International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2013 Vol. 3 (4) October-December, pp.18-22/Srinivasan et al.
Research Article

PENETRATION OF LIQUID FUEL DROPLETS FOR DIFFERENT FUEL INJECTION VELOCITIES IN THE TAPER CAN GAS TURBINE COMBUSTION CHAMBER

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ABSTRACT
The effect of fuel injection velocity on penetration and vaporization of atomized liquid fuel dropletswhich is sprayed in a turbulent swirling flow of air inside taper can gas turbine combustor has been simulated using the commercial Computational fluid dynamics (CFD) code star CD. It has been observed that the variation of fuel injection velocity plays a significant role on penetration, vaporization and combustion. The results have been presented with help of droplet track files and plot of average temperature.

INTRODUCTION
Fuel injection velocity is one of the important factors that influence the rate of combustion in a gas turbine combustion chamber. Many researchers have been working over a decade to predict the influence of fuel injection velocity on combustion. The rate of vaporization of fuel plays a pivotal role in combustion and it is dependent on the temperature prevailing in the primary zone of the combustor. With the temperature maintained constant, the determination of appropriate fuel injection velocityis the most challenging task. This can be substantiatedwith lower fuel injection velocities, the penetration is lower and causes regions of localised high temperature due to localised high fuel concentrations which has resulted in higher formation of soot and nitric oxideemissions. With furtherincrease in fuel injection velocity, the penetration of the fuel droplets inside the combustor also increases and the time available for vaporization and combustion of fuel droplets decreases i.e. the resident time of fuel droplets decreases and many a times the fuel may leave the combustion chamber unburnt.

Literature Survey
There are a large number of works available in literature on spray combustion related to separated flow model, that treat finite rate of exchange of mass, momentum and energy between the phases. It has been observed that most of the separated flow analysishas utilized Particle-Source-In-Cell (PSIC) method as mentioned by Crowe *et al.,* (1977). In this approach, the complete spray is split into a finite number of representative droplet categories, whose motion and transport in the flow field have been determined employing a Lagrangian formulation, whereas the Eulerian formulation is employed to solve conservation equations within the gas phase. The dispersion of droplets that occurs due to turbulence in the gas phase was taken into consideration in a stochastic Separated Flow model (SSF), however it was neglected in deterministic Separated Flow model (DSF). According to Faeth (1983) the droplet trajectory prediction using SSF model lies very close to experimental results, whereas for DSF model underestimates the radial spread of the droplets to some extent.
Illustrative works with the separated flow models were presented on the evaporating spray close to the atomizer by Crowe (1974,1978), on the reciprocating direct injection stratified charge engine by Gosman and Johns (1980) and Butler *et al.,* (1980), on the turbine combustors by Boyson *et al.,* (1981) and on a centrebody combustor by Raju and Sirignano (1989). Different approaches to separated flow model were described as statistical or Continuous droplet Model (CDM) which was developed by Williams (1962). In their approach, the spray was modelled using the conservation equation by a statistical distribution function that has been defined in a multidimensional space of time, velocity, position, droplet diameter, temperature etc. It is an integro-differential equation and its solution is very expensive in terms of computer storage and time unless simplifications are introduced, like assumption of non-existence of slip

between the droplets and the gases. This technique was implemented by Westbrook (1976) and Ganesan and Spalding (1979). Another technique of modelling spray with separated flow approach adopts the method of continual formulation of the conservation equations for both the phases i.e liquid and gases (CFM). The movement of both droplets and gas were treated as through interpenetrating continua with both the phases being solved in Eulerian frame of reference. Mostafa and Elghobashi (1985) and Mostafa and Mongia (1987) have implemented this technique for the computation of turbulent jets with droplet vaporisation. In their study the simplified assumptions such as constant droplet temperature and isothermal flow condition were used. This model was adopted for the analysis of turbulent evaporating spray along with consideration of droplet heating by Hallmann *et al.,* (1995).

In most of the applications there is a specified amount of fuel or fluids that has to be sprayed which are generally dense in nature. So, the concept of dense sprays in turbine engines, industrial furnaces and diesel engines using group combustion of drop cloud was developed by Chiu and Liu [15]. In accordance the group combustion theory presented by of Chiu and Liu (1977), Chiu *et al.,* [1978), Chiu and Croke (1981), Chiu *et al.,* (1982) and Kim and Chiu (1983), the collective behaviour of all droplets present in the liquid spray forms a fuel – rich mixture within the core region of the fuel spray. It can be stated that combustion cannot occur at spray core of the mixture due to insufficient air penetration. It was observed that the radial transport of gaseous fuel occurs by convection and diffusion finally ends up in the formation of inflammable mixture located at some distance from the centre of the spray. In group combustion models the collective behaviour of drops has to be accounted for simultaneous analysis of both i.e. a heterogeneous inner region and also a homogenised outer gas phase region. Sirignano (1986) mentioned the suitability of various formulation techniques in predicting spray behaviour and also highlighted the adoption of statistical approach in spray analysis.

MATERIALS AND METHODS

Methodology

Figure 1: Meshed model of gas turbine combustion chamber

The commercial computational fluid dynamics code star-CD is used for the simulation. The domain is an axis-symmetric model modeled and meshed with total 7 sectors for 360^0. For simplicity a sector having total number of cells is 162137 with an angle of 51.42^0 is taken for analysis. There are three air inlets with primary inlet in axial direction, secondary and dilution inlets in radial direction. All peripheral boundaries are taken as wall with adiabatic nature. The two sectional sides of sector which are separated by an angle of 51.42^0 has been taken as symmetry. A portion of axial inlet is taken as wall with adiabatic in nature and the rest has been taken as an air inlet and the other end is taken as outlet. The inlet air pressure is assigned a value. The turbulence model is K-ε with standard wall treatment and thermal model includes static enthalpy with chemico-thermal option as the combustion reaction has to take place. Since fuel and air enter into the combustor separately non-premixed reaction with Magnussen's eddy break-up (EBU) model is selected. The reaction involving fuel and oxygen results in formation of carbon dioxide and water is defined. A specified number of cells in the domain are assigned as ignition cells which get activated for a limited number of iterations so as to initiate combustion. During combustion the emissions are undesirable products formed i.e. Nitric oxide model with thermal option soot model have been activated. The fuel droplets are tracked by using lagrangian multiphase model due to involvement of two phases with a specified number of droplet parcels that are injected in combustor. The basic flow equations like continuity, momentum, emergy, species concentration are solved for this process it is switched on. The droplet break model is chosen as reitz model and the droplet wall interaction model is taken Bai model. Later the fuel injected in the combustion chamber is selected. Then the droplet diameters and probability density functions has been defined by rosin-rammler method along the fuel injection velocities, mass flow rate at each injection point with specified number of parcels and the location of fuel injection points. The values of air at different inlets have been assigned. Finally the domain has been verified and the setup is run for the convergence /specified number of iterations as discussed by Srinivasan *et al.*, (2013).

RESULTS AND DISCUSSION

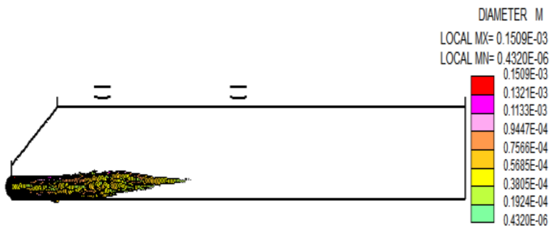

Figure: 2(a)

Figure: 2(d)

Figure: 2(b)

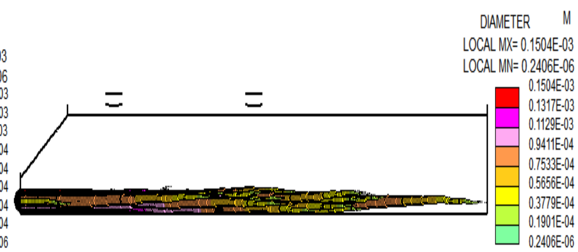

Figure: 2(e)

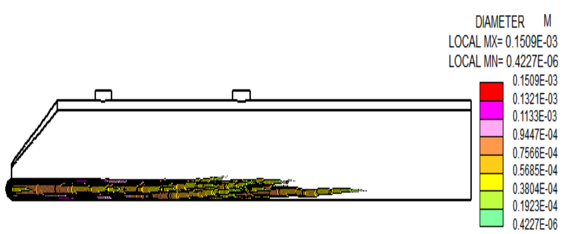

Figure: 2(c)

Figure: 2(f)

Figure: 2(g)

Figure: 2(a) to (g) penetration of droplets for different fuel injection velocities (a) 10 m/s, (b) 20 m/s, (c) 25 m/s, (d) 30 m/s, (e) 40 m/s, (f) 50 m/s and (g) 60 m/s

An investigation has been carried out for different fuel injection velocities with an increment step size of 10m/sec and in order to get the precise value one case has been run at mid step size of 25m/s. The results are presented below in the figures from (a) to (g) for fuel injection velocities 10m/s, 20m/s, 25m/s, 30m/s, 40m/s, 50m/s and 60m/s respectively. The following parameters like inlet air swirl of 0.37, inlet air temperature of 600 K, density of air at inlet of 0.5807kg/m^3, fuel injection temperature of 350 K, fuel injection angle of zero degrees are taken as constant for the present analysis.

Location of Fuel Droplets in the Combustor for Different Fuel Injection Velocities

The Figure 2(a) to (g) shows that the fuel droplet penetration has been affected with increase in fuel injection velocities and the path traced by the fuel droplets has been taken from the track file. It is observed from the above figures that the penetration of droplets has gradually increased with rise in the fuel injection velocities. Further any increase in fuel injection velocities appears to extend beyond the combustor thereby indicating a portion of fuel droplets may leave the combustor unburnt.

Mass Average Temperature for Different Fuel Injection Velocities

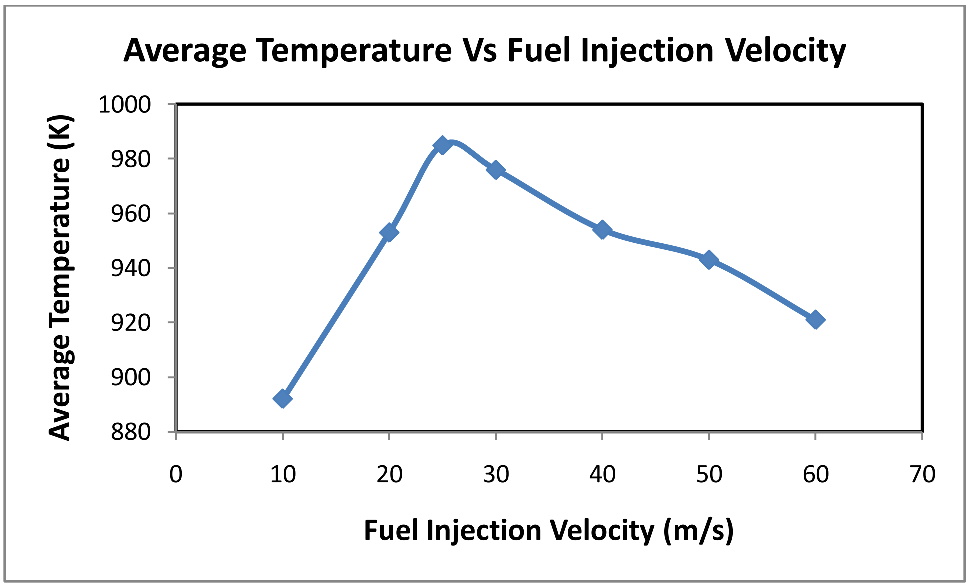

Figure 3: Variation of average temperature with fuel injection velocity

The simulation of combustion process has been carried out with variation of fuel injection velocities and the results are presented in the form of graph with average tempereature along y-axis and fuel injection velocity along x-axis. It is observed from the Figure 3 that the average temperature increases with rise in fuel injection velocity to a maximum value of 985 K for fuel injection velocity of 25m/s.With further rise in fuel injection velocity the averagetemperature appear to drop indicating that a portion of fuel droplets leave the combustor unburnt.

Conclusion

The penetration and vaporization of liquid fuel droplets injected into a turbulent swirling air flow in a gas turbine combustion chamber for various fuel injection velocities has been predicted from the analysis of gas droplet flow on a two phase separated model. It has been seen the penetration of atomized fuel droplets increases with increase in fuel injection velocities. The mass average temperature has a maximum value of 985 K for fuel injection velocity of 25m/second and with any further increase in fuel injection velocity has resulted in decrease in mass average temperature. It has been concluded that the fuel injection velocity with a value of 25m/second is found to give better penetration and combustion than with the other fuel injection velocities.

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