Analysis of Combustion Chamber for Low Energy Fuels Application using CFD

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Abstract:- **With the modernization of the society, and the non-judicious use of fossil fuels, there is a need for the development of a more environmental friendly, renewable fuel. Moreover, gaseous fuels are gaining more prominence as cleaner fuels for power generation. The use and research of Producer Gas is one good prospect because of the availability and usability. The producer gas combustor is one major area which uses producer gas as a fuel.**

Combustor being the component where the combustion process takes place, produces emissions (using solid fuels like charcoal and wood) thereby, making the fuels less environment friendly. But, with the use of producer gas as fuel for combustor, the emissions are reduced to a considerable extent. Producer gas is obtained from gasifiers where the reactants undergo a number of conversion processes to form the product. The constituents of producer gas include CO, CO2, H2, CH4 and N2.

The producer gas combustor uses the producer gas and aids in the combustion process. It is obtained by injecting a blast of air and steam through a layer of coke. The carbon interacts with oxygen of the air to form carbon dioxide, meets the hot unburnt coke or coal to form carbon monoxide in reduction zone. The water vapor also interacts with the fuel to form carbon monoxide and hydrogen. It is used in a variety of applications mainly in gas turbines. It can also be used in various types of kilns or furnaces and also generators to replace oils. The world is facing a grave problem of energy crisis because of over usage of conventional fuels in automobile, power generation and various thermal applications. Heat transfer analysis is carried out inside the combustor by using the industrial standard RANS (Reynolds Average Navier Stokes) tool for sizing optimization of combustor.

Keywords: CFD, Tetrahedron Mesh elements, Heat transfer modes, Combustion, Combustor, Air to Fuel ratio, Producer Gas.

1. INTRODUCTION:

The melting of metals and non metals is required for various applications for industrial and domestic purpose. In the Casting industry the molten metal is fed into the mold and solidified to get the desired shape. India is a major exporter of engineering goods such as fasteners, bearings, steel pipes, tubes and other instruments. The molten materials in form of finished products are used in building a variety of products utilized in Automobiles, Power generators, Rail road cars, Oil pipelines, Military hardware and Medical instruments. Thus the proper execution of melting process influences the quality, composition and chemical properties of final products. This process involves use of heat or electrical energy to supply adequate amount phase transformation energy therefore higher efficiency of melting process lowers the energy consumption and higher cost effectiveness.

The increased cost and availability of fuels has made the metal casting industry to invest more time and money to develop new technologies to improve process efficiency. The melting process involves multiple stages that include,

- Preparation of molten metal by removal of dirt, moisture and other volatiles to prevent the risk of explosion in furnace.
- Melting of Metal is furnace.
- Refining, handling tapping and transporting the molten material.

Although the energy consumption in the melting process has been a significant concern in foundry operations, the industry continues to use melting technologies with low energy efficiencies. The studies show that implementation of better technological practices, iron and aluminum melting can save approximately 1.27 and 3.2 GJ per ton respectively. Nearly 60 % of energy required for the melting application is supplied by natural gas[1].

The per capita energy consumption in India as per January 2012 is reported to 778 kWh[2] as compared to 96 kWh in rural areas and 288 kWh in urban areas during 2009 in contrast to the worldwide per capita annual average of 2600 kWh and 6200 kWh in the European Union[3].

The objective of present analysis is focus to control the wall temperature of combustor and keep maintain the pressurized combustible fluid flow with uniform temperature at the exit of the fluid domain. Imposition of emission norms by government regulating bodies to reduce environmental pollution lead to the search for cleaner burning fuel. The natural choice is a nonconventional energy sources. Producer gas is one such source, some of the work is reported in the literature pertaining to combustors using hydrocarbon fuels. However, a very little work is available on the same when using producer gas as a fuel. Present work is aim to develop CFD modeling and simulation for combustor & producer gas as a fuel. Efficient combustor is necessary to meet the emission norms with controlled A/F ratio. The combustor is modeled to yield the required conditions around the wall & outlet of the combustor.

The modeling includes several stages of modification until the required outcomes are attained. Complete combustion of reactants takes place within the combustor. Also the care is taken so that exhaust gases should not trace H_2, CH_4 and CO as well as minimum NO_x emissions. The combustor modeled is of can type in which the fuel and air are mixed in the combustor and undergoes ignition. The combustor is modeled using ANSYS ICEM CFD and the analysis is carried out using ANSYS CFX.

2. COMBUSTOR MODEL:

The combustion difficulties for low heating value (LHV) gases like producer gas derived from biomass have led to more investigations into LHV gas combustors. A geometry optimized combustor of 20kW to provide good air/fuel mixing with long residence time for melting application with producer gas is to be designed. High Alumina Ceramic liner is used to reduce radiant thermal losses.
The combustor to be modeled using the CFD program CFX as chemistry models. Gas combustors, providing information from which practical combustors have been designed and applied in industrial furnaces and heating equipment. The combustors consist of combinations of an injector, in which low pressure air injects fuel gas, followed by a refractory-lined combustion chamber i.e. high alumina ceramic liner in which the air/gas mixture is burned, and the burned gases, at or near flame temperature, are accelerated through an exit or outlet of combustor. The Can Combustor model is as shown in Fig (1). The computational meshed model can be seen in Fig (2) and Fig (3).

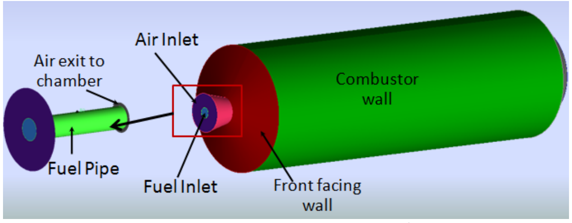


Fig (1): Geometric modeling of combustor

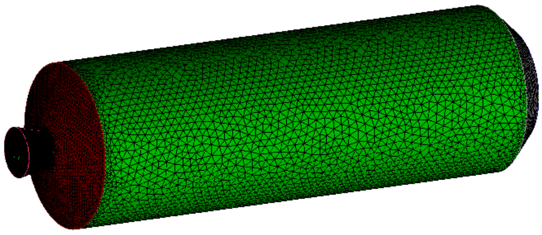
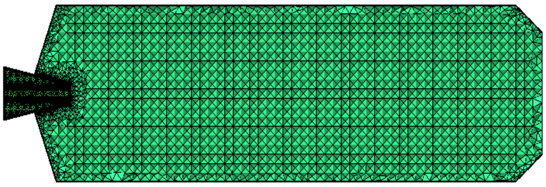


Fig (2): Isometric view of computational model with tetrahedronmeshes



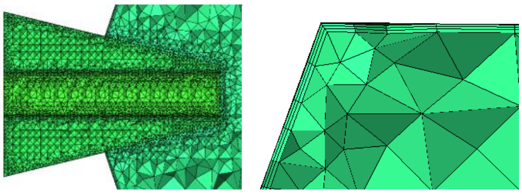


Fig (3): Sectional view of computational model, prism layers are considered to analyze the wall effects

3. PROBLEM STATEMENT:

A combustor domain encompasses with two inlets, middle part of the combustor has small tube and it control fuel flow and around the tube ambient air passes (fig.1 and 2), which are designed for air to fuel ratio, for control supply to the computational domain. The fluid is considered as incompressible air and producer gas. The combustion simulation uses the standard RANS equations for mass, momentum and energy and the turbulence is simulated with the k-epsilon model known to have given the most acceptable results in the validation made in the earlier investigation [4]. A no-slip and adiabatic wall conditions are imposed at the wall of the combustor domain. The outlet maintains almost uniform temperature and it can be connected for any applications like boiler, domestic purpose, etc., the numerical code uses an industry standard CFD code solving 3D RANS equations with a second order upwind scheme. The solution sought is for steady state and a diminishing residuals falling by 10^{-6} is set as the criteria for convergence. For a clarity the main equations considered for the solution is provided below.

1. The Continuity Equation:

$$\frac{\partial \bar{U}_j}{\partial x_j} = 0$$

2. The Momentum Equation:

$$\frac{\partial}{\partial t}(\rho \bar{U}_i) + \frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j) = -\frac{\partial \bar{P}}{\partial x_i} - \frac{\partial}{\partial x_j}\left(\bar{\tau}_{ij} + \rho \overline{u_i'' u_j''}\right)$$

3. The Energy Equation:

$$\frac{\partial}{\partial t}(\rho \bar{h}) + \frac{\partial}{\partial x_j}(\rho \bar{U}_j \bar{h}) = -\frac{\partial}{\partial x_j}\left(Q_j + \rho \overline{u_i'' h''}\right)$$

4. RESULTS AND DISCUSSION:

The below figures 4 and 5 show the temperature profile obtained of the entire combustor. It gives us an indication of how the flame burns and how the temperature varies throughout the combustor. We can see a maximum temperature of 1765 ^{0}C is obtained at the location of the flame. The blue color indicates 195 ^{0}C hence showing that the combustor walls are not being exposed to higher temperatures which is safe.

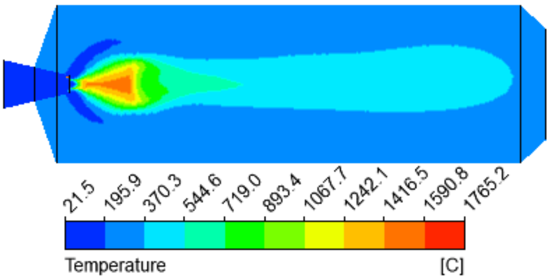


Fig (4): Temperature distribution inside the combustor along X-Y Plane

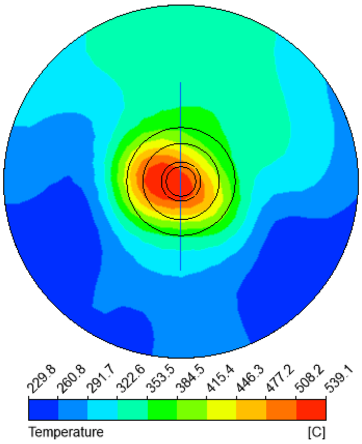


Fig (5): Temperature distribution inside the combustor at middle of the cylinder cross section

Figures 6, 7 and 8 show the mass fractions of CH_4, H_2 and CO respectively. The figures show how the concentration of these gases reduces over the length of the combustor. The Blue color shows that the concentration of gas is 0 indicating complete burning. Under complete combustion, when CH_4 is burnt it produces CO_2 and H_2O, H_2 produces H_2O and CO which converts to CO_2. This can be seen from figures 9 and 10 where we see a constant increase of CO_2 and H_2O during and after burning of fuel.

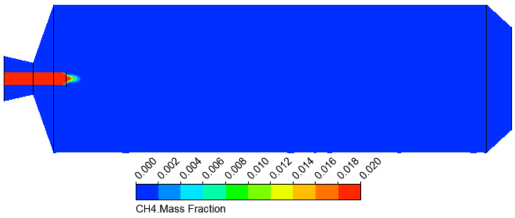


Fig (6): CH_4 distribution inside the combustor axial plane

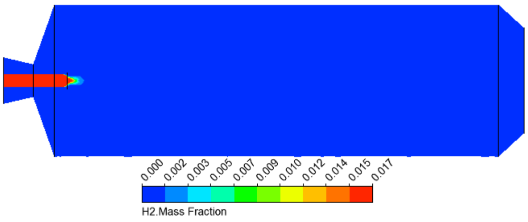


Fig (7): H_2 distribution inside the combustor axial plane

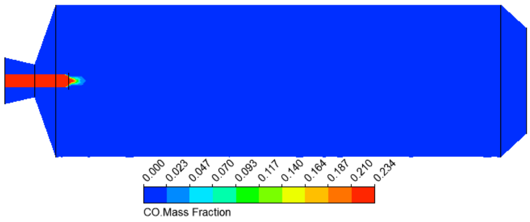


Fig (8): CO distribution inside the combustor axial plane

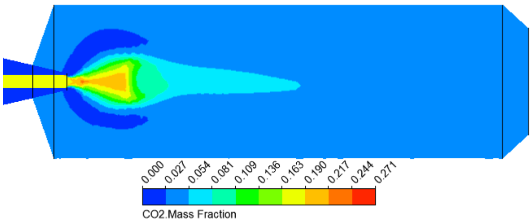


Fig (9): CO_2 distribution inside the combustor axial plane

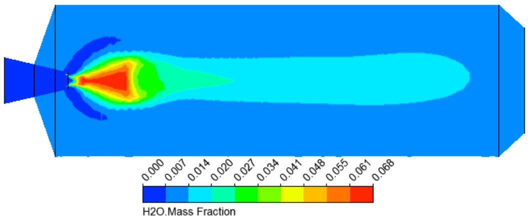


Fig (10): H_20 distribution inside the combustor axial plane.

Figure 11 provides us the results that are obtained at the outlet of the combustor. The temperature profile shows us the variation in temperature at the outlet. A variation of 50 ^{0}C is obtained which is within the tolerance limits. If the temperature variation is too high it can result in fracture of the turbine blades due to high thermal stresses being developed in them. Figure 12 provides us an idea of the velocity obtained at the outlet which shows uniformity which is highly desired.

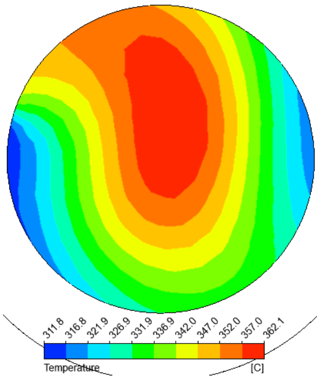


Fig (11): Combustor outlet temperature distribution

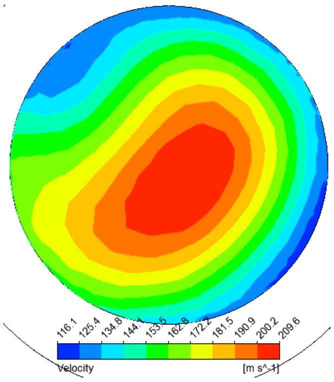


Fig (12): Combustor outlet velocity profile

5. CONCLUSION:

Motivated with the literature survey, initial dimensions of the combustor were arrived at, several combustor concepts were developed after considering all the specifications and this concept is finalized for computational tests and analyzed the results.

After numerous modifications based on results obtained, this concept is reasonable agreement with the theoretical calculations and technical specifications were selected and taken to the detailed design stage and drafts of parent and child parts. During analysis of the best performing models the following were observed:

The Emissions are nil, which indicate complete combustion. The adiabatic flame temperature calculated theoretically and observed during analysis nearly converges. The wall temperature of the chamber is maintained below 700K as shown by the analysis results as a safety precaution. The outlet temperature difference also, as shown in the analysis is maintained well below the required value, i.e., 100K, hence preventing thermal stresses from being developed on the turbine blades.

6. REFERENCES:

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