

## Numerical analysis of exhaust emission for combustion chamber of gas turbine power plant

Nikul Patel<sup>1\*</sup>, Vimal Patel<sup>2</sup>

<sup>1,2</sup>Department of Mechanical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

**ABSTRACT:** Combustion chamber is used to burn fuel-air mixture to produce energy. This energy are then supply to enter the nozzle and then into the turbine. Current state-of-the-art in Computational Fluid Dynamics (CFD) provides reasonable reacting flow predictions and is already used in industry to evaluate new concepts of gas turbine engines. In parallel, optimization techniques have reached maturity and several industrial activities benefit from enhanced search algorithms. The numerical simulation of can type combustion chamber for utran power plant is carried out using commercial CFD code CFX. Turbulence is modeled using k- $\epsilon$  turbulence model. For the liner flow, it is observed that on moving axial from inlet to outlet, velocity, temperature contours become more uniform symmetric in circumference plane. Mass fraction CH<sub>4</sub> and O<sub>2</sub> decreases where concentration of CO<sub>2</sub>, increases in the axial direction. Different boundary condition are applied for find out the required exit temperature and reduced nitric oxide (NO) in parts per million. Changes geometry finds out require exit temperature and produced less emission NO, CO<sub>2</sub>. Variation of number of elements in mesh studied the different parameter effect increase the number of element. Variation of different mass fraction likes CH<sub>4</sub>, O<sub>2</sub>, CO<sub>2</sub>, and temperature, velocity along center line axial direction form inlet to outlet and also graphs are plotted.

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**Keywords:** Combustion Chamber, Gas turbine, nozzle, emission

### 1. Introduction

Air-craft gas turbine combustor technology has been developing gradually and continuously, rather than a dramatic change. The basic geometry of combustor is derived by the need for its length and frontal area to remain within limits set by other engine components, the necessity of a diffuser is to minimize pressure loss, and the requirement of a liner to provide stable operation over a wide range of air-fuel ratios. In spite of more a arduous operating condition like high pressure, temperature, and inlet velocity these days combustors continue to exhibit 100 percent combustion efficiency over the normal working range, demonstrate substantial reductions in pressure loss and pollutant emission, and allow a linear life that is significantly longer than those of many other engine components. As gas turbine technology advances into 21st century; combustion engineers are faced with the challenges of achieving of higher compression ratios, higher turbine inlet temperature in aero gas turbine engines. At the same time, as interest in pollutant emissions from gas turbine increases, combustion engineers are also required to consider new means for pollutant reduction. The desired performance requirement, in terms of higher engine thrust ratio and lower specific fuel consumption will call for higher turbine inlet temperatures and closer adherences to the design temperature profile at the turbine inlet. At the same time

\* Corresponding author e-mail: [nikulatmsu@gmail.com](mailto:nikulatmsu@gmail.com)  
Tel.: +91 9429926405

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the demand for greater reliability, increased durability, and lower manufacturing, development and maintenance costs seems likely to assume added importance in the future. To meet these challenges, designers have searched for concept that would simplify both the basic design data and methods of fabrication. This searched for concept that would simplify both the basic design data and method of fabrication. This search has lead to the development of advanced cooling configurations and the increased use of refractory coatings within the combustion system. Figure 1 (a) shows a simple cycle gas turbine which has main three component (1) compressor (2) combustor (3) turbine. Figure 1 (b) shows a conventional “pressure-volume” diagram for a gas turbine, in which it shows that between the compressor and the turbine there is a stage where air expands at constant pressure. This expansion is achieved through heating of air by injection and the following combustion of a hydrocarbon fuel in a device that is commonly described as a combustor or chamber. The work output of the gas turbine is directly related to the area enclosed within the pressure-volume diagram. Thus a large degree of expansion that is, a barge horizontal separation of points 2 and 3 in figure 1 (b), will give a large amount of work. However, since the gas is being expanded by raising its temperature, a practical limit is set by the maximum temperature the material of the engine components located at the outlet of the combustor, notably the turbine blades can accept. In actual process a pressure loss is always incurred.

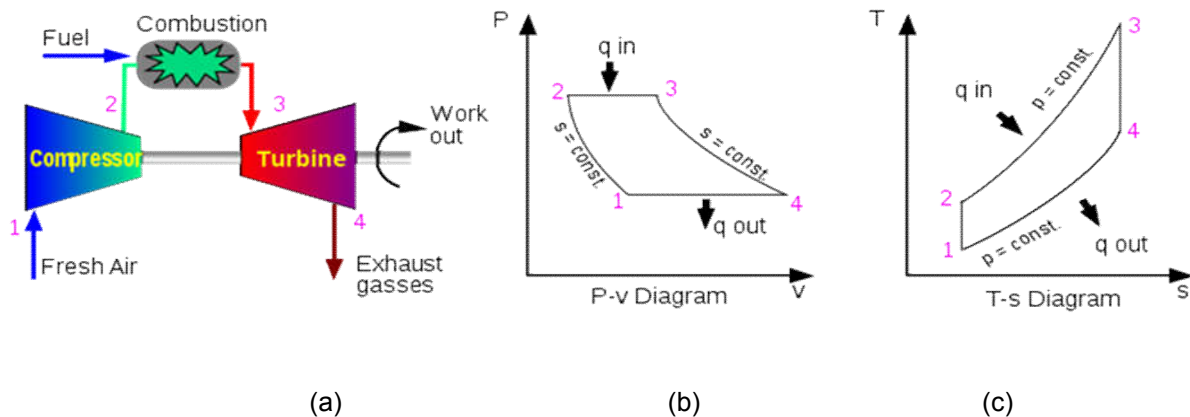


Figure 1 P-V and T-S diagram for a simple gas turbine

An important design objective is to keep this pressure loss as low as possible, since at reduction in the area of the pressure-volume diagram constitutes a loss in engine power output. Other important combustor design requirements are high combustion efficiency, reliable and smooth ignition, wide stability limits, low pollutant emission and outlet temperature distribution. Heat input to the gas turbine cycle is provided by a combustor. Air enters combustor from the compressor which is delivered at elevated temperature to the turbine (ideally with no pressure loss). Thus, the combustor is a direct-fired air heater in which fuel is burned almost stoichiometrically with one third or less of the compressor discharge air. Combustion products are then mixed with the remaining air to arrive at a suitable turbine inlet temperature. There are many types of combustor, but the three major types are tubular, turbo-annular, and annular. Despite the any design differences, all gas turbine combustion chambers have three features A recirculation zone, A burning zone (with a recirculation zone which extends to the dilution region) and A dilution zone. The function of the recirculation zone is to evaporate, partly burn, and prepare the fuel for rapid combustion within the remainder of the burning zone. Ideally, at the end of the burning zone, all fuel should be burnt so that the function of the dilution zone is solely to mix the hot gas with the dilution air. The mixture leaving the chamber should have a temperature and velocity distribution acceptable to the guide vanes and turbine. Generally, the addition of dilution air is so abrupt that if combustion is not complete at the end of the burning zone, chilling occurs and prevents completion. However, there is evidence with some chambers that if the burning zone is run over rich, some combustion does occur within the dilution region. Combustor inlet temperature depends on engine pressure ratio, load and engine type, and whether or not the turbine is regenerative or non-regenerative especially at the low-pressure ratios. The new industrial turbine pressure ratios are between 17:1 and 35:1, which means that the combustor inlet temperatures range from

454°C to 649°C. Fuel rates vary with load, and fuel atomizers may be required for flow ranges as great as 100:1. The loss of pressure in a combustor is a major problem; since it affects both the fuel consumption and power output; total pressure loss is usually in the range of 2-8 % of static pressure. This loss is the same as a decrease in compressor efficiency. The result is increased fuel consumption and lower power output that affect the size and weight of the engine. The average inlet temperature to the turbine affects both fuel consumption and power output. A large combustor outlet gradient will work to reduce averages gas temperature and consequently reduce power output and efficiency. Some factors are very important that affects satisfactory operation and life of the combustor. To achieve satisfactory operation, the flame must be self-sustaining, and combustion, must be stable over a range of fuel-to-air ratios to avoid ignition loss during transient operation. Minimum carbon deposits and smoke emissions also help assure satisfactory operation.

## 2. Modelling, Meshing and Simulation

The aerodynamic process plays a vital role in the design and performance of a gas turbine combustion system. The flow in the combustion chamber is generally complex, due to highly turbulent nature of the flow field, coupled with complex geometric configuration. Further, the additional complications of combustion like fuel evaporation, radiative and convective heat transfer, and chemical kinetics are also involved. The interaction between the diffuser and the combustor external flows plays a key role in controlling the total- pressure loss, flow distribution around the combustor liner, durability, and stability. All dimensions of the can type combustion chamber of utran gas power plant was taken from the site. As shown in figure 2 is the actual inner liner of the combustion chamber. Figure 3 shows total length of the inner liner is 702 mm. the inner liner combustion chamber have a first two row is primary hole, third one row intermediate hole and Last one row is dilution hole. As shown in fig 3 First row number of 8 hole is 20 mm, second row number of 8 hole is 15 mm, third row number of 8 hole is 13 mm, and dilution hole row is 45 mm.



Figure 2 Inner Liner Combustion Chamber

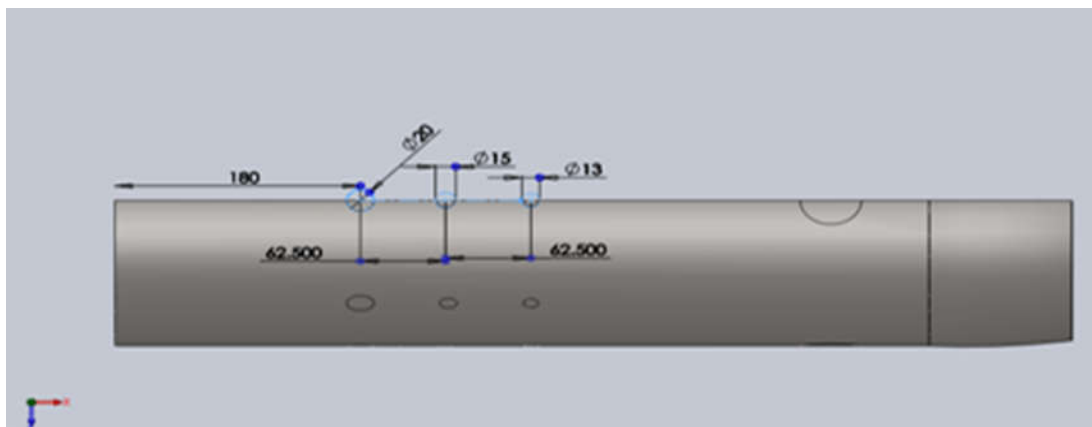


Figure 3 Dimensions of the geometry used

All dimensions are taken after that the geometry is done by the solid works 2009 to obtain the cavity model. The cavity model is meshed in Meshing software (WORKBENCH ICEM CFD). Then it is being analyzed in the Ansys cfx by applying proper boundary conditions order heading should be 10 size Arial bold with 1.15 line spacing, initially capitalized, flush left, with one blank line before, and one blank line after. In 3D computer graphics, 3D modeling is the process of developing a mathematical representation of any three-dimensional surface of the object via specialized software. The product is known as the 3D model. Figure 4 shows that by using the all dimension available, the Cavity model of a combustion chamber inner liner, which is to be drawn in Solid Works 2009 X64 editions SPO. This modeling is generated fluid flow volume after transferring to the workbench.

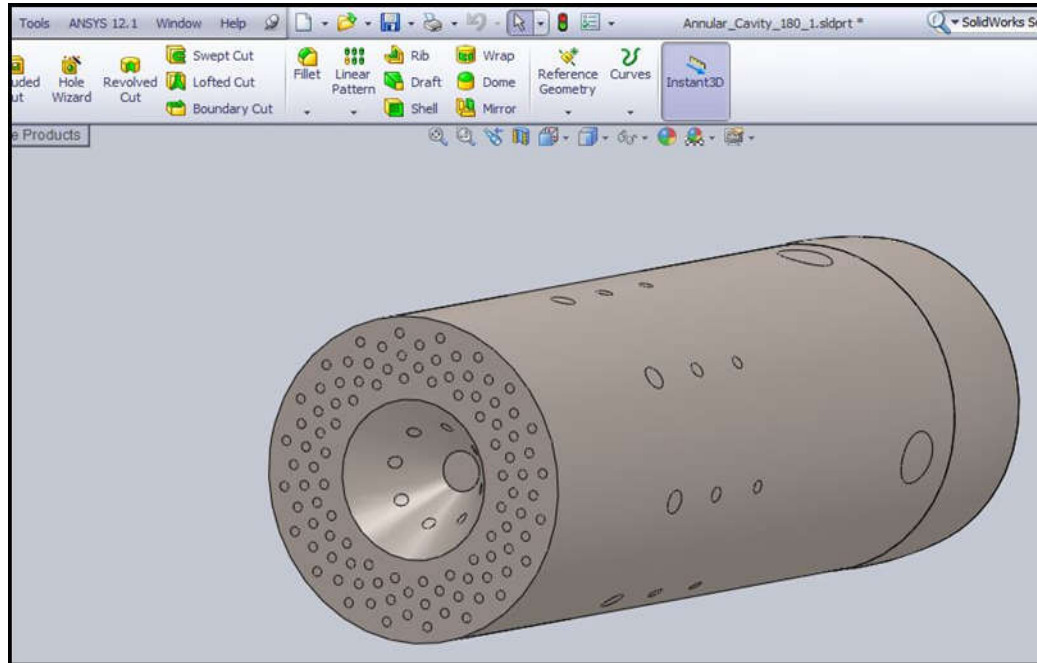


Figure 4 Modeling of Combustion Chamber

All Meshing is the method to define and brake up the model into small elements. In general a finite element model is defined by a mesh network, which is made up of the geometric arrangement of elements and nodes. Nodes represent points at which features such as displacements are calculated. Elements are bounded by set of nodes, and define localized mass and stiffness properties of the model. Once geometry has been imported, the fluid domain is meshed in workbench's ICEM CFD. Specify the different parameters like element type and size of element. After the select the option create mesh is automatic, tetrahedral, hexahedral, wedge, ect. Figure shows the change the mesh size. Figure 5 shown the after completing the create a mesh. Figure 4.6 shows the cross section of the domain meshed. The details of the meshed parameters are given in meshing report shown in table 1.

Table 1. Number of elements and nodes in mesh

Element Type	Tetrahedral
Number of Nodes	198466
Number of Elements	1072546

After meshing the boundary conditions are specified. Here we are simulating the combustion chamber inner liner of the 30 MW power plant of the utran. The data obtained from the power plant are used to determine the boundary conditions for the analysis.

Boundary condition calculation from RQL theory

Data from the utran power station (current working condition)

Gas flow to	=	2.403 kg/sec
Fuel gas pressure	=	18.64 kg/cm <sup>2</sup>
Fuel gas temperature	=	100°C
Compressor air exit temperature	=	84°C
Compressor air exit pressure	=	9 bar
Mass flow rate of air Ma (total)	=	11.34 kg/sec
Mass flow rate of fuel Mf	=	0.24 kg/sec
Velocity of fuel	=	39.93 m/sec
Mass flow rate fuel air ratio (Mf/Ma) actual	=	0.0212

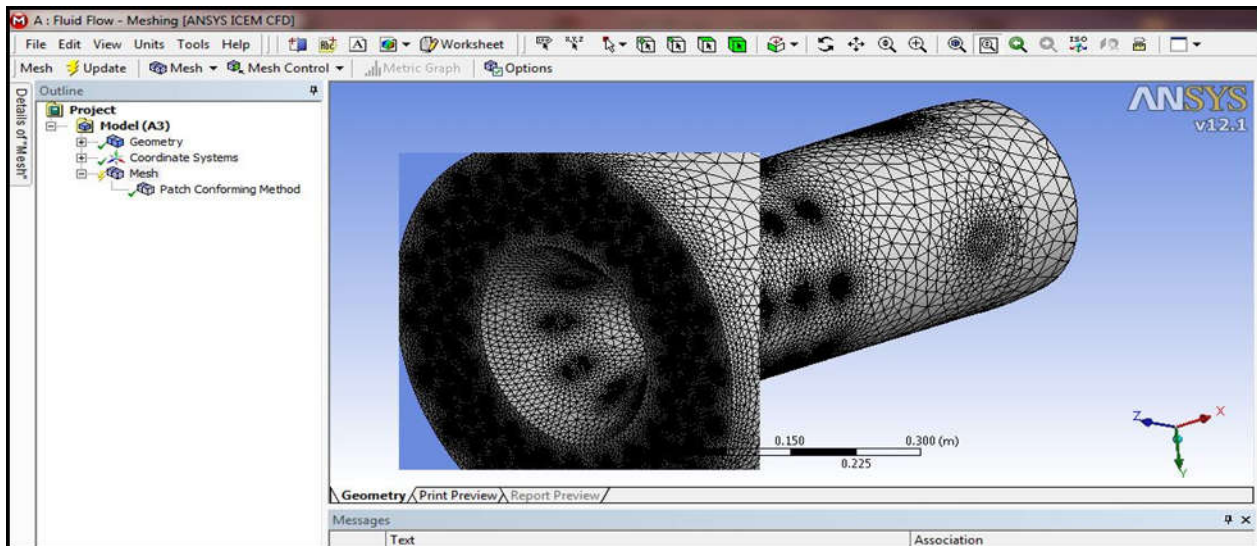


Figure 5 Meshing [ANSYS ICEM CFD]

Burning of fuel inside the combustion chamber leads to generation of high flame temperature. As the temperature at the end of the combustion is having limitation by the material used in turbine blades. The peak gas temperature should be in the primary reaction zone and thereafter the gas temperature decreases after the primary reaction zone due to the dilution of the flame with the secondary air.

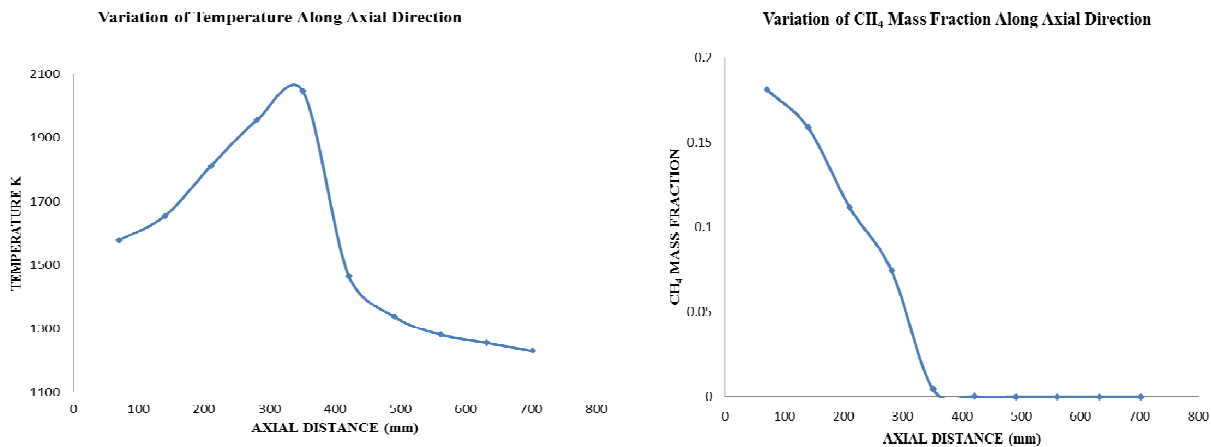


Figure 6 Profile Of Temperature Along Center Line

Figure 7 Profile of CH<sub>4</sub> mass fractions along center line

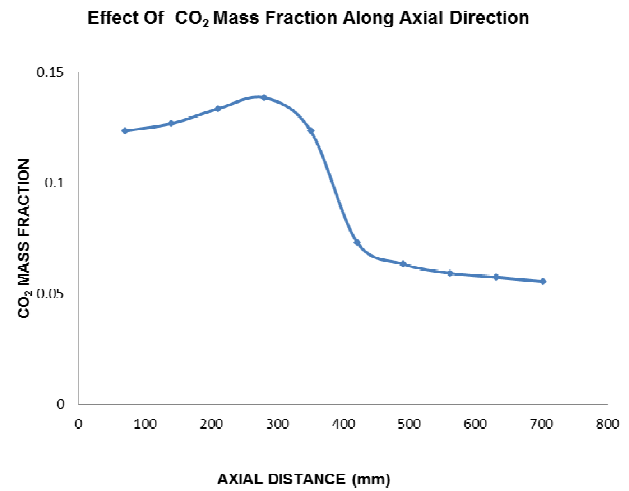
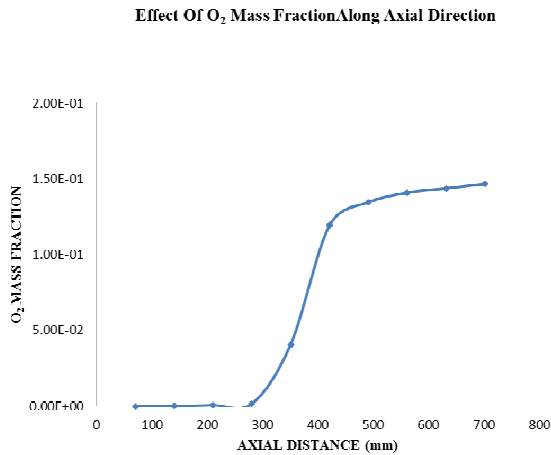


Figure 8 Profile of O<sub>2</sub> mass fractions along center line

Figure 9 Profile of CO<sub>2</sub> Mass Fractions along Center Line

As shown in figure 6 the temperature is varying from inlet to the exit of combustion chamber and it is observed that exit temperature is 1230 K. This temperature is maintained so that turbine blade has no effect. Fuel injected in the combustion chamber is methane. Complete combustion of fuel is must in any combustion process as it will lead to less emission. Methane combustion is a chemical reaction that occurs from burning methane gas which is an odorless and colorless fossil fuel causing high amounts of heat and pressure to be produced. Methane by itself cannot be caused to burn effectively without using oxygen as an additive. This combination is what causes methane to begin burning, which is called methane combustion. What is the variation in quantity of fuel as it progress in the combustion process is very difficult to visualize practically but with the help of simulation we can find what mass fraction of fuel is burnt and what is remain as combustion progresses. We can clearly observe that value of mass fraction is higher near to fuel injection zone because, pure fuel is injected there. But we move along center line of combustor, its concentration will significantly reduce due to more and more methane will utilize for combustion Figure 7 shows that at axial distance  $z=350$  mm which representing downstream of secondary air inlet zone, value of mass fraction of methane is approaching to zero. At outlet of combustor CH<sub>4</sub> value is also zero. This indicate that complete combustion has done, there is no fuel present at that region. Shown in figure 8 It is quite observe that concentration of O<sub>2</sub> is higher at exit region of combustor compare to center region because of air as oxidant entering from secondary air inlet region and air composition by weight it contains 23.2 % O<sub>2</sub> and 76.8 % N<sub>2</sub>. At center region its value is zero up to axial distance  $z=300$  mm the upstream region of secondary air inlet, further movement after the region of secondary air inlet, increment in mass fraction of O<sub>2</sub> significantly due to more and more air is introduced from the secondary air inlet holes. O<sub>2</sub> increased in exit condition gradually. Carbon dioxide is a product of the combustion process, and it is primarily mitigated by reducing fuel usage. Carbon dioxide emissions will continue to drop as manufacturers make gas turbine engines more efficient. It is afraid that the atmospheric temperature might be increased on account of the greenhouse effect by CO<sub>2</sub> and the climate might be changed on global scale. Hence it is required to reduce the emission of CO<sub>2</sub> into the atmosphere. Shown in Figure 9 the carbon dioxide (CO<sub>2</sub>) produce when the burning the fuel and after the gradually decrease to exit condition.

## Conclusion

The utran power plant working boundary condition apply of Rich Burn Quick Mix Lean Burn inner liner for

combustion chamber is carried out using methane as a fuel as part of development of can type inner liner combustion chamber and the model is verified using Numerical exit temperature and plant exit temperature. The qualitative agreement of CFD result with result suggests that the basic assumptions & boundary condition for CFD analysis can be applied to understand the flow phenomena, temperature, CH<sub>4</sub>, O<sub>2</sub>, CO<sub>2</sub>, for combustion chamber.

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