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Design and Analysis of Biomass Gasification Reactor

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Abstract: Biomass can be utilized as a renewable source of energy through various processes, and its theory involves understanding the principles of biomass composition, conversion technologies, and environmental implications. The objective of current research is to evaluate the thermal and fluid flow characteristics of gasification reactor using CFD tool. From the CFD tool, the temperature distribution at the combustion zone, mixing zone and exit zone are evaluated. The effect of turbulent mixing in gasification is evaluated. The application of Computational Fluid Dynamics (CFD) analysis in the study of biomass gasification reactors has proven to be a valuable tool for understanding and optimizing the complex processes involved. CFD simulations provide insights into the intricate interactions between biomass particles and gasifying agents, offering a detailed understanding of fluid flow patterns, temperature distributions, and species concentrations within the reactor.
Keywords: Biomass, CFD, Thermal Analysis

I. INTRODUCTION

Biomass gasification stands at the forefront of sustainable energy solutions, offering a transformative approach to harnessing the energy stored in organic materials. This innovative process involves converting biomass, such as agricultural residues, wood, or organic waste, into a versatile gas known as syngas, comprised mainly of hydrogen, carbon monoxide, and methane. Unlike traditional combustion methods, biomass gasification is an advanced thermochemical process conducted in a controlled environment, ensuring higher efficiency and lower environmental impact. This technology holds immense promise for addressing both energy security and environmental concerns, providing a clean and renewable energy source that can be utilized for power generation, heating, and even biofuel production. In this intricate interplay of chemistry and engineering, biomass gasification emerges as a key player in the global pursuit of sustainable energy solutions. One of the significant advantages of biomass gasification lies in its versatility, as syngas can be utilized for various applications. The syngas produced can be used directly as a clean-burning fuel in engines or turbines for electricity generation. Alternatively, it can serve as a precursor for the production of biofuels, such as synthetic diesel or aviation fuels. The ability to generate a range of valuable products from a single biomass source makes gasification an attractive and sustainable technology in the broader context of the bioenergy landscape.

II. LITERATURE REVIEW

Sadaka et al. [1] developed a fluidized bed gasifier that converts wheat chaff into gas using a steam-air mixture. The performance of the fluidized bed gasifier was influenced by factors such as the rate at which steam is discharged, the ratio of biomass to steam, and the velocity of fluidization. This effect had an impact on various aspects of the gasifier, including its temperature, pressure decrease, heating value, and syngas discharge rate. The gasification platform reached a maximum temperature of 891°C. The problem of agglomeration was successfully resolved by introducing an extra mixture of vapor and air. The highest heating values achieved were 2.47 Nm3/min for the flow rate and 10.63 MJ/Nm3 for the syngas production. The acceptable range for the decrease in bed pressure is between 37.2 and 51.6 cmH2O, ensuring a satisfactory level of fluidization quality.

Bharatha et al. [2] conducted a study on the co-gasification of Indian coal and rice husk in a foaming fluidized bed gasification reactor. Both of these materials have a considerable amount of ash. Under normal conditions, the reactor required a thermal input of 40 kW. The application of rice husk significantly improved the response properties of synthetic gas, such as calorific value, total carbon conversion, and cold gas efficiency. A significant portion of the electricity, around 50 to 75 percent, was produced using rice fiber. This resulted in carbon conversion and cold gas efficiencies of approximately 89 and 78 percent, respectively.

Yin et al. [3] conducted a study on the gasification of rice husks in a circulating fluidized bed as part of a biomass gasification process to generate electricity for a rice mill. The system is composed of a circulating fluidized bed gasifier and a gas cleaner, which includes two water scrubbers, a cyclone, a filter, an inertial separator, and a venture. The gasifier can operate reliably within a temperature range of 700°C to 850°C.

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Chen and Rei [4] conducted a study on the gasification of rice husk, exploring temperatures between 600°C and 700°C. The thermal energy required for the gasification process was provided by electric heaters. These heaters were used in a fluidized bed reactor with an internal diameter of 0.05 meters. The bed material consisted of alumina sand, while superheated steam was used as the gasification agent. The heating value experienced a significant increase from 12.8 to 18.5 MJ/m3, while the syngas production also saw a rise from 0.38 to 0.55 m3/kg. The samples of synthgas showed varying concentrations of carbon monoxide (CO), hydrogen (H2), methane (CH4), and carbon dioxide (CO2), ranging from 3.6% to 13.1%, 14.4% to 13.5%, 52.2% to 51.1%, and 23.0% to 14.6%, respectively.

Walawender et al. [5] conducted a study to examine the gasification of straw in a fluidized bed gasifier with a diameter of 0.23 m. Steam was used as the gasifying agent in this investigation.

The gasifier operated within a temperature range of 552 to 757°C. The biomass to syngas conversion rates ranged from 32% to 73% over a temperature range of 552°C to 757°C. At a temperature of 672°C, the heating value of the syngas reached its highest point at 12.3 MJ/Nm3, showing a curved relationship with temperature. The Shengli lignite's high concentration of alkali metals and its large surface area make it an ideal choice for co-gasification with thermally pre-treated wheat straw to produce hydrogen. This process is particularly effective at a temperature of 400 °C.

Singh et al. [6] conducted a comparison of the properties of syngas generated through steam gasification of cottonwood branches in a fluidized bed gasifier with that of pure cellulose. The analysis revealed that the syngas derived from cottonwood had lower mass yield, energy recovery, carbon conversion, and syngas thermal value compared to the syngas produced from pure cellulose.

Groves et al. [7] conducted a study on the gasification of waste from cotton gins. They used a gasifier with an internal diameter of 0.3 m. The gasifier operated in a fluidized bed with air at temperatures ranging from 649°C to 87°C. The heating value of syngas and energy recovery both experienced significant improvements. The former saw a remarkable increase of 53% from 27%, while the latter rose by 4.3 MJ/Nm3 from 3.4 MJ/Nm3. Non-woody biomass is easily accessible and cost-effective agricultural by products that are plentiful. One method to improve fuel quality is by combining non-woody biomass with a small amount of high-quality carbon from coal or biochar through co-gasification.

III. OBJECTIVES

The objective of current research is to evaluate the thermal and fluid flow characteristics of gasification reactor using CFD tool. From the CFD tool, the temperature distribution at the combustion zone, mixing zone and exit zone are evaluated. The effect of turbulent mixing in gasification is evaluated.

IV. METHODOLOGY

The gasification reactor is modeled initially using sketching and extrude tools available. The sketch of longitudinal section is developed and extruded. The air inlet and fuel inlet nozzles are modeled thereafter as shown in figure 1.

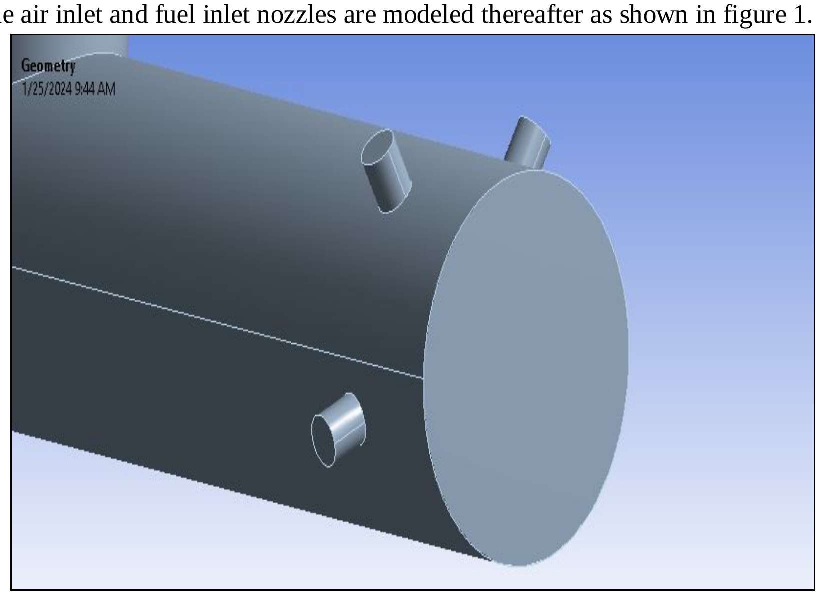

Figure 1: CAD design of biomass reactor

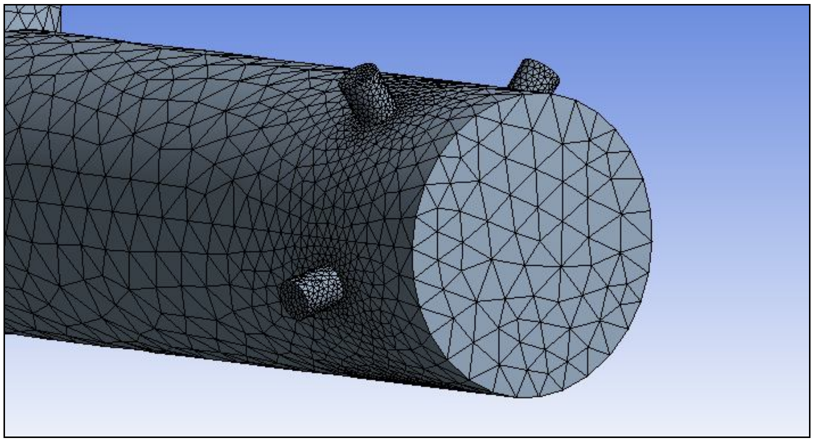

Figure 2: Meshed model of biomass reactor

After modeling, the discretization of gasification reactor is done. The discretization process involves setting up of element size and relevance setting. The element type selected for meshing is tetrahedral type. The discretized model of biomass reactor is shown in figure 2.

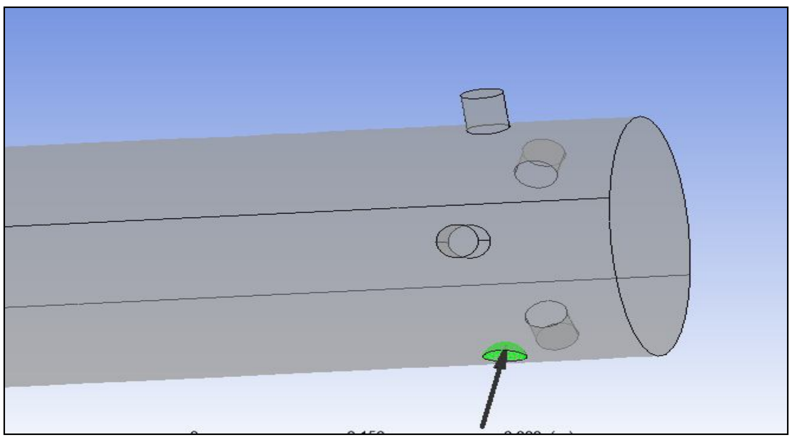

Figure 3: Fuel inlet definition

The fuel inlet definition is applied at the bottom nozzle of the reactor. The inlet definition includes hydro carbon definition, mass fraction of constituents. The domain type is set to fluid type and reference pressure is set to 1 atm.

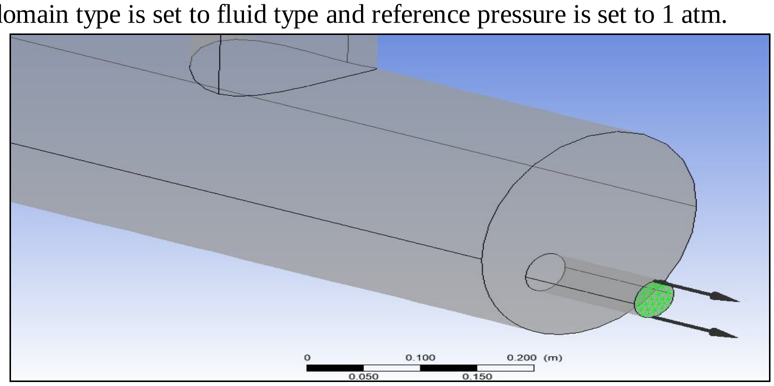

Figure 4: Outlet definition

The outlet definition includes setting of outlet boundary as shown in figure 4. The reference pressure is defined for outlet at 0 Pa. In solution stage, the solver controls are defined which includes RMS residual values, convergence criteria and double precision settings.

V. RESULTS AND DISCUSSION

From the CFD simulation, the variation of temperature and gases are determined. The temperature distribution plot is obtained from the analysis is shown in figure

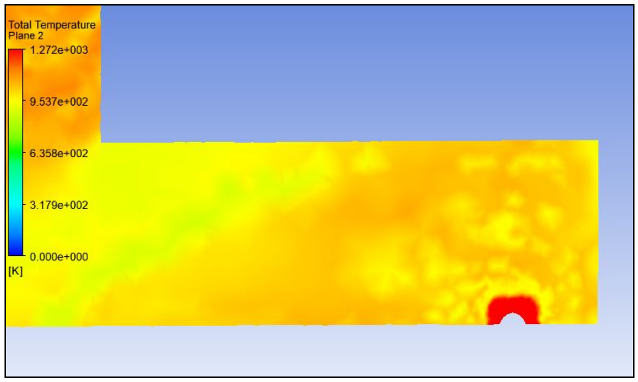

Figure 5: Temperature distribution plot

The temperature is higher near the biomass inlet zone which lies at the combustion zone as represented by red colored zone. The temperature at the outlet zones reaches 1015K.

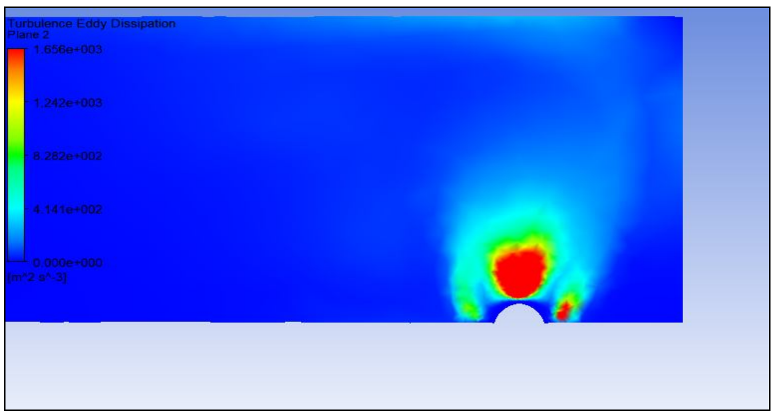

Figure 6: Turbulence eddy dissipation plot

Eddy dissipation refers to the breakup of large eddies into smaller ones, contributing to better homogeneity in temperature and composition within the reactor. This is crucial for achieving uniform gasification reactions. The turbulence eddy dissipation plot is obtained for combustion zone as shown in figure 6. The maximum turbulence eddy dissipation of 1656 m^2/s^3.

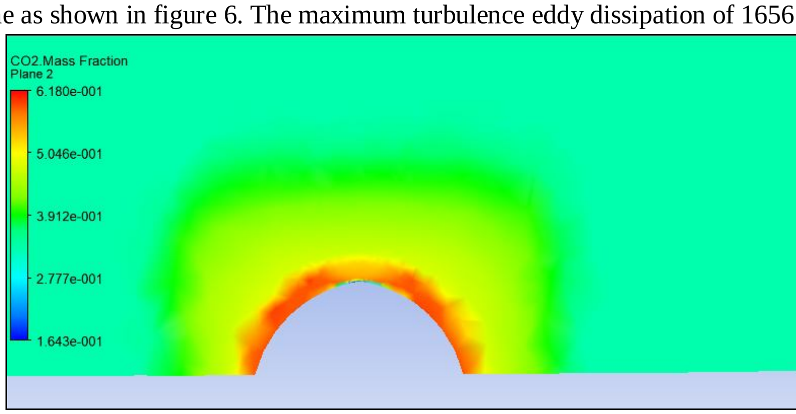

Figure 7: CO_2 mass fraction plot

The mass fraction plots are obtained for different product gases. The product gases include CO_2, H_2O and CH_4. The CO_2 mass fraction obtained is at the combustion zone which is represented by green colored zone.

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VI. CONCLUSION

The turbulence and eddy dissipation are crucial factors in biomass gasification reactors as they impact mixing, reaction rates, heat transfer, and the overall efficiency of the gasification process. Proper management of these factors contributes to the production of high-quality syngas with minimal byproducts. The application of Computational Fluid Dynamics (CFD) analysis in the study of biomass gasification reactors has proven to be a valuable tool for understanding and optimizing the complex processes involved. CFD simulations provide insights into the intricate interactions between biomass particles and gasifying agents, offering a detailed understanding of fluid flow patterns, temperature distributions, and species concentrations within the reactor.

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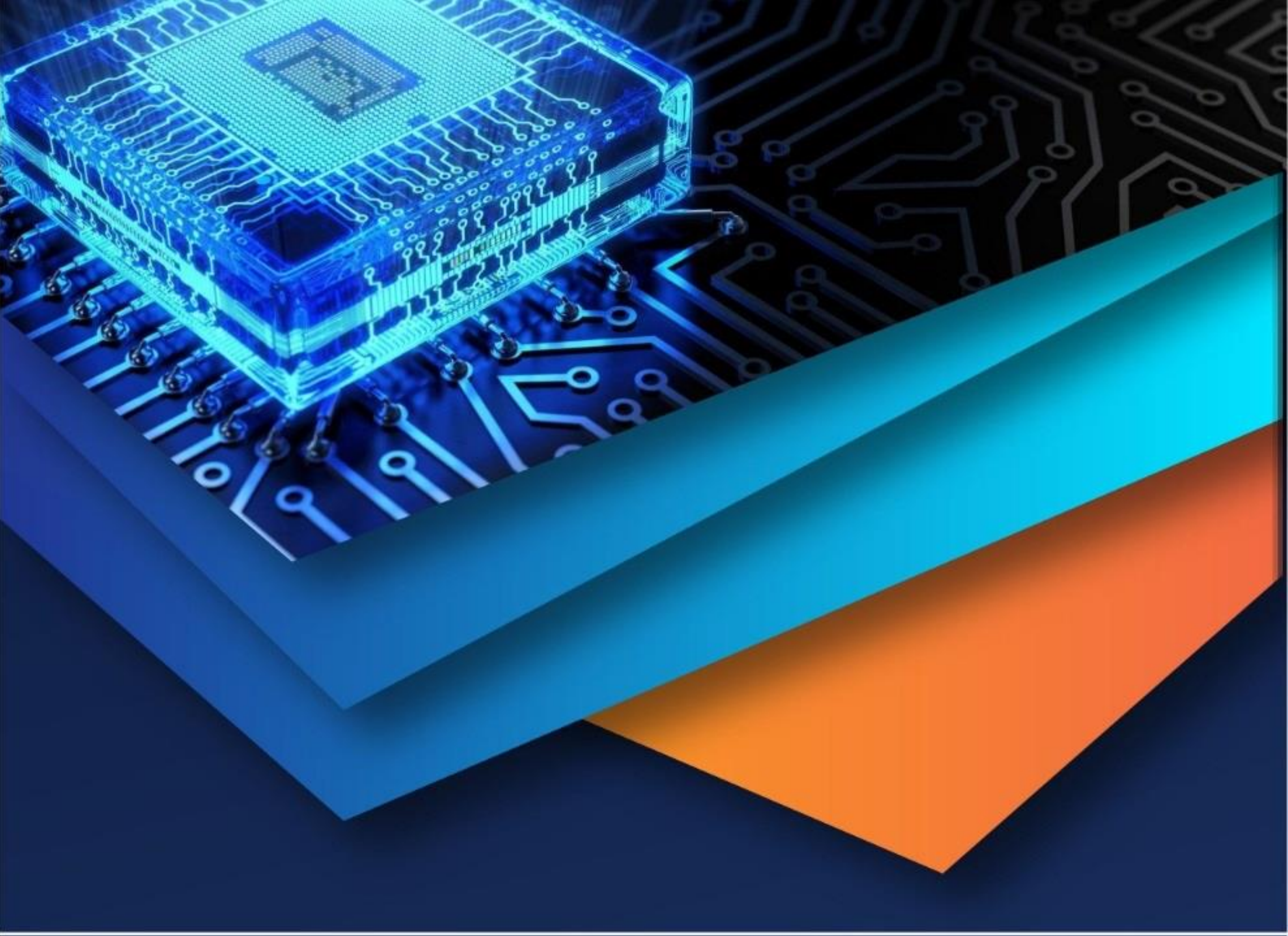

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