ABSTRACT

The impact of energy crisis and growing concern for the environment have put more thrust on Internal Combustion engines, Gas Turbines and Rocket Motors to perform as more efficient, versatile and environment friendly ones. The present work, comprising five chapters, has been made with this motivation to throw light on some specific aspects of gas turbine combustors to optimize their performance in achieving the desired goals of energy economy and clean environment. The Chapter 1. discusses the practical importance of the problem highlighting the state of art and scope of present work. The Chapter 2. discusses a general theoretical formulation of the present work. The remaining three chapters (Chapters 3, 4, and 5) of the thesis address three specific problems of gas turbine combustion as follows:

- **Penetration of Vaporizing Fuel Droplets and Minimum Ignition Energy in a Gas Turbine Combustor: Influence of Fuel volatility at Different Operating Conditions**

- **Influence of Fuel Volatility on Combustion and Emission Characteristics at Different Operating Conditions**

- **Energy and Exergy Balance in the Process of Spray Combustion in a Gas Turbine Combustor: Influence of Fuel Volatility at Different Operating Conditions**

The Chapter 2. describes a numerical model of a typical diffusion controlled spray combustion process in a gas turbine combustor. The numerical model is based on a typical Eularian gas phase and Lagrangian droplet phase formulation of a gas-droplet flow, in which coupling between the two phases is taken care of through interactive source terms generated from the droplet phase information on a Lagrangian frame. The gas phase chemical reaction between the fuel vapor and the oxidizer has been considered as a single step, irreversible, finite rate controlled one. The mean reaction rate is determined either by Arrehenius model or by eddy-dissipation combustion model depending upon the relative magnitude of kinetic and turbulent diffusive speeds of reaction. The emission of thermal NO is predicted from the kinetics of Zeldovich mechanism. A radiation model for the gas phase based on modified first order method, has been adopted in consideration of the gas phase as gray absorbing-emitting medium. Calibration of the present numerical model has been made through a comparison of the results predicted from the model with those of earlier works from literature, under identical situations.

In Chapter 3. an attempt has been made to address on the penetration histories of fuel spray and minimum ignition energy in a gas turbine combustor, The basic objectives of the work are as follows:

To predict the influences of fuel volatility and operating parameters, namely, inlet air pressure, air temperature, air swirl, and spray cone angle of fuel injection on penetration of vaporizing fuel droplets in a non-reactive ambience within the combustor.

Prediction of minimum ignition energy as a function of operating and initial spray parameters.

It is found from the study that the influence of inlet air pressure on penetration of vaporizing fuel droplets is contrasting in nature for fuels with high and low volatilities. While an increase in inlet air pressure decreases spray penetration for a higher volatile fuel, it increases the same for a lower volatile one. An increase in inlet air swirl results in a decrease in spray penetration. The trend is almost the same for fuels with different volatilities. The influence of inlet air swirl is more prominent at a higher pressure than compared to that at a lower pressure. An increase in spray cone angle results in a decrease in droplet penetration. The trend is independent of fuel volatility. Amongst the different operating and spray parameters, the inlet air pressure has the most profound influence on the minimum ignition energy. An increase in both the inlet air pressure and the inlet air swirl, increases the minimum ignition energy density. While an increase in the

initial SMD of fuel spray increases the minimum ignition energy density, the spray cone angle has almost a negligible influence on the same.

The Chapter 4. describes the influences of fuel volatility at different operating parameters like inlet air pressure, air swirl, as well as the spray parameters like, initial SMD and cone angle of the spray on important combustion and emission characteristics, namely, combustion efficiency, exit temperature and NO_x distributions, of a spray combustion process in a gas turbine combustor. The major observations from the study are as follows:

- An increase in fuel volatility increases the combustion efficiency only at a higher inlet air pressure for any given inlet swirl number. For a given fuel, an increase in inlet air pressure for a fixed inlet air temperature always reduces the combustion efficiency. The combustion efficiency is almost uninfluenced by the inlet swirl to the flow of air at a lower pressure, while it decreases with an increase in inlet air swirl at a higher pressure. The combustion efficiency is reduced drastically with a decrease in fuel volatility at a lower spray cone angle, but remains almost uninfluenced with fuel volatilities at a higher spray cone angle. For any given fuel, both at lower spray cone angle and lower initial SMD, there is a significant reduction in combustion efficiency.

- The influence of inlet pressure on pattern factor is contrasting in nature for fuels with lower and higher volatilities. For a higher

volatile fuel, a reduction in inlet air pressure decreases the value of pattern factor, while the trend is exactly the opposite in case of fuels with lower volatilities. The reduction in pattern factor with inlet swirl is marginal in case of a higher volatile fuel while it is significant for lower volatile fuels. The Pattern Factor is reduced with a decrease in initial SMD for all fuels. The influence of spray cone angle on Pattern Factor is contrasting in nature for fuels with higher and lower volatilities. The Pattern Factor decreases with an increase in spray cone angle for a higher volatile fuel, whereas the reverse happens in case of lower volatile fuels.

- A decrease in fuel volatility or an increase in inlet air pressure for a given inlet air temperature, increases the bulk NO_x concentration at exit considerably. The variation of exit NO_x with inlet air pressure is found to have a pressure ratio exponent ranging between 0.75 to 1.2. An increase in spray cone angle increases the bulk exit NO_x , though the increase is modest for higher volatile fuel. An increase in initial SMD, increases the bulk exit NO_x for lower volatile fuels only.

In chapter 5, an exergy balance, on the basis of flow availability, in the process of spray combustion in a tubular gas turbine combustor has been made to depict a comparative picture of the variation in combustion efficiency and second law efficiency of the process, for fuels with different volatilities at different operating conditions. The major objective is to throw light on the trade-off between the effectiveness of combustion and the lost work due to thermodynamic irreversibilities in the process of combustion. The major observations from the study are as follows:

- An increase in fuel volatility increases combustion efficiency only at a higher inlet air pressure for any given inlet air temperature and swirl. The combustion efficiency is uninfluenced by the inlet air swirl at a lower air pressure, while it decreases with an increase in inlet air swirl when the pressure of inlet air is high. The second law efficiency increases with a decrease in fuel volatility and an increase in inlet air pressure. At a higher air pressure, an increase in inlet air swirl decreases both the combustion efficiency and second law efficiency.

- When the spray cone angle is increased, the combustion efficiency increases drastically for a lower volatile fuel, while for a higher volatile fuel, the influence of spray cone angle on combustion efficiency is relatively marginal. The second law efficiency decreases with an increase in spray cone angle for all the fuels considered.

- The combustion efficiency increases with an increase in initial SMD of fuel spray up to a value of 50 μm , but a further increase in initial SMD causes a decrease in combustion efficiency. The second law efficiency shows a monotonic decreasing trend with initial SMD.

It is evident from the present work that a fine spray with a larger cone angle of a high volatile fuel in a combustor with low inlet air pressure but with high inlet temperature, is the most favorable situation from the view point of high combustion efficiency (an efficient conversion of energy quantity). On the other hand, a fine spray with lower cone angle of a low volatile fuel in a combustor with high inlet air pressure but with a low inlet air temperature, seems to be more conducive for a higher second law efficiency (an efficient conservation of energy quality).