International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 1, Jan-Feb-2024, ISSN (Online): 2395-566X

CFD Analysis of Horizontal Biomass Gasification Reactor

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Abstract- 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. The modern world and the structure of our society are inextricably related to energy production. In the present scenario, the global population has become highly dependent on the production of energy through the industrial burning of fossil fuels. The scarcity of fossil fuels has led to the use of alternative energy sources like solar, wind, hydropower, geothermal, and biomass for sustainable development. In this study, the Performance of a horizontal agitator gasification reactor was investigated. Computational Fluid Dynamics (CFD) simulation of horizontal biomass gasification process has been carried out. The gas-solid interaction, thermal-flow behavior, and biomass gasification process inside a horizontal gasifier were studied using the software named commercial CFD solver ANSYS CFX. The influence of gasification air velocity on the eddy viscosity on the performance of horizontal gasifiers was examined. Using ANSYS.

Index Terms- Turbulence Eddy dissipation, CFD, ANSYS, Biomass gasification

I. INTRODUCTION

Biomass can undergo conversion through biochemical and thermochemical routes. In thermochemical conversion, the primary driver is the production of thermal energy. Gases generated by biomass can be used directly or employed in the synthesis of other compounds. Thermochemical reactions include gasification, direct combustion, and pyrolysis. When compared to fossil fuels, traditional biomass combustion is less efficient because of its poor energy utilization rate. However, commercialization of biomass gasification for combined heat and power (CHP) generation has been achieved in several nations, and it offers far greater energy efficiency.

In the current global scenario, our world and societal structure are intricately linked to energy production. The increasing global population heavily relies on the industrial burning of fossil fuels for energy production.

The diminishing availability of fossil fuels necessitates a shift towards alternative energy sources such as “solar, wind, hydropower, geothermal, and biomass to ensure sustainable development. Biomass, comprising renewable organic matter like crops, wood, organic components of municipal and industrial wastes, and animal waste,” has been a historical contributor to energy production. Among the various conversion routes for biomass, thermal conversion, particularly through the gasification route, emerges as a prominent and efficient choice.

Increasing recognition of the need for energy conservation and mounting apprehensions about climate change have become prevalent. Presently, the rapid consumption of fossil fuels such as coal, oil, and natural gas poses a looming threat to their future availability. According to BP statistics [1], it is projected that natural gas reserves will be depleted in 60 years and oil reserves in 42 years. Although coal, with estimated worldwide reserves of 826x109 tons, could potentially serve as a substitute for oil and gas, it is expected to last only 120 years at the current consumption rate.

In addition to the depletion of energy reserves, the heightened concentration of carbon dioxide (CO2) in the atmosphere, stemming from the combustion of high-carbonaceous fuels like coal and oil, is contributing to global warming. Carbon dioxide molecules absorb infrared radiation from the sun, converting it into heat that is subsequently released into space. The urgent imperative to meet energy demands while minimizing environmental pollution is manifest.

Recent environmental conferences, such as the one convened in Copenhagen, Denmark [2], have underscored climate change as one of the foremost challenges of our era, advocating for significant reductions in global emissions. Numerous alternative energy sources, including biomass, solar, wind, geothermal, and tidal power, have been suggested to alleviate CO2 emissions. Nevertheless, aside from biomass, the feasibility of these sources is impeded by substantial capital investments.

Because of its comparatively low incremental CO2 emissions relative to coal and oil, biomass has long been considered as an alternative fuel source. It can be refined into compatible alternative fuels such as bio-oil through pyrolysis and synthetic gas (syngas) with gasification. Yet, pyrolysis produces char, requiring further conversion into utilizable gaseous energy.

Gasification is the controlled thermal conversion of carbonaceous fuels into syngas with a medium, be it air, oxygen, steam, or CO2. The result includes H2, CO, CO2, CH4, and also "tar," referring to reforming liquid fuels such as H2 and methane (CH4), whose chemical energy is often as substantial as half that of crude oil. Tars, which are hydrocarbons with molecular weights higher than benzene (C6H6), are released during the heating of biomass volatiles & contain considerable chemical energy.

Biomass gasification has been used in a variety of applications as internal combustion engines, gas turbines, boilers, and cooking stoves. Yet the gasification plant can also be distributed in rural areas so that it can power electrical systems and pump water effectively with feedstock from agricultural or municipal wastes. However, the presence of tar in the syngas has created numerous technological challenges, as tar-forming compounds can form deposits on many surfaces and cause obstructions. Various methods are used to reduce tar in the syngas stream, such as water scrubbers or sorbent materials. But these methods cause some energy losses from tar. Still, other tar treatment methods exist in thermal crackings and catalysts, for both of which the latter has the benefit of operating at lower temperatures compared to the intensive heating required by thermal cracking (>1200 °C) (approx. 350 oC).

II. RESEARCH METHODOLOGY

CFD model results can predict both qualitative and, in many instances, accurate quantitative information. This tool proves highly effective for designing and developing innovative ideas and technologies. In general, the movement of gases and liquids is governed by partial differential equations (PDE) that ensure the conservation of mass, momentum, and energy. This forms the basis for computational fluid dynamics (CFD) modeling, which involves dividing the simulated flow area into small cells. The ordinary differential equations of mass, momentum, and energy balances are discretized and expressed in terms of the variables at the positions located in the middle of the cells.

These equations are then iteratively solved until the solution is near laminar. In biomass thermochemical conversion applications CFD modeling techniques are being used more and more often, particularly in biomass gasification and combustion.

1. Model Description

Simulation modeling of the horizontal gasifier was conducted using ANSYS software, a parametric sketch-based tool developed by PTC for optimizing gasifier parameters [20, 21]. The CAD model for the horizontal gasifier reactor was created for two different configurations: one with a length of 1200 mm and a diameter of 275 mm (Fig. 3.1), and the other with a constant diameter of 275 mm and a length of 1400 mm (Fig. 3.2). In both cases, the gasifier material chosen for simulation was mild steel (MS) with a thickness of 5 mm (Table 3.1).

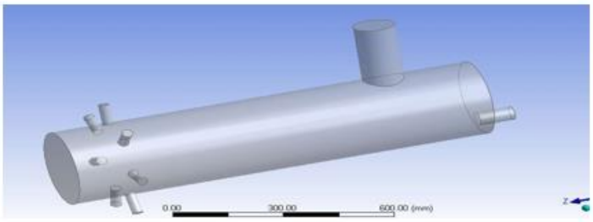


Fig.1. CFD Model (Length =1200mm)

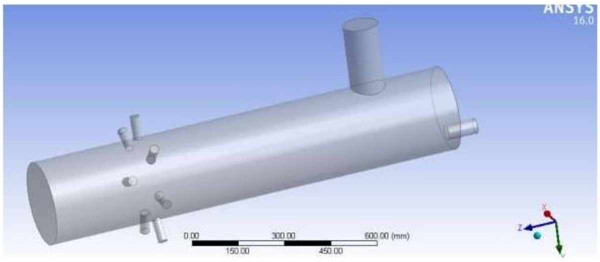


Fig. 2: CFD Model (Length =1400mm)

2. CFD Modelling

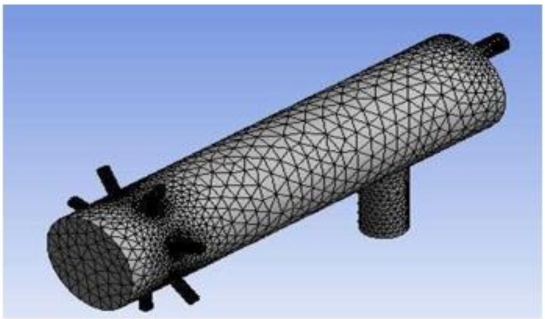
With the progress in computational hardware and the availability of numerical methods, CFD has emerged as a potent tool for forecasting fluid dynamics in diverse scenarios, facilitating precise design. CFD functions as an advanced method for examining not just the behavior of fluid flow, but also the phenomena of heat and mass transfer.

“The numerical analysis utilized in this study involves the application of the standard continuity equation to conserve mass, the Navier–Stokes equation to conserve momentum, and energy equations to predict conjugate heat transfer. The analysis is performed under the specified assumed conditions:”

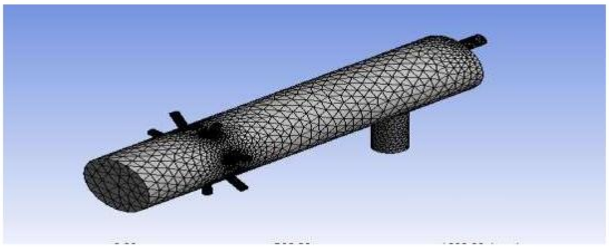
- “Steady fluid flow and heat transfer.
- Incompressible fluid.
- Laminar flow.
- Negligible radiative heat transfer.
- Constant solid and fluid flow properties.

3. Meshing of Domain

In CFD simulations based on the Finite Volume Method, the surfaces of the body/domain are discretized into smaller sub domains known as cells or elements. The governing equations used for simulation are solved within each cell/node location.



(a) Case 1(Length =1200mm)



(b) Case 2(Length =1400mm)

Fig 3: Mesh model (no. of nodes=122640, no. of elements= 104719)

4. Boundary Conditions

This study uses FLUENT 16 software, which makes use of the finite volume method (FVM) for its numeric. It employs the SIMPLE algorithm to investigate parameters such as pumping power, friction factor, and Nusselt number. The finite-element model was meshed and constructed using Ansys software.

Considering turbulent flow, appropriate boundary conditions and interfaces are defined. Air was used as the fluid in this numerical analysis, and its thermo-physical properties were calculated for 306 K, the same temperature as those of experimental investigations.

- The temperature of air entering is 300K.
- The inlet velocity is uniformly constant.
- The no slip boundary condition is given to all the surfaces.
- At the outlet of the biomass gasifier, zero pressure is used.

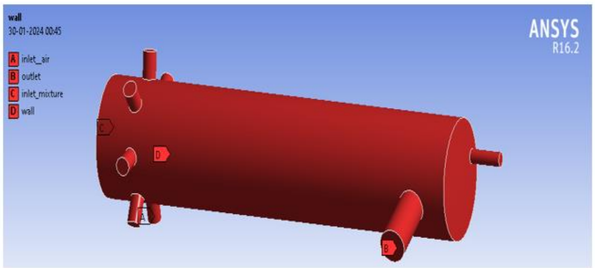


Fig. 4: Boundary condition in CFD

III. RESULTS AND DISCUSSION

1. Model-1: Simulation with Length of Gasification Reactor =1200 Mm

In the first case (length 1200 mm and dia. 275 mm), eddy viscosity (Y-axis) was plotted against turbulence kinetic energy (X-axis). The vector plot reveals that the maximum velocity is located at the air inlet, which is supplied at the bottom right portion of the reactor, with a velocity of 3.5 m/s.

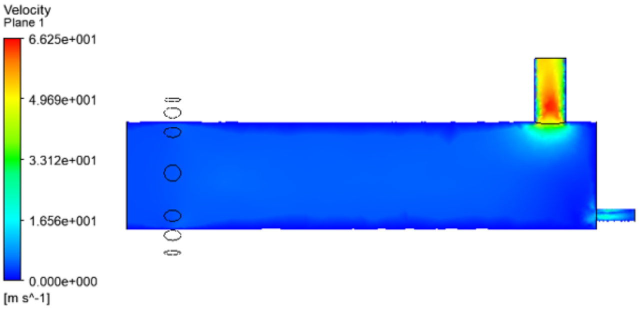


Fig. 5: Velocity plot for model 1 and case 1

Fig. 6: Pressure plot for model 1 and case 1

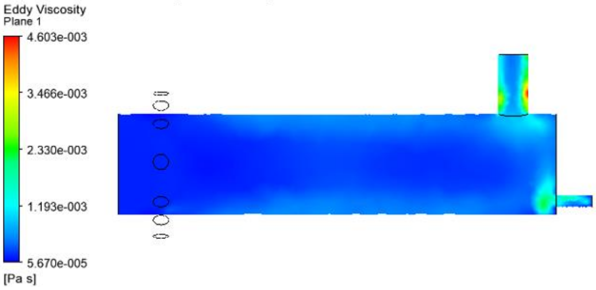


Fig. 7: Eddy viscosity plot for model 1 and case 1

2. Model-1: Simulation with Length of Gasification Reactor =1400 Mm

In the first case (length 1400 mm and dia. 275 mm), eddy viscosity (Y-axis) was plotted. The vector plot reveals that the maximum velocity is located at the air inlet, which is supplied at the bottom right portion of the reactor, with a velocity of 3.5 m/s.

Case-2

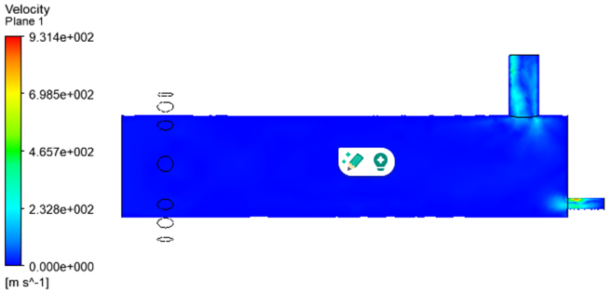


Fig. 8: Velocity plot for model 1 and case 2

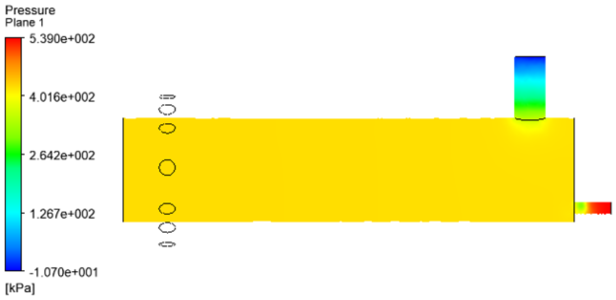


Fig. 9: Pressure plot for model 1 and case 2

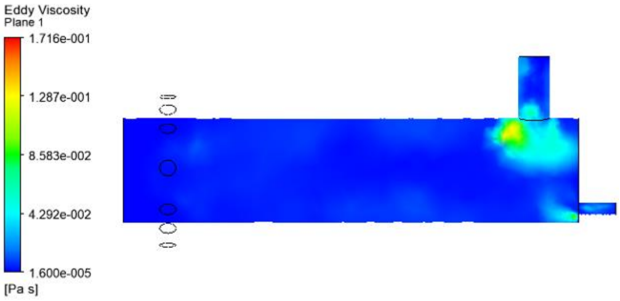


Fig. 10: Eddy viscosity plot for model 1 and case 2

The multiple regions of swirls generated show eddy formation processing turbulence kinetic energy in the reactor. Due to turbulence retention time, the generated producer gas would be more. Apart from that, it will also help to improve the quality of producer gas in the reactor. The effect of reactor dimensions on eddy viscosity is also calculated with the help of CFX tools of ANSYS (Table 5.1). A close look at the figure above clearly indicates that with the continuous reactions and influx of biomass, the eddy viscosity increases along with zones. High eddy viscosity is formed near the inlet, and concentration eddy dissipation starts diluting once we move toward the outlet of the reactor.

A critical analysis of the table clearly indicates that the velocity decreases with an increase in the length of the gasification reactor. Higher values of turbulence kinetic energy could be obtained for a smaller length of the reactor. Higher values of turbulence kinetic energy help to improve producer gas retention time in a reactor and, hence, produce clean gas due to the thermal cracking of hydrocarbons. Therefore with increase in length, velocity and eddy viscosity increases.

Table 1: Effect of reactor dimensions on velocity and eddy viscosity

Design	Reactor dimension in mm	Velocity (m/s)	TED, m^2 s^{-3}
Model 1, case 1	L=1200 D= 275	6.62	4.60×10^{-3}
Model 2, case 1	L=1400 D= 275	9.31	1.71×10^{-1}
Model 1, case 2	L=1200 D= 275	4.93	1.47×10^{-2}
Model 2, case 2	L=1400 D= 275	8.397	5.34×10^{-1}

IV. CONCLUSION

In this study, Computational Fluid Dynamics (CFD) simulations were employed to analyze the operation of a horizontal agitator gasification reactor during the biomass gasification process. The study focused on investigating gas-solid interaction, thermal-flow behavior, and the overall biomass gasification process within the horizontal gasifier using the ANSYS CFX commercial CFD solver. Additionally, the study comprehensively explored the effects of gasification air velocity, turbulence eddy dissipation, and eddy viscosity on the performance of the horizontal gasifier.

The relationship between velocity, length, and eddy viscosity in a gasifier system is complex and can depend on various factors such as the specific design of the gasifier, the type of fuel being used, and the operating conditions. However, in general terms, the velocity and length of a gasifier can influence the eddy viscosity in the following ways:

Higher Velocity: Increasing the velocity of the gas flow within the gasifier can lead to changes in the eddy viscosity. Higher velocities may enhance turbulence and mixing within the gasifier, affecting the size and intensity of eddies.

Turbulence Effects: Turbulent flow generally has higher eddy viscosity compared to laminar flow. As velocity increases, turbulence becomes more significant, influencing the eddy viscosity within the gasifier.

Longer Gasifier Length: The length of the gasifier can impact the flow patterns and turbulence within the system. In a longer gasifier, the flow may experience more opportunities for turbulence development, influencing the eddy viscosity.
Residence Time: The length of the gasifier can also affect the residence time of the gases within the system. Longer residence

times may contribute to increased turbulence and, consequently, eddy viscosity.

The interaction between velocity and length is crucial. For instance, a combination of high velocity and a longer gasifier may lead to more complex flow patterns and increased turbulence, affecting eddy viscosity. Further, our results reveal that eddy viscosity increases with an increase in velocity.

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