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A Comprehensive Review of Biomass Gasification Reactor Technologies

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Abstract: The biomass is abundantly available which could be used to generate producer gas using biomass gasification reactor. The objective of current research is to review the existing work in the field of biomass synthesis and its use in biomass gasification reactor. The sophisticated and cutting-edge process of biomass gasification has the potential to replace traditional fossil fuels. Despite the vast amount of knowledge available to us, it is crucial to make advancements in biomass technology. This comprehensive study provides a thorough analysis of biomass gasification, including its underlying technologies and the key factors that determine the production of valuable byproducts such as syngas, biofuels, biochar, electricity, heat, and fertilizer. Possible uses for these products involve fuel cells and power generation systems. The review also encompasses use of different types of additives, base materials and other materials in the development of biomass gasification reactor. The research findings of various scholars have shown that biomass gasification emerges as a key player in contributing to a sustainable and environmentally friendly future.
Keywords: Biomass, reactions, clean energy

I. INTRODUCTION

Alongside a notable surge in prosperity, the present period is characterized by an uptick in pollution levels and a resulting deterioration in public health. This can be largely attributed to the increasing reliance on fossil fuels for industrial and post-industrial growth. As a result, there has been a global effort to discover different methods of generating energy. Consequently, prominent organizations from different countries have been working together to establish a unified legal framework that supports the advancement of renewable energy sources.

This would greatly broaden the range of energy alternatives by replacing conventional energy providers. When considering different alternative energy sources, biomass has become an important factor in energy discussions related to policy. The European Union has shown a strong interest in biomass due to its ability to effectively incorporate environmental protection and conservation measures into development plans. Biomass has significant potential in generating biofuels for transportation, electricity, and heat generation. Additionally, it could be a valuable renewable energy resource. Efforts like the "Multi-Year Plan" of the United States Department of Energy and the "Biomass Action Plan" of the European Commission highlight the importance of bioenergy in industrialized regions from both political and economic perspectives. The importance of reducing carbon dioxide (CO2) emissions to fulfill the obligations set forth in the Kyoto Protocol is highlighted in the statement. Furthermore, it highlights the importance of sharing information about the topic of global warming, which has gained significant international attention recently, especially in relation to countries that have not yet officially approved it. Biomass is a completely renewable energy source due to its combustion and utilization processes, which do not contribute to an increase in atmospheric carbon dioxide. This is because biomass comes from biogenic sources. In simple terms, plants use the carbon dioxide (CO2) that is released into the atmosphere when other plants decompose to power their metabolic processes and support their own growth.

II. LITERATURE REVIEW

Molino et. al. [1] The study provides practical suggestions for enhancing biogas production through economic and technological methods, resulting in the production of biomethane. This biomethane can be distributed to residential areas, commercial establishments, and the power grid. On the other hand, it can be used as a propellant for vehicles powered by compressed natural gas (CNG). The main focus of this research is to examine the numerical modeling of PEEK-SEPTM hollow fiber membranes manufactured by PoroGen Corporation, an American organization that specializes in industrial separation processes. The computer simulation employed various gases as fuel for the membrane, accurately replicating the composition of biogas generated from the anaerobic digestion of organic waste. This study aims to showcase the feasibility of generating conditioned biomethane through the integration of an anaerobic digestion facility and an on-site polymeric membrane purification system.

Rajagopalan et. al. [2] A recently discovered type of bacteria has the ability to transform synthesis gas components (CO, CO2, and H2) into liquid forms such as ethanol, butanol, and acetic acid. A thorough examination was performed on the stability and productivity of the bacteria after they were separated from an agricultural lagoon. For this analysis, the bacteria were subjected to synthetic mixtures of CO, CO2, and N2 in a continuous 4.5-liter bubble column bioreactor, maintaining a temperature of 37°C. The article provides initial information on the rates of cellular proliferation, substrate consumption, and product formation, as well as cellular and product yields derived from carbon monoxide. The cell's CO production at a constant state was 0.25g/mol. The yields of ethanol, butanol, and acetic acid were clearly observed to be 0.15, 0.075, and 0.025 (mole C in products per mole CO consumed), respectively. By using carbon dioxide as the only input in the ethanol production process, it is possible to achieve a theoretical ethanol yield of 0.33. An analysis was performed to compare the actual yield of ethanol production, which was 67%, with the conversion of CO to CO2, which was approximately 60%. In a similar study on fermentation, researchers used Clostridium ljungdahlii in batch cultures to determine the yields of ethanol and acetic acid. The results showed ethanol yield to be 0.062 and acetic acid yield to be 0.094. In addition, it was found that the cell yield was 1.378g/mol. The results of this study were compared with those obtained from another bacterium that produces ethanol.

Demirbas et. al. [3] Biofuels include a variety of different types, such as biohydrogen, bioethanol, biobutanol, biodiesel, vegetable oils, biomethanol, pyrolysis oils, and biogas. Two liquid transportation fuels made from biomass have the potential to replace petrol and diesel worldwide. Bioethanol and biodiesel fall under the category of biofuels. In 2007, approximately 68 billion liters of biofuel were produced worldwide. Bioethanol is primarily produced using corn and sugarcane as raw materials. Bioethanol serves as an alternative to or substitute for petrol. Bioethanol is widely used as a biofuel for transportation worldwide. Over 60% of the global bioethanol production comes from sugarcane, while the remaining 40% is sourced from other commodities. Biodiesel is a fuel that is produced from monoalkyl ester and has similar characteristics to diesel fuel. There has been a growing fascination with the production of biodiesel from residual oil, sludge, and inedible vegetable oil. Once the necessary details such as capacity, process technology, raw material expenses, and chemical expenditures are determined, it is possible to evaluate the economic feasibility of a biodiesel facility. The primary objectives of the biofuel strategy are to promote environmental conservation, enhance overall corporate productivity, and foster employment growth.

Drift et. al. [4] The production of H2 and CO (syngas) from biomass is widely recognized as a crucial requirement for the synthesis of various second generation biofuels. Biosyngas is mainly generated through entrained flow gasification and fluidized bed gasification with the use of a catalytic reformer. A significant pre-treatment is required for the second method, which may involve torrefaction, gradual pyrolysis, low-temperature fluidized bed gasification, or flash pyrolysis. Refined and treated biosyngas enables the production of second generation biofuels such as Fischer-Tropsch fuels, methanol, DME, blended alcohols, and pure hydrogen. The study provides a detailed overview of different technological options for generating, purifying, and processing bio-syngas. Furthermore, a concise analysis of the challenges related to the size and transportation of biomass is provided.

Molino et. al. [5] This research aims to investigate the sequential process of gasifying water under supercritical conditions (SCWG), and then enhancing the resulting gaseous phase through catalytic means. This procedure involves the thermal transformation of municipal waste leachate (MWL) into synthetic natural gas (SNG). The optimized combination demonstrates superior effectiveness in converting biomass compared to traditional methods. There is an expectation that the use of supercritical water (SCW) in combination with catalysis will improve the production of syngas and increase the concentration of hydrogen. The presence of certain carboxylic acids in the initial liquid phase of biomass is a common occurrence during the decomposition process of biomass in SCWG. Based on experimental investigations, it has been shown that the SCWG technology can generate a Higher Heating Value (HHV) of 15-17 MJ/kg, depending on the discharge rate of the MWL. The concentrations of hydrogen and methane in the synthgas that was generated varied between 25% to 47% v/v and 11% to 18% v/v, respectively. Through the utilization of a nickel-based catalyst in the syngas upgrading process, the concentration of methane SNG was significantly raised to 50% v/v.

Musmarra et. al. [6] There has been a growing interest in the biomass gasification process due to the rise of renewable energy sources in recent years. Biomass is a commendable alternative to fossil fuels as a renewable energy source. The gasification process entails the transformation of an organic molecule through thermochemistry, resulting in the production of two valuable byproducts: syngas, a gaseous substance, and char, a solid material. Biomass gasification is a highly efficient technique for generating hydrogen, energy, and second-generation biofuels. This study explores the advantages and disadvantages of syngas, its potential applications, and the latest advancements in biomass gasification technology. While the authors recognize the significance of syngas cleansing in evaluating gasification processes, they argue that a separate assessment is necessary. Therefore, this study does not include an analysis of syngas cleaning.

Sikarwar et. al. [7] This study highlights the advantages of using biofuels produced through biomass gasification as a feasible alternative. This article examines the analysis of the sustainability and environmental impact of gasification-to-biofuels technology. The content covers the latest advancements in gasification techniques, key factors in biofuel production, process design and integration, and the social and environmental impacts of biofuel generation. This discussion revolves around the advancements in technology, catalysts, and reactors used in the synthesis of various biofuels. These include bio-methanol, bio-ethanol, higher alcohols, bio-dimethyl ether, Fischer Tropsch fuels, bio-methane, bio-hydrogen, and fuels derived from phytoplankton. We conduct a thorough examination of thermodynamic studies for each biofuel. The purification of syngas is a crucial step in the biofuel manufacturing process, as evidenced by the available data. Novel methodologies used in the production of methanol, such as those implemented by BioMCN in the Netherlands and Choren Industrietechnik in Germany, have shown impressive effectiveness. Our research highlights the promising use of Co or Fe catalysts for converting syngas into FT transportation fuels, such as diesel and gasoline. This presents a positive outlook for the future of biofuels. Bio-methane has emerged as a financially feasible alternative to conventional transportation fuel, providing similar advantages to natural gas, including a plentiful supply, strong trade, and established distribution networks. A thorough investigation is currently being conducted into the production of H2, with a focus on addressing significant challenges such as storage concerns and the need to improve manufacturing processes to make them more cost-effective and efficient. Algae-based fuels have proven to be commercially viable due to their adaptability, ability to sequester large amounts of CO2, and fast growth in different environments. However, it is crucial to have the right process configurations in order to create the most efficient plant designs. Due to its effectiveness, comprehensive process integration is a valuable approach for developing new processes and enhancing existing ones. In addition, the text provides a brief analysis of Life Cycle Assessment (LCA) and the ethical factors that need to be taken into account. It is evident that the use of food commodities, rather than the disposal of food refuse, is a topic that sparks debate and calls for personal reflection.

Rauch et. al. [8] There are many different approaches that can be used to create and utilize synthesis gas obtained from biomass. Through the use of reactors equipped with entrained flow or fluidized bed technology, biomass can be transformed into synthesis gas. Gasification agents such as oxygen, vapor, or mixtures are used in the process. Over the past few decades, biomass gasification has found its main application in the production of heat and/or energy. In recent times, the increasing expenses linked to fossil fuels and growing apprehensions about the environment have highlighted the importance of renewable fuels in the transportation industry. Currently, there is a growing interest in the production of hydrogen, methanol, mixed alcohols, substitute natural gas (SNG), and Fischer-Tropsch (FT) liquids from biomass. This article explores the latest and most fascinating initiatives and applications related to synthesis gas, including Choren, BioTfueL, GoBiGas, and BioLiq. Additionally showcased are the microchannel technology developed by Oxford Catalysts and the decentralized, distributed production of small quantities of substitute natural gas (SNG). In addition, the demonstration of the synthesis platform in Güssing, Austria, is taking place. The FICFB gasification facility in Güssing is involved in a range of initiatives, including the production of FT liquids, hydrogen, blended alcohols, and BioSNG. Furthermore, this article explores the theoretical foundations and practical uses of sorption-enhanced reforming, a technique that allows for the adjustment of the H2/CO ratio in the gasification byproduct gas. The conclusion offers an in-depth analysis of the thermochemical process involved in the production of transportation fuels.

Bridgwater et. al. [9] Bioenergy is widely recognized for its significant potential in the future renewable energy portfolio. There are three main ways to produce biofuels: thermal, physical, and biological conversion. Every methodology employs a distinct setup and assortment of chemical reactor. The primary objective of this study is to analyze thermal conversion processes, particularly reactors designed to create ideal conditions for maximizing efficiency. The principal and secondary products can encompass a wide variety of substances, such as gases, liquids, solid fuels, and electricity. The challenges related to the implementation aspects, both technical and non-technical, are acknowledged. Additionally, a summary of the core conversion processes and their outcomes is presented.

Asadullah et. al. [10] Gasification is a highly promising technique for transforming biomass into gaseous fuels that can be used for generating electricity in decentralized settings. Nevertheless, the practicality of biomass energy generation is impeded by various technical and operational challenges. This study aims to provide a comprehensive understanding of the challenges faced throughout the entire process, including biomass collection and electricity generation. We will be discussing the impact of different factors on supply chain management, the process of preparing and converting biomass into gas, and the subsequent purification and use of gas for power generation. Based on the latest research findings, gas purification and biomass gasification are considered to be the most challenging areas. Accurate specifications regarding the gas composition and hydrocarbon content in the produced gas are crucial for power generation, regardless of the technology used, whether it be gas turbines or engines. A significant amount of research has been dedicated to studying various methods for separating tar, both physically and catalytically.

In addition, there is a wide range of gasifier designs available, including downdraft and updraft models, that have been specifically developed to streamline the gasification process. However, the most widely used and lucrative one has yet to be developed for commercial purposes. Through the implementation of advanced gasification and gas purification techniques, it is possible to generate a highly combustible gas with lower hydrocarbon levels. This has the potential to significantly reduce the amount of biomass required to produce the required energy. New research suggests that by utilizing an enhanced gasification method and implementing efficient creosote removal, it becomes feasible to significantly decrease the required biomass quantity. As a result, this could help alleviate the challenges related to biomass pretreatment and logistics.

Ahmad et. al. [11] Biomass as an energy source has gained significant attention worldwide due to the reliable availability of feedstock. When it comes to comparing biomass fuels to fossil fuels, it's worth noting that biomass fuels have some advantages. For one, they produce less ash and release fewer contaminants into the atmosphere. Additionally, biomass fuels have significantly lower sulfur content. Biomass is a promising raw material for syngas production due to its abundant availability, making it a highly sought-after option. The generation of syngas can occur when biomass is subjected to gasification. Due to the nature of the reaction, a significant amount of energy is needed for this process. The gasifier's design and thermal efficiency are primarily constrained by the energy demands associated with the gasification process. Therefore, to achieve a sustainable utilization of these renewable natural resources, it is necessary to make significant improvements and optimizations to the current gasification process. This review article aims to showcase the performance and characteristics of different gasifiers, focusing on the influence of process variables on gas composition and final product yields. Furthermore, we will delve into the wide range of models used in simulations, strategies for optimizing gasification conditions, and approaches for economically evaluating the gasification process.

Molino et. al. [12] At a prototype facility with a rotating kiln, researchers conducted investigations to evaluate the effectiveness of steam gasification on refuse-derived fuel (RDF). To evaluate the properties of the gas, we adjusted the feeding ratio (FR) within a range of 0.4 to 2.67, while maintaining a constant temperature of 850 °C. Before evaluating the effects of enhancing the FR on the energy content and composition of the gas, extensive experimental trials were carried out to identify the best values for key operational parameters, including kiln temperature and residence times for particulates and gas. As the fuel-to-air ratio (FR) increases, the gas energy content decreases, as shown by the data. The gas energy content reaches its peak within the tested range at a FR of 0.4. The gas composition in terms of volume is as follows: methane (CH_4) accounts for 3%, hydrogen (H_2) accounts for 59.1%, carbon monoxide (CO) accounts for 16.8%, and carbon dioxide (CO_2) accounts for 20.1%.

Olalde et. al. [13] Lignin, which is abundant in biomass, can be used as a precursor for producing various valuable products, including biofuels. However, the inclusion of lignin in process modeling studies presents difficulties due to its complex chemical makeup, consisting of three distinct types of phenylpropane units - coumaryl, coniferyl, and sinapyl. Based on the findings of this study, it is recommended to consider using the guaiacol molecule instead of softwood lignin in the H_2 + CO syngas process. This is because softwood lignin is mainly made up of coniferyl units. A Gibbs reactor was used in ASPEN PLUS to combine water and guaiacol in various ratios, ranging from 0.5 to 20. The experimental parameters covered a wide temperature range from 200 to 3200 °C and a range of pressures from 0.05 to 1.01 MPa. The effluent stream was determined to contain graphite due to the presence of H_2, CO, CO_2, CH_4, O_2, and C. This text explores the different factors that influence the production of syngas, such as the water-to-guaiacol ratio, temperature, and pressure conditions. It also examines how these factors can affect the H_2/CO ratios in the syngas. From the data we have, it seems feasible to prevent the breakdown of C into water and graphite. This allows us to find the best operational parameters for maximizing syngas production.

Salam et. al. [14] The transition from an energy system dependent on fossil fuels to one that embraces sustainable and renewable energy sources is primarily driven by concerns about energy security, global warming, and climate change. Hydrogen is often regarded as a promising renewable energy option to replace fossil fuels. Through the integration of steam into biomass gasification, a solution is formed that is both sustainable and environmentally friendly, with long-lasting benefits. In addition, it offers a promising option for the efficient production of hydrogen on a large scale and meeting the growing demand for this resource. However, this approach encounters challenges related to the production of bitumen and the release of unwanted carbon dioxide. Lately, there has been a lot of attention on calcium oxide (CaO) due to its easy availability and affordable price. It has been acknowledged as a key factor in the generation of gaseous hydrogen. However, the ongoing production of hydrogen and economic factors pose challenges to the deactivation of CaO after the carbonation process. Lately, there has been growing interest in utilizing CaO-based chemical looping gasification (CLG) as a viable solution to address this issue. Moreover, the use of biomass as feedstock in CaO-based CLG is gaining popularity due to its positive impact on the environment and its energy-efficient characteristics. This study explores the process of conventional steam gasification of biomass without the use of catalysts, with the goal of generating a product gas that is rich in hydrogen.

This study aims to explore the effects of various factors on the production of hydrogen-enriched gas. These factors include biomass properties, gasifier temperature, steam-to-biomass ratio (S/B), and equivalency ratio (ER). Recent research and developments serve as the foundation for this investigation. Next, we explore the process of reducing creosote content and collecting CO2 on-site, as well as the use of CaO in the steam gasification of biomass to produce hydrogen. Biomass fuel used in CaO-based CLG is an environmentally friendly and renewable method of producing hydrogen.

Sikarwar et. al. [15] Biomass gasification is a widely used thermochemical process that greatly enhances the value and potential usefulness of the materials used as feedstock. The progress of this technology necessitates the creation of gasification techniques that are at the forefront of innovation, economically feasible, and capable of achieving maximum efficiency. An evaluation is conducted on the fundamental elements of biomass gasification, encompassing the origins of feedstock, the impact of different operational factors, the formation and breakdown of tar, and the methodologies used for modeling. In addition, the authors perform an analysis and comparison of different conventional gasification methods with newer advancements in biomass gasification. This topic focuses on the implementation of cutting-edge techniques and specialized gasifiers to propel this technology towards new applications that demand greater adaptability and effectiveness. Technological advancements and efforts to address the negative social and environmental impacts can enhance the long-term viability and financial sustainability of biomass gasification. This investigation explores different aspects of biomass gasification as a sustainable and environmentally friendly technology.

Sansaniwal et. al. [16] Biomass has proven to be a highly efficient energy carrier, capable of satisfying the growing need for a sustainable energy source that can accommodate the development of society. Biomass gasification, along with biofuel production through fermentation, shows great potential as a thermochemical process for converting biomass into gaseous fuel. This propellant has the ability to generate both heat and electricity. Nevertheless, the limited accessibility of these gaseous fuels for residential and commercial use indicates the presence of several challenges, one of which is the insufficient amount of research conducted in this area. This article discusses various challenges associated with technology, such as managing the biomass supply chain, implementing conversion technology, pretreating biomass, addressing common issues, and conditioning gas. A recent study has highlighted a number of significant challenges related to the use of combustion gas for heat and power generation, compliance with government regulations, gas treatment, and biomass conversion. Despite the wide range of gasifier reactor designs available, finding an exceptionally efficient and commercially viable design has proven to be a challenge. Thus, through the integration of an advanced gasification system and effective gas conditioning technology, the potential challenges can be significantly minimized.

Ramos et. al. [17] Biomass is widely recognized as a promising renewable energy source due to its environmentally friendly method of producing fuel and electricity, resulting in the reduction of carbon dioxide emissions. Co-gasification has shown great potential in converting residues by producing valuable byproducts, which enhances its position compared to other thermal processes. Consequently, the consequences of using up non-renewable resources are reduced and steps are taken to prevent their complete exhaustion. After conducting an extensive literature review, it was unexpectedly found that there were limited publications on the co-gasification of waste and biomass. The current study focuses on the thermal conversion process within the given context, highlighting the considerations related to the equipment, operational environment, and complex physicochemical phenomena involved. The study's main discovery focused on the interconnected relationship between the two fuel sources, indicating that co-gasification has the potential to address various challenges related to gasification. Furthermore, it enhances productivity and enhances the overall quality of the end products when compared to the individual utilization of biomass or waste. In addition, co-gasification has proven to be environmentally friendly by emitting minimal amounts of greenhouse gases. Furthermore, several patterns were discovered regarding the effects of biomass-to-waste ratios, along with the specific mechanisms that govern how they interact. The molecular reactions that occur during pyrolysis and the transfer of hydrogen from waste polymers to biomass derivatives are the main factors that drive these phenomena. Furthermore, a thorough assessment was carried out on the experimental parameters, leading to the determination that fluidized beds are the optimal reactors for handling biomass and refuse. This conclusion takes into consideration a diverse array of operational parameter combinations. We aim to enhance our understanding of this subject, its noteworthy characteristics, and its significant potential through a comprehensive discussion.

III. CONCLUSIONS

Through the use of biomass gasification reactor, the municipal waste can be effectively converted in to synthetic natural and facilitates biomass utilization. The researches have also shown that with the possible use of catalysts the effectiveness of gasification reactor can be improved significantly. The production of biosyngas along with methanol, blended alcohols is vital for development of second generation high calorific value fuels. Challenges related to biomass size and transportation are acknowledged, emphasizing the importance of effective pre-treatment methods.

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