Abstract

Oxy-coal combustion has attained a considerable interest among researchers as a leading technology for the mitigation of greenhouse gases emission of the coal-fired power generation system. The oxy-coal combustion technique employs approximately 95% pure oxygen and recycled flue gases (RFG) mainly consisting of carbon dioxide and water vapour instead of air for combustion. The furnace design and operational characteristics of oxy-coal combustion atmosphere are a challenging task; hence, computational fluid dynamics (CFD) modelling should be appropriately employed for the purpose. CFD modelling technique can analyze reactive flow field, temperature distribution, species concentration and heat transfer properties of oxy-coal combustion atmosphere effectively and efficiently.

Based on the state-of-the-art review on the characteristics of oxy-coal combustion, the models and submodels of combustion mainly focusing on radiative heat transfer and char combustion have been modified to model the pulverized coal combustion characteristics under oxy-fuel combustion atmosphere. The developed CFD model employing the RANS turbulence models has been validated by the available experimental and numerical results. The RANS predictions of axial velocity, tangential velocity, temperature distribution and species concentration have been compared with experimental and large eddy simulation

(LES) results available in the literature for the validation. The RANS based turbulence models are unable to estimate internal recirculation zone (IRZ) size and turbulent mixing in the char combustion region. At position close to the burner, the discrepancies between the predicted axial velocity profile and experimentally measured values are mainly due to incorrect assumption of uniform velocity profiles at the burner and/or shortcoming of the turbulence model in the swirling flow prediction. Velocity profile at burner outlet is not available from the experiment; the constant value of axial velocity (similarly tangential velocity) has been used at the inlet boundary condition. RANS turbulence models are able to capture the qualitative trend of temperature profile having variations in the range of 5-15% with the experimental results. The differences between the numerical prediction of temperature profile with the experimental results are attributed due to the inability of the model to predict the strong recirculation zone, which has been formed by the distribution of burner cold stream. The deviations in the prediction of oxygen mole fraction distribution are found due to their differently predicted flow field and mixing process. Although there are some discrepancies between current RANS prediction and experimental data for temperature and oxygen mole fraction close to the burner, the developed model is able to capture qualitative trend with comparable accuracy to the LES modelling at all axial locations.

The developed and validated CFD models are employed for the numerical investigation of the influences of swirl strength, combustion environments (obtained by varying the composition of feed gas), inlet temperature and pressure of feed gas on the reactive flow field and combustion characteristics. Furthermore, a quantitative analysis showing the influence of swirl strength, various combustion environment, inlet temperature and pressure of feed gas on length of internal recirculation zone (IRZ) and flame front has been presented. Both the reactive flow field and flame characteristics are significantly affected by the swirl strength. Longer internal recirculation zone (IRZ) has been formed along the axis, and flames spread out in the radial direction at higher swirl strength. The oxy-coal combustion atmospheres having higher oxygen concentration has produced narrow and short flames with higher flame temperature due to shifting of ignition position close to the burner. Increase in inlet temperature of feed gas resulted in higher axial velocity due to reduced density. Both the strength and axial dispersion of the internal recirculation zone (IRZ) are enhanced at higher inlet temperature. Increase in inlet pressure of feed gas decays the strength of internal recirculation zone (IRZ) created along the axis, whereas its length increases.

Numerical investigation of the influence of higher concentration steam addition on oxy-coal combustion process has been studied as the burning of pulverized coal particle takes place under enriched steam conditions under practical combustion cases. Steam is added by 10-50% to obtain various wet oxy-coal combustion cases. Comparison between ideal dry recycle oxy-coal combustion case with wet oxy-coal combustion cases (10-50% H_2O) and oxy-steam combustion case (CO_2 is replaced by H_2O in the oxidizer) is also presented. Addition of H_2O would considerably affect combustion characteristics of oxy-coal combustion by varying heat capacity, gasification and radiation due to distinct chemical and physical properties of steam than CO_2. Higher flame temperature under enriched steam oxy-coal combustion cases are obtained due to lower volume heat capacity of H_2O than

CO_2. Steam enrichment has also enhanced char gasification reaction, which has affected temperature distribution and incident radiation profile inside the combustion chamber.

Based on the literature review, it has been found that the char gasification reactions strongly influenced oxy-coal combustion characteristics. Studies presenting the influence of gasification reactions are mainly limited to drop tube furnaces. Hence, the influence of char gasification reactions on the species distribution and temperature profile has been investigated in this work. The result shows that the temperature profile in the furnace has been significantly influenced by endothermic gasification reactions at the char particle surface. CO_2-char gasification reaction has a more pronounced influence than the H_2O-char gasification reaction. The consideration of gasification reactions has resulted in approximately 5% reduction in peak temperature. Furthermore, the computation of NO_x concentration under oxy-coal combustion atmosphere has also been presented in this work. The result showed that higher NO_x emission is produced under oxy-coal combustion cases having higher O_2 concentration in the oxidizer due to enhanced conversion rate of coal_N to NO_x.

In the second part of this work, a thermodynamic analysis of 660 MW pulverized coal-fired power plant retrofitted to oxy-coal combustion has been presented. A steady-state numerical model for the integrated oxy-combustion power plant has been developed and verified employing process simulation tool Aspen plus (V 10.0). 660 MW boiler working under typical Indian climatic condition employing the high ash Indian coal has been simulated, taking into account that it can provide supercritical steam parameters to reduce the energy penalty related to ASU and CPU. The oxy-coal combustion power plant consists of air separation unit (ASU), oxy-coal combustion unit, steam cycle and CO_2 compression and purification unit (CPU). Incorporation of ASU and CPU in power generation system has reduced the net plant efficiency as these units consumed sufficient power. Advantage of retrofitting conventional air-fired power plant to work under oxy-coal has been observed in term of high CO_2 recovery and high CO_2 purity. The results show that the oxy-coal combustion power generation case has 10.4% reduction in net efficiency due to incorporation of ASU and CPU. Oxy-coal combustion power generation case has been able to capture carbon dioxide with 95% purity and 96% recovery rate.