

DETERMINATION OF PROPERTIES OF RESIDUAL CHAR AFTER GASIFICATION OF BAGASSE

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Abstract

Bagasse ranks among Vietnam's most abundant agricultural residues. The application of bagasse for energy generation via biomass gasification technology presents an innovative approach. Nevertheless, prevailing biomass gasification methodologies exhibit relatively limited efficacy and produce a substantial surplus of char following the gasification procedure. This investigation, however, focuses on acquiring and evaluating residual char produced from the gasification of bagasse within a commercial system. Proximate and ultimate analyses indicate that the char derived from bagasse gasification possesses low ash content while retaining a significant carbon fraction. SEM-EDS examination reveals that both bagasse and its chars consist of distinct thin layers with a rough and non-uniform surface. Additionally, bagasse char displays considerable porosity, as demonstrated by its specific surface area of 749 m²/g, determined using the nitrogen adsorption technique. This outcome places it in the same category as particular commercial activated carbons. The physical and chemical attributes of bagasse char post-gasification affirm its potential as an economical and eco-friendly adsorbent material.

Keywords: Bagasse; residual char; gasification; biomass; adsorbent.

1. Introduction

Sugarcane is grown across various regions globally, with notable production in Brazil and India. Beyond its primary output of sugar, approximately 30% of the total weight of processed sugarcane constitutes bagasse [1]. On a worldwide scale, the sugar sector yields a substantial volume of sugarcane bagasse, approximated at 0.6 billion tons annually [2]. In Vietnam, a considerable quantity of bagasse, around 8 million tons, is discharged each year. Nationally, just few factories utilize bagasse for internal heat and electricity generation purposes [3]. Consequently, considering the solid waste it generates, the sugar processing industry is regarded as one of the most environmentally detrimental sectors in Vietnam.

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Bagasse contains a significant proportion of sugar, endowing it with a high heating value [4, 5]. Consequently, harnessing bagasse as a biomass feedstock for energy generation is particularly pertinent, especially in facilities requiring heat and electricity. An effective approach to fully capitalize on this residue involves employing it as a raw material for gasification. Gasification, a thermochemical conversion process, transforms carbon-rich materials into hydrogen and carbon monoxide-enriched gas known as syngas [6]. Syngas finds diverse applications, including heat and power generation or conversion into transportation fuels. Several Asian nations, including China, India, Myanmar, Cambodia, and Thailand, have witnessed an increasing inclination towards utilizing rice straw as a feedstock for gasification [7]. Fixed-bed technology is the prevalent choice for gasifying rice husks, primarily due to its straightforward design and cost efficiency. Nonetheless, the existing technology exhibits drawbacks, providing only moderate efficiency and generating significant waste, as underscored in prior researches [7, 8].

Consequently, a significant quantity of residual material is generated during the gasification process, which still retains certain carbon content. Previous investigations have examined the characteristics of these post-gasification residues in search of suitable applications [9, 10]. In certain instances, the surface area of these residues has been found to be comparable to that of expensive commercial activated carbons, indicating their potential to serve as cost-effective replacements. Residues resulting from the gasification of agricultural materials possess an advantageous combination of high carbon content and substantial porosity, rendering them well-suited for use as adsorbents or construction materials [7, 11]. These studies underscore the promising prospects of repurposing gasification residues as adsorbents. Nevertheless, the use of residual char after gasification remains somewhat limited.

Therefore, the purpose of this study was to characterize the residual char after gasification and enhance its application as environmentally friendly and economically viable adsorbents.

2. Materials and methods

2.1. Bagasse and its residual char collection

Bagasse was sourced from a facility located in Northern Vietnam. The feedstock was subjected to one week of air-drying to eliminate moisture and was also cleaned to remove any dust or impurities prior to further characterization. The gasification process was conducted using a commercial gasifier (PP20 All Power Lab) with the default configuration. Approximately 50 kg of bagasse was utilized for gasification, carried out

over a span of 2 hours. Following the gasification process, the resulting residual char was collected and stored in containers for subsequent experiments.

2.2. Characterization techniques

Proximate analysis, conducted under dry conditions, was utilized to determine the volatile matter (in accordance with the ASTM D-3175 standard), ash content (following the ASTM D-3174 standard), and fixed carbon content (calculated by the difference) for both the bagasse feedstock and its corresponding char.

Ultimate analysis of both bagasse and its resultant char was carried out using a PerkinElmer 2400 Series II Elemental Analyzer. The morphology of the bagasse and char was examined through the scanning electron microscopy (SEM) technique.

Nitrogen adsorption/desorption analysis was performed using the BELSORP mini II analyzer to characterize the pore surface area and pore size distribution of the bagasse char. The specific surface area of the char was determined using the Brunauer-Emmett-Teller (BET) method, while the pore size distribution and pore volume were assessed employing the Barrett-Johner-Halenda (BJH) method.

3. Results and discussions

3.1. Proximate analysis

Table 1 offers a concise overview of several characteristics, encompassing volatile matter, ash content, and fixed-carbon content, derived from the proximate analysis of both bagasse and its char. Bagasse exhibits a comparatively low bulk density (97 kg/m^3), and its elevated moisture content poses challenges in terms of transportation and utilization as a feedstock [12]. In contrast, the resulting char displays higher bulk density (210 kg/m^3) and lower moisture content, rendering it suitable for various applications [13, 14].

Table 1. Proximate analysis of bagasse and its char

Biomass type	Bagasse	Residual char
Moisture (wt%, <i>as received</i>)	12.5	2.8
Bulk density (kg m^{-3})	97	210
Proximate analysis (wt%, <i>db.</i>)		
A	1.05	5.14
FC	16.40	91.79
V	82.55	1.25

A: Ash; FC: Fixed-carbon; V: Volatile

One significant advantage of bagasse, as well as its resulting char, lies in its remarkably low ash content. This characteristic helps prevent issues when utilizing it as an energy source, as excessive inorganic elements can impede the conversion process or lead to blockages in the system over time [15, 16]. Bagasse's fixed carbon content is relatively low compared to some other biomass sources, such as macadamia nut shells or cashew nut shells, resulting in a reduced production of residual char [10, 17]. Furthermore, the low ash content is essential for advanced applications of char. Notably, the carbon content of the residual char is exceptionally high, estimated at 91.79%, opening up possibilities for the reutilization of bagasse char following gasification.

3.2. Ultimate analysis

Table 2 presents the results of the ultimate analysis conducted on bagasse and its residual char. This analysis is crucial for predicting the heating value and the overall quality of the energy product [18]. Typically, the four key elements: carbon (C), nitrogen (N), hydrogen (H), and oxygen (O) were determined in the samples.

Table 2. Ultimate analysis of bagasse and its char (wt%, dry-ash-free basis)

Biomass type	Bagasse	Residual char
C	46.01	86.15
H	6.38	3.47
N	0.12	0.31
O	47.49	10.07

The data presented in Table 2 clearly show that bagasse has lower carbon (C) and hydrogen (H) contents compared to woody biomass [19]. The higher oxygen content (O) in bagasse suggests that it can easily ignite during gasification, and once initiated, the gasification process can be maintained automatically. Moreover, the bagasse samples exhibit significantly lower nitrogen (N) content, which is advantageous as it indicates minimal potential for nitrogen emissions. On the contrary, the residual char has a high carbon (C) content, accounting for 86.15 wt%, and much lower oxygen (O) content compared to bagasse. These ultimate analysis results once again emphasize that the residual char contains a substantial amount of carbon, making it suitable for various purposes.

3.3. Morphology and surface elements

The SEM technique was employed to analyze the morphology of both bagasse and its residual char, capturing images from various locations on the sample surfaces (Fig. 1).

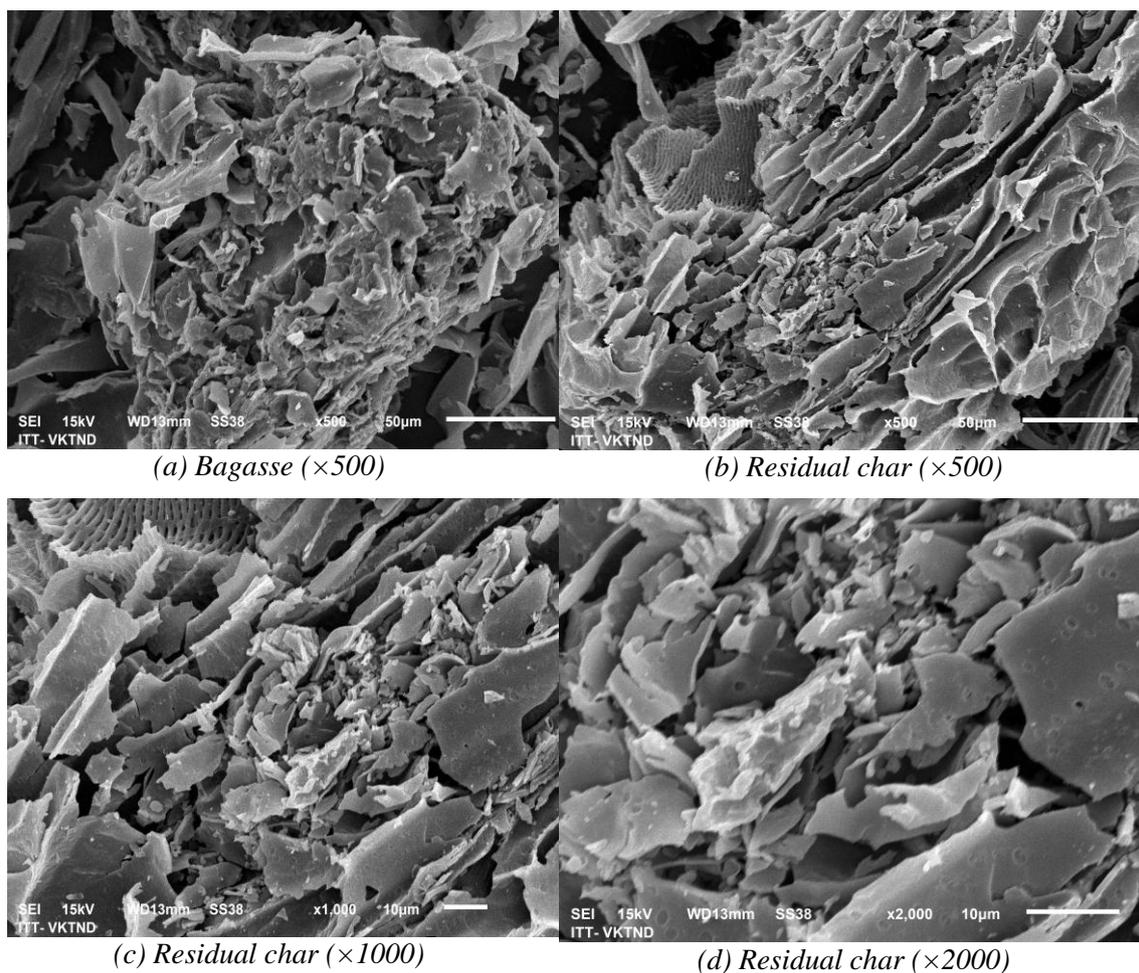


Fig. 1. SEM images of bagasse and its residual char.

The morphological characteristics of bagasse reveal that it consists of distinct thin layers with a rough and non-uniform surface. This structure indicates significant porosity and excellent heat transfer capabilities of the material. The char obtained after gasification maintains a similar layered structure. However, at higher magnifications, it becomes evident that many structures have been disrupted due to the relatively weak structure of bagasse, likely induced by the heat during gasification. Some bright spots on the surface may be attributed to the presence of inorganic materials that become exposed on the surface following the gasification process.

Based on the comprehensive EDS analysis results, which are presented in Table 3 and visually represented in Fig. 2, several noteworthy findings can be observed. Notably, the bagasse residual char, when subjected to surface analysis, exhibited exceptionally high carbon (C) content. Intriguingly, there was also the presence of

certain alkaline elements, including phosphorous (P), magnesium (Mg), and silicon (Si), albeit in relatively lower percentages compared to carbon.

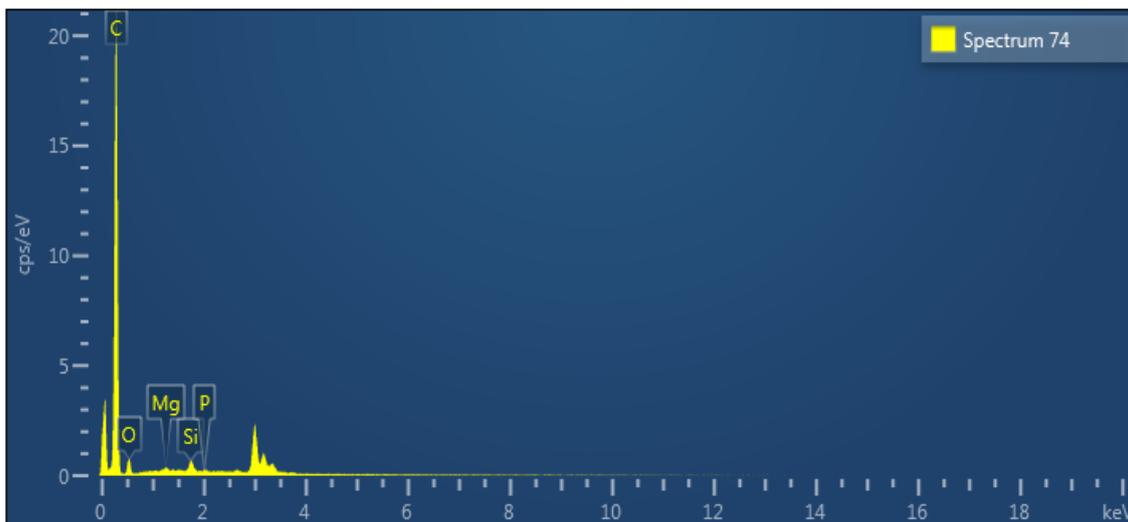


Fig. 2. EDS spectra of residual char.

Further analysis revealed that these alkaline elements predominantly existed in their respective oxide forms, such as magnesium oxide (MgO), silicon dioxide (SiO₂), and phosphorous pentoxide (P₂O₅), within the ash components of the post-gasification residue [20]. This observation solidifies the fact that the residual char maintains a remarkable carbon-rich composition while maintaining low levels of inorganic constituents. Such a composition is highly advantageous, as it aligns with the characteristics desirable for a wide range of applications, akin to engineered biochars.

Table 3. EDS results of bagasse residual char

Element	Weight %	Atomic %
C	84.57	88.40
Si	1.02	0.46
O	13.91	10.91
Mg	0.26	0.14
P	0.25	0.10
Total	100.00	100.00

3.4. Porosity

An in-depth analysis of the N₂ adsorption/desorption isotherms, meticulously illustrated in Fig. 3, unveils intriguing insights into the porous structure of the residual char obtained from the gasification of bagasse. The isotherms portray a fascinatingly continuous distribution of pore sizes, indicative of a versatile and complex pore network within the material.

Intriguingly, at lower relative pressures (p/p_0 below 0.05), there is a conspicuous surge in adsorption, underscoring the presence of small micropores that are adept at capturing gas molecules. This initial phase highlights the material's capacity for accommodating minute particles. As the relative pressures p/p_0 progress beyond this threshold, a discernable deceleration in the rate of adsorption is witnessed, signifying the emergence of larger mesopores and macropores. These larger pores provide additional pathways for gas molecules to penetrate, thereby further expanding the material's adsorption capabilities.

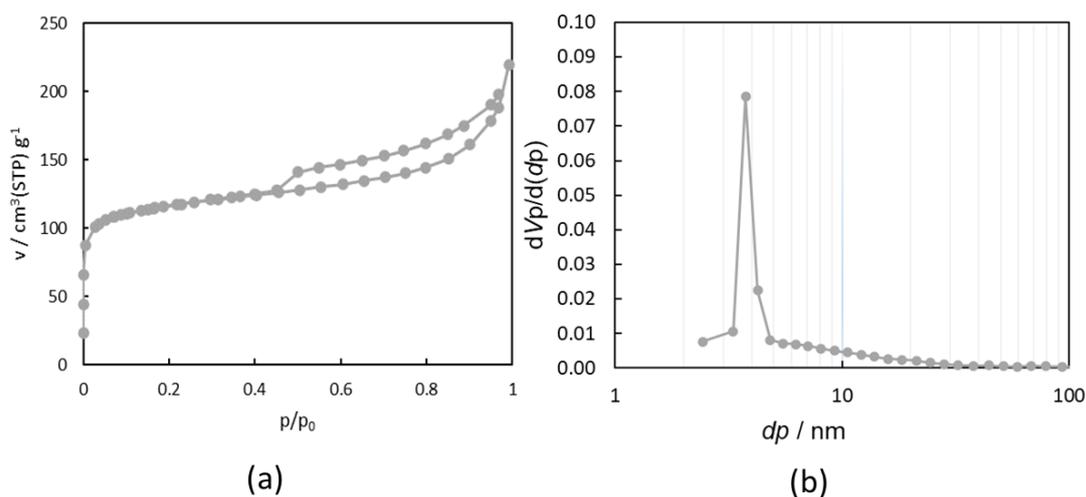


Fig. 3. Nitrogen adsorption/desorption (a) and pore size distribution (b).

The isotherms take a notable turn at higher relative pressures (p/p_0 above 0.5), showcasing the phenomenon of capillary condensation. This intriguing occurrence results in a conspicuous upturn in the isotherms, underscoring the material's ability to effectively capture and retain gases under these conditions. Furthermore, the desorption isotherm assumes a position higher than that of the adsorption isotherm, unveiling the presence of desorption hysteresis. This intricate phenomenon can be elucidated by considering the variance between the relative pressure thresholds of agglomeration and evaporation [21], demonstrating the material's intricate interplay with gases under different pressure conditions.

Upon comprehensive analysis, it is discerned that the bagasse char boasts an impressive BET surface area of $749 \text{ m}^2/\text{g}$. This substantial surface area is further complemented by the volume of micropores, accounting for approximately $0.27 \text{ cm}^3/\text{g}$ within the overall volume of $0.46 \text{ cm}^3/\text{g}$. Remarkably, nearly half of the total volume is

attributed to these micropores, a significant proportion that contributes to the remarkable surface area exhibited by the bagasse char. This level of porosity stands out prominently when compared to a plethora of biochars previously documented in the scientific literature [9, 15, 22]. Such noteworthy disparities underscore the bagasse char's distinctiveness in the realm of porosity and surface area. The prevalence of micropores and mesopores within the material accentuates its inherent adsorption properties, shedding light on its potential to serve as a cost-effective and highly efficient adsorbent material.

In summation, the intricate porous architecture of the bagasse char, characterized by its extensive surface area and abundant micropores, positions it favorably as a formidable candidate for diverse applications necessitating superior adsorption capabilities. These findings illuminate the material's potential to serve as an environmentally friendly and economically viable adsorbent.

4. Conclusion

The investigation encompassed an extensive examination of diverse properties inherent to the residual char generated subsequent to the gasification of bagasse. The char, while registering notably high ash content, intriguingly retained a substantial reservoir of carbon within its matrix. The analysis extended beyond the confines of elemental composition to encompass a comprehensive exploration of the morphology and structure of the char. This multifaceted investigation was facilitated through the utilization of advanced techniques, including scanning electron microscopy (SEM) and nitrogen adsorption/desorption analyses. These techniques collectively unveiled a relatively intricate and multifarious structural landscape underlying the char's constitution. A particularly noteworthy observation emerged concerning the char's porous architecture. The revelation of a high surface area, coupled with a relatively substantial volume of micropores, elicited keen interest. These findings collectively underscored the inherent potential harbored by the residual char stemming from the gasification of bagasse. This potential-positions the char as a promising contender in the realm of adsorbent materials.

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XÁC ĐỊNH ĐẶC TÍNH CỦA THAN THẢI SAU QUÁ TRÌNH KHÍ HÓA BÃ MÍA

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Tóm tắt: Bã mía là một trong những phế thải nông nghiệp phổ biến nhất tại Việt Nam. Ứng dụng bã mía để tạo năng lượng thông qua công nghệ khí hóa sinh khối đang là một cách tiếp cận bền vững. Tuy nhiên, các phương pháp khí hóa sinh khối hiện hành thường có hiệu quả hạn chế và tạo ra một lượng lớn tro sau quá trình khí hóa. Nghiên cứu này tập trung vào việc thu thập và đánh giá than thừa từ quá trình khí hóa bã mía trong một hệ thống thương mại. Phân tích kỹ thuật và nguyên tố cho thấy than thừa có hàm lượng tro thấp, đồng thời vẫn giữ một lượng cacbon đáng kể. Kết quả SEM-EDS cho thấy cấu trúc than tương đối phức tạp với một số ít nguyên tố vô cơ tồn tại trên bề mặt. Ngoài ra, than bã mía còn có tính rỗng xốp đáng kể, được chứng minh bằng diện tích bề mặt riêng 749 m²/g, xác định bằng phương pháp hấp phụ nitơ. Kết quả này có thể so sánh được với một số sản phẩm than hoạt tính thương mại. Các đặc điểm vật lý và hóa học của than bã mía sau quá trình khí hóa xác nhận khả năng sử dụng nó như một nguyên liệu hấp phụ có giá thành thấp và thân thiện với môi trường.

Từ khóa: Bã mía; than thừa; khí hóa; sinh khối; chất hấp phụ.

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