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Daily and Seasonal Changes of Air Pollution in Kuwait

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***Abstract*—**This paper focuses on assessment of air pollution in Umm-Alhyman, Kuwait, which is located south to oil refineries, power station, oil field, and highways. The measurements were made over a period of four days in March and July in 2001, 2004, and 2008. The measured pollutants included methanated and non-methanated hydrocarbons (MHC, NMHC), CO, CO_2, SO_2, NO_X, O_3, and PM_{10}. Also, meteorological parameters were measured, which includes temperature, wind speed and direction, and solar radiation. Over the study period, data analysis showed increase in measured SO_2, NO_X and CO by factors of 1.2, 5.5 and 2, respectively. This is explained in terms of increase in industrial activities, motor vehicle density, and power generation. Predictions of the measured data were made by the ISC-AERMOD software package and by using the ISCST3 model option. Finally, comparison was made between measured data against international standards.

***Keywords*—**Air pollution, Emission inventory, ISCST3 model, Modeling

I. INTRODUCTION

MEASUREMENTS and analysis of air pollution in Kuwait is a continual research venue, where data and analysis results provide the legislature body can assess the air pollution status and means for control and reduction. The following is a brief review of recent air pollution studies conducted in Kuwait. Abdul-Wahab et al. [1] studied ozone level in Shuaiba Industrial Area in Kuwait. A statistical model was developed from ambient air quality data. It was concluded that the relation between the ozone level and the temperature below 27ºC is positive. On the other hand, it was negative at temperature above 27ºC. In addition, it was found that the variation of ozone level is a strong function of the NO_X levels. A measurement of air pollution over a period of one year has been conducted in Shuiaba Industrial Area of Kuwait by Abdul-Wahab et al. [2]. A mobile laboratory was used for collecting the data. The diurnal and monthly variations for the major primary and secondary pollutants were calculated. Two maxima diurnal variations were observed for the concentration of the primary pollutants where a single maximum was observed for the secondary pollutants. On the other hand, SO_2 and NO_X were showed maximum values during warm months. Ozone concentration was increased at temperature below 27ºC.

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However, the concentration was decreased at temperature above 27ºC. The wind speed and direction are the most important controller of the pollution concentrations. It was found that at low wind speed the mean concentrations are low except for CO, O_3 and relative humidity. Air pollution in Kuwait is generated by several sources, which includes motor vehicles, power plants, oil fields, petroleum refineries, construction sites, and other industries Ettouney et al. [3] estimated the emission inventory of SO_2, CO and NO_X from these sources in Kuwait. They used these estimates and the ISCST Ettouney et al. [4] model to predict pollutant dispersion and compare it against the pollutants data base for 2003 in Al-Jahra, Kuwait. Furthermore, ozone concentration was forecasted by using two feed forward artificial neural network (ANN). Also, the predictions of the ISCST model and the data base were nearly the same for the hourly average but a difference was observed for the hourly maxima. Finally, the ANN method proved that with high wind speed, the ozone concentration will be high. Air quality data were assessed by Ettouney et al. [5] from two monitoring stations in Kuwait named as Al-Jahra and Umm-Alhyman. The data were covered a period of four years and was analyzed for annual hourly and 1-h maxima. Concentrations of CO, CO_2, MHC, NMHC, NO_X, SO_2, O_3, and PM_{10} were considered. Moreover, meteorological parameters were included which are temperature, wind speed, wind direction and solar intensity. It was concluded that all data are within the air quality standards except for PM_{10} due to short rain season. Also, it was observed that the NO_X concentrations increase because of increasing industrial activities and vehicles.

II. MEASUREMENTS AND LOCATION

Measurements were made in the Kuwait Environmental Public Authority (KEPA) fixed and mobile stations in Umm-Alhyaman, Kuwait, Fig. 1. Details of the measuring instruments can be found in Ettouney [5]. Umm-Alhyman is a residential area located at 45 km south-east of Kuwait city. As shown in Fig. 1, it is surrounded by various sources of air pollutants, which includes a large oil field, power plant, three oil refineries (Al-Ahmadi, Shuiaba, and Mina-Abdullah), chemical manufacturing and petroleum industries, and several highways.In this study, the pollutant concentrations were collected in 2001, 2004, and 2008 from Umm-Alhyman station. Pollutants were measured at five minutes intervals for 24 hours a day in addition to measurements of meteorological parameters. The pollutants concentrations were taken for methanated and non-methanated hydrocarbons (MHC, NMHC), CO, CO_2, SO_2, NO_X, O_3, and PM_{10} Moreover, the meteorological data included wind speed, wind direction, ambient temperature and solar intensity.

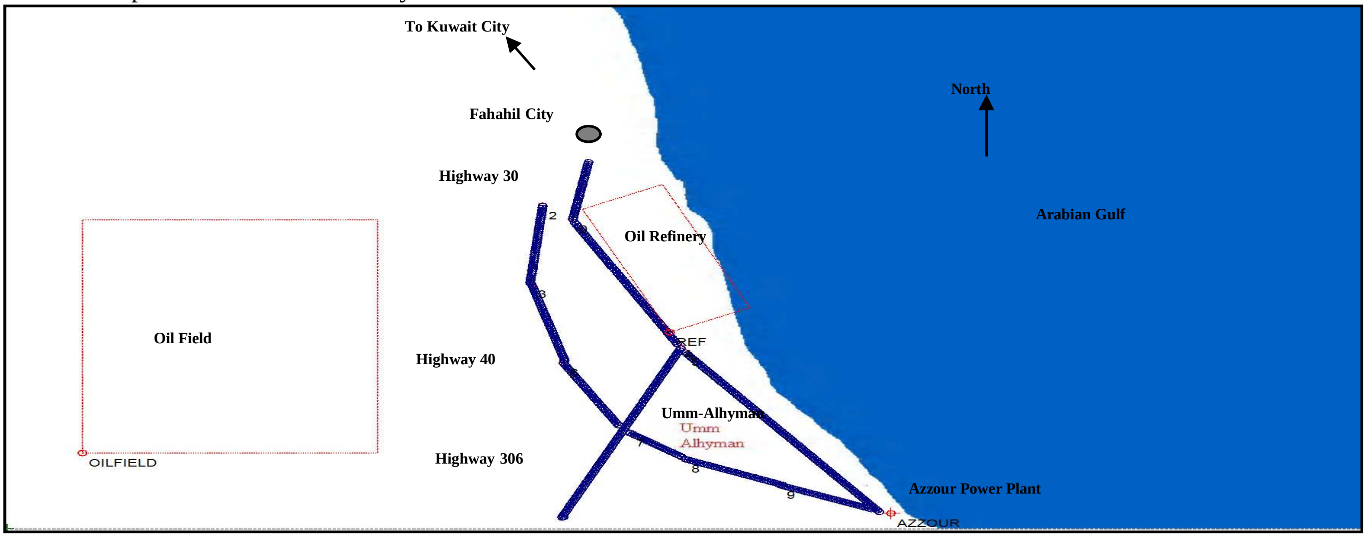

Fig. 1 Umm-Alhyman location and sources of pollutants

III. SOURCE EMISSION RATE

Models for estimates of source emission rates can be found in Ettouney [3], [4] and [5]. Tables I - IV show summary of emission rate data from oil fields, power plants, refineries, and motor vehicles. Summary of the emission data show that the main source for CO is motor vehicles (78%) and the main source for SO_2 (53%) and the main source for NO_X (46.9%) is power plant.

IV. ISCST3 MODEL

Industrial Source Complex Short Term Model (ISCST3) provides options to model emissions from five basic sources, which include point, volume, area, line and open pit sources The ISCST3 model requires information on source, meteorological data, and receptor [7].

V. MEASURED AND PREDICTED DATA

Graph of the measured and predicted values for SO_2 concentrations at Umm-Alhyman are shown in Fig. 2. As shown excellent fit is obtained between measured and predicted values with R^2 values equal 0.99.To obtain a good fit of the ISCST3 model prediction and the measured data it was necessary to adjust the value of the emission rates from various sources. This procedure showed that the best fitting results were obtained upon adjustment of the emission rates from the oil field and the oil refineries. On the other hand, the emissions of the power plant and motor vehicles were kept constant in all calculations and it exhibited negligible effect on the accuracy of the fit. The ratio of the adjusted to the model values of the refineries varied over a range of 0.1-0.98. Similarly, the ratios for the oil fields varied between 0.11-0.38.

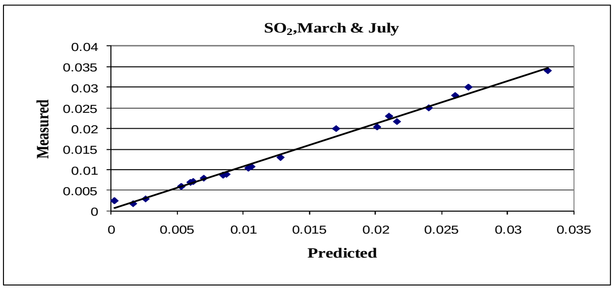

Fig. 2 Measured and Predicted concentrations of SO_2

Graph of the measured and predicted values for NO_X concentrations at Umm-Alhyman are shown in Fig. 3. Measured and predicted concentrations were close more than SO_2 concentrations and excellent fit is obtained with R^2 value equal 0.998. The emission rates were adjusted for motor vehicles and oil field only which showed the best fitting results. The emissions of the power plant and oil refineries were kept unchanged in all calculations. The ratio of the adjusted to the model values of the motor vehicles varied over a range of 0.11-0.440. As well as, the ratios for the oil field varied over a range of 0.108-0.993

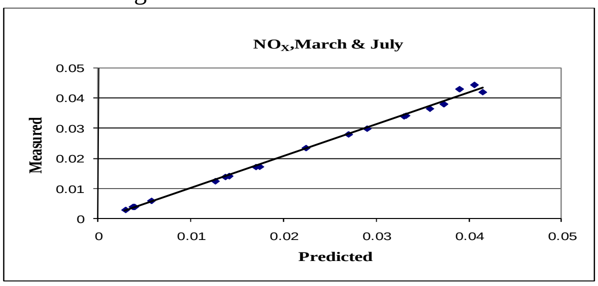

Fig. 3 Measured and Predicted concentrations of NO_X

Graph of the measured and predicted values for CO concentrations at Umm-Alhyman are shown in Fig. 4. As shown the best fit in comparison between SO_2, NO_X and CO is obtained for CO between measured and predicted values with R^2 equals 0.999. The emission rates from motor vehicles and oil field sources were adjusted. This gave the best fitting results. The ratio of the adjusted to the model values of the motor vehicles varied over a range of 0.336-0.904. Also, the ratios of the adjusted to the model values for the oil field varied between 0.682-1.000.

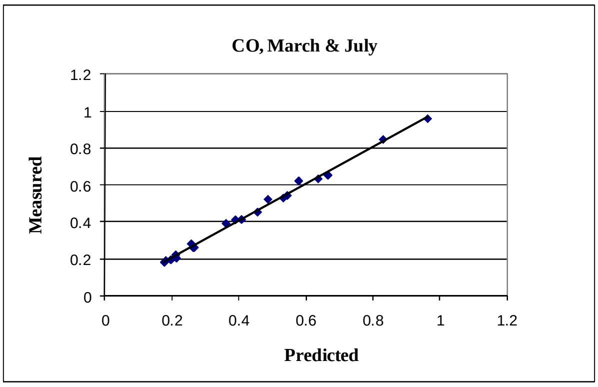

Fig. 4 Measured and Predicted concentrations of CO

VI. Comparison Against Epa Standards

To assess the air pollution data, it was compared against international standards given by US-EPA. The comparison was made for the measured data in March and July of 2001, 2004, and 2008. Tables V - IX show comparison of the measured data and the international standards for SO_2, NO_X, and CO.

The measured SO_2 concentrations are indicative of the large effect of flaring of untreated vapors and gases in the oil field. As shown the measured 1-hr SO_2 concentrations vary between 14-71% of the international limits. Similarly, the measured 24-hr averages vary between 10-47% of the international limits.

There is consistent increase in the measured NO_X concentration between 2001 and 2004, where its 1-hr averages were fluctuating between 20-65% of the international standards. This trend is also supported by comparison of the annual averages between 2001 and 2004. The increasing trend in NO_X is attributed to continuous increase in population and the number of motor vehicles. Furthermore, in 2008 the measured 1-hr NO_X concentration exceeded the international standard.

Examining the CO pollution data show a large difference against the international standards, where the 1-hr average of the measured data vary between 2-10% of the international limits. Similarly, the 8-hr averages give smaller values than the international limits, where the measured data varied between 5-13% of the international standards. These low values can be attributed to the high temperature averages in Kuwait, where maximums close to 50 °C can be found during the summer time and the minimums fluctuates between 10-15 °C in the winter time. Therefore, emitted CO gases are easily oxidized to CO_2 and other more complex carbon based compounds.

TABLE I
EMISSION RATES FOR THREE REFINERIES IN KUWAIT

Parameter	Ahmadi	Abdullah	Shuaiba	Total
SO_2 (kg/hr)	186	108	88	382
CO_2 (kg/hr)	34913	20191	16405	71509
Total flue gas (kg/hr)	175499	101493	82463	359455
Volumetric Flow Rate (m3/hr)	10693	6184	5024	21902
Stack Diameter (m)	0.5	0.38	0.34	1.228

TABLE II
AGGREGATED EMISSION RATES FOR OIL FIELDS IN KUWAIT

Pollutant	Ton/yr	kg/hr
SO_2	65000	7420.091
CO	15000	1712.329
NO_2	5000	570.7763

TABLE III
HOURLY EMISSION RATES AND STACK DIAMETER FROM AZZOUR POWER PLANTS

Lcoation	Power (MW)	SO_2 (kg/hr)	NO_X (kg/hr)	total (kg/hr)	total (m^3/hr)	Diameter (m)
Azzor North	2500	2500	375	7514375	457850.9	3.3
Azzor South	3511	3511	526.65	10553188.25	643005.8	3.9

TABLE IV
ANNUAL AND HOURLY EMISSION RATES FOR MOTOR VEHICLES IN KUWAIT

Parameter	Value	Units
Specific emission rate CO	12.98666	gm/km/car
Specific emission rate NO_X	0.863706	gm/km/car
Annual distance travelled	20,000	km/yr/car
Annual emission rate CO	259.7332	kg/yr/car
Annual emission rate NO_X	17.27412	kg/yr/car
Number of cars per 1,000 inhabitants in Kuwait	332	-
Kuwait population	2.00E+06	inhabitants
Total number of cars in Kuwait	6.64E+05	cars
Annual emission rate CO	1.72E+08	kg/hr
Annual emission rate NO_X	1.15E+07	kg/hr
Hourly emission rate CO	19,687.54	kg/hr
Hourly emission rate NO_X	1,309.362	kg/hr

TABLE V
COMPARISON OF MEASURED DATA IN UMM-ALHYMAN AND EPA CRITERIA IN 2008

Pollutant	Measured (ppm)	EPA Criteria (ppm)	Average Time
CO	2.780	35	1-hr
CO	1.065	9	8-hr
NO_X	0.153	0.15	1-hr
NO_X	N/A	0.0795	Annual
SO_2	0.026	0.14	1-hr
SO_2	0.008	0.075	24-hr

TABLE VI
COMPARISON OF MEASURED DATA IN UMM-ALHYMAN AND EPA CRITERIA IN 2004

Pollutant	Measured (ppm)	Measured (ppm)	EPA Criteria (ppm)	Average Time
CO	1.190	3.159	35	1-hr
CO	0.750	1.089	9	8-hr
NO_X	0.094	0.030	0.15	1-hr
NO_X	0.027	0.027	0.0795	Annual
SO_2	0.020	0.061	0.14	1-hr
SO_2	0.013	0.023	0.075	24-hr

TABLE VII
COMPARISON OF MEASURED DATA IN UMM-ALHYMAN AND EPA CRITERIA IN 2001

Pollutant	Measured (March) (ppm)	Measured (July) (ppm)	EPA Criteria (ppm)	Average Time
CO	1.246	0.792	35	1-hr
CO	0.672	0.481	9	8-hr
NO_X	0.065	0.098	0.15	1-hr
NO_X	0.017	0.017	0.0795	Annual
SO_2	0.099	0.033	0.14	1-hr
SO_2	0.035	0.008	0.075	24-hr

VII. CONCLUSION

This study continues previous efforts on assessment and analysis of air pollution in Kuwait. Several studies were performed in Kuwait during the past two decades aiming at studying air pollutant patterns, dispersion, and photochemical mechanisms. From data analysis, it was found that the measured pollutants concentrations were increased by factors of 1.2, 5.5, and 2 for SO_2, NO_X, and CO respectively between 2001 and 2008 due to the increase of Kuwait's population. The increase in the amount of measured SO_2 is explained in terms of increase in the industrial activities in the vicinity of Umm-Alhyman, which may include expansions in oil field production, refinery activities, as well as small scale and private industries that includes paper mills, iron and steel, etc. Fitting of the ISCST3 model predictions and the measured data were made through adjustment of the emission rates from various sources. This was necessary to reflect seasonal and daily variations in the emission rates due to increase/decrease in production of power and oil as well as fluctuations in traffic volume. Excellent fits were obtained between measured and predicted values with R^2 close to one.

The ratio of the measured 1-hr averages of SO_2, NO_X and CO to the international limits in 2001 and 2004 varied over the following ranges 14-71%, 20-65%, and 2-10%, respectively. However, NO_X concentration exceeded the international standards in 2008 but SO_2 and CO concentrations varied over similar ranges as those found in 2001 and 2004. The 24-hr averages of SO_2 were found to vary between 10-47% of the international limits over the study period, which included 2001, 2004 and 2008. The 8-hr averages of the measured data were found to vary between 5-13% of the international standards for CO. The annual averages for NO_X in 2001 and 2004 varied over a range of 22-33% of the international limits.

Air pollution measurements and analysis provides insights into the status and levels of air pollution and how it compares to international limits. The results and analysis presented in this study show that current status of air pollution for CO and SO_2 remains to be on the safe limits with values much lower than the international limits. On the other hand, the status of NO_X levels indicates that the international limits were exceeded in 2008.

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