초임계 순산소 연소 조건하 대향류 비예혼합 화염에 대한 복사열전달 효과 예측

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Prediction of Radiative Heat Transfer Effect on Counterflow Non-premixed Flames under Supercritical Oxy-fuel Combustion Conditions

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As one of next-generation power cycles for enhancing the cycle efficiency and meeting environmental regulations, a direct-fired supercritical carbon dioxide (sCO_2) power cycle, or the Allam cycle, has been highlighted since it was first proposed. This cycle adopts oxy-fuel combustion in which natural gas is designed to burn with O_2 diluted with burned gas and can literally generate no NO_X emissions.

Several three-dimensional numerical simulations are carried out to understand the overall flame characteristics under sCO_2 oxy-fuel combustion conditions [1, 2]. However, these studies do not take into account the radiative heat transfer although there is a lack of evidence for the assumption on adiabatic condition. On the one hand, there are large amounts of strong absorbers such as H_2O and CO_2 in sCO_2 oxy-fuel combustor, and thus, the effect of radiative heat transfer would be important. On the other hand, the flame thickness at 300 atm is $\mathcal{O}(0.1)$ mm which would significantly reduce the temperature drop by the radiative heat loss. In this context, the effect of radiative heat transfer on the flame temperature in sCO2 oxy-fuel combustor is not clear, which motivates the present study.

Therefore, the main objective of the present study is to predict the radiative heat transfer effect on the sCO_2 oxy-fuel combustor by performing one dimensional numerical simulation of counterflow non-premixed flames at high pressures up to 300 bar.

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Note that there exists no suitable radiation model validated under the extremely-high pressure condition. For instance, the weighted sum of gray gases (WSGG) model based on statistical narrow band model (SNB) [3] is the best compromise between accuracy and computational demand under atmospheric pressure condition. For the relatively-high pressures up to 30 bar, the pressurized WSGG model has been proposed [4]. Although these models can be adopted for the combustion simulation at relatively-low pressure conditions, they are inappropriate at extremely high pressure such as sCO_2 oxy-fuel combustion conditions. Therefore, we propose two WSGG models by extrapolating the conventional and pressured WSGG models and estimate the effect of radiative heat loss on the flame temperature of counterflow flame.

In this study, CH_4 versus O_2/CO_2 counterflow non-premixed flames under sCO_2 oxy-fuel combustion conditions is simulated at various pressures by using a modified OPPDIFF code [5], which incorporates real gas effects. The GRI-Mech 3.0 [6] is adopted for methane oxidation.

We first calculate the absorption coefficient, $\boldsymbol{\kappa_{p,i}}$, at high pressures by introducing two different models. The first is the WSGG-Linear model, which adopts a linear interpolation of $\boldsymbol{\kappa_{p,i}}$ based on the data at atmospheric pressure. The other is the WSGG-Log model, which estimates $\boldsymbol{\kappa_{p,i}}$ by using the logarithmic extrapolation. Figure 1 shows the estimated $\boldsymbol{\kappa_{p,i}}$ of four gray gases at 300 atm obtained from WSGG-Log and WSGG-Linear model. As shown in Fig.1, the estimated $\boldsymbol{\kappa_{p,i}}$ of four gray gases for the WSGG-Linear model is approximately two orders of magnitude larger than those of the WSGG- Log model.

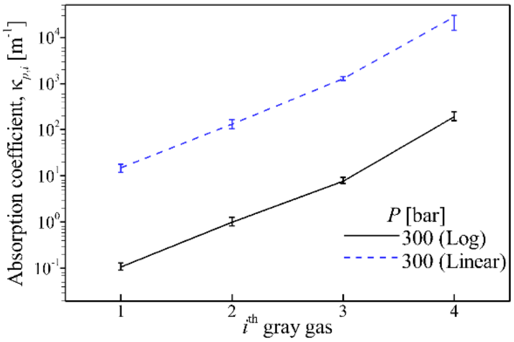

Fig. 1 Absorption coefficients, $\kappa_{p,i}$, of four gray gases and values estimated by using two different methods.

Based on the above estimation, the radiative heat loss effect on CH_4 versus O_2/CO_2 counterflow non-premixed flames at 300 bar is investigated by varying $\boldsymbol{a}$. Figure 2 shows the flame temperature, T_f, between the adiabatic and each WSGG model. It is interesting to note that even though $\boldsymbol{\kappa_{p,i}}$ between two WSGG models are significantly different, the difference in T_f is negligible at $\boldsymbol{a} >$ 50 s^{-1}. This is mainly attributed to the highly-thin flame thickness, and thus, it implies that the importance of radiative heat loss under practical sCO_2 combustor in which overall strain rate is high may be negligible.

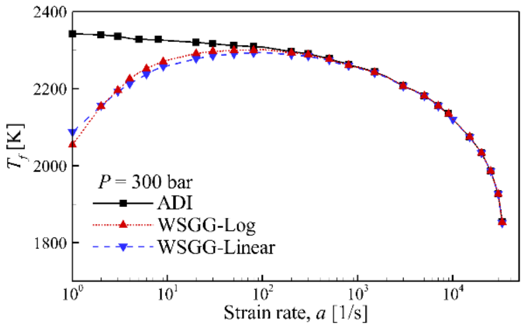

Fig. 2 Flame temperature profile of non-premixed counterflow flame as a function of strain rate obtained by different radiative heat transfer models.

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