Simulation of Flare Discharged from Oil Fields, Integration of Remote Sensing, Laboratory and Mathematical Models

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Abstract—**The prevailing practice in Iraq and the Middle East involves the flaring of gas into the atmosphere by a majority of oil and gas industries. This practice, however, is causing significant harm to the environment, personnel, and equipment. Consequently, determining the optimal location for the flare stack within an oil field has become a primary concern in the design of oil field processes. To address this issue, an in-depth analysis of the flame distribution from oil field flare stacks has been undertaken, focusing on assessing both the size and configuration of the flare. The investigation specifically concentrated on the diffusion of the heat around flare discharged from a vertically positioned cylindrical pipe into the atmosphere. To facilitate this exploration, geographic information system was used and an environmental laboratory experiment was conducted using a scaled flare stack, allowing for measurements under various conditions. During this experiment, thermal images of the flare at different gas flow rates were captured and analyzed using MATLAB software to precisely measure the dimensions and shape of the flare. Consequently, predicting the shape and size of flare profiles becomes possible when key parameters, such as discharge gas flow rate, are known. The overarching objectives of this study are to forecast the shape and size of the flare as well as the diffusion zone, contributing to a more effective and environmentally friendly oil field process design.**

Index Terms—**Flare, Geographic information system, Heat diffusion, Remote sensing, Thermal image.**

I. Introduction

In the oil and gas industries, the unwanted gas will be burned using gas flaring. Gas flaring could be on ground level or vertical through a flare stack. Gas flaring is a continuous process to protect the pressurized equipment and reduce the environmental impacts. The burning process produces emissions such as CO, CO_2, and hydrocarbons (Ibañez-Gómez, et al., 2022). Two types of flares predominate in industry; the ground flare and the elevated flare. The high elevation reduces potential flaring hazards because ground-level radiation is lower and better dispersion of gases occurs should the flame be snuffed out. Environmentally, flaring wastes potentially valuable resources and produces emissions that can affect human health, livestock, and pollute the local environment (Ali and Khodakarami, 2014). Gas flaring, as a major source of acid rain and air pollution, has negative consequences for agriculture, forests, and buildings. This negative impact demonstrates why flaring of gas should be prohibited (Bello and Ogunjemilusi 2022). There are global efforts to eliminate gas flaring, with initiatives such as the Zero Routine Flaring by 2030 led by the World Bank and the United Nations (World Bank, 2023). Although significant progress has been made, achieving zero flaring by 2030 may take longer due to various challenges, including high costs, lack in infrastructures, and regulations in some regions (IEA, 2020).

Gas flare is a globally, regionally, and locally significant source of atmospheric pollutants. They can be detected by geospatial technology. Satellite imagery has become an indispensable tool in various fields, including environmental monitoring, urban planning, and resource management. In oil and gas industries, the detection and monitoring of gas flares are essential due to their environmental and economic impacts. Remote sensing is widely used for detecting gas flaring, assessing their emission, and thermal diffusion by using sensors; such as Landsat and Modis (Morakinyo, et al., 2022). Satellite imagery is cost-effective for managing gas flaring over large geographic areas (Khodakarami, et al., 2023). Extensive studies exist on the geospatial modeling of gas flaring. Adole (2011) investigated the effects of gas flaring on vegetation using a geographic information system (GIS). Chowdhury, et al. (2014) employed Landsat 8 for daytime gas flare detection. Ndunagu, et al. (2021) compared satellite analysis with regulatory gas flaring volumes. Faruolo, et al. (2022) utilized a tailored approach and remote sensing for gas flaring investigation. Another study by Faruolo, et al. (2023) explored gas flaring using multi-temporal satellite data. Heimerl, Malki,

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and Mehana (2023) integrated a geospatial analysis of satellite and operator-reported data with viable mitigation strategies. Dollah, Weli, and Eludoyin (2023) examined land cover dynamics around gas flaring sites using geospatial modeling. Very few previous studies have identified the exact surrounding area affected by gas flares. The novelty of the current study lies in its high-resolution geospatial model of the flare and heat diffusion zone, which has not been predicted by earlier research. This study integrates geospatial modeling with laboratory and mathematical work, distinguishing it from other studies. The study aims to develop a model to estimate the area around a flare affected by the flame. This study utilizes Landsat 8 data, specifically the thermal bands (Band 10), for the detection and temperature estimation of gas flares associated with oil fields.

II. Methodology

In this research study, three different methodologies have been used to investigate the gas flaring; geospatial analysis, laboratory experimental work, and mathematical model. GIS and remote sensing techniques and Landsat imagery were used in the analysis. A thermal infrared camera was used in the laboratory experimental work to capture thermal and digital images. Numerical method; finite difference was used to solve the involved equations with computer software MATLAB to produce the flare images.

III. Geospatial Analysis

To prepare the land surface temperature (LST) map, we utilized Landsat 8 satellite data to a certain oil field in the Kurdistan region. After obtaining the satellite imagery, the following equations were applied to calculate the LST. Subsequent to preparing the LST map, we convert it to a contour line to map the flare's surrounding area (Barsi, et al., 2014; Khodakarami, et al., 2022; Avdan and Jovanovska, 2016; Khodakarami, 2024).

IV. Experimental Thermal Analysis

The experiments were carried out at the laboratory using a small stack made of steel with dimensions 50cm height and 5 cm diameter. A thermal imaging camera was used to take images of the flare for each run. The discharged gas flow rate is maintained by the flow control valve. The gas was supplied from a gas cylinder through a hose. Several experimental runs were undertaken at room temperature, with the gas discharged at different flow rates during each run. The flow rates influenced the size of the flare. The objective of the experiments was to perform tests under variable conditions, such as differing flow rates without wind effects. To avoid disturbing the flare's behavior, non-destructive tools were used for the measurements, including a thermal camera, digital camera, and camcorders.

The experimental results are illustrated in Fig. 1. The left-hand side shows the thermal image, while the right-hand side represents the same image in digital form. The red spot indicates the flare flame, while the surrounding area depicts the heat diffusion profile.

V. Mathematical Analysis

The mathematical work is focusing on finding the heat diffusion profile and shape of the flare. The domain in Fig. 2 illustrates the gas flow directions, the coordinates, and the diffusion coefficient directions involved in the mathematical model. The comprehensive equation for the dispersion of a certain property of fluid is the advection-diffusion equation (9) was used in the current analysis. To solve this equation assumptions are required, it is assumed that the gas flow is in a steady state, with vertical movement and lateral diffusion. To produce the model, it is considered that the coefficient of heat diffusion is applied accordingly to suit the characteristics in the lateral and vertical directions – that is along the gas flow and width-wise. The flow, along the y-axis, which is considered longitudinal along the flare stack, is velocity-dependent. To simplify the equation further, a steady state

Equation 1	TOA=Ml×Qcal+Al	Where, Ml is the irradiance band number, Qcal is the digital number, Al is the additive band number. For band 10 (2) (Equation 2)
Equation 2	TOA=0.0003342×"Band 10"+0.1	
Equation 3	BT=K2/(ln [K1/L]+1)−273.15	Where K1 and K2 are the band-specific constants, L is the TOA radiance. For band 10, substituting the constants yields.
Equation 4	$T=\frac{777.89}{\ln\left(\frac{1321.08}{0.00341802\times DN+149}+1\right)}-273.15$	
Equation 5	$NDVI=\frac{NIR-R}{NIR+R}$	Where, NIR represents the near-infrared band (Band 5) and □ represents the red band (Band 4).
Equation 6	$PV=(\frac{NDVI-NDVImin}{NDVImax-NDVImin})^2$	
Equation 7	LSE=0.004×PV+0.986	
Equation 8	$LST=\frac{BT}{1+(0.00115\times\frac{BT}{1.4388})}\ln\left(\varepsilon\right)$	

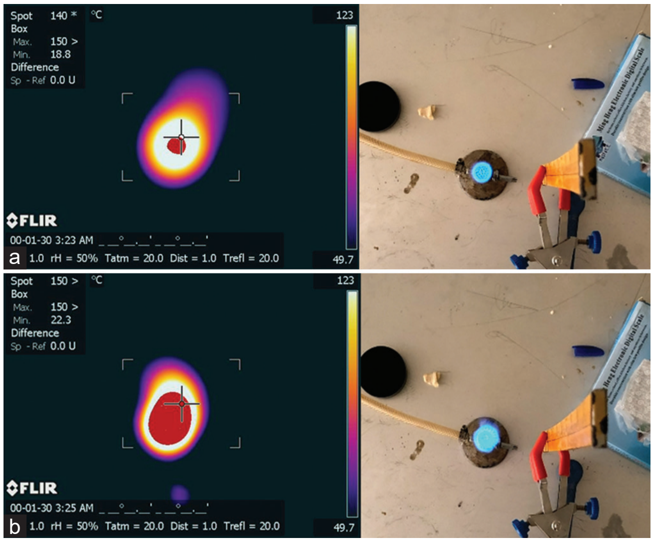

Fig. 1. (a and b) Thermal image of flare.

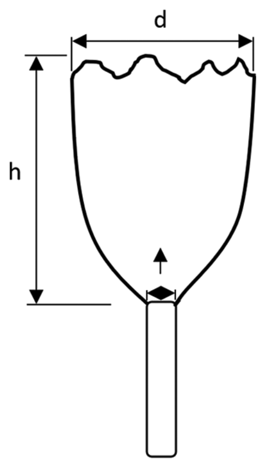

Fig. 2. Flare schematic.

condition is considered to be when the temperature does not change with time.

$$\frac{\partial T}{\partial t}+vx\frac{\partial T}{\partial x}+vy\frac{\partial T}{\partial y}+vz\frac{\partial T}{\partial z}=cx\frac{\partial^2 T}{\partial x^2}+cy\frac{\partial^2 T}{\partial y^2}+cz\frac{\partial^2 T}{\partial z^2} \quad (9)$$

Where T is the temperature at the flare tip, t is time, vx, vy, vz are flare gas velocity in all directions while cx, cy, cz are coefficients of diffusion along the x, y and z direction, respectively. These coefficients are the main parameters affecting the shape of the flare. Molecular diffusion is not considered in the equation because its value is much smaller than the turbulent diffusivity (Ali, 2014).

Solve (9) using the finite difference method and MATLAB, replace the parameters, and the heat diffusion profile will be predicted, Figs. 3 and 4.

VI. Results and Discussion

The study investigated flare heat diffusion using geospatial analysis, laboratory experiments, and mathematical

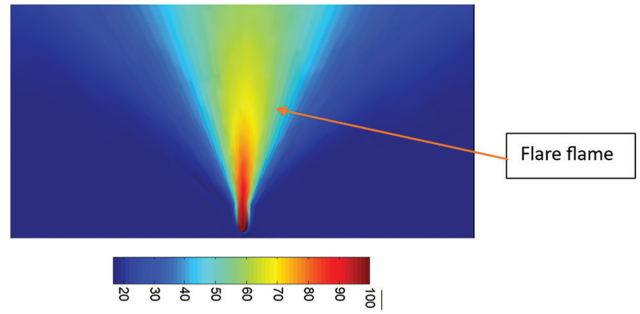

Fig. 3. Flare het diffusion profile.

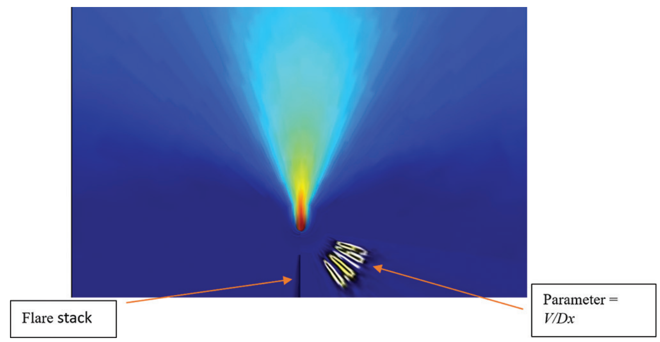

Fig. 4. Heat diffusion profile.

modeling. Good results were obtained and illustrated in the previous sections. Clear heat diffusion profiles resulting from GIS and remote sensing are presented in Fig. 5. The thermal imaging profile using a thermal infrared camera in the laboratory for a smaller flare model is presented in Fig. 1. The mathematical heat diffusion produced by the developed model is illustrated in Figs. 3 and 4. In all the analyses, it was found that the lateral heat diffusion at a fixed diameter decreases with an increase in the discharge gas flow, and vice versa Figs. 6 and 7. As the flow rate increases, the flare becomes taller but narrower Fig. 8, resulting in a smaller ground-heated zone.

Fig. 9 presents the relative heat diffusion around the flare for the GIS model, laboratory, and mathematical work. It demonstrates a close alignment of the three results, indicating the validation of the current study. The results of this study are significant for the oil and gas industry, as they help improve gas flaring by enabling the placement of flares in locations that minimize their impact on humans, equipment, and the environment. Knowing the size of a flare plays a significant role in mitigating environmental problems, as it directly affects key environmental factors such as gas emissions, flaring efficiency, noise, and radiation. By selecting the optimum flare size, the adverse effects on both humans and the environment can be reduced (Ismail and Umukoro, 2025).

As a result of this study, it is recommended that companies run the current or similar models during the initial stages of field design or gas processing to ensure the flare stack is positioned correctly.

The aim of this study is to improve the gas flaring process by predicting the shape of flares from round and vertical

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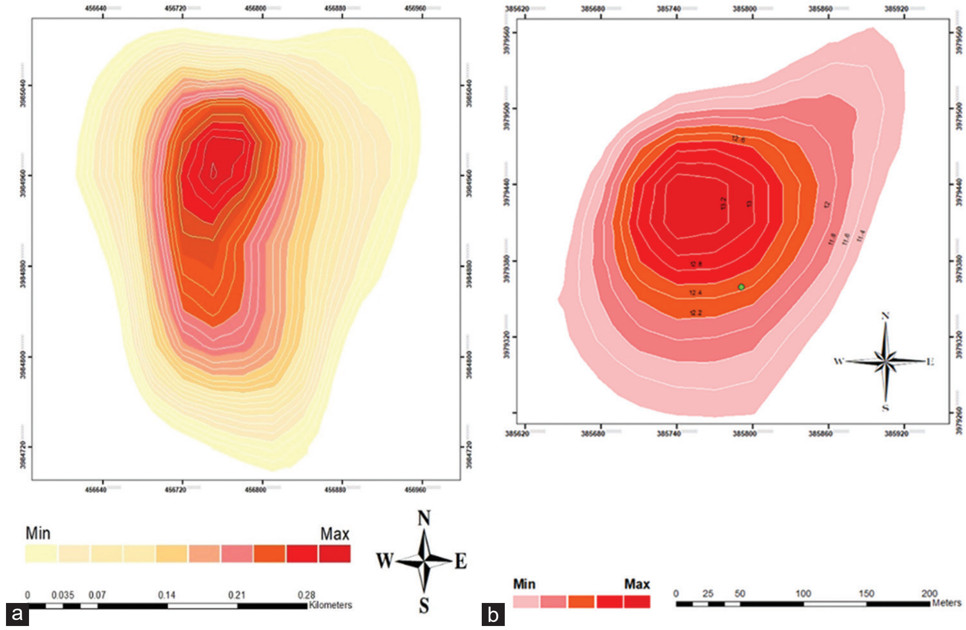

Fig. 5. (a and b) Flare heat diffusion.

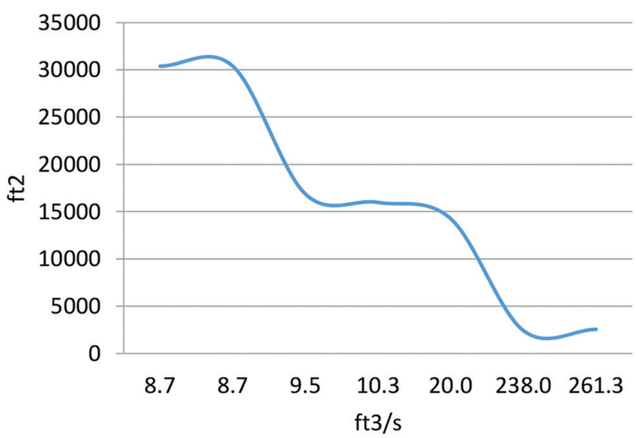

Fig. 6. Heat diffusion zone as function of discharge gas flow rate.

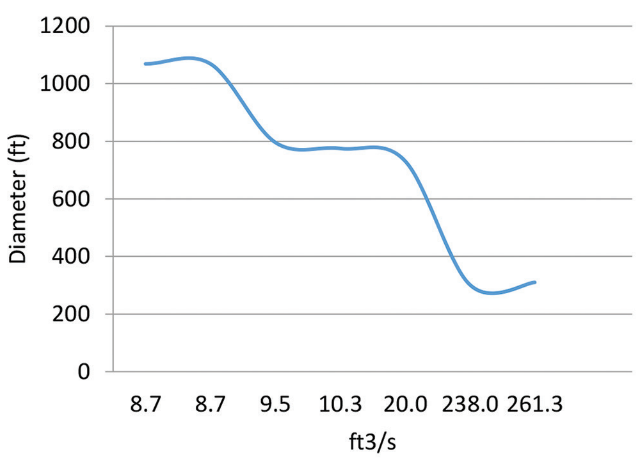

Fig. 7. Diameter of the heated zone.

stacks. This enables the prediction of both the flare shape and heat diffusion of ground flares.

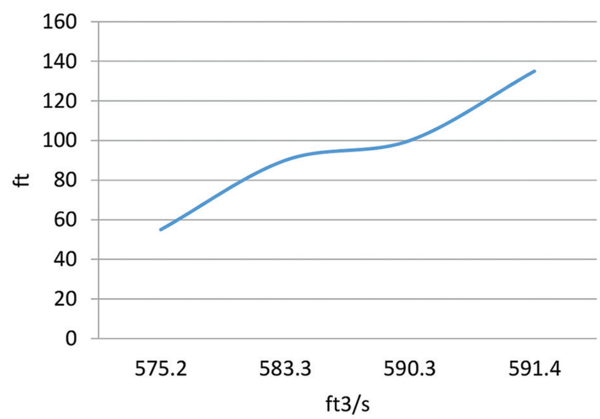

Fig. 8. Linear relation of flare height and discharge gas flow.

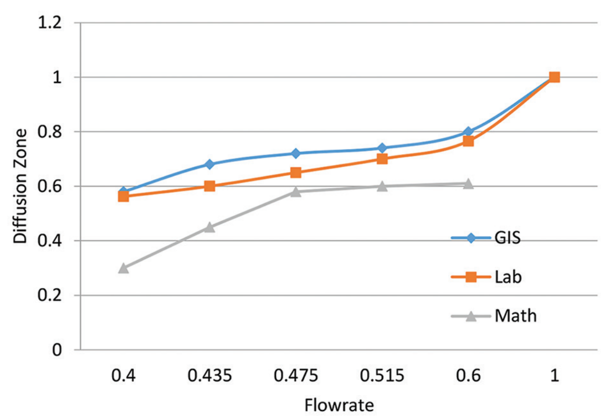

Fig. 9. Heat diffusion zone for the geographic information system, laboratory and mathematical analysis.

For future work, it is recommended to employ additional equations of motion to account for the effects of wind on heat diffusion and flare shape.

VII. Conclusion

The heat diffusion zone around gas flaring is a critical concern for oil field operators and environmental agencies. From this study, it is concluded that at a certain gas flow rate discharge, the heated zone can be predicted, determining the extent to which the heat can spread and the height of the flare.

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