Proceedings of the 3rd IASME/WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING AND ENVIRONMENT, Corfu, Greece, August 20-22, 2005 (pp360-365)

Numerical Assessment of the Allowed Sulphur Content in the Fuel Used by the Power Stations in Kuwait – Part 1

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Abstract:- In Kuwait, most of the power stations use fuel oil as the prime source of energy. The sulphur content (S%) of the fuel used as well as other factors have a direct impact on the ground level concentration of sulphur dioxide (SO_2) released by the power stations into the atmosphere. The SO_2 ground level concentration has to meet the environmental standards as set by Kuwait Environmental Public Authority (KEPA). In parts 1 & 2 of this communication we present the results obtained using the Industrial Sources Complex Short Term (ISCST3) model. The model calculated the SO_2 concentration resulting from existing power stations assuming entire reliance on Heavy Fuel Oil (HFO) with different S%, i.e. 1, 2, 3 and 4S%. Part 1 reports on the model used, assumptions made, scenarios considered and results for CASE 1 for Zour South power station. The accompanying Part 2 contains the rest of the results, discussion and recommendations for future work.

Key-Words:- Sulphur Dioxide, Air Pollution, Air Quality, ISCST3 Numerical Model

1 Introduction

Recent years have shown an increase in public and government concerns with air quality in urban cities. Eradicating elements that pose risk to human health has become of paramount importance. Fossil-fired electric power plants emit six common "criteria air pollutants" as identified by the US Environmental Protection Agency (US-EPA). These pollutants are by-products of electricity generation and include volatile organic compounds (VOCs), sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), lead and particulate matter less than 10 microns in diameter (PM_{10}). Several of these pollutants contribute to acid rain and urban smog, and some may contribute to global climate change, [1, 2 and 3].

The completeness of the combustion process as well as other factors, e.g. controls, determine the composition of emissions dispersed from the stacks of electric power stations. The primary fuels burned in electric power plants, be it coal, natural gas or distillate or residual oils, are carbon-hydrogen compounds that produce water vapour and CO_2 by-products when completely oxidised. Fossil fuels other than natural gas also contain varying amounts of sulphur. Sulphur oxidises to sulphur dioxide (SO_2) during combustion. The level of SO_2 emitted is a function of the control measures used, e.g. desulphurisation units, and the sulphur content in fuel burned. Sulphur exists in virtually all coals and fuel oils at levels ranging from trace amounts to 6S% by weight, [4]. Under the right conditions, sulphur dioxide and nitrogen oxides gradually react with water vapour to form acid rain. Hundred of lakes in the USA and Scandinavia have become so acidic that they no longer can support marine life, [5].

SOx vehicular emission is relatively small compared to power station and refinery contributions. According to [3], the World Bank estimates that the transport sectors' contribution to global SO_2 emissions is between 2 and 6S%. With this in mind, the importance of capping the SO_2 emissions from power stations is apparent. In order to plan the required fuel quality for the existing and planned power stations, it is imperative to consider the variation of air pollutant concentrations due to different types of fuels as well as the behaviour of these pollutants in response to meteorological parameters such as temperature, relative humidity, wind speed and direction. The presented work was undertaken to study the effect of the power stations fuel S% on the SO_2 concentrations in the atmosphere around power stations.

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2 Locations Of Current Power Stations In Kuwait

The main sources that contribute to air emissions in Kuwait are refineries, industry, power stations, motor vehicles, etc. The major air pollutants that are released from refineries and power stations stacks are NO_x, SO_x, CO, hydrocarbons (methane and non-methane) and PM_{10}. Fig. 1 shows the locations of the refineries and power stations in Kuwait. The existing five power stations in the State of Kuwait are:

1. Doha East (DE) power station. Capacity: 1158 MW - 7 steam turbine generator units and 6 gas turbine generator units.
2. Doha West (DW) power station. Capacity: 2400 MW - 8 steam turbine generator units.
3. Subiya (S) power station. Capacity: 2400 MW - 8 steam turbine generator units.
4. Zour South (ZS) power station. Capacity: 2511 MW - 8 steam turbine generator units and 4 gas turbine generator units.
5. Shuaiba South (SH) power station. Capacity: 804 MW - 6 steam turbine generator units.

3 ISCST3 Model

The Industrial Source Complex - Short Term (ISCST3) dispersion model is an air-quality model based on the Gaussian-plume simplification of the diffusion equation that assumes time independence in the input meteorology and source concentration. The ISCST3 algorithm calculates pollutant concentrations and/or deposition fluxes from a wide variety of sources associated with industrial source complex at a specified receptor grid in level or gently rolling terrain. The pollutants considered are relatively non-reactive and suspended particles. The model does not take into account changes due to photo-reactions. The ISCST3 dispersion model from the US-EPA, was designed to support the US-EPA's regulatory modelling options, as specified in the Guidelines on Air Quality Models. The model is capable of predicting results within 25km radius from the point source, hence "Short Term". Some of the ISCST3 modelling capabilities are:

a) ISCST3 model may be used to model primary pollutants and continuous releases of toxic and hazardous waste pollutants.
b) ISCST3 model can handle multiple sources, including point, volume, area, and open pit source types. Line sources may also be modelled as a string of volume sources or as elongated area sources.
c) Source emission rates can be treated as constant or may be varied by month, season, hour-of-day, or other optional periods of variation. These variable emission rate factors may be specified for a single source or for a group of sources.
d) The model can account for the effects aerodynamic downwash due to nearby buildings on point source emissions.
e) The model contains algorithms for modelling the effects of settling and removal (through dry deposition) of large particulates and for modelling the effects of precipitation scavenging for gases or particulates.
f) Receptor locations can be specified as gridded and/or discrete receptors in a Cartesian or polar coordinate system.
g) ISCST3 incorporates the COMPLEX1 screening model dispersion algorithms for receptors in complex terrain.
h) ISCST3 model uses real-time meteorological data to account for the atmospheric conditions that affect the distribution of air pollution impacts on the modelling area.
i) Results can be output for concentration, total deposition flux, dry deposition flux, and/or wet deposition flux.

4 Basic Input Data Requirements

Provided the numerical model used is very accurate, the prediction of the ground level concentration of SO_2 can only be as reliable as the input (i.e. meteorological and other source parameters) data used. For an accurate prediction, the meteorological data must be of high quality and it must span a sufficient length of time. The model was run using five years (1999-2003) of meteorological data of Kuwait for which the source parameters were obtained. Fig. 2 shows the windrose plot for 1999-2003.

Several types of input to the model are needed to obtain reasonable estimates of SO_2 concentrations. The required information includes:

- Pollutants emission rate (g/s)
- Location coordinate in Universal Transverse Mercator (UTM)
- Stack elevation from sea level (m)
- Stack exit inner diameter (m)
- Stack exit gas temperature (K)

- Stack exit gas speed (m/s)
- Meteorological information for the region of interest, including surface temperature, Pasquill stability category, wind speed and direction and mixing height
- Receptor information

The SO_2 emission rate for each of the existing power stations (SH, DE, DW, ZS and S) was expressed as a function of the sulphur content (S%) and the fuel-rate of consumption. Each power station was considered as a point source as done by [6, 7 and 8]. The daily and annual cycle of fuel consumed by the power stations was provided by the MOE.

5 Assumptions

1. The background SO_2 level (due to refineries, transport) is assumed zero, similar to what was done by [8].
2. Due to the limitation of the ISCST3 model for calculations within 25km radius from the point source, the model was run for each station individually with the station located at the centre of the calculation grid. At present, we are running another software (CALPUFF View) which has a range of 300km.
3. SH uses natural gas for electric power generation and it was decided to exclude it from this study.
4. The remaining four power stations were assumed to rely entirely on HFO. This assumption though seems pragmatic, had to be made to simplify the modelling part of the project. A careful examination of the fuel consumed by the 4 existing power stations showed that the fuel used by them varied from natural gas to gas oil fuel to crude oil fuel to HFO with no specific trend. So to simplify the modelling, the total energy generated from each station was calculated, then the amount of HFO required to produce this amount of energy under operating conditions was found. S% was then varied to cover 1, 1.5, 2, 3, 4S%.
5. The emission rates of all the stations were assumed constant with time. No load cycle was used.
6. No desulphurisation units were assumed to be used in the stations.
7. The effect of building downwash was not considered.
8. Kuwait Airport meteorological data was assumed valid for the entire State of Kuwait.
9. No plume depletion, whether wet or dry, was used.

6 Scenarios Considered

a) S% content in the fuel used was varied from 1, 2, 3 and 4S% for each station.
b) DE and DW were included in one run
c) DE and DW were included in one run with the grid position optimised to take into account the north-western prevailing wind direction.

7 Results and Discussion

In the isopleths plots presented, regions of SO_2 concentrations below the threshold defined by KEPA for residential areas are not shown. The hourly data plots are not shown due to space restrictions. The KEPA threshold values are shown in Table 1.

7.1 CASE 1: Zour South Power Station

7.1.1 Hourly

The hourly SO_2 concentration exceeds the 444μg/m^3 specified by KEPA for all S% considered. All the hourly SO_2 concentrations exceed the threshold value throughout the calculation region which encompasses urban, rural and sea regions. The scatter of the hourly data makes its interpretation a difficult task. The hourly concentration data is quite useful to decide whether the pollution levels comply with the KEPA regulations or not. The maximum concentration point was always at a point 1.6km from the station on the southwest (angle = 113^o). The sign convention is the normal one, i.e. North = 0^o with CCW rotation.

7.1.2 Daily

Figs. 3 show the daily SO_2 concentrations around ZS. Here the region of SO_2 concentration above the KEPA value of 157μg/m^3 is small for the smaller S% values. As S% exceeds 1S%, the area of SO_2 concentration violating the KEPA threshold spans most of calculation region and it continues growing for higher S%. The point of highest concentration is closer to the station (at 1.5km) compared to the hourly case, but the effect of the prevailing north-

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western wind direction onsets to be apparent as this point moves to an angle of 177^o from the station (southwest). The maximum daily concentrations are listed in Table 2.

7.1.3 Annual

Figs. 4 show the daily SO_2 concentrations around ZS. For 1S% sulphur content, the SO_2 annual concentration is above the annual threshold value specified by KEPA (80μg/m^3). As the S% increases, the SO_2 annual concentration increases too, but it remains offshore, not affecting the beach region up until 1.5S% (not shown here). As S% reaches 2S%, the region of SO_2 annual concentration violating the KEPA value encompasses the beach on the southern part. Here the effect of the prevailing north-western wind direction is indisputable. The maximum concentration point is always at a point 4km from the station on the southeast (angle = 243^o). The maximum annual concentrations are listed in Table 3.

References:

[1] Vesilind, P. Aarne, Peirce, J. Jeffrey and Weiner, Ruth F. 1990. Environmental pollution and control, third edition, Butterworth-Heinemann (Reed Publishing Inc.) USA.

[2] Carlin, John. 2002. Environmental externalities in electric power markets: acid rain, urban ozone, and climate change; Feature article on Internet 2002: www.eia.doe.gov

[3] Hamzeh, Ali. 2004. Improving Air Quality by Reducing Emissions from Electric Power Industry. Case Study: Thermal Power Plants in Syria. Proceedings, Dubai International Conference on Atmospheric Pollution. Feb. 2004.

[4] Loophole, Lethal. 2003. Internet Website: www.pirg.org 2003.

[5] NAPAP, 1992. Report to Congress. www.eia.doe.gov

[6] Al-Ajmi, D.; and Y. Marmoush. 1992. Estimating the air quality impact of Kuwait oil field fires during July-September 1991. Kuwait Institute for Scientific Research, Report No. KISR 4132, Kuwait.

[7] Al-Ajmi, D.; and Y. Marmoush. 1996. Ground-level concentration of sulphur dioxide at Kuwait's major population centers during the oil-field fires. *Environmental International,* 22(3): 279-287.

[8] Al-Awadhi, J.; M. Al-Sudairawi; and Y. Marmoush. 2000. The ground-level concentration of the pollutant sulphur dioxide released by the power stations until the year 2010

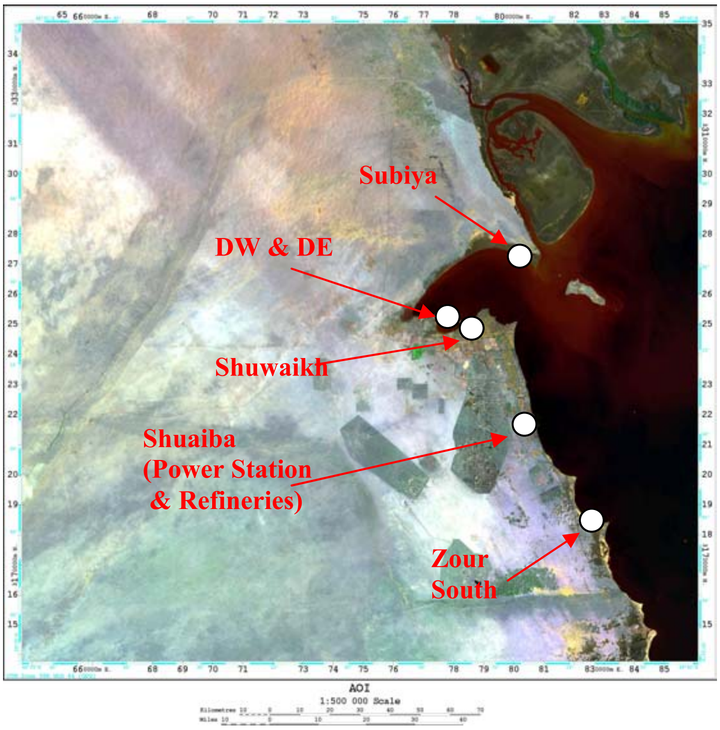


Fig. 1: Power stations and refineries in Kuwait

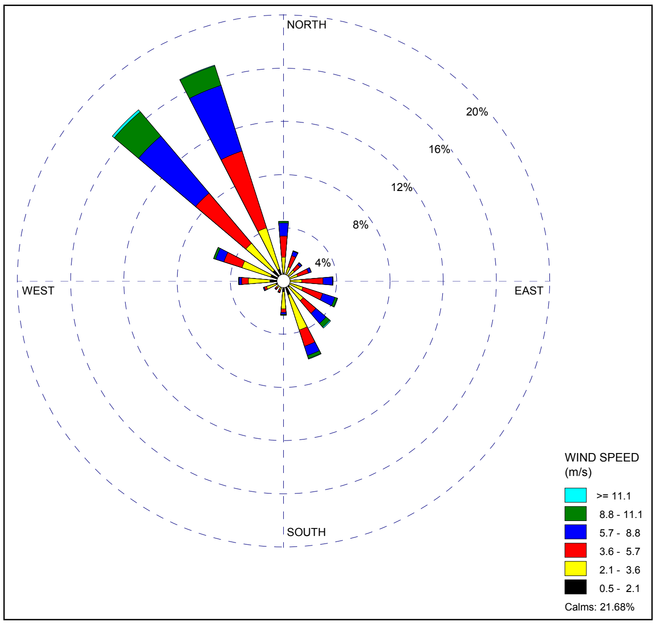
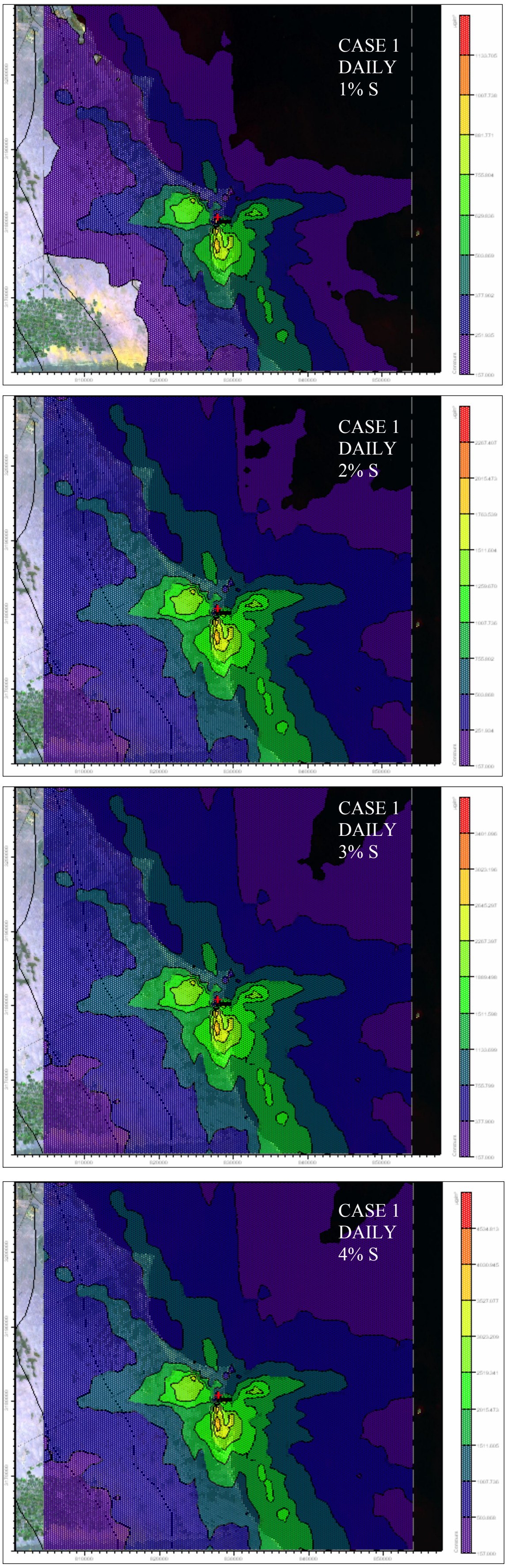
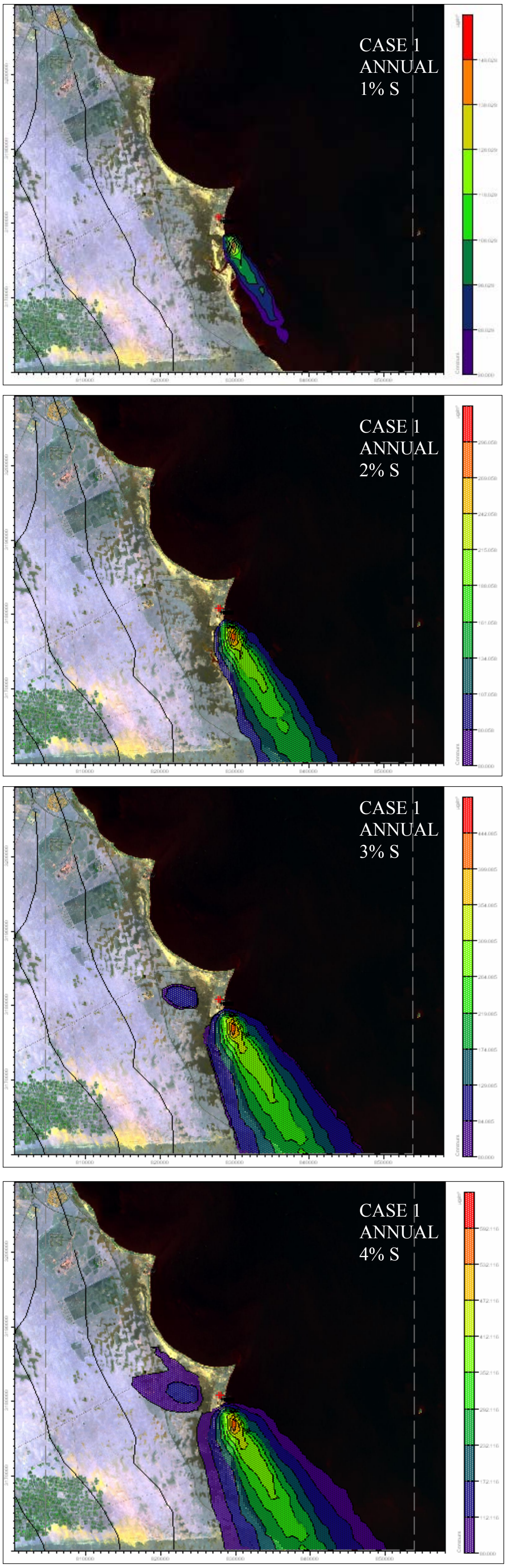


Fig. 2: Hourly wind data for Kuwait (1999-2003)



Figs. 3: Daily SO_2 concentrations due to Zour South power station for different S%



Figs. 4: Annual SO_2 concentrations due to Zour South power station for different S%

	Hour*		Day**		Year	
	ppb	μg/m^3	ppb	μg/m^3	ppb	μg/m^3
(SO_2) Residential[B]	170	444	60	157	30	80

* Average hour should not occur more than twice during the period of 30 days on the same site.
** Daily average (24 hours) should occur once during the year.
B: Should apply in residential dominated areas that lie on the border of industrial areas.

Table 1: Ambient air quality standards for industrial and residential areas in Kuwait
Taken from Kuwait Al Youm, Appendix of Issue No. 533 – Year 47 on Tuesday, 2/10/2001

	S%	Max. 24Hr	LOCATION		Dist (km)	Angle	Actual angle	Dir
			Long	Lat				
1	0.50%	566.9	827882.5	3179249	1.5	87.26	177.26	SW
2	0.75%	850.3	827882.5	3179249	1.5	87.26	177.26	SW
3	1%	1133.7	827882.5	3179249	1.5	87.26	177.26	SW
4	1.50%	1700.5	827882.5	3179249	1.5	87.26	177.26	SW
5	2%	2267.4	827882.5	3179249	1.5	87.26	177.26	SW
6	3%	3401.1	827882.5	3179249	1.5	87.26	177.26	SW
7	4%	4534.8	827882.5	3179249	1.5	87.26	177.26	SW

Table 2: Maximum daily SO_2 concentrations and their locations (Zour South)

	S%	Max. 1Yr	LOCATION		Dist (km)	Angle	Actual angle	Dir
			Long	Lat				
1	0.50%	74	829767.8	3177154	4.0	117.04	242.96	SE
2	0.75%	111	829767.8	3177154	4.0	117.04	242.96	SE
3	1%	148	829767.8	3177154	4.0	117.04	242.96	SE
4	1.50%	222	829767.8	3177154	4.0	117.04	242.96	SE
5	2%	296.1	829767.8	3177154	4.0	117.04	242.96	SE
6	3%	444.1	829767.8	3177154	4.0	117.04	242.96	SE
7	4%	592.1	829767.8	3177154	4.0	117.04	242.96	SE

Table 3: Maximum annual SO_2 concentrations and their locations (Zour South)