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Numerical Investigation of Wind Effects on the Flame Shape of Sarkhoon and Qeshm's Refinery Flares

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1- Introduction

Combustion flares are widely used in oil and gas refinery units in order to burn the unwanted and unused gases. Due to high volumes of the flares feed gases and also the large heights of the flares (even more than 100 meters), appropriate way of providing the combustion air and air-fuel mixing, have significant effects on the flare combustion efficiency and pollutants emissions. One of the main affecting parameters is the wind speed at the site, where the flare is mounted. As the wind speed increases, not only the combustion efficiency of the flare decreases, but also the flame lies on the flare wall and results in increased temperature of the flare wall. Repeated occurrence of this phenomenon can lead to severe damages in the flare wall, as has been observed in Sarkhoon and Qeshm's refinery.

In this study, a CFD simulation of the Sarkhoon and Qeshm refinery flare has been performed with special focus on the wall temperature distributions at various wind speeds. The main novelty of the present study is in two fold: a) the simulations are performed at real dimensions, while all the previous studies have been performed on the laboratory scales, b) temperature distributions in the flare wall have been determined at various wind speeds.

2- Governing Equations and Solution Procedure

The governing equation of turbulent reacting flows are solved using the Fluent commercial software for the steady-state condition using the pressure-based solver. Reynolds-averaged equations are used to consider the turbulence effects. The numerical results obtained using the Reynolds Stress Model (SSM) show the best agreement with the experiments in comparison with other turbulence models. Effects of flame radiation are also considered using the Discrete Ordinate (DO) model. The flow turbulence effects on the chemical reaction rates are taken into account using the Probability Density Function (PDF) model with the chemical equilibrium assumption and the Beta distribution for the probability density function.

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3- Geometry and Boundary Conditions

The geometry and dimensions of the computational domain are depicted in Fig. 1. The height of Sarkhoon and Qeshm flare is 60 *m*, its inner diameter is 0.814 *m* and the outer diameter is 1 *m*. For the simulations, only the flare's tip is taken into account which its high is 3.6 *m*, as shown in Fig. 1. The applied boundary conditions are also depicted in this figure. The simulations are performed for various wind speeds, from 2 up to 30 *m/s*. The chemical composition of the burning gases is given in Table 1. These gases are exiting from the flare with a speed of 0.503 *m/s*.

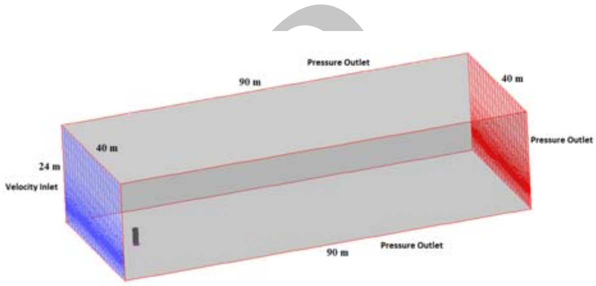

Fig. 1. Computational domain and boundary conditions.

Table 1. The chemical composition of the burning gases of the Sarkhoon and Qeshm refinery.

Species	Mole Fraction
CH_4	75.399
C_2H_6	9.788
C_3H_6	5.651
C_4H_{10}	3.365
C_5H_{10}	1.554
C_6H_{14}	0.559
C_7H_{16}	0.001
N_2	1.647
CO_2	1.584
H_2O	0.164

4- Results and Discussion

Figures 2-5 shows the flame shape and the temperature distributions of the flare wall at various wind speeds. Figures show that as the wind speed increases, the flame axis deviates from the vertical direction and bends towards the horizontal direction. At low wind speeds, the buoyancy forces and also the momentum of the flare gases, outweighs the momentum of the wind. Hence, the flame axis is close to the vertical direction. However, as the wind speed increases, the wind momentum gains weight and causes the flame axis to bend toward the horizontal direction. This causes the flame to get closer to the flare wall and increases its temperature, as can be seen in the figures. In other words, although increasing the wind speed decreases the maximum flame temperature, it produces a higher temperature region on the flare wall. As the wind speed changes, the position of the maximum temperature on the flare wall is also changed which can cause significant thermal stresses and also possible fatigue damages. Fig. 7 shows a damaged flare of this type in the refinery.

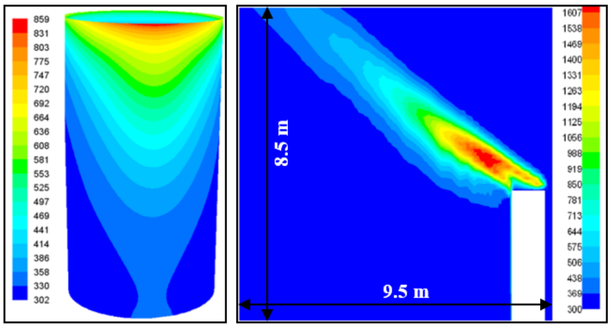

Fig. 2. Flame shape and the temperature distribution of the flare wall at wind speed of 2 *m/s*.

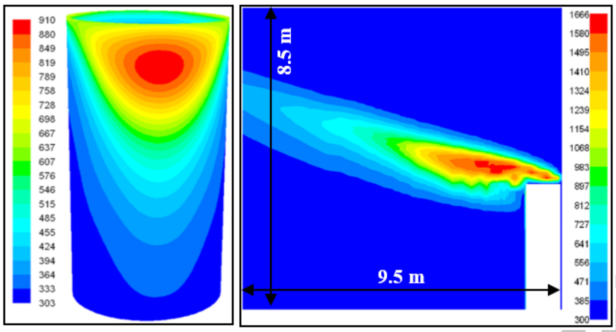

Fig. 3. Flame shape and the temperature distribution of the flare wall at wind speed of 5 *m/s*.

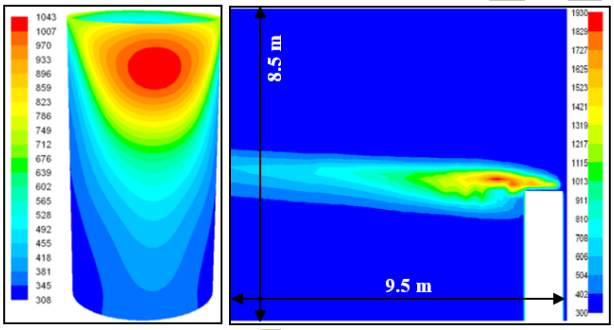

Fig. 4. Flame shape and the temperature distribution of the flare wall at wind speed of 10 *m/s*.

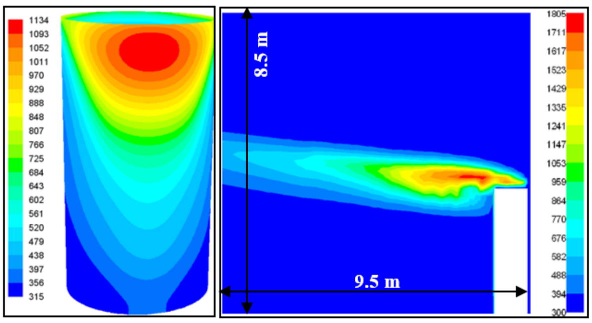

Fig. 5. Flame shape and the temperature distribution of the flare wall at wind speed of 15 *m/s*.

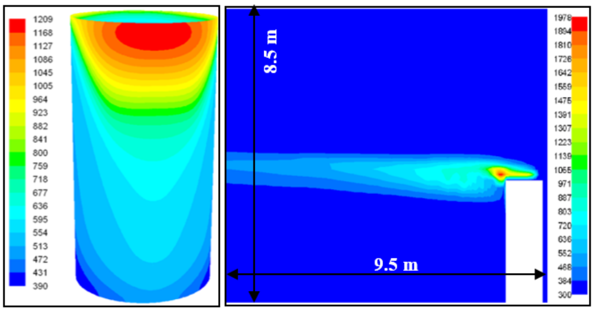

Fig. 6. Flame shape and the temperature distribution of the flare wall at wind speed of 30 *m/s*.

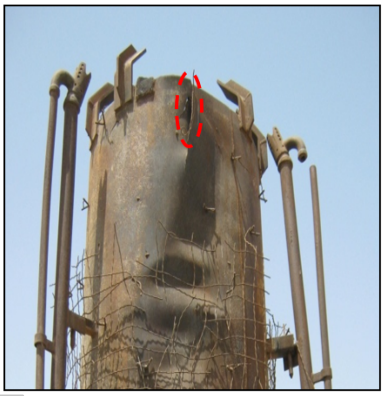
Fig. 7. A damaged flare at the refinery.

5- Conclusions

In this study, the wind effects on the flame shape and also the temperature distribution of the Sarkhoon and Qeshm refinery are studied numerically. The governing equations of the turbulent reacting fluid flows are solved using the commercial software Fluent, where the RSM turbulence model is used for considering turbulence effects. The beta-PDF model is used for considering the turbulence effects on the rate of chemical reactions and the DO model is used for considering the radiation heat transfer. Results show that as the wind speed increases, the maximum flame temperature decreases. However, the flame bends towards the horizontal direction and gets closer to the flare wall. The variations of the flare wall maximum temperature and its location at various wind speeds, leads to significant thermal stresses and possible damage of the flare.