Modelling of Non- Premixed Methane BERL Combustor through CFD Approaches and Prediction of Methane Burning

Sakshi Sharma−1[1] , Dr. S Prasad−2[*]

1[1] *PG Scholar, Madhav Institute of Technology and Science, Gwalior, (M.P.)*

2[*] *Associate Professor Chemical Engineering Department, M.I.T.S., Gwalior, (M.P.)*

***Abstract*-This paper focuses on the modeling of methane burner engineering research laboratory (BERL) combustor through non premixed models by CFD approaches and the prediction of methane burning in order to produce energy and the prediction of NOX formation that is, in the form of pollutants .This model works on large eddy simulation (LES).LES mainly works on two parameter that is probability density function (PDF) and mixture fraction.PDF is applicable under non adiabatic condition and mixture fraction is calculated on the basis of mole and mass fraction of element .The aim of combustion process is to reduce NOX formation and produce energy.**

I. INTRODUCTION

In the case of non premixed methane BERL combustor ,there are two ports incorporated one is for fuel and another one for swirling combustion air .It is unstaged burner, with swirl stabilization ,swirl combustor are stabilized due to presence of central circulation zone and outer circulation zone. Once the fuel and air get injected into the burner ,the burning inside the burner for energy generation is due to, turbulent flame diffusion. The combustion mainly occur at the interface.

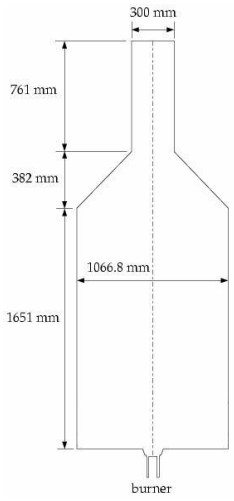
The equation used for simulation of burner is based on low mach number .The selection of model has a dependency on Mach no, as on the basis of Mach no, the selection of model is done .Pressure based solver are generally used for low mach no. and pressure field is extracted by solving pressure and pressure correction equation.

The following simulation of methane BERL combustor is done by ANSYS FLUENT SOFTWARE 15.0

Turbulent mixing plays an important role in Non premixed combustion ,as it changes density ,temperature ,heat capacity, molar mass and also the mixture transport properties .To understand the turbulent field it is necessary to have an accurate an accurate prediction of turbulent velocity field .In this paper, the basic concept of mixture fraction ,pdf are introduced on the basis of their importance.

II. PROBLEM FORMULATION

The flow considered is an unstaged natural gas flame in a 300KW swirl-stabilized burner .The furnace is a vertically-fired and of octagonal cross section with a cylindrical exhaust duct .The furnace wall are capable of being refractory lined and water cooled .The combustor dimensions are shown in figure , and the figure shows a close up of burner assuming 2-D axis symmetry**.**



Non-premixed combustion modeling

For the non-premixed combustion modelling ,the mixture fraction, f is the parameter r, and is necessary to describe the mixing process and ignition of mixer. Mixture fraction can be defined as , It tracks the mixing of fuel and oxidizer.

$$F=\frac{Z_i - Z_{i,ox}}{Z_{i,fuel} - Z_{i,ox}}$$

Z_i is the elemental mass fraction for element i

$Z_{i,ox}$ is the value at the oxidizer stream inlet

$Z_{i,fuel}$ is the value at fuel stream inlet

Mixture fraction can also be related with the excess air and fuel air equivalence ratio. The other parameter that is incorporated in non premixed modeling is the interaction of turbulence and chemistry is accounted for with a probability density function (PDF).

Large eddy simulation with PDF approach provides the turbulence-chemistry interaction .The PDF approach is used to represent the combustion process .The PDF approach directly solves a transport equation for the Favre averaged filtered PDF ,which is defined in the context of LES as,

F_L ($_\varphi$,x,t)=$\int_{-\infty}^{\infty} \rho(y,t)\xi[_\varphi,,(y,t)]$ G(y-x)dy-(1)

$\xi[_\varphi, \phi ,(y,t)] = \delta [_\varphi - \phi(y-t)]$,-(2)

δ is an N-dimensional delta function for an N-species system and $_\varphi$ is the random variable in the composition domain.

Another form of PDF expression, is in the form of density weighted. Thus PDF are considered formally as Mass-density function,N_S chemical species are considered .At low mach no. ,the mixture mass density ρ and chemical production rate s as a function species mass fraction y, enthalpy h, and reference pressure $p_0$that is at most, a function of time.The mean momentum and enthalpy equation have a form

$$\frac{\partial[<\rho>u_i]}{\partial t} + \frac{\partial[<\rho>u_{i,j}]}{\partial x_j} = -\frac{\partial<p>}{\partial x_j} + \frac{\partial[<\tau_{j,i}>+\tau_{j,i}]}{\partial x_i} \text{-(3)}$$

III. SIMULATION OF COMBUSTOR

The first step, which is prerequisite requirement for simulation is the creation of geometry and meshing.

Geometry creation- the geometry creation include the making of BERL combustor and the dimension of combustor and the dimensions are shown in problem formulation.

Meshing creation-It generally include the scaling of combustor, and it also include the all domain extent in millimeters. The x (mm) has a domain extension of 2989 and y (mm) has a domain extension of 533.4001mm.

Once, the scaling of mesh is done ,the checking of mesh ,as checking of mesh gives an idea that the quality of mesh has not been compromised.

The second step that is necessary for simulation is the solver, this step is very essential in the choice of solver.

IV. PRESSURE BASED SOLVER

these models are generally used for low-speed incompressible flow, in this the pressure field is extracted by solving a pressure or pressure correction equation which can be obtained through manipulating continuity and momentum equation. The pressure based models has a dependency on mach number and dynamic pressure which is defined as

$$Q=\frac{\gamma}{2} PM^2 \text{.....(4)}$$

Where

P= static pressure

M= Mach number

γ=Ratio of specific heat of gas at constant pressure to heat at constant volume.

V. ENERGY EQUATION

For the generation, with the help of burning energy equation is used. The energy equation used for non-premixed combustion model, when non adiabatic combustion is used, the equation is as follows-

$$\frac{\partial}{\partial t}(\rho H)+\nabla.(\rho VH) = (\nabla.\frac{k_t}{C_p}\nabla H) + S \text{……(5)}$$

Where

k_t=thermal diffusivity

ρ=density

H=Enthalpy

V=Velocity

$C_{p=}$specific heat

S=source term

In the case of incompressible flow, the kinetic energy and pressure work is often negligible and when we are using pressure based solver , then by default it do not contain any kinetic energy and pressure work term.

The radiation model include P1 , which shows the effect of scattering and the WSGGM (weighted sum of gray model)is a reasonable compromise between the oversimplified gray gas model and a complete oversimplified gray gas model and a complete model. It is represented in the form of emissivity

$$\epsilon = \sum a_{\epsilon,i}(T)\,(1-e^{-k_{ips}}) \text{…….(6)}$$

Where

ϵ = Emissivity weighting factor for I ficticious gray gas.

k_i = Absorption coefficient of i^{th} gray gas.

P = Sum of partial pressure of all absorbing gas.

S = Path length

VI. K-EPSILON MODEL

It consist of a new formulation for turbulent viscosity .K-ε model is that it more accurately predict the spreading rate of both planar and round jets. It provides the superior performance for flows involving rotation, boundary layers under strong adverse pressure gradient, separation and recirculation. Realizable k epsilon model consider combining Boussinesq hypothesis and Eddy viscosity definition.

$$-\rho u_i u_j = \mu_t\left(\frac{\partial ui}{\partial xj} + \frac{\partial uj}{\partial xj}\right) - \frac{2}{3}(\rho_k + \mu_t \frac{\partial uk}{\partial xk}$$

The main advantage of this model is that, it provides low computational costs associated with turbulent viscosity which is defined as

$\mu_t = \rho c_\mu \frac{k^2}{\varepsilon}$.....(8)

The value of turbulent viscosity can be obtained using k and epsilon value.

VII. BOUNDARY CONDITIONS

The boundary condition includes the mixture fraction value and the value of fuel in the form of mole fraction , operating pressure and temperature value.

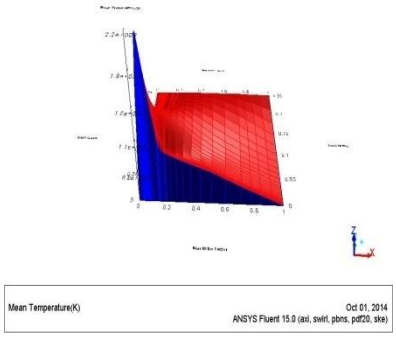
Te reaction used is

$CH_4 + 2O_2 + 3.76N_2 \rightarrow CO_2 + 2H_2O + 3.76N_2$

On the basis of rection ,the mixture fraction f is calculated is 0.062 and the mole fraction of fuel on the basis of this reaction

Species	Mole Fraction
ch4	0.965
n2	0.013
c2h6	0.017
c3h8	0.001
c4h10	0.001
co2	0.003

The next step is the generation of PDF as it relates the mixture fraction with temperature and generally incorporated in the case of non- adiabatic process



The temperature has a maximum value of 1300 k and the operating pressure has a value of 101325 pascal.

The material used for simulation of combustor is the PDF mixture having an absorption coefficient in WSGGM domain.

The following temperature and internal emissivity are kept

VIII. SOLUTION METHOD

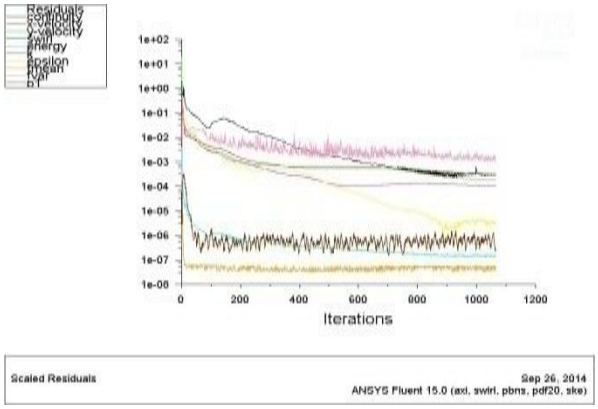
In the pressure velocity coupling simple scheme is used and the PRESTO as for volume of fluid is used the second order discretisation is used for accuracy and the parameter taken are as follows-

Under-Relaxation Factor	Value
Pressure	0.5
Density	0.8
Momentum	0.3
Turbulent Kinetic Energy	0.7
Turbulent Dissipation Rate	0.7
P1	1

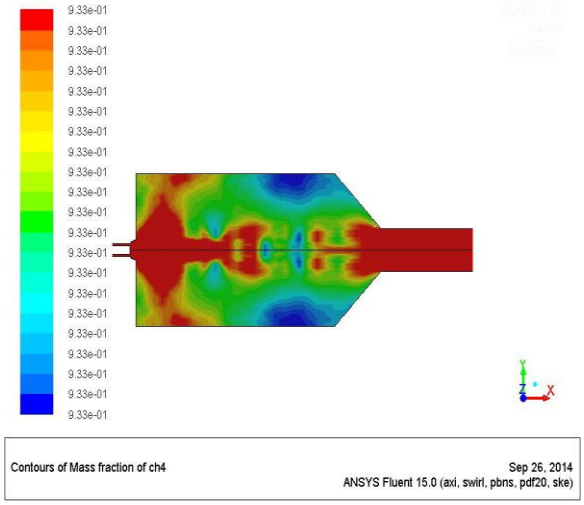
IX. RESULTS AND DISCUSSION

Convergence Criteria

In this convergence criteria the main parameter that give impact on combustion are as follows

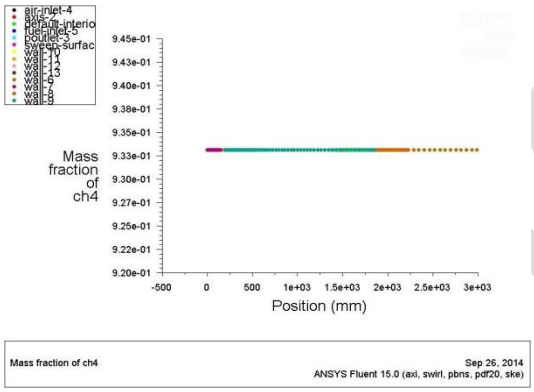


Contours of mass fraction of methane



As the methane starts burning more of the carbon get converted into carbon dioxide for the production of energy.

Mass fraction of methane burning



plot shows the variation of methane burning with respect to position

REFERENCES

[1] M.R.H. Sheikh a ,*, T.G. Drozdaa , P. Givia , F.A. Jaberib S.B. Popec Proceedings Large eddy simulation of a turbulent non premixed piloted methane jet flame (Sandia Flame D) of the Combustion Institute 30 (2005) 549–556

[2] Zimmermann,1, M. Pfitzner Combustion Modeling of Non Premixed and Partially Premixed Flames THIRD EUROPEAN COMBUSTION MEETING ECM 2007.

[3] E .Knudsen and H. pitsch Large eddy simulation for combustion system THE OPEN THERMODYNAMICS JOURNAL 2010.

[4] C.D. Pierce and P.Moin progress variable approach for large eddy simulation of non premixed turbulent combustion. J fluid Mech.(2004) vol. 504.

[5] J.E. Floyd ,H.R. Baum, and K.B. Mc Grattan ,A mixture fraction combustion model for fire simulation using cfd 2001.

[6] Chong M.Cha, Transported PDF modeling of turbulent non premixed combustion, center for turbulence research annual research briefs 2001.

[7] Kazui Fukumoto and Yoshifumi Ogami Simulation of H2-Air Non-Premixed Flame Using Combustion Simulation Technique to Reduce Chemical Mechanisms.

[8] Klimenko,A. Yu., “Multicomponent diffusion of various admixtures in turbulent flow”, Fluid Dynamics, 25, pp.327-334 (1990).

[9] Mell, W.E., Nilsen , V., Kosaly, G. and Riley, J.J., "Direct Numerical Simulation Investigation of the Conditional Moment Closure Model for Non premixed turbulent reacting flows", Combust. Sci. Technol., 91, 179-186, 1993