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ANALYSIS OF BIOMASS GASIFICATION USING ASPEN PLUS SIMULATION TOOL

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Abstract— **Biomass gasification stands as a beacon of hope in the quest for sustainable energy, offering a pathway to utilize organic matter for power generation while mitigating environmental impact. By converting biomass into a versatile syngas, this process holds immense potential in transitioning towards cleaner energy alternatives. Employing Aspen Plus, a robust process simulation tool, this study delves deep into biomass gasification, employing an equilibrium non-stoichiometric model at a precise temperature of 850°C. Through meticulous analysis, the focus lies on optimizing operational parameters to maximize both syngas production and subsequent power generation in a turbine. The findings underscore the efficacy of the approach, revealing key insights through sensitivity analysis and optimization techniques. By fine-tuning operational parameters, an optimal balance is achieved, yielding significant enhancements in syngas output and consequent power generation. These results not only serve as a practical guide for aspiring chemical engineers but also offer invaluable insights for industry professionals seeking to harness biomass resources for sustainable energy production.**

Keywords— **Low Heating Value (LHV), Integrated Gasification, Combined Cycle (IGCC), Peng – Robinson (PR), Redlich-Kwang Soave (RKS), Peng Robinson Boston Mathias (PR-BM)**

I. INTRODUCTION

In today's world, power is an essential resource for a wide range of applications, from industrial machinery to household electronics. The growing global demand for power, driven by population growth and urbanization, has largely been met by conventional methods such as coal-based thermal plants, which contribute significantly to electricity generation worldwide [1]. However, this approach comes with environmental challenges, as finite fossil fuel resources and their combustion release pollutants that contribute to climate change and air pollution.

To address these challenges, there is a pressing need to explore eco-friendly alternatives for power generation. One promising avenue is biomass-based power production, offering a renewable and biodegradable alternative to coal. Biomass, derived from sources such as agricultural waste and discarded tree parts, can be converted through processes like gasification, combustion, and pyrolysis [2]. Biomass gasification, in particular, emerges as an environmentally friendly solution, producing fewer pollutants compared to coal gasification. Syngas is the main product of gasification consisting of a mixture of H2, CO, CO2, CH4, N2, and some other light hydrocarbons [3].

The gasification process involves distinct stages such as drying, pyrolysis, combustion, cracking, and reduction [4]. Simulation of biomass gasification, a complex process influenced by factors like moisture content and composition, is crucial for optimizing its efficiency [4]. Aspen Plus, a simulation software, proves instrumental in modelling biomass gasification, employing equations of state like PR and RK. While challenges like tar formation complicate accurate modelling, focusing on non-stoichiometric equilibrium reactors in Aspen Plus allows for insightful analysis and utilization of the gasification products, paving the way for sustainable and environmentally conscious power generation [4]. Biomass, which includes organic materials such as wood, crop residues, and animal waste, possesses several properties that influence the gasification process. Moisture content, volatile matter content, ash content, and heating value are key properties that impact biomass utilization [4, 5]. For example, wood chips typically have a moisture content of 20-60%, volatile matter content of 70-90%, ash content of 0.5-2%, and heating value of 17-21 MJ/kg [5]. These properties affect the gasification process by influencing reaction kinetics and gas product composition [4].

Moisture content is a critical property that affects the overall energy efficiency of biomass. High moisture content can reduce the heating value and increase the energy required for drying prior to utilization [6]. Volatile matter content represents the combustible fraction of biomass, which can be converted into gases during gasification, contributing to the overall energy yield [7]. Ash content impacts the handling and utilization of biomass, with high ash content leading to slagging and fouling issues in gasification systems, reducing operational efficiency [8]. The heating value of biomass determines its energy content, with higher heating values indicating greater energy potential [6]. Other properties such as density, particle size, and elemental composition also play important roles in biomass gasification, affecting storage, transportation, reaction kinetics, and the chemical composition of gas products. In the Aspen Plus software, biomass gasification can be simulated using various methods such as the equilibrium method, kinetic method, and Gibbs minimization method. The equilibrium method assumes that gasification reactions reach equilibrium, while the kinetic method considers reaction kinetics [4]. The Gibbs minimization method minimizes Gibbs free energy to predict gas product composition. These simulation methods, combined with detailed knowledge of biomass properties, enable the optimization of biomass gasification processes for sustainable and efficient power generation.

By exploring biomass gasification as a viable alternative to conventional power generation methods, researchers can contribute to a more sustainable and environmentally friendly energy future. Through advanced simulation techniques and a deep understanding of biomass properties, the path towards maximizing the efficiency and effectiveness of biomass gasification for power generation becomes clearer, offering a promising solution to the challenges of meeting global energy demands while minimizing environmental impact.

Author (Year)	Title of the Paper	System Used	Finding
K Sun (2015)	Optimization of biomass gasification using woody biomass	Dual fluidized bed gasifier	Preheating feed air preferred over steam; Increased steam to biomass ratio enhances hydrogen yield but reduces LHV and gasification efficiency; Optimal temperature: 750-850°C; Optimal steam to biomass ratio: 0.4-0.6; Operational parameters vary with product gas demand.
Megwai G.U. et al. (2016)	Impact of capital cost on electricity requirement and environment	Aspen Plus	Biomass gasification with gas power systems achieves higher electrical efficiency; Internal combustion engines emit more nitrogen oxides, requiring gas cleaning; Small-scale production Favors internal combustion and Stirling engines, while steam and gas turbines suit medium to large-scale production due to higher investment costs.
Tavares R. et al. (2020)	Effect of parameters on syngas and hydrogen production	Aspen Plus	Higher temperatures Favor syngas with high hydrogen content and heating value when air is used as a gasification agent; Steam as gasification agent yields better syngas due to more water shift reactions; Optimal conditions vary based on agent and process.
Mutlu O.C. et al. (2020)	Review of simulation papers on biomass gasification	Aspen Plus, MATLAB	Equilibrium modelling prevalent with complete char conversion and no tar formation; Challenges include tar modeling and deviations from experimental data, improved with combined software use.
Pilar González-Vázquez M. et al. (2021)	Comparison of stoichiometric and non-stoichiometric models	Aspen Plus	Both models overestimate H2 production and underestimate CO; Stoichiometric model more reliable under experimental conditions; Higher oxidizing agent and temperature reduce deviation; Syngas composition affected by temperature, stoichiometric ratio, and steam to biomass ratio.
Puig-gamero M. et al. (2021)	Comparison of biomass gasification models	Bubbling fluidized reactor	All models overestimate H2 production; Deviations increase with equivalence ratio above 3.0; Tar formation favoured at low ER and temperature; Particle size affects tar concentration.
Zhu F.et al. (2022)	Simulation of an improved updraft biomass gasifier	Aspen Plus	Improved gasifier increases gas yield and reduces tar content; Volatile matter content correlates with higher gas yield and efficiency except for wood due to high carbon content; CO and H2 content dependent on biomass

			composition; Optimal air and steam ratios for highest yield and efficiency determined.
Li J. et al. (2018)	Gasification of lignocellulosic biomass for hydrogen production	Fluidized bed gasifier	Utilization of lignocellulosic biomass for hydrogen production; Higher gasification temperature enhances hydrogen yield but reduces gasification efficiency; Optimal temperature range: 800- 900°C.
Wang Y. et al. (2019)	Catalytic Steam gasification of biomass for syngas production	Catalytic steam gasification reactor	Catalytic steam gasification enhances syngas production; Higher steam to biomass ratio increases hydrogen content in syngas; Optimal conditions for maximum syngas production and quality identified.
Chen H. et al. (2020)	Integration of biomass gasification with combined heat and power	Integrated gasification combined cycle	Integration of biomass gasification with combined heat and power systems; Improved energy efficiency and reduced emissions compared to conventional systems; Optimal operational parameters for enhanced performance determined through simulation.
Singh A. et al. (2021)	Kinetic modeling of biomass gasification using Aspen Plus	Kinetic gasification model	Kinetic modeling provides detailed insights into biomass gasification; Predicts gas composition and tar formation more accurately; Crucial for designing and optimizing gasification processes; Optimal kinetic parameters determined for different biomass feedstocks.
Yang L. et al. (2023)	Co-gasification of biomass and coal for syngas production	Co-gasification reactor	Co-gasification of biomass and coal enhances syngas production; Synergistic effects observed in terms of gas yield and quality; Optimal blend ratios identified for maximum syngas production and quality.

The literature review showcases diverse approaches and findings in biomass gasification simulation. Across various studies, Aspen Plus emerges as a crucial tool for investigating optimal conditions and system designs. Preheating feed air in dual fluidized bed gasifiers is important and the steam-to-biomass ratio affects product yield and efficiency [9]. Economic implications of capital costs on different gasification systems were studied, noting the superiority of gas power systems in achieving high electrical efficiency [10]. Operational parameters affect syngas composition and gasifier performance, revealing temperature and biomass composition dependencies [11, 12]. Different reviews of biomass gasification simulations, emphasize equilibrium models prevalence and challenges [4]. A study validates simulation results with experimental values, identifying discrepancies and factors influencing tar formation [13]. A study has compared stoichiometric and non-stoichiometric models, elucidating their accuracy and reliability under different conditions [14]. Together, these studies underscore Aspen Plus's versatility in simulating biomass gasification processes and advancing understanding towards sustainable energy solutions.

II. METHODOLOGY

The process starts from decomposition of non-conventional biomass component to conventional components. The next step is gasification of the biomass followed by combustion of the biomass in presence of compressed air. The fuel produced is provided to the turbine to produce power.

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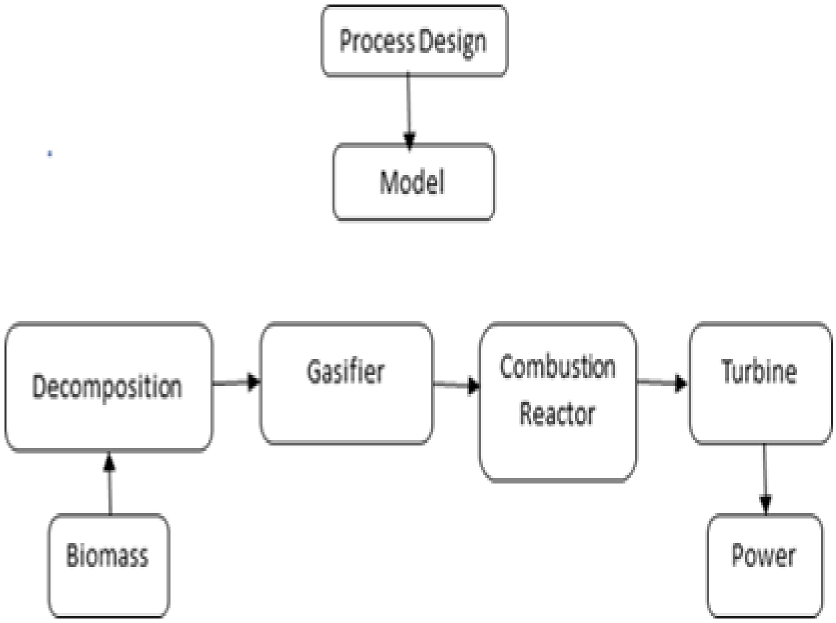

Fig. 1 Design simulation of the process

The flowchart depicts a biomass gasification and power generation system, starting with the initial stage of biomass decomposition. In this stage, various types of biomasses, such as wood chips, crop residues, or animal waste, are introduced into the system. The biomass undergoes decomposition, which involves breaking down complex organic compounds into simpler molecules through processes like drying and pyrolysis. After decomposition, the biomass enters the gasifier at the second stage of the process. The gasifier is a reactor where the biomass is converted into a combustible gas mixture known as syngas. This conversion is achieved through a thermochemical process that occurs in a low-oxygen environment, typically at elevated temperatures. The syngas contains primarily carbon monoxide (CO), hydrogen (H_2), and methane (CH_4), along with other trace gases.

Next, the syngas flows into the combustion reactor at the third stage of the process. In the combustion reactor, the syngas is combusted with air or oxygen to produce high-temperature flue gas. This combustion process releases heat energy, which can be harnessed for various applications, such as steam production or electricity generation. Finally, the high-temperature flue gas from the combustion reactor enters a turbine at the final stage of the process. The turbine is connected to a generator, where the kinetic energy of the moving gas is converted into electrical energy. The generator produces electricity, which can be used to power various devices, such as lights, appliances, or machinery.

Overall, the flowchart represents a closed-loop system where biomass is converted into syngas through gasification, which is then combusted to generate heat energy, and finally converted into electrical energy through a turbine and generator. This process offers a sustainable and environmentally friendly alternative to conventional fossil fuel-based power generation, since biomass is a renewable resource that can help reduce greenhouse gas emissions and dependence on finite fossil fuels.

In our simulation, we employed three reactors to produce syngas from 2000 kg/h of biomass, utilizing data from the proximate and ultimate analysis as per Ke Sun's paper (2015) [9]. The property method selected for simulation was PR-BM, known for its application in gas processing, petroleum, and refinery industries [15]. Initially, the RYield reactor was used to convert nonconventional biomass into conventional compounds such as C, S, O_2, H_2, Cl, etc. Subsequently, we utilized the RGibbs reactor, an equilibrium model, for gasification. While real-life operations do not achieve equilibrium, such models are valuable for identifying main components and setting yield limits [16].

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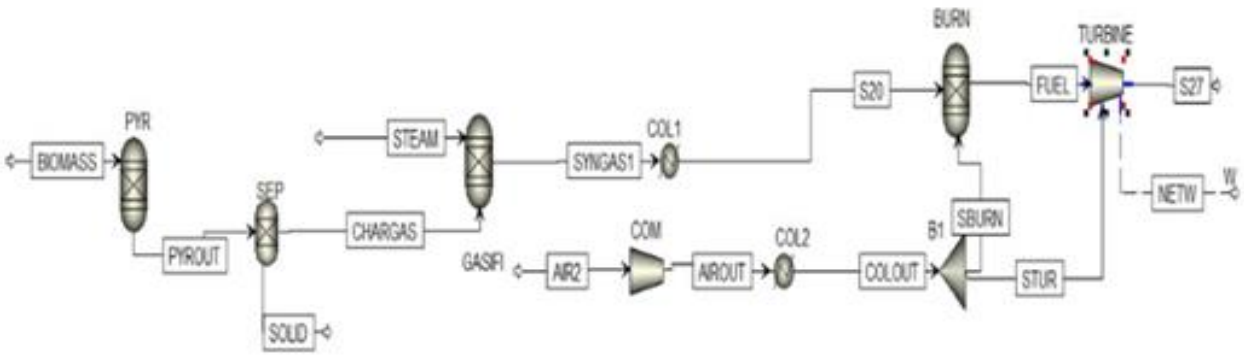

Table I
PROXIMATE ANALYSIS of BIOMASS

Element	**Value (Dry basis)**
Moisture	20
Fixed Carbon	18.84
Volatile matter	80
Ash	1.16

Table II
ULTIMATE ANALYSIS of BIOMASS

Element	**Value (Dry basis)**
Ash	1.16
Carbon	51.19
Hydrogen	6.08
Nitrogen	0.2
Chlorine	0.05
Sulphur	0.02
Oxygen	41.3

To duplicate steam and feed streams, we incorporated duplicators before sending them to the RGibbs reactor. Various power systems can convert biomass into power, including gas turbines, micro gas turbines, internal combustion engines, steam turbines, and Stirling engines [10]. Our chosen power system includes a compressor, turbine, and combustion blocks [17]. The turbine power system, consisting of a Gibbs reactor and compressor blocks, simulates a turbine to generate power. The Gibbs reactor serves as the combustion chamber, producing fuel in the presence of air. This fuel is then fed to the turbine to generate power. Both the compressor and turbine operate under isentropic conditions. In a sensitivity analysis, we assessed the mass flow rate of air at which we could achieve reduced power consumption without compromising the power generated from burning the fuel.

III. RESULT ANALYSIS & VALIDATION

Aspen Plus's sensitivity analysis feature can be a useful tool for determining how adjustments to the input parameters impact the simulation's result. In your instance, sensitivity analysis was utilized to ascertain the necessary air flow rate to the compressor in order to attain a particular turbine power output. This procedure probably involves adjusting the air flow rate parameter while maintaining the same values for the other variables, then monitoring the changes in the turbine power output.

You may improve the efficiency of your system by carrying out this sensitivity study, which will provide you with insights into the connection between the air flow rate and turbine power output. It enables you to pinpoint the crucial elements that have a big influence on the result you want and adjust them appropriately to fulfill your goals. Your system may operate more effectively and perform better overall as a result of this iterative approach.

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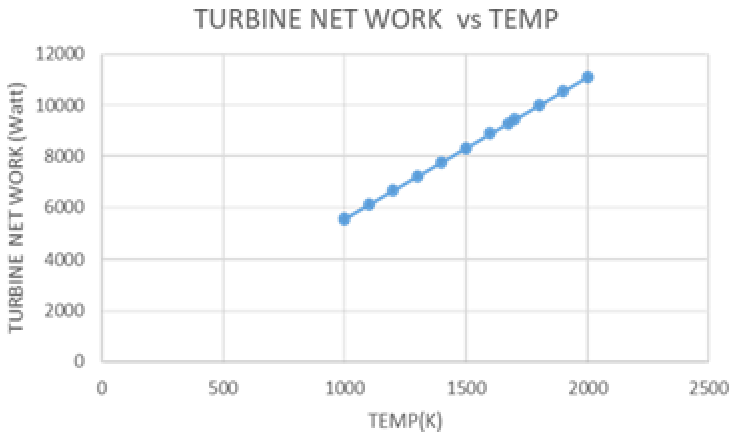
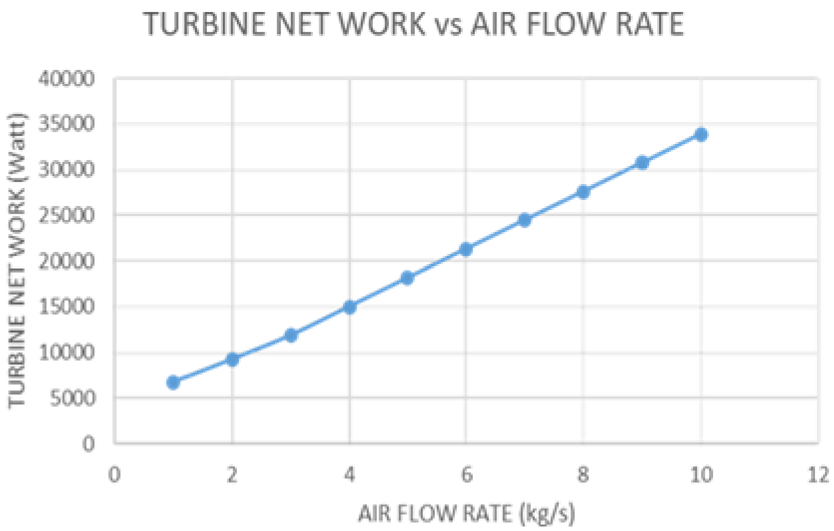


The graph depicts the relationship between temperature (in Kelvin) and turbine network (in Watts). It appears to show how the turbine network output varies with changes in temperature. As the temperature increases from 1000 K to 1700 K, the turbine network also increases steadily. This indicates that there is a positive correlation between temperature and turbine network within this range. As the temperature rises, more energy is available for the turbine to convert into work, resulting in higher power output.

Around the temperature of 1673.7952 K, there seems to be a notable increase in turbine network compared to the trend observed before this point. This could indicate a point of increased efficiency or optimized operation of the turbine within this temperature range. Beyond 1700 K, the rate of increase in turbine network appears to slow down. While the turbine network continues to increase as temperature rises further, the rate of increase becomes less steep. This suggests that there may be diminishing returns or other factors coming into play that limit the efficiency or effectiveness of the turbine at higher temperatures. Overall, the graph provides valuable insights into how temperature influences turbine performance and power output. It demonstrates the importance of understanding the relationship between operating parameters and system performance in order to optimize the design and operation of turbine systems for maximum efficiency and output.



The graph illustrates the relationship between the compressed air mass flow rate (expressed in kg/s) and the corresponding turbine network output (measured in Watts). Each data point on the graph represents a specific combination of compressed air mass flow rate and turbine network output, derived from the sensitivity analysis conducted in the Aspen Plus simulation software. As we observe the graph, there is a clear positive correlation between the compressed air mass flow rate and the turbine network output. As the mass flow rate of compressed air increases, so does the turbine network output rate. This relationship is intuitive and aligns with the fundamental principles of thermodynamics and fluid mechanics.

At lower compressed air mass flow rates, the turbine network output is relatively low. This could be due to insufficient air flow to drive the turbine efficiently, resulting in lower power generation. However, as the mass flow rate of compressed air increases, the turbine's ability to generate power improves significantly. This is because higher air flow rates provide more energy to drive the turbine, resulting in increased power output. The graph also demonstrates that the relationship between compressed air mass flow rate and turbine network output is not linear. Instead, it appears to exhibit a diminishing rate of increase as the mass flow rate increases. This phenomenon may be attributed to factors such as turbine efficiency, system constraints, or diminishing returns in power generation as the air flow rate reaches higher levels. Overall, the graph provides valuable insights into the sensitivity of turbine network output to changes in compressed air mass flow rate. It highlights the importance of optimizing air flow rates to achieve the desired power output from the turbine, thereby informing the design and operation of the system for maximum efficiency and performance.

IV.CONCLUSION

In conclusion, this paper delves into the promising realm of biomass gasification as a sustainable energy solution, particularly focusing on its simulation and optimization using Aspen Plus software. By converting biomass into syngas, this process offers a cleaner alternative to conventional power generation methods, mitigating environmental impact while harnessing renewable resources. Through meticulous analysis and sensitivity studies, the research highlights the efficacy of operational parameter optimization in maximizing syngas production and subsequent power generation in turbines. The findings underscore the significance of understanding biomass properties and gasification processes for efficient energy production. Through Aspen Plus simulations, employing equilibrium non-stoichiometric models, researchers can gain valuable insights into system behavior and performance, paving the way for sustainable energy solutions. Sensitivity analysis and optimization techniques provide practical guidance for chemical engineers and industry professionals seeking to harness biomass resources for power generation.

The literature survey showcases diverse approaches and findings in biomass gasification simulation, with Aspen Plus emerging as a crucial tool for investigating optimal conditions and system designs. From the decomposition of biomass to the combustion in turbines, the research elucidates the intricacies of the process, offering valuable insights for designing and optimizing biomass gasification systems.

In summary, this research contributes to advancing the understanding and implementation of biomass gasification for sustainable energy production. By leveraging simulation tools like Aspen Plus and optimizing operational parameters, the path towards a cleaner and more efficient energy future becomes clearer, offering practical solutions to the challenges of meeting global energy demands while minimizing environmental impact.

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