Flame structure and lift-off height of biogas combustion in jet-in-hot coflow flame

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Abstract

The utilization of renewable energy sources is attracting increasing attention because of the need to decrease our dependence on fossil fuels and in order to avoid the negative environmental impact derived from their use. Biogas is one of these renewable sources of energy. Nevertheless, due to its low calorific value, and lower flame stability the conventional existing combustion equipment cannot be directly used for the combustion of biogas. In order to provide possible solutions for the conversion form biogas chemical energy to useful thermal energy, we report on a study of stabilization of biogas flames for the case of MILD (Moderate or Intense Low-Oxygen Dilution) combustion.

In the present work the stabilization mechanism and the structure of a turbulent non-premixed flame of a biogas mixture in a hot and diluted coflow mimicking the MILD combustion are studied experimentally and numerically. Biogas-like fuel is obtained by the CO_2 dilution of Dutch natural gas (DNG). Experimental observations are performed by high speed recording of the flame luminescence. Numerical simulations are conducted by solving the RANS equations using RSM as turbulence model in combination with EDC (Eddy Dissipation Concept) and transported probability density function (PDF) as turbulent-chemistry interaction models. The DRM19 reduced mechanism is used as the chemical kinetics for EDC model. Further, to reduce the computational time, a tabulated chemistry model based on the so called Flamelet Generated Manifold (FGM) is adopted in the PDF method.

To characterise flame stabilization, the emphasize is placed on the study of the flame lift-off height. The results of biogas combustion are also compared with those of DNG combustion in Delft-Jet-in-Hot-Coflow (DJHC) burner. The performance of EDC and PDF in predicting the lift-off height is then evaluated against the experimental measurements.

Luminescence measurements show that compared to the lift-off height of the DNG flame, addition of 30% carbon dioxide to the fuel increases the lift-off height by less than 10%. The results obtained using EDC/DRM19 and PDF/FGM are in excellent agreement with experiments.

Moreover, it is observed for DNG and biogas fuels that, as the temperature of the coflow increases, the flame length increases, the lift-off height decreases and the flame becomes more luminous. The EDC/DRM19 and PDF/FGM predict the experimentally observed decreasing trend of lift-off height with decrease of the coflow temperature. However, in comparison with PDF/FGM, the EDC/DRM19 leads to the results in better agreement with experiments.

Numerical results show that when the coflow temperature in increased by 200K the lift-off height decreases by 50%. Moreover, by increasing the coflow temperature, the flame length increases and the value of OH mass fraction increases. Whereas, increasing the fuel temperature by 200K the flame lift-off height decreases by 11%. In addition, in this limit the flame width increases.

In summary, in hot coflow burner mimicking the MILD regime, the stabilization mechanism and the flame lift-off height for biogas are very similar to those of natural gas. The result shows that the MILD combustion is promising technique for stable combustion of biogas with low emissions.