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ANALYSIS OF COMBUSTION CHARACTERISTICS OF METHANE/AIR MIXTURE IN COAXIAL COMBUSTOR

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ABSTRACT

The present work is a simulation and analysis of a partial premixed methane flame performed in coaxial combustor model. To analyze the combustion process 2-D combustion chamber is modelled in Ansys workbench. The objective of this study was to analyse effects of the air fuel mixture ratio, inlet temperature of the air-fuel and inlet velocity of the air-fuel on flame characteristics and finally investigate the species concentration and temperature distribution within the chamber with Methane (CH_4) as a fuel. The comparison of combustion parameters in partial premixed and non–premixed condition are plotted in form of contours and graph. It is observed that higher oxygen content give the maximum temperature and CO_2 emissions. Higher velocity and temperature of the air decreases the temperature and CO_2 emissions.

Keywords: Premixed; Combustor; Computational Models; Simulation; Stiochometric Ratio;

I. INTRODUCTION

Combustion is the conversion of a substance called a fuel into chemical compounds known as products of combustion by combination with an oxidizer. The combustion process is an exothermic chemical reaction, i.e., a reaction that releases energy as it occurs. Thus combustion may be represented symbolically by:

$$\text{Fuel + Oxidizer} \longrightarrow \text{Products of combustion + Energy}$$

In most premixed combustion techniques the chemical reactions occur in small region, while the rest of the combustion chamber is not used with respect to the main chemical reactions as a result thin combustion zone occurred. [**11-12**]They are categorized by free flame structures, which are very thin. The reason for the thin combustion zone lies in the poor heat transfer properties of the gas mixture.[**8-9**]Combustion has many important applications in industry. The correct phenomenon representation is important to predict equipment efficiency and non-desired behaviour. The challenge in combustion modelling is to describe reaction and fluid flow, which evolution happens in different time scales. Both numerical and experimental investigations of turbulent flames characteristics have been the subject of broad research during current years for a number of gas fuels and liquid fuels, because methane/air mixtures combustion is a complex phenomenon and they are very important for the understanding of complex interactions between the turbulent flow and chemical reactions. There are several models in both ANSYS FLUENT and CFX for different combustion regimes.[**7**]

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Abdelhamid Bounif et. al, (**2014**) carried out simulation of Turbulent Non-Premixed CH_4-Air Flame using Eddy-Dissipation Concept (EDC).The model has been applied in a simulation natural gas/air flame. Later they compare computational results with experimental data for the temperature and various chemical species. [**1**] Ibrahim I. A (**2014**) performed analysis on effects of inlet thermal load, air swirl number and combustor exit diameter on flame characteristics and find that temperature levels and the flame length decreases with increasing in air swirl number and the combustor exit to swirler diameter ratio Dexit/Ds while Increasing the inlet thermal load, the high temperature level size, the flame length increased.[**2**] Eswara Kumar(**2015**) observed in their analysis of combustion parameters of Methane-Air Mixture that CO_2 emissions and turbulence kinetic energy during combustion depend on inlet air temperature and oxygen content. When oxygen content is increasing, it result maximum temperature in the combustion chamber and CO_2 emissions are increasing but the turbulence kinetic energy is decreasing. In other hand maximum temperature in the combustion chamber and CO_2 emissions are decreasing when the inlet air temperature is increasing, but the T.K.E is increasing. [**3**].

K. Saito et al, (**2015**) presented numerical simulation results of turbulent non-premixed coaxial methane/air diffusion flame combustion. Thereby, the numerical simulation result used to forecast the effects of species concentrations of reactants on the thermal and NO_x formations, their self contributions, and outlet temperature of chamber.[**4**] Henry W. Mulkey (2009) examined GO_X/Methane combustion efficiency of a swirl coaxial injector and found that combustion efficiency, depending on injector arrangement, is directly related to characteristic chamber length L^*. Efficiency of characteristic velocity ηc^* decreases with increase in characteristic chamber length .In order to increase ηc^* at increased chamber length additional chamber insulation required. They found that without the implementation of combustion chamber insulation the swirl coaxial injector arrangements requires shorter L^* to achieve higher efficiencies. A higher value of L^* actually resulted in decreased ηc^*, mainly due to heat loss through the chamber walls which can be minimize by combustion chamber insulation.[5] James f. Driscoll et al, (1991) demonstrates how to maximize the amount of coaxial air that can be provided to a nonpremixed jet flame without causing the flame to blow out by optimizes different parameters. They investigated that in order to minimize NO_x emission and size of combustor, coaxial air flow jet flame with no swift, must have minimum possible flame lengths and the corresponding maximum air velocities. As per their measurement show that the ratio of fuel velocity to fuel tube diameter (UF/dF) must be reduced below a critical value in order to shorten the jet flame at a desired amount by using coaxial air. They presented effects of varying fuel type and fuel-to-air tube diameter ratio was for both zero swirl flames and for the swirl-stabilized flames. Both types of flames shows that improved stabilization occurred as the ratio df/dA is increased and as the highest laminar burning velocity is increased. [**6**]

II. NUMERICAL MODELING

2.1 Governing equations for gas flow and kinetics

In this section, corresponding equations and the numerical solution procedure will be presented. A combustion process can be described by the governing equations for a gas flow combined with kinetics. The governing equations for a gas flow include;

• Mass conservation (continuity)

• Mass conservation of the different species

• Conservation of moment

• Energy conservation

2.2 Mass conservation

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} \qquad (1)$$

Where $\dot{m}_{in}$ and $\dot{m}_{out}$ are mass flow rates in and out of a control volume.

Species conservation -The general form of conservation of species A in a control volume, with inlet at x and outlet at x+Δx (one dimensional case) is given by

$$\frac{dm_A}{dt} = \left[\dot{m}''_A\ A\right]_x - \left[\dot{m}''_A\ A\right]_{x+\Delta x} + \dot{m}'''_A\ V \quad (2)$$

Where $\dot{m}''_A$ the mass is flux (mass flow pr area) and $\dot{m}'''_A\ V$ is the produc- tion or destruction of species *A* due to chemical reactions.

When species *A* and *B* are mixed in a control volume, Ficks law can be used for diffusion

$$\dot{m}''_A = Y_A(\dot{m}''_A + \dot{m}''_B) - \rho D_{AB}\frac{dY_A}{dx} \qquad (3)$$

Y_A is the mass fraction of component *A*, ρ is the density of the mixture and D_{AB} is the diffusion coefficient between species *A* and *B*.

Combining (2) and (3) give

$$\frac{d(\rho Y_A)}{dt} = -\frac{\partial\left[Y_A\,\dot{m}'' - \rho D_{AB}\frac{dY_A}{dx}\right]}{\partial z} + \dot{m}'''_A \quad (4)$$

2.3 Momentum conservation

A general one-dimensional form is given by-

$$\sum F = \dot{m}_{vout} - \dot{m}_{vin} \qquad (5)$$

Where *F* is force and v is velocity. Letting the forces be given by pressures and again assuming a one-dimensional geometry, we get the following differential equation

$$-\frac{dP}{dx} = \rho v_x \frac{dv_x}{dx} \qquad (6)$$

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2.4 Energy conservation

A rather general energy balance can be formulated as-

$$Q - \dot{W} = -\dot{m}\left[\Delta h + \frac{\Delta v^2}{2} + g\Delta z\right] \quad (7)$$

Where Q is heat, W is work, h is enthalpy, g is the gravity constant and z is elevation. If potential energy is neglected, this can be formulated as

$$-\frac{d\dot{Q}''_x}{dx} = \dot{m}''\left(\frac{dh}{dx} + v_x\frac{dv_x}{dx}\right) \qquad (8)$$

The heat flux $\dot{Q}''_x$ is given by Fourier's law

$$\dot{Q}''_x = -k\frac{dT}{dx} + \sum \rho Y_i\,(v_{ix} - v_x)H_i \quad (9)$$

2.5 Kinetics

The simplest way to model the chemical kinetics is to use one global reaction, for instance

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (10)$$

And then assume instantaneous and full combustion (all methane is burned and transformed to CO_2 and water instantaneously). However, when studying combustion, the reaction rates might be important as they introduce time delays.

2.6 Stoichiometric ratio

If the minimum air is used following the stoichiometry of the combustion reaction then the air is called the stoichiometric air. The ratio of actual air to stoichiometric air is called stoichiometric ratio.[NPTEL]. For example, stoichiometric air for burning of methane is

$$\Phi = \frac{\text{Actual air}}{\text{Stoichiometric air}}$$

A flame with an equivalence ratio/ Stoichiometric ratio larger than one (Φ>1) is called a fuel-rich, while a flame with an equivalence ratio smaller than one (Φ<1) is called a fuel-lean. M. I. Hassan et al. studied both experimentally and computationally, effects of positive flame stretch on the laminar burning velocities of methane/air flames and Predicted Properties of Laminar Premixed Methane/Air Flames at Various Pressures. They conclude that methane/air flames exhibit unstable preferential-diffusion behavior at lean conditions like hydrogen/air flames, which agrees with traditional facts about effects of unstable preferential diffusion of reactant species on flame stability. [**10**]

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III. PROBLEM STATEMENTS

To analyze the combustion process 2-D combustion chamber is modelled in Ansys workbench. The coaxial combustor is considered and methane – air combustion simulation is performed and their simulation result is compared in partial premixed and non-premixed air fuel mixture condition. The major species involved in the combustion process are CH_4, O_2, CO_2, CO, H_2O and N_2.

3.1 Meshing, Loads & Boundary conditions

Finer mesh is performed on the combustion chamber to get better accurate results. The combustion chamber contains coaxial inlets for fuel and other for air. Axial inlet velocity of 10 m/s is assigned for cases of Oxygen content and temperature of the inlet air.

Different parameters value

Air	
conditions	value
Axial-Velocity	10 m/s
Turbulent Intensity (%)	9.9999998
Hydraulic Diameter	0.0254 m
Turbulent Viscosity Ratio	10

Outlet – Air-fuel	
conditions	value
Backflow Turbulent Intensity (%)	9.9999998
Backflow Hydraulic Diameter	0.13 m
Backflow Turbulent Viscosity Ratio	10

Under-Relaxation factors	
conditions	value
Axial-Velocity	10 m/s
Swirl-Velocity	30 m/s
Turbulent Intensity (%)	9.9999998
Hydraulic Diameter	0.0254 m
Turbulent Viscosity Ratio	10

Discretization and computational model step.	
Variable	Relaxation Factor
Pressure	0.3
Density	1
Body Forces	1
Momentum	0.7
Swirl Velocity	0.9

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Turbulent Kinetic Energy	0.8
Turbulent Dissipation Rate	0.8
Turbulent Viscosity	1

IV. RESULTS & DISCUSSIONS

Fig 1 shows the typical diagram of temperature distribution in combustion chamber with velocity of 10m\s at inlet 1. It can be observed that maximum temperature of 1920K is existed at the end side.

Solver Type	**Pressure Based**
2D - space	Axisymmetric
Pressure-Velocity Coupling	Simple
Pressure	Second Order
Momentum	Second Order Upwind
Swirl Velocity	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Turbulent Dissipation Rate	Second Order Upwind

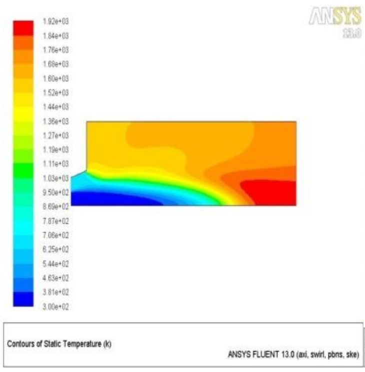
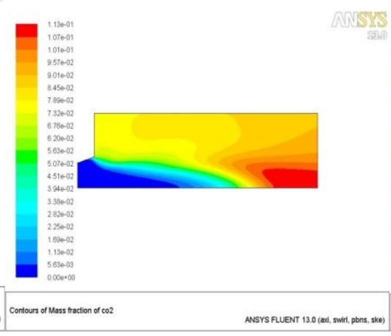
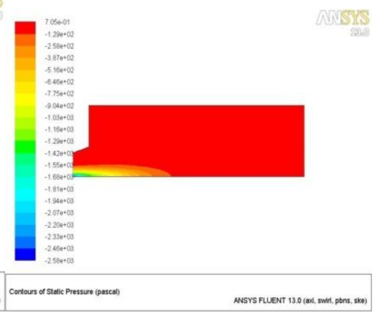

Fig 1: Contour of maximum temperature Fig 2: Contour of CO2 emissions Fig.3 Total pressure

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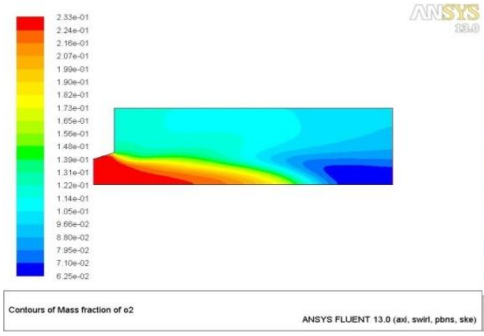


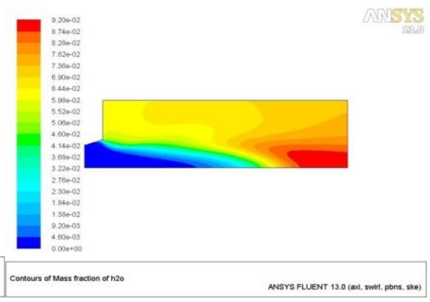


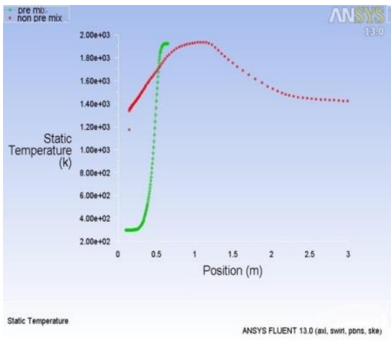
Fig.4 O2 Mass fraction **Fig.5 H2O mass fraction**

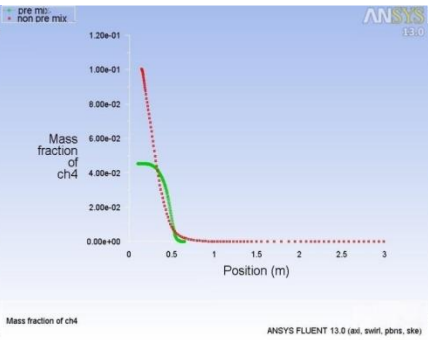
Fig2 shows the typical diagram of CO_2 emissions at outlet of combustion chamber. Fig 3indicates the total pressure variation in the combustion chamber .according to this fig the total pressure throughout the combustion chamber is equal so the combustion chamber is in stable condition. The pressure at the boundaries of a combustion chamber is constant so there is no much effect on the combustion chamber. Fig.4 indicates the oxygen mass fraction. The oxygen is entered from the air inlets. The combustion process is takes places because of this oxygen. The red colored region indicates the oxygen concentration. The blue colored region is fuel .The concentration of air is decreased because of combustion process. Fig.5 indicates the water mass fraction in the air. The water mass fraction is gradually decreased in the combustion chamber because of combustion process. The blue colored region area is indicates the water in air .this H_2O comes from the air inlets with air. The concentration of water molecules is decreased because large amount of heat is produced during the combustion process so the water molecules are evaporated easily.

V. RESULT COMPARISON IN PARTIAL PREMIXED AND NON-PREMIXED AIR-FUEL CONDITION

5.1 Temperature field

Fig. 6 shows the contour plot of the temperature for partial premixed and non-premixed condition. In partial premixed condition sudden rise of temperature take place while in non-premixed condition slowly temperature rise take place with respect to combustor axial distance.





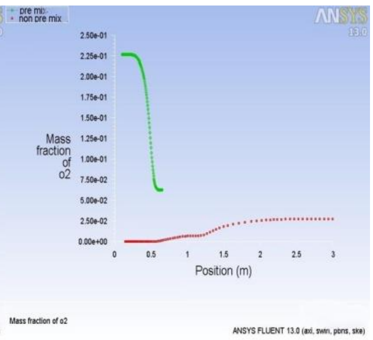


Fig. 6 Comparison of the axial temperature profiles Fig. 7 Axial concentration of CH_4 Fig. 8 Axial concentration of O_2

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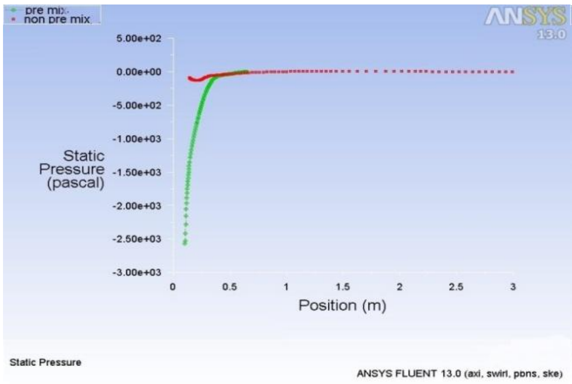
5.2 CH_4 and O_2 concentrations profiles

Figs.7-9 shows CH_4 and O_2 concentration profiles. The axial distribution of the concentration of CH_4 is represented in fig 7

5.3 Pressure and CO_2 variation profiles

In partial premixed condition initial pressure is less and its value varies with combustor axial distance, in other hand overall pressure in non-premixed condition is uniform and does not change with respect to combustor axial distance.



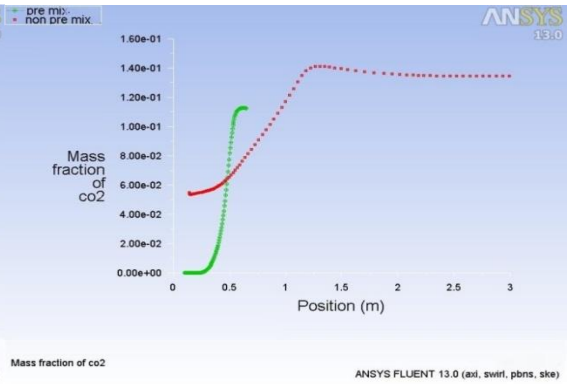


Fig.9 Pressure variation profile

Fig.10 CO_2 variation profile

VI. CONCLUSION

The above analysis reaches to the following conclusions mentioned below:

- The static temperature is very high in the regions where combustion takes place and goes on decreasing towards the outlet. The maximum temperature reached is 1920 K which indicates that there is efficient combustion process.
- The numerical simulation was used to predict the effects of species concentrations of reactants on the thermal and prompt NO formations, their individual contributions, and the chamber outlet temperature.

REFERENCES

[1] Abdelhamid Bounif, Guessab Ahmed, Aris Abdelkader, Abdelhamid Bounif Iskander Gökalp, “Reduced Chemical Kinetic Mechanisms: Simulation of Turbulent Non-Premixed CH4-Air Flame ’’, Journal of Mechanical and Industrial Engineering, April 2014, 66-74

[2] Ibrahim I. A., Gad H. M., Shabaan M. M., “Numerical simulation of combustion characteristics of methane flame in an axisymmetric combustor model”, Global Journal of Engineering Science, December-2014, 2349-4506

[3] A. Eswara Kumar, Naveen Janjanam, “CFD Analysis of Combusition Parameters of Methane-Air Mixture”, International Journal of Engineering Research & Technology, May 2015, 2278-0181

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

[4] K. Saito, S. Poozesh, N. Akafuah, "NO formation analysis of turbulent non-premixed coaxial methane/air diffusion flame", Int. J. Environ. Sci. Technol., August 2015, 513–518

[5] Henry W. Mulkey, Marlow D. Moser,and Matthew A. Hitt, "GOX/Methane Combustion Efficiency of a Swirl Coaxial Injector", August 2009, 2009-5141

[6] James f. Driscoll, Douglas feikema, Ruey-hung chen, "Blowout of Nonpremixed Flames: Maximum Coaxial Air Velocities Achievable, with and without Swirl", Combustion and flame, 1991, 347-358

[7] ANSYS Fluent Getting Started Guide.

[8] IIT Kharagpur NPTEL Phase – II study material "Combustion Technology" Module 5

[9] Isidoro Martinez "Combustion Kinetics", Book

[10] M. I. HASSAN, K. T. AUNG, and G. M. FAETH, "Measured and Predicted Properties of Laminar Premixed Methane/Air Flames at Various Pressures", Combustion and flame - Elsevier Science, 1998, 539–550

[11] Power Generation Handbook, McGraw-Hill, 2004

[12] Antonio Ficarella, "Combustion System", 2013 ,Book