Numerical Simulation of Compartment Fire with Flamelet Generated Manifold and Comparison with Other Combustion Models

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ABSTRACT

In this paper, the LES was used and the one-equation method was adopted as the sub-grid method. In addition, the simulations are performed in three-dimensional, unsteady and single-phase case and the Froude number is considered 0.000255. To investigate the effect of the combustion model, the combustion model of flamelet generated manifold is used in the simulation of fire in the room and the results of this combustion model are compared with infinite fast chemistry models and eddy dissipation models. Comparing the results, it can be seen that in the fire scenario in the room with a heat release rate of 62.9 kW, the mean temperature in the flame is approximately 1500 Kelvin. Also, the results of the eddy dissipation combustion model and infinite fast chemistry predict the temperature results better than the flamelet generated manifold combustion model; but, all three combustion models are close to experimental results with a relative error of less than 10%, in predicting the velocity. Due to the low computational cost of the flamelet generated manifold model and the ability to use detailed kinetics in this combustion model, as well as its acceptable accuracy, it is appropriate to use this model in the compartment fire simulation.

KEYWORDS

Compartment fire, large eddy simulation, combustion model, flamelet generated manifold.

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1. Introduction

The compartment fire scenario is a significant part of common fires. In this scenario, the closed space causes changing the pattern of flame formation relative to the pool fire, which in some cases even causes the flame to be extinguished [1]. If the compartment fire is connected to the open air through a duct or door, hot gases are released and fresh air enters the room, which can cause the flame to deflect. Depending on the outlet duct area, the fire to be extinguished or reached steady state [2].

In the first numerical research, basic combustion models such as volumetric heat source were used, which no combustion reactions are seen and no reactive species can be obtained in this combustion model. Gradually, combustion models such as eddy dissipation model (EDM), eddy dissipation concept (EDC) and infinite fast chemistry (IFC) were also used in numerical simulation of fire, (of course, these combustion models are still widely used). The weaknesses of these combustion models are the inability to model flame extinction, the inability to model all species involved in combustion, and the response to one or two-step kinetics.

Due to the weaknesses of these combustion models, in more recent research, the use of flamelet combustion models has been suggested [3]. The flamelet generated manifold (FGM) combustion model is one of the flamelet models that, have the positive points such as low computational time, the ability to use complete kinetics and additionally the flame extinction.

In limited studies of fire numerical simulation, the combustion model of FGM has been used. Safarzadeh et al. [4] investigated the effect of radiation application on this combustion model using discrete ordinate radiation model and it was observed that the flame temperature decreases in the room due to the reduction of available oxygen and as a result the use of radiation does not has a significant effect on the results. Safarzadeh et al. [5] used the FGM and modeled the different toxic species produced in fires. In this study, it was observed that the results of carbon monoxide species, have a relative error less than 15%, with the experimental results.

According to the review of studies, it can be seen that the combustion model has a significant role in fire simulation. In addition, the researcher has tried to model accurate details of the combustion and species by low computational time. Therefore, in recent numerical studies, a tendency has been found towards flamelet combustion models. Among the flamelet models, the FGM combustion model with advantages such as fire extinguishing modeling, low computational time and the possibility of using complete kinetics, can be considered as one of the most reliable combustion models in fire simulation. Examining the results of this model in different fire scenarios can show the efficiency of this combustion model more than before; therefore, the need to compare the results of different combustion models with the FGM model in the compartment fire scenario is one of the gaps in previous studies.

In this study, the compartment fire is examined using the large eddy simulation method and the FGM combustion model, (which is a complete combustion model that predicts the exact details of fire hazardous species). The velocity and temperature fields of the FGM combustion model is compared with IFC and EDM combustion models.

2. Equations

Fire is a non-premixed flame which, equations related to reaction flow such as continuity, momentum, energy, mixture fraction and turbulence equations can be filtered and used in simulation using the Favre filtering method [6]. For each of the combustion models, the related equations have been used, which can be referred to references [4, 6] for more information.

3. Numerical Method

Discretization methods for all terms of the equations of momentum, sub-grid kinetic energy, energy transfer, species, reaction progress variable, mixture fraction and its variance, the second-order approximation was used and for the time derivative expression in all equations, the Euler method was used [7]. Pimple was adopted as an algorithm for applying the dependence between velocity, pressure, temperature and mixture fraction parameters and its variance [8].

4. Results and Discussion

In this section, the compartment fire scenario is selected according to Stekler's experimental results [9] and the results of the FGM combustion model are examined. For this purpose, first the quality of the mesh is investigated with LES_iq index and then the temperature and velocity results of the FGM are compared with other combustion models. According to the experimental geometry, the numerical geometric domain, which shown in Figure 1, was created.

The boundary condition of the walls was non-slip with adiabatic temperature. The inlet of the fuel bed was considered as the boundary condition of velocity of 0.020 m/s with methane fuel (A heat release rate of 64 kW was used). Surrounding boundaries (extra space) were additionally assumed to be at ambient pressure (101 kPa).

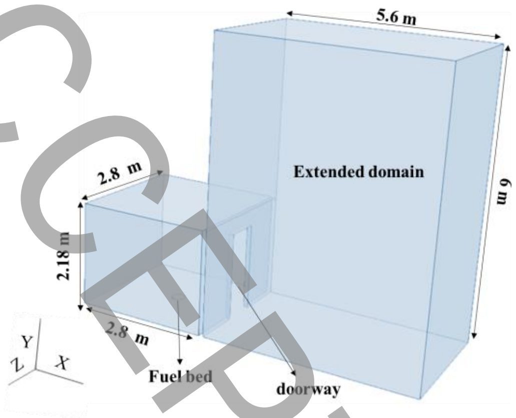

Figure 1. Numerical geometry domain

In Figure 2, the mean temperature and velocity results are seen versus the height at the doorway. The numerical results of three combustion models at the heights below the 1m, are consistent with the experimental results; But at higher heights, where hot gases exits the room, the results of the EDM and IFC combustion models are much consistent than the FGM. In general, according to the results of the mean temperature in the doorway, it is observed that the results of the EDM and IFC are better than the FGM combustion models.

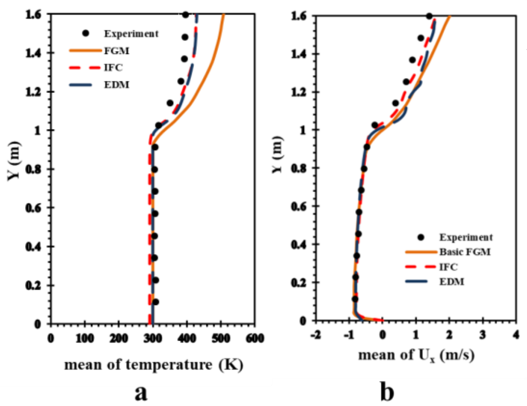

Figure 2. a) Temperature and b) velocity at the doorway

As can be seen, the numerical results of the velocity in the three combustion models are in good agreement with the experimental results; Although at higher altitudes there is some difference with the experimental results, however, in general, the mean velocity results are more accurate than the experimental results compared to the mean temperature results. So that at height less than 0.1 m, the numerical results of the three combustion models, there is less than 2% relative error with the experimental results and at higher height, there is less than 10% relative error in the three combustion models.

5. Conclusions

In order to investigate the importance of the combustion model in compartment fire simulation, the FGM combustion model was used and the results were compared with IFC and EDM combustion models. The results of the IFC and EDM have a 10% lower relative error in predicting temperature results than the FGM combustion model. In addition, all three combustion models had a relative error of less than 10% in predicting the velocity, inlet air flow to the room and the height of the neutral line, which shows the appropriate accuracy of these combustion models.

6. References

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