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ENHANCING BIOMASS GASIFICATION: ANALYZING CRUCIAL PARAMETERS FOR SUSTAINABLE ENERGY PRODUCTION

Biomass gasification is a promising technology for converting organic materials into valuable gases such as syngas, hydrogen, methane, and chemical feedstocks. This process involves complex thermochemical reactions influenced by various parameters. This article explores key factors affecting product quality during biomass gasification, including feedstock composition, moisture content, particle size, operating conditions, catalysts, and sorbent-to-biomass ratio. The study sheds light on the advantages and disadvantages of different gasifier types, such as updraught, downdraught, fluidised bed, and entrained flow, highlighting their suitability for specific applications. It also delves into the significance of parameters like steam-to-biomass ratio and air equivalence ratio. The findings underscore the importance of optimizing these factors to enhance gasification efficiency and minimize undesired byproducts. Biomass gasification holds significant potential for sustainable energy production and should be explored further to harness its benefits effectively.

Keywords: Biomass, alternative source of energy, bioenergy, biofuel, biomass gasification, gasifier types.

Introduction

Biomass is any organic substance that is renewable over a period of time relating to plants and animal derived materials. Biomass consists of C and a mixture of H, O_2, N and little amount of alkali, alkaline earth, and heavy metals. The most used techniques for biomass analysis are the ultimate and proximate analysis, where the ultimate analysis is used for biomass composition of the hydrocarbon, and the proximate analysis used for moisture, fixed carbon, and ash [1].

Biomass gasification has been used to produce syngas, H_2, methane (CH_4), and chemical feedstocks. To produce these gases, biochemical and thermochemical routes can be employed. The thermochemical pathway can accommodate a broad range of biomass, and has high efficiency [2].

Fluidised bed, fixed bed gasifiers and entrained flow gasifiers are the most common type of gasifiers. Updraft gasifiers generate around 10 to 20 wt% tar in the gas [3].

Air or O_2 is added and the temperature increases to 1200-1400°C burning or pyrolysing the fuel feedstock. At the bottom of the bed the combustion gases are decreased to H_2 and C_O [3].Initial research covered information of the parameters influencing the product quality during biomass gasification. Figure 1 represents gasifier types, while table 1 shows their advantages and disadvantages.

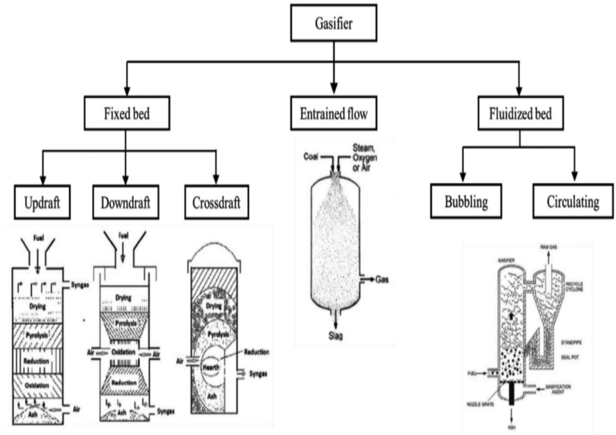

Figure 1 – Gasifier types [4]

Table 1 – advantages and disadvantages of gasifier types[4]

Gasifier type	Advantages	Disadvantages
Updraught	- minimal pressure loss; - high thermal efficiency; - rapid response to load fluctuations; - simplified construction.	- elevated tar content in producer gas; - prolonged ignition time; - significant pressure loss; - vulnerable to feedstock variations.

Downdraught	- reduced tar content in producer gas; - simplified construction.	- requires tailored design for specific feedstock; - diminished heating value producer gas; - lower thermal efficiency.
Fluidised bed	- enhanced heating value in producer gas.	- intricate construction
Entrained flow	- well-suited for fine-size feedstock and large scale facilities	- unsuitable for highly moist feedstock; - limited residence time.

Materials and methods

Parameters affecting product quality during biomass gasification:

Feedstock and moisture content

The main elements of biomass are hemicellulose, cellulose, and lignin. They play an essential part during the thermochemical conversion processes. Generally, the cellulose to lignin ratio ranges between 0.5 and 2.7 [5].

More than 2260 kJ of extra energy is required per kilogram of biomass moisture to evaporate water. Updraft fixed gasifiers can withstand up to 60 % moisture content (wet % basis), while downdraft gasifiers can tolerate feedstock content of 25 % (wet % basis). If the moisture content of a feedstock is higher than 30 wt %, it can lead to less gas production and higher tar content. Thus, the actual moisture content should be considered while calculating the steam to biomass ratio.

Figure 2 shows the moisture content impact on the biomass consumption rate. It can be seen that if biomass moisture content rises, the biomass consumption rate will decline. It might be because of high energy demand in pyrolysis and drying of the moisture biomass.

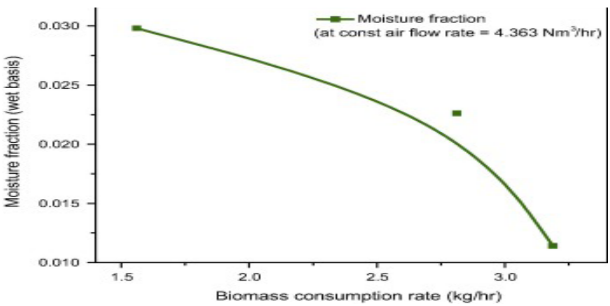

Figure 2 – Moisture content impacts on biomass consumption rate [6].

Particle size and density

It was found that feedstock particle dimensions have direct influence on produced gas. Temperature and particle heating rate have a significant impact on weight loss during BG. Small particle dimensions have perfect fluid-particle heat transfer. More regulated gasification is obtained with unchanging temperatures throughout the feedstock particle [3].

Residual char yield is higher by incomplete pyrolysis because of greater heat transfer resistance from large particles. Syngas efficiency can be improved by decreasing particle size, which can also reduce tar yields [7].

Usually, biomass feedstocks have a small densely porous structure. It was assumed that links between products and reactants occurs via non-restricted molecular transport. The low density of feedstocks can lead to unchanging temperature throughout the particles that demonstrate homogeneous gasification. Therefore, a non-homogeneous gas composition is achieved [4].

Operating conditions:

Temperature, heating rate, and the partial pressure of the gasifying agent are also essential criteria that have an impact on exit gas yield and overall biomass conversion. The reactor pressure of EFG is between 20 to 70 bar. A fast heating rate brings significant gas yields and low tar production, while a slow heating rate brings high tar production. In case of temperature increase, the Boudouard reaction (1) and the thermal cracking reaction (2) can efficiently degrade residual char and tar. The reactor temperature in FBG is about 1100°C, in FBG it is kept below 1000°C, and in EFG is greater than 1900 °C [8].

$C + CO_2 – {}_2CO + 172$ kJ mol-1 Eq.(1) [8]

Tar + heat – $CO_2 + CO + H_2 + CH_4$ + coke Eq.(2) [8]

Figure 3 represents the impact of temperature on the produced gas composition.

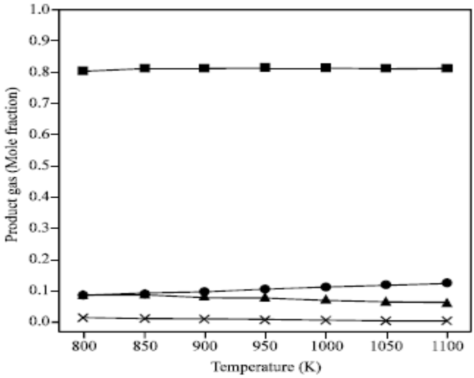

Figure 3 – Temperature effects on product gas composition. Steam-to-biomass ratio: 3. Sorbent-to biomass ratio: 1. H_2 (■), CO (●), CO_2 (▲), CH_4 (✕) [9]

Steam-to-biomass ratio (S/B):

Steam to biomass ratio has a significant impact on product yields. High S/B ratio leads to a higher H_2 yield and has a high calorific value in syngas with low tar production. Little S/B produces greater amounts of CH4 and char. Process efficiency due to energy in the surplus steam, which also detrimentally affects the temperature in the gasifier, leading to lower tar cracking. These problems highlight the importance of recognising an optimum S/B in steam BG [8].

Figure 4 demonstrates the produced gas composition for growing steam-to-biomass ratio.

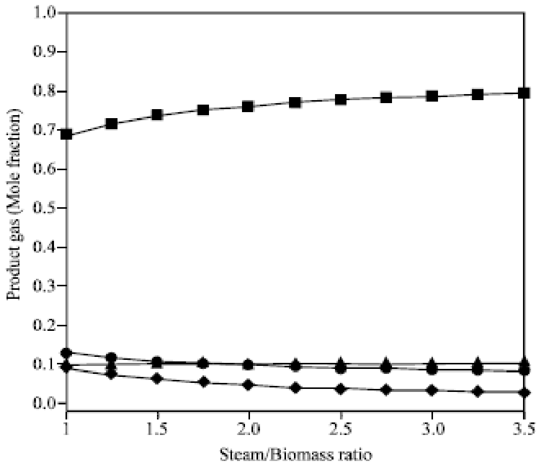

Figure 4 - Impact of S/B ratio on gas.
Biomass feed rate: 0.072 kg/ h. Temperature: 800 K. Sorbent-to-biomass ratio:
1. H_2 (■), CO (●), CO_2 (▲). CH_4 (◆) [9].
Air equivalence ratio (ER):

A high ER can decrease the yields of H_2 and CO, which raises CO_2 and decreases the calorific content of the gas. The amount of moisture and volatile species in the feedstock also has influence on ER. If moisture content is up to 15 %, it will increase gas amount and ER. A moisture content higher than 15 % will lead to irregular temperature variations [7].

Gasification occurs in an air scarce environment. Downdraft gasifiers need a value of ER ~0.25 to achieve optimal product gas yield. Efficiency in FBG is improved with the amount of ER ~0.26. In practice, a desired value of ER is 0.2–0.3. Values less than 0.2 will result in more char formation [3].

Figure 5 represents the impact of raising the air flow rate on biomass consumption rate. A rise in biomass consumption is linear to a rise in the air flow rate, because the air flow rate increment increases the combustion and a larger amount of biomass is consumed. Great amount of heat is released due to the increased rate of biomass combustion [8].

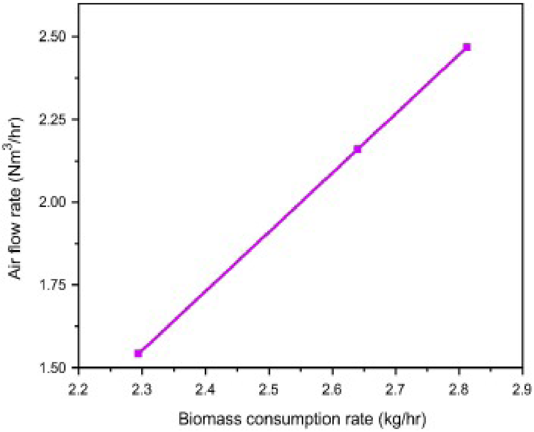

Figure 5 – Air flow rate effects on biomass consumption rate (moisture fraction = 0.0226) [8].

Catalysts:

Catalysts simplify the thermal and mass transfer resistance and play an essential part in BG. It has been found that catalysts have a positive effect in stimulating gasification. Catalysts are engaged in situ or after gasification reactions [6]. Catalysts include alumina and zeolites, Ni-based, Zn-based, dolomites and limestones, platinum- and ruthenium-based materials. A positive impact on gasification extent has alkaline metal oxides, dolomite, and Ni-based catalysts due to the capability to encourage the reformation reactions. Alumina silicates are very useful in enhancing char gasification, while Ni-based catalysts are best for the conversion of lighter hydrocarbons. Effective catalysts are under development, with the focus to improve the quality of products [3].

SER – sorbent-to-biomass ratio:

Biomass could be carbon-negative if the CO_2 released during gasification is captured and stored. Metal-based sorbents, dolomite, aluminium oxide, Ni-based sorbents, and rhodium have been researched as sorbents in biomass gasification. It was proven that solid sorbents are better than liquid sorbents in the case of CO_2 capture during BG. Sorbents remove CO2 from the BG and enhance H_2 yield. Thus, using an appropriate sorbent is desirable, and it should not hamper economic considerations [10].

Results and discussion

Feedstock and Moisture Content: The composition and moisture level of biomass significantly impact gasification outcomes. High moisture content can reduce gas production and increase tar content.

Particle Size and Density: The size of biomass particles affects gasification, with smaller particles leading to better gasification efficiency and lower tar yields.

Operating Conditions: Factors like temperature and heating rate play a crucial role in gasification efficiency and product quality. Different types of gasifiers require specific temperature ranges.

Steam-to-Biomass Ratio (S/B): The S/B ratio influences gasification product yields, with a high ratio increasing H2 yield and calorific value while reducing tar production.

Air Equivalence Ratio (ER): ER affects gas composition and calorific content, with optimal values varying for different gasifier types.

Catalysts: Catalysts can enhance gasification extent and product quality by simplifying thermal and mass transfer resistance.

Sorbent-to-Biomass Ratio (SER): Solid sorbents show promise in capturing and storing CO_2 released during gasification, potentially making the process carbon-negative.

Conclusion

Biomass gasification represents a promising avenue for sustainable energy production, offering a way to convert organic materials into valuable gases and chemical feedstocks. However, achieving optimal product quality during biomass gasification requires careful consideration of several key parameters. This study has highlighted the importance of feedstock composition, moisture content, particle size, operating conditions, catalysts, and sorbent-to-biomass ratio in influencing gasification outcomes.

Different gasifier types have their advantages and disadvantages, making them suitable for specific applications based on the desired product and operating conditions. Factors like steam-to-biomass ratio and air equivalence ratio play a crucial role in determining gas composition and overall process efficiency.

It is evident from this research that optimizing these parameters can lead to higher gas yields, lower tar production, and increased calorific value in the resulting syngas. Moreover, the use of catalysts and appropriate sorbents can further enhance gasification extent and product quality.

In conclusion, biomass gasification holds great promise for a sustainable and environmentally friendly energy source. Continued research and development efforts should focus on refining the understanding of these key parameters and optimizing gasification processes to unlock the full potential of biomass as a renewable energy resource.

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БИОМАССАНЫ ГАЗДАНДЫРУДЫ ЖЕТІЛДІРУ: ТҰРАҚТЫ ЭНЕРГИЯ ӨНДІРУ ҮШІН НЕГІЗГІ ПАРАМЕТРЛЕРІН ТАЛДАУ

Биомассаны газдандыру – органикалық материалдарды сингаз, сутегі, метан және химиялық шикізат сияқты бағалы газдарға айналдырудың перспективті технологиясы. Бұл процесс әртүрлі параметрлердің әсерінен болатын күрделі термохимиялық реакцияларды қамтиды. Бұл мақалада биомассаны газдандыру *кезінде өнім сапасына әсер ететін негізгі факторлар, соның ішінде жем құрамы, ылғалдылық, бөлшектердің мөлшері, жұмыс жағдайлары, катализаторлар және сорбент пен биомасса қатынасы қарастырылады. Шолуда жоғары ағын, төмен ағын, сұйылтылған төсек және тартылған ағын сияқты газдандыру құрылғыларының әртүрлі түрлерінің артықшылықтары мен кемшіліктері зерттеліп, олардың нақты қолданбаларға жарамдылығы көрсетіледі. Будың биомассаға қатынасы және ауа эквиваленттік коэффициенті сияқты параметрлердің маңыздылығы да қарастырылады. Нәтижелер газдандыру тиімділігін арттыру және қажетсіз жанама өнімдерді азайту үшін осы параметрлерді оңтайландырудың маңыздылығын көрсетеді. Биомассаны газдандыру тұрақты энергия өндіру үшін маңызды әлеуетке ие және оның артықшылықтарын тиімді пайдалану үшін одан әрі зерттеуді қажет етеді.*

Кілтті сөздер: биомасса, баламалы энергия көзі, биоэнергетика, биоотын, биомассаны газдандыру, газдандырғыштардың түрлері.

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УЛУЧШЕНИЕ ГАЗИФИКАЦИИ БИОМАССЫ: АНАЛИЗ КЛЮЧЕВЫХ ПАРАМЕТРОВ ДЛЯ УСТОЙЧИВОГО ПРОИЗВОДСТВА ЭНЕРГИИ

Газификация биомассы - перспективная технология преобразования органических материалов в ценные газы, такие как сингаз, водород, метан и химическое сырье. Этот процесс включает в себя сложные термохимические реакции, на которые влияют различные параметры. В данной статье рассматриваются основные факторы, влияющие на качество продукта при газификации биомассы, включая состав сырья, его влажность, размер частиц, условия эксплуатации, катализаторы и соотношение сорбента и биомассы. Обзор рассматривает преимущества и недостатки различных типов газификаторов, таких как восходящие, нисходящие, с псевдоожиженным слоем и с увлекаемым потоком, подчеркивая их пригодность для решения конкретных задач. Также рассматривается значение таких параметров, как соотношение пара *и биомассы и коэффициент эквивалентности воздуха. Полученные результаты подчеркивают важность оптимизации этих параметров для повышения эффективности газификации и минимизации нежелательных побочных продуктов. Газификация биомассы обладает значительным потенциалом для устойчивого производства энергии и требует дальнейшего изучения для эффективного использования ее преимуществ.*

Ключевые слова: биомасса, альтернативный источник энергии, биоэнергетика, биотопливо, газификация биомассы, типы газификаторов.

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