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Experimental and theoretical investigation of environmental effect in gas emissions from Mellitah Oil and Gas Plant

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Abstract
This study evaluated the effects of routine activity in oil and gas plants involves the atmospheric release of several gases (SOx, NOx, H2S, CO2), with a potential impact on quality of life of the surrounding population. The measurements of the concentrations of H2S and SO2 are recorded in five places around the Mellitah oil and gas Plant during month of time. Simulations of H2S and SO2 concentrations were conducted at these five locations around the Mellitah Oil and Gas Plant. The Aspen flare system analyzer was used as a simulation of pollutant emission rate in this research. Gaussian atmospheric dispersion model and ALOHA air dispersion software were used to simulate the dispersion behavior of pollutants within the area. The experimental results were compared with the results of mathematical modeling. The theoretical value of the hydrogen sulfide concentration in one of the stations was 0.09791 ppm, while the average practical values in the same station were about 0.00133 ppm.

Keywords: Hydrogen Sulphide, Sulphur Oxide, carbon dioxide, H2S, SO2, Mellitah oil and gas Plant.

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1. Introduction

Natural gas mainly consists of light hydrocarbon gases such as Methane, ethane, and many other undesired materials. These impurities should be removed from the raw gas to produce natural gas. The removed hydrogen sulphide gas is converted to solid sulphur for easy handling and exportation [1]. When oil or gas is extracted from these formations, H2S may leak when gas is vented, when flared gas is incomplete combustion or via fugitive emissions from equipment. Its removal from the gas oil or a mixture of both from the well head is crucial in the production process within dedicated plants (e.g. Claus plant). The H_2S is then treated. In the case of Claus plants, the treatment process is the partial combustion of H_2S and sulphur dioxide (SO_2), and the subsequent catalyzed reaction between the two compounds to produce elemental sulphur and water, which is condensed. All forms of combustion, including the flares, produce Sulphur dioxide. Sulphur oxides are also predominantly emitted from combustion processes [2]. They are produced by the oxidation of the sulphur present in the fuel. Emission of SO_2 can also derive from industrial processes, such as desulfurization: in this case, sulphur dioxide represents a process emission [3].

Routine activity in oil and gas plants involves the atmospheric release of several gases (SOx, NOx, H_2S, CO_2). This will have a significant impact on the quality of life of the surrounding population. However, H_2S is often present in fewer concentrations in natural gas processing plants than other chemicals or gases emitted.

The quality of the atmosphere in the cities required an extensive analysis. Therefore, monitoring programs should be performed in the surrounding area of the industrial plants to protect the environment. This research aims to describe the levels of air concentrations and identify factors that predict concentrations of H_2S and SO_2 in the surrounding area of Mellitah Plant. The measurements of the concentrations of H_2S and SO_2 will take place in five places around the Plant [4].

1. Materials and Methods

1.1 Aspen flare system analyzer (Aspen HYSYS V.11)

In this study, the flow rate of polluting gases (H_2S, SO_2) entering the chimney and those emitted from atmospheric glow chimneys will be calculated, considering the excess air and the effect of temperature. These data will be used in the Gaussian scattering model and the Aloha program. Figure 1 shows the flare system at the Mellitah gas plant. The feed to the flare system at Mellitah gas plant consists of the Claus tail gas, MDEA unit waste gas, flash gas, and fuel gas [5].

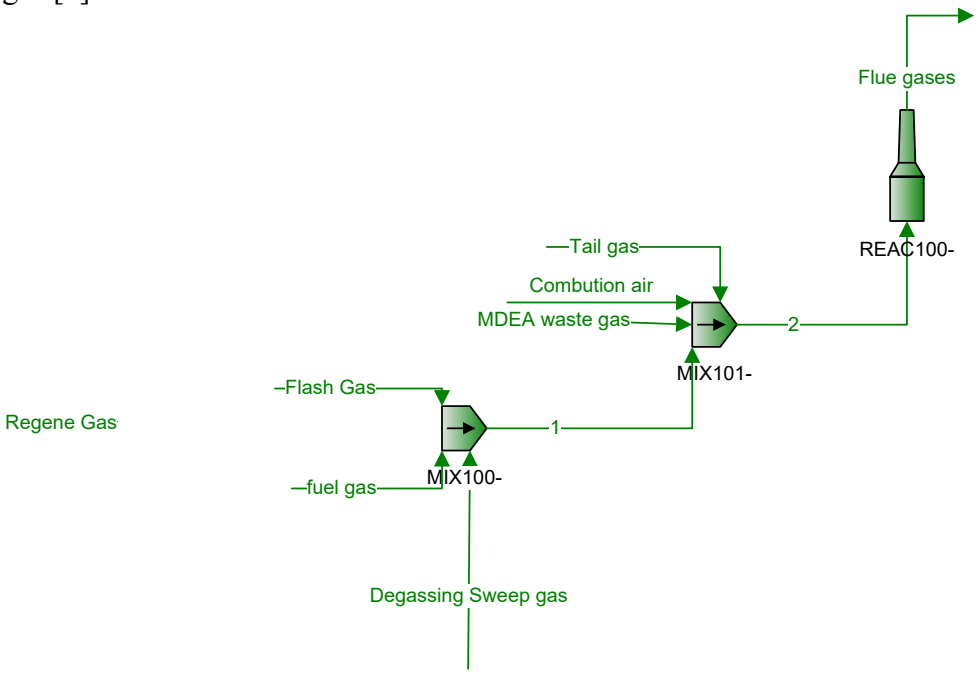

Figure 1 Process flow sheet of Aspen HYSYS flare system analyzer (Mellitah gas plant).

1.2 Atmospheric dispersion model, ALOHA

The computer-based dispersion model ALOHA is based on two air dispersion models, the Gaussian and the dens gas models. The problem with ALOHA is that it cannot manipulate and model all the different leaking scenarios. This is because ALOHA has a simplified source emissions module. In this study, ALOHA was used for a comparison purpose to examine the Gaussian model against the dens gas model.

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1.3 Experimental work

In this project, several practical experiments (concentration measurement) were carried out at Mellitah Gas Plant. H_2S and SO_2 gas detectors (existing and portable) were obtained by the Libyan Environment Public Authority and included (Gastec Detector Tube Systems (GV-100S), Air Boxx, Batch: ARRM-1861, and the shape of the devices is present in a, b, c, d, e. In addition, meteorological indicators, which include measurements of temperature, atmospheric pressure, humidity, speed, wind direction and gases emitted in the vicinity of Mellitah Complex, will be measured and include the following areas.

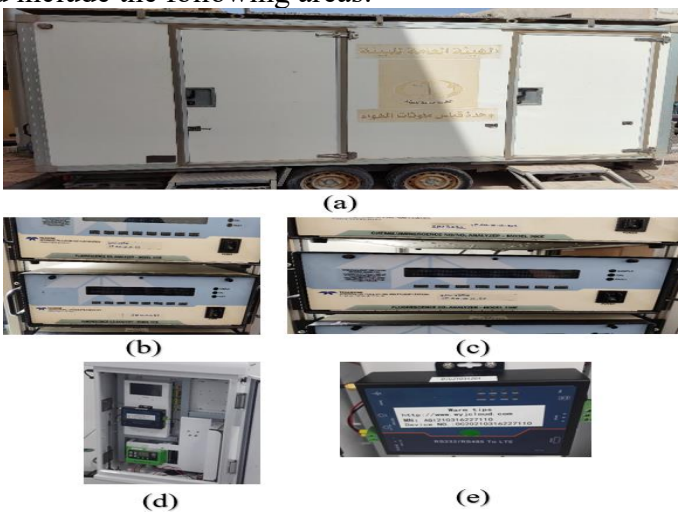

Figure 2 The measuring devices used

The measurement points were distributed in the form of a semi-pork around the complex and according to specialized studies conducted to find out the probability ratios to the direction of the wind. The concentrations resulting from the factor, and their impact on the surrounding climatic conditions so that the measurement is done for two areas per day provided that the area is chosen according to the direction of the prevailing wind on the day of the measurement process. Table 1 shows the unobserved point with the coordinates.

Table 1 Site of air quality control stations

Station number	**The coordinates of the site**		**Location**	**The Distance between the centre of mellitah complex**
AQMS#1	East 12° 8′41.81’’	North 32° 49′6.15’’	Sweet Bear	10
AQMS#2	East 12° 9′57.54’’	North 32° 48′17.26’’	Jinan bin Nasib	9
AQMS#3	East 12° 15′28.46’’	North 32° 48′27.52’’	Farikh	5
AQMS#4	East 12° 13′36.48’’	North 32° 51′1.64’’	Compound fence	1
AQMS#5	East 12° 15′46.81’’	North 32° 48′29.93’’	Al Jadida	6

After these gases are measured, they are compared to the permissible limits according to international standards, as both the Libyan requirements to protect the air from pollution and

the requirements of the World Health Organization have been approved. These requirements are shown in Table 2.

Table 2 Extreme limits of air pollutants [6].

Pollutant	World health organization	Average time
H2S	30ppb	24Hour
SO_2	140ppb	24Hour

2 Theory and Calculation

2.3 Mathematical Expressions and Symbols

The MATLAB code is written using the Gaussian model of air pollutants to investigate the dispersion process and distribution of pollutants (H_2S, SO_2) emitted from the elevated flares of the Mellitah gas plant. The Gaussian equation was previously used in several programmed mathematical models to find ground-level concentrations of H_2S SO_2 gaseous pollutants.

The Equation for Gaussian–Plume Dispersion modelling of gas in flare systems with Continuous Steady-State Source at Ground Level and Wind Moving in **x** Direction is identical to an Equation (1), at Constant average wind speed u [7].

$$\mathbf{C(x,y,0)} = \frac{\mathrm{Q}}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\left(\frac{y}{\sigma_y}\right)^2+\left(\frac{H}{\sigma_z}\right)^2\right)\right] \qquad (1)$$

2.3.1 Mathematical Expressions and Symbols

- **The emission rate of pollutants:**

The emission rate of pollutant (Q) from (the Aspen flare system analyzer) is required for the model ($\mathbf{Q}H_2S$ = 371 Kg/hr , $\mathbf{Q}SO_2$ = 50.24 Kg/hr).

- **Meteorological Data:**

The programmed model finds the pollutant concentrations in all weather conditions that may take place in the study region. These conditions imply submitting carefully selected meteorological data and adapting the actual meteorological conditions at the study region recorded Meteorological Station, defined in PGT (Pasquill Gifford-Turner).

- **Wind speed and direction:**

At each site, the pollutant concentrations were calculated at the upper and lower bounds of wind speed, and the best result was at u= 5 m/s, with each stability class defined. This technique provides a way to obtain a range defined by the maximum and minimum concentration values that may occur for each forecast weather condition. The criterion used to determine atmospheric stability is the Atmospheric Stability Classes Pasquale, which categorized the number of atmospheric turbulence classes.

2.3.2 Mathematical Expressions and Symbols

The dispersion Coefficients $\boldsymbol{\sigma_x}$, and $\boldsymbol{\sigma_y}$, for continuous source. Calculating the dispersion coefficients **(σy, σz)** are:

$$\sigma y = 0.16x(1+0.0004x)^{-1/2} \qquad (2)$$

$$\sigma z = 0.14x(1+0.0003x)^{-1/2} \qquad (3)$$

2.3.3 Mathematical Expressions and Symbols

As mentioned previously, the effective height (H) is the sum of flare stack height and plume rise (Δh). $H = h + \Delta h$,h =80 m, neglect it (Δh=0).

3 Results and Discussion

3.3 Aspen flare system analyzer (Aspen HYSYS V.11)

The result (**Q**H_2S = 371 Kg/hr, **Q**SO_2 = 50.24 Kg/hr) of this simulation for the flare system will be used to calculate the Gaussian equation is utilized to investigate the dispersion process and distribution of pollutants (H_2S, SO_2) emitted from the elevated flares of the Mellitah gas plant.

3.4 Gaussian model (ALOHA 5.7.7)

The dispersion-modelling tool ALOHA 5.7.7 was used to compare and evaluate Gaussian and dense gas models since it is based on these models. Figure 3 and Figure 4 show contour plots of H_2S SO_2 plume concentrations simulated using Gaussian and dense gas models, respectively, using ALOHA 5.7.7.

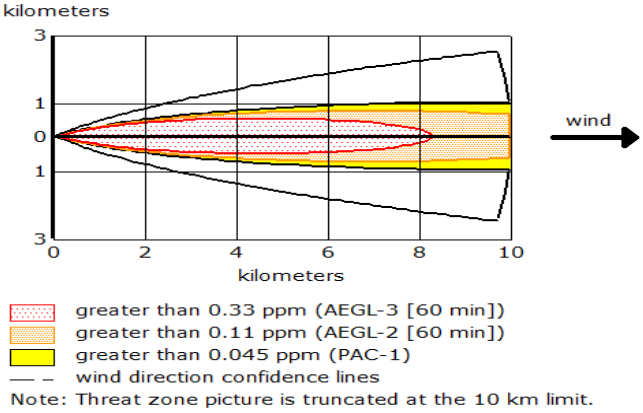

Figure 3 Contour plot of plume H_2S dispersion simulated using ALOHA based on Gaussian

Simulations were accomplished using similar source conditions and similar atmospheric conditions. The figures show that the Gaussian model simulated the centerline concentrations downwind of 1000 m around 0.045 ppm of H_2O and 0.2 SO_2. Similar results were obtained when using different weather conditions and different terms. However, the effectiveness of the Gaussian model has been shown as a suitable model for applying the dispersion simulations of H_2sand SO_2 gases.

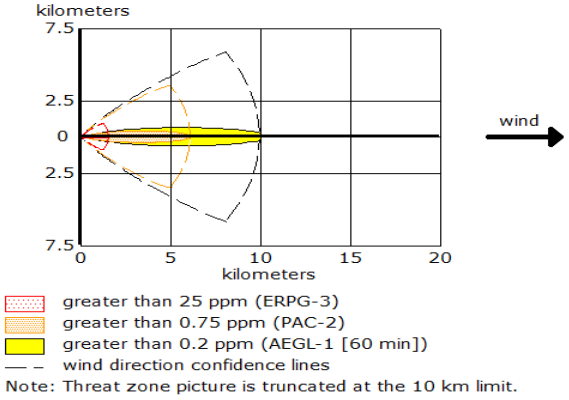

Figure 4 Contour plot of plume SO_2 dispersion simulated using ALOHA based on Gaussian models.

3.5 *Gaussian model (Matlab)*

Figures 5 shows concentration contour plots of Gas dispersion simulated using Matlab based on Gaussian models atmospheric stability D and (flare flow rate of H2S = 0.103 kg/s, SO2= 0.014 kg/s) , wind speed (5m/s), H=80m, X=1000.

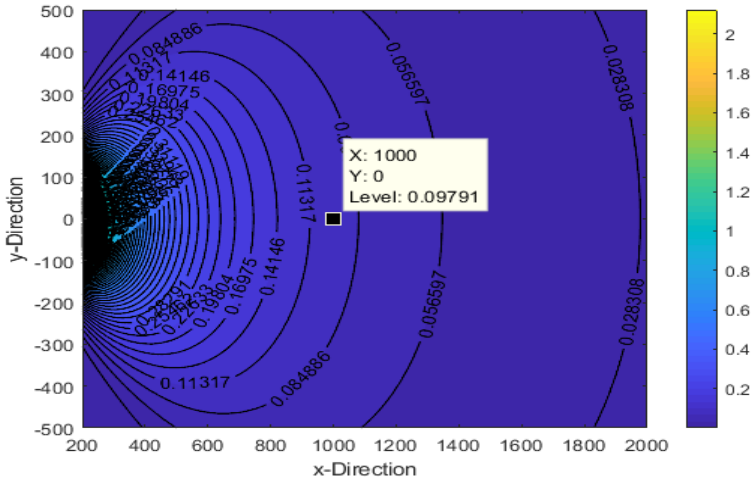

Figure 5 Concentration contour plot of H_2S gas dispersion simulated using Matlab based on Gaussian models of (x=1000m).

Figure 6 shows concentration contour plots of Gas dispersion simulated using Matlab based on Gaussian models atmospheric stability D and 0.014 kg/s of flare flow rate SO_2, wind speed (5 m/s), H=80m, X=1000m). Figure 5 and 6 shows, As the stability of (D) produces low gas concentration, where the dispersion of the plume in the atmosphere is quick and therefore leads to less gas concentration levels at a given downwind. Similar results were obtained when different leakage flow rates were used. In this work, D stability class have been used because it produces worst-case scenarios for the platform workers. According to the wind speed effete towards the H_2S, SO_2 gases dispersion behaviour, the simulations were done by varying the wind speed value (5 m/s) and D atmospheric stability condition. As a result, the wind speed increases and the plume centreline concentration decreases.

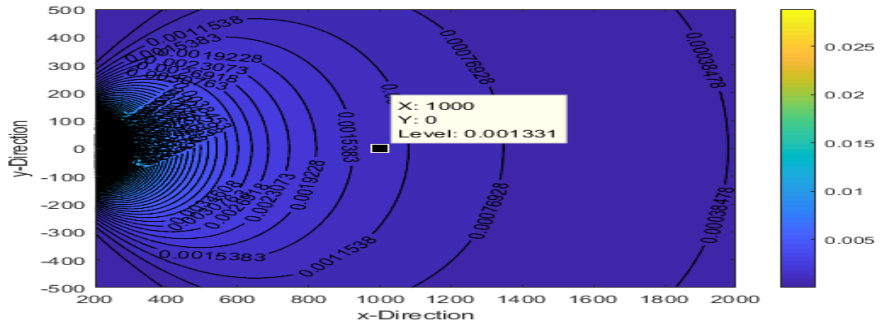

Figure 6 Concentration contour plot of SO_2 gas dispersion simulated using Matlab based on Gaussian (x=1000m) models.

3.6 *Experimental results*

3.6.1 H_2S *gas concentration meter*

Four monitoring stations (AQMS 1 to AQMS 4) distributed in different locations adjacent to the Mellitah industrial facilities were selected. The hydrogen sulfide gas concentration was

measured from the period (1\10\2021 to 31\10\2021) in these four stations. Figure 7 shows that the highest hydrogen sulfide gas concentration values were observed in Station 2, followed by Station 4. The highest hydrogen sulfide gas concentration value was monitored in Station No. 2, about 30.79 ppb. The ambient air quality standards, according to the specifications of the World Health Organization, indicate that the highest value should not exceed 30 ppb for 24 hours [8]. The figure shows that the hydrogen sulfide gas concentration values of all other monitoring stations were within the permissible range according to international air quality standards. The higher hydrogen sulfide gas concentration values in Station No. 1 indicate that the hydrogen sulfide gas is caused by the incomplete combustion of hydrogen sulfide in flared gas.

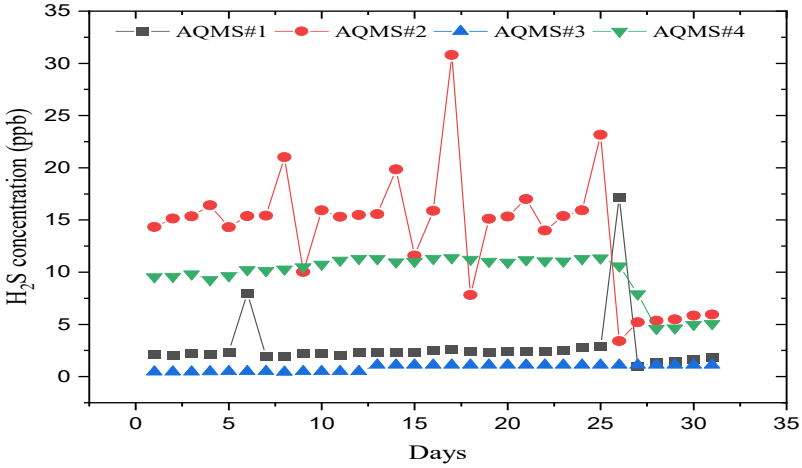

Figure 7 shows the hydrogen sulfide gas concentration in the various monitoring stations from (1/10/20201 to 31/10/2021) at 12:00 AM.

3.6.2 SO_2 gas concentration meter

Four monitoring stations (AQMS 1, AQMS 2) distributed in different locations adjacent to the Mellitah industrial facilities were selected, and the Sulfur dioxide gas concentration was measured from the period (1\10\2021 to 31\10\2021) in these two stations. Figure 8 shows that the highest sulfur dioxide gas concentration values were observed in Station 2. The highest sulfur dioxide gas concentration value was monitored in Station No. 2, where the value was about 5.36 ppb. The ambient air quality standards, according to the specifications of the World Health Organization, indicate that the highest value should not exceed 140 ppb for 24 hours [8]. Therefore, the figure shows that the sulfur dioxide concentration values for the two plants were within the allowable range according to international air quality standards.

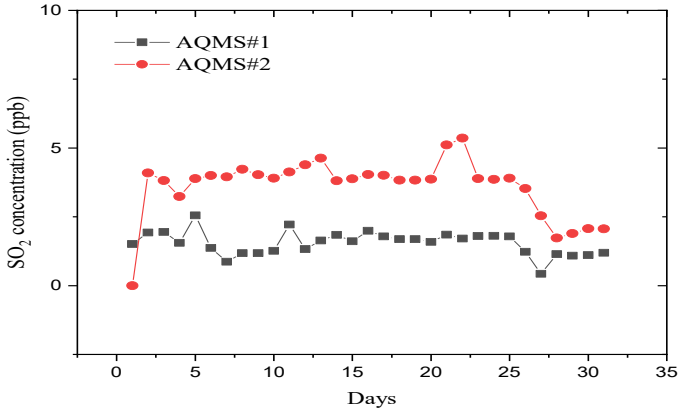

Figure 8 shows the concentration of sulfur dioxide gas in the various monitoring stations during the period from (1/10/20201 to 31/10/2021) at 12:00 AM.

3.7 Comparison of practical and theoretical results

Predicting the concentration of pollutants and calculating them using pollutant modelling should be accompanied by a field measurement process to verify the concentration value and compare the practical results with the results of mathematical modelling, where the theoretical importance of hydrogen sulfide and sulfur dioxide concentrations are shown in Table 3. The particle values are shown in Table 4.

From Table 3, the theoretical values resulting from the dispersion model of the Gaussian equation for hydrogen sulfide gas equal 0.09791ppm and sulfur dioxide gas equal 0.001331ppm. Table 4, contains the measured, practical values of hydrogen sulfide gas and sulfur dioxide gas. This table shows that hydrogen sulfide gas equals 0.03079 ppm, and the highest value of sulfur dioxide gas equals 0.00199 ppm. It turns out that the theoretical value resulting from the dispersion model of the Gauss equation and the practical value of hydrogen sulfide gas are almost close and higher than the permissible limit according to international air quality standards. As for the theoretical value resulting from the dispersion model of the Gauss equation and the practical value of sulfur dioxide gas, they are almost close and are less than the permissible limit.

Table 3 Theoretical results resulted from the concentration of hydrogen sulfide and sulfur dioxide gases for Mellitah Gas Complex.

Distance (m)	**H_2S, gas concentration (ppm)**	**SO_2, gas concentration (ppm)**
1000	0.09791	0.00133

Table 4 Practical results of Hydrogen sulfide gas, Sulfur dioxide gas concentration during the period (15/10/2021 to 20/10/2021).

Data	**H_2S, gas concentration (ppm)**	**SO_2, gas concentration (ppm)**
15\10	0.01160	0.00161
16\10	0.01587	0.00199
17\10	0.03079	0.00179
18\10	0.00782	0.00169
19\10	0.01511	0.00169
20\10	0.01532	0.00159

4 Conclusions

The levels of air concentrations and identifying factors that predict concentrations of H2S and SO_2 in the surrounding area of Mellitah oil and gas Plant have been investigated. This study focused on the routine activity in oil and gas plants involving the atmospheric release of several gases (SOx, NOx, H2S, CO2), with a potential impact on the quality of life of the surrounding population. This study has summarised the following conclusions:

1. Pollutants are emitted in the direction of the prevailing winds, where the higher the wind speed increases the emissions and dispersal of pollutants.
2. The stability of the atmospheric atmosphere that prevails during the night affects the dispersal of pollutants.
3. The instability of the atmosphere that prevails during the day helps to disperse pollutants, which reduces the concentration of pollutants at the ground level.
4. Predicting the concentration of pollutants and calculating them using pollutant modelling must be accompanied by a field measurement process in order to verify the

concentration value and compare the practical results with the results of the mathematical modelling, where the theoretical hydrogen sulfide concentration value was equal to 0.09791ppm, and one of the observed values were approximately 0.001331 ppm.

5. One of the most effective means of spreading pollutants on a large scale and reducing their concentration is the height of the flare, where the height of the chimney in the Mellitah complex is 100m, and its diameter is 1.2192m.

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