Chapter 7

Conclusions and Scope for Future Work

7.1 Overview

Studies on fundamental characteristics of oxy-coal combustion due to different physical and chemical properties of CO_2 than the N_2 has been presented in the previous chapters. A detailed discussion on various submodels of oxy-coal combustion has also been provided. Furthermore, the developed CFD model is validated by available experimental data of Toporov et al. (2008) and numerical findings of Warzecha and Boguslawski (2014a). Then the developed CFD model is applied to oxy-coal combustion in a tubular combustor to investigate the influence of important operating parameters such as swirl strength, oxygen concentration, inlet feed gas temperature and pressure, steam addition and gasification reactions on flow field and combustion characteristics. In the chapter 6, we have applied the oxy-coal combustion concept to a 660 MW supercritical power plant working under air-fired combustion atmosphere. The thermodynamic analysis of the same power plant is performed to find out the energy penalty, CO_2 product purity, recovery rate and auxiliary power consumption due to incorporation of ASU and CPU. We have also performed the sensitivity analysis to identify the important operating parameters.

7.2 Conclusions of Numerical Modelling of Oxy-Coal Combustor

A computational modelling has been performed to study the influence of swirl strength combustion environment, inlet temperature and pressure of feed gas on the flow field and combustion characteristics. The effect all the parameters on the length of internal recirculation zone (IRZ) and the flame front has been quantitatively summarized. We have also investigated the influence of higher concentration steam addition on flow field and combustion characteristics. Comparison of various wet oxy-coal combustion cases (obtained by varying the steam concentration in the oxidizer) with the dry oxy-coal combustion (0% steam) and oxy-steam combustion case (whole CO_2 is replaced by H_2O) has been performed. Furthermore, the influence of gasification reactions on temperature and species concentration has also been assessed. The influence of the important operating parameters on NO_x emission has been also provided in this work. The key conclusions are summarized as:

7.2.1 Influence of Swirl Strength and Combustion Atmosphere

- The variation of swirl strength has affected both flow field and flame characteristics significantly. At higher swirl strength, longer internal recirculation zone (IRZ) formed along the axis and flame spread out in the radial direction. More intense and stable flames have been obtained at higher swirl strength due to enhanced mixing of fuel and oxidizer streams.
- Narrow flame with higher flame temperature has been obtained with increasing oxygen concentration due to shifting of ignition position close to the burner. The

flame temperature of oxy-coal combustion case having 21% O_2 was 300 K lower than the oxy-coal combustion case having 35% O_2.

- The devolatilization and char combustion processes of pulverized coal combustion were enhanced with an increase in O_2 concentration in the oxidizer, which resulted in increased flame temperature and burning rate. Oxy-coal combustion cases having 25%, 30% and 35% O_2 in the oxidizer produced 10%, 18% and 24% higher flame temperature than the oxy-coal combustion cases having 21% O_2 in the oxidizer.
- The temperature and radiative properties should be identical in both conventional air combustion and oxy-coal combustion for retrofitting purpose. Due to higher heat capacity of CO_2 than N_2, lower peak temperature was obtained in oxy-coal combustion atmosphere having 21% O_2 in the oxidizer. With an increase in O_2 concentration in the oxidizer, the value of peak temperature rises and oxy-coal combustion case having 30% O_2 in the oxidizer produced somewhat identical temperature and incident radiation distribution profiles as obtained in conventional air combustion.
- The temporal history of particle volatile and char mass fraction has a strong dependency on the residence time in the combustor and particles penetration into the higher temperature region. Both these parameters favourably contributed with an increase in O_2 concentration in the oxidizer and the time required for the completion of devolatilization and char combustion was reduced.
- Enhanced conversion rate of coal N to NO_x has been observed at higher oxygen concentration, which resulted in the higher NO_x emission inside the combustion

chamber for oxy-coal combustion cases having higher oxygen concentration in the oxidizer. NO_x emission at the outlet has been increased by 12%, 35% and 46% for oxy-coal combustion atmosphere having 25%, 30% and 35% O_2 in the oxidizer than the oxy-coal combustion case having 21% O_2.

7.2.2 Influence of Inlet Temperature and Pressure of feed gas

- With an increase in feed gas inlet temperature at a constant flow rate, the density of feed gas reduces, which results in higher peak axial velocity. The peak axial velocity was increased by 27% and 70%, when the feed gas inlet temperature was increased from 313 K to 500 K and 800 K, respectively.
- Shorter flames with higher flame temperature were obtained with an increase in feed gas inlet temperature due to earlier initiation of the combustion process at higher feed gas temperature. The peak flame temperature was increased by 3% and 9%, when the feed gas inlet temperature was increased from 313 K to 500 K and 800 K, respectively.
- With an increase in feed gas inlet pressure at a constant flow rate, the density of feed gas increases, which results in lower peak axial velocity. The peak axial velocity was reduced by 80% and 90%, when the feed gas inlet pressure was increased from 1 bar to 5 bar and 10 bar, respectively.
- The axial dispersion of the flame front was restricted with an increase in inlet feed gas pressure due to the increased density of the gas phase. The flame length was

reduced by 16% and 32%, when the feed gas inlet pressure was increased from 1 bar to 5 bar and 10 bar, respectively.

- Increasing inlet feed gas pressure decays the strength of internal recirculation zone (IRZ) created along the axis. Inlet feed gas pressure of 5.0 bar and 10 bar have 35% and 38% increase in IRZ length.
- Earlier initiation of NO_x formation has been observed at higher inlet feed gas temperature (500 K and 800 K) due to faster volatile release and earlier initiation of char combustion at higher inlet temperature.
- Slower flame propagation speed at higher inlet feed gas pressures (5 bar and 10 bar) due to increased gas phase density resulted in short and narrow flames. Hence, the NO_x concentration profile shifted towards the burner with slightly higher value at higher inlet feed gas pressures (5 bar and 10 bar) than the inlet feed gas pressure 1 bar.

7.2.3 Influence of Steam Addition

- Higher flame temperature was obtained with an increase in H_2O concentration in oxidizer due to lower volumetric heat capacity of H_2O than CO_2. The oxygen consumption was increased close to the burner quarl due to combined influence of lower volumetric heat capacity and faster oxygen diffusion rate of H_2O than CO_2.
- With an increase in H_2O concentration in oxidizer, the gasification reactions are enhanced, which promoted the faster burnout. H_2O addition to the oxidizer had

more pronounced influence on the temporal profile of char mass fraction than the volatiles mass fraction.

- The gradient of CO_2 concentration diminishes with increase in H_2O concentration, oxy-steam combustion case has produced the lowest gradient of CO_2 concentration. Peak H_2O mole fraction shifts along axial direction with an increase in steam concentration.

- Addition of steam in the oxidizer has considerable influence on NO_x concentration inside the combustion chamber. Under enriched steam combustion atmosphere, char_N conversion to NO has been enhanced which ultimately resulted in increased NO_x concentration inside the combustion chamber.

7.2.4 Influence of Gasification reactions

- The influence of gasification reactions was observed from entrance to axial location ~1.0 m along the combustor. In the gasification zone, lower temperature, higher consumption of CO_2 and H_2O was found.

- Improved burnout was obtained due to the consideration of char gasification reactions in oxy-coal combustion atmosphere. The oxy-coal combustion case considering the gasification reaction has noticeable decrement in gas temperature due to the endothermic nature of gasification reaction.

- Maximum temperature drops of 77 K, 71 K, 62 K and 55 K has been found for the oxy-coal combustion case having an oxygen concentration of 21%, 25%, 30% and 35% in the oxidizer respectively.

- The char-CO_2 gasification reaction has more a pronounced influence than the char-H_2O gasification reaction. The influence of H_2O-char gasification reaction has been observed closer to the burner quarl.

7.3 Conclusions of Thermodynamic Analysis of 660 MW Super Critical Power Plant Retrofitted to Oxy-Coal Combustion

A 660 MW oxy-combustion pulverized coal-fired supercritical power plant has been simulated and analyzed to study the operation characteristics of the oxy-combustion process. Steady state numerical model for the 660 MW super critical power plant working under typical Indian climatic condition employing the high ash Indian coal has been developed and verified employing process simulation tool Aspen plus (V 10.0). The simulation results under oxy-fuel combustion atmosphere have been compared with the base case of conventional air-fired combustion. The sensitivity analysis of important operating parameters such as oxygen concentration, recycle ratio and oxygen purity were also discussed. Furthermore, the environmental interactions of both air-fired and oxy-fired power plant were also presented. The key conclusions are summarized as:

- There was 10.4% reduction in net efficiency for oxy-coal combustion power generation case due to incorporation of ASU and CPU units. Oxy-coal combustion power generation case was able to capture carbon dioxide with 95% purity and 96% recovery rate.
- The formation of CO_2 was promoted, whereas the formation of CO was suppressed with an increase in oxygen concentration due to availability of excess oxygen on the carbon surface, which promoted complete combustion.

- With an increase in oxygen concentration from 21% to 36%, the power consumption of ASU and CPU was increased by 51% and 15%, respectively. At oxygen concentration of 25%, the optimum values of both CO_2 purity and CO_2 recovery rate was obtained.
- The environmental interaction showed that the CO_2 content in the flue gas was 13.15% and 70% under air-fired combustion case and oxy-coal combustion case, respectively. The content of CO_2 in the flue gas under oxy-coal combustion case was further increased to 92% by employing the CPU unit.

7.4 Scope for Future Work

The oxy-fuel combustion technology has gained recognition as the most powerful CCS technique for the mitigation of greenhouse gases emission. A significant contribution has been added in this field by researchers and scientist during the last two decades. However, oxy-fuel combustion technology is still not free from engineering challenges needed to be overcome before deployment of this technology to the large-scale furnaces and industries. In the present work, computational investigation of oxy-coal combustion has been demonstrated employing the appropriate models and submodels. The challenges and research need in other aspects of oxy-pulverized coal combustion are summarized below.

Reactive flow field and flame characteristics analysis using LES

The earlier pilot scale experimental investigations have reported on flame stability problem of oxy-coal combustion. The combustion stability problem of oxy-coal combustion is associated with ignition delay, reduced AFT and lower burning rate. LES modelling approach is able to resolve the dynamic properties in combustion. Hence the flame characteristics such as blow off and destabilization can be accurately dealt employing LES modelling approach.

Studies on combustion and heat transfer characteristics of large-scale boilers

The design of the furnace has a strong dependency on heat transfer characteristics. Although CFD investigations of large-scale boiler have been performed to study the heat transfer and combustion characteristics, but still this area needs more attention.

Development of Lab Scale Experimental Set Up and Advanced Oxy-Burner Designs

There is need for more intense experimental studies on oxy-coal combustion under lab scale combustion facilities to understand complex combustion phenomenon of oxy-coal combustion.

In-Depth Techno-Economic Analysis and Studies on Advance Combustion Technology

There is a need for in-depth techno-economic analysis for the optimization of the oxy-fired power plant and carbon capture and sequestration (CCS) technologies for the improvement of efficiency and reduction of energy penalty and capital cost. Due to inherent environmental benefits of advanced combustion technologies such as IGCC and chemical looping combustion, it is necessary to pay more attention to these technologies.