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PRELIMINARY CHARACTERIZATION OF RESIDUAL CHAR AFTER GASIFICATION OF RICE STRAW

PHÂN TÍCH ĐẶC TÍNH CỦA THAN THẢI SAU QUÁ TRÌNH KHÍ HÓA RƠM

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ABSTRACT

Rice straw is the most abundant agricultural waste in Vietnam. Utilizing rice straw for energy purposes through biomass gasification technology is an advanced solution. However, current biomass gasification technologies have relatively low efficiency and generate a significant amount of excess char after the gasification process. In this study, residual char from rice straw gasification in a commercial system was collected and analyzed to provide a basis for reutilization. Proximte and ultimate analysis revealed that the char from rice straw gasification has high ash content, but substantial carbon content remains. SEM-EDX analysis showed that the char has a relatively complex structure with various inorganic particles present on the surface. Furthermore, the rice straw char has a high porous structure, as indicated by its specific surface area ($438 m^2/g$), determined using the nitrogen adsorption method. The physico-chemical properties of the rice straw char after gasification demonstrate its suitability as an inexpensive and environmentally friendly adsorbent material.

Keywords: *Rice straw, gasification, residual char, adsorbent, biomass.*

TÓM TẮT

Rơm là rác thải nông nghiệp có trữ lượng nhiều nhất tại Việt Nam. Việc sử dụng rơm cho mục đích năng lượng bằng công nghệ khí hóa sinh khối là một giải pháp tiên tiến. Tuy nhiên các công nghệ khí hóa sinh khối hiện tại có hiệu suất tương đối thấp, tạo ra nhiều than thừa sau quá trình khí hóa. Trong nghiên cứu này, than thừa sau quá trình khí hóa rơm trên hệ thống thương mại được thu thập và phân tích nhằm cung cấp cơ sở dữ liệu cho việc tái sử dụng. Phân tích kỹ thuật và nguyên tố cho thấy than rơm sau khí hóa có hàm lượng tro cao, tuy nhiên làm lượng cacbon vẫn tương đối đáng kể. Phân tích SEM-EDX cho thấy than rơm có cấu trúc tương đối phức tạp với nhiều hạt vô cơ hiện diện trên bề mặt. Ngoài ra than rơm có độ rỗng xốp cao, thể hiện qua diện tích bề mặt riêng ($438 m^2/g$), xác định bằng phương pháp hấp nhả nitơ. Các đặc tính lý - hóa của than rơm sau quá trình khí hóa cho thấy sự phù hợp của than rơm sau quá trình khí hóa như một chất hấp phụ rẻ và thân thiện môi trường.

Từ khóa: *Rơm, khí hoá, than thừa, chất hấp phụ, sinh khối.*

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1. INTRODUCTION

Paddy is cultivated in more than 80 countries worldwide. The production of paddy, estimated at 750 million tons in 2016, generates a corresponding amount of approximately 750 million tons of rice straw due to the 1:1 ratio between paddy and rice straw [1]. Rice straw has traditionally found applications in low-value uses like direct combustion for cooking, construction material, and animal husbandry practices in various countries [2]. During harvest seasons, when rice straw accumulates significantly in rice mills, open burning has been a common disposal method chosen by farmers [2-4]. Unfortunately, this practice leads to severe environmental pollution and adverse health effects for local communities [5]. Nevertheless, rice straw holds potential as a valuable resource for efficient energy processes, such as gasification.

Biomass gasification is a thermochemical process that converts biomass into syngas, primarily composed of carbon monoxide (CO) and hydrogen (H_2), along with smaller amounts of carbon dioxide (CO_2), and methane (CH_4) [6]. Syngas can be utilized for heat production, electricity generation, or as a transportation fuel. In several Asian countries, such as China, India, Myanmar, Cambodia, and Thailand, there has been a growing trend in using rice straw as a feedstock for gasification [7]. Fixed-bed technology is commonly employed for gasifying rice husks due to its simple design and cost-effectiveness. However, the current technology has limitations, offering only moderate efficiency and resulting in substantial waste generation, as highlighted in previous studies [7-9].

As a result, a considerable volume of residue is produced during the gasification, and it still contains a certain amount of carbon. Previous studies have investigated the properties of these residues after gasification to identify suitable applications. The surface area of post-gasification residues in some cases can be comparable to that of expensive commercial activated carbons. This suggests that they have the potential to replace costly activated carbons [10]. Residues resulting from the gasification of agricultural materials have demonstrated a valuable combination of high carbon content and significant porosity, making them suitable for use as adsorbents [11-13]. Additionally, research has confirmed the feasibility of utilizing residues from pinewood gasification as adsorbents for capturing volatile compounds [14]. These studies emphasize the promising prospects of repurposing gasification residues as adsorbents. Despite these encouraging findings, the utilization of post-gasification residues remains relatively limited. Therefore, further comprehensive research is needed to explore and refine the application of post-gasification residues as cost-effective and environmentally friendly adsorbents.

Therefore, this study aimed at characterizing the residual char after gasification of rice straw using a commercial system, serving for its potential reutilization.

2. MATERIALS AND METHODS

2.1. Biomass feedstock and residual char collection

Rice straw was collected from the Red river Delta in Vietnam. The feedstock was air-dried for one week and gets rid of dust for other characterization. The gasification was done using a commercial gasifier (PP20 All Power Lab) using the default setup. About 50kg of rice straw was used for gasification in 2 hours. After gasification, the residual char was collected and stored in boxes for oher experiments.

2.2. Characterisation of rice straw and residual char

Proximate analysis, conducted on a dry basis, was employed to determine the volatile matter (following ASTM D-3175 standard), ash content (following ASTM D-3174 standard), and fixed carbon content (determined by the difference) of both rice straw feedstock and its corresponding char. Ultimate analysis of rice straw and its corresponding char was performed using a PerkinElmer 2400 Series II Elemental Analyzer. The morphology of rice straw and char was analyzed using scanning electron microscopy (SEM) technique.

Nitrogen adsorption/desorption analysis, carried out with the BELSORP mini II analyzer, served to characterize the pore surface area and pore size distribution of rice straw char. The specific area of the char was calculated using the Brunauer-Emmett-Teller (BET) method, while the pore size distribution and pore volume were determined using the Barrett-Johner-Halenda (BJH) method.

3. RESULTS AND DISCUSSIONS

3.1. Proximate analysis

Table 1. Proximate analysis of rice straw and its char

Biomass type	Rice straw	Residual char
Moisture (wt%, *as received*)	12.5	3.1
Bulk density (kg m^{-3})	97	190
Proximate analysis (wt%, *db.*)		
A	14.65	55.38
FC	14.95	44.02
V	70.40	0.60

Table 1 provides a summary of various properties, including volatile matter, ash content, and fixed-carbon content, obtained through proximate analysis of both rice straw and its char. The rice straw has a relatively low bulk density (97kgm^{-3}), and high moisture content leads to difficulties in the transport and usage of this type of feedstock [15]. Meanwhile, its residual char has higher bulk density (190kg/m^3) and low moisture content, which is suitable for use of different purposes [16,17].

However, high ash content of rice straw and its residual char was also detected, suggesting that the biomass usually contains a large amount of mineral contents. This could bring some troubles when using it as a source of energy, as some inorganic elements could inhibit the conversion rate, or block some part of the system after a certain time of usage [18,19]. It is noteworthy that the carbon content of residual char is still high, estimated at 44.02%, offering ideas for reutilization of rice straw char after gasification.

3.2. Ultimate analysis

Table 2 provides the ultimate analysis outcomes for rice straw and its residual char. This analysis enables the prediction of the heating value and the quality of the resulting energy product [20]. The samples typically comprise four primary elements: carbon (C), nitrogen (N), hydrogen (H), and oxygen (O). Even minor variations in the concentrations of C, H, and O within the biomass can have an impact on the composition of the energy product.

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

Biomass type	Rice straw	Residual char
C	43.85	85.29
H	4.75	2.55
N	0.25	0.29
O	51.15	11.87

According to the results mentioned in Table 2, low C and H contents compared to woody biomass was detected in the rice straw. Significantly low content of N was also present in the collected samples. This is advantageous as the potential emission of nitrogen could be neglected. The residual car, on the contrary, has a high C content, and much lower O compared to that of the rice straw.

3.3. Morphology

The morphology of rice straw and its residual char was analyzed using the SEM technique, taken at different locations on the surface of the samples.

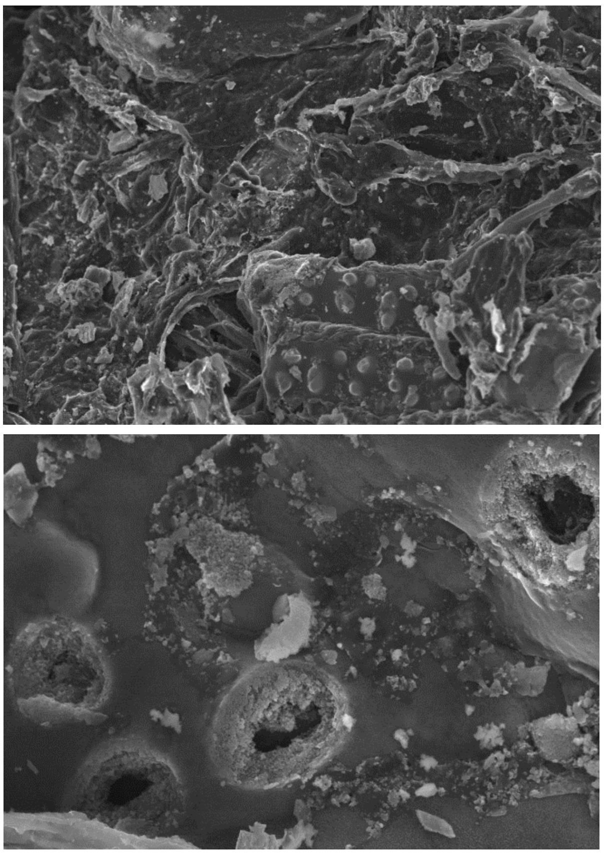
The morphological characteristics of various rice straw exhibited remarkable complexities and high heterogeneity (Figure 1). The significantly rugged outer surface of the rice straw was observed. It displays nodes, predominantly composed of silica coated with a thick cuticle. In terms of the residual char derived from rice straw, an increased number of nodes were observed on the surface. This phenomenon is indicative of higher ash content, resulting in the presence of inorganic materials exposed on the sample's surface.

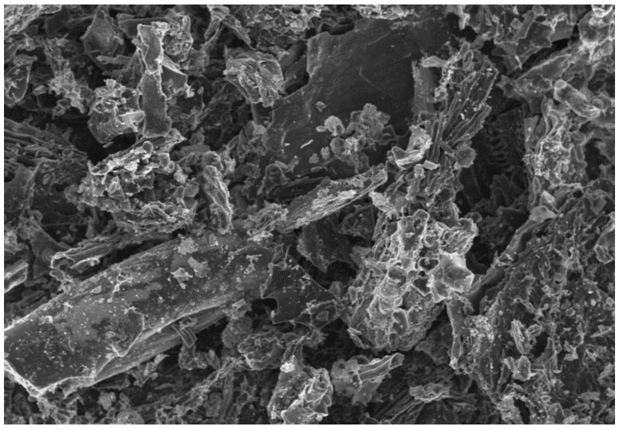
3.4. Porosity

The N_2 adsorption/desorption isotherms (Figure 2) of the residual char derived from rice straw exhibited a relatively continuous distribution of pore sizes. At low relative pressures (p/p_0 below 0.05), there was a significant increase in adsorption, indicating the presence of small micropores. As the relative pressures p/p_0 increased, the rate of adsorption increase slowed down, signifying the existence of mesopores and macropores. At higher relative pressures (p/p_0 above 0.5), capillary condensation became apparent, resulting in an upturn in the isotherms. Additionally, the desorption isotherm was positioned higher than the adsorption isotherm, indicating the occurrence of desorption hysteresis. This phenomenon can be explained by the difference between the relative pressure of agglomeration and that of evaporation [21].

The rice straw char exhibited a BET surface area of 438m^2/g, with the volume of microspores accounting for approximately 0.15cm^3/g of the total volume of 0.34cm^3/g. While the volume of micropores was relatively small in proportion to the total volume, it resulted in a significantly high surface area in the rice straw char. This level of porosity is notably higher when compared to other biochars reported in the literature [11, 13, 18]. These findings emphasize that the residual char possesses adsorption properties attributed to its micropores and mesopores, underscoring its potential as a cost-effective and efficient adsorbent.

Rice straw





Residual char of rice straw

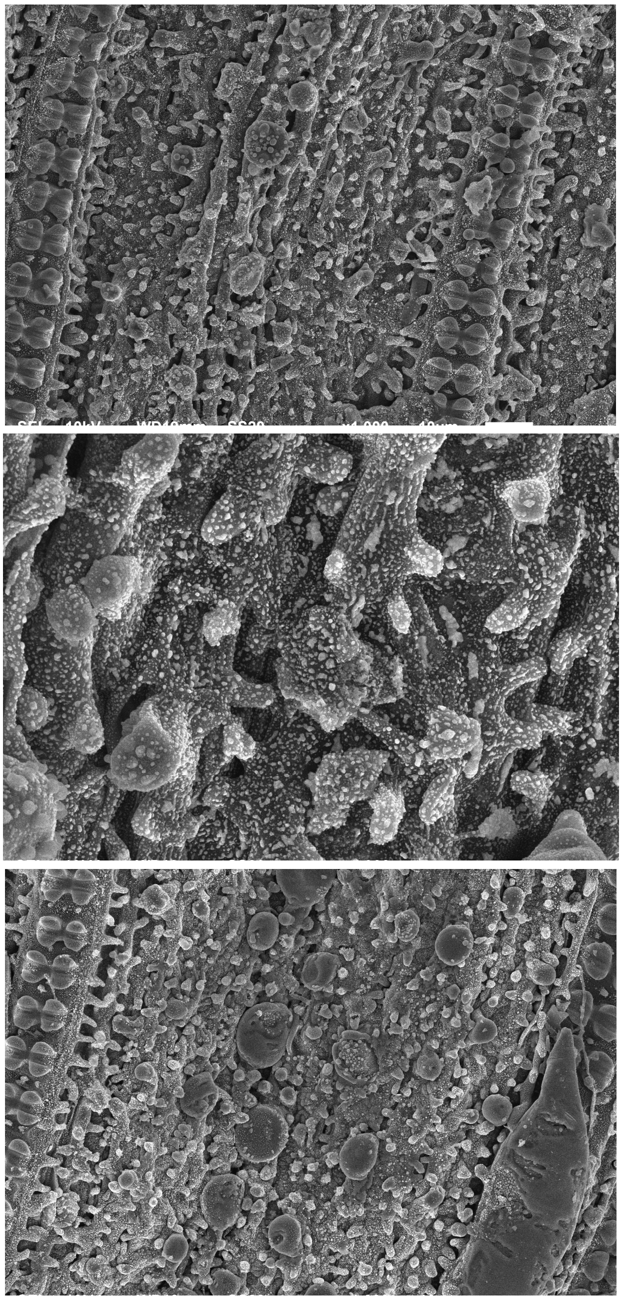


Figure 1. SEM images of rice straw and its residual char

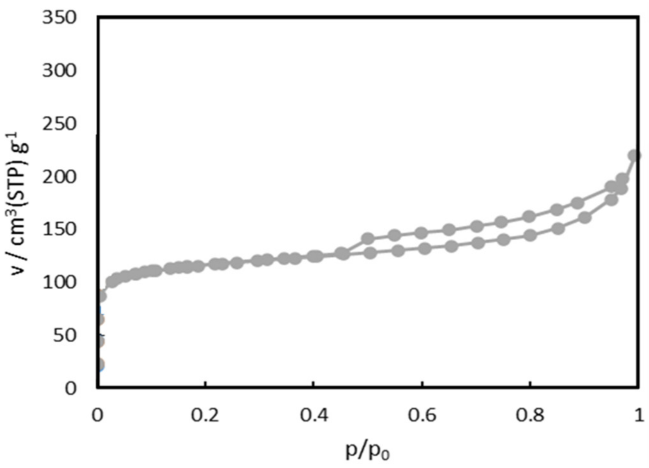


Figure 2. N_2 adsorption/desorption of residual char

4. CONCLUSION

Several properties of residual char after the gasification of rice straw were analyzed. The results of proximate and ultimate analysis revealed that the char, despite having a high ash content, still contained a significant amount of carbon. The morphology and structure of the char were relatively complex, as evidenced by SEM images and N_2 adsorption/desorption techniques. Furthermore, the high surface area with a relatively large volume of micropores suggests that residual char resulting from the gasification of rice straw has the potential to serve as a cost-effective and efficient adsorbent.

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