Quasi-Two-Dimensional Flamelet Models for a Three-Feed Non-Premixed Combustion System

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（３フィード非予混合燃焼システムに対する準二次元火炎片モデル）

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論　文　内　容　の　要　旨

This dissertation mainly develops an extension of the one-dimensional flamelet progress-variable (FPV) approach in order to tackle with the issues in a three-feed non-premixed combustion system into which a diluent is injected. The conventional one-dimensional FPV is based on the two-feed counterflow system which is composed of a fuel port and an oxidizer port. Since the mixture fraction space is one-dimensional, for a one-dimensional flamelet model it cannot interpret the mixing flow in a three-feed system. However, the flamelet-based model is such a powerful approach which can not only allow us to get access to the detailed chemistry mechanism but also solve the temperature and species transport equations prior to the simulation; these make it appealing in terms of turbulent combustion issues. So it is of great significance to develop a flamelet-based model to address the three-feed non-premixed combustion challenges. In the current work, three quasi-two-dimensional flamelet (Q2DF) models are proposed, and they are validated by means of direct numerical simulation (DNS) first, afterwards, with proper modelings of the tracking parameters proposed they are also applied in large-eddy simulation (LES) on a lab-scale facility.

CO is a dominant composition in the three-feed non-premixed combustion system in this work, but it was pointed out that the CO concentration cannot be captured accurately by the FPV in some researches, and an unsteady flamelet model (USFM) is considered as a good remedy. However, the USFM is not desirable in the current research due to its excessive dimensions in the library. The purpose of this work is to develop a flamelet model with the additional dimension in it called the diluent fraction; the diluent fraction is the very focus. So the extension on the basis of the one-dimensional FPV would be favorable if the CO could be predicted reliably. Considering conditions have been varied from those researches, a priori test is necessary and of significance. A LES is applied in a lab-scale facility by means of the one-dimensional FPV, in which the CO is a product and plays an important role and coal tar species are taken into account. According to the results, the prediction of the CO can achieve good agreement with the experimental data, and it is concluded that the FPV is suitable to be an extension base.

The Q2DF models in this work are derived based on the two-dimensional flamelet (2DF) model. By setting a zero scalar dissipation rate for the diluent stream mixture fraction in the three-feed counterflow system, the 2DF can be reduced to the one-dimensional flamelet model, and a series of one-dimensional flamelet libraries can be integrated by the parameter diluent fraction. These Q2DF models are derived from the 2DF, but the reduced flamelet model can still keep the influence of the third stream; this is the reason we call it quasi-two-dimensional flamelet model. These models are validated by DNS first, in which no turbulence model is employed. Comparisons are made between three model cases and a reference case in which the identical detailed mechanism coupled with the Arrhenius formation (ARF) is used. It has been confirmed that three Q2DF model cases can obtain good agreements with the ARF case, however, differences among the three models are not apparent.

To have further understanding of these models and apply them in the industry field, LES has been implemented. LES modelings for the Q2DF models are quite essential, and they would be complicate especially when the nonlinear connection for the mixture fractions turns up. Instead of solving the transport equations, the LES modelings for the mean value and its variance have been figured out directly based on the connection of the three mixture fractions in this work. According to the results by comparing the simulation and experiments, these modelings are confirmed to be quite effective and accurate. Based on the LES and flamelet formulations solving results, comparisons are made between Q2DF models and 2DF model in terms of the cross-scalar and scalar dissipation rates. It has been confirmed that the Q2DF models are essentially the 2DF model in which the cross-scalar and scalar dissipation rates are considered incompletely and diluent fraction is discretely distributed. Furthermore, the fluxes of the streams in the three-feed non-premixed combustion system also affect the performances of the Q2DF models through the tracking parameters such as mixture fraction with its variance, as well as the diluent fraction. Therefore, the models can be selected according to the dominant stream flux in the flow field. The best accuracy may could be achieved by the complete 2DF model, however, owing to too excessive dimensions of the library, especially in terms of the LES, it is still undesirable.

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