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CO_2 Capture from Biomass Gasification Current Technologies, Challenges and Future Prospects

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Abstract: Biomass, encompassing agricultural and forestry residues, urban waste, and more, presents a renewable and abundant energy source with low pollution and zero CO_2 emissions. This paper delves into the potential of biomass gasification for CO_2 capture, emphasizing its versatility, scalability, and adaptability, especially in the context of China's dispersed biomass resource characteristics. The study also highlights the significance of drying and heating equipment in agricultural processing and the challenges posed by traditional heating methods. With China's abundant biomass energy resources, the rational utilization of biomass fuels promotes sustainable ecological development and energy structural transformation. The paper further explores various CO_2 capture technologies, including pre-combustion, oxygen-enhanced combustion, and industrial separation, and discusses the challenges associated with investment, energy consumption, and capture costs. The research underscores the need for continuous innovation and development to reduce costs and enhance the efficiency of CO_2 capture technologies.

Keywords: Biomass Gasification, CO_2 Capture, Renewable Energy, Energy Consumption, Capture Technologies.

1. Introduction

Biomass encompasses agricultural and forestry residues, urban and industrial organic waste gases, animal feces, and plants, among other sources[1]. Biomass energy possesses renewable and abundant attributes, as well as characteristics of cleanliness, low pollution, and zero CO_2 emissions, offering wide distribution and high yield. It holds advantages such as low unit mass calorific value and low energy density, presenting substantial developmental potential. Biomass gasification for CO_2 capture demonstrates versatility and scalable implementation, serving as an effective approach for context-based biomass utilization. Decentralized biomass gasification for CO_2 capture technology enjoys widespread user applicability, adaptable feedstock varieties and scales, lower financial entry barriers, and economic feasibility across different scales, rendering it more amenable to commercialization than centralized alternatives. From a perspective of biomass resource utilization, decentralized biomass gasification for CO_2 capture aligns with China's dispersed biomass resource characteristics, lending itself to distributed utilization and industrial applications, showcasing strong adaptability and viability. Therefore, the application prospects for developing biomass gasification for CO_2 capture technology in China are promising.

Drying and heating equipment stand as pivotal components within agricultural processing, playing crucial roles in tasks like nut drying and grain storage[2]. Traditional heating equipment often relies on fuels such as coal, straw, wood, diesel, and electric heating. However, each fuel type has its own drawbacks regarding combustion efficiency and quality. Coal, for instance, boasts lower costs but generates harmful gases during combustion, leading to environmental pollution and equipment damage. Diesel use escalates production costs, and seasonal supply concerns may cause shortages. Nonetheless, with recent government emphasis on the development and utilization of biomass energy, the adoption of biomass gasification for CO_2 capture furnaces to provide heat for drying equipment has addressed these challenges. This approach not only enhances heat utilization efficiency and mitigates the depletion of non-renewable resources but also holds ecological significance, aligning with the development philosophy of 'green mountains and clear waters are as valuable as mountains of gold and silver'.

As an agricultural powerhouse, China possesses abundant biomass energy resources, particularly agricultural biomass resources[3]. For instance, substantial quantities of crop straw are produced annually, alongside significant forestry residues. Thus, the rational utilization of biomass fuels not only promotes sustainable ecological development but also propels energy structural transformation and upgrading. Nonetheless, regional disparities in agricultural biomass resources necessitate an adaptive 'context-based' principle in China's approach to biomass fuel utilization. Given China's rich biomass resources, biomass is a pivotal clean and renewable energy source. The dual fluidized bed biomass gasification for CO_2 capture technology, by segregating the gasification for CO_2 capture and combustion processes, elevates the quality of product synthesis gas. The incorporation of calcium oxide in the bed material for CO2 absorption further enhances the quality of synthesis gas and creates conditions conducive to CO_2 enrichment and capture.

2. Biomass Gasification for CO_2 Capture Technology Overview

2.1. Principles of Biomass Gasification for CO_2 Capture

Biomass gasification for CO_2 capture is a process carried out under incomplete combustion conditions, utilizing oxygen from air or oxygen-containing substances as gasifying agents to convert biomass into combustible gases such as CO,

H_2, and CH_4[4]. Currently, gasification technology represents one of the most practical forms of thermochemical conversion of biomass, transforming low-grade solid biomass into high-grade combustible gases that can be employed in applications ranging from internal combustion engines, thermal engines for power generation, agricultural irrigation equipment, cooking, heating, to crop drying. Given that biomass feedstock consists of cellulose, hemicellulose, lignin, and other components with high oxygen and volatile content, and strong reactivity, it is particularly conducive to gasification. Depending on the gasification medium and the gasifier, the heating value of the produced gas may vary. When air is used as the gasifying agent, the heating value of the gas will fall within the range of 4 to 18 MJ/m³. Gasification reactions encompass processes of solid fuel drying, thermal decomposition reactions, oxidation reactions, and reduction reactions.

2.2. Processes of Biomass Gasification for CO_2 Capture

Biomass gasification for CO_2 capture encompasses various methods, depending on the gasification environment, including air gasification, oxygen-enriched gasification, steam gasification, and pyrolysis gasification. Air gasification directly employs air as the gasifying agent, resulting in high gasification efficiency. This technique is widely applied, being the simplest and most economical among all gasification methods. However, due to the presence of substantial nitrogen, which dilutes the combustible gas content, nitrogen constitutes 50% to 55% of the total volume, resulting in a relatively low heating value of the gas, typically around 5 to 6 MJ/m³. It can be directly used for gas supply, industrial boilers, and similar purposes. Oxygen-enriched gasification utilizes oxygen-rich gas as the gasifying agent. With the same equivalence ratio as air gasification, this process involves higher reaction temperatures and accelerated reaction rates, yielding medium-calorific-value gas with lower tar content. The heating value generally ranges from 10 to 18 MJ/m³, comparable to urban gas. However, the approach requires additional oxygen production equipment, leading to elevated power consumption and costs. Under specific circumstances, it can yield significant benefits by reducing overall production costs, finding utility in large-scale integrated gasification combined cycle (IGCC) systems and solid waste-to-energy applications.

Steam gasification involves the reaction of biomass with steam at high temperatures. The process entails reduction reactions involving steam and carbon, transformation reactions of CO and steam, and methaneification reactions, alongside thermal decomposition of biomass within the gasifier. The gas quality is favorable, with a high hydrogen content (30% to 60%) and heating value ranging from 10 to 16 MJ/m³. However, due to the need for steam generators and superheating equipment, external heat sources are generally required, making the system less independent and technologically complex. Most research in this area is conducted within fluidized bed reactors. In the research by Gil et al. within a pressurized bubbling fluidized bed reactor, the effects of three different gasifying agents—air, steam, and steam-oxygen mixtures—on gasification products were investigated. Steam was found to yield the highest percentage of hydrogen content when used as the gasifying medium[5].

Pyrolysis gasification, also known as dry distillation gasification, does not employ a gasifying medium. It generates fixed carbon, liquids (tar), and combustible gases, with a heating value ranging from 10 to 13 MJ/m³.

2.3. Reactor Equipment for Biomass Gasification for CO_2 Capture

Based on the differential rates and directions of combustible gas and material flow within the gasifier[6], biomass gasification for CO_2 capture can be classified into fixed bed gasification and fluidized bed gasification. In fixed bed gasifiers, gasification reactions take place within a relatively static bed layer in a furnace, exhibiting a compact structure that is easy to operate with high thermal efficiency.

2.3.1. Fixed Bed Gasifiers

Fixed bed gasifiers consist of a furnace chamber housing the raw material and a grate that supports the reaction bed layer. Two commonly applied types are down-draft gasifiers and up-draft gasifiers, illustrated in Figure 1 and Figure 2, respectively. In down-draft gasifiers, raw materials are introduced from the upper section and descend via gravity. Passing through the drying zone, moisture evaporates, and the materials enter the high-temperature pyrolysis zone, generating charcoal, cracking gases, tar, etc. Continuing their descent, they undergo oxidation-reduction reactions, converting charcoal and tar into CO, CO_2, CH_4, H_2, and other gases in the lower reduction zone. Operating temperatures in the gasifier range from 400 to 1200°C, and the generated gas is drawn from the lower reaction zone, while ash and slag are discharged from the bottom. Down-draft gasifiers exhibit stability and can crack part of the tar into permanent small-molecule gases within the high-temperature zone, enhancing gas heating value and reducing tar content in the gas at the outlet. In up-draft gasifiers, the movement direction of the raw material is opposite to that of the gas flow. Gasifying agents are introduced into the furnace through an inlet at the bottom, producing gases that flow upward, exiting through a gas outlet at the top. The outlet gas has low ash content and high gasification efficiency, but challenges like sealing and convenient feeding persist.

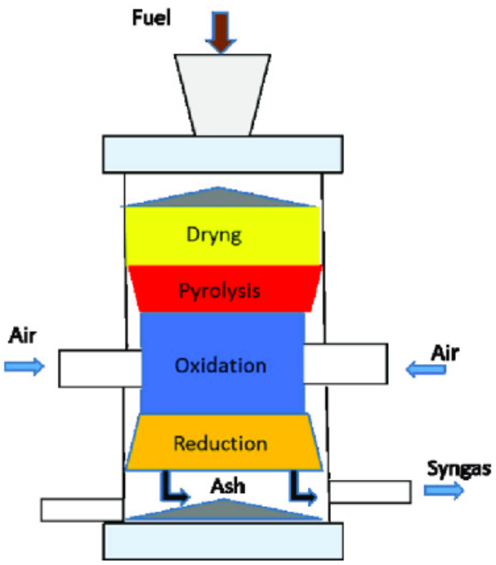

Figure 1. Structure and principle of down draft gasifier

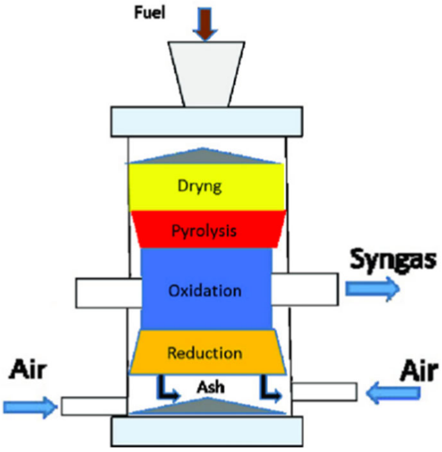

Figure 2. Structure and principle of up draft gasifier

2.3.2. Fluidized Bed Gasifiers

In fluidized bed gasifiers, under the action of introduced gasifying agents, material particles, sand, and gasification media come into full contact, resulting in uniform and thorough heating[7]. The reactor operates in a 'boiling' state, characterized by rapid gasification reaction rates and high gas production rates. In contrast to fixed bed gasifiers, fluidized bed gasifiers lack a grate. A basic fluidized bed consists of a combustion chamber and a distribution plate through which gasifying agents enter the fluidized bed reactor. Based on gasifier structure and gasification processes, fluidized beds can be categorized into bubbling fluidized beds and circulating fluidized beds, as shown in Figures 3 and 4.

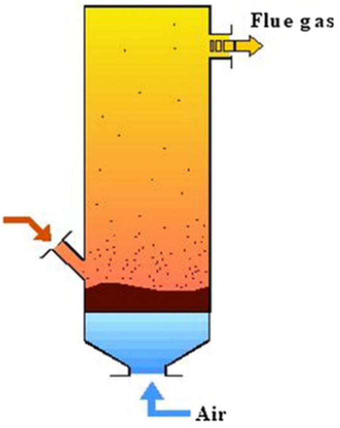

Figure 3. Principle of bubbling bed gasifier

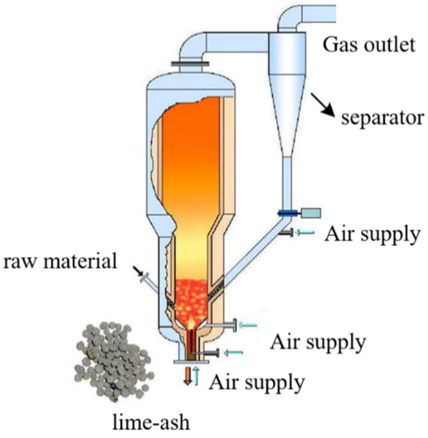

Figure 4. Principle of CFB qasifier

Bubbling fluidized bed gasifiers are the simplest form of fluidized bed reactors. The gas flow rate is relatively slow, making them suitable for coarser biomass feedstock particles that often require the addition of a heat carrier. On the other hand, circulating fluidized bed gasifiers are equipped with cyclone separators or bag filters at the gas outlet. These gasifiers have higher fluidization rates and are better suited for smaller biomass particles. Typically, no additional heat carrier is needed, making their operation simpler. They also exhibit excellent mixing characteristics and higher gas-solid reaction rates. The operating temperature of fluidized bed gasifiers is generally maintained between 700°C and 900°C.

2.3.3. Applicability of Fixed Bed and Fluidized Bed Gasifiers

Comparing fluidized bed gasification to fixed bed gasification, fluidized bed gasification exhibits more uniform temperature distribution, higher gasification intensity, and a requirement for smaller particle sizes. It is particularly suitable for small to medium-scale gasification power generation systems operating continuously with feedstocks such as wood processing residues and rice husks from rice mills. However, due to the relatively lower bed temperature in fluidized beds, the cracking of tar is suppressed, resulting in higher tar content in the produced gas. This necessitates complex purification systems for power generation. Additionally, the higher gas flow velocity within fluidized beds causes increased wear on inert heat carriers like quartz sand against the bed walls. The fine fuel particles also lead to higher carryover of particulates in the gas, thus increasing the system's operational burden.

Fixed bed gasification is adaptable to various feedstocks with less stringent requirements on particle size. The higher reaction zone temperatures are conducive to tar cracking, leading to relatively low ash content in the product gas. The investment in the system is lower compared to circulating fluidized beds. However, fixed bed gasification has limited gasification intensity and typically operates in intermittent mode, making it less suitable for continuous operation compared to fluidized beds. Currently, it finds extensive applications in rural centralized gas supply and heating systems, as well as small to medium-scale gasification power generation.

Both fixed bed and fluidized bed gasifiers possess distinct characteristics and specific applicability ranges, as presented in Table 1. Fixed bed gasifiers exhibit a simple structure, convenient operation, and flexible operation modes, suitable for medium-scale production. In contrast, fluidized beds are more suitable for industrial-scale and large-scale applications, albeit with complex equipment and higher investment requirements. Thus, selecting the most suitable technology pathway while considering the actual conditions of the target market is of paramount importance.

2.4. Biomass Gas Cleanup

During the gasification process in the gasifier, a portion of ash and liquid tar is present in the produced gas. It is essential to separate these constituents to prevent pipeline blockage. Ash treatment is relatively straightforward from a technical perspective, as improved gasification efficiency leads to easier ash handling post-sintering. However, tar removal is more complex and can be addressed on a certain scale through catalytic cracking. The generally viable approach involves a combination of physical and chemical methods.

Table 1. The main types and characteristics of biomass gasifier in China

Gasifier type	Upward suction fixed bed	Downdraft fixed bed	fluidized bed
Type of raw materials	Straw, waste wood	Straw, waste wood	Rice husk, sawdust, straw
Particle size/mm	5~100	20-100	<10
Gasification temperature/℃	~1100	~1000	650~850
Gasification efficiency/%	70~75	seventy-five	65~75
Gasification intensity/(kg/m2. h)	200~300	200-600	1000~2000
application area	Boiler heating	Centralized gas supply and boiler heating	Rice mills and wood processing plants generate electricity

Currently, the methods employed for tar removal in biomass gasification coupled with CO_2 capture primarily encompass conventional techniques and catalytic cracking. The conventional methods for tar removal can be categorized into wet and dry methods. Wet tar removal is the most common approach in gas purification technology for biomass gasification coupled with CO_2 capture. It includes water washing and water filtration methods, which utilize water to rapidly cool the gas, causing tar condensation and subsequent separation from the gas. Dry tar removal entails placing highly adsorbent materials (such as carbon particles or corncobs) in a container. When gas passes through the adsorption material and a filter, tar is filtered out. Catalytic cracking involves using catalysts like dolomite ($MgCO_3$-$CaCO_3$) and nickel-based catalysts to decompose tar into permanent small-molecule gases at a certain temperature. The cracked products are similar in composition to the gas components. Due to cost considerations, small to medium-scale gasification power generation or centralized gas supply systems commonly adopt the water washing method. This method offers simultaneous tar, dust, and cooling removal benefits. However, a drawback is that the resulting washing wastewater generates a certain degree of secondary pollution. Currently, in domestic straw gasification projects, washing wastewater is generally recycled and not discharged externally. An effective treatment process for washing wastewater is not yet mature and is under laboratory research both domestically and internationally.

The composition of tar in biomass gas is complex, and effective detection methods are currently lacking. Over 200 compounds can be analyzed, with the majority being derivatives of benzene. In general, tar content is influenced by reaction temperature, heating rate, and gasification process residence time. Tar energy content in the total energy of the gas is considerable (tar energy content in biomass gasification coupled with CO_2 capture can range from 5% to 15%). This energy fraction is challenging to utilize together with combustible gases at lower temperatures, resulting in significant waste and a substantial reduction in gasification efficiency. Tar production at different gasification reaction temperatures is illustrated in Figure 5.

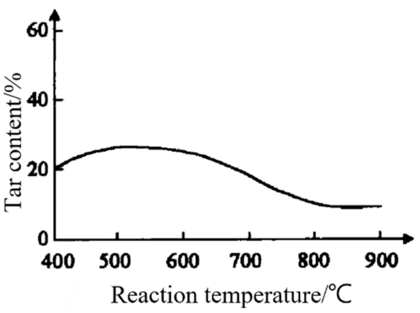

Figure 5. The amount of tar under different temperature

3. Current Status of Biomass Gasification CO_2 Capture

3.1. Post-Combustion CO_2 Capture Technologies

Separating CO_2 from flue gases generated by industrial facilities and subsequently capturing the CO_2 is accomplished through post-combustion CO_2 capture methods[8]. Chemical solvent absorption is presently the most mature method for post-combustion CO_2 capture. It exhibits high capture efficiency and selectivity, along with relatively low energy consumption and capture costs. Aside from chemical solvent absorption, other methods include adsorption and membrane separation, with membrane separation showing the most developmental potential. Commonly used absorbents in the adsorption process are amine or ammonia-based solvents, which are regenerable. As the task involves capturing a small quantity of CO_2 (typically 3% to 15% by volume) from flue gas primarily composed of nitrogen, with the presence of N_2, O_2, and other contaminants, extensive gas treatment is required before the gas enters the absorption tower. This pretreatment includes steps such as water washing, cooling, dehydration, electrostatic dust removal, desulfurization, and denitrification. Post-combustion CO_2 capture techniques are relatively straightforward, but due to the low CO_2 concentration in flue gas, the cost of the absorbent used is currently high. Further breakthroughs are needed to reduce capture costs, decrease energy consumption during the process, and facilitate large-scale demonstrations.

3.2. Pre-Combustion CO_2 Capture Technologies

In facilities that burn fossil fuels (such as oil, natural gas, or coal) or during natural gas production, CO_2 is separated from the natural gas before CO_2 emissions occur or during the gasification process. Compared to post-combustion methods, the concentration of CO_2 in the flue gas is higher, making separation easier. However, the process is more complex and costly. In the case of fossil fuel pre-combustion, the fuel is processed in a reactor containing steam and air or O_2 to produce a mixed gas primarily composed of CO and H_2. This mixture then reacts with steam to generate H_2 and CO_2. The separated streams consist of one H_2 gas flow and one CO2 gas flow. Currently, various separation methods are employed, including pressure swing adsorption, chemical absorption, physical absorption, and membrane separation. CO_2 is separated and captured from the mixed gas, while CO_2 is stored, and H_2 is used as fuel for gas turbine combined cycle power generation. Pre-combustion CO_2 capture technology has found extensive applications in the fertilizer manufacturing and hydrogen production industries.

3.3. Oxygen-Enhanced Combustion CO_2 Capture Technologies

This approach involves using an ample supply of pure oxygen or oxygen-enriched air (to ensure complete combustion) instead of regular air as the combustion medium for fossil fuels. The resulting flue gas mainly contains steam and CO_2. These gases have a significantly elevated CO_2 concentration, with CO_2 constituting 80% to 98% of the flue gas volume after cooling water condensation. This higher concentration enhances CO_2 capture efficiency, making subsequent storage or utilization easier. Oxygen-enhanced combustion CO_2 capture technology has been experimentally tested and demonstrated in laboratory-scale projects in countries such as Germany, Japan, Australia, and the United States. CO_2 captured using this method is stored geologically or in the ocean. Companies like RWE in the UK plan to establish integrated gasification combined cycle power plants with CO_2 capture and storage facilities in Europe. Research is also underway to incorporate oxygen-fueled systems into gas turbine systems, although these concepts are still in the research stage. In theory, oxygen-fueled systems can capture nearly all of the produced CO_2. However, the need to add gas treatment systems for removing pollutants such as sulfur and NOx reduces the CO_2 capture level (slightly above 90%).

With a high CO_2 content in flue gas, oxygen-enhanced combustion CO_2 capture technology holds significant potential. However, challenges remain in terms of reducing capture costs, managing combustion effectively, mitigating the effects of concentrated CO_2 streams on boiler corrosion and slag formation, as well as enhancing combustion and heat transfer control. Achieving a reduction in energy consumption, especially in the context of minimizing the energy consumption of oxygen separation devices and systems, also requires breakthroughs.

3.4. Industrial Separation CO_2 Capture Technologies

Since 1996, the Norwegian company StatoilHydro has been separating CO_2 from the natural gas produced in the Sleipner gas field in the North Sea and injecting millions of tons of separated CO_2 into the seabed annually. Industrial separation CO_2 capture technology is mature but has limited applications.

4. Challenges in Biomass Gasification CO2 Capture

4.1. Investment

CO_2 capture involves additional energy consumption and operational costs. Due to the scarcity of large-scale demonstration projects, the number of widely applicable CO_2 capture technologies is limited. Coupled with other uncertainties, estimating costs exhibits a wide range. Based on current research, precise calculations of marginal CO_2 capture costs are not feasible. For instance, in the case of a 300,000 kW power station with an annual CO_2 capture of 1 million tons, the addition of CCS equipment nearly doubles the investment.

4.2. Energy Consumption

Processes such as impurity removal, separation, concentration, absorbent production and regeneration, and waste disposal during CO_2 capture require additional energy consumption. Oxygen-enhanced combustion CO_2 capture technology also incurs higher energy consumption due to the separation of oxygen from air. Moreover, the CO_2 capture process itself requires significant energy. Power plants equipped with CCS equipment (with a geological or ocean storage pathway) consume approximately 10% to 40% more energy than equivalent plants without CCS equipment. The majority of this additional energy is used for CO_2 capture and concentration. Taking the example of the CO_2 capture demonstration project at the Huaneng Beijing Thermal Power Plant, which incurs costs of around 28.5 million RMB and captures approximately 3,000 tons of CO_2 annually (0.075% of the total emissions), CO_2 capture consumes over 30% of the plant's total energy consumption. According to estimates from the Xi'an Thermal Power Research Institute, installing a post-combustion CO_2 capture system in China currently increases power generation costs by 20% to 30% and reduces power generation efficiency by 8% to 10%. It is evident that significant energy consumption is required when utilizing existing CO_2 capture technologies.

4.3. Capture Costs

The major issue with CCS equipment is the high cost of CO2 capture, accounting for about three-quarters of the total CCS equipment cost. Research from the Global Energy Technology Strategic Plan (GTSP) indicates that the CO_2 capture costs for ethanol, ethylene, integrated gasification combined cycle (IGCC), and refinery applications are estimated to be \$6-\$12, \$6-\$12, \$25-\$40, and \$35-\$55 per ton, respectively. The first CO_2 capture demonstration project in China, conducted at the Huaneng Beijing Thermal Power Plant, has a CO_2 capture cost of around 300 RMB per ton. Table 2 presents research results for CO_2 capture costs in industries such as cement and refining.

Table 2. CO_2 Capture Costs in Selected Industries

industry	Euro/t	industry	Euro/t
cement	28	Refinery	29~42
steel	29	H_2 (mixed flue gas)	36
Ammonia water (mixed flue gas)	36	Ammonia water (pure CO_2)	30
Ammonia water (pure CO_2)	20	Petrochemical	32~36

Beyond the elevated cost associated with CO_2 capture, CO_2 capture systems demand substantial energy to ensure their operation, resulting in a decrease in net efficiency for enterprises. However, emerging technologies under development are expected to substantially reduce costs, contingent on the proliferation and application of commercial technologies in the market, along with continuous research and development efforts. Simultaneously, the reduction of capture costs and the development of new technologies form the basis for large-scale deployment and commercial operation of CO_2 capture technology. Several CO_2 capture demonstration projects have succeeded in operation or entered the construction phase, with the captured CO_2 being converted for use in industries such as food, fire safety, and pharmaceuticals. This approach can potentially balance or even generate profits from CO_2 capture, providing economic support for the subsequent operation of capture facilities and furnishing reliable data for future large-scale CO_2 capture and utilization research. Both the operational Huaneng Beijing Thermal Power Plant and the upcoming China Huaneng Group Shanghai Shidongkou Second Thermal Power Plant plan to convert the captured CO_2 (estimated annual capture of 1.0 million tons) for utilization. As no storage is involved, the captured CO_2 is essentially released again within a short timeframe. Thus, although CO_2 capture research holds significant demonstration value, it cannot be considered a genuine CO_2 reduction measure.

5. Prospects for Biomass Gasification CO_2 Capture

5.1. Catalytic Cracking of CO_2 Tar in Biomass Gasification Capture

Tar is an inevitable byproduct during gasification, causing significant operational challenges for the entire gasification system. Liquid tar easily clogs pipes due to ash and water bonding; it exerts strong corrosive effects on gasification equipment made of metal and PE plastic pipelines. Additionally, tar contains considerable energy content, reducing gasification efficiency and gas heating value. Presently, catalytic cracking is one of the main research directions for biomass gasification CO_2 capture. In the process of tar conversion, steam and carbon dioxide play a significant role in the cracking reaction, promoting the rearrangement of the tar molecules to produce CO and H_2, thereby enhancing the yield and heating value of combustible gases. The reaction process can be represented as follows:

$$\mathrm{C}_n\mathrm{H}_m + n\mathrm{H}_2\mathrm{O} \rightarrow n\mathrm{CO}+(2n+m)/2\mathrm{H}_2 \qquad (1)$$

$$\mathrm{C}_n\mathrm{H}_m + n\mathrm{CO} \rightarrow 2n\mathrm{CO} + m/2\mathrm{H}_2 \qquad (2)$$

Various catalysts have been investigated for catalytic cracking of CO_2 tar from biomass gasification, including dolomite, nickel-based catalysts, and alkali metal catalysts. Dolomite has gained widespread application due to its effectiveness in tar removal, low cost, and practical value for CO_2 capture from biomass gasification. It can be directly mixed with biomass before gasification or used as a protective bed in downstream reactors. Researchers both domestically and internationally have conducted in-depth investigations into dolomite, making it one of the most extensively studied catalysts in the field of biomass gasification CO_2 capture. Nickel-based catalysts can rearrange hydrocarbons and adjust the composition of gas products during the cracking of biomass tar, showing a high cracking rate at 750°C and exhibiting excellent catalytic performance. However, carbon deposition and sintering on the catalyst surface lead to catalyst deactivation, and the addition of promoter catalysts can improve its performance. Numerous researchers have dedicated substantial efforts to this area[9]. Studies by Aznar and others have demonstrated that commercial nickel-based catalysts can achieve tar conversion rates exceeding 99% and adjust the gas product composition[10].

Alkali metal catalysts are generally mixed with biomass feedstock and added to gasification reactors, but their recovery is challenging and leads to increased ash disposal from the gasifier, thus hindering the further development of alkali metal catalyst technology. Encinar and others have studied the catalytic cracking effect of alkali metal chlorides on tar and analyzed the impact of various catalysts and their concentrations on gasification[11]. Mudge and others have investigated the activity of several alkali metal carbonates and natural mineral catalysts in catalyzing the steam gasification of sawdust[12].

5.2. Biomass Gasification CO_2 Capture for Hydrogen and Methanol Production

Biomass can be subjected to a series of thermochemical reactions and chemical processes, including steam reforming, water-gas shift, and pressure swing adsorption (PSA) hydrogen separation, at high temperatures to produce high-purity hydrogen. Rapagna and others in L'Aquila, Italy, conducted gasification experiments on almond shells using catalysts, yielding a gas with a hydrogen content of 60%[13]. Extensive research has been conducted by other scholars in this area[14]. Biomass gasification CO_2 capture for hydrogen production offers diverse pathways that may potentially provide an efficient and clean route for large-scale hydrogen generation.

After undergoing thermal decomposition gasification, gas purification, steam reforming, H_2/CO ratio adjustment, methanol synthesis, and separation and purification processes, biomass can be synthesized into methanol. Companies and research institutions in the United States, European Union, Japan, and other regions have been devoted to developing technologies for biomass-to-methanol synthesis and have established demonstration facilities for biomass methanol production.

5.3. Supercritical Biomass Gasification

The current research focus of supercritical biomass gasification pertains to catalytic hydrogen production through supercritical water gasification. In supercritical water, biomass gasification can achieve a gasification rate of 100%, with hydrogen content exceeding 50%. Supercritical water gasification of biomass is complex[15], and systematic summaries of its industrial utilization rules have yet to be established from both theoretical and technological perspectives; it remains in the stage of small-scale laboratory research.

6. Conclusion

The current status of the application and development of biomass gasification CO_2 capture reveals several key challenges:

Economically, the foremost challenge lies in resource collection. The majority of rural areas in China operate as agricultural households, leading to dispersed resources that hinder the scaled application of gasification technology. From a cost perspective, the scalability of this technology could result in larger biomass collection radii and elevated transportation expenses, potentially compromising economic viability.

Technologically, the issue of secondary pollution remains largely unresolved in current biomass gasification CO_2 capture methods. Most small to medium-sized gasification power generation facilities employ water washing techniques, which yield wastewater containing ash and tar substances; this water is usually recirculated internally and not externally discharged. The transition to large-scale implementation will significantly augment water consumption, and the biochemical treatment process for tar-laden wash wastewater is still underdeveloped. Presently, tar treatment technologies are not yet mature, and approaches like catalytic cracking demand a certain level of equipment scale for effective application. While biomass gasification CO_2 capture has the potential to mitigate environmental pollution, if the reduction of carbon dioxide emissions coincides with an increase in tar pollution, the significance of this technology diminishes. Consequently, the comprehensive resolution of tar pollution presents a critical avenue for future research efforts.

Biomass gasification CO_2 capture holds vast developmental prospects. In the future, biomass energy is poised to play a crucial role in renewable energy, with gasification technology anticipated to make breakthroughs. Biomass gasification CO_2 capture is expected to transition gradually from producing low-calorific-value gas to intermediate-to-high-calorific-value gas. Regarding gasification for hydrogen production, steam gasification and supercritical water catalytic gasification are noteworthy. Biomass's relatively low energy density can be compensated by using water as a medium for hydrogen production, which maintains gas calorific value with high energy conversion efficiency. Moreover, these hydrogen production methods exhibit robust organic waste disposal capabilities, operate under mild conditions, and yield high-energy products. When combined with the renewability of biomass and the recyclability of water, they offer a potential avenue for energy conversion, utilization, and harmonious circulation with nature.

Concerning the production of liquid fuels through biomass gasification CO_2 capture, with the innovative advancement of gas purification technology and the intensified development of novel techniques, costs are expected to substantially decrease, enhancing economic viability. Supported by relevant policies, this approach is poised to gradually replace certain non-renewable resources such as petroleum and attain scalable and industrialized utilization. Presently, centralized gas supply from gasification and small to medium-sized gasification power generation technologies will continue to develop, introducing a constant stream of new processes and equipment. Concurrently, reliability and maturity will significantly improve, paving the way for the commercial application of regional combined heat and power (CHP) technologies.

References

[1] Demirbaş A., Biomass resource facilities and biomass conversion processing for fuels and chemicals, Energy Convers. Manag., 2001, 42, 1357–1378

[2] Lingayat A.B., Chandramohan V.P., Raju V.R.K., Meda V., A review on indirect type solar dryers for agricultural crops–Dryer setup, its performance, energy storage and important highlights, Appl. Energy, 2020, 258, 114005

[3] Islam M.R., Islam M.R., Beg M.R.A., Renewable energy resources and technologies practice in Bangladesh, Renew. Sustain. Energy Rev., 2008, 12, 299–343

[4] Adnan M.A., Hossain M.M., Co-gasification of Indonesian coal and microalgae–A thermodynamic study and performance evaluation, Chem. Eng. Process. Intensif., 2018, 128, 1–9

[5] Gil J., Corella J., Aznar M.P., Caballero M.A., Biomass gasification in atmospheric and bubbling fluidized bed: effect of the type of gasifying agent on the product distribution, Biomass and Bioenergy, 1999, 17, 389–403

[6] AlNouss A., McKay G., Al-Ansari T., A comparison of steam and oxygen fed biomass gasification through a techno-economic-environmental study, Energy Convers. Manag., 2020, 208, 112612

[7] Hai I.U., Sher F., Yaqoob A., Liu H., Assessment of biomass energy potential for SRC willow woodchips in a pilot scale bubbling fluidized bed gasifier, Fuel, 2019, 258, 116143

[8] Merkel T.C., Lin H., Wei X., Baker R., Power plant post-combustion carbon dioxide capture: An opportunity for membranes, J. Memb. Sci., 2010, 359, 126–139

[9] Sutton D., Kelleher B., Ross J.R.H., Review of literature on catalysts for biomass gasification, Fuel Process. Technol., 2001, 73, 155–173

[10] Aznar M.P., Caballero M.A., Gil J., Martin J.A., Corella J., Commercial steam reforming catalysts to improve biomass gasification with steam− oxygen mixtures. 2. Catalytic tar removal, Ind. Eng. Chem. Res., 1998, 37, 2668–2680

[11] Encinar J.M., Beltrán F.J., Ramiro A., González J.F., Pyrolysis/gasification of agricultural residues by carbon dioxide in the presence of different additives: influence of variables, 1998, 55, 219–233

[12] Robertus B.J., Mitchell D.H., Mudge L.K., Weber S.L., Sealock L.J., Use of catalysts in biomass gasification, Altern. Energy Sources, 1980

[13] Rapagnà S., Provendier H., Petit C., Kiennemann A., Foscolo P.U., Development of catalysts suitable for hydrogen or syn-gas production from biomass gasification, Biomass and Bioenergy, 2002, 22, 377–388

[14] Huber G.W., Shabaker J.W., Dumesic J.A., Raney Ni-Sn catalyst for H2 production from biomass-derived hydrocarbons, Science (80-.)., 2003, 300, 2075–2077

[15] Antal Jr M.J., Allen S.G., Schulman D., Xu X., Divilio R.J., Biomass gasification in supercritical water, Ind. Eng. Chem. Res., 2000, 39, 4040–4053