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Design Optimization of Can Type Combustor

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***Abstract* - The combustor in a gas turbine is to add energy to the system to power the turbines, and produce high velocity gas to exhaust through the nozzle in aircraft applications. Combustion chambers must be designed to ensure stable combustion of the fuel injected and optimum fuel utilization within the limited space available and over a large range of air/fuel ratios. In a gas turbine engine, the combustor is fed by high pressure air by the compression system. A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process.**

The design of Can-type combustion chamber, modified can -type combustion chamber geometry and numerical investigations is carried out. The k-ω model used for analysis and also the mean temperature, reaction rate, and velocity fields are almost insensitive to the grid size. Numerical investigation on Can-type combustion chamber and a modified can -type combustion chamber geometry is gives less NOx emission as the temperature at the exit of combustion chamber is less. For methane as fuel and with initial atmospheric conditions, the theoretical flame temperature produced by the flame with a fast combustion reaction is 1950 K. The predicted maximum flame temperature is 1850 K of the combustion products compares well with the theoretical adiabatic flame temperature. Temperature profiles shows increment at reaction zone due to burning of air-methane mixture and decrement in temperature downstream of dilution holes because more and more air will enter in combustion chamber to dilute the combustion mixture along center line . Specie namely NOx is increasing and achieving peak point at reaction zone because they are products of combustion along center line. Due to increase in equivalence ratio, temperature and mass fraction of NOx increases because more fuel is utilized. There in not much variation in temperature and NOx emission by shifting the axial location of dilution holes. In modified can -type combustion chamber geometry Temperature profiles shows increment at reaction zone along the axis due to burning of air-methane mixture and decrement in temperature downstream the walls. In modified can-type combustion chamber clearly shows that temperature and pressure profiles decrease and contribute to cool the chamber walls but the exit velocity profile contributes for some losses. The streamline wall cooling is provided by installing the vanes in the combustion chamber at different position which enables the proper wall cooling for the design considered.

Keywords: NOx, Combustor, Swirler, CFD

I. INTRODUCTION TO COMBUSTION

Combustion is a chemical process in which a substance reacts rapidly with oxygen and gives off heat. The original substance is called the fuel, and the source of oxygen is called the oxidizer. The fuel can be a solid, liquid, or gas, although for airplane propulsion the fuel is usually a liquid. A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder. In a gas turbine engine, the combustor or combustion chamber is fed high pressure air by the compression system. The combustor then heats this air at constant pressure. After heating, air passes from the combustor through the nozzle guide vanes to the turbine. In the case of a ramjet or scramjet engines, the air is directly fed to the nozzle.

A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process.

Early gas turbine engines used a single chamber known as a can type combustor. Today three main configurations exist: can, annular and cananular (also referred to as can-annular tubo-annular). Afterburners are often considered another type of combustor. Combustors play a crucial role in determining many of an engine's operating characteristics, such as fuel efficiency, levels of emissions and transient response (the response to changing conditions such a fuel flow and air speed).

II. COMBUSTION SECTION

The combustion section contains the combustion chambers, igniter plugs, and fuel nozzle or fuel injectors. It is designed to burn a fuel-air mixture and to deliver combusted gases to the turbine at a temperature not exceeding the allowable limit at the turbine inlet. Theoretically, the compressor delivers 100 percent of its air by volume to the combustion chamber. However, the fuel-air mixture has a ratio of l5 parts air to 1 part fuel by weight. Approximately 25 percent of this air is used to attain the desired fuel-air ratio. The remaining 75 percent is used to form an air blanket around the burning gases and to dilute the temperature, which may reach as high as 3500º F, by approximately one-half. This ensures that the turbine section will not be destroyed by excessive heat.

The air used for burning is known as primary air; that used for cording is secondary air. Secondary air is controlled and directed by holes and louvers in the combustion chamber liner. Igniter plugs function during starting only; they are shut off manually or automatically. Combustion is continuous and self-supporting. After engine shutdown or failure to start, a pressure-actuated valve automatically drains any remaining unburned fuel from the combustion chamber. The most common type used in Army gas turbine engines is the external annular reverse-flow type. The primary function of the combustion section is, of course, to bum the fuel-air mixture, thereby adding heat energy to the air. To do this efficiently, the combustion chamber must —

- Provide the means for mixing the fuel and air to ensure good combustion.
- Bum this mixture efficiently.
- Cool the hot combustion products to a temperature which the turbine blades can withstand under operating conditions.
- Deliver the hot gases to the turbine section.

The location of the combustion section is directly between the compressor and turbine sections. The combustion chambers are always arranged coaxially with the compressor and turbine, regardless of type, since the chambers must be in a through-flow position to function efficiently.

All combustion chambers contain the same basic elements:

- Casing
- Perforated inner liner.
- Fuel injection system.
- A fuel drainage system to drain off unburned fuel after engine shutdown.

A. *Case*

The case is the outer shell of the combustor, and is a fairly simple structure. The casing generally requires little maintenance. The case is protected from thermal loads by the air flowing in it, so thermal performance is of limited concern. However, the casing serves as a pressure vessel that must withstand the difference between the high pressures inside the combustor and the lower pressure outside. That mechanical (rather than thermal) load is a driving design factor in the case.

B. *Diffuser*

The purpose of the diffuser is to slow the high speed, highly compressed, air from the compressor to a velocity optimal for the combustor. Reducing the velocity results in an unavoidable loss in total pressure, so one of the design challenges is to limit the loss of pressure as much as possible. Furthermore, the diffuser must be designed to limit the flow distortion as much as possible by avoiding flow effects like boundary layer separation. Like most other gas turbine engine components, the diffuser is designed to be as short and light as possible.

C. *Liner*

The liner contains the combustion process and introduces the various airflows (intermediate, dilution, and cooling, see Air flow paths below) into the combustion zone. The liner must be designed and built to withstand extended high temperature cycles.

D. *Snout*

The snout is an extension of the dome (see below) that acts as an air splitter, separating the primary air from the secondary air flows (intermediate, dilution, and cooling air; see Air flow paths section below).

E. *Dome / Swirler*

The dome and swirler are the part of the combustor that the primary air (see Air flow paths below) flows through as it enters the combustion zone. Their role is to generate turbulence in the flow to rapidly mix the air with fuel. Early combustors tended to use bluff body domes (rather than swirlers), which used a simple plate to create wake turbulence to mix the fuel and air. Most modern designs, however, are swirl stabilized (use swirlers). The swirler establishes a local low pressure zone that forces some of the combustion products to re-circulate, creating the high turbulence. However, the higher the turbulence, the higher the pressure loss will be for the combustor, so the dome and swirler must be carefully designed so as not to generate more turbulence than is needed to sufficiently mix the fuel and air.

F. *Fuel Injector*

The fuel injector is responsible for introducing fuel to the combustion zone and, along with the swirler (above), is responsible for mixing the fuel and air. There are four primary types of fuel injectors; pressure-atomizing, air blast, vaporizing, and premix/pre-vaporizing injectors.

G. *Igniter*

Most igniters in gas turbine applications are electrical spark igniters, similar to automotive spark plugs. The igniter needs to be in the combustion zone where the fuel and air are already mixed, but it needs to be far enough upstream so that it is not damaged by the combustion itself. Once the combustion is initially started by the igniter, it is self-sustaining and the igniter is no longer used.

III. AIR FLOW PATHS

A. *Primary air*

This is the main combustion air. It is highly compressed air from the high pressure compressor (often decelerated via the diffuser) that is fed through the main channels in the dome of the combustor and the first set of liner holes. This air is mixed with fuel, and then combusted.

B. *Intermediate air*

Intermediate air is the air injected into the combustion zone through the second set of liner holes (primary air goes through the first set). This air completes the reaction processes, cooling the air down and diluting the high concentrations of carbon monoxide (CO) and hydrogen (H2).

C. *Dilution air*

Dilution air is airflow injected through holes in the liner at the end of the combustion chamber to help cool the air to before it reaches the turbine stages. The air is carefully used to produce the uniform temperature profile desired in the combustor. However, as turbine blade technology improves, allowing them to withstand higher temperatures, dilution air is used less, allowing the use of more combustion air.

D. *Cooling air*

Cooling air is airflow that is injected through small holes in the liner to generate a layer (film) of cool air to protect the liner from the combustion temperatures. The implementation of cooling air has to be carefully designed so it does not directly interact with the combustion air and process. In some cases, as much as 50% of the inlet air is used as cooling air.

IV. MODELLING

A. *Introduction to ANSYS ICEM*

Meeting the requirements for integrated mesh generation and post processing tools for today’s sophisticated analysis. ANSYS ICEM CFD provides geometry acquisition, mesh generation, mesh optimization, and post processing tools.

Maintaining a close relationship with the geometry during mesh generation and post processing, ANSYS ICEM CFD is used especially in engineering applications such as computational fluid dynamics and structural analysis. ANSYS ICEM CFD's mesh generation tools offer the capability to parametrically create meshes from in numerous formats

- Multi-block structured
- Unstructured hexahedral
- Cartesian with h grid refinement
- Hybrid Meshes comprising hexahedral, tetrahedral, pyramidal and/or prismatic elements
- Quadrilateral and triangular surface meshing

B. DESIGN OF BASIC CAN TYPE COMBUSTION CHAMBER GEOMENTRY

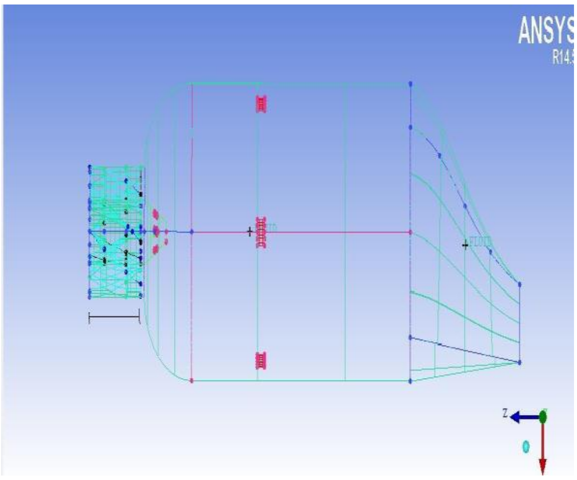


Figure-1(a): Geometry for Basic Can type combustion chamber.

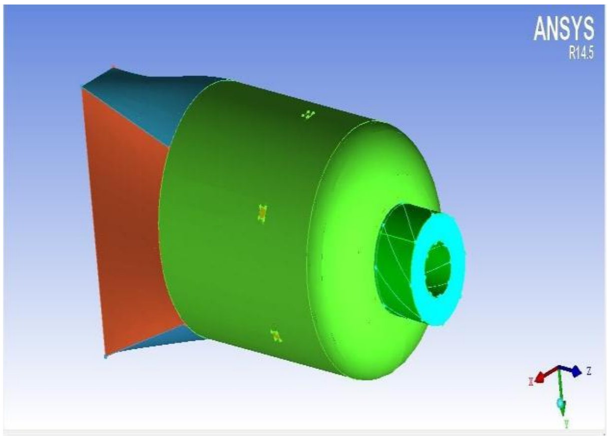


Figure-1(b): Complete Design of Basic Can Type Combustion Chamber.

C. DESIGN OF MODIFIED CAN TYPE COMBUSTION CHAMBER GEOMENTRY

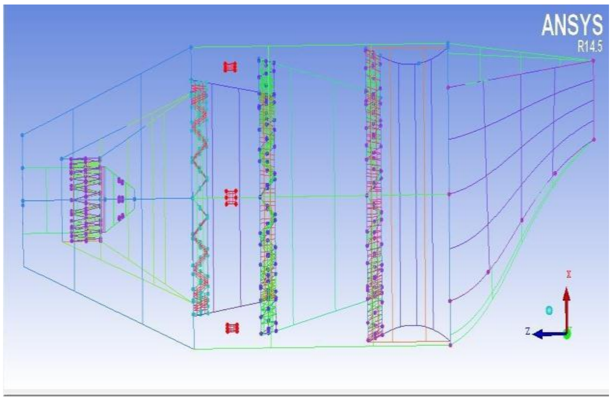


Figure-2(a): Geometry for Modified Can Type Combustion Chamber.

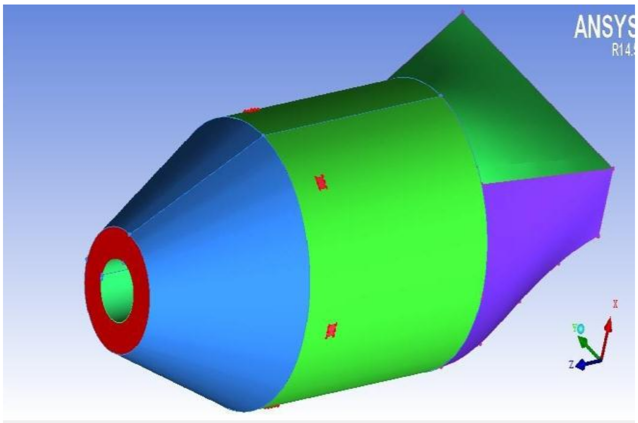
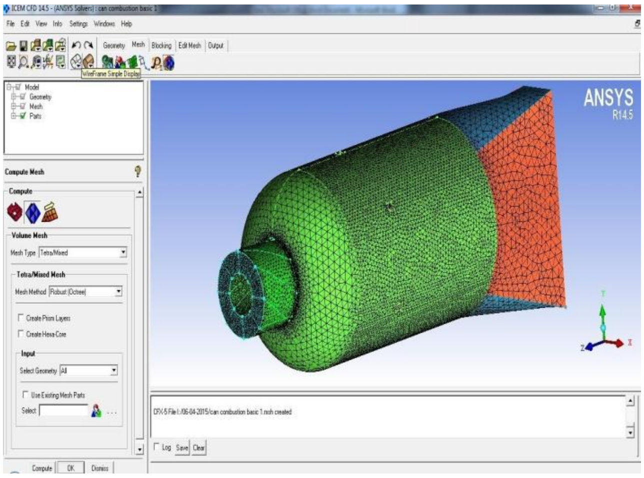


Figure-2(b): Complete Modified Can Type Combustion Chamber Design

V. MESHING

A. Meshing Of Basic Can Type And Modified Combustion Chamber Design


ICEM CFD 14.5 - (ANSYS Solvers) : can combustion basic 1

Mesh Type: Tetra/Mixed

Mesh Method: Robust (Octree)

☐ Create Prism Layers

☐ Create Hexa-Core

Select Geometry: All

☐ Use Existing Mesh Parts

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CFX-5 File I:/06-04-2015/can combustion basic 1.msh created
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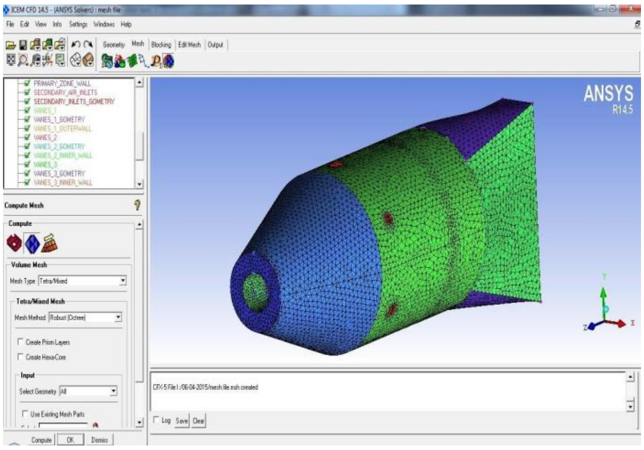

Volume Mesh
Mesh Type: Tetra/Mixed

Tetra/Mixed Mesh
Mesh Method: Robust (Octree)

☐ Create Prism Layers
☐ Create Hexa-Core

Input
Select Geometry: All

☐ Use Existing Mesh Parts

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CFX-5 File I:/06-04-2015/mesh file.msh created
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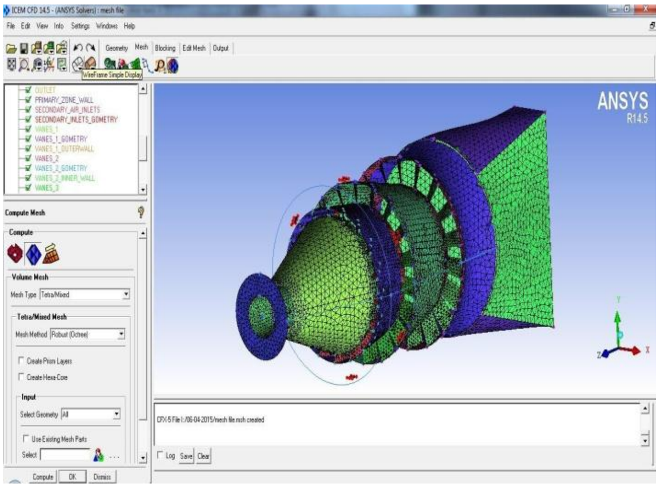
Figure-3: Computing meshing file for Total surface.



Volume Mesh
Mesh Type: Tetra/Mixed

Tetra/Mixed Mesh
Mesh Method: Robust (Octree)

☐ Create Prism Layers
☐ Create Hexa-Core

Input
Select Geometry: All

☐ Use Existing Mesh Parts
Select:

```
CFX-5 File I:/06-04-2015/mesh file.msh created
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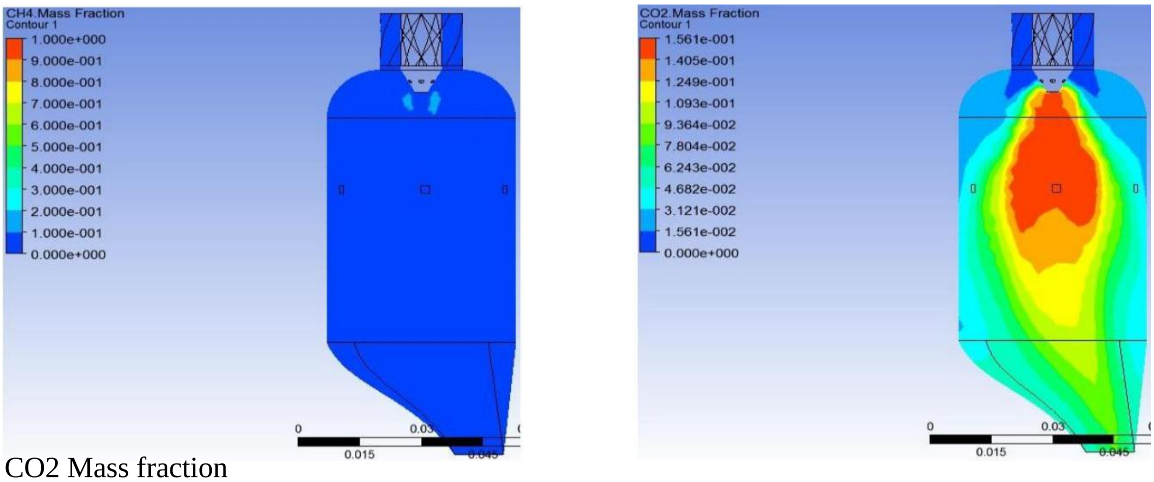
VI. RESULTS & DISCUSSIONS

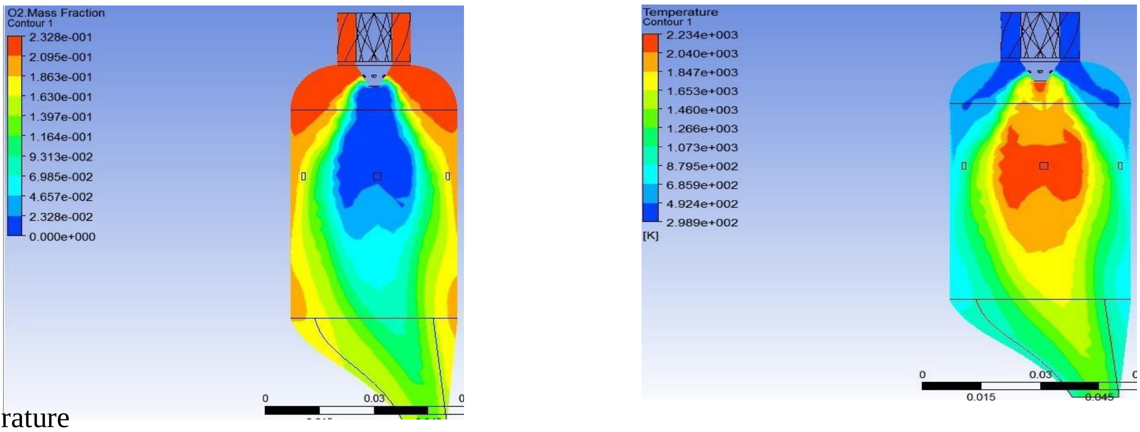
A. FOR BASIC CAN TYPE INLET FLOW VELOCITY AT 60 m/sec

CH 4 Mass fraction

O2 Mass fraction



CO2 Mass fraction



Temperature

Pressure

Velocity

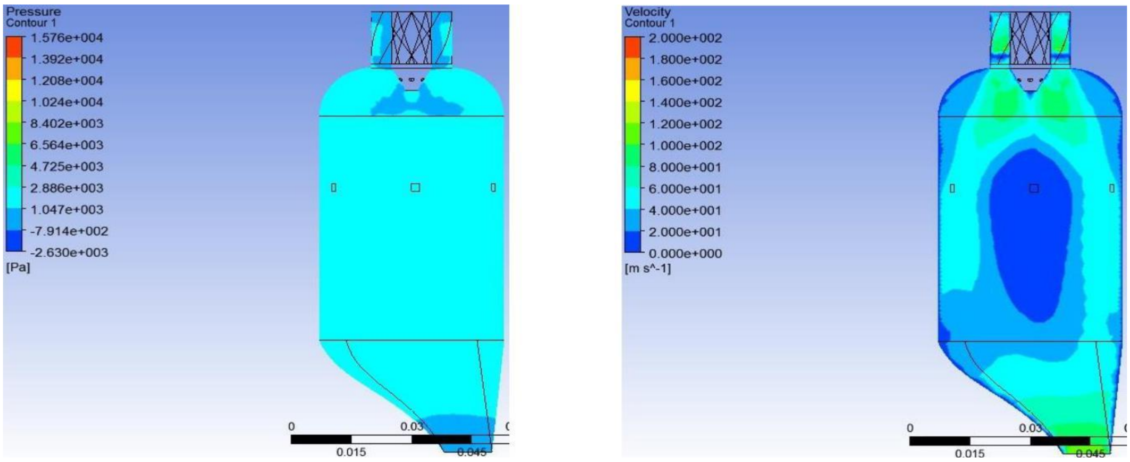
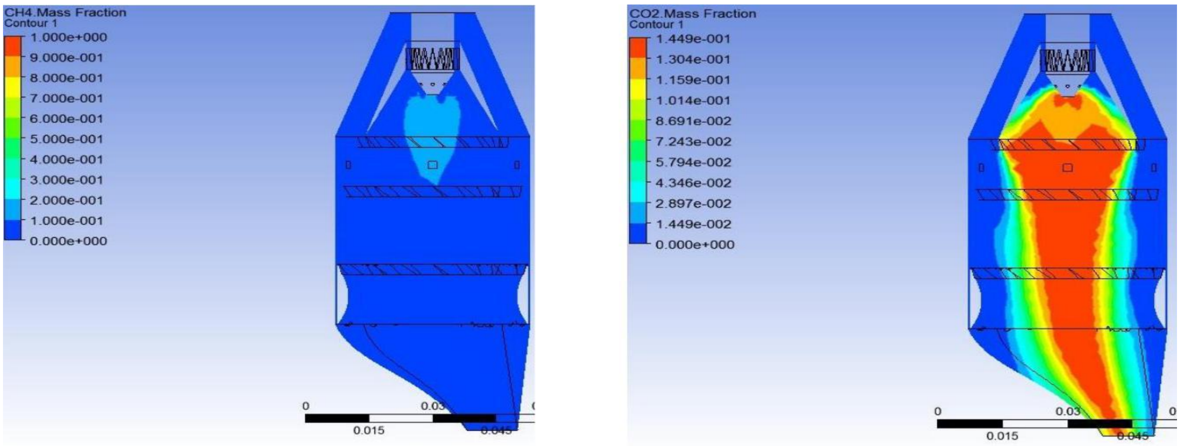
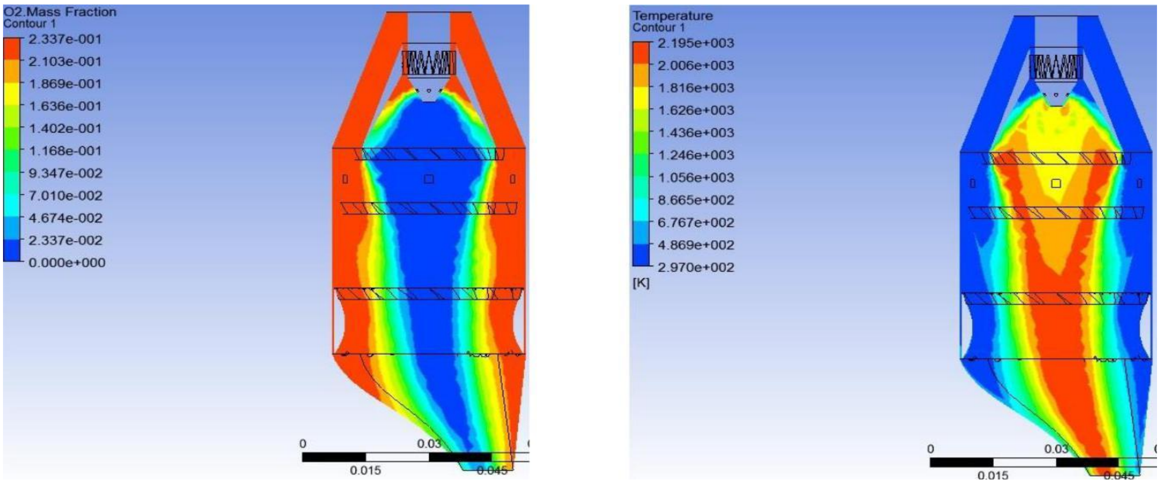


Figure-4: Temperature, Pressure and Velocity results for basic design

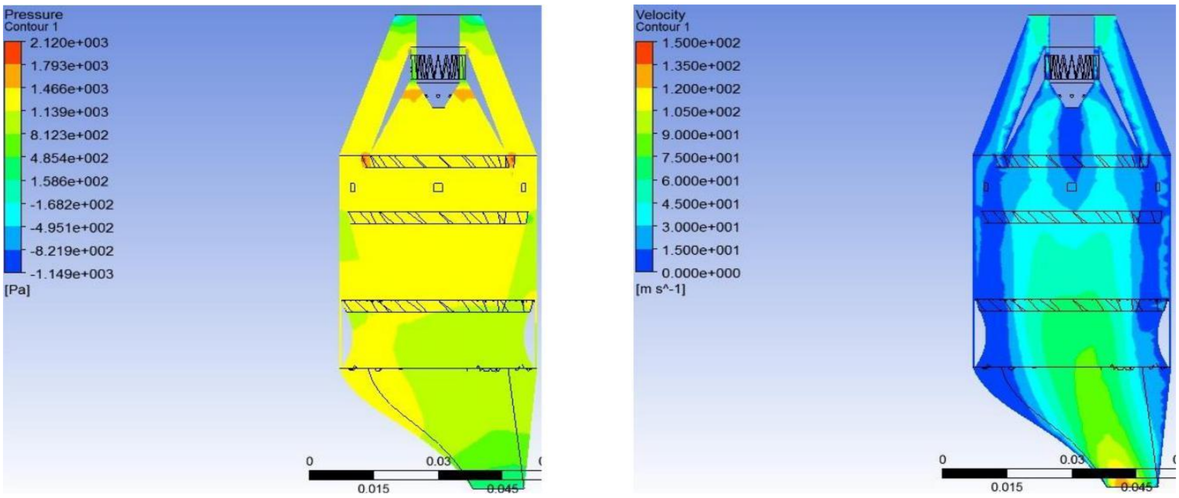
B. FOR MODEFIED CAN COMBUSTION CHAMBER INLET FLOW VELOCITY AT 60 m/sec


CH4 Mass fraction

CO2 Mass fraction


O2 Mass fraction

Temperature


Pressure

Velocity

Figure-5: Temperature, pressure and velocity results for modified type combustor

C. COMPARISON OF BOTH BASIC CAN TYPE AND MODEFIED CAN TYPE

1. *Comparison of Temperature Contours*

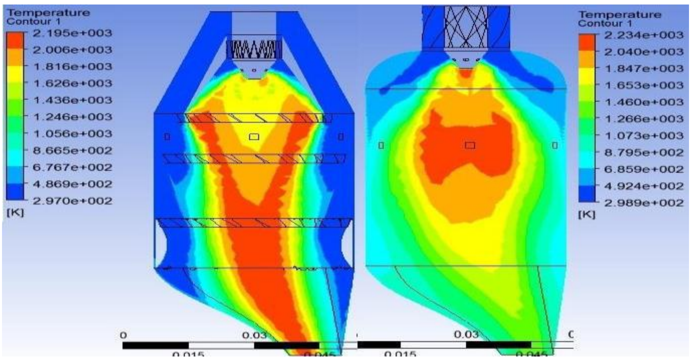


Figure-6(a): Comparison of Temperature Contours for both Basic & Modified Can Type at 60 m/sec.

Air Inlet velocity	60 m/sec
Fuel inlet velocity	180 m/sec
Secondary air inlets velocity	20 m/sec
Outlet temperature	
Modified design	2.195e+003
Basic design	1.460e+003
Maximum temperature	
Modified design	2.195e+003
Basic design	2.234e+003

2. Comparison of Velocity Contours

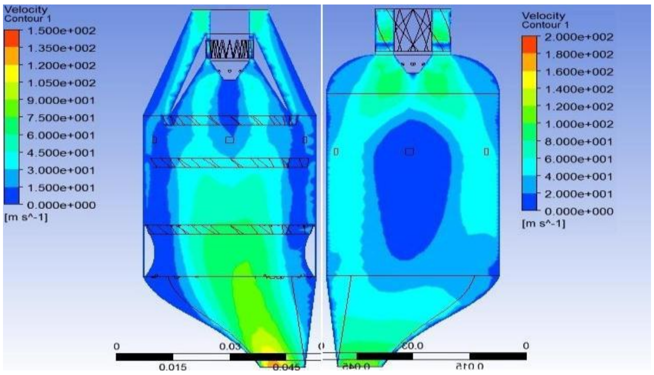


Figure-6(b): Comparison of Velocity Contours for both Basic & Modified Can Type at 60 m/sec.

Air Inlet velocity	
Fuel inlet velocity	180 m/sec
Secondary air inlets velocity	20 m/sec
Outlet velocity	
Modified design	1.350e+002
Basic design	1.200e+002
Maximum velocity	
Modified design	2.000e+002
Basic design	2.000e+002

3. *COMPARISION OF PRESSURE CONTOURS*

At inlet velocity of 60 m/sec

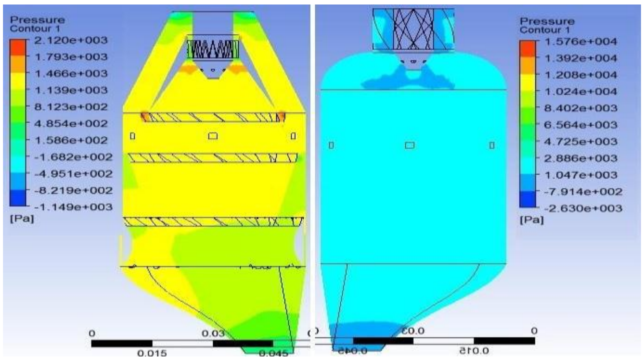


Figure-6(c): Comparison of Pressure Contours for both Basic & Modified Can Type at 60 m/sec.

Air Inlet velocity	60 m/sec
Fuel inlet velocity	180 m/sec
Secondary air inlets velocity	20 m/sec
Outlet pressure	
Modified design	4.840e+002
Basic design	1.042e+003
Maximum pressure	
Modified design	2.120e+003
Basic design	1.576e+004

VII. CONCLUSION

The design of Can-type combustion chamber, modified can -type combustion chamber geometry and numerical investigations is carried out. The k-ω model used for analysis and also the mean temperature, reaction rate, and velocity fields are almost insensitive to the grid size. Numerical investigation on Can-type combustion chamber and a modified can -type combustion chamber geometry is gives less NO emission as the temperature at the exit of combustion chamber is less. For methane as fuel and with initial atmospheric conditions, the theoretical flame temperature produced by the flame with a fast combustion reaction is 1950 K. The predicted maximum flame temperature is 1850 K of the combustion products compares well with the theoretical adiabatic flame temperature. Temperature profiles shows increment at reaction zone due to burning of air-methane mixture and decrement in temperature downstream of dilution holes because more and more air will enter in combustion chamber to dilute the combustion mixture along center line . Specie namely NO is increasing and achieving peak point at reaction zone because they are products of combustion along center line. Due to increase in equivalence ratio, temperature and mass fraction of NO increases because more fuel is utilized. There in not much variation in temperature and NO emission by shifting the axial location of dilution holes. In modified can -type combustion chamber geometry Temperature profiles shows increment at reaction zone along the axis due to burning of air-methane mixture and decrement in temperature downstream the walls. In modified can -type combustion chamber clearly shows that temperature and pressure profiles decrease and contribute to cool the chamber walls but the exit velocity profile contributes for some losses. The streamline wall cooling is provided by installing the vanes in the combustion chamber at different position which enables the proper wall cooling for the design considered.

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