CFD Analysis of Horizontal Biomass Gasifier using Different Turbulence Models

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Abstract— To lessen the dependence of energy generation using coal or fossil fuels, biomass gasification reactor could play a significant role fulfilling the increased energy demand worldwide. This research investigates the horizontal biomass gasifier using ANSYS CFX software. The CAD model of biomass gasification reactor is developed in Creo 2.0. The numerical method used for analysis is Computational Fluid Dynamics (CFD). The CFD analysis is conducted using different turbulent models namely k-epsilon, RNG k-epsilon and k-omega. The temperature plot and static enthalpy are generated from CFD simulation.

Keywords: Biomass, CFD, Turbulence Model

I. INTRODUCTION

As the price of oil and gas as well as the energy crisis are continuously increasing, there is a growing demand for the energy which is environmentally friendly and less expensive. Biomass is one of the choices among these kinds of energy resources. This oldest source of energy known to the mankind does not make any addition to the earth's carbon dioxide levels. Because most of the biomass grow through photosynthesis by absorbing carbon dioxide from the atmosphere. When it converts to energy, only recently absorbed carbon dioxide will release. Biomass can be reproduced and does not take millions of years to develop, which is considered as a renewable energy. Besides, a wide variety of biomass can be used as raw material for the production of energy such as waste wood chips, agricultural crops and animal waste etc. In this respect, biomass is one of the most promising energy sources in the immediate future. Biomass can be converted via biochemical route and thermochemical route. For thermochemical conversion, production of thermal energy is the main driver for this conversion. Biomass is converted into gases and then synthesized into the desired chemicals or used directly. Direct combustion, pyrolysis and gasification can be included as thermochemical process. Traditional combustion of biomass shows low efficiency in utilizing energy and therefore cannot compete with fossil fuels. Biomass gasification for combined heat and power (CHP) production offers much higher energy efficiency. This technology has been commercialized successfully in some countries. Biomass refers to any organic materials which come from plants or animals that is alive or recently dead. As a sustainable energy resource, botanical biomass grows through photosynthesis by absorbing carbon dioxide from the atmosphere in the presence of water and sunlight. Biological species consume botanical or other biological species to support their lives. Microorganisms break down the dead organisms into constituent parts and potential energy. The amount of carbon dioxide which releases through the combustion or the microbial decomposition of the biomass was absorbed by the biomass in the recent past. As a result, utilizing biomass as an energy resource does not increase the global CO_2 emission level. Thus, biomass is considered as green-house gas neutral.

II. LITERATURE REVIEW

Yang et al. [1] concluded that fixed bed gasification is the most common technology for the energy use of biomass and solid municipal wastes. During the biomass gasification process, this renewable material undergoes different sub-processes. In a first step, biomass is dried up. Then, as the temperature increases, biomass is pyrolyzed and the lignin and cellulose are decomposed into volatile molecules such as hydrocarbons, hydrogen, carbon monoxide and water. Finally, the remaining solid fraction, which is called vegetal char, is oxidized when an excess of oxygen is available (combustion). When combustion developed with less oxygen than the stoichiometric, vegetal char is gasified by the pyrolysis and oxidation gases. This process is governed by the chemical reduction of hydrogen, carbon dioxide and water by char. The inorganic components in the biomass are not volatilized and remain in solid state as ash. However, at present, generating energy from biomass is rather expensive due to technological limits related to lower conversion efficiency.

Zainal et al. [2] performed experimental study on a downdraft biomass gasifier using wood chips and charcoal, varied the equivalence ratio from 0.259 to 0.46. It is found that the calorific value increases with equivalence ratio and reaches a peak value of 0.388, for which the calorific value is reported to be 5.34 MJ/Nm3. It is also observed that complete conversion of carbon to gaseous fuel has not taken place even for the optimum equivalence ratio.

J. F. Perez et.al [3] has been developed a steady, one-dimensional model of the biomass gasification process, which has been validated with biomass of different size and varying the air superficial velocity. This model allows evaluating the effect of the physical, chemical and energy properties of biomass (size, density, proximate and ultimate analysis, and heating value) on the gasification process. Moreover, it enables the study of the gasifier geometry, the heat exchange and the different injection points of the gasifying agent.

Dogru et al. [4] carried out gasification studies using hazelnut shell as a biomass.Jayah et al. [5] investigated the gasification of chips of rubber wood of varying moisture content (12.5-18.5 %) and chip size (3.3–5.5 cm) in an 80 kW downdraft throated gasifier, which was double walled with an air gap in between. B.V.

Babu et al [6] varied the range of air-to-fuel ratio 1.37–1.64 Nm3/kg and that of equivalence ratio varied is 0.262–0.314 and reported that optimum operation of the gasifier is found to be between 1.44 and 1.47 Nm3/kg of air-to-fuel ratios at the values of 4.06 and 4.48 kg/h of wet feed rate, which produces the producer gas with a calorific value of about 5 MJ/m3.

III. OBJECTIVES

The objective of current research is to conduct CFD analysis of horizontal biomass gasification reactor with different turbulence models reactor using ANSYS software. The CFD analysis is conducted using different operating conditions which would be discussed one by one.

IV. METHODOLOGY

The dimensions of horizontal biomass gasification reactor are taken as shown in figure 1 below. The schematic shows the location of thermocouples at specific distances from right face of reactor. The CAD model of schematic shown below is modelled using Creo 2.0 software.

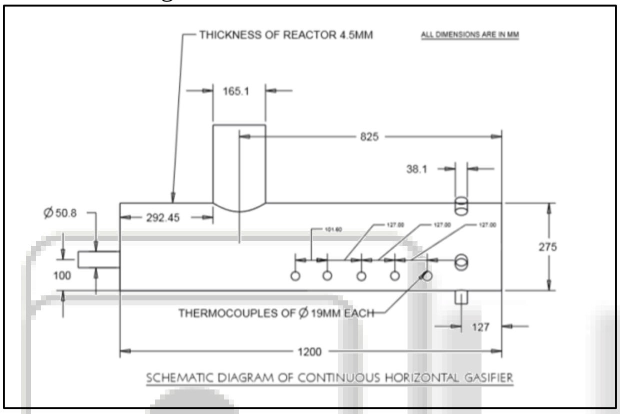

Fig. 1: Schematic of horizontal biomass gasification reactor

The CAD model is developed in CREO which is sketch based parametric 3d modelling software developed by PTC and has properties of bidirectional associativity and parent child relationship. The CAD model in .iges format is imported in ANSYS and geometry cleanup is performed using various tools. The CAD model is checked for hard edges and other geometric errors.

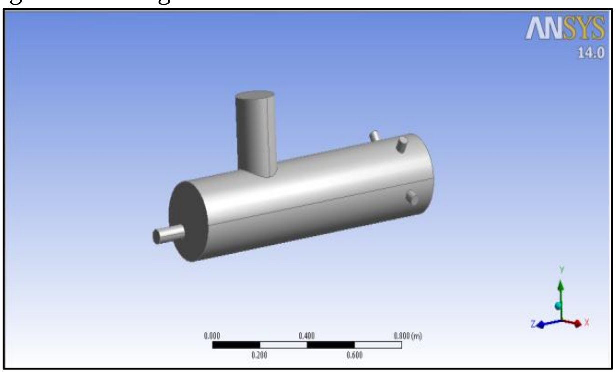

Fig. 2: Imported CAD model of gasification reactor in ANSYS

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.

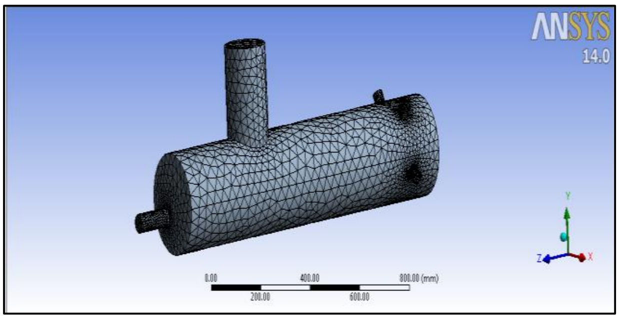

Fig. 3: Meshed model of gasification reactor in ANSYS

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.

REACTION DETAILS	REACTION RATE (MOL M^3 S^-1)
$C + O_2 = CO_2$	10E3
$C + CO_2 = 2CO$	100
$C + H_2O = CO + H_2$	10E3
$C + H_2 = CH_4$	3E-3

Table 1: Reaction rates simulated in ANSYS CFX

In the setup the domain is defined as reacting mixture and the energy model is set to thermal energy. The turbulence model for analysis is set to k epsilon along with finite rate chemistry as shown in figure 4. The air inlet of 2.5m/sec is defined at bottom portion of chamber. The air outlet is set at zero relative pressure shown in figure 5. The biomass inlet is defined with constant flow of .00172 kg/sec.

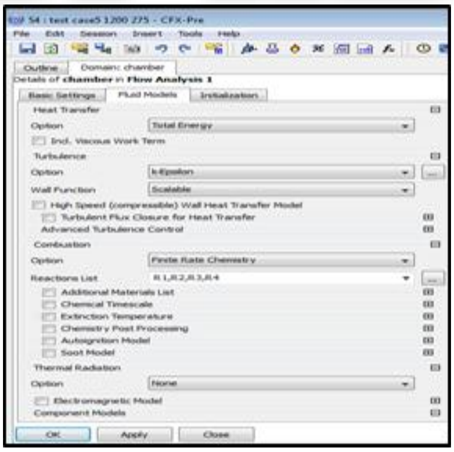

Fig. 4: Domain definition

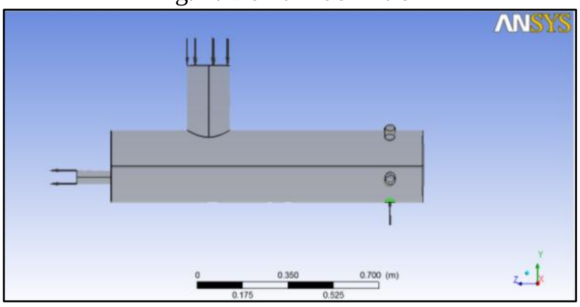

Fig. 5: Loads and Boundary Conditions

After the geometry has been made then the next step is to do the flow calculations. Calculations are performed to obtain the solution for the governing equations. CFD solver does the flow calculations and displays the results obtained. FLUENT, CFX and POLYFLOW are some of the types of solvers. Numerous iterations are performed till the solution converges and the results obtained. The first step is the setting of the under-relaxation factors which are essential for the solution convergence as wrong or improper under relaxation factors can hamper the convergence.

V. RESULTS AND DISCUSSION

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 case constant inflow of biomass with initial mass fraction of biomass is 70% of total volume is considered.

AIR INLET VELOCITY	3.5m/sec
TURBULENCE MODEL	K-EPSILON
BIO MASS INFLOW	.00172 Kg/s
CO_2 MASS FRACTION	.2
H_2 MASS FRACTION	0
H_2O MASS FRACTION	.2
O_2 MASS FRACTION	AUTOMATIC
CH_4 MASS FRACTION	0
BIOMASS MASS FRACTION	.7

Table 2: Operating conditions using k-epsilon turbulence model

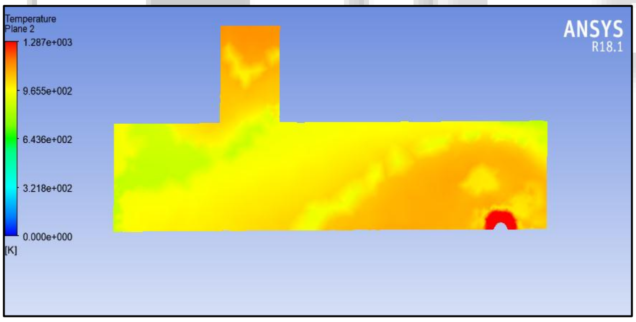

Fig. 6: Temperature plot using K-epsilon turbulence model

As can be seen from figure 6 above the maximum temperature attained is 1287K near air inlet shown by dark red color contour.

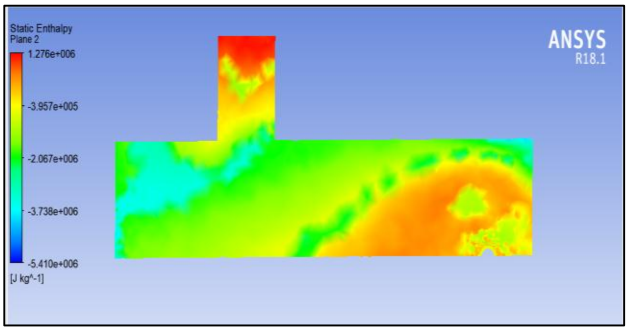

Fig. 7: Static Enthalpy plot using K-epsilon turbulence model

As can be seen from figure 6 above the maximum temperature attained is 1287K near air inlet shown by dark red color contour. Further analysis is conducted using RNG k-epsilon turbulence model under same operating conditions.

AIR INLET VELOCITY	3.5m/sec
TURBULENCE MODEL	RNG K-EPSILON
BIO MASS INFLOW	.00172 Kg/s
CO_2 MASS FRACTION	.2
H_2 MASS FRACTION	0
H_2O MASS FRACTION	.2
O_2 MASS FRACTION	AUTOMATIC
CH_4 MASS FRACTION	0
BIOMASS MASS FRACTION	.7

Table 3: Operating conditions using RNG k-epsilon turbulence model

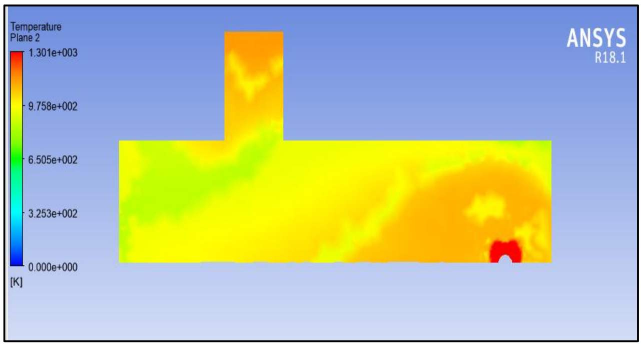

Fig. 8: Temperature plot using RNG K-epsilon turbulence model

The temperature plot using RNG K-epsilon turbulence model is shown in figure 8 above shows maximum temperature near air inlet zone as shown by dark red color contour with magnitude of 1301K.

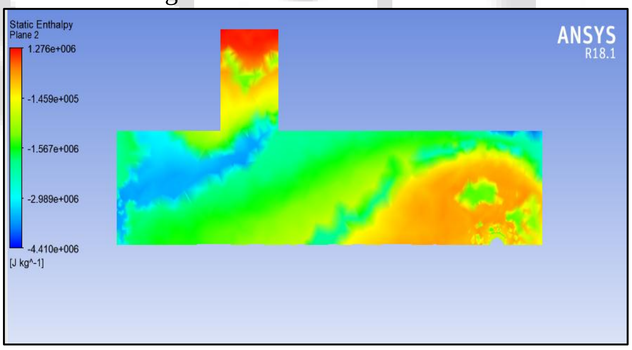

Fig. 9: Static Enthaply plot using RNG K-epsilon turbulence model

The static enthalpy plot using RNG K-epsilon turbulence model shown in figure 9 above shows maximum magnitude near biomass inflow zone with magnitude of 1276000J/Kg.

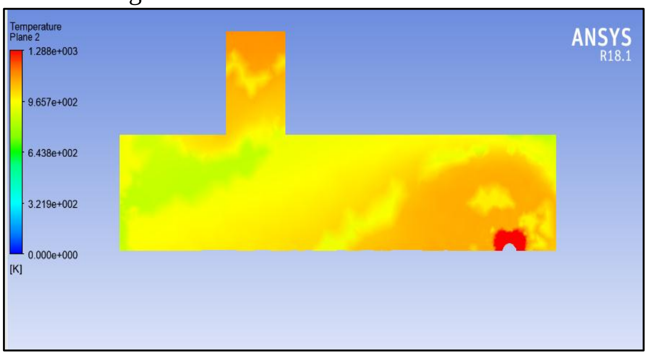

Fig. 10: Temperature plot using k-omega turbulence model

The temperature plot using k-omega turbulence model is shown in figure 10 above which shows maximum temperature near air inlet with magnitude of 1288K.

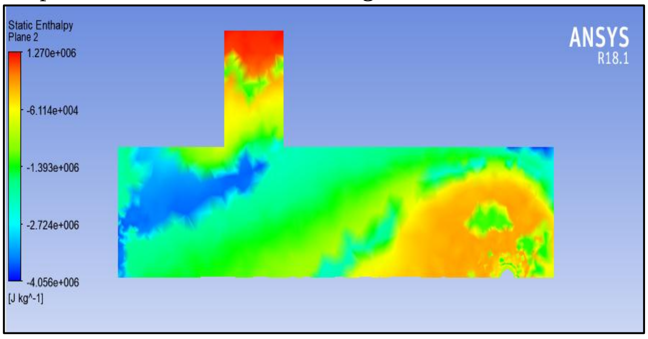

Fig. 11: Static Enthalpy plot using k-omega turbulence model

The static enthalpy plot using K-omega turbulence model shown in figure 9 above shows maximum magnitude near biomass inflow zone with magnitude of 1270000J/Kg.

VI. CONCLUSION

CFD analysis of horizontal biomass gasification reactor is conducted using ANSYS CFX software. The analysis is conducted using 3 different turbulence models namely k-epsilon, RNG k-epsilon and k-omega. The detailed findings are:

1) In the third case of analysis when simulation is conducted with initial biomass content and reaction modelling the maximum temperature attained is 1171K using k-epsilon, 1221 K using RNG k-epsilon and 1307K using k-omega turbulence model.
2) In the third case of analysis when simulation is conducted with initial biomass content and reaction modelling the maximum enthalpy attained is 55880 J/kg using k-epsilon, 54570J/kg using RNG k-epsilon, 54750 using k-omega turbulence model.
3) In the fourth case of analysis when simulation is conducted with initial biomass content and constant inflow and reaction modeling the maximum temperature is 1287 K using k-ϵ, 1301 K using RNG k-ϵ, 1288 K using k-ω turbulence model.
4) In the fourth case of analysis when simulation is conducted with initial biomass content and constant inflow and reaction modeling the maximum enthalpy attained is 1276 KJ/kg using k-ϵ, 1276 KJ/kg using RNG k-ϵ, 1270 KJ/kg using k-ω turbulence model.

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