Minimization of SO₂ Emissions at ADGAS (Das Island, UAE): II- Impact on Air Quality

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Abstract

In Part I of this work, two SO₂ minimization schemes, namely, Fuel Gas Sweetening (FGS) and Seawater-Flue Gas Desulfurization (SW-FGD) schemes have been proposed to be implemented at the ADGAS plant (Das Island, UAE). The implementation of such schemes is expected to reduce the SO₂ emissions by 77%. The FGS scheme is expected to reduce the H₂S content in the fuel gas system by 94% and results in decreasing the total SO₂ emissions due to fuel gas usage by 98%. The SW-FGD scheme is expected to reduce the SO₂ emissions due to incomplete sulfur recovery by 99.5%.

This work is based on on-site measurements and data collected from specific locations at the ADGAS plant and over the Das Island, UAE. These data were loaded into air dispersion model software (AERMOD 7, 2008) and simulated to predict future air quality on the Island. The SO₂ Ground Level Concentrations (GLCs) were predicted for the current conditions and for the proposed SO₂ minimization schemes (presented in Part I of this work) using the BREEZE AERMOD Pro software model. Upon implementing the proposed SO₂ minimization schemes, the predicted GLCs were found to comply with the United Arab Emirates Federal Environment Agency (UAE-FEA) standard limits at all sites in the ADGAS plant and over the Island. Also the remaining SO₂ emissions have the potential to challenge any future stringent limits set by the UAE-FEA with a high level of confidence since the emission rates after implementing the proposed SO₂ minimization schemes will be reduced to around 5% of the current standard emission limit (25 mg/Nm²).

Lastly, the general approach presented in this work may be of value in application to other similar systems worldwide.

Keywords: SO₂ emission; Ground level concentration (GLC); Air quality; Modeling and simulation

Acronyms

ADGAS: Abu Dhabi Gas Liquefaction Company; ADMA-OPCO: Abu Dhabi Marine Operating Company; BFW: Boiler Feed Water; DEA: Diethanol Amine; FEA: Federal Environmental Agency; FGD: Flue Gas Desulfurization; GLC: Ground Level Concentration; MW: Molecular Weight; ppm: parts per million; SD: Standard Deviation; SRU: Sulfur Recovery Unit; UAE: United Arab Emirates; UGA: Utility Gas Absorber; US EPA: United States Environmental Protection Agency; WHB: Waste Heat Boiler; WHO: World Health Organization

Introduction

Das Island is an Emirati island in the Arabian Gulf. It is part of the emirate of Abu Dhabi, United Arab Emirates (UAE) but lies well offshore, about 160 km north-west of the mainland. It covers approximately 1.21 km² by 2.4 km, and is almost rectangular in shape. It is characterized as a rocky-low island with about 10 m (highest point is 50 m) above sea level. The island is inhabited by oil and gas industry personnel. It exports crude oil and liquefied natural gas by tankers as far as Japan and Europe. The island was formerly a noted breeding site for turtles and seabirds. Despite the oil and gas production, turtles still feed safely in the area and the island is still remained an important landfall for migrant birds.

Throughout its history, the ADGAS Plant at Das Island suffers high rates of SO₂ emissions. The source of SO₂ emissions is mainly coming from the H₂S containment in the feed natural gas. The SO₂ is the dominant air pollutant to the high pollution levels in the Western Region of the UAE. The high levels of SO₂ emissions there necessitate the need to research all possible means to combat the SO₂ impacts. Lewis et al. [1] described a Model Predictive Control (MPC) that can dramatically result in the minimization of flaring from fuel gas supply networks at the LNG facility at ADGAS. In our opinion, this will also contribute to the reduction of sulfur-containing gases emitted into the atmosphere.

Globally, the SO₂ emitted has the potential to travel in any direction for hundreds of kilometers depending on the meteorological conditions. SO₂ is relatively stable in the atmosphere and has the ability to travel as far as 1000 km [2]. The health and environmental impacts of SO₂ can be found elsewhere [3]. Jie [4] constructed a model to study the impact of SO₂ pollution on health over 78 Chinese counties and found that, after attaining the threshold (8 µg/m³), continuous increase in industrial SO₂ emission density will raise the ratio of population suffering chronic diseases, among which respiratory diseases occupy a significant proportion.

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In general, the workers of ADGAS (and other inhabitants) are subject to be exposed to the outdoor air at all locations within the Das Island during their stay time. There is a lack of long-term studies on the effect of exposure on the health of the workers. Such studies will help in determining the highest continuous exposure time an employee can withstand during his stay at the Island. In fact, the average exposure duration for the Das Island inhabitants to the various SO2 GLCs for the various time averages cannot yet be easily determined.

The aim of Part I of this work was to explore feasible technologies that can be implemented at the ADGAS plant at Das Island (UAE) that will result in minimizing SO2 emissions [5]. Two modifications on the SO2 minimization schemes have been proposed and suggested to be applied on the current Fuel Gas Sweetening (FGS) and Flue Gas Desulfurization (FGD) systems. It is worth noting that the effect of implementing the SO2 minimization schemes on plant operations through the FGS and FGD schemes aspects has been discussed elsewhere [5]. The total SO2 emission rates from ADGAS three LNG trains under current and proposed SO2 minimization schemes are presented in Table 1. The contribution of the various sources at the ADGAS plant toward total SO2 emission rates at current and proposed conditions is shown in Figure 1.

Based on the results of part I of this work [5], the current contribution of fuel gas usage of Trains 1 & 2 is 37% of the total SO2 emissions (Figure 1). Upon implementation of the proposed FGS scheme, the total SO2 emissions due to fuel gas usage will be reduced by 98.34% (Table 1) and result in reducing the contribution of fuel gas usage to only 3% of the total SO2 emissions. On the other hand, the current contribution of the Sulfur Recovery Units (SRUs) to the total SO2 emissions is 41% (Figure 1) and upon implementation of the proposed FGD scheme the SO2 emissions due to incomplete sulfur recovery in the SRUs will be reduced by 99.50% (Table 1) and it will become only 1% of the total SO2 emissions upon the implementation of the proposed SO2 minimization schemes.

Furthermore, the implementation of the proposed schemes is expected to result in reducing the total SO2 emissions from the ADGAS plant by 76.88% (Table 1) and it will result in minimizing the SO2 emissions from the fuel gas usage and incomplete sulfur recovery but leaves the SO2 emissions from the Continuous Flaring of Flash Gas (CFFG) as the main contributor to the total SO2 emissions. If the contribution of the flash gas flaring is excluded, the SO2 minimization schemes will reduce the SO2 emissions by 98.96% (from 21,391 to 224 ton/yr), which can be considered as the optimum minimization level [5].

The ultimate goal of this work was to investigate the impact of our proposed minimization schemes of SO2 emissions [5] on the ambient air quality of the Das Island. The "BREEZE AERMOD GIS Pro" has been used in this work as the air quality model to establish and predict the baseline of the SO2 GLC at the Das Island post the implementation of the proposed SO2 minimization schemes. More about the steady-state air dispersion model used in this work can be found elsewhere [6-9].

Al-Nuaimi [10] studied the effect of upgrading of the SRUs at the ADGAS plant from conventional Claus to SuperClaus technology and used the Industrial Source Complex (ISC) model to only estimate the highest SO2 GLCs at the Das Island. The study resulted in a maximum reduction of 33.9%, 0% and 11.4% for the 1-h, 24-h and 1-yr base, respectively. Deligiorgi et al. [11] have used AERMOD steady-state dispersion model to model air pollutant emission from a power plant and identified the dispersion patterns in complex topography in the Chania plain on the Crete Island (Greece). The meteorological assessment is based on a two year dataset (August 2004 – July 2006) from six automated surface meteorological stations. Case studies of the predicted GLCs of SO2 are presented for days with commonly observed meteorological phenomena. Saqer et al. [12] used AERMOD to estimate the total emissions of SO2, non-methanated hydrocarbons (VOCs) and NOx from flares in two petroleum refineries and assessed the impact of these pollutants on air quality in industrial and suburban areas in Kuwait.

Currently the Das Island is lacking continuous monitoring of SO2 GLCs, which is the indicator of effectiveness of any minimization scheme. However, starting from 2003, ADGAS hired a private company to carry out air quality monitoring at Das Island twice a year. Various pollutants, including SO2, were measured at specific locations for a period of 24-h. The used methodology in this work includes the following:

- Establishing the design basis for the AERMOD GIS Pro software in order to predict the SO2 ground-level concentrations under current conditions and predict the 1-h, 24-h and 1-year SO2 levels on the Das Island. This will acquire site meteorological and air quality data, selection of receptors locations for SO2 GLCs, and characteristics and rates of all SO2 emission sources from the ADGAS plant.
- Using the AERMOD GIS Pro software to predict the SO2 GLCs upon implementing the proposed fuel gas sweetening and flue gas desulfurization schemes by simulating the 1-h, 24-h and 1-year SO2 levels over the Das Island.
- Exploring the compliance of the predicted SO2 emission levels upon implementation of the proposed SO2 minimization schemes to the United Arab Emirates Federal Environment Agency (UAE-FEA) standards.

### Design Basis for the Modelling of the SO2 Ground-Level Concentrations

The design basis for running the BREEZE AERMOD Pro software includes (1) physical characteristics of all SO2 emission sources, (2)
locations of the selected receptor within the Das Island where the SO2 GLCs are to be predicted, and (3) SO2 emission rates from the various sources at the ADGAS plant under current conditions. These data, along with site meteorological data (obtained from AERMOD GIS Pro), are required to run the AERMOD air dispersion model to simulate the background SO2 GLCs (measured by ADGAS) and predict them once they are required to run the AERMOD air dispersion model to simulate the SO2 GLCs over the Island. The physical characteristics of these receptors are given in Table 2.

Physical characteristics of the SO2 emission sources

The physical characteristics of the SO2 emission sources include the physical parameters and SO2 emission rates from each emission source. The locations of the SO2 emission sources have been obtained from the ADGAS plant records and placed on the Das Island Map. Each location was oriented through the determination of its longitude and latitude ordinates. The diameter and height of each emission source were also obtained. The available physical data were then collected from the data sheets of each stack at the ADGAS plant. See Table 3. It is worth mentioning here that each SO2 emission source has been individually considered in this study and all the data from the various sources were fed into the AERMOD software. It is also assumed that the plant emissions are evenly distributed over the time.

Estimation of SO2 emission rates from various sources at ADGAS

All the data necessary to estimate the SO2 emission rates from all sources were collected. The SO2 emission rate (kg/h) from each source was determined using the data available from the fuel gas usages (that are emitted from all non-flare sources such as boilers and gas turbines) and the data from flared gases in the continuous flaring of flashed gas sources. The data acquired are the flow rates (mol/h) and the H2S concentration (mol %) of the fuel gas usage and flare gas systems. The SO2 emission rates were then calculated based on the following equations (1 and 2):

\[
2\text{H}_2\text{S}(g) + 3\text{O}_2(g) \rightarrow 2\text{SO}_2(g) + 2\text{H}_2\text{O}(g)
\]

(1)

\[
\text{SO}_2 \text{ Emission Rate(kg/h)} = \left(\frac{\text{mol}\%\text{H}_2\text{S}}{100}\right) \left(\frac{\text{mol}\text{SO}_2}{\text{mol}\text{H}_2\text{S}}\right) \left(\frac{\text{MW}_{\text{SO}_2}}{\text{kmol} \text{SO}_2} \right) \left(\text{Gas Flow} \right) \left(\frac{\text{kmol}}{\text{h}}\right)
\]

(2)

Table 4 presents a summary of the estimated H2S and SO2 emission rates under current conditions from the various sources at ADGAS. Table 5 summarizes the SO2 emission rates at the current and proposed meteorological data provided by AERMOD GIS Pro have been used in this work.

Receptors’ locations for prediction of SO2 ground level concentrations

An aerial view map of the Das Island along with the location of the receptors is shown in Figure 2. The rationale for the receptors’ distribution is mainly to monitor the air quality in the residential and recreation areas on the Island. Three locations on the Island had been selected by ADGAS Company for monitoring of air quality and they were selected here as receptors prediction of the SO2 GLCs over the Island. The physical characteristics of these receptors are given in Table 2.

Site meteorological data

The meteorological data of the site at hand has to be possessed, and if not available, well established meteorological data at the nearest station has to be used. Meteorological data of the Das Island are not available and the nearest meteorological station (i.e., Abu Dhabi International Airport) is about 160 km away from the Island. However, meteorological data for numerous locations around the world are available through “AERMOD GIS Pro”. Acquisition of such data from the “AERMOD GIS Pro” supplier is considered the best choice because these data are reliable and accurate and the supplier provides the necessary data in a format that suits the software itself. Thus the necessary data in a format that suits the software itself. Thus the
SO₂ minimization conditions as well as percent reduction in SO₂ emission upon implementation of the proposed minimization schemes.

**Prediction of SO₂ Ground Level Concentrations**

The main objective of air quality models is, in general, to simulate and/or predict the ambient level concentrations of any pollutant given the necessary emissions’ source data (i.e., stack size, location and emission rate), and terrain description and meteorological data of the site of interest. Typical outputs of any air quality model include location and magnitude of the pollutant highest GLC and the magnitude of the pollutant GLC at specified receptor locations. Air quality models are also used to verify air quality standards’ compliance of existing or proposed industrial facilities, and to assist in the design of effective control strategies to reduce emissions of harmful air pollutants [17].

In fact, the absence of continuous SO₂ GLC monitoring on the Das Island necessitates the use of air quality models in order to simulate the SO₂ GLCs under current conditions and reveal the effectiveness of the proposed SO₂ minimization schemes on the SO₂ GLCs, in particular, and air quality over the Island, in general.

**Assessment of the SO₂ GLCs at the selected receptors**

Table 6 shows a summary of the 1-h, 24-h and 1-year SO₂ GLC averages at the selected receptors for the years 2003 to 2007 under current conditions and proposed SO₂ minimization schemes. It also shows the corresponding SO₂ GLC standards for ambient air quality set by the UAE-FEA [18]. It is clear from Table 6 that the 1-h SO₂ GLC highest averages under the current conditions always exceed the UAE-FEA at the three receptors. However, the 24-h and 1-yr SO₂ GLCs highest averages do not exceed the standards except for the 24-h SO₂ level at Al-Jimi receptor. The Al-Sahil and Al-Jimi receptors show SO₂ levels of almost 500 µg/m³ or more for the 1-h average periods; this imposes serious health effects as per the WHO Air Quality Guidelines [19]. The 24-h SO₂ levels at the receptors frequently comply with UAE-FEA set standards but are far exceeding the WHO 24-h set standards (20 µg/m³). Exposure to such levels may exert serious health effects as per the WHO Air Quality Guidelines [19]. The 24-h SO₂ levels at the receptors frequently comply with UAE-FEA set standards but are far exceeding the WHO 24-h set standards (20 µg/m³). Exposure to such levels may exert serious health effects as per the WHO Air Quality Guidelines [19].

**Table 4: Estimated H₂S and SO₂ Emission Rates from Various Sources at ADGAS under Current Conditions.**

| Emission Source | Current Total (ton/year) | Modified Total (ton/year) | % Reduction |
|-----------------|--------------------------|---------------------------|-------------|
| Combined Sweet & H₂S Flare - Trains 1 & 2 | 1.60 | 0.08 | 94.75 |
| Sour Gas High Level Flare - Trains 1 & 2 | 4,636.71 | 4,636.71 | 0.00 |
| Sour Gas High Level Flare - Train 3 | 1,503.36 | 1,503.36 | 0.00 |
| LNG / LPG Flare, LPG Tankage Flare, Sour (Warm) Liquid Burner | 12.69 | 0.66 | 94.75 |
| LNG Burner | 12.68 | 0.67 | 94.75 |
| Power Generation Gas Turbine | 468.84 | 28.18 | 93.99 |
| ADMA Power Generation Gas Turbine | 7,429.77 | 23.07 | 99.69 |
| Plant 3 Regeneration Gas Heater | 43.70 | 2.64 | 93.97 |
| Plant 9 Regeneration Gas Heater | 41.78 | 2.52 | 93.95 |
| Plant 31 Boilers 1, 2, 3, & 4 | 2,081.08 | 109.88 | 94.72 |
| SRU Incinerator - Trains 1 & 2 | 9,027.44 | 45.14 | 99.50 |
| SRU Incinerator - Train 3 | 2,271.96 | 11.36 | 99.50 |
| Total | 27,531.61 | 6,364.27 | 76.88 |

**Table 5: SO₂ Emission Rates from ADGAS Plant under Current and Modified SO₂ Minimization Schemes.**

A comparison between the measured and AERMOD predicted 24-h highest SO₂ GLCs at the three receptors for the years 2003 to 2007 are shown in Table 7. In fact, AERMOD only predicts the highest SO₂ levels.
pollutant GLC for a given average. So for various receptors, AERMOD predicts the 24-h highest SO\textsubscript{2} GLCs for a given year. As seen in Table 7, the predicted SO\textsubscript{2} GLC is not occurring in the period when the actual SO\textsubscript{2} GLC measurements were made. Thus, the AERMOD model cannot be verified for the ADGAS SO\textsubscript{2} GLC database because the available data are not sufficient for validation purposes. In addition, the measured SO\textsubscript{2} GLCs are not indicative because there is a possibility that the meteorological conditions during the test period allow for the SO\textsubscript{2} GLCs to be lower than should be.

**Temporal variations of highest SO\textsubscript{2} GLC distribution**

The predicted temporal variations in the SO\textsubscript{2} highest GLC averages over the Das Island for the years 2003 to 2007 show similar trends for the 1-h, 24-h and 1-yr toward the distribution of the SO\textsubscript{2} GLC highest GLCs. This can be observed through examining the location of the highest SO\textsubscript{2} GLC averages, and the comparison of SO\textsubscript{2} GLCs at the selected receptors.

1) Location of the Highest Averages of the SO\textsubscript{2} GLCs

Currently, the 1-h highest SO\textsubscript{2} levels are centered in the mid-west part of the Island; more specifically at the end of the Das Island Airport runway. This runway is used by individuals for exercise and run around in the evening (the last flight leaves Das Island at 2 pm). Thus this might lead to increasing the potential of exposure to high SO\textsubscript{2} concentrations. The 24-h highest SO\textsubscript{2} levels occur in either the middle of the Island (for 2003, 2004 and 2006) or in the north-west part of the Island (for 2005 and 2007). The middle area of the Island is an empty area where almost no activities take place while the north-west area is an industrial area. The 1-yr highest SO\textsubscript{2} levels take place either in the middle of the Island (for 2005, 2006 and 2007) or in the north-east part of the Island (for 2003 and 2004) toward the LNG/LPG storage tanks area. It has been noticed under the current conditions that the locations of the highest predicted SO\textsubscript{2} GLCs at the Das Island are not much affected over the 5-years test period.

2) Comparison of the SO\textsubscript{2} GLCs at the Selected Receptors

The average 1-h, 24-h and 1-yr, the mean and the Standard Deviation (SD) of the SO\textsubscript{2} levels at the selected receptors are presented in Table 8. The standard deviations for the 1-h, 24-h and 1-yr averages of the highest SO\textsubscript{2} level are considered low; hence this indicates that the predicted SO\textsubscript{2} levels at each receptor for the specified duration are close to each other. This in turn implies that the variations in SO\textsubscript{2} levels over the 5-years period is small, and, therefore, the effect of yearly-temporal variations does not impact the SO\textsubscript{2} levels at the specified receptors.

**Simulation of the SO\textsubscript{2} ground level concentrations**

Upon acquisition of the necessary data, the SO\textsubscript{2} GLCs on the Das Island have been predicted using the BREEZE AERMOD GIS Pro software. The 1-h, 24-h and 1-yr highest averages of SO\textsubscript{2} GLCs were predicted at the selected receptors’ locations under current and modified SO\textsubscript{2} minimization schemes for the years 2003 to 2007. Upon these results, the impact of process modifications on the air quality has been predicted. Figure 3 shows a sample of the results for the 1-yr highest SO\textsubscript{2} GLCs at the three receptors under current and proposed conditions for the year 2007. Table 9 shows the predicted 1-h, 24-h and 1-yr highest SO\textsubscript{2} GLC averages at the same receptors under current and proposed conditions.

| Location | Date       | Measured GLC (µg/m\textsuperscript{3}) | Predicted GLC (µg/m\textsuperscript{3}) |
|----------|------------|----------------------------------------|----------------------------------------|
| Al Sahil | 18-05-2004 | 18                                      | 124.94 (26-09-2004)                    |
|          | 20-05-2004 | 21                                      |                                        |
|          | 21-05-2004 | 4                                       |                                        |
|          | 5/12/2004  | 10                                      |                                        |
|          | 6/12/2004  | 10                                      |                                        |
|          | 7/12/2004  | 6                                       |                                        |
|          | 16-03-2005 | 86                                      |                                        |
|          | 17-03-2005 | 78                                      |                                        |
|          | 18-03-2005 | 42                                      |                                        |
|          | 19-11-2005 | 51                                      |                                        |
|          | 13-06-2006 | 60                                      |                                        |
|          | 14-06-2006 | 49                                      |                                        |
|          | 15-06-2006 | 71                                      |                                        |
|          | 11/11/2006 | 34                                      |                                        |
|          | 12/11/2006 | 40                                      |                                        |
|          | 13-11-2006 | 37                                      |                                        |
|          | 6/9/2007   | 13                                      |                                        |
|          | 7/9/2007   | 12                                      |                                        |
|          | 8/9/2007   | 18                                      |                                        |
|          | 18-05-2004 | 87                                      | 136.90 (08-02-2004)                    |
|          | 21-05-2004 | 21                                      |                                        |
|          | 23-05-2004 | 8                                       |                                        |
|          | 5/12/2004  | 10                                      |                                        |
|          | 6/12/2004  | 14                                      |                                        |
|          | 6/12/2004  | 17                                      |                                        |
|          | 16-03-2005 | 67                                      |                                        |
|          | 17-03-2005 | 172                                     |                                        |
|          | 18-03-2005 | 81                                      |                                        |
|          | 17-11-2005 | 44                                      |                                        |
|          | 111.06 (30-01-2006) |          |                                        |
|          | 118.82 (24-03-2005) |          |                                        |
|          | 18-11-2005 | 12                                      |                                        |
|          | 19-11-2005 | 30                                      |                                        |
|          | 13-06-2006 | 44                                      |                                        |
|          | 14-06-2006 | 63                                      |                                        |
|          | 16-06-2006 | 40                                      |                                        |
|          | 11/11/2006 | 63                                      |                                        |
|          | 12/11/2006 | 116                                     |                                        |
|          | 13-11-2006 | 83                                      |                                        |
|          | 6/9/2007   | 88                                      |                                        |
|          | 7/9/2007   | 109                                     |                                        |
|          | 8/9/2007   | 97                                      |                                        |

Table 6: Average SO\textsubscript{2} GLCs under Current and Proposed SO\textsubscript{2} Minimization Schemes for the Selected Receptors over the 2003-2007 period.
The BREEZE AERMOD GIS Pro software has been used in this work to generate the contour plots of the predicted \( \text{SO}_2 \) GLCs over the Das Island. The generated contour plots for the 1-yr highest average under current and proposed \( \text{SO}_2 \) minimization schemes for the year 2007 are shown in Figures 4 and 5, respectively, for comparison purposes. The complete set of the contour plots of the \( \text{SO}_2 \) GLC distribution over the Das Island is available elsewhere [20].

Based on these contour plots, the highest 1-h highest averages under current conditions occur in the central-west part of the Das Island (residential area). The 24-h highest averages occur in the middle and north-west parts of the Island while the 1-yr highest averages occur in the middle and north-east parts of the Island. Table 10 shows the \( \text{SO}_2 \) highest GLCs under current and proposed \( \text{SO}_2 \) minimization schemes for the years 2003 to 2007.

As seen in Table 10, the current conditions highest \( \text{SO}_2 \) levels within Das Island, over the years 2003-2007, frequently exceed the standard limits set by the UAE-FEA. The 1-h highest \( \text{SO}_2 \) level is 1869 \( \mu \text{g/m}^3 \) (0.65 ppm). However, exposure to 0.15-0.25 ppm \( \text{SO}_2 \) (which is less than the current highest 1-h level at Das Island) has the potential to cause cardio respiratory effects to human body. The WHO limit is not to exceed 500 \( \mu \text{g/m}^3 \) \( \text{SO}_2 \) in 10-minutes periods as this imposes health risks on humans in the form of changes in pulmonary functions and respiratory symptoms [19]. On the other hand, the 24-h highest average \( \text{SO}_2 \) level is 507 \( \mu \text{g/m}^3 \) (or 0.18 ppm); the WHO 24-h average limit is 20 \( \mu \text{g/m}^3 \). The effect of this is similar to that of the 1-h highest level. Moreover, the 1-yr highest average \( \text{SO}_2 \) level is 74 \( \mu \text{g/m}^3 \) (or 0.02 ppm); long time exposure to such concentration may have serious effects. Thus, the 1-h, 24-h and 1-yr highest \( \text{SO}_2 \) levels under the current conditions represent threat to the health of the Das Island residents.

Table 10 also shows the highest \( \text{SO}_2 \) levels at Das Island, over the years 2003 to 2007, upon implementation of the proposed \( \text{SO}_2 \) minimization schemes. The 1-h highest \( \text{SO}_2 \) level is 636 \( \mu \text{g/m}^3 \) (or 0.22 ppm); the exposure to such level is associated with cardio respiratory response effect on human health. The 24-h and 1-yr highest \( \text{SO}_2 \) levels are 158 and 37 \( \mu \text{g/m}^3 \), respectively; the exposure to such levels has the potential to affect the health of the Island residents. However, none of these highest GLC levels exceed the UAE-FEA standards.

Lastly, it should be kept in mind that upon implementation of the proposed \( \text{SO}_2 \) minimization schemes, the highest 1-h, 24-h and 1-yr \( \text{SO}_2 \) levels will be shifted to the north and north-east parts of the Island. The north-east part of the Island is no more than an industrial area. See Figures 4 and 5. This shift in \( \text{SO}_2 \) levels to non-residential areas is justified by the elimination of the \( \text{SO}_2 \) emissions from the ADMA Gas Turbines (GTs) and the SRU incinerators of Trains 1, 2 and 3. In this case the only remaining contributor to the \( \text{SO}_2 \) emissions at the Island is the CFFG from the fuel gas sweetening units of Trains 1, 2 and 3 which is

| Location | 2003 | 2004 | 2005 | 2006 | 2007 | Mean | SD, % |
|----------|------|------|------|------|------|------|-------|
| Al-Sahil | 118.97 | 124.94 | 203.26 | 94.28 | 142.11 | 136.71 | 36.64 |
| Sailing Club | 373.56 | 377.45 | 362.67 | 383.68 | 384.11 | 376.29 | 7.87 |
| Al-Jimi | 484.64 | 490.41 | 493.99 | 486.70 | 486.64 | 488.48 | 3.33 |
| 1-h (µg/m³) | **187.57** (16-03-2004) | **221.21** (30-12-2005) | **194.92** (10-07-2006) | **192.17** (11-03-2007) |

Table 7: Measured vs. AERMOD-Predicted 24-h Highest \( \text{SO}_2 \) GLCs for the years 2004 to 2007.

Table 8: Highest \( \text{SO}_2 \) GLCs at the Selected Receptors for the years 2003 to 2007.

Table 9 also shows the AERMOD predictions using the proposed \( \text{SO}_2 \) minimization schemes once the CFFG is eliminated. The elimination of the CFFG under the proposed \( \text{SO}_2 \) minimization schemes will result in reducing the \( \text{SO}_2 \) GLCs at the selected receptors by about 97%. In this case, the highest \( \text{SO}_2 \) GLC averages at the selected receptors will be about 4.6 \( \mu \text{g/m}^3 \) for the 1-hr basis and less than 1 \( \mu \text{g/m}^3 \) for the 24-h and 1-yr bases, which represent the minimum that can be achieved at the ADGAS plant.

**Spatial distribution of highest \( \text{SO}_2 \) ground level concentrations**

The BREEZE AERMOD GIS Pro software has been used in this work to generate the contour plots of the predicted \( \text{SO}_2 \) GLCs over the Das Island. The generated contour plots for the 1-yr highest average under current and proposed \( \text{SO}_2 \) minimization schemes for the year 2007 are shown in Figures 4 and 5, respectively, for comparison purposes. The complete set of the contour plots of the \( \text{SO}_2 \) GLC distribution over the Das Island is available elsewhere [20].
as mentioned above, can be routed back to the ADGAS plant gas feed inlet and will result in the reduction of the SO2 levels to much less than the UAE-FEA standard limits.

Compliance of the Predicted SO2 Emission Levels with the UAE-FEA Standards Upon Implementation of the Proposed SO2 Minimization Schemes

Currently, the SO2 emission from the ADMA-GTs and the SRU incinerators of Trains 1, 2 and 3 are not complying with the UAE-FEA standard limits. Also, the current SO2 emission rates from the Fuel Gas Users of Trains 1 & 2 are 89.54% of the UAE-FEA standard limits. This makes these sources susceptible to exceeding these limits in case of malfunction (sudden decrease in the UGAs removal efficiency as a result of process parameters changes). However, upon implementation of the proposed FGS scheme, the SO2 emission rates (from the Fuel Gas Users of Trains 1 & 2) will be only 5.37% of the UAE-FEA limits (i.e., it will decrease the current SO2 emission rates by 94%). Furthermore, Table 11 shows that the implementation of the proposed SO2 minimization schemes has resulted in all SO2 emission sources at the ADGAS plant to comply with the UAE-FEA limits and have the potential to challenge any future stringent limits imposed by the UAE-FEA with high level of confidence.

| Year | Receptor Location | Condition | 1-h Highest (Standard = 350) | 24-h Highest (Standard = 150) | 1-yr Highest (Standard = 60) |
|------|-------------------|-----------|------------------------------|------------------------------|-----------------------------|
| 2003 | Al-Sahil          | Current   | 587.32                       | 118.97                       | 22.27                       |
|      |                   | Proposed  | 230.57                       | 36.02                        | 4.59                        |
|      |                   | Proposed + CFFG | 4.78                     | 0.68                        | 0.12                        |
|      | Sailing Club      | Current   | 373.56                       | 119.79                       | 32.39                       |
|      |                   | Proposed  | 253.41                       | 31.61                        | 7.06                        |
|      |                   | Proposed + CFFG | 4.02                 | 0.73                        | 0.21                        |
|      | Al-Jimi           | Current   | 484.64                       | 239.47                       | 45.57                       |
|      |                   | Proposed  | 218.89                       | 40.07                        | 8.03                        |
|      |                   | Proposed + CFFG | 5.11                   | 0.97                        | 0.28                        |
| 2004 | Al-Sahil          | Current   | 587.37                       | 124.94                       | 20.62                       |
|      |                   | Proposed  | 203.70                       | 30.25                        | 3.90                        |
|      |                   | Proposed + CFFG | 4.74                    | 0.82                        | 0.12                        |
|      | Sailing Club      | Current   | 377.45                       | 136.90                       | 34.24                       |
|      |                   | Proposed  | 216.02                       | 38.18                        | 7.49                        |
|      |                   | Proposed + CFFG | 4.05                 | 0.76                        | 0.21                        |
|      | Al-Jimi           | Current   | 490.41                       | 187.57                       | 47.43                       |
|      |                   | Proposed  | 255.77                       | 41.34                        | 8.01                        |
|      |                   | Proposed + CFFG | 4.91                   | 1.03                        | 0.29                        |
| 2005 | Al-Sahil          | Current   | 579.69                       | 203.26                       | 32.29                       |
|      |                   | Proposed  | 317.44                       | 31.03                        | 4.35                        |
|      |                   | Proposed + CFFG | 4.64                | 1.16                        | 0.18                        |
|      | Sailing Club      | Current   | 362.67                       | 118.62                       | 39.84                       |
|      |                   | Proposed  | 333.13                       | 48.75                        | 7.12                        |
|      |                   | Proposed + CFFG | 3.93                   | 0.92                        | 0.25                        |
|      | Al-Jimi           | Current   | 493.99                       | 221.21                       | 61.26                       |
|      |                   | Proposed  | 376.00                       | 65.48                        | 9.69                        |
|      |                   | Proposed + CFFG | 5.18                   | 1.19                        | 0.38                        |
| 2006 | Al-Sahil          | Current   | 586.75                       | 94.28                        | 28.45                       |
|      |                   | Proposed  | 200.22                       | 30.60                        | 5.19                        |
|      |                   | Proposed + CFFG | 4.73                | 0.69                        | 0.16                        |
|      | Sailing Club      | Current   | 383.68                       | 111.06                       | 35.21                       |
|      |                   | Proposed  | 227.14                       | 42.16                        | 8.91                        |
|      |                   | Proposed + CFFG | 4.07                   | 0.86                        | 0.23                        |
|      | Al-Jimi           | Current   | 466.70                       | 194.92                       | 49.49                       |
|      |                   | Proposed  | 258.21                       | 54.31                        | 10.66                       |
|      |                   | Proposed + CFFG | 5.09                   | 1.08                        | 0.32                        |
| 2007 | Al-Sahil          | Current   | 585.96                       | 142.11                       | 27.43                       |
|      |                   | Proposed  | 210.88                       | 34.92                        | 4.76                        |
|      |                   | Proposed + CFFG | 4.72                | 0.72                        | 0.15                        |
|      | Sailing Club      | Current   | 384.11                       | 150.13                       | 36.76                       |
|      |                   | Proposed  | 240.25                       | 47.68                        | 6.06                        |
|      |                   | Proposed + CFFG | 5.22                   | 1.14                        | 0.23                        |
|      | Al-Jimi           | Current   | 486.64                       | 192.17                       | 52.46                       |
|      |                   | Proposed  | 283.25                       | 53.00                        | 9.76                        |
|      |                   | Proposed + CFFG | 4.05                   | 1.52                        | 0.32                        |

Table 9: Predicted SO2 GLCs (µg/m3) under Current and Proposed SO2 minimization schemes and post Elimination of Continuous Flaring of Flash Gas (CFFG) at the Three Selected Receptors' Locations for the years 2003 to 2007.

Citation: Abu-Eishah SI, Babahar HSA, Maraqa M (2014) Minimization of SO2 Emissions at ADGAS (Das Island, UAE): II- Impact on Air Quality. J Pet Environ Biotechnol 5: 172. doi:10.4172/2157-7463.1000172
The compliance of the SO2 levels with the UAE-FEA standards for the 1-h, 24-h and 1-yr at the Das Island have been plotted using the BREEZE AERMOD GIS Pro software. Figures 6(a) and 6(b) respectively represent the 1-yr compliance plot under current and under proposed SO2 minimization schemes for the year 2007. The red color on these plots means the SO2 GLC exceeds the limit set by the UAE-FEA. The complete set of the compliance plots is available elsewhere [20]. Table 11 shows the compliance results for the ADGAS plant SO2 emission sources under current conditions and after implementation of the proposed SO2 minimization schemes.

On the other hand, Table 12 summarizes the main observations of the spatial distribution compliances at the current and proposed SO2 minimization schemes.

On the other hand, the contour plots indicate that the implementation of the proposed SO2 minimization schemes will result in a greater area of the Das Island and most of the Island residential areas comply with the UAE-FEA air quality standards. Another aspect is that even though the northern part of the Island does not entirely comply with the 1-h standard, its air quality will be improved. Also the highest predicted SO2 level around the northern part of the Island will be about 650 µg/m3 compared to the current 2000 µg/m3 highest level. This means that under the proposed SO2 minimization schemes all the Das Island area will comply with the 24-h and the 1-yr limits of the UAE-FEA.

Lastly, the present study is expected to be of importance to modeling experts and managers of ADGAS plant at the Das Island. Also, the outcome of this study could further assist managers of ADGAS, and similar gas processing plants, on the methodology to reduce SO2 emissions to meet air quality standards. Meanwhile, the general approach presented here may be of value in application to other similar plants and systems around the world.

Conclusions

Currently the SO2 emission rates from the ADGAS plant at Das Island are as follows:

- The SO2 emission rates from the SRU incinerators of Trains 1, 2 & 3 and ADMA-GTs do not comply with the UAE-FEA standards. The SO2 emission rates from Fuel Gas Users of Trains 1 and 2 are 89.54% of the UAE-FEA limits. This makes these sources susceptible to exceeding the standards’ limits in case of malfunctions.
• All locations in the Das Island do not comply with the 1-h SO$_2$ GLC of the UAE-FEA air quality standard (350 µg/m$^3$), most of the Island does not comply with the 24-h regulatory limit (150 µg/m$^3$), while most of the Island complies with the 1-yr limit (60 µg/m$^3$).

• The highest 1-h, 24-h and 1-yr SO$_2$ levels are 1869, 507 and 74 µg/m$^3$, respectively.

• The locations of the highest SO$_2$ levels are more of Residential Areas which represent a threat to the health of the Das Island residents.

Upon implementation of the proposed SO$_2$ minimization schemes, the situation at the Das Island will be as follows:

• The 1-h, 24-h and 1-yr SO$_2$ GLC highest averages at the specified receptors will comply with the UAE-FEA air quality standard. In addition, SO$_2$ levels > 500 µg/m$^3$ will not be experienced for short periods.

• The average of the 1-h highest SO$_2$ levels is 636.2 µg/m$^3$. The averages of the 24-h and 1-yr highest SO$_2$ levels are 157.6 and 37.2 µg/m$^3$, respectively. The highest SO$_2$ GLC will shift to the north-east part of the Island (i.e., the Industrial Area).

• The temporal variations in the SO$_2$ highest averages in the Das Island through years 2003 to 2007 show similar trends toward the distribution of SO$_2$ GLC levels for the 1-h, 24-h and 1-yr highest averages.

• Generally, the SO$_2$ GLC in the north part of the Island exceeds the 1-h limits of the UAE-FEA air quality standard. However, the residential areas comply with these standards. The highest 1-h SO$_2$ GLCs are 650 µg/m$^3$, which is 32.5% of the highest current averages of 2000 µg/m$^3$). Moreover, all the Das Island area complies with the UAE-FEA 24-h (150 µg/m$^3$) and 1-yr (60 µg/m$^3$) limits.

• A greater area of the Das Island will comply with the UAE-FEA air quality standard. Also all the Island area will comply with the 24-h and 1-yr UAE-FEA standard.

• The implementation of the proposed SO$_2$ minimization schemes along with the elimination of the continuous flaring of flash gases will result in 99.2% reduction in the total SO$_2$ emissions at ADGAS. Once the flash gas flaring is eliminated, the SO$_2$ GLC 1-h highest averages at the selected receptors will be about 4 - 5 µg/m$^3$ while the 24-h and 1-yr highest averages will be < 1 µg/m$^3$.

Figure 6a: Compliance plot of the 1-yr SO$_2$ GLC under current conditions for the year 2007. Each square on the diagram is 200 m x 200 m.

Figure 6b: Compliance plot of the 1-yr SO$_2$ GLC under proposed SO$_2$ minimization schemes for the year 2007. Each square on the diagram is 200 m x 200 m.
The routing of the Continuous Flaring of the Flash Gas (CFFG) back to the inlet feed gas of the plant trains will result in 99.19% reduction in the total SO₂ emissions at the ADGAS plant.

Lastly, based on the results of this work, it is recommended:

- To implement the proposed SO₂ minimization schemes presented in Part I of this work (i.e., fuel gas sweetening and flue gas desulfurization) in order to maintain good air quality at ADGAS and in the Das Island. This also requires the replacement of the HYPAK packing of the UGAs of Trains 1 and 2 by IMTP packing.
- To have continuous monitoring of the air quality on the Island that should be easily accessed by the Island workers through brochures and/or broadcasting. This will help to warn the workers on occasions of high levels of SO₂ emissions.
- To carry out comprehensive studies on the occupational health of the workers and residence of the Island.

On the other hand, Table 12 summarizes the main observations of the spatial distribution compliances at the current and proposed SO₂ minimization schemes.

**Table 11:** Compliance of the Various SO₂ Emission Sources at ADGAS with the UAE-FEA Emission Standards.

| Basis     | Current Conditions                                                                 | Proposed Conditions                                                                 |
|-----------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 1-h       | All of the Das Island areas do not comply with the UAE-FEA limit (390 µg/m³)        | Generally, the GLC in the northern part of the Das Island exceeds the limits. Residential areas comply with the standards. The highest concentration is about 650 µg/m³, which is 32.5% of the highest current average (2000 µg/m³) |
| 24-h      | Most of the Das Island areas do not comply with the UAE-FEA limit (150 µg/m³)       | All of the Das Island areas comply with the UAE-FEA limit (150 µg/m³)                 |
| 1-yr      | Most of the Das Island areas comply with the UAE-FEA limit (60 µg/m³) except the Middle and Jetty areas. | All of the Das Island area complies with the UAE-FEA limit (60 µg/m³)                  |

**Table 12:** Compliances of SO₂ GLCs Spatial Distribution under Current and Proposed SO₂ Minimization Schemes.

- The routing of the Continuous Flaring of the Flash Gas (CFFG) back to the inlet feed gas of the plant trains will result in 99.19% reduction in the total SO₂ emissions at the ADGAS plant.

Lastly, based on the results of this work, it is recommended:

- To implement the proposed SO₂ minimization schemes presented in Part I of this work (i.e., fuel gas sweetening and flue gas desulfurization) in order to maintain good air quality at ADGAS and in the Das Island. This also requires the replacement of the HYPAK packing of the UGAs of Trains 1 and 2 by IMTP packing.
- To have continuous monitoring of the air quality on the Island that should be easily accessed by the Island workers through brochures and/or broadcasting. This will help to warn the workers on occasions of high levels of SO₂ emissions.
- To carry out comprehensive studies on the occupational health of the workers and residence of the Island.

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