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Abstract

Fluid catalytic cracking unit is of great importance in petroleum refining industries as it treats heavy fractions from various process units to produce light ends (valuable products). FCC unit feedstock consists of heavy hydrocarbon with high sulphur contents and the catalyst in use is zeolite impregnated with rare earth metals i.e. Lanthanum and Cerium. Catalytic cracking reaction takes place at elevated temperature in fluidized bed reactor generating sulphur-contaminated coke on the catalyst with large quantity of attrited catalyst fines. In the regenerator, coke is completely burnt producing SO_2, PM emissions. The impact of the FCC unit is assessed in the immediate neighborhood of the refinery. Year long emission inventories for both SO_2 and PM have been prepared for one of the major petroleum refining industry in Kuwait. The corresponding comprehensive meteorological data are obtained and preprocessed using Aermet (Aermod preprocessor). US EPA approved dispersion model, Aermod is used to predict ground level concentrations of both pollutants in the selected study area. Model output is validated with measured values at discrete receptors and an extensive parametric study has been conducted using three scenarios, stack diameter, stack height and emission rate. It is noticed that stack diameter has no effect on ground level concentration, as stack exit velocity is a function of stack diameter. With the increase in stack height, the predicted concentrations decrease showing an inverse relation. The influence of the emission rate is linearly related to the computed ground level concentrations.

Keywords: Dispersion model, Aermod, emissions, FCC, pollutants exeedance

1. Introduction

Fluid catalytic cracking (FCC) of heavy ends into high value liquid fuels is a common practice in the oil refining industry. In this process the heavy feedstock containing sulphur as a major contaminant is cracked to light products. Sulphur is redistributed in the liquid and gaseous products and coke on the catalyst. In the regenerator coke with sulphur contamination is completely burnt and flue gas containing SO_2 is discharged. In the present work, a comprehensive emission inventories from FCC unit in an oil refinery have been prepared. These inventories are calculated based on complete combustion of sulphur and coke impregnated on the catalyst in the regenerator. Mainly for both SO_2 and particulate matters (PM) emission rates are calculated accurately using material balance for a yearlong period considering seasonal variations in the operation of the process unit in one of the main refinig industry in Kuwait, Yateem et al., (2010). These results reflect the variation of sulphur in feedstock that comes from various refinery units. SO_2 and PM emission inventories are completed and used in dispersion model to assess their impact on the immediate surroundings of the refinery.

The most advanced dispersion model AERMOD has been selected for prediction ground level concentration of SO_2 and PM based on comprehensive year long emission inventories of FCC unit.

Aermod is a dispersion model that uses Gaussian distribution for the stable conditions and non-Gaussian probabilities density function for the unstable conditions. Aermod has two preprocessors; Aermet that provides planetary boundary layer parameters over a high altitude to yield accurate predicted concentration values for a given meteorological conditions. It can accommodate large meteorological data (multiple years). Aermap generates regular receptors over a given terrain for the evaluation of pollutants ground level concentrations.

The meteorological data for year 2008 are obtained and are used in preprocessor AERMET to generate planetary boundary layers parameters. These generated data are used in AERMOD for fixed emission rate to assess the influence of prevailing meteorological conditions at this particular site. AERMOD has been used for actual yearlong inventories to predict ground level concentrations and validate the model by comparing the results against the recorded values from Kuwait Environmental Public Authority (K-EPA) monitoring stations.

2. Background

Heavy fractions from different refining units are cracked in FCC unit to useful products, generating SO_2 and PM emissions. SO_2 emission inventory is prepared from elemental sulphur balance over the unit, Yateem et al., (2010).

Whitcombe et al., (2003) showed the formation of fines in a fluidized catalytic cracker unit (FCCU) due to catalyst attrition and fracture as a major source of catalyst loss. The petroleum industry employs fluid catalytic cracking units (FCCUs) as the major tool to produce gasoline from crude oil. At the center of this unit is regenerator which is used to burn coke from the surface of the spend catalyst. As the regeneration process is very turbulent, a large amount of catalyst material is discharge to the atmosphere. In addition to the fine particles present in the catalyst, the turbulent conditions inside the FCC alter the particle size distribution of the catalyst generating fine particles and significant amount of aerosols, which has been identified in the stack emission of FCCUs

Caputo et al., (2003) conducted an inter-comparison between Gaussian, Gaussian segmented plumes and Lagrangian codes. Gaseous emissions are simulated under real meteorological conditions for dispersion models Aermod, HPDM, PCCOSYMA and HYSPLIT. The AERMOD and HPDM meteorological preprocessors results are analyzed and the main differences found are in the sensible heat flux (SHTF) and u* (friction velocity) computation, which have direct effect on the Monin–Obukov length and mixing height calculation. Gaussian models (Aermod, HPDM) computed the dispersion parameters by using the similarity relationships, whereas Gaussian segmented model (PCCOSYMA) used P-G stability class to evaluate these parameters. Lagrangian transport model (HYSPLIT) advected the puff and calculated its growth rate with local mixing coefficients. Meteorological parameters have great effect on the performance of air dispersion models. Therefore, Aermod and HPDM have developed effective and sophisticated meteorological parameters preprocessors. It is noticed that HPDM computed the most stable condition and the lowest mixing height. The comparison also showed a significant discrepancy between HPDM and other Gaussian models. The maximum ground level concentration predicted by Aermod, HPDM and PCCOSYMA are similar.

Rama Krishna et al., (2004) examined the assimilative capacity and the dispersion of pollutants resulted from various industrial sources in the Visakhapatnam bowl area, which is situated in coastal Andhra Pradesh, India. Two different air dispersion models (Gaussian plume model, GPM and ISCST-3) are used to predict ground level concentrations of Sulphur Dioxide and oxides of Nitrogen and assimilative capacity of the Visakhapatnam bowl area's atmosphere for two seasons, namely, summer and winter. The computed 8-hr averaged concentrations of the two pollutants obtained from the GPM and ISCST-3 are compared with those monitored concentrations at different receptors in both seasons and the validation carried out through Q-Q plots. Both models outputs showed similar trend with the observed values from the monitoring stations. The GPM output showed over-prediction, whereas the ISCST-3 showed under-prediction in comparison with the observed concentrations. Terrain features and land/sea breeze influences are not considered in this study, which strongly affected the models outputs.

Venkatram et al., (2004) evaluated dispersion models for estimating ground level concentrations in the vicinity of emission sources in the urban area of university of California, Riverside. Aermod-PRIME and ISC-PRIME dispersion models are used to predict SF_6 at different receptors, where SF_6 is used as tracer in a simulated non-buoyant release from a small source in urban area. Both models output are compared with hourly-observed concentrations. The comparison showed that both models overestimate the highest concentrations, whereas lower range of concentrations is underestimated. It is concluded that Aermod can predict reliable concentrations if turbulent velocity measurements are used to estimate plume dispersion.

Lopez et al., (2005) assessed the impact of natural gas and fuel oil consumption on the air quality in an Industrial Corridor, Mexico to determine the optimal NG and fuel oil required to reduce SO_2 concentration. Air dispersion model Aermod is used to compute ground level concentration of SO_2. Model output is then validated against SO_2 field measurements. Different hypothetical emission scenarios are performed to examine the impact of NG and fuel oil mixture. The obtained results in this work indicate that dispersion model Aermod presented good correlation with the measured concentrations. It is also concluded that increasing 40 % of NG consumption will reduce SO_2 concentration by 90 %.

Kesarkar et al., (2007) studied the spatial variation of PM_{10} concentration from various sources over Pune, India. Guassian air pollutant dispersion model Aermod is used to predict the concentration of PM_{10}. Weather research and forecasting (WRF) model is used to furnish Aermod with planetary boundary layer and surface layer parameters required for simulation. Emission inventory has been developed and field-monitoring campaign is conducted under Pune air quality management program of the ministry of Environment and Forests. This inventory is used in Aermod to predict PM_{10}. A comparison between simulated and observed PM_{10} concentration showed that the model underestimated the PM_{10} concentration over Pune. However, this work is conducted over a short period of time, which is not sufficient to conclude on adequacy of regionally averaged meteorological parameters for driving Gaussian models such as Aermod.

Isakov et al., (2007) examined the usefulness of prognostic models output for meteorological observations. These models outputs are used for dispersion applications to construct model inputs. Dispersion model Aermod is used to simulated observed tracer concentrations from Tracer Field Study conducted in Wilmington, California in 2004. Different meteorological observations sources are used i.e. onsite measurements, National Weather Services (NWS), forecast model output from ETA model and readily available and more spatially resolved forecast model from MM5 prognostic model. It is noted that MM5 with higher grid resolution than ETA performed better in describing sea breeze related to flow patterns observed and provided adequate estimates of maximum mixed layer heights observed at the site. It is concluded that MM5 and ETA prognostic models provided reliable meteorological inputs for dispersion models such as Aermod, because wind direction estimates from forecast models are not reliable in coastal areas and complex terrain. Therefore, comprehensive prognostic meteorological models can replace onsite observations or NWS observations.

Abdul Wahab et al., (2002) studied the impact of SO_2 emissions from a petroleum refinery on the ambient air quality in Mina Al-Fahal, Oman. Dispersion model ISCST is used to predict SO_2 ground level concentration. The study is performed over a period of 21 days. Computed SO_2 concentrations are compared with the measured values of SO_2 for maximum hourly average concentration, maximum daily concentration and total period average concentration. It is noted that the model output under-predicted the SO_2 concentration for all the three cases due to unavailability of background concentrations and the presence of more dominant sources. Based on the maximum daily average concentration and the total period maximum concentration, the model under-predicted the average measured concentration by 31.77 % and 41.8 % respectively. The model performed slightly better based on maximum hourly average concentration and under-predicted by 10.5 %.

Zou et al; (2010) evaluated the performance of Aermod in predicting SO_2 ground level concentration in Dallas and Ellis counties in Texas as these two counties are populous and air pollution has been a concern. Two emission sources are considered in this study i.e. point sources and on-road mobile sources. Aermet is used to calculate the hourly planetary boundary layer parameters such as Monin-Obikhov length, convective scale, temperature scale, mixing height and surface heat flux. Dispersion model Aermod is used to simulate SO_2 ground level concentration at different time scale i.e. 1hr, 3hr, 8hr, daily, monthly and annually for both counties separately. The results are validated with the observed concentrations. The results showed that Aermod performed well at the 8hr, daily, monthly and annual time scale when combined point and mobile emission sources are used in the simulation as model input. It is also noticed that Aermod is performed much better in simulating the high end of the spectrum of SO_2 concentrations at monthly scale than at time scales of 1hr, 3hr, 8hr and daily.

Alrashidi et al; (2005) studied the locations of Kuwait Environmental Public Authority (K-EPA) monitoring station, which measure SO_2 concentrations emitted from the power stations in the state of Kuwait. The major sources of SO_2 emissions in Kuwait are from west Doha, east Doha, Shuwaikh, Shuaiba, and Az-Zour power stations. The Industrial Source Complex Short Term (ISCST3) dispersion model is used to predict SO_2 ground level concentrations over residential areas. Yearlong meteorological data are obtained from Kuwait International Airport and used in the simulation of the dispersion model. Different discrete receptors in the residential areas are selected. It is observed that the weather pattern in Kuwait, specially the prevailing wind direction, has strong influence on the ground level concentration of SO_2 in the residential areas located downwind of the both east and west Doha stations. The comparison between the predicted and the measured concentrations of SO_2 from the monitoring stations located at the major populated areas showed that most of these monitoring stations locations are not adequate to measure SO_2 concentrations emitted from the power stations. Therefore, relocation of the monitoring stations is highly recommended to accurately record the highest ground level concentrations of SO_2 emitted from the power stations in Kuwait.

3. Model Application

3.1 Input Data

Aermod dispersion model implementation requires three main input data. These are:

1. Source information: including pollutant emission rate (g/s), location coordinates in Universal Transverse Mercator (UTM) (m), base elevation from the sea level (m), stack height (m), exit stack inner diameter (m), exit stack gas velocity (m/s), and exit stack gas temperature (^oK).
2. Meteorological information for the region of interest: includes anemometer height (m), wind speed (m/s), wind direction (flow vector from which the wind is blowing) (in degrees clockwise from the north), ambient air temperature (^oC), stability class at the hour of measurement (dimensionless) and hourly mixing height (m).
3. Receptor information: This can be specified or generated by the program to predict the pollutants' concentrations at the selected receptors.

The entire required source input data are obtained from FCC unit in the refinery. A stack of 80 m height, an inner diameter of 2.3 m, with an average exit gas velocity of 20 m/s and exit gas temperature of 550 ^oK are fed into the model. Monthly emission variation is considered with total SO_2 emission rate of 6089.2 g/s and total PM emission rate of 302 g/s as presented in detail (Yateem et al. 2010).

3.2 Area of Study

The area of study in this work covers portion of Ahmadi governorate in the state of Kuwait. Fahaheel area is adjacent to the petroleum refinery has one of the Kuwait EPA air quality monitoring station located at a polyclinic. Both areas Fahaheel and Ahmadi are surrounded by arid desert in the west side and bordered by the Gulf from the east.

Two different types of receptor coordinates are used as input to the Aermod model to predict the ground level concentration of SO_2, these are:

1. Discrete Cartesian receptors specified at the sensitive areas viz., a school, a shopping area and EPA monitoring stations in Fahaheel. A hospital and petroleum services companies' offices are selected in Ahmadi.
2. Uniform Cartesian Grid receptors covering the entire area of study, where the FCC stack (emissions source) is located almost in the center of the mesh grid.

The receptors selected are based on the actual sites in a UTM location coordinate of the area of interest map. Table 1 shows the selected discrete receptors information.
The uniform grid receptors of a total 1764 (42 x 42) were divided into (Δx = 300 m x Δy = 250 m) to cover about 12 x 10 km area of study. The optimum selection of the mesh size is based on the computational accuracy and time.

Table1. The selected discrete receptors information

ID Number	Discrete receptor identity	X-coordinate	Y-coordinate
1	Fahaheel Polyclinic	219854.25	3219765.79
2	Petroleum Services Offices in Ahmadi	216666.87	3220105.63
3	School in Fahaheel	220300.00	3219820.85
4	Ahmadi Hospital	213458.86	3221523.64
5	Shopping area in Fahaheel	219274.32	3219554.21

4. Results And Discussion

A yearlong comprehensive metrological data are processed by AERMET to generate boundary layer parameters and to pass all meteorological observations to AERMOD.

Figure 1 shows wind direction and magnitude for a period of year 2008. It is observed that most of the time; the prevailing wind direction is from North West. There is strong influence from the neighboring Gulf as the refinery is located at the coast, resulting into strong sea breeze blowing from East direction. Wind class frequency distribution for the entire year confirming 2 % calm conditions, while 39.8 % is between 3.6 - 5.7 m/s. the highest wind class 8.8-11.1 m/s is less than 1%.

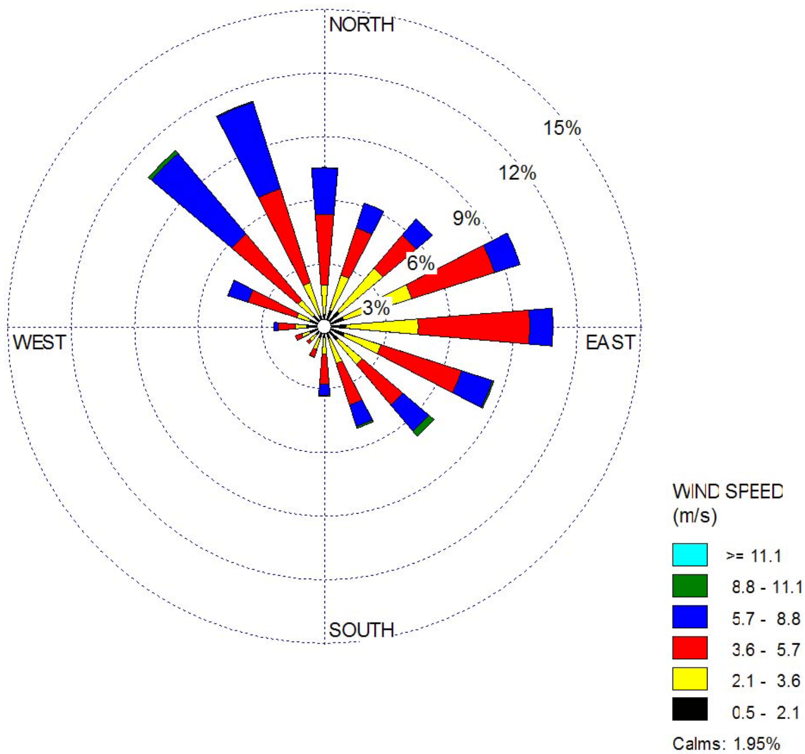

Fig. 1 wind rose for a period of year 2008

A model run is performed for actual monthly emission variation with total annual SO_2 emission rate of 6089.2 g/s and total PM emission rate of 302 g/s independently. Monthly emission factors for both pollutants are tabulated in Table 2 and 3 respectively.

A discrete receptor is selected at Kuwait Environmental Public Authority monitoring station located at polyclinic in Fahaheel area. Concentrations of SO_2, NO_x, H_2S, O_3, CO, CO_2, methane, non-methane hydrocarbon, Benzene, Toluene, Xylenes, ethylbenzene, total suspended particulates and meteorological parameters are continuously recorded on hourly basis.

Table 2 SO_2 monthly emission factors

January	February	March	April	May	June
0.077	0.083	0.096	0.1	0.077	0.088
July	August	September	October	November	December
0.067	0.067	0.088	0.077	0.1	0.075

Table 3 PM monthly emission factors

January	February	March	April	May	June
0.093	0.097	0.091	0.079	0.079	0.083
July	August	September	October	November	December
0.064	0.063	0.085	0.079	0.079	0.1

Hourly predicted ground level concentrations at specified discrete receptor showed large scatter due to variation in meteorological conditions and the recorded values influenced by the contribution of various emission sources, resulting into specific background concentration that has made the comparison impracticable. There is large fluctuation in the background concentration, which is difficult to quantify. Hence, zero background concentration has been assumed to resolve this uncertainty. Therefore, daily average measured concentrations of SO_2 were compared with the daily-predicted concentrations to validate the model output.

Figure 2 shows the plot between the measured top 20 daily average values versus the daily predicted top 20 values at the discrete receptor, Kuwait-EPA monitoring station.

The slope is equal to 0.72, reflecting high measured values compared to predicted values, depicting the contribution of other emission sources. The correlation coefficient is equal to 0.91 reflecting an acceptable validation of the model output with measured average daily SO_2 concentrations.

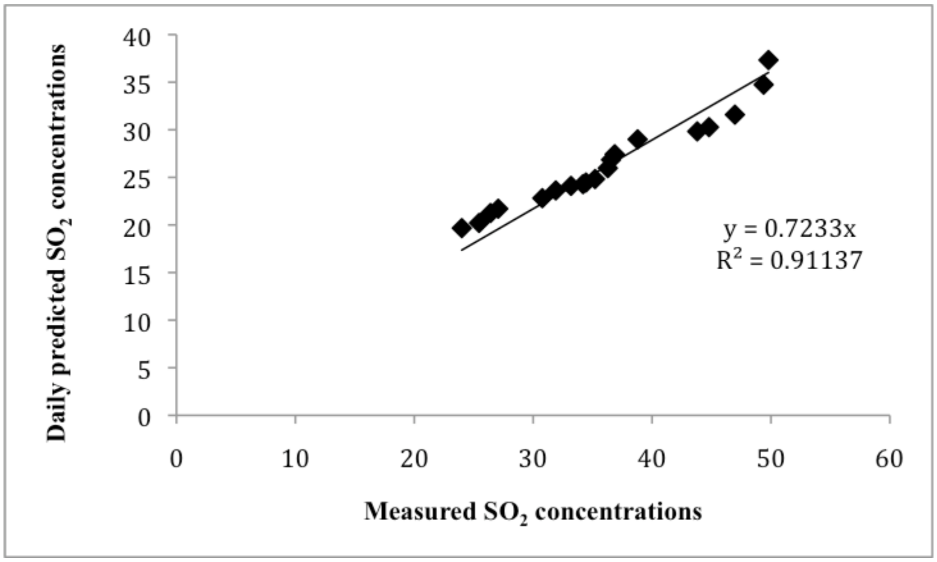

Fig. 2 Daily predicted SO_2 concentrations vs. measured SO_2 concentrations

The predicted hourly average ground level concentrations of SO_2 are compared with Kuwait-EPA Ambient Air Quality Standards (AAQS) at all of the selected receptors.

The maximum allowable level for the hourly average concentration of SO_2, specified by Kuwait-EPA, is 444 µg/m^3. Fig. 3 shows the isopleths of the predicted hourly average ground level concentration of SO_2 calculated at the selected uniform grid receptors.

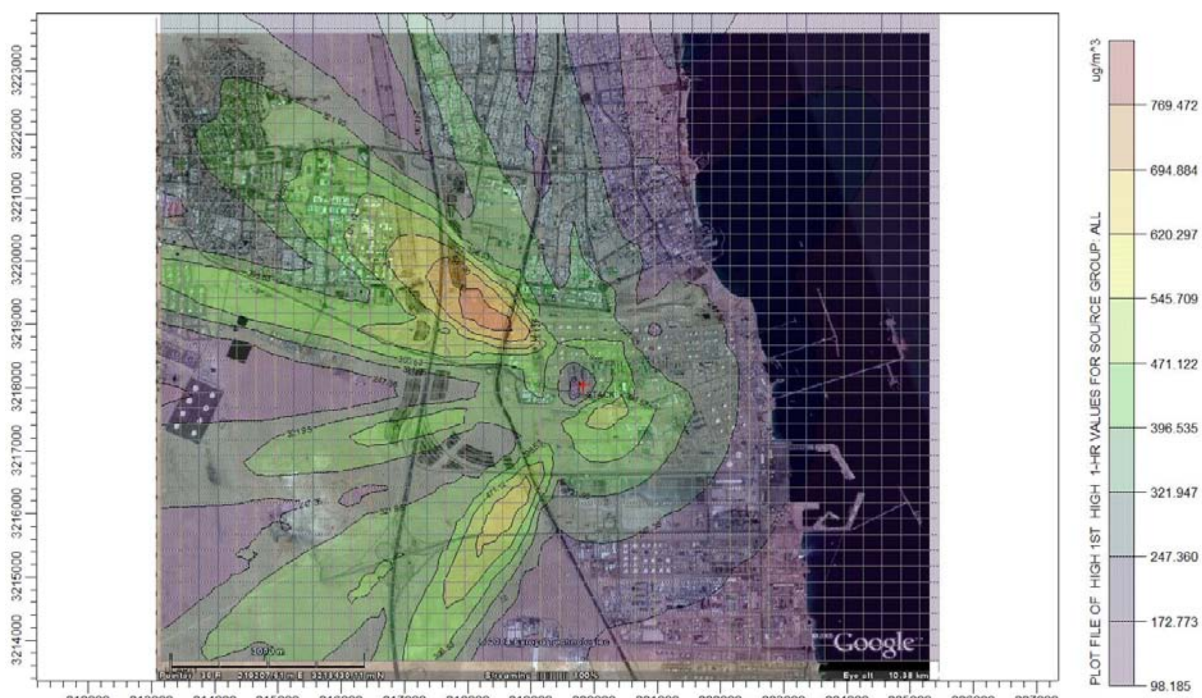

Fig. 3 Isopleths plot of the predicted hourly average ground level concentration of SO_2

The isopleths indicate the predicted spatial variations of the ground level concentrations of SO_2. The maximum predicted hourly average ground level concentration of SO_2 in the vicinity of the refinery exceeded by as much as 300 μg/m^3. The highest predicted concentration is equal to 769 μg/m^3, observed on the 8th of March 2008 at 8:00 hour and about 1. 713 km in the NW direction from the FCC stack, and not far from the Fahaheel and Ahmadi areas at the receptor coordinates of X = 218557.94, Y = 3219169. This high value of the predicted SO_2 concentration is expected due to the elevated SO_2 emission rate, which resulted from the high sulphur content in the FCC feedstock and other operational conditions and the prevailing meteorological conditions (temperature, humidity, wind speed, wind direction, stability class and planetary boundary layer).
A thorough inspection on fig. 3 indicates that predicted concentrations of SO_2 exceed the allowable hourly limit at 5.3 % of the study area from North West and South West direction from the stack.

Similarly, the predicted daily average ground level concentration of SO_2 is compared with Kuwait EPA ambient air quality standards at all receptors. The allowable level for the daily average concentration of SO_2 is 157 μg/m^3. Fig. 4 shows the isopleths of the predicted daily average ground level concentration of SO_2 computed at the selected uniform grid receptors.

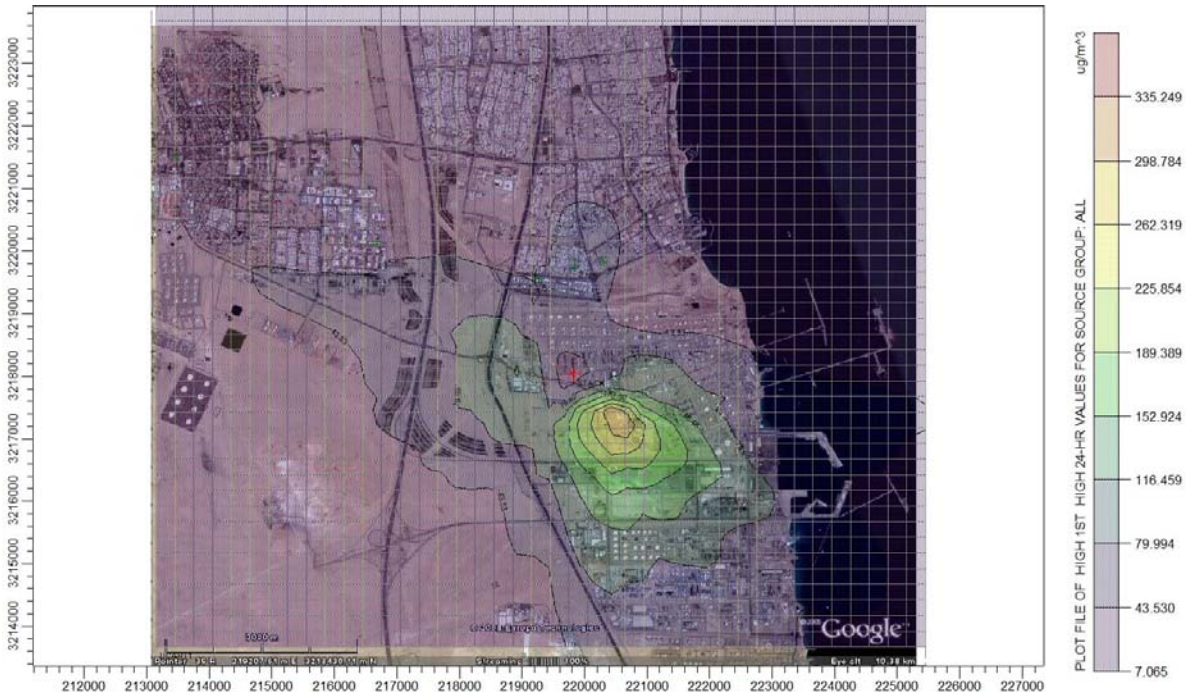

Fig. 4 Isopleths plot of the predicted daily average ground level concentration of SO_2

The isopleths indicate the daily predicted spatial variations of the ground level concentrations of SO_2 in the area of study. The highest daily predicted concentration is equal to 335 µg/m^3, observed on the 9th of November 2008 and about 0.75 km in the SE direction from the stack, at a receptor coordinates of X = 220357.94, Y = 3217419 affecting the neighboring Shuaiba industrial area, Kuwait main industrial complex. This high value of the daily predicted SO_2 concentration is exceeded the allowable level by 157 µg/m^3 and obviously influenced by the prevailing meteorological conditions, especially the predominant North West wind and other meteorological factors.

Discrete receptor 2, is located at Petroleum services offices, has shown the highest SO_2 hourly concentration equal to 544 µg/m^3 on 27th February at 8:00 hours. The hourly exceedance is occurred four times at this location throughout the study period. The highest daily concentration at the same receptor is equal to 39 µg/m^3 on 8th March.

Discrete receptor 3, is located at school, has shown the highest SO_2 hourly concentration equal to 279 µg/m^3 on 2nd March at 4:00 hours. This concentration is below the Kuwait EPA hourly standards. The daily highest concentration is equal to 57 µg/m^3 on 2nd

March.

Discrete receptor 4, is located at Ahmadi hospital, has shown the highest SO_2 hourly ground level concentration equal to 288 µg/m^3 on 27th February at 8:00 hours. This value is also below the specified hourly limit set by Kuwait EPA. The daily predicted concentration is equal to 23 µg/m^3 on 30th April.

Discrete receptor 5, is located at shopping area, has shown the highest SO_2 hourly ground level concentration is equal to 336 µg/m^3 on 23rd October at 8:00 hours. The daily predicted concentration is equal to 45 µg/m^3 on 22nd April. Both hourly and daily predicted values are below Kuwait EPA hourly and daily ambient air quality standards.

Kulkarni et al., (2009) have reported that Lanthanum and Lanthanides are used as markers for particulate matters pollution as $PM_{2.5}$ in petroleum refineries, mainly from FCC units.

US EPA daily $PM_{2.5}$ standard is 35 µg/m^3. In the present work, the application of Aermod to predict ground level concentration of PM is considered as $PM_{2.5}$ for rare earth metals i.e. Lanthanum and Cerium. $PM_{2.5}$ is inhalable and has adverse impact on public health causing cardiovascular diseases. Kuwait EPA has no standard for $PM_{2.5}$ and has only specified daily and yearly standard for PM_{10}. Figure 5 shows the isopleths of the predicted hourly average ground level concentration of PM calculated at the selected uniform grid receptors.

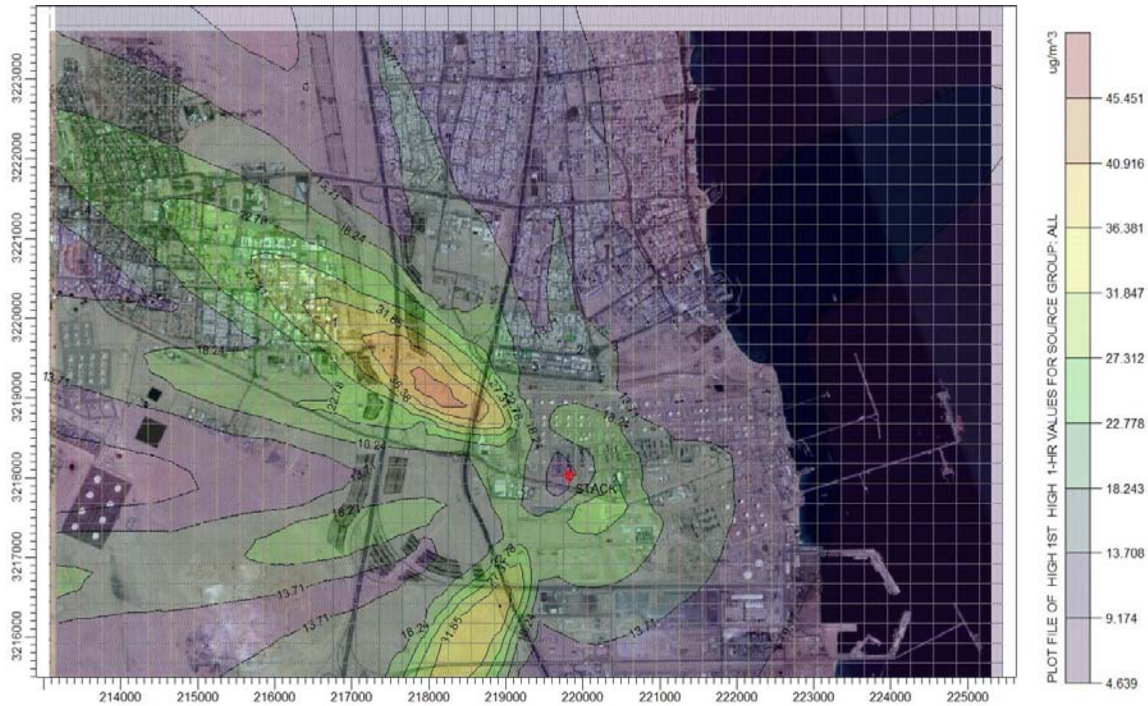

Fig. 5 Isopleths plot of the predicted hourly average ground level concentration of PM

The isopleths indicate the hourly predicted spatial variations of the ground level concentrations of PM. The maximum hourly predicted average ground level concentration of PM is equal to 45 μg/m^3, observed on the 27th of February 2008 at 8:00 hour and about 1.56 km in the NW direction from the FCC stack, and at receptor coordinates of X = 218557.94, Y = 3218919.

Similarly, the predicted daily average ground level concentration of PM is compared with US EPA ambient air quality standards for $PM_{2.5}$ at all receptors. Figure 6 shows the isopleths of the predicted daily average ground level concentration of PM computed at the selected uniform grid receptors.

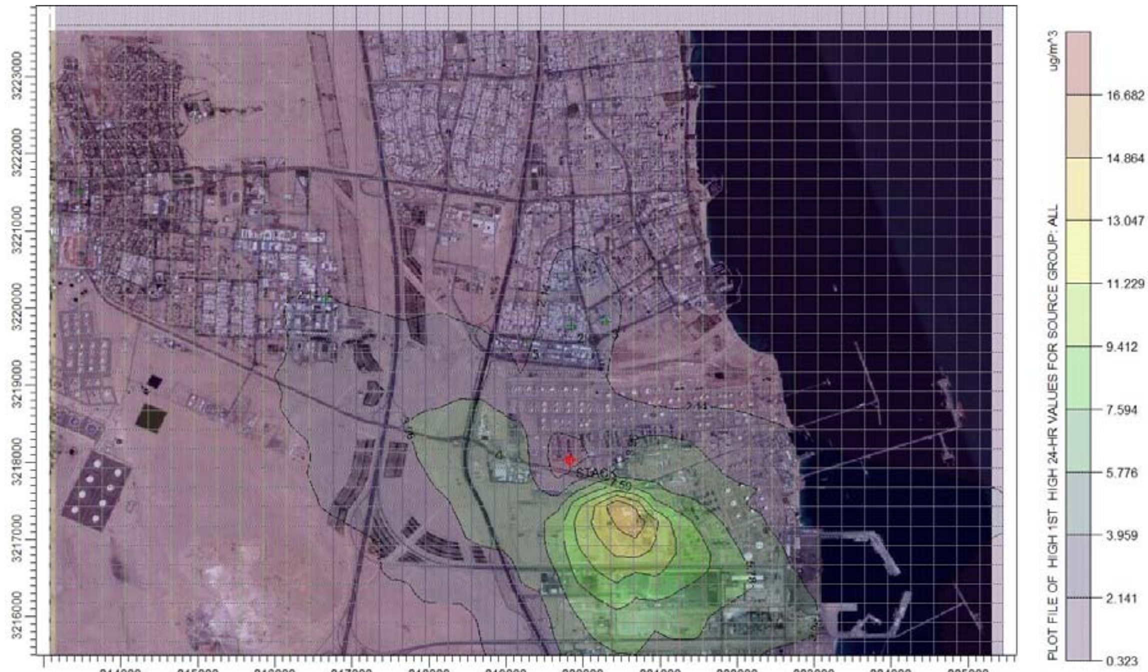

Fig. 6 Isopleths plot of the predicted daily average ground level concentration of PM

The isopleths indicate the daily average predicted spatial variations of the ground level concentrations of PM in the area of study. The highest daily predicted concentration is equal to 16 $\mu g/m^3$, observed on the 29th of December 2008 and about 0.75 km in the SE direction from the stack, at a receptor coordinates of X = 220657.94, Y = 3217419 due to the influence of the prevailing meteorological conditions, especially the predominant North West wind and other meteorological factors.

To observe the computational model sensitivity, another scenario run is performed adding two finer meshes consisting of 21 x 21 uniform receptor points, the first one covering hourly highest ground level concentration area, the other one covering daily highest predicted ground level concentration area. The output accuracy has improved for both pollutants due to application of interpolation using small values of Δx = 150 m, Δy = 110 m for the first mesh and Δx = 100 m, Δy = 100m for the second mesh. There is 0.65% increase in the hourly highest ground level concentration and 2.8% increase in the daily highest ground level concentration, which are insignificant. Therefore, the only parent mesh is used in the computational process for all the other scenarios considered in the parametric studies.

FCC stack sensitivity analysis is performed on 3 scenarios (stack height, SO_2 emission rate and stack diameter).

In scenario 1, analysis for stack heights 50 m, 80 m, 120 m, 160 m and 200 m is conducted while keeping the emission rate, exit flue gas velocity, exit temperature and stack diameter constant.

The influence of stack height is shown in fig. 7. It is obvious from the figure that the highest predicted hourly and daily ground level concentrations of SO_2 are reduced substantially as stack height is increased. The reduction in the highest computed hourly ground level concentration of SO_2 is almost 50% when stack height is doubled. The decrease in evaluated hourly SO_2 concentration as a function of stack height is given as an exponential expression $C(\mu g/m^3) = 1600.7e^{-9.071x10^{-3}h}$ and r^2 is 0.999, where h is the stack height (m). The hourly gradient dC/dh $=14.52e^{-9.071x10^{-3}h}$ becomes insignificant at higher stack elevations. The highest daily predicted ground level concentration as a function of stack height is given as $C(\mu g/m^3) = 1409.8e^{-1.732x10^{-2}h}$ and r^2 is 0.984. The daily highest prdicted concentration gradient is dC/dh$= 24.42e^{-1.732x10^{-2}h}$. The locations of hourly highest predicted concentrations of SO_2 from the stack, as a function of stack height is shown in figure 7 and related as $D(km) = 0.597e^{1.16x10^{-2}h}$ and r^2 is 0. 978.

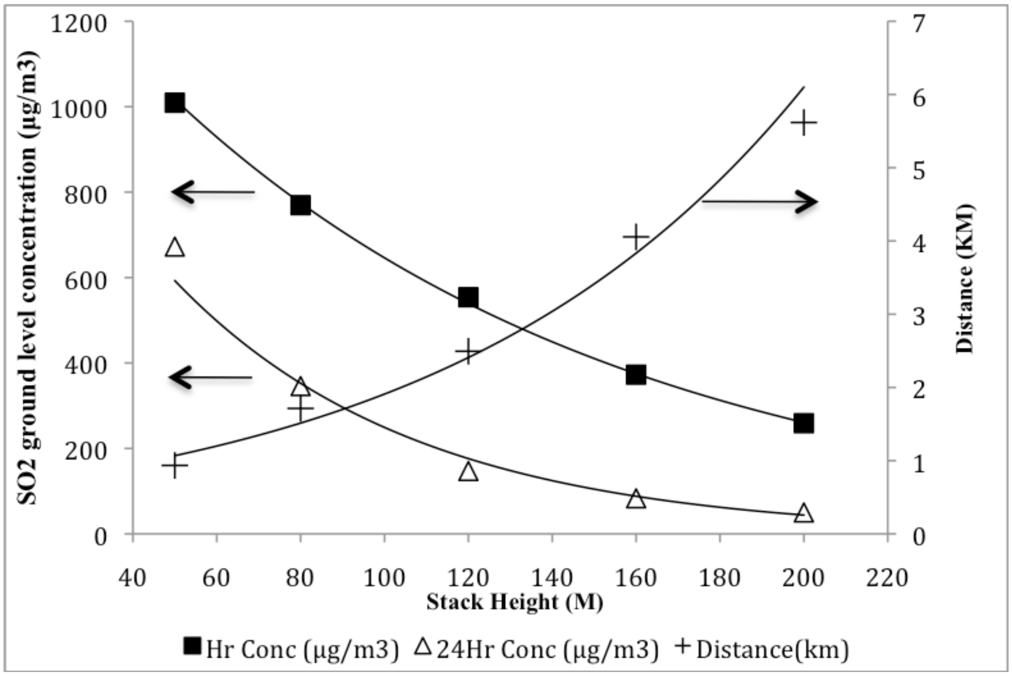

Fig. 7 Stack height vs. hourly and daily predicted ground level concentrations of SO_2

In scenario 2, SO_2 emission rate effect from FCC stack is tested at stack height of 80 m for different total monthly emission rates of 3000 g/s, 4000 g/s, 5000 g/s, 6000 g/s, 7000 g/s and 8000 g/s, taking into consideration the monthly emission variations (by using emission factors, table 2) and fixing other stack parameters i.e. exit temperature, exit flue gas velocity and stack diameter.

It is noticed from fig. 8 that the highest predicted hourly and daily ground level concentrations of SO_2 is substantially decreased as SO_2 emission rate is reduced. At 50% reduction in the emission rate, the highest hourly and daily ground level concentrations decreased by 50%.

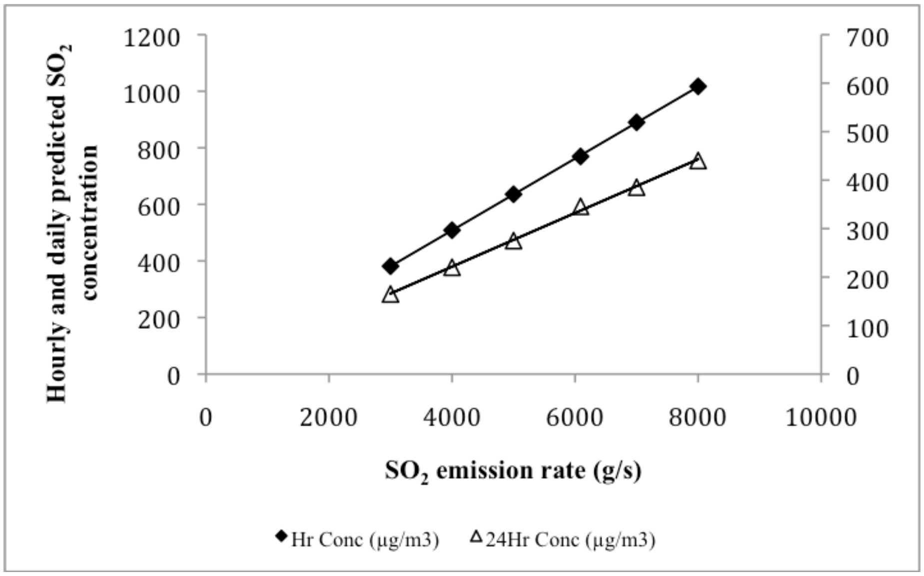

Fig. 8 SO_2 emission rate vs. hourly and daily predicted SO_2 ground level concentrations

In scenario 3, FCC stack diameter effect is examined at stack height of 80 m for different diameters of 1.5 m, 2.3 m, 3 m and 4 m. The exit flue gas velocity is also changed as directly related to the square of the diameter for a fixed exit flue gas flow rate. It is observed that the dispersion and rise of the plume are not affected by diameter variation and the predicted ground level concentration of SO_2 remained almost unaltered. The hourly and daily predicted concentrations of SO_2 are almost identical for all the cases.

Conclusion

FCC unit in a refinery is major contributor of SO_2 and PM emissions those are responsible for adverse impact on the immediate neighborhood of the refinery. A complete comprehensive emission inventories for a year long period have been prepared for both SO_2 and Particulate Matters.

A model run performed for actual monthly emission variation with total SO_2 emission rate of 6089.2 g/s and total PM emission rate of 302 g/s independently, taking into consideration monthly emission factors for both pollutants. The daily predicted ground level concentrations of SO_2 are compared with Kuwait EPA monitoring station daily measured SO_2 concentrations at the same discrete receptor and showed acceptable validation of the model output.

The highest hourly predicted concentration of SO_2 is equal to 769 $\mu g/m^3$. It is observed on the 8^{th} of March 2008 at 8:00 hour, due to elevated SO_2 emission rate in this month and the prevailing meteorological conditions, especially sea breeze effect in the early morning hours. The highest daily predicted concentration is equal to 335 $\mu g/m^3$. It is observed on the 9^{th} of November 2008, and obviously influenced by the predominant North West wind and high SO_2 emission rate in the month of November.

The maximum hourly predicted average ground level concentration of PM is equal to 45 $\mu g/m^3$. It is observed on the 27^{th} of February 2008 at 8:00 hour. The highest daily predicted concentration is equal to 16 $\mu g/m^3$, observed on the 29^{th} of December 2008.

The stack sensitivity is explored by changing stack height, total emission rate and stack diameter independently. It is observed that the higher stack facilitated good dispersion, thus lowering the ground level average concentration of the pollutant up to 50% when the stack height doubled.

It is notice that the highest predicted hourly and daily ground level concentrations of SO_2 are substantially decreased as SO_2 emission rate is reduced. At 50% reduction in the emission rate, the highest hourly and daily ground level concentrations decreased by almost 48%.

The influence of stack diameter inherently changed the exit flue gas velocity due to invariable flue gas flow-rate. The plume rise and dispersion are related to the exit flue gas velocity, which decreased with the increase of stack diameter because of proportionality to the square of diameter. For a fixed load there is no noticeable change in the average hourly and daily predicted ground level concentrations of SO_2.

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