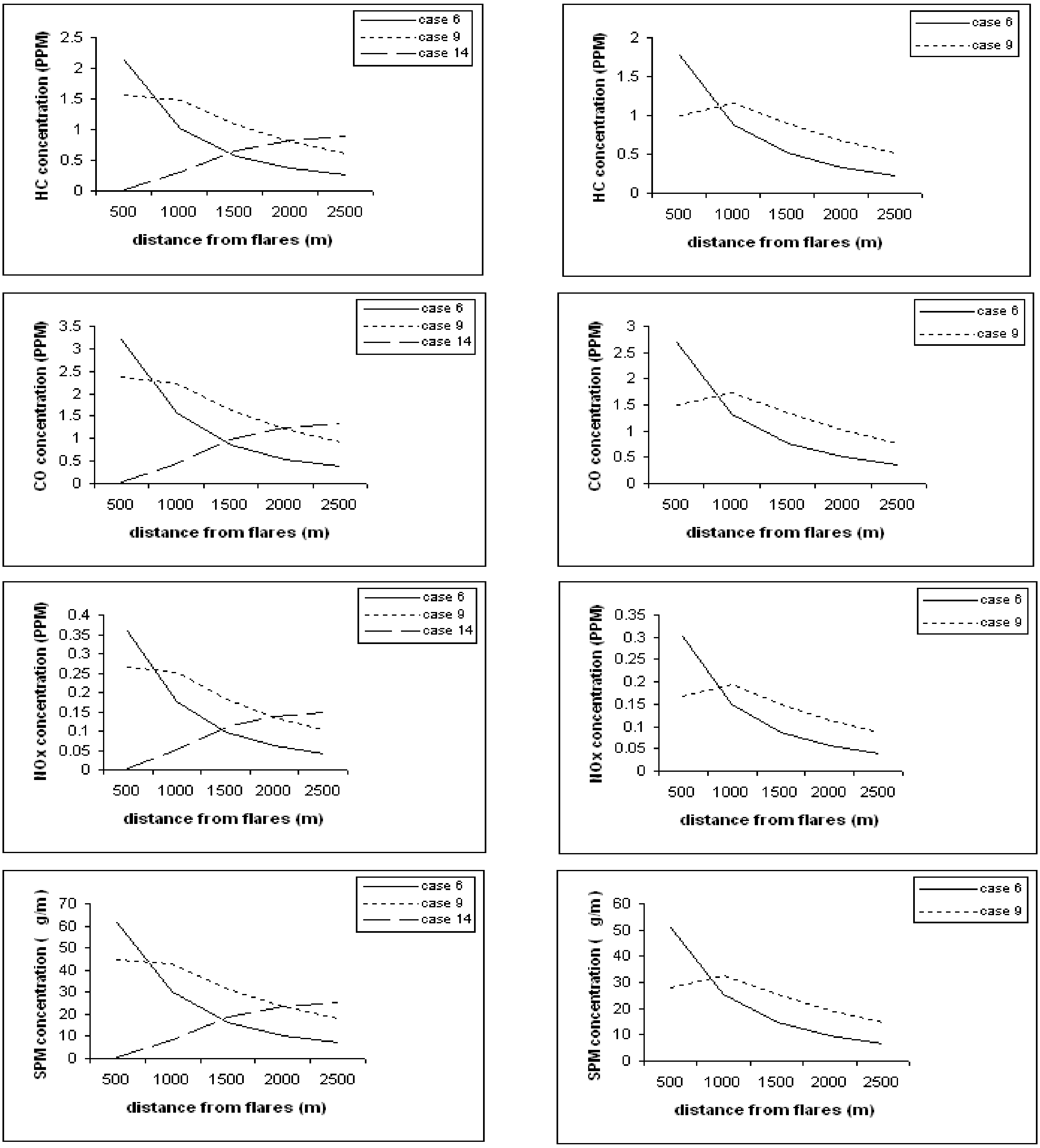
The emission of pollutants; HC, CO, NO_x , and SPM ; and dispersion from flares are studied in this paper. A Gaussian plume model was utilized to find the ground level concentrations of the above pollutants for the three situations (factories) of South Gas Company in Iraq. The emission of pollutants; HC, CO, NO_x , and SPM ; and dispersion from flares are studied in this paper. A Gaussian plume model was utilized to find the ground level concentrations of the above pollutants for the three situations (factories) of South Gas Company in Iraq.

The meteorological data which are entered to the model were carefully selected to be comprehensive and represent all the cases of expected meteorological conditions that may take place at the study region. The data were adopted on the recorded meteorological information by Al-Basrah Meteorological Station near the study region. The stability categories related to wind speed of PGT and ASME systems were utilized to define the 24 cases which they selected as a meteorological condition required to the programmed model. The results indicate that the maximum concentrations occur at unstable atmospheric conditions.



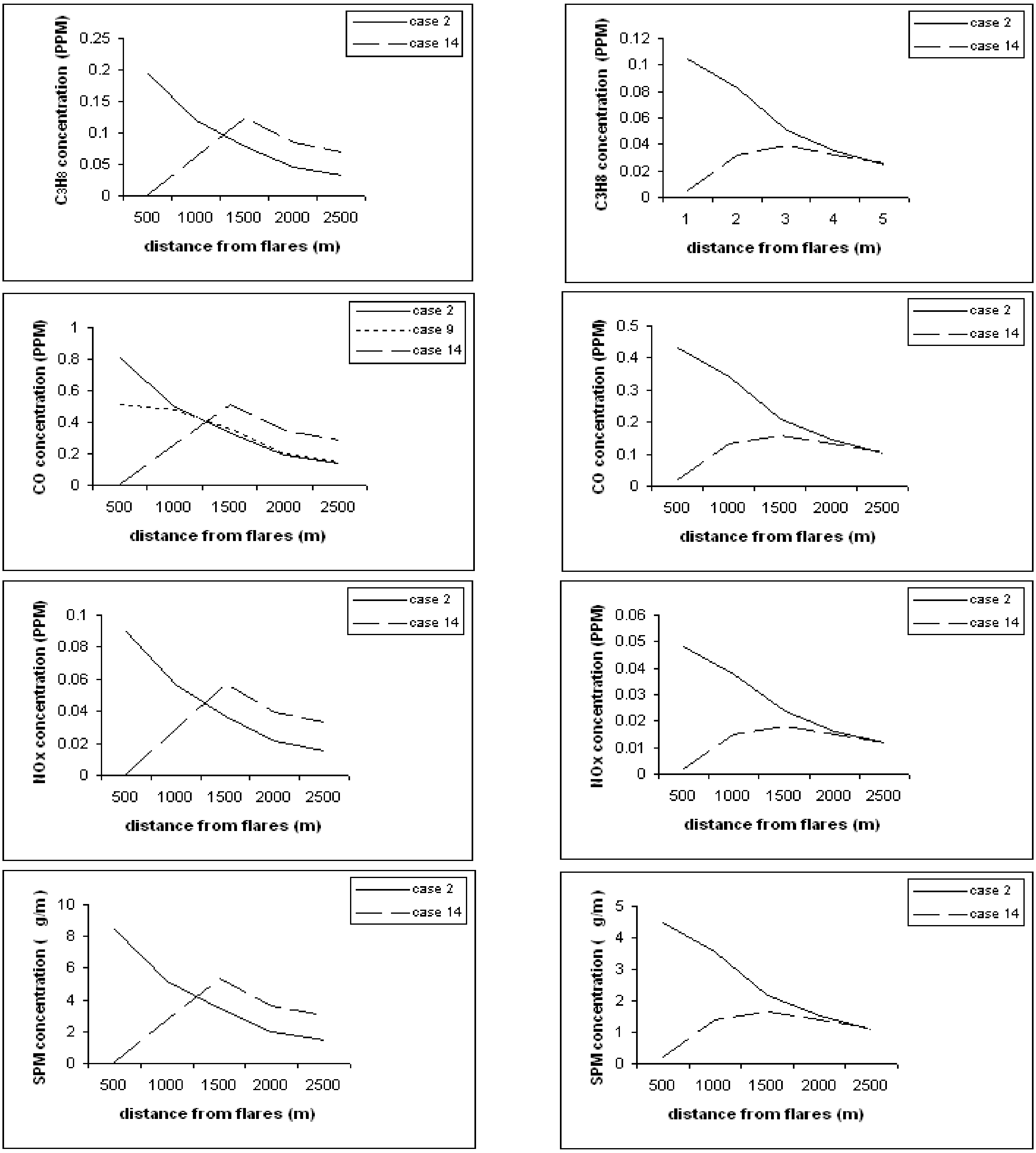
(a) *(b)*

Fig.(4): The change and distribution of concentrations of HC , CO , NOx , SPM emitted from combustion of hydrocarbon mixture in flares , with distance, (a) south-east of Khor Al- Zubair Plant (b) north-west of flares inside and outside of Khor Al- Zubair Plant, at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 6 , 9 , 10).



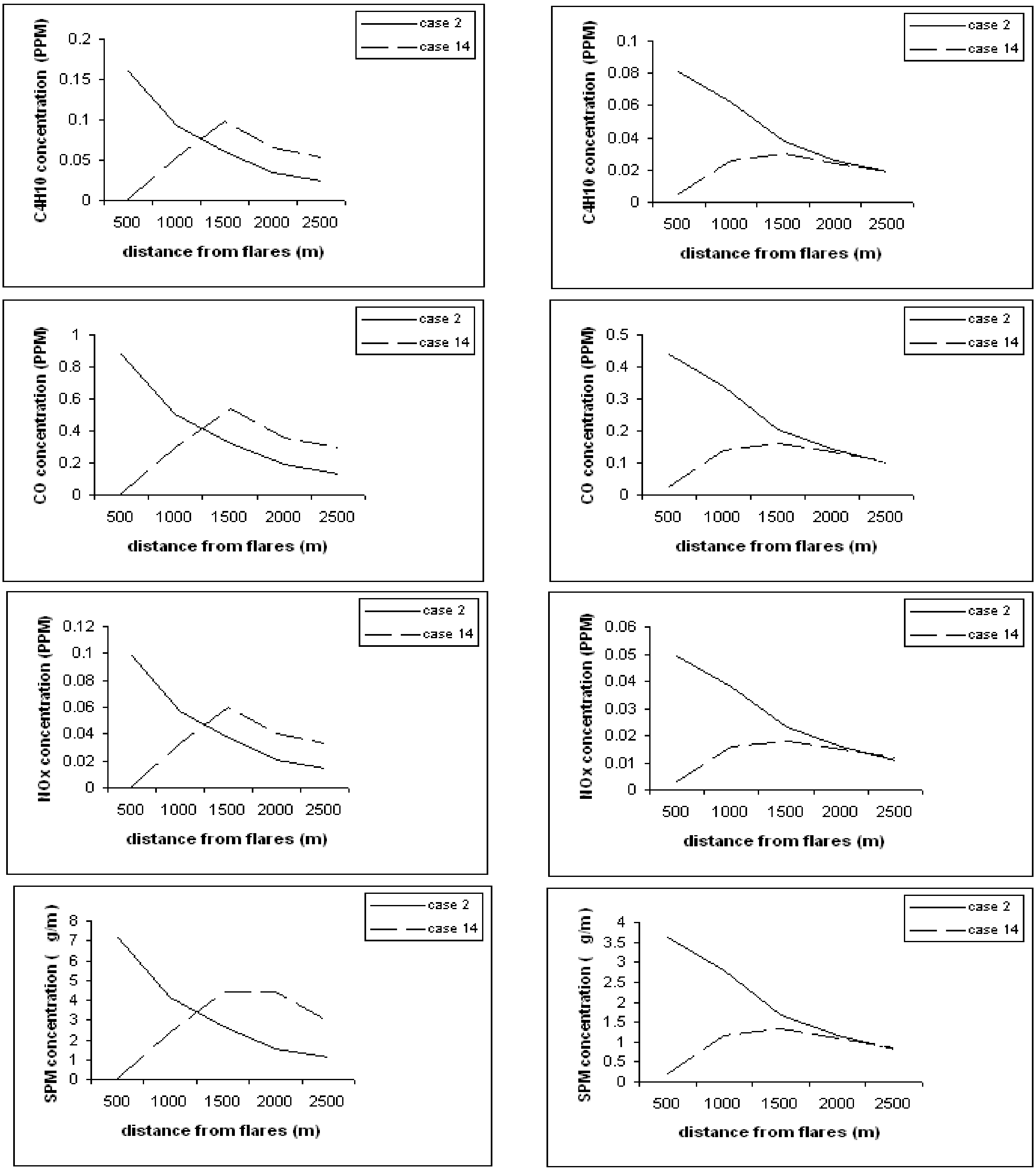
(a) *(b)*

Fig. (5): The change and distribution of concentrations of HC , CO , NOx , SPM emitted from combustion of hydrocarbon mixture in flares , with distance, (a) south-east of flares of Al-Rumaila Plant (b) north-east inside and outside of Al-Rumaila Plant, at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 6 , 9 , 14).



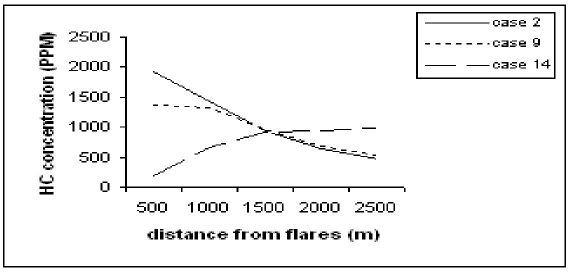
(a) (b)

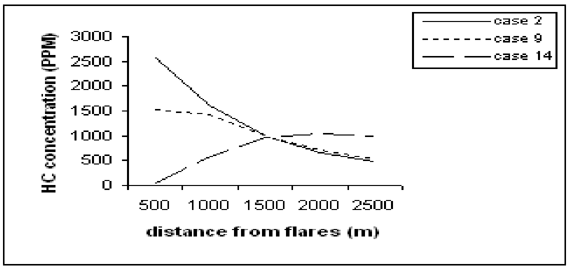
Fig.(6): The change and distribution of concentrations of C_3H_8 , CO , NOx , SPM emitted from combustion of propane in flares , with distance, (a) south-east of the Storage Complex (south-east of flares), (b) north-west of flares inside and outside of the Storage Complex, at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 2 , 9 , 14).



(a) *(b)*

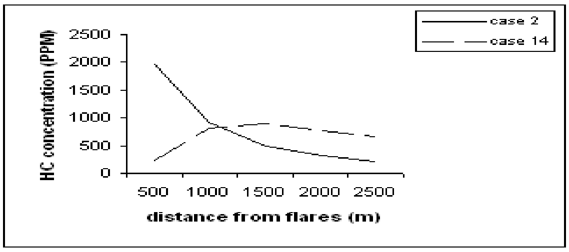
Fig.(7): The change and distribution of concentrations of C_4H_{10} , CO , NOx , SPM emitted from combustion of butane in flares , with distance, (a) south-east of the Storage Complex (south-east of flares), (b) north-west of flares inside and outside the Storage Complex, at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 2, 14).

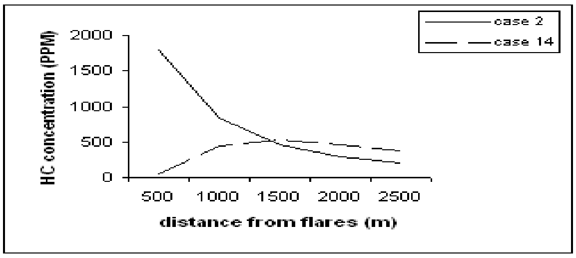




(a) *(b)*

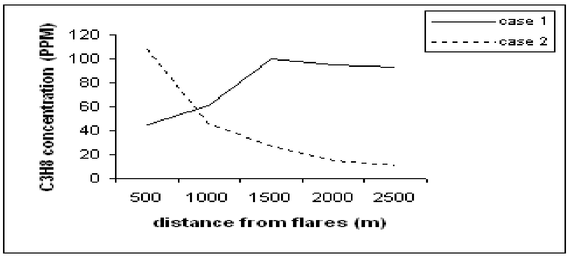
Fig. (8): The change and distribution of hydrocarbons concentration emitted from flare stacks in case of combustion failure, with distance at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 2, 9, 14). (a) south-east of Khor Al-Zubair Plant (south-east of flares), (b) east of flares inside and outside of Khor Al-Zubair Plant.

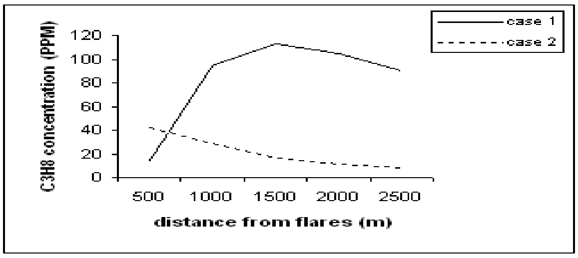




(a) *(b)*

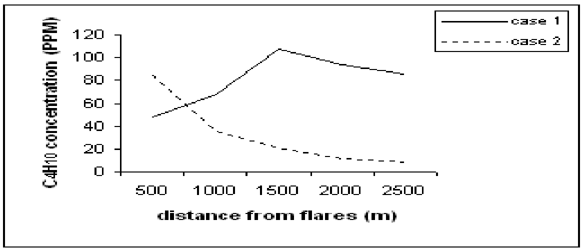
Fig.(9): The change and distribution of hydrocarbons concentration emitted from flare stacks in case of combustion failure, with distance at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 2, 14). (a) south-east of North Al-Rumaila Plant, (b) North-east of flares inside and outside of North Al-Rumaila Plant.



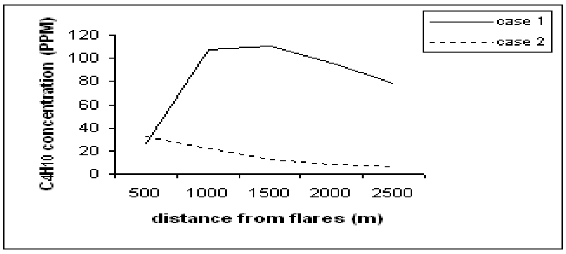


(a) *(b)*

Fig.(10): The change and distribution of propane (C_3H_8) concentration emitted from flare stacks in case of combustion failure, with distance at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 1, 2). (a) south-east of Storage Complex (south-east of flares), (b) North-west of flares inside and outside of Storage Complex.



(a)



(b)

Fig. (11): The change and distribution of butane (C_4H_{10}) concentration emitted from flare stacks in case of combustion failure, with distance at the meteorological cases which the maximum concentrations at the sites are occurred (cases number 1, 2). (a) south-east of Storage Complex (south-east of flares), (b) North-west of flares inside and outside of Storage Complex.

Table (8)

The maximum concentrations of pollutants in ambient air , which are emitted from combustion of hydrocarbon gas mixture in flares , and the maximum concentrations of pollutants in case of combustion failure at the top of flare stack in khor Al-Zubair Plant.

Site No.	Maximum ground level concentrations				
	Pollutants emitted from the combustion of hydrocarbonic gases (HC) in flares				HC in case of combustion failure (PPM)
	HC (PPM)	CO (PPM)	NO_x (PPM)	SPM ($\mu g/m^3$)	
1	3.026	4.575	0.512	82.96	1916.59
2	2.280	3.447	0.386	63.27	1432.16
3	1.937	2.929	0.328	53.83	966.60
4	1.551	2.345	0.263	42.92	948.20
5	1.264	1.910	0.214	34.96	978.16
6	2.778	4.200	0.470	79.65	2568.54
7	2.059	3.113	0.348	58.89	1609.75
8	1.803	2.725	0.305	51.22	996.35
9	1.482	2.240	0.251	41.76	1040.98
10	1.205	1.821	0.204	33.78	1001.69
11	2.192	3.314	0.371	60.88	1480.18

Table (9)

The maximum concentrations of pollutants in ambient air , which are emitted from combustion of hydrocarbon gas mixture in flares , and the maximum concentrations of pollutants in case of combustion failure at the top flare stack in North Al-Rumaila Plant.

Site No.	Maximum ground level concentrations				
	Pollutants emitted from the combustion of hydrocarbonic gases (HC) in flares				HC in case of combustion failure (PPM)
	HC (PPM)	CO (PPM)	NO_x (PPM)	SPM ($\mu g/m^3$)	
1	2.122	3.208	0.359	61.73	1966.39
2	1.481	2.239	0.251	42.83	929.41
3	1.081	1.635	0.183	31.35	889.44
4	0.818	1.236	0.138	23.38	771.39
5	0.882	1.333	0.149	25.33	658.20
6	1.776	2.685	0.301	50.91	1793.64
7	1.147	1.734	0.194	32.68	836.90
8	0.893	1.350	0.151	25.62	522.65
9	0.676	1.022	0.114	19.47	469.87
10	0.509	0.769	0.086	14.68	377.03

Table (10)

The maximum concentrations of pollutants in ambient air , which are emitted from combustion of propane (C_3H_8) in flares , and the maximum concentrations of propane in case of combustion failure at the top of flare stack in Storage Complex.

Site No.	Maximum ground level concentrations				
	Pollutants emitted from the combustion of C_3H_8 in flares				C_3H_8 in case of combustion failure (PPM)
	C_3H_8 (PPM)	CO (PPM)	NO_x (PPM)	SPM ($\mu g/m^3$)	
1	0.194	0.805	0.090	8.42	108.16
2	0.120	0.498	0.056	5.21	61.42
3	0.123	0.511	0.057	5.34	100.17
4	0.084	0.347	0.039	3.63	95.01
5	0.070	0.149	0.033	3.03	92.92
6	0.104	0.430	0.048	4.49	42.07
7	0.083	0.342	0.038	3.58	94.30
8	0.051	0.210	0.024	2.19	112.88
9	0.035	0.146	0.016	1.52	104.81
10	0.026	0.106	0.012	1.11	90.55

Table (11)

The maximum concentrations of pollutants in ambient air , which are emitted from combustion of butane (C_4H_{10}) in flares , and the maximum concentrations of butane in case of combustion failure at the top of flare stack in Storage Complex.

Site No.	Maximum ground level concentrations				
	Pollutants emitted from the combustion of C_4H_{10} in flares				C_4H_{10} in case of combustion failure (PPM)
	C_4H_{10} (PPM)	CO (PPM)	NO_x (PPM)	SPM ($\mu g/m^3$)	
1	0.160	0.876	0.098	7.19	84.17
2	0.093	0.506	0.057	4.16	67.73
3	0.098	0.536	0.060	4.40	107.37
4	0.066	0.358	0.040	2.94	94.40
5	0.054	0.295	0.033	2.42	85.99
6	0.081	0.441	0.049	3.62	32.29
7	0.062	0.341	0.038	2.80	107.37
8	0.038	0.206	0.023	1.69	110.27
9	0.026	0.143	0.016	1.17	95.59
10	0.019	0.106	0.012	0.87	78.71

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الخلاصة

ان الهدف من هذا البحث دراسة انبعاث الملوثات مثل الهيدروكاربونات (HC) ، اول اوكسيد الكاربون (CO) ، اكاسيد النتروجين (NOx) ، والدقائق المادية العالقة (SPM) وانتشارها من الشعلات المرتفعة لثلاثة مواقع لشركة غاز الجنوب لانتاج الغاز النفطي المسال في محافظة البصرة في العراق، وهذه المواقع الثلاث هي موقع خور الزبير، موقع الرميلة الشمالية، وموقع مجمع الخزن . ان عدد الشعلات في هذه المواقع هي 5 ، 3 ، 2 على التوالي.

تم تطوير نموذج رياضي مبرمج في الحاسوب كُتبَ بلغة فيجوال بيسك (Visual Basic). الغرض من هذا النموذج ايجاد التراكيز الأرضية للملوثات اعلاه المنبعثة من الشعلات المرتفعة في اماكن مختارة داخل وخارج كل موقع من المواقع الثلاثة عند مسافات مختلفة.

تم ايجاد معدلات انبعاث الملوثات اعلاه اعتماداً على التحاليل المختبرية لكافة انواع الغازات التي تحرق في قمة عمود الشعلة، كذلك بالاعتماد على الطرق الحديثة لوكالة حماية البيئة الامريكية (US EPA) لايجاد معدلات ابعاث الملوثات الناتجة من احتراق الغازات في الشعلات.

ان نتائج البحث تحدد وتوضح الحالات الجوية التي تكون أكثر تاثيراً في اعطاء التراكيز الارضية العظمى للملوثات وخاصة عند ظروف عدم الاستقرار للجو وسرعة الرياح.

من جهة اخرى وبالاستفادة من النموذج المبرمج المطور تم ايجاد تراكيز الهيدروكاربونات (HC)، البروبان (C_3H_8)، والبيوتان (C_4H_{10}) التي تطرح إلى الجو في حالة فشل احتراق هذه الغازات عند قمة عمود الشعلة.