American Journal of Environmental Sciences 4 (5): 491-501, 2008
ISSN 1553-345X

Impact of Green House Gases (GHG) Emissions from Oil Production Facilities at Northern Kuwait Oilfields: Simulated Results

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Abstract: Air pollution and its effects on the ecosystem has been a source of concern for many environmental pollution organizations in the world. In particular climatologists who are not directly involved in petroleum industry sometimes express concerns about the environmental impacts of gaseous emissions from flaring at various despised points. For environmental and resource conservation reasons, flaring should always be minimized as much as practicable and be consistent with safety considerations. However, any level of flaring has a local environmental impact, as well as producing emissions which have the potential to contribute to the global warming. In this study the Industrial Source Complex (ISCST3) Dispersion Model is used to calculate the ground level concentrations of two selected primary pollutants (i.e. methane and non-methane hydrocarbons) emitted from flaring activities at oil production facilities at North Kuwait. Model validation is based on the comparison of the 50 highest daily measured values and their respective predicted concentrations of methane and non-methane hydrocarbons. At discrete receptors, it is noticed that the predicted values are in good agreement with the observed data (accuracy range of 60-90%) from the monitoring stations maintained by the Kuwait Environmental Public Authority (EPA). The predicted results are based on emission inventories. Therefore, accurate emission inventory strategy for Kuwait Oil Company (KOC) as means of monitoring and minimizing the impact of methane and non-methane hydrocarbons emissions is of prime importance.

Key words: Kuwait oilfields, iscst3 model, flaring, air pollution, green house gases

INTRODUCTION

Kuwait is a major oil exporting country and its economy, growth and prosperity is heavily dependent on oil production. KOC is at the heart of the petroleum production in Kuwait. The oilfields involve various types of industrial operations and activities, such as drilling, production of crude oil, fuel combustion, and flaring of gases which all result in gas emission into atmosphere. In practice, all other sources of emissions are small compared with emissions from flaring. Consequently, a wide range of air pollutant emissions is generated on various sites on oil fields. Such emissions include carbon dioxide, nitrogen and sulfur oxide gases, methane and non-methane hydrocarbons and Suspended Particulates Matter (SPM).

A comprehensive emission inventories from Kuwait Oilfields has been published[1], which provides a comprehensive account and estimates of all emissions of primary pollutants associated from flaring activities in the Kuwait Oilfields. This inventory records the annual emissions of air pollutants: NO_X, SO_2, CO, CO_2, methane and non-methane hydrocarbons. The emissions are generated from various point sources and aggregated to obtain total pollutants load of ambient air in and around oil fields. The emissions of pollutants from the flaring associated with all types of operations in the oilfields, Gathering Centers (GC), booster stations (BS), tank areas and other oil production related emission activities.

In this work the data are used as the necessary input for the ISCST3 model. Obviously methane and non-methane hydrocarbons are not the only pollutants gasses, which result from flaring activities, but their high concentrations in ambient air is a matter of grave concern. Methane and non-methane hydrocarbons are

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GHG with a large impact factor. Therefore, ground level concentrations have been evaluated using the latest US EPA approved dispersion model (ISCST3).

EPA MONITORING STATIONS IN THE STATE OF KUWAIT

Kuwait EPA has established a number of fixed monitoring stations to collect air quality data in the urban areas. These stations continuously measure the concentration levels of pollutants such as SO_2, NO_2, CO, NO, CO_2, H_2S, O_3, and TSP (total suspended particles) in the air. The hourly air pollutants concentrations are recorded continuously by fixed ambient air stations located over the State of Kuwait.

It is important to note that, in general, all of the monitoring stations are considered as urban stations distributed within the residential areas except for Um Al-Aish station, which is located in the northern part of the country far away from the residential areas. Figure 1, shows the area map and the locations of Kuwait-EPA air quality monitoring sites. These monitoring stations are equipped with the latest instruments and analyzer for above mention pollutants with meteorological sensors.

In order to assess the air quality in Kuwait, the recorded concentrations of pollutants are analyzed from the Kuwait-EPA air quality-monitoring network. Kuwait-EPA has specified the concentration of non-methane hydrocarbons for early morning 3 h 6:00-9:00 AM not exceeding 0.24 ppm. The major sources of methane and non-methane hydrocarbons are oil activities as oil production, transport, refineries, storage and utilizations (traffic).

Fig. 1: Location of the Air Quality Monitoring Network in the State of Kuwait

KUWAIT METEOROLOGICAL DATA ANALYSIS

Kuwait has an area of about 17,818 km^2. At its most distant points, is about 200 km north to south and 170 km east to west. Kuwait is shaped roughly like a triangle, surrounded by land on its northern, western and southern sides and sea on its eastern side, with 195 kilometers of coastlines. The bulk of the Kuwaiti populations live in the coastal area of Kuwait. Smaller populations inhabit the nearby city of Al-Jahrah. Kuwait's land is mostly flat and arid with little or no ground water.

Kuwait has a typical desert climate, hot and dry most of the time. Rainfall varies from seventy five to 150 millimeters a year across the country, however, rainfall ranging from twenty-five millimeters a year to as much as 325 millimeters have also been recorded.

In summer, average daily temperatures range from 42°C to 46°C, the highest recorded temperature has been 51.5°C. The summers are relentlessly long, punctuated mainly by dramatic dust storms in June and July when northwesterly winds cover the cities in sand. In late summer, there is slight increase in humidity that ditches the temperature by a few degrees. Winters (November through February) are cool with some precipitation and average temperatures around 13°C (56°F) with extremes from -2°C to 27°C. The spring season (March) is warm and pleasant with occasional thunderstorms. Surface coastal water temperatures range from 15°C (59°F) in February to 35°C (95°F) in August. The winter months are often pleasant, featuring some of the region's coolest weather, with daytime temperatures hovering around 18°C (64°F) and nights being genuinely chilly. Sandstorms occur throughout the year but are particularly common in spring.

The meteorological conditions govern the dispersion of the pollutions. Therefore, the real existing meteorological conditions were recorded and used in ISCST3 model.

To work out the computation using the ISCST3 model a pre-processing program based on the U.S. EPA. PCRAMMET is utilized to convert meteorological data into right format to facilitate the computation of ground level concentration of the respective pollutants.

One year hourly record of the surface and upper air meteorological data for year 2006 obtained from the Kuwait International Airport (KIA) weather station and are used in the present study for simulation of the dispersion of methane and non-methane hydrocarbons emitted from flaring in North Kuwait Oilfields.

Table 1: Mean Monthly Meteorological Conditions for year 2006

Month	Mean Wind Speed (m/s)	Mean Ambient Temperature (°C)
January	3.18	13.50
February	3.73	15.94
March	4.10	21.17
April	4.01	26.30
May	4.27	34.25
June	5.23	38.52
July	6.07	40.04
August	3.75	39.34
September	3.66	34.41
October	3.76	30.18
November	3.43	19.58
December	3.33	11.61
Average	4.04	27.07

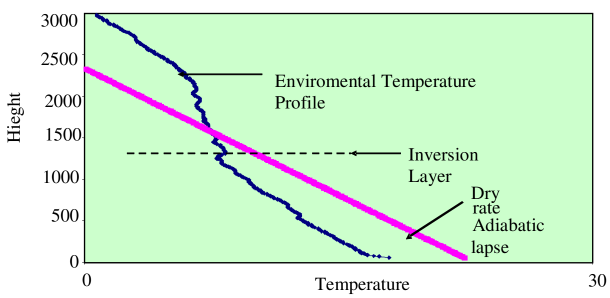

Fig. 2: Upper air temperature profile and formation of the temperature inversion

The most important meteorological factors that strongly affect continuously the behavior of the pollutants trends during a day are the mixing height and depth of the mixing layer. The estimation of mixing heights from upper air meteorological data is a critical parameter for understanding the formation, dispersion and transfer of ozone and precursors during pollution episodes[2] [3] [4]. The upper air meteorological data are obtained from routine measurements at the KIA weather station for the year 2006. These data were used to calculate the mixing heights Fig. 2. and to investigate the effects of upper air meteorological data in the diurnal behaviors of ozone and its precursors. The morning and afternoon mixing height estimates are determined based on the method described by Holzworth[5] and Hanna[6].

The prevailing wind in Kuwait is along the north westerly quadrant most of the year. Figure 3a presents the wind rose plot for winter (November-March) where calm conditions are about 19.1% of the total time and an average wind speed of 4.35 m/s. Figure 3b provides the wind rose plot for summer (April -October) where calm conditions are about 10.9% of the total time and an average wind speed of 4.9 m sec^{-1}.

For the frequency distribution of the winds for year 2006, the highest wind >11.1 m sec^{-1}was about 0.7% of wind speed record, 8.8 and 11.1 m sec^{-1} was

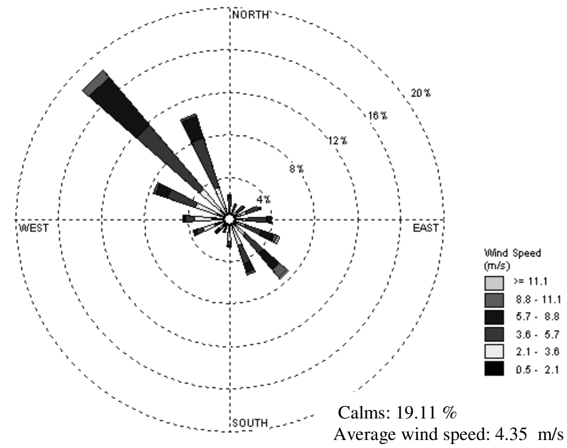

Fig. 3a: Wind rose plot for winter (November-March)

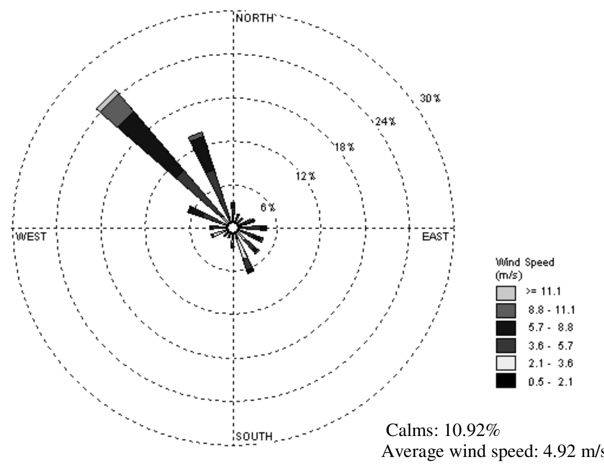

Fig. 3b: Wind rose plot for sum

5.7 and 8.8 m sec^{-1} was about 19.4%, 3.6 and 5.7 m sec^{-1}was about 32.2%, 2.1 and 3.6 m sec^{-1} was about 17.5% and 0.5 and 2.1 m/s was about 26.4%.

Table 1, presents the Mean Monthly Wind Speed (MMWS) and the Mean Monthly Ambient Temperature (MMAT) for 2006. These mean monthly meteorological data were computed from the hourly records during each day of 2006. The annual mean wind speed in 2006 is low being only 4.04 m/s, while MMWS reaches its highest in June (5.23 m sec^{-1}) and in July (6.07 m/s), and its lowest in January (3.18 m sec^{-1}). The annual mean temperature was 27°C where the lowest MMAT recorded during the year was 11.6°C in December and the highest MMAT was 40°C in July. This variation of temperature and wind speeds has serious consequences on dispersion the level of air

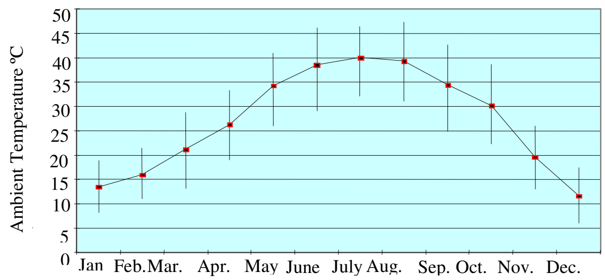

Fig. 4: The mean monthly, maximum and minimum record of ambient air temperature for year 2006

Fig. 5: The grid area under study

pollutants and hence the air quality, especially in residential areas closes or downwind of NK Oilfields.

Figure 4 shows the MMAT, maximum and minimum temperatures recorded for each month. The maximum temperature in summer ranges from 40 to 51°C.

MATHEMATICAL MODEL

Industrial Source Complex (ISCST3) dispersion model modified by the US EPA [3] [4] in 1999 is used in the present study. The ISCST3 algorithm is based on a Gaussian plume dispersion model (i.e. it solves the steady-state Gaussian plume equation) and calculates short-term pollutant concentrations from multiple point sources at a specified receptor grid on a level or gently sloping terrain. The ISCST3 model includes a wide range of options for modeling air quality impacts of pollution sources, making it a popular choice for the modeling community in a variety of applications.

The ISCST3 model implementation requires three main inputs data as follows;

Source Information: The source parameters required for the ISCST3 numerical model are pollutant emission rate g sec^{-1}, location coordinates (UTM), source height (m), exit inner diameter (m), exit gas speed (m/s), and exit gas temperature (°C). The required information on all the location coordinates, the respective emission rates and stacks characteristic (height, diameters), flue gas velocity and temperature at the discharge have been obtain from all flaring activities from NK oil field[1].

Receptor Information: The ISCST3 model have considerable flexibility in the specification of receptor locations, has the capability of specifying multiple receptor networks in a single run, and may also mix Cartesian grid receptor networks and polar grid receptor networks in the same run.

Two different kinds of Cartesian coordinate receptors were used as an input to the ISCST3 model, these are;

- The course mesh covers approximately 40 km by 40 km with 441 receptors superimposed with two finer meshes of 26km by 18km and 21km by 14km to facilitate accurate interpolated results. The grid base elements are a square with side length of 1 kmx1km. Figure 5 describes the grid for the area under study.

- Discrete Receptors points corresponding to the location of the major population centers and the existing monitoring stations in the State of Kuwait. This means that concentrations in each point in the grid, which is 1km apart, are estimated in addition to the discrete point of the population centers and existing monitoring stations. The matrix of concentrations is plotted as a contour map for the selected meteorological data file.

These receptors are selected based on actual sites in UTM location coordinate of Kuwait map as shown in Fig. 5.

Meteorological Information: The meteorological data required are anemometer height (m) wind speed (m/s), wind direction (degree) clockwise from the north, air temperature, total and opaque cloud cover (%), stability class at the hour of measurement (dimensionless) and mixing height (m). The anemometer height about 10 m, wind speed, wind direction, air temperature and cloud cover have been obtained from direct measurements from KIA.

The hourly stability class mixing height is estimated using PCRAMMET that is a meteorological pre-processor for preparing National Weather Service (NWS) data for use in the ISCST3 US-EPA. The routine measurements of the surface and upper air

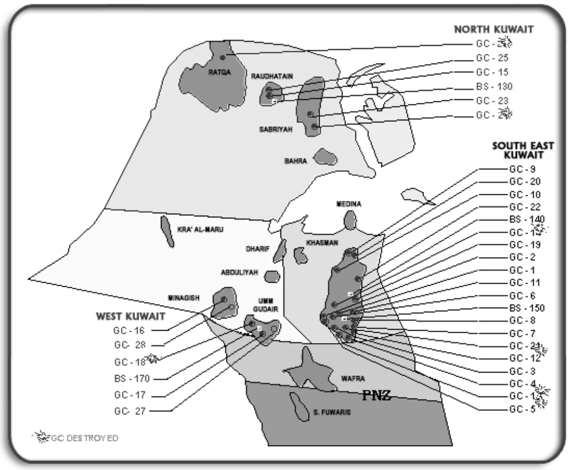

Fig. 6: Major Oilfields and Gathering Center (GC) in the State of Kuwait

meteorological data obtained from KIA for the year 2006 is used to run the PCRAMMET to generate an hourly ASCII input meteorological file containing the meteorological information parameters needed for the running of the ISCST3 model.

The stability class was defined on the basis of Pasquill categories, which are mainly a function of the hour of measurement, wind speed and sky cover (i.e., the amount of clouds). Based on temperature profile measurements, the mixing height was estimated by the model.

STUDY AREA

The study area covers North Kuwait oil producing zones. Figure 6, shows the Kuwait map with the location of the NK oil producing area.

The ground level concentrations of methane and non-methane hydrocarbons were calculated in and around NK Oilfields consist of Ratqa, Raudatin and Sabiriyah that had 3 GCs and one BS.

RESULTS AND DISCUSSIONS

ISCST3 model was used to simulate the ground level concentrations of methane and non-methane hydrocarbons emitted from NK compute flaring activities in KOC at all points covered by the receptors information. ISCST3 model was then executed by summing the steady state concentration contributions from each source at each receptor point in the study area. The calculations were done based on the model input parameters as described in the previous sections. The simulated results of the emission scenarios using the ISCST3 are on an hourly mean predicted ground level concentrations of methane and non-methane hydrocarbons.

The hourly, daily and annual average maximum ground level concentrations of methane and non-methane hydrocarbons were predicted and output results were compared with Kuwait Ambient Air Quality Standards (KAAQS) at all of the grid point receptors under the study area (443 receptors) as shown in Fig. 5. Allowable levels of pollutants specified by KAAQS are shown in Table 2. The computed ground level concentrations were compared with KAAQS to determine ambient air quality.

Effect of meteorological conditions: In general, clear sky, high temperature and airborne dust is the feature of the summer season whereas mid to relatively cold with light rain is feature of the winter season. These two contrasting weather conditions would have opposite effects on the dispersion of the pollutants and the concentrations levels through the processes of transport and reaction in the atmosphere. In winter season, the presence of the cloud cover results in the reduction of the solar energy, ambient temperature and wind speed, these conditions decrease the photochemical reactions for the formation of ozone and increase the incidence of the surface based inversion that results in lower mixing height. Thus, these meteorological conditions during winter season would tend to increase the concentrations of the primary pollutants.

The modeling results for the first five highest hourly ground level concentrations of methane are resulted in winter. The top high hourly ground level concentration of methane is 32.2 ppm at 02:00 Hr on 19th Janurary 2006. The second high hourly ground level concentration of methane is 27.6 ppm at 01:00 Hr on 27th February 2006. Third high hourly ground level concentration of methane is 25.4 ppm at 01:00 Hr on 5th December 2006. The fourth high hourly ground level concentrations of methane is 24.2 ppm at 01:00 Hr on 16th December 2006 and the fifth high hourly ground level concentrations of methane is 23.5 ppm at 03:00 Hr on 26th November 2006. From the above results, it is clear that all the five highest ground level concentrations of methane occur in winter early morning where inversion layer, temperature and wind speed are low adversely effects the dispersion.

Model performance and validation: The performance of the model is evaluated based on the comparison of 50 highest daily measured and predicted concentrations of methane and non-methane hydrocarbons from NK flaring activities at each monitoring station. It is clear that the model predictions are in good agreement with the observed data with accuracy of 60-90% at the monitoring stations used by Kuwait EPA Fig. 7.

Table 3a: ISCST3 output data modeling results for the 50 highest hourly average concentrations of methane

Rank	CONC. (ppm)	(DDMMYYHH)	Distance km	Direction	Rank	CONC. (ppm)	(DDMMYYHH)	Distance Km	Direction
1	7.95	16/01/06 19:00	11.0	104 °ESE	26	4.44	12/09/06 06:00	11.2	108 °ESE
2	7.13	27/12/06 23:00	0.6	341 °WNW	27	4.35	10/12/06 03:00	1.0	283 °WNW
3	6.81	04/01/06 19:00	11.8	105 °ESE	28	4.31	29/09/06 08:00	11.2	108 °ESE
4	6.79	16/12/06 22:00	1.0	346 °WNW	29	4.30	05/09/06 04:00	11.0	104 °ESE
5	6.74	27/05/06 05:00	11.0	104 °ESE	30	4.24	19/01/06 20:00	0.6	341 °WNW
6	5.78	10/01/06 09:00	0.6	341 °WNW	31	4.18	05/02/06 24:00	11.0	104 °ESE
7	5.62	11/01/06 02:00	11.8	105 °ESE	32	4.10	16/01/06 20:00	11.0	104 °ESE
8	5.57	03/04/06 23:00	11.8	105 °ESE	33	4.08	25/11/06 04:00	1.4	314 °WNW
9	5.49	31/01/06 20:00	11.8	105 °ESE	34	4.07	31/05/06 23:00	12.1	109 °ESE
10	5.38	13/09/06 06:00	11.0	104 °ESE	35	4.04	13/01/06 02:00	11.0	104 °ESE
11	5.33	26/01/06 21:00	0.6	341 °ESE	36	3.98	13/09/06 05:00	11.6	100 °ESE
12	5.24	18/01/06 21:00	12.3	104 °ESE	37	3.98	22/02/06 02:00	11.0	104 °ESE
13	5.21	12/12/06 06:00	0.6	341 °WNW	38	3.90	14/02/06 07:00	0.6	341 °WNW
14	5.05	16/11/06 05:00	11.2	108 °ESE	39	3.84	26/09/06 18:00	0.6	341 °WNW
15	5.05	04/09/06 04:00	11.0	104 °ESE	40	3.81	9/9/2006 22:00	11.2	108 °ESE
16	5.03	18/01/06 08:00	11.2	108 °ESE	41	3.79	21/11/06 06:00	11.2	108 °ESE
17	5.01	02/01/06 08:00	12.1	109 °ESE	42	3.78	28/01/06 03:00	1.0	283 °WNW
18	4.89	01/05/06 20:00	12.3	104 °ESE	43	3.76	7/9/2006 21:00	12.1	109 °ESE
19	4.69	04/04/06 20:00	11.8	105 °ESE	44	3.70	26/11/06 23:00	11.2	108 °ESE
20	4.69	05/04/06 01:00	11.8	105 °ESE	45	3.70	19/01/06 18:00	11.8	105 °ESE
21	4.56	01/11/06 06:00	1.0	4 °ENE	46	3.69	21/12/06 19:00	11.8	105 °ESE
22	4.55	18/09/06 05:00	11.2	10 °ESE	47	3.68	21/04/06 05:00	1.0	283 °WNW
23	4.55	20/04/06 02:00	11.0	104 °ESE	48	3.67	3/6/2006 02:00	12.1	109 °ESE
24	4.52	18/04/06 19:00	0.6	341 °ESE	49	3.66	16/09/06 20:00	0.6	161 °ESE
25	4.50	11/01/06 03:00	1.0	4 °ENE	50	3.63	18/01/06 20:00	11.8	105 °ESE

Table 3b: ISCST3 output data modeling results for the 50 highest daily average concentrations of methane

Rank	CONC. (ppm)	(DDMMYYHH)	Distance km	Direction	Rank	CONC. (ppm)	(DDMMYYHH)	Distance Km	Direction
1	0.66	04/01/06	11.8	105 °ESE	26	0.35	10/04/06	12.1	109 °ESE
2	0.60	16/01/06	11.0	104 °ESE	27	0.34	19/02/06	11.0	104 °ESE
3	0.53	06/09/06	0.6	341 °WNW	28	0.34	30/09/06	0.4	151 °ESE
4	0.50	23/01/06	0.6	341 °WNW	29	0.34	30/01/06	11.6	100 °ESE
5	0.49	01/02/06	12.1	103 °ESE	30	0.33	03/09/06	12.1	109 °ESE
6	0.45	07/06/06	0.6	341 °WNW	31	0.33	12/11/06	0.6	341 °WNW
7	0.43	04/04/06	11.8	105 °ESE	32	0.33	02/05/06	1.0	346 °WNW
8	0.42	14/02/06	0.6	341 °WNW	33	0.33	01/11/06	11.8	105 °ESE
9	0.41	07/09/06	12.1	109 °ESE	34	0.33	04/09/06	11.0	104 °ESE
10	0.41	12/10/06	12.1	109 °ESE	35	0.32	10/01/06	0.6	341 °WNW
11	0.40	03/01/06	11.8	105 °ESE	36	0.32	31/01/06	11.8	105 °ESE
12	0.40	16/12/06	1.0	346 °WNW	37	0.31	28/04/06	11.8	105 °ESE
13	0.39	05/04/06	11.8	105 °ESE	38	0.31	01/01/06	10.3	107 °ESE
14	0.39	03/01/06	1.0	4 °ENE	39	0.31	01/04/06	0.2	15 °ENE
15	0.38	16/11/06	11.2	108 °ESE	40	0.31	27/12/06	0.6	341 °WNW
16	0.38	27/05/06	11.0	104 °ESE	41	0.31	26/09/06	12.1	109 °ESE
17	0.37	14/04/06	11.0	104 °ESE	42	0.30	14/09/06	11.0	104 °ESE
18	0.37	16/09/06	0.6	341 °WNW	43	0.30	21/04/06	1.0	103 °ESE
19	0.37	07/01/06	0.6	341 WNW	44	0.30	29/11/06	12.1	109 °ESE
20	0.36	19/01/06	11.8	105 °ESE	45	0.29	13/09/06	11.0	104 °ESE
21	0.36	03/04/06	11.8	105 °ESE	46	0.29	18/01/06	12.3	104 °ESE
22	0.36	28/01/06	1.0	103 °ESE	47	0.29	25/11/06	1.4	314 °WNW
23	0.36	11/01/06	11.8	105 °ESE	48	0.29	12/12/06	0.6	341 °WNW
24	0.36	09/10/06	12.1	109 °ESE	49	0.29	01/11/06	1.0	4 °ENE
25	0.36	05/11/06	0.6	161 °ESE	50	0.29	16/04/06	0.6	341 °WNW

North Kuwait Oilfield Area Results

Methane Concentrations: Tables 3a-c show the modeling results for the 50 highest hourly, 50 highest daily and the 50 highest annual maximum ground level concentrations of methane resulting from 12 stacks with total emission rate equal to 218.32 g sec^{-1}. The calculated values from the uniform grid receptors are described in proceeding section and GC-15 (receptor coordinate of X = 763597, Y = 3308152) is considered as a reference point to interpret the location of high concentration. Figures (8a-c) depict the concentration variations in different zones. These present the maximum hourly,

Table 3c: ISCST3 output data modeling results for the 10th highest annual average concentrations of methane

RANK	CONC. (ppb)	Distance km	Direction
1ST	62.6	11.0	104 °ESE
2ND	44.7	0.6	341 °WNW
3RD	33.4	11.8	105 °ESE
4TH	31.6	12.1	109 °ESE
5TH	24.9	12.8	116 °ESE
6TH	21.3	1.4	314 °WNW
7TH	18.7	10.4	102 °ESE
8TH	17.3	12.4	112 °ESE
9TH	16.8	11.2	108 °ESE
10TH	16.8	12.2	106 °ESE

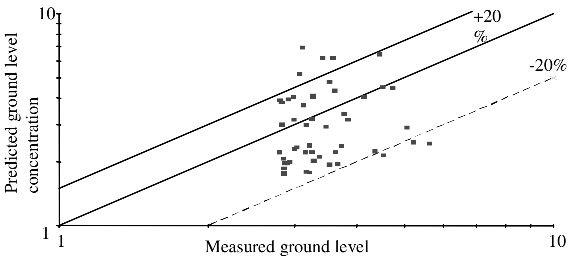

Fig 7: Comparison of the highest 50 measured recorded and predicted ground level concentrations of methane in NK Oilfields

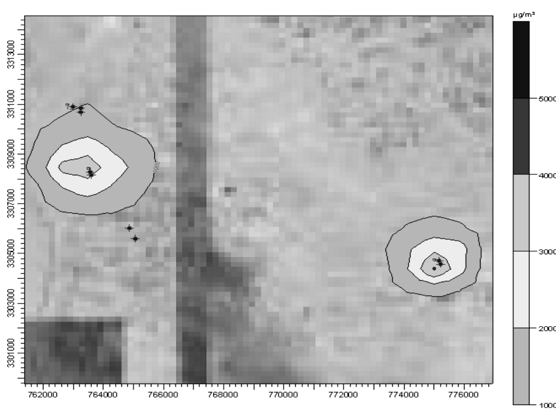

Fig. 8a: Isopleths plot for the maximum hourly average ground level concentrations of methane in µg m^{-3}

daily and annual ground level concentration of methane in ppm calculated at the specified uniform grid receptors.

The background concentration of methane in the ambient air prior to computation input data were considered negligible (Zero).

The results presented in Tables 3a-c and Fig. 8a-8c reveals that predicted ground level concentrations of methane.ss

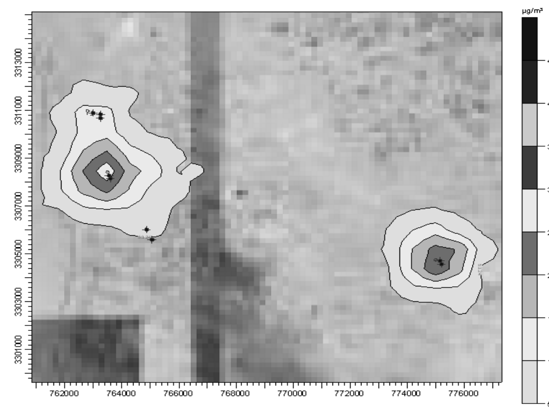

Fig. 8b: Isopleths plot for the maximum daily average ground level concentrations of methane in µg/m^3

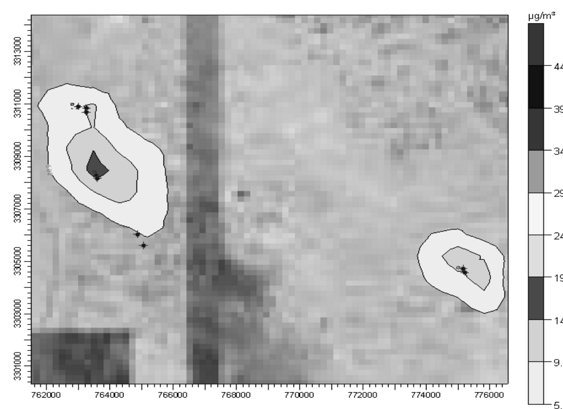

Fig. 8c: Isopleths plot for the maximum annual average ground level concentrations of methane in µg m^{-3}

As shown in Table 3a the predicted maximum hourly average ground level concentration of methane in the study areas is 7.95 ppm at 19:00 Hr on 16th January 2006 at the receptor located nearly 11 km bearing 104°N, confirming the strong influence of prevailing north west wind in cold January hours evening. Most of the highest values predicted were in winter and early morning hours.

The predicted maximum daily average ground level concentration of methane in the study areas in Table 3b is 0.66 ppm on 4th January 2006. This value is 12 times less than the maximum hourly average ground level concentration value. Inspection of Fig. 8b, this receptor is located nearly 11.8 km bearing 105°N. It is not surprising that the highest annual maximum concentration of methane also at the same spot as the maximum hourly and daily. The highest

Table 4a: ISCST3 output data modeling results for the 50 highest hourly average concentrations of non-methane hydrocarbons

Rank	CONC. (ppm)	(DDMMYYHH)	Distance km	Direction	Rank	CONC (ppm)	(DDMMYYHH)	Distance km	Direction
1	38.0	16/01/06 19:00	11.0	104°ESE	26	20.0	05/02/06 20:00	11.0	104 °ESE
2	32.5	4/1/2006 19:00	11.8	105°ESE	27	19.6	16/01/06 20:00	11.0	104 °ESE
3	32.2	27/05/06 05:00	11.0	104°ESE	28	19.5	31/05/06 23:00	12.1	109 °ESE
4	30.3	27/12/06 23:00	0.6	341°WNW	29	19.4	01/11/06 06:00	1.0	356 °WNW
5	28.9	16/12/06 22:00	1.0	346°WNW	30	19.3	13/01/06 02:00	11.0	104 °ESE
6	26.8	11/01/06 02:00	11.8	105°ESE	31	19.2	18/04/06 19:00	0.6	341 °WNW
7	26.6	04/03//06 23:00	11.8	105°ESE	32	19.1	11/01/06 03:00	1.0	356 °WNW
8	26.2	31/01/06 20:00	11.8	105°ESE	33	19.0	13/09/06 05:00	11.6	100 °ESE
9	25.7	13/09/06 06:00	11.0	104°ESE	34	19.0	22/02/06 02:00	11.0	104 °ESE
10	25.0	18/01/06 21:00	12.3	104°ESE	35	18.5	10/12/06 03:00	1.0	283 °WNW
11	24.6	10/01/06 21:00	0.6	341°WNW	36	18.2	09/09/06 22:00	11.2	108 °ESE
12	24.1	16/11/06 05:00	11.2	108°ESE	37	18.1	21/11/06 06:00	11.2	108 °ESE
13	24.1	04/09/06 04:00	11.0	104°ESE	38	18.1	19/01/06 20:00	0.6	341 °WNW
14	24.0	18/01/06 08:00	11.2	108°ESE	39	17.9	07/09/06 21:00	12.1	109 °ESE
15	23.9	02/01/06 08:00	12.1	109°ESE	40	17.7	26/11/06 23:00	11.2	108 °ESE
16	23.4	01/05/06 20:00	12.3	104°ESE	41	17.7	19/01/06 18:00	11.8	105 °ESE
17	22.7	26/01/06 21:00	0.6	341°WNW	42	17.6	21/12/06 19:00	11.8	105 °ESE
18	22.4	04/04/06 20:00	11.8	105°ESE	43	17.5	03/06/06 02:00	12.1	109 °ESE
19	22.4	05/04/06 01:00	11.8	105°ESE	44	17.4	25/11/06 04:00	1.4	314 °WNW
20	22.2	12/12/06 18:00	0.6	341°WNW	45	17.3	18/01/06 20:00	11.8	105 °ESE
21	21.7	18/09/06 05:00	11.2	108°ESE	46	17.3	01/02/06 22:00	12.1	103 °ESE
22	21.7	20/04/06 02:00	11.0	104°ESE	47	17.1	30/01/06 03:00	11.0	104 °ESE
23	21.2	12/09/06 06:00	11.2	108°ESE	48	17.1	20/09/06 21:00	11.0	104 °ESE
24	20.6	29/09/06 08:00	11.2	108°ESE	49	16.9	12/11/06 21:00	11.8	105 °ESE
25	20.6	05/09/06 04:00	11.0	104°ESE	50	16.8	25/09/06 05:00	12.2	106 °ESE

Table 4a: ISCST3 output data modeling results for the 50 highest hourly average concentrations of non-methane hydrocarbons

Rank	CONC. (ppm)	(DDMMYYHH)	Distance km	Direction	Rank	CONC (ppm)	(DDMMYYHH)	Distance km	Direction
1	3.14	04/01/06	11.8	105 °ESE	26	1.58	16/09/06	0.6	341 °WNW
2	2.89	16/01/06	11.0	104 °ESE	27	1.57	07/1/06	0.6	341 °WNW
3	2.34	01/02/06	12.1	103 °ESE	28	1.56	01/11/06	11.8	105 °ESE
4	2.27	06/09/06	0.6	341 °WNW	29	1.55	04/09/06	11.0	104 °ESE
5	2.14	23/01/06	0.6	341 °WNW	30	1.53	28/01/06	1.0	283 °WNW
6	2.04	04/04/06	11.8	105 °ESE	31	1.53	31/01/06	11.8	105 °ESE
7	1.95	07/09/06	12.1	109 °ESE	32	1.51	05/11/06	0.6	341 °WNW
8	1.95	12/10/06	12.1	109 °ESE	33	1.50	28/04/06	11.8	105 °ESE
9	1.93	07/06/06	0.6	341 °WNW	34	1.49	01/01/06	10.3	107 °ESE
10	1.92	03/01/06	11.8	105 °ESE	35	1.46	26/09/06	12.1	109 °ESE
11	1.87	05/04/06	11.8	105 °ESE	36	1.45	14/09/06	11.0	104 °ESE
12	1.80	14/02/06	0.6	341 °WNW	37	1.43	30/09/06	0.4	151 °ESE
13	1.80	16/11/06	11.2	108 °ESE	38	1.41	29/11/06	12.1	109 °ESE
14	1.80	27/05/06	11.0	104 °ESE	39	1.41	12/11/06	0.6	341 °WNW
15	1.78	14/04/06	11.0	104 °ESE	40	1.40	13/09/06	11.0	104 °ESE
16	1.73	19/01/06	11.8	105 °ESE	41	1.39	02/05/06	1.0	346 °WNW
17	1.72	03/04/06	11.8	105 °ESE	42	1.39	18/01/06	12.3	104 °ESE
18	1.71	11/01/06	11.8	105 °ESE	43	1.38	28/01/06	10.9	101 °ESE
19	1.70	9/10/06	12.1	109 °ESE	44	1.37	13/01/06	11.0	104 °ESE
20	1.68	16/12/06	1.0	346 °WNW	45	1.37	10/1/2006	0.6	341 °WNW
21	1.67	10/04/06	12.1	109 °ESE	46	1.35	02/01/06	12.1	109 °ESE
22	1.64	03/01/06	1.0	4 °ESE	47	1.33	18/01/06	11.2	108 °ESE
23	1.61	19/02/06	11.0	104 °ESE	48	1.33	30/08/06	11.0	104 °ESE
24	1.60	30/01/06	11.6	100 °ESE	49	1.32	01/04/06	0.2	15 °ESE
25	1.59	03/09/06	12.1	109 °ESE	50	1.31	27/12/06	0.6	341 °WNW

annual maximum concentration of methane is 62.6 ppb which is 11 times less than the maximum daily average ground level concentration value.

Non-methane hydrocarbon concentrations: Table 4a-4c show the modeling results for the 50 highest hourly, 50 highest daily and the 50 highest annual maximum ground level concentrations of non-methane hydrocarbons resulting from 12 stacks with total emission rate equal to 2909.08 g sec^{-1}. The calculated values from the uniform grid receptors are described in proceeding section and GC-15 (receptor coordinate of X = 763597, Y = 3308152) is considered as a reference point to interpret the location of high concentration.

Table 4c: ISCST3 output data modeling results for the 10th highest annual average concentrations of non-methane hydrocarbons

RANK	CONC. (ppb)	Distance km	Direction
1ST	298.7	11.0	104 °ESE
2ND	190.6	0.6	341 °WNW
3RD	159.4	11.8	105 °ESE
4TH	150.7	12.1	109 °ESE
5TH	116.3	12.8	116 °ESE
6TH	90.9	1.4	314 °WNW
7TH	88.8	10.4	102 °ESE
8TH	81.3	12.4	112 °ESE
9TH	80.0	12.2	106 °ESE
10TH	79.5	11.2	108 °ESE

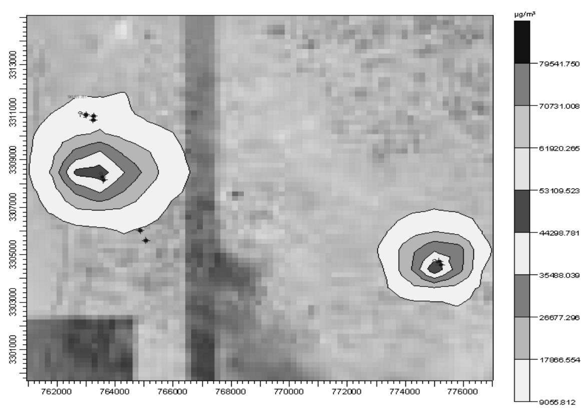

Fig. 9a: Isopleths plot for the maximum hourly average ground level concentrations of non-methane hydrocarbons in µg/m^3

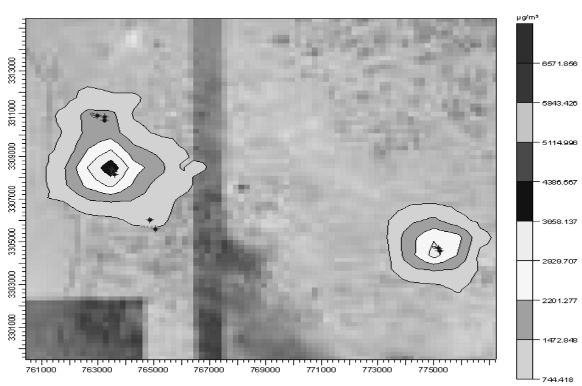

Fig. 9b: Isopleths plot for the maximum daily average ground level concentrations of non-methane hydrocarbons in µg/m^3

Isopleths plots (contours) were generated, as shown in figures 9a-c. The hourly, daily and annual ground level concentration of non-methane hydrocarbons in ppm calculated at the specified uniform grid receptors.

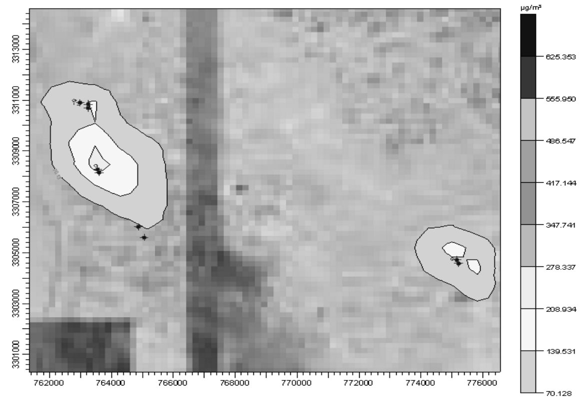

Fig. 9c: Isopleths plot for the maximum annual average ground level concentrations of non-methane hydrocarbons in µg/m^3

As clear from Table 4a and Fig. 9a, the predicted maximum hourly average ground level concentration of non-methane hydrocarbons in the study area is 38 ppm at 19:00 Hr on 16th January 2006 at the receptor located nearly 11 km bearing 104°N, confirming similar source strength with identical meteorological conditions.

The predicted maximum daily average ground level concentration of non-methane hydrocarbons in the study area given in Table 4b is 3.14 ppm on 4th January 2006. This value is 11 times less than the maximum hourly average ground level concentration value. For the same location, Table 4c and Fig. 9c show that the highest annual maximum concentration of non-methane hydrocarbons equal 298.7 ppb, which is 11 times less than the maximum daily average ground level concentration value.

Kuwait-EPA has specified the concentration of non-methane hydrocarbons for early morning 3 Hours 6:00 -9:00 AM not exceeding 0.24 ppm. The computed 3 hours average data reveal that the predicted ground level concentration of non-methane hydrocarbons for the specified time 6:00 -9:00 AM has exceeded 190 times of the KAAQS ambient air quality standard.

The above results reflect the increase in flaring in January 2006, due to regular shut down of Condensate Recovery Unit (CRU's) in NK Oilfields and the prevailing wind direction in Kuwait. Considering Table's 3a-c, 4a-c and Fig. 8a-c, 9a-c together, it can be concluded the weather pattern in Kuwait in January 2006, especially the mean prevailing wind direction, significantly contributed to high concentrations of methane and non-methane hydrocarbons at ground level in residential areas located nearly 11 km bearing 104°N.

CONCLUSION

Methane and non-methane hydrocarbons are not the only green house gasses which result from flaring activities. The flaring of excess gas is the largest single source of atmospheric emissions arising from KOC operations. However, flaring produces carbon dioxide, oxides of sulphur and nitrogen (NOx) and other chemical species that are produced due to incomplete combustion, such as carbon monoxide, aldehydes, ketones and other organic compounds known as VOCs (Volatile Organic Compounds). However the methane and non-methane hydrocarbons gases provide typical samples which are focus of this work and their emissions from flaring activities in NK oilfields are used as an input for the ISCST3 model to investigate of the impact on the air quality and GHG levels. The statistical comparison between the 50 highest daily measured and predicted concentrations at Kuwait existing air quality monitoring site showed a good agreement validating the model results.

The simulated results from the latest dispersion model in and around the NK Oilfields for the year 2006, by implementing all the major sources, from oil production facilities indicate the following;

- Predicted methane ground level concentrations have exceeded 2ppm level over about 40% of the total study area (40kmx40km).
- The highest average ground level concentration of methane hourly, daily and annually were in the months of January and September due to high emission rates resulted malfunctioning of condensate recovery unit. The prevailing meteorological conditions in the month of January have resulted into the top highest ground concentrations due to low temperatures and low inversion layer and calm wind conditions.
- The emission rate in September is the same as that of January but meteorological conditions influence resulted into only 11 hourly values from the top 50 values and 8 daily values.
- There is a need for an accurate emission inventory for KOC to minimize the impact of methane and non-methane hydrocarbons released from flaring activities over the urban area of Kuwait.
- For non-methane hydrocarbons, NMHC ground level concentrations, the emission rates are calculated in the similar way as for methane but the daily variation of methane composition in flared gas has contributed in different emissions.
- The predicted NMHC ground level concentration have violated Kuwait EPA standards over 190 times in year 2006 while in general all most all the air quality monitoring stations indicated high violation of this pollutant due to additional sources, oil storage, petroleum refining, petrochemical industries, oil transport and power generation and road traffic etc.
- Predicted NMHC ground level concentrations have exceeded 0.25 ppm level over about 90% of the total study area (40kmx40km), the selection of 0.24 ppm is due to Kuwait EPA standard in early morning 3 hours 6:00 AM to 9:00 AM.
- The highest mean ground level concentration of NMHC hourly, daily and annually were in the months of January and September due to high emission rates as explained in preceding section. The prevailing meteorological conditions in the month of January have resulted into the top highest ground concentrations due to low temperatures and low inversion layer and calm wind conditions. The emission rate in September is similar to January and has identical influence as methane 11 hourly high values in September out of total 50 and 8 daily values from top 50 values.

Overall it seems that the levels of pollutants in winter period are higher than summer. This is because the winters in Kuwait portray a low temperature, low inversion layers, lesser wind movements, which relegate the dispersion of pollutants as compared to summers, which have high temperature, high inversion layers, and high wind movements strongly influencing the dispersion of pollutants. The work is in progress to include other pollutants such as NO_X, SO_2, CO and CO_2 with detailed accurate emission inventory to minimize the impact of NO_X, SO_2, CO, CO_2, methane and non-methane hydrocarbons emissions from flaring activities emissions.

ACKNOWLEDGMENT

The authors would like to thank Kuwait Oil Company for the field data used in this study and their permission to publish the results. Also, the authors would like to thank the Environmental Public Authority of Kuwait and Kuwait International Airport for the field data used in this study.

REFERENCES

1. Khaireyah Kh. AL-Hamad and A. R. Khan, 2007. "Total Emissions from Flaring in Kuwait Oilfields", American Journal of Environmental Sciences 4: 31-38, 2007, ISSN 1553-345X © 2007 Science Publications.
2. U.S. Environmental Protection Agency, 1999. "PCRAMMET User's Guide (Revised)", EPA-454/R-96-001. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711.
3. U.S. Environmental Protection Agency, 1995." User guide for the industrial source complex (ISC3) dispersion models", Volume I, User Instructions", EPA-450/B-95-003a. Research triangle park, n.c: environmental protection agency. office of air quality planning and standards, emissions, monitoring and analysis division.
4. U.S. Environmental Protection Agency, 1992." User guide for the industrial source complex (ISC) dispersion models", EPA-450/4-92-008A. Research Triangle Park, N.C: Environmental Protection Agency. Office of Air Quality Planning and Standards.
5. Holzworth, G.C. (1972) "Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States", Office of Air Prog. pub. AP-101,USEPA, RTP, NC.
6. Hanna, S.R.: 1969, 'The Thickness of the Planetary Boundary Layer',Atmos. Envir.,3, 519-536.