論文の内容の要旨
Abstract of Dissertation

Title of Dissertation: Numerical Study on Unsteady Propagation of a Laminar Premixed Flame in the Presence of an External Heat Source

(論文題目　外部加熱された層流予混合火炎の非定常伝播に関する数値解析の研究)

氏　　名　　ホセイン　アクター

1. Introduction

Most of the combustion process in practical combustors is associated with a strong turbulent environment where local non uniform temperature distribution plays a vital role on flame dynamics. Recently, Tsuchimoto [1a] and Kyozu [1b] et al. examined the effect of non uniform temperature distribution on flame dynamics by imposing an external heat source such as laser ray along the center line of a combustion tube. They observed the flame oscillation during propagation in the combustion tube. Since the complete mechanism of the flame oscillation phenomenon has is not been confirmed yet, the goal of this study is to figure out the mechanism of the flame oscillation phenomenon observed in experiments [1a] and [1b].

2. Numerical Simulation

In this study, a two-dimensional time-dependent system of governing equations for reacting flows, in the absence of the Soret effect, Dufour effect, pressure gradient diffusion, gravity and radiation, is chosen and is discretized by using finite volume method (FVM) on a hexahedral structured grid cells and solved them by adopting Front Flow Red, a multi-scale and multi-physics computational fluid dynamics (CFD) solver under the low Mach number approximation in a two dimensional channel. The combustion chemistry is modeled by the single-step irreversible overall chemical reaction between ethylene and oxygen.

3. Results and discussion

To reach the stated goal, we have divided our investigation into four stages as below:

In the first stage, we have investigated the influence of the motion vortices, evolved from the sudden gas expansion at the larger ignition zone, on the propagation of a laminar premixed flame in a channel [see Fig. 1(a)]. The strong instantaneous movement of these vortices rapidly deformed and enlarged the flame surface area, which gives rise to flame oscillation during the propagation and is shown in Figs. 2 and 3. The results observed in this stage suggest that the suppression of this type of strong vortex evolution is essential for the investigation of the main issue of this dissertation.

In the second stage, we have successfully controlled evolution of the large vortices by reducing the ignition zone over the channel [see Fig. 1(a)]. It is found that the propagation is very stable instead of showing oscillation during propagation and is displayed in Fig. 4. Therefore, the smaller ignition zone makes a suitable platform for the investigation of the main issue.

In the third stage, we have investigated the external heat source induced in-line pre-heating effect, along the center line of a combustion channel with a width of 1 mm [see Fig. 1(b)], on the flame dynamics. The highly deformed flame front is observed due to pre-heating effect and the propagation speed is significantly accelerated compared to non pre-heating effect (see Fig 5). This high deformation in the flame front induces a negative velocity distribution (see Fig. 7) ahead of flame tip (see Fig. 6), which generates a very weak pair vortex in front of flame tip at the side of reactant (see Fig. 8). This phenomenon is seemed to be related to the flame oscillation phenomenon observed in experiment [1a] and [1b] as the interaction between a flame and vortex often generates flame oscillation during the propagation.

In the final stage, we have investigated the influence of flow-induced instability ahead of a flame tip at the side of a reactant due to a very thin pre-heating treatment of width 0.5 mm along the center line of a combustion channel [see Fig. 1(b)]. It is observed that the flame front is extremely deformed due to the narrow pre-heating effect along the center line of the channel. The deformed flame front induces a thin vortex sheet that is attached on the frontal side of the deformed flame front. This thin vortex sheet induces a strong negative velocity ahead of the flame tip, which enhances the generation of a strong pair vortex at the side of the reactant. The pair vortex interacts with the flame tip [see Fig. 9] and rolling up along the flame surface towards upstream during the propagation. The interaction between the flame and vortex shows oscillatory behavior during the propagation in the combustion channel. This flame-vortex interaction would be one of the possible sources of laser induced flame oscillation in experiments [1a] and [1b].

4. Conclusion

In this study, we have obtained a pair vortex ahead of flame tip, due to highly deformed flame front driven negative velocity distribution, induced by an in-line pre-heating treatment. This induced vortex pair not only plays a vital role to explain the instability mechanism but also very useful to develop an efficient flame model to simulate the local non uniform temperature variation in practical devices during turbulent combustion.

References

[1a] Tsuchimoto M., Kyozu A., Fujita O., Ito H., Nakamura Y., The flame oscillation phenomena induced by external radiation, Transactions of the Japan Society of Mechanical Engineers, Vol. 73, pp. 803-808 (2007) (in Japanese).

[1b] Kyozu A., Nakamura Y., Fujita O., Observation of flame oscillation phenomenon induced by external radiation in microgravity, Proc. Forty-Third Symposium (Japanese) on Combustion, pp.250-151 (2005) (in Japanese).

[1c] Personal communication for data with Prof. Osamu Fujita, Division of Mechanical and Space Engineering, Hokkaido University, Japan.

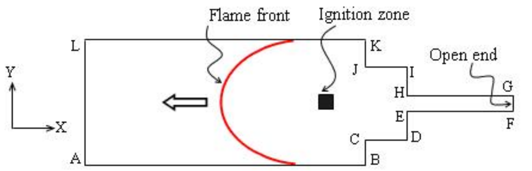

Fig. 1(a) Schematic view of the simulation domain and coordinate system.

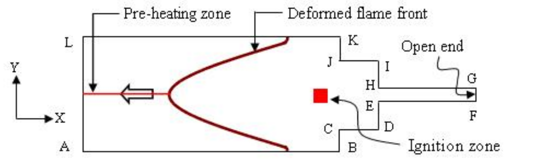

Fig. 1(b) Schematic view of the installation of pre-heating zone in the calculation domain.

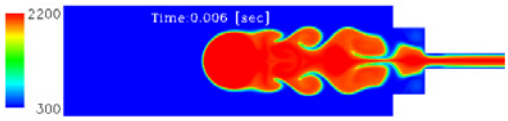

Fig. 2 Temperature distribution in the channel with ignition zone of 25 mm^2 for time 0.006 [sec]

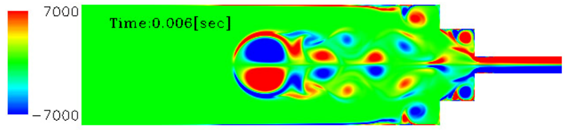

Fig. 3 Vorticity distribution in the channel with ignition zone of 25 mm^2 for time 0.006 [sec]

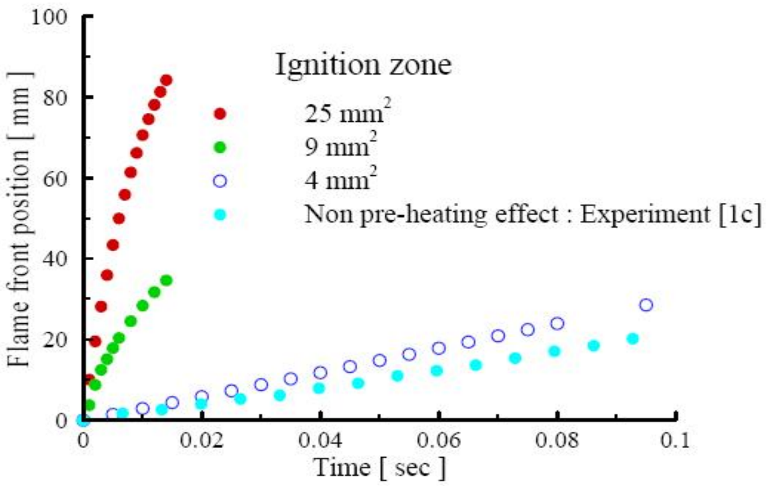

Fig. 4 The flame front location versus time along the center line (y = 25 mm) of combustion channel.

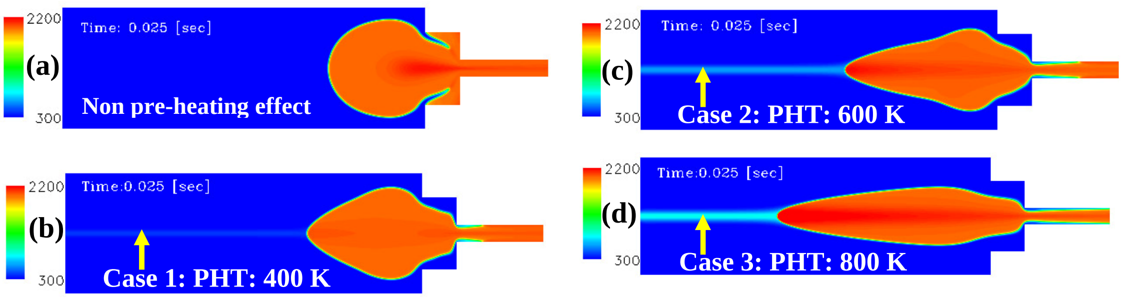

Fig. 5 The temperature distribution in the combustion channel: (a) for non pre-heating effect and (b) for PHT of Case 1, (c) for PHT of Case 2, and (d) for PHT of Case 3 at time 0.025 sec with 1 mm pre-heating width (PHW), (Here, PHT: stands for pre-heating temperature)

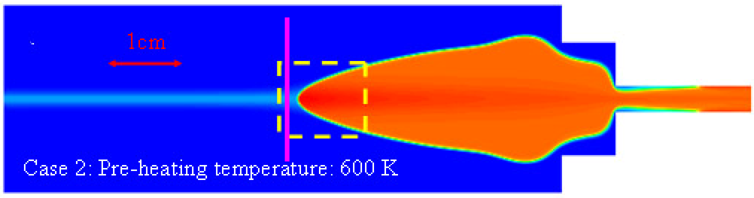

Fig. 6 Instantaneous temperature distribution for PHT : 600 K and PHW : 1mm.

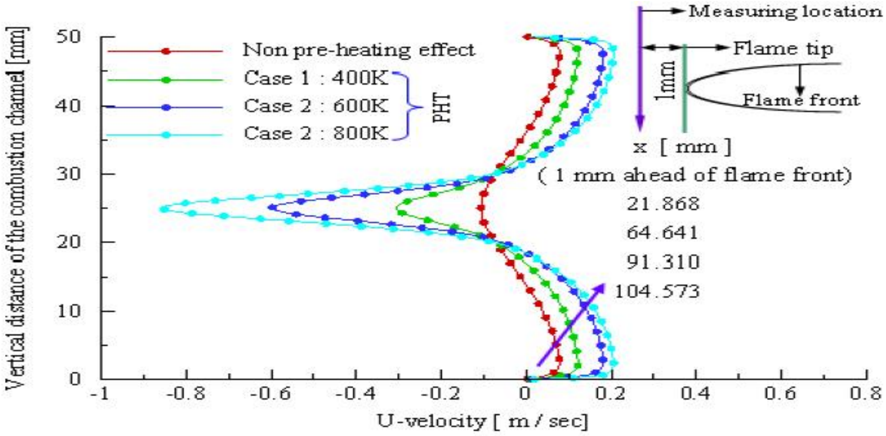

Fig. 7 The detailed negative velocity distribution 1 mm ahead (it is located at the pink-colored vertical line in Fig. 6) of flame tips for pre-heating and non pre-heating effect.

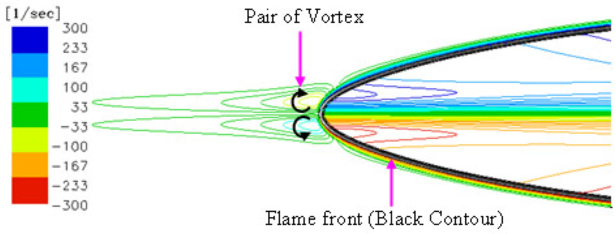

Fig. 8 Visualization of weak pair vortex (by vorticity contour) ahead of flame tip due to negative velocity distribution (shown in Fig. 7)

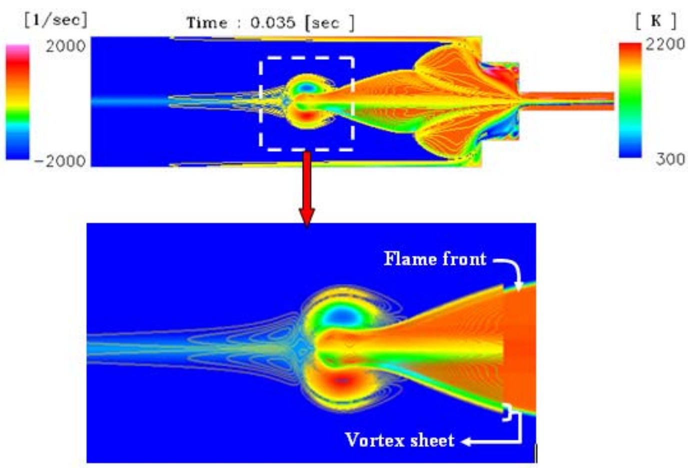

Fig. 9 Visualization of the strong flame-vortex interaction by the temperature (in solid) and vorticity [1/sec] (in contour) distribution for PHT: 600 K and PHW: 0.5 mm.