Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 697-700
DOI: 10.22060/mej.2020.17303.6568

Comparison Study of Compartment Fire Simulation with Steady Laminar Flamelet and Eddy Dissipation Model

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ABSTRACT: The present study is conducted to find a compatible combustion model, in case of single room compartment fire. The large eddy simulation was used with one-equation sub-grid scale turbulence model by steady laminar flamelet and eddy dissipation models were acquired as the combustion model. OpenFOAM solver based on C++ programming language was developed to use the flamelet model. The benefit of the flamelet model employment than the eddy dissipation model was regarding the lower computational cost which was about 14 percent lower in this case. Moreover, steady laminar flamelet model considered the detailed chemical kinetic of GRI 3.0, however, eddy dissipation model treated the chemical kinetics of the model with an irreversible single-step Arrhenius global reaction which is only able to estimate the main products of combustion. Deviations of velocity and temperature at the doorway showed that the steady laminar flamelet model predictions were accurate with an uncertainty error of 3.3 % for temperature and 8 % for velocity, respectively. Prediction of the temperature inside the room with a steady laminar flamelet model was estimated to have 3.2 % accuracy.

Review History:

Received: Oct. 31, 2019
Revised: Mar. 14, 2020
Accepted: May. 03, 2020
Available Online: May. 09, 2020

Keywords:

Compartment fire
Large eddy simulation
Eddy dissipation model
Steady laminar flamelet model

1. Introduction

Understanding the dynamic of the studied fire scenario increases the ability to predict the behavior of fire and the amount of heat and smoke generated by it. Different approaches are possible to evaluate the dynamics of fire. Due to the less cost and risk of numerical methods in comparison to experimental ones, computational fluid dynamics was acquired to simulate the flow. The Large Eddy Simulation (LES) method is used to model the flow to consider the detailed description of the flow.

Many studies have attempted to select different sub-grid scale models to simulate the flow, in order to conclude the compatible model. Recently, the Steady Laminar Flamelet (SLF) combustion model has been employed in fire simulations. Wen et al. [1] modeled a pool fire in a one-room space using the steady laminar flamelet model with detailed kinetics (including 37 species and 112 reactions). Rawat et al. [2] simulated the large-scale methane pool fire with the unsteady laminar flamelet model and one step reduced chemical kinetics. Dejardin et al. [3] tried to simulate the same case to evaluate various Probability Density Function (PDF) distributions to form the flamelet library. Yuen et al. [4] attempted to assess the compatibility of different turbulence models with a steady laminar flamelet model to simulate a compartment fire. Marchand et al. [5] compared the eddy dissipation model and steady laminar flamelet to simulate a small-scale line fire. Results showed that the steady laminar Fflamelet model had slightly under-predicted the temperature in the center of the burner.

Low computational cost of the flamelet model helps to simulate reactive flows with detailed chemical kinetics in order to consider the influence of intermediate species in combustion. In the current study, a comparison between the effect of using the steady laminar flamelet and eddy dissipation model has been conducted to simulate a compartment fire in a single-room space. It should be noted that due to the lack of the steady laminar flamelet model in the OpenFOAM software, a customized solver has been developed to employ this software with the detailed GRI 3.0 chemical kinetics.

2. Methodology

In the current study, the single room compartment of the study of Steckler et al. [6] has been examined. It is necessary to add a space next to the room so that the behavior of the flow in this area is simulated precisely. According to Fig. 1, in addition to the room where the fire source is located, the extended space with dimensions of is included.

OpenFOAM which is an open source C++ based software is adopted to simulate the flow. Customized solver is implemented to OpenFOAM in order to use the steady laminar flamelet model. In the pre-processing stage of the solver, CHEMKIN software is used to form the laminar flamelet library then PDF functions are used to account for the influence of turbulence on the library. Finally, non-reactive scalar in the flow field is calculated and used to extract the thermochemical properties from the corresponding library.

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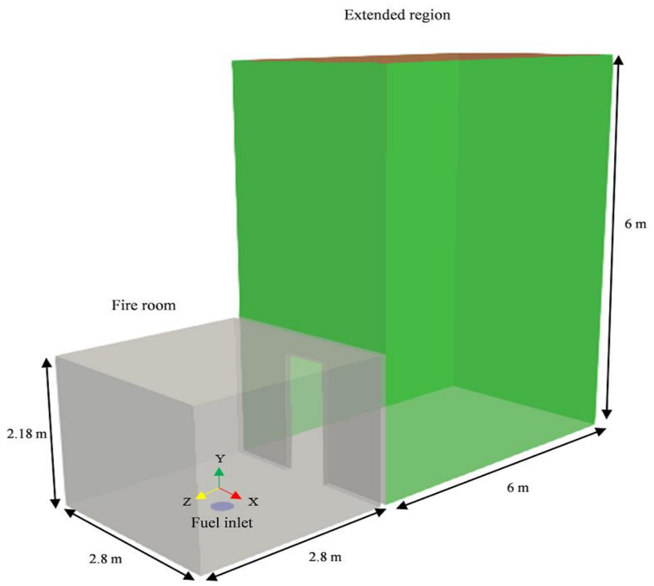

Fig. 1. Geometry of the one-room compartment in the current study

Table 1. Different model characteristics

Combustion model	Chemical kinetic	Species no.	Time (hr)
Steady laminar flamelet model	GRI 3.0	53	136
Eddy dissipation model	One step arrhenius	5	156

Table 1 describes the condition of each simulation for combustion models. Although the steady laminar flamelet model uses detailed chemical kinetics, it has a 15% less computational cost than the eddy dissipation model.

3. Results and Discussion

Compartment fire has a different dynamic because of the effect of solid boundaries and openings. Fig. 2 depicts the contour of temperature and velocity vectors in the center plane of the compartment. The ceiling of the room causes the combustion products of the fire to accumulate in the hot layers under the ceiling of the room. Due to the pressure difference between the fire room and the outside space, fresh air enters from the lower opening area. The hot air flow also leaves the room from the top of the opening.

According to Fig. 3, the result of the average temperature at the center of the opening for each model was compared with experimental results. As the opening height increases, the air temperature increases. On the other hand, the average temperature in the upper half of the opening from the numerical solutions is slightly higher than the experimental results. This could be due to the nature of the two combustion models used, assuming very fast chemistry to model the combustion. Around the height of 1.4 m, the flamelet model has a better trend than the eddy dissipation model. However, as the flow reaches near the ceiling, the predicted temperature increases. In the case of the eddy dissipation model, the temperature reaches a constant value which is due to solving the energy transport equation and considering the ceiling boundary condition.

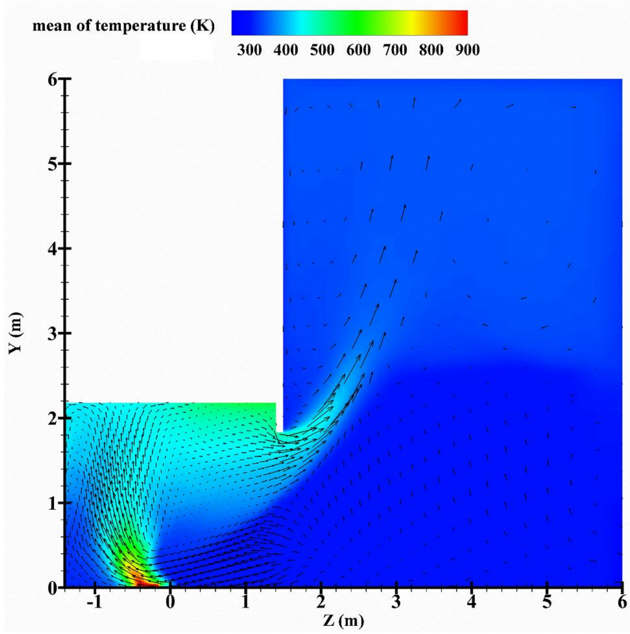

Fig. 2. Temperature contour and velocity vectors in the compartment

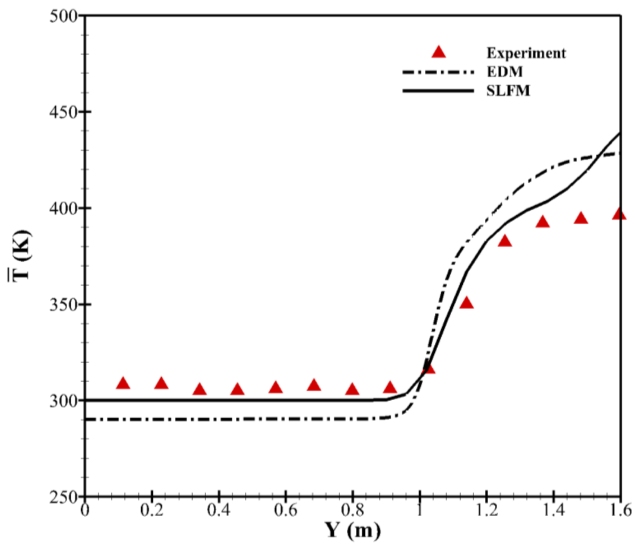

Fig. 3. Comparison of numerical and experimental results for the average temperature at the doorway

4. Conclusions

A comparative study was performed between the combustion models of steady laminar flamelet and the eddy dissipation model to select compatible the combustion model with the physics of single room compartment fire. Averaged temperature and velocity deviations at the opening were compared with the experimental results for both models. The results show that the steady laminar flamelet model is quite better in predicting the temperature and velocity in the opening of the room. Moreover, the computational cost of the laminar flamelet model was 15% less than the eddy dissipation model even though the detailed chemical kinetic was acquired for the flamelet model.

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HOW TO CITE THIS ARTICLE

S. M. J. Razeghi, M. Safarzadeh, H. Pasdarshahri, Comparison Study of Compartment Fire Simulation with Steady Laminar Flamelet and Eddy Dissipation Model, Amirkabir J. Mech. Eng., 53(5) (2021) 697-700.

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