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COMBUSTION ANALYSIS OF HORIZONTAL BIOMASS GASIFICATION REACTOR USING ANSYS CFX

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ABSTRACT

With depletion of fossil fuels, the biomass can be used as an alternative source of energy which is efficient and aides in proper utilization of waste. The energy from biomass can be extracted using biomass gasification reactor. The recent research uses CFD to analyse the thermal performance of a horizontal biomass gasification reactor. The biomass gasification reactor CAD model is analysed using ANSYS CFX and developed in software of Creo design. The temperature, enthalpy and mass fraction are determined. The analysis is conducted using model of eddy dissipation and finite rate chemistry. Results have shown significant difference in enthalpy generation and temperature with the use of different combustion models.

Key words: Biomass, CFD, Energy, Gasification, ANSYS CFX

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1. INTRODUCTION

With gas and oil prices and the power crisis continually on the rise, the need for environmentally sustainable and cheaper costs for energy is growing. Among these types of energy resources, biomass is a choice. This oldest energy source known to mankind doesn't add carbon dioxide levels to the earth. Since most biomass grows by photosynthesis through absorption of CO_2 from the atmosphere. Just recently absorbed carbon dioxide is released as it is converted to energy. The biomass that is called renewable energy does not require millions of years to expand and can be reproduced. A broad range of biomass is also using as the raw material for

energy production like agricultural crops, animal waste, waste wood chips, & so forth. In such a way, more exciting energy source is biomass in the near term.

2. LITERATURE REVIEW

Liinanki et al [1] For the gasification of wheat straw, cotton stalk & coir dust the double conical hopper and rotating grate were introduced in the downdraft gasifier. The fuel was densified into briquettes and had a lower density and greater content of ash than wood. The gasifier's double conical hopper provided space to expand the fuel briquettes as we were heated up, preventing bridging in the pyrolysis field. Before agglomeration in the gasifier, the slag particles were fed out through a rotating grate.

Sasidharan et al. [2] It has been reportable that ceramic-lined downdraft gasifiers have a greater lifetime and a lower cost than downdraft austenitic steel gasifiers for a system of biomass gasifiers of less than 500 kw. The gasifiers formed of a steel failed in the region ofair nozzle &throat because of corrosion and high temperature oxidation mainly within 1500 hours of operation. kaolin (16-20%), Alumina (50-70%), talc (3-7 percent) and feldspar (10-15%) were compositions of ceramic material.

Warren et al. [3] Ingasifier of downdraft throated is used for the gasification of coppice willow &poplar wood chips grate spacing was reduced and grate height was increased so that it did not block with char. The fine wood chips particles block the air flow, decreasing the temperature in certain parts of the throat.

Mukunda, et al. [4] The open top gasifiers containing of an open top and an underlying vertical tubular reactor was developed. In order to avoid high temperature corrosion, the lower two-thirds of the reactors are covered with ceramic material. An annular jacket made of stainless steel is consisted by the upper part of the reactor. The producer gas had been drawn below the grate & carried to the upper reactor annulus through an insulated pipe (re-circulating duct), in which some of the gas's sensitive heat was converted to the cold wood chips within the reactor, enhancing the system's thermal performance. With aluminosilicate blankets, all of the reactor surface and the recirculating duct were insulated.

Dasappa et al. [5] The cylindrical vessel formed of mild steel, by ceramic inner linings has developed the reburn reactor of open top downdraft. The air nozzles around the combustion field were provided. By placing these nozzles at 2 various heights, a uniform air distribution along the section was founded. A dual air entry from top and the nozzles at high temperatures favored a high gas residence time which abolishing tar. The reactor top loaded fuel. A screw was driven on the basis of biomass ash content and / or a drop in reactor pressure. For ash extraction, 2 discharge outlets have been provided.

Altafini et al. [6] The open top stratified gasifier was designed to recirculate the internal gas, that could burn the gas portion that could increase the gasification’s temperature. The gasifiers contained of a rotating shaft by the grate of casting iron. In the reduction area to extract ash& to mix sawdust. Rods have been fixed to the shaft. A device like a venturi in the centre of the gasifier sucked a portion of the gas produced to be burned into a chamber. Gasification of 12 kg/h of moisture content sawdust (9-11 percent) was used for the gasification. The ratio of air/sawdust was kept above 1.5 in order to achieve 60 percent cold gas efficiency without recirculation of gases. The ratio for recirculation of the gases was lower that is 1.1-1.4.

Barrio et al. [7] During the wood pellets gasification at feeding rates of 5 kg/h the small-scale downdraft gasifier (30 kW) was used. The design of the gasifier enables the air injection point to vary along the gasifier length. A perforated plate with a manually shaken crank was used as a grate. When air from top (80 percent) and side (20 percent) of gasifier was taken in, the ratio of equivalence was lesser. When 100% air was taken from the top(traditional open core), which was 0.4-0.45.

3. OBJECTIVE

There are a many researchers have done research in this field. The uniqueness of the objective of current research is to conduct CFD analysis on biomass reactor with horizontal configuration to determine the effect of combustion model on enthalpy and temperature. Creo design software is used to develop the CAD model of the gasification reactor, and ANSYS CFX is used to perform the CFD analysis.

4. METHODOLOGY

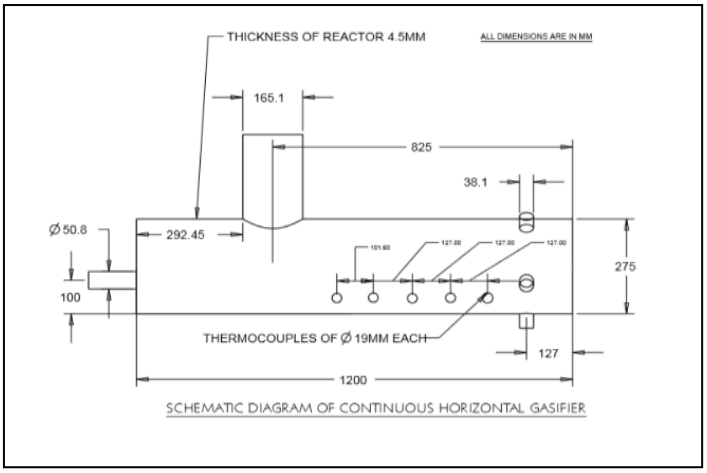

Figure 1 Schematic of Biomass gasification Reactor

Developed the CAD model in CREO and has the properties of parent child relationships& bidirectional associativity as well as a sketch dependent parametric 3d modelling software. The CAD model in. IGES format is imported in ANSYS and geometry cleanup is performed using various tools. Checked the CAD model for other geometric errors and hard edges.

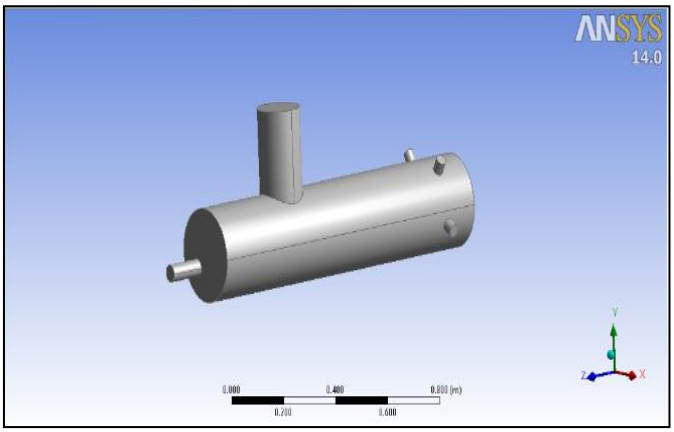

Figure 2 Imported CAD model of gasification reactor in ANSYS

The model is meshed with tetrahedral elements with relevance set to fine sizing. Inflation and growth rate set to normal. The elements of geometry near inlet pipe juncture, outlet pipe juncture and biomass inlet pipe is refined to for smooth transitions. Total number of elements is 59970 and nodes is 12022.

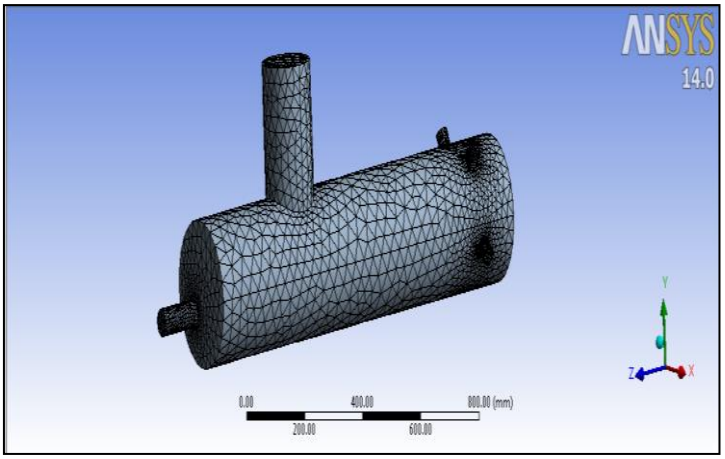

Figure 3 Meshed model of gasification reactor in ANSYS

The simulation is carried out for five different cases. In the first case simulation is carried without biomass to study air flow and other characteristics like eddy dissipation and turbulence kinetic energy. In second case simulation is carried with biomass or with initial mass fraction of biomass. In third case simulation involved chemical reaction without constant inflow of biomass. For 4th and 5th case constant inflow of biomass together with variation in initial mass fraction of biomass of 70% and 50% of total volume is considered.

5. RESULTS AND DISCUSSION

The terms of chemical source are computed by using Arrhenius expression in a model of laminar finite rate, which neglects the effect of turbulent fluctuation, because of the high-non-linear Arrhenius chemical kinetics, but is usually not accurate for turbulent flames. Furthermore, with relative slow chemistry combustion and with small turbulence-chemistry interactions, like supersonic fires, the laminar model can be acceptable. The sum of the Arrhenius reaction sources for the reaction from which the participating species is computed as a net source of chemical species following the reaction:

$$R_i = M_{w,i} \sum_{r=1}^{N_R} \hat{R}_{i,r} \tag{1}$$

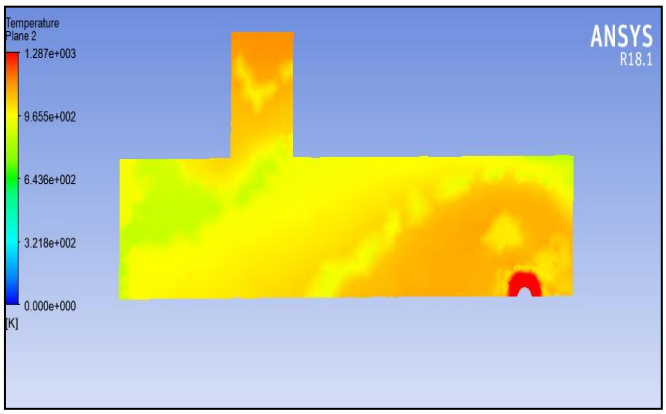

Figure 4 Temperature plot using K-epsilon turbulence model

Wherever Mw,i is really the species' molecular weight i . In reaction r, ˆ Ri, r is the species'smolar rates of Arrhenius of creation/destruction i. The reactions will occurs in the continuously phase b/wspecies of continuous-phase only, or at the surface on wall that lead in a continuous-phase species to surface evolution or deposition. The maximum temperature is obtained at zone of combustion which is near the air inlet as shown by dark red colour region. The temperature decreases on moving away from combustion zone (just above air inlet)

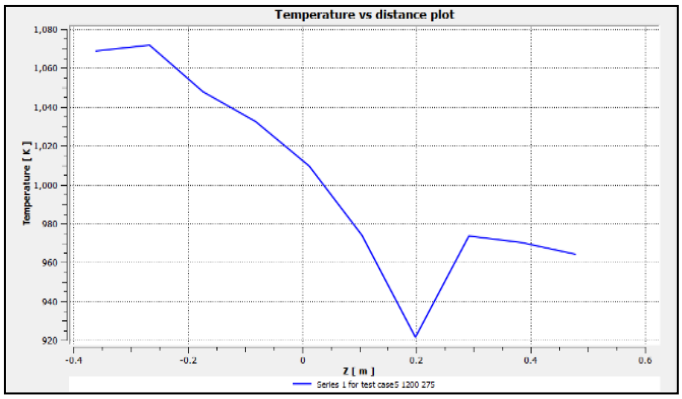

Figure 5 Temperature vs distance plot

The temperature vs distance plot is shown in figure 5 above. The temperature is maximum at combustion with magnitude of more than 1070K and it decreases gradually on moving towards outlet and reaches minimum at a distance of 0.2m from combustion zone (920K) and then increases and reaches 970K towards outlet. This gain in temperature is due to large eddy mixing scale governs the chemical reaction. As presence of turbulence accumulation in the flow initiates combustion without additional ignition source.

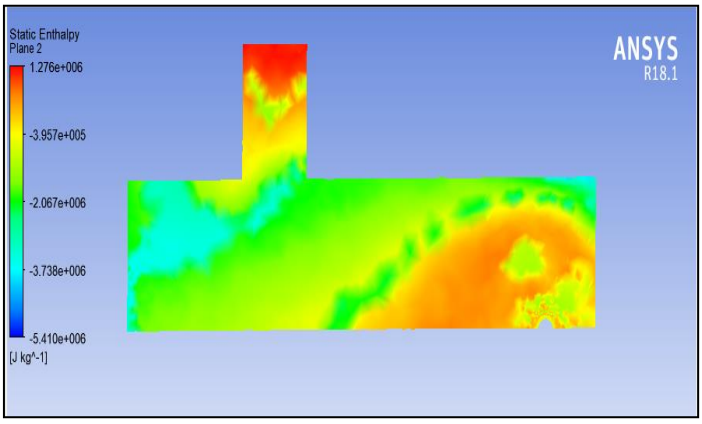

Figure 6 Static Enthalpy plot using K-epsilon turbulence model

Figure 6 shows above the static enthalpy plot (energy due to temperature and pressure). The plot exhibits higher magnitude of enthalpy near biomass inlet & near air inlet as shown by red and orange colour. The enthalpy near combustion zone is shown by green colour. The reaction modelling is done using eddy dissipation combustion model. Many fuels burn rapidly, and turbulent mixing controls the overall rate of the reaction. Turbulence conveys fuel and oxidizer to the reaction areas, which are quickly burned, slowly in unpremixed flames. When a reaction occurs rapidly, turbulences slowly transmit/mix cold reactants & hot products in precipitated flames. The combustion in these cases is also said to be limited by the mixing, and rates of chemistry kinetic in the complex & often unknown situations are safely ignored. In the following terms the smaller (i.e. limiting value) gives the net development species rates I due to reaction r, Ri, r:

$$R_{i,r} = \nu'_{i,r} M_{w,i} A \rho \frac{\epsilon}{k} \min_{\mathcal{R}} \left(\frac{Y_{\mathcal{R}}}{\nu'_{\mathcal{R},r} M_{w,\mathcal{R}}} \right) \quad (2)$$

$$R_{i,r} = \nu'_{i,r} M_{w,i} AB \rho \frac{\epsilon}{k} \frac{\sum_P Y_P}{\sum_j^N \nu''_{j,r} M_{w,j}} \quad (3)$$

A specific R-mass reaction's fraction is YP. The empirical constant is A of 4.0, B of 0.5 and the mass fraction of any product species. When the process is started

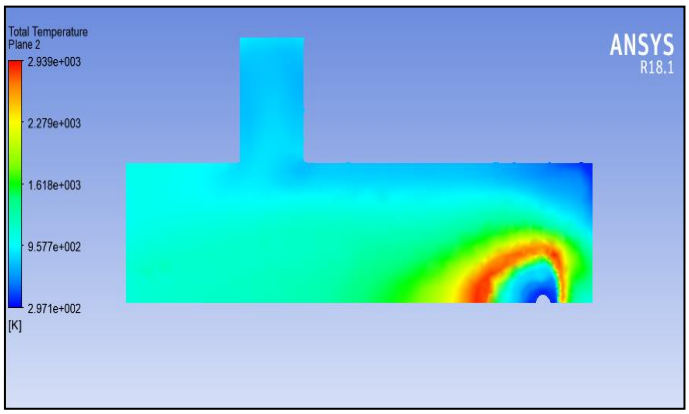

Figure 7 Temperature plot using K-epsilon turbulence model

The temperature distribution (figure 7) obtained using eddy dissipation combustion model is very different from temperature distribution plot obtained using finite rate chemistry model as shown in figure 8. The variation of temperature in reactor is very high using eddy dissipation combustion model. For eddy dissipation combustion, the temperature is maximum at combustion zone which is slightly above air inlet unlike the finite rate chemistry model. The maximum temperature at combustion zone is nearly 2800K (red color) which is much higher than finite rate chemistry. The temperature reduces on moving from combustion zone towards outlet as shown in graph 8 below.

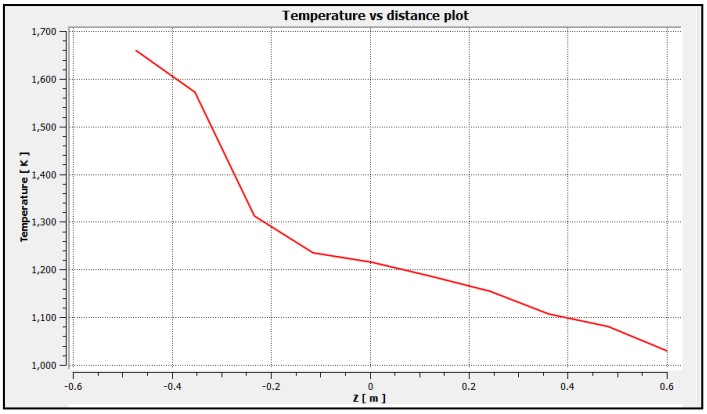

Figure 8 Temperature vs distance plot

The temperature at the region of combustion zone is 1660K which is higher than results obtained from finite rate chemistry model. The temperature reduces on moving towards exit as shown in figure 8 above. The temperature at outlet is nearly 1010K.

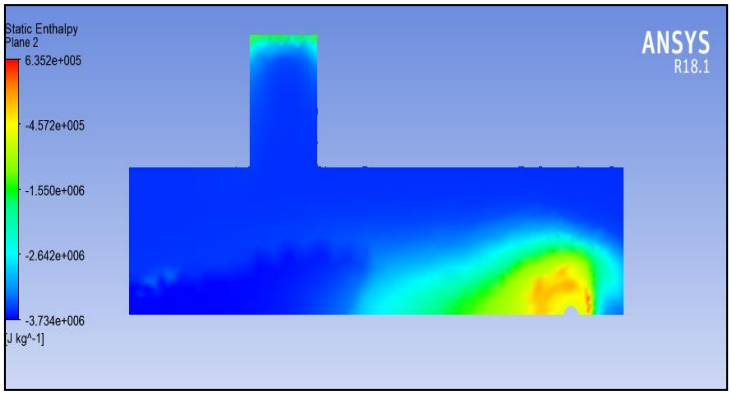

Figure 9 Static Enthalpy plot using K-epsilon turbulence model

The (positive) static enthalpy is highest near combustion zone as shown by yellow and red coloured region and minimum on outer zones of combustion. The maximum positive enthalpy is 635200 J/Kg.

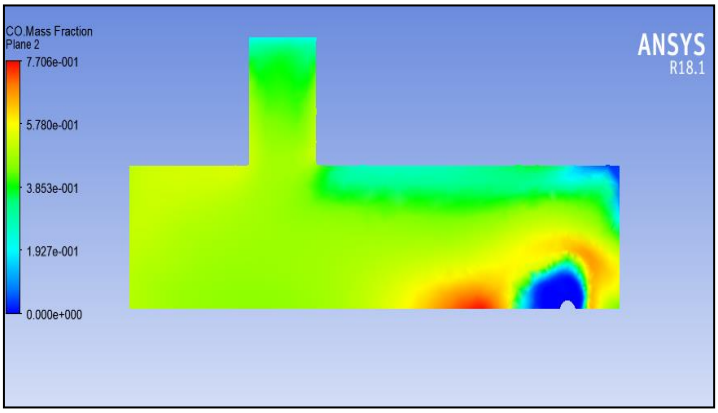

Figure 10 Mass fraction of CO

Figure 10 shows the plot of Mass Fraction of CO is shown in. The maximum magnitude of mass fraction is .77 near wall of gasification reactor and is shown by red colour while other regions have nearly .38 mass fraction.

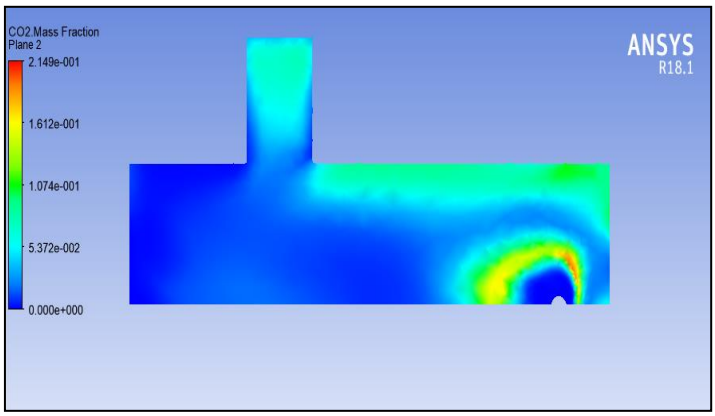

Figure 11 Mass fraction of CO_2

The plot of CO_2mass fraction is shown in figure 11. The maximum magnitude of mass fraction is .214 near wall of gasification reactor and is shown by red colour while other regions have nearly .1 mass fraction.

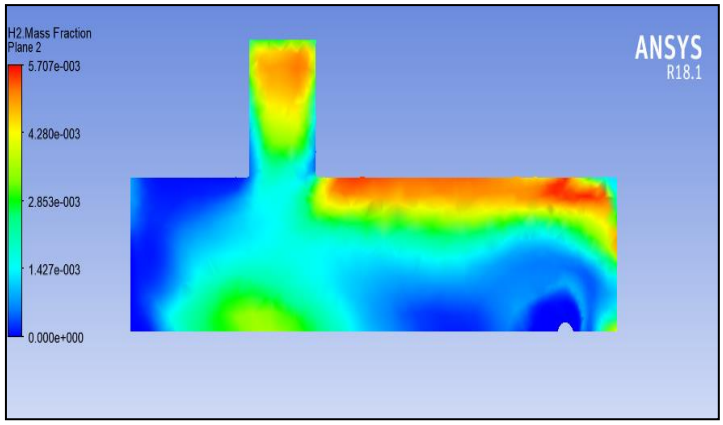

Figure 12 Mass fraction of H_2

The plot of H_2 and CH_4mass fraction is showing in figure 11& figure 12 respectively. The mass fraction of H_2 is maximum on outer top right region of reactor as shown by red colour with magnitude of .005 and other regions have lower mass fraction. The mass fraction of CH_4 is maximum at regions away from combustion zone as shown by red colour (figure 13). The maximum mass fraction obtained is .26

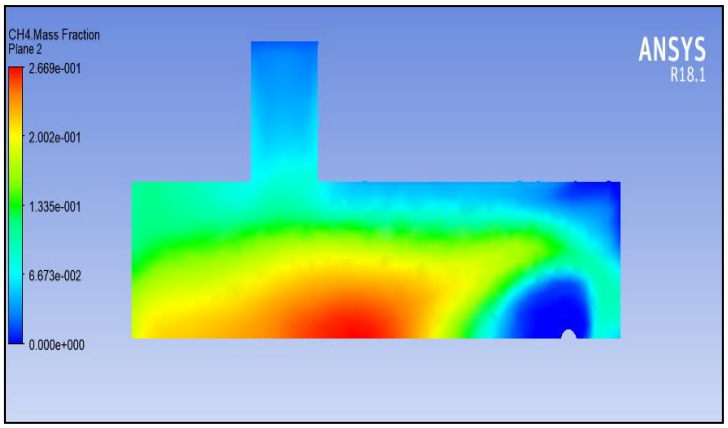

Figure 13 Mass fraction of CH_4

Table 1 Mass fraction comparison of different gases

Mass Fraction	CO	CO_2	H_2
Finite Rate Chemistry	0.48	0.61	0.33
Eddy Dissipation	0.77	0.21	0.005

The mass fraction of all the gases i.e. CO, CO_2 and H_2 are determined using both eddy dissipation &finite rate chemistry model.

Table 2 Temperature and Enthalpy values

Combustion Model	Combustion Zone Temp(K)	Outlet Temperature(K)	Static Enthalpy (J/Kg)
Finite Rate Chemistry	1287	967	1275590
Eddy dissipation model	1665	1020	635181

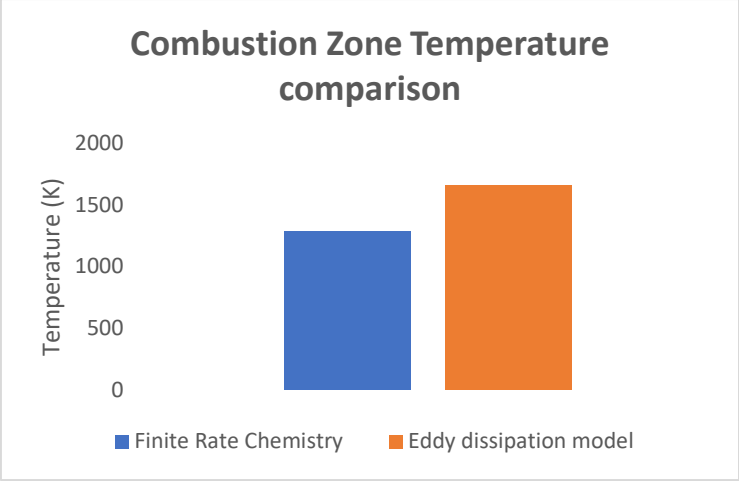

Figure 14 Combustion zone temperature comparison

Figure 14 shows the combustion zone temperature plot shows higher magnitude for eddy dissipation model as compared to the model of finite rate chemistry. The increased turbulence and higher intermixing resulted in higher zone temperature in eddy dissipation model.

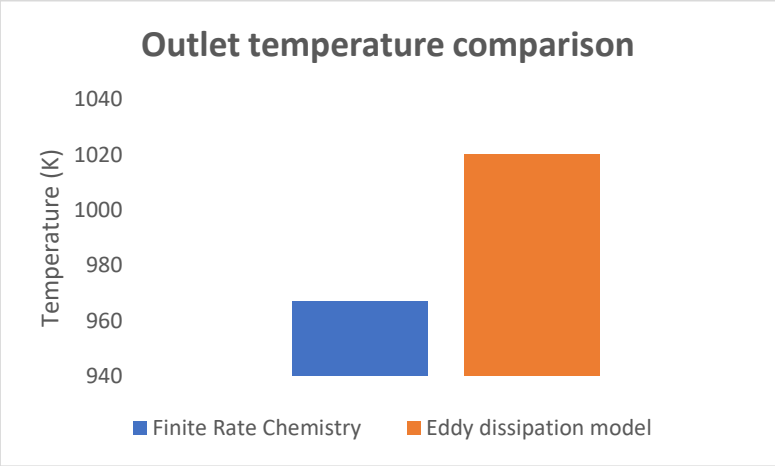

Figure 15 Outlet temperature comparison

The outlet temperatures comparison for both model of eddy dissipation combustion& finite rate chemistry is shown in figure 15 above. The plot shows the higher exit temperature using eddy dissipation combustion model as compared to finite rate chemistry model. The greater temperatures in results of combustion zone in higher outlet temperature.

5. CONCLUSION

CFD analysis of horizontal biomass gasification reactor is conducted using ANSYS CFX software. The analysis is conducted for gasification reactor without any initial biomass or any inflow. Subsequent analysis is conducted with initial biomass and with biomass inflow (without combustion). The maximum temperature in combustion zone, exit temperature and maximum static enthalpy is predicted using model of finite rate chemistry and eddy dissipation combustion. The detailed findings are as follows:

- When simulation is conducted with initial biomass content and reaction modelling the maximum temperature in combustion zone attained using finite rate chemistry model is 1287K.

- When simulation is conducted with initial biomass content and reaction modelling the maximum temperature in combustion zone attained using eddy dissipation combustion model is 1665K.
- When simulation is conducted with initial biomass content and reaction modelling the maximum enthalpy attained using finite rate chemistry model is 1275590 J/Kg.
- When simulation is conducted with initial biomass content and reaction modelling the maximum enthalpy attained using eddy dissipation combustion model is 635181 J/Kg.
- When simulation is conducted with initial biomass content and constant inflow and reaction modelling the max. outlet temperature using finite rate chemistry combustion model is 967K.
- When simulation is conducted with initial biomass content and constant inflow and reaction modelling the max. outlet temperature using eddy dissipation combustion model is 1020K.

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