Abstract

The impact of energy crisis and growing concern for the environment has put more thrust on efficient utilization of energy resources. Coal is the most abundant natural energy resource, and hence, it is responsible for a large portion of world's primary commercial energy use including the generation of electricity. In most of the situations, the primary step involves the combustion of pulverized coal. The present work, comprising five chapters, has been made with this motivation to throw light on some specific aspects of pulverized coal combustion for physical understanding of the processes and achieving the desired goal of energy economy. The Chapter 1 discusses the practical importance of the problem highlighting the state of art and scope of the present work. The work is then divided into four distinct parts and is described in the four remaining chapters of the thesis as follows:

- **(Chapter 2) Modeling of Transport Processes and Associated Thermodynamic Irreversibilities in Ignition and Combustion of a Pulverized Coal Particle.**

- **(Chapter 3) Influences of Inlet air pressure, air temperature and Secondary air swirl on Penetration histories of Pulverized Coal Particles in a Tubular Combustor.**

- **(Chapter 4) Energy and Exergy Balance in the Process of Pulverized Coal Combustion in a Tubular Combustor.**

- **(Chapter 5) Numerical Predictions on the Influences of Air Blast Velocity, Initial Bed Porosity and Bed Height on Shape and Size of Raceway Zone in a Blast Furnace.**

In Chapter 2, a comprehensive mathematical model of various physical processes and associated thermodynamic irreversibilities of combustion of a pulverized coal particle in the surrounding of a quiescent hot gas has been developed to predict the temperature and life histories, ignition characteristics and temporal variations of process irreversibilities of coal particles as a function of free stream temperature of gas phase, initial coal particle diameter and composition of coal.

The major observations from the study are as follows:

- An increase in free stream temperature results in a steeper temperature rise of the particle and increases the maximum temperature and the steady state temperature attained by the particle and decreases its lifetime.
- An increase in particle diameter results in a relatively slower temperature-time response of the particle but a higher value of the maximum temperature attained by it. The steady state temperature of the particle is almost uninfluenced by the particle diameter.

- For a given value of free stream gas phase temperature, there is a minimum particle diameter below which the spontaneous ignition of the pulverized coal particle in the hot gaseous medium is not possible. This minimum limiting particle diameter decreases with an increase in free stream gas phase temperature and in the volatile matter content of the coal particle.
- The thermodynamic irreversibilities in the process of combustion of a pulverized coal particle are mainly due to chemical reaction and coupling effect of heat and mass transfer in gas phase. The irreversibility rate in the process is initially very low but it suddenly shoots up to a high value at the onset of ignition followed by a sharp rise and then a gradual decrease to a final steady state value.

In Chapter 3, a full-scale numerical model has been developed for the combustion of polydispersed pulverized coal particles into a turbulent swirling flow of air in a typical tubular combustor. The main objective of the work is to evaluate the temperature and mass histories of coal particles along their trajectories in the combustor at different values of inlet pressure and temperature of air and secondary air swirl.

The major observations from the study are as follows:

- The coarser particles have got larger radial dispersion for all operating conditions. The radial dispersions of particles are suppressed at higher pressure.
- The penetration of particles in gas phase is reduced with pressure and secondary air swirl.
- For both lower and higher pressure, the coarser particles exhibit a relatively larger mass depletion when there is no swirl in the flow of air.

In contrast, the finer particles exhibit a relatively larger mass depletion when there exists a swirl of secondary air.

- All particle classes attain almost a constant temperature near the end of the combustor. For both lower and higher pressure, coarser particle class shows a steeper change in temperature with axial distance in the combustor when there is no air swirl. The trend is reversed at higher air temperature and with secondary air swirl.

In Chapter 4, a theoretical model of exergy balance, based on availability transfer and flow availability, in the process of pulverized coal combustion in a tubular combustor has been developed. The total thermodynamic irreversibility in the process has been determined from the difference in the flow availability at inlet and outlet of the combustor. The principal objective of the work is to depict a comparative picture of the variations of combustion efficiency and second law efficiency at different operating conditions, like inlet pressure and temperature of air, total air flow rate and inlet air swirl, initial mean particle diameter and length of the combustor. This is made to throw light on the trade-off between the effectiveness of combustion and the lost work in the process of pulverized coal combustion in a tubular combustor.

The major observations from the study are as follows:

- An increase in inlet air pressure increases the combustion efficiency and decreases the second law efficiency. The influences are more prominent in a shorter length of combustor and at a low value of inlet air swirl. An increase in swirl number from $S = 0.0$ to 0.32 increases the combustion efficiency, whereas a further increase in swirl number from $S = 0.32$ to 0.77 results in a decrease in the combustion efficiency. The second law efficiency is relatively lower for lower swirl number ($S = 0.32$) where the combustion efficiency is high, while it shows a relatively higher value at a high swirl number of $S = 0.77$ where the combustion efficiency is low.

- An increase in air temperature decreases the combustion efficiency for a shorter length of combustor but increases the combustion efficiency for a higher length of combustor. The second law efficiency follows a trend which bears an inverse relationship to that in combustion efficiency with air temperature.
- At low values of inlet air swirl ($S = 0.0$ to 0.32), an increase in the initial SMD of coal particle decreases the combustion efficiency. At a higher value of inlet air swirl ($S = 0.77$), combustion efficiency increases with an increase in SMD from 50 μm to 95 μm and thereafter it decreases with a further increase in SMD of coal particle from 95 μm to 145 μm. The second law efficiency always increases with an increase in the particle diameter, whereas, at high swirl of $S = 0.77$, this trend shows an optimum particle diameter with an initial decreasing trend of second law efficiency followed by an increasing one with the particle diameter.

In Chapter 5, a numerical model has been developed to predict the shape and size of raceway zone (a void space), created by the injection of blast air at high velocity through the tuyeres in a packed coke bed of a blast furnace. The main objective of the work is to predict the influences of air blast velocity, initial porosity of coke bed and as well as the bed height on the shape and size of raceway zone.

The major observations from the study are as follows:

- An increase in air blast velocity increases the size of the raceway zone.

- The size of raceway zone is increased with a decrease in initial bed porosity for a specified blast velocity.
- With an increase in bed height, the size of raceway decreases together with a change in its shape.
- There is a critical bed height above which the raceway shape and size remains constant. The critical bed height increases with an increase in flow velocity of air at inlet but is independent of initial bed porosity.