# Computational fluid dynamics of crosswind effect on a flare flame

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**Abstract.** This paper presents the results obtained from the application of computational fluid dynamics (CFD) to modelling the crosswind effect on a turbulent non-premixed flame. A pre-processor software GAMBIT was employed to set up the configuration, discretisation, and boundary conditions of the flame being investigated. The commercial software Fluent 6.3 was used to perform the calculations of flow and mixing fields as well as combustion. Standard k-ε and eddy dissipation models were selected as solvers for the representation of the turbulence and combustion, respectively. The results of all calculations are presented in the forms of contour profiles. During the investigation, the treatment was performed by setting a constant velocity of fuel at 20 m/s with varied cross-wind velocity and by keeping the cross-wind velocity constant at 1.1 m/s with varied fuel velocity. The results of the investigation showed that the standard k-ε turbulence model in conjunction with Eddy Dissipation Model representing the combustion was capable of producing reliable phenomena of the flow field and reactive scalars field in the turbulent non-premixed flame being investigated. Other results of the investigation showed that increasing the velocity of the crosswind, when the fuel velocity was kept constant, significantly affected the flow field, temperature and species concentrations in the flare flame. On the other hand, when the velocity of the fuel was varied at the constant crosswind velocity, the increasing velocity of the fuel gave positive impact as it enabled to counteract the effect of crosswind on the flare flame.

**Key words:** CFD, crosswind, turbulent non-premixed flame, standard k-ε, eddy dissipation model.

## Introduction

Combustion is a very complex phenomena that involves the interaction between physical and chemical processes. In most cases of combustion system such as internal combustion engine, rocket engines, industrial combustors and chimney, combustion takes place and is associated with highly turbulent flows, because turbulent mixing increases burning rates, allowing more power to be produced per unit volume. However, since experimental and analytical studies are difficult to perform due to the complexity of the measurement, numerical modeling with the aid of computational fluid dynamics becomes an attractive alternative in combustion research. This does not mean the modeling problem can be solved without any challenge, because essentially even without turbulence, the combustion itself is already complex process. Another complexity arises from the turbulence itself due to the presence of length and time scales in the reacting flow which up to day still can not be described in detail even with the use of a super-fast computer. Another important aspect to be considered in the study of combustion modeling is the interaction between turbulence and combustion. In a turbulent flame, the turbulence is affected by combustion due to a change in the acceleration of the front flame as a result of heat release. On the contrary, the turbulence affects the structure of the flame which enhances the chemical reactions.

A number of studies have been reported with regard to modeling of turbulent flame in chimney. Tamanini (1977) employed the *k-ε* standard turbulence model to simulate the effect of buoyancy on a turbulent diffusion flame. He found out that the influence of buoyancy was small in the flow having low Reynolds number. Crauford et al. (1985) also employed the standard *k-ε* model in conjunction with the flamelet combustion model to simulate a turbulent flame while Johnson and Kastiuk (2000) conducted a study using the standard k-ε turbulent model coupled with non-premixed combustion model. They suggested that increasing the velocity of the fuel could reduce the influence of the crosswind.

Since there are still uncertainties with regard to the influence of crosswind on the flame, the present study was performed to numerically investigate the effect of varying the crosswind velocities on the flare flame. In addition, another study was also performed to investigate the influence of varying the velocity of fuel when the velocity of crosswind is kept constant. The results of will be presented in the forms of contours of temperature and species predictions.

**Simulation Methodology**

The geometry of a flare flame was considered to be similar to a nozzle in which a fuel was issued into atmosphere and burnt. Figure 1 showed the configuration of the geometry of the domain of calculation drawn using Gambit mesh generator where the nozzle is located at the bottom of the domain.

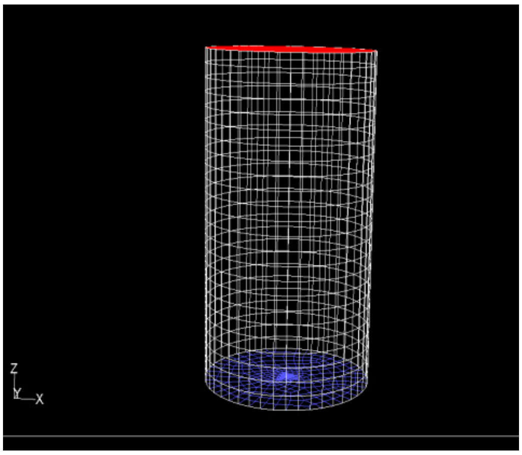


Figure 1. Three-dimensional Geometry of the flare flame domain

The flow field calculation was performed using Fluent 6.3 (Fluent. Inc., 2005) CFD ware of which serves as a processor as well as post-processor, with standard k-ε selected to represent the mixing fields. The fuel in this flame is assume to be propane. Upon the flow field calculation reaching convergence, the combustion calculation was started. The Eddy Dissipation Model (EDM) was selected to represent the reactive scalar field in the flame. Radiation resulted from the combustion was represented with a simple P1 model. The first study was performed by varying the crosswind velocity, keeping the velocity of the fuel constant. While the other study was run by keeping the velocity of the crosswind constant, with the velocity of the fuel varied.

**Results and Discussion**

***Effects of crosswind velocities on flame with constant fuel velocity***

Figure 2 presented the temperature contour profile of propane flame at various crosswind velocities when the fuel velocity was kept constant. Inspection of the figure shows that the flame started to bend when the crosswind velocity $U_\infty$ = 0.3 m/s. Although at the crosswind velocities of 0.3 m/s to 1.5 m/s the flame tends to bend to the direction of wind, it still has a direction towards atmosphere. At the crosswind velocities of 3.77 m/s to 10 m/s, however, the direction of the flame has been already flat toward the direction of the wind. This indicated that the structure of the flame was much more dominated by the crosswind. At this situation the pollutants resulted from the combustion tend to fall not far from the stack due to the wash out phenomenon. These results suggest that the flame with a fuel velocity of 20 m/s will be significantly affected by crosswind having velocities of 0.3 – 10 m/s.

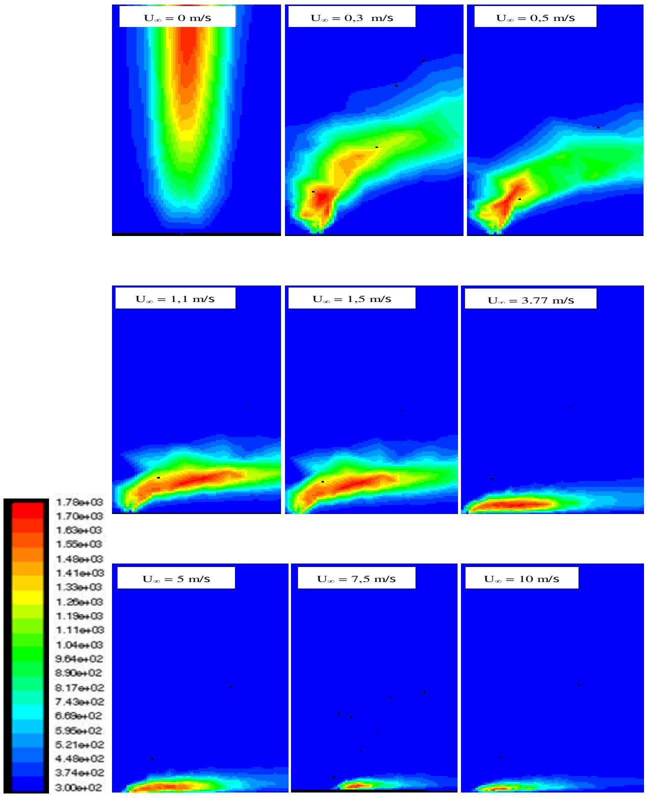


Figure 2. Temperature contour profile of propane flame at various crosswind velocities

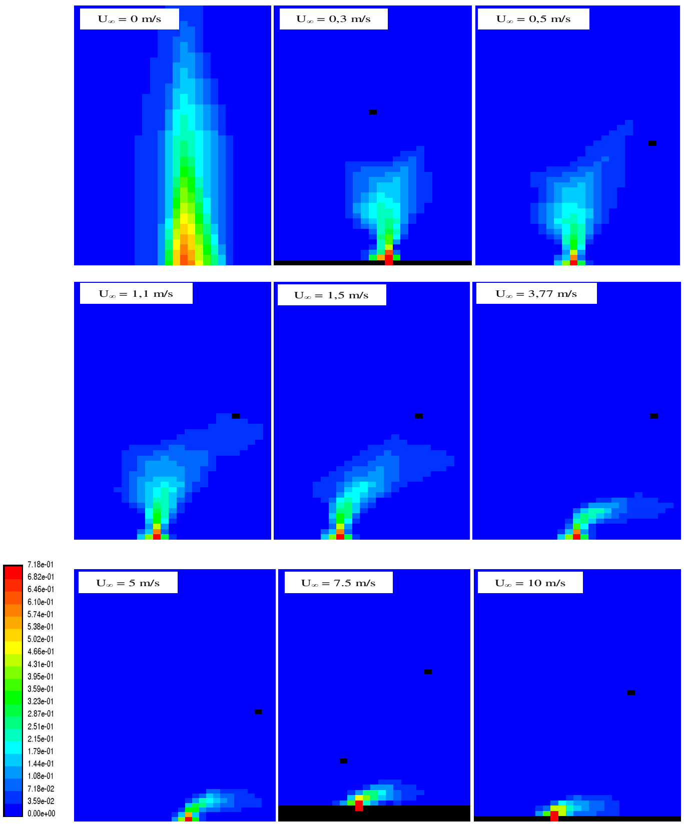


Figure 3. $C_3H_8$ contour profile of propane flame at various crosswind velocities

Figure 3 illustrated the contour profile of $C_3H_8$ species mass fraction at different cross wind velocities when the velocity of the fuel was fixed at 20 m/s. The $C_3H_8$ masss fraction at the nozzle tip was at the highest and decreased due to the progression of combustion process up to the tip of the flame. As the crosswind velocity was increased, the area of the $C_3H_8$ mass fraction was decreasing, as a comparison at the crosswind velocity of 3.77 m/s the area of $C_3H_8$ mass fraction was smaller than that of the crosswind velocity of between 0.3 m/s and 1.5 m/s. This indicated that the increasing crosswind velocity resulted in significant loss of propane mass fraction into atmosphere leading to low combustion efficiency.

***Effects of constant crosswind velocity on flame with varying fuel velocities***

Figure 4 depicted the effect of constant crosswind velocity at 1.1 m/s when the fuel velocity varied. Qualitatively, as the fuel velocity increased, the length of the flame also increased to counteract the crosswind speed of 1.1 m/s. With respect to the temperature, as the fuel velocity increased, the temperature of the flame also increased, with the highest temperature occurred at the fuel speed of 30 m/s.

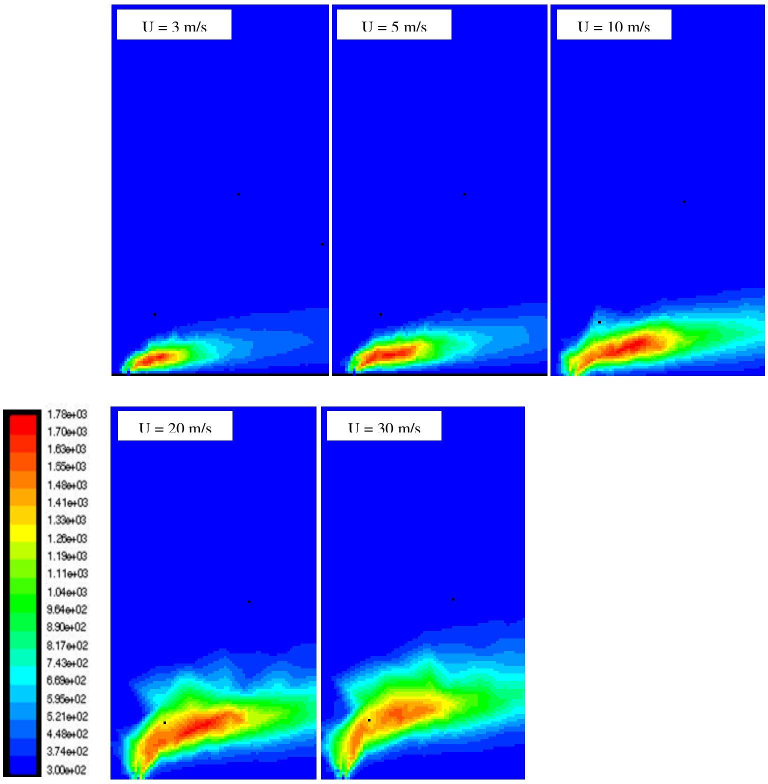


Figure 4. Temperature contour profile of propane flame at various fuel velocities

Figure 5 illustrated the contour profile of $C_3H_8$ spesies mass fraction at various fuel velocities when the crosswind was kept at a constant velocity of 1,1 m/s. The $C_3H_8$ spesies mass fraction at the nozzle tip was again at its highest value and continuously decreased with the height due to the conversion of $C_3H_8$ in to combustion products. Having a contrast result with the case of varying crosswind speed, here the area of $C_3H_8$ spesies mass fraction was increasing as the fuel velocity increased. This indicated that as the fuel velocity was increased the $C_3H_8$ spesies mass fraction significantly increased leading to an improvement in the combustion process.

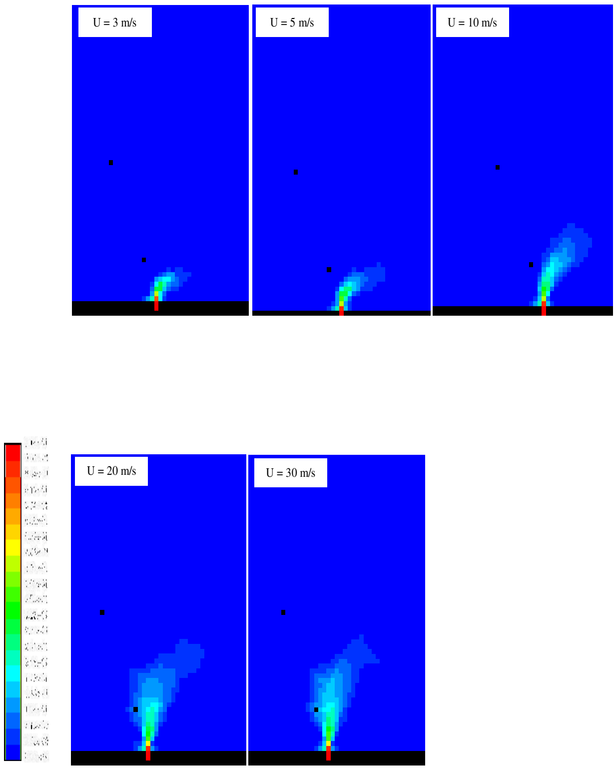


Figure 5. $C_3H_8$ contour profile of propane flame at various fuel velocities

**Conclusions**

From the results and discussions, it is concluded that the crosswind velocity significantly affects the combustion and the flame when the crosswind velocity increases. The combustion of the flame can be improved by increasing the velocity of the fuel

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