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EFFECT OF HYDROTHERMAL TEMPERATURE ON SAWDUST HYDROCHAR PRODUCTION PRODUCED THROUGH MICROWAVE-ASSISTED ARTIFICIAL COALIFICATION

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ABSTRACT

A microwave mode of heating was utilized to produce sawdust hydrochar through the artificial coalification process. Hydrochar was synthesized at temperatures 180, 200 and 220 °C with a 1:10 solid to water ratio and residence time of 40 minutes. Hydrochar was characterized for proximate properties and energy quality. With the increase in the temperature from 180 to 220 °C, hydrochar yield decreased from 76.69 to 58.35 %. The volatile matter and ash content depicted a decreasing trend and the energy content of hydrochar showed an increasing trend with the increase in the process temperature. The ratio of energy densification of hydrochar was in the range of 1.04 to 1.26.

KEY WORDS: Sawdust, Hydrochar, Microwave, Artificial coalification, Energy quality

INTRODUCTION

In the past few decades, interest in solid fuel generation from renewable sources is gaining a lot of attention (Maniscalco *et al*., 2020). The huge increase in energy demand necessitates the excess utilization of conventional fossil fuel resources causing global warming and the enormous release of greenhouse gases into the atmosphere, which results in ecosystem degradation (Zhang *et al*., 2018). The transformation from conventional energy resources to low-cost and renewable sources is a viable and effective way to fulfill the global energy demand in a sustainable way (Ingrao *et al*., 2019). Biomass is one of the potential renewable energy sources and is available plenty in nature. It is increasingly utilized for heat and power generation applications (Chen *et al*., 2012). Direct utilization of lignocellulosic materials is limited because of the lower energy value and transportation and storage issues caused by the complex structure and lower density associated with the biomass (Messineo *et al*., 2014).

There are several ways for synthesizing carbon-rich solid products from lignocellulosic biomass materials to convert waste into valuable products which may be used as an alternative solid fuel for energy applications. The conversion methods may be chemical, biological, physical or thermochemical (Guiotoku *et al*., 2011). Artificial coalification is one of such energy-efficient thermochemical conversion techniques in which feedstock is heated in a subcritical water environment at 180-250 °C under pressure to produce hydrochar (Lucian *et al*., 2018). The increased higher heating value and reduced ash content are the main objective of solid fuel synthesis which can be achieved through artificial coalification (Reza *et al*., 2013). Microwave technology delivers selective, quick and homogeneous heating, which greatly decreases processing time and costs and is more energy-efficient than conventional heating (Guiotoku *et al*., 2009). The microwave mode of heating involves high-frequency electromagnetic radiation that ranges from 300 MHz to 300 GHz. Although conventional hydrothermal treatment has been extensively studied, studies on microwave hydrothermal treatment have been reported very rarely. This study aims to explore microwave-assisted artificial coalification for hydrochar synthesis and to study the effect of hydrothermal temperature on the solid product yield and higher heating value.

MATERIALS AND METHODS

Feedstock collection

Sawdust was collected from nearby sawmills at Coimbatore. The collected sawdust was sieved (0.2 mm) for uniformity of particle size and dried in a solar dryer. The dried sawdust was stored in an air-tight bag for further studies.

Hydrochar synthesis

Sawdust hydrochar was produced in a microwave system (Milestone, Ethos Easy) having two magnetrons of 950 W capacity with 2.45 GHz. Sawdust and distilled water mixed in a 1:10 solid to liquid ratio was placed in the digestion vessel and capped tightly. The process temperature varied from 180 to 220 °C with a temperature interval of 20 °C and residence time of 40 minutes. After the completion of the process, the char and liquid slurry was filtered using filter paper (Whatman No. 3). The wet solid material retained in the filter paper was dried in a conventional electrical hot air oven at 105 °C for 24 h. The dried hydrochar was stored in an air-tight bag for further characterization studies. The synthesized hydrochar at 180, 200 and 220 °C were denoted as SDHC 180, SDHC 200 and SDHC 220 respectively.

The yield of hydrochar was calculated using Eqn. 1.

$$\text{Hydrochar yield}(\%) = \frac{\text{Mass of sawdust hydrochar (g)}}{\text{Mass of sawdust (g)}} \times 100 \quad .. (1)$$

Characterization of sawdust and hydrochar

The proximate analysis of sawdust was analyzed as per ASTM procedure to determine moisture (D3173), volatile matter (D3175) and ash content (D3174). The fixed carbon content of sawdust was calculated by subtracting the volatile and ash content from a total of 100. The Higher Heating Value (HHV) was determined using a digital bomb calorimeter (C200, IKA, USA). The degree of densification of energy obtained in the hydrochar was assessed using Eqn. 2.

$$\text{Ratio of energy densification } (\%) = \frac{\text{HHV of sawdust hydrochar (g)}}{\text{HHV of sawdust (g)}} \times 100 \quad .. (2)$$

RESULTS AND DISCUSSION

The results obtained for the experimental study and detailed characterization of the synthesized hydrochar were discussed below.

Physicochemical properties of sawdust

The proximate analysis of sawdust was carried out to determine the volatile matter, ash content and fixed carbon content of the feedstock. The volatile matter was found to be 77.6 % and ash content was found to be 1.3 %. The fixed carbon content of sawdust was determined by subtracting volatile and ash content from 100. The fixed carbon content of sawdust was 21.1 %. The energy content of sawdust in terms of HHV was 19.7 MJ/kg. At the raw material stage, sawdust possessed higher volatile matter and lower fixed carbon content. The yield of hydrochar and characterization of hydrochar are shown in Table 1.

Effect of temperature on the yield of sawdust hydrochar

With the increase in the artificial coalification process temperature from 180 to 220 °C, the yield of hydrochar decreased from 76.69 to 58.35 %. The decreasing trend of hydrochar yield with the increase in process temperature was also observed for rice husk (Nizamuddin *et al.*, 2018) and green

Table 1. Sawdust hydrochar yield and characterization

Material	Temp (°C)	Time (min)	SDHC Yield (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	HHV (MJ/kg)	Ratio of energy densification
Sawdust	-	-	-	77.6	1.3	21.1	19.7	-
SDHC 180	180	40	76.69	73.5	1.2	25.3	20.43	1.04
SDHC 200	200	40	69.17	69.7	0.9	29.4	21.91	1.11
SDHC 220	220	40	58.35	64.1	0.7	35.2	24.82	1.26

waste (Shao *et al.*, 2019). The severity of the process intensified with the increase in process temperature, which aids in the enhanced degradation of biomass under a hot compressed water environment. The improved degradation with the higher temperature may be the reason for the lower hydrochar yield at 220 °C.

Effect of temperature on the proximate properties of sawdust hydrochar

The volatile matter of sawdust hydrochar displayed a reducing trend from 73.5 to 64.1 % with the increase in process temperature from 180 to 220 °C. Due to hydrolysis, dehydration and decarboxylation reactions, the volatile compounds present in the sawdust were eluted from the biomass matrix under the pressurized water environment, which may be the reason behind the volatile matter reduction. The ash content also showed a decreasing trend from 1.2 to 0.7 % for sawdust hydrochar produced in the temperature range of 180 and 220 °C. Leaching of inorganic ash content materials into the hydrochar liquor due to the respective temperature and pressure may be the reason for the ash content reduction with the increase in temperature. The reduction in both volatile and ash content in hydrochar ultimately increased the hydrochar fixed carbon content from 25.3 to 35.2 %. A similar kind of decreasing trend of volatile matter and ash content was also evident in different studies carried out for willow wood (Knappe *et al.*, 2018), corncob (Arellanoa *et al.*, 2016) and empty fruit bunches (Parshetti *et al.*, 2013).

Effect of temperature on energy quality of sawdust hydrochar

The energy content of hydrochar was an important index to determine the utility potential of hydrochar as a solid fuel. The energy value of hydrochar increased from 20.43 to 24.82 MJ/kg with the increase in the process temperature from 180 to 220 °C. This increasing trend was also evident from studies carried out for rapeseed husk (Elaigwu and Greenway, 2016) and coconut shells (Elaigwu and Greenway, 2019). Due to the increase in the process severity conditions in terms of temperature, the enhanced degradation of sawdust was initiated through different process reactions including hydrolysis, dehydration, decarboxylation, polymerization and aromatization. The improved degradation of biomass under a subcritical water environment preserved the partial lignin structure unaffected with partial or complete degradation of hemicellulose and cellulose, which may be the reason for the increase in the energy content of hydrochar with the increase in the process temperature. The ratio of energy densification was increased by 4, 11 and 26 % when compared to the unmodified raw sawdust.

CONCLUSION

In this study, Sawdust hydrochar was synthesized at 180, 200 and 220 °C with a 1:10 solid to liquid ratio and 40 minutes of residence time. Hydrochar produced at 220 °C possessed improved characteristics in terms of higher heating value (24.82 MJ/kg) and fixed carbon content (35.2 %). The microwave mode of heating can be utilized for hydrochar synthesis because of the reduced processing time and improved quality of hydrochar. The results of the study reveal that the hydrochar produced at 220 °C through microwave-assisted artificial coalification can be used as a solid fuel for heating applications.

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REFERENCES

Arellanoa, O., Flores, M., Guerra, J., Hidalgo, A., Rojas, D. and Strubinger, A. 2016. Hydrothermal carbonization (HTC) of corncob and characterization of the obtained hydrochar. *Chem. Eng.* 50 : 1-6.

Chen, W. H., Ye, S. C. and Sheen, H. K. 2012. Hydrothermal carbonization of sugarcane bagasse via wet torrefaction in association with microwave heating. *Bioresour. Technol.* 118 : 195-203.

Elaigwu, S. E. and Greenway, G. M. 2014. Biomass derived mesoporous carbon monoliths via an evaporation-induced self-assembly. *Mater. Lett.* 115 : 117-120.

Elaigwu, S. E. and Greenway, G. M. 2016. Microwave-assisted hydrothermal carbonization of rapeseed husk: a strategy for improving its solid fuel properties. *Fuel Process. Technol.* 149 : 305-312.

Elaigwu, S. E. and Greenway, G. M. 2019. Characterization of energy-rich hydrochars from microwave-assisted hydrothermal carbonization of coconut shell. *Waste and Biomass Valorization*. 10(7) : 1979-1987.

Guiotoku, M., Rambo, C. R., Hansel, F. A., Magalhães, W. L. E. and Hotza, D. 2009. Microwave-assisted hydrothermal carbonization of lignocellulosic materials. *Mater. Lett.* 63(30) : 2707-2709.

Guiotoku, M., Rambo, C., Maia, C. and Hotza, D. (Ed.) 2011. Synthesis of carbon-based materials by microwave-assisted hydrothermal process. Microwave Heating. Intech Open.

Ingrao, C., Bacenetti, J., Adamczyk, J., Ferrante, V., Messineo, A. and Huisingh, D. 2019. Investigating energy and environmental issues of agro-biogas derived energy systems: A comprehensive review of Life Cycle Assessments. *Renew. Energy*. 136: 296-307.

Knappe, V., Paczkowski, S., Tejada, J., Robles, L. A. D., Gonzales, A. and Pelz, S. 2018. Low temperature microwave assisted hydrothermal carbonization (MAHC) reduces combustion emission precursors in short rotation coppice willow wood. *J. Anal. Appl. Pyrolysis*. 134 : 162-166.

Lucian, M., Volpe, M., Gao, L., Piro, G., Goldfarb, J. L. and Fiori, L. 2018. Impact of hydrothermal carbonization conditions on the formation of hydrochars and secondary chars from the organic fraction of municipal solid waste. *Fuel*. 233 : 257-268.

Maniscalco, M. P., Volpe, M. and Messineo, A. 2020. Hydrothermal carbonization as a valuable tool for energy and environmental applications: A review. *Energies*. 13(16) : 4098.

Messineo, A., Ciulla, G., Messineo, S., Volpe, M. and Volpe, R. 2014. Evaluation of equilibrium moisture content in ligno-cellulosic residues of olive culture. *ARPN J. Eng. Appl. Sci.* 9 : 5-11.

Nizamuddin, S., Siddiqui, M. T. H., Baloch, H. A., Mubarak, N. M., Griffin, G., Madapusi, S. and Tanksale, A. 2018. Upgradation of chemical, fuel, thermal, and structural properties of rice husk through microwave-assisted hydrothermal carbonization. *Environ. Sci. Pollut. Res.* 25(18) : 17529-17539.

Parshetti, G. K., Hoekman, S. K. and Balasubramanian, R. 2013. Chemical, structural and combustion characteristics of carbonaceous products obtained by hydrothermal carbonization of palm empty fruit bunches. *Bioresour. Technol.* 135 : 683-689.

Reza, M. T., Lynam, J. G., Uddin, M. H. and Coronella, C. J. 2013. Hydrothermal carbonization: Fate of inorganics. *Biomass and Bioenergy*. 49 : 86-94.

Shao, Y., Long, Y., Wang, H., Liu, D., Shen, D. and Chen, T. 2019. Hydrochar derived from green waste by microwave hydrothermal carbonization. *Renew. Energy*. 135 : 1327-1334.

Zhang, B., Heidari, M., Regmi, B., Salaudeen, S., Arku, P., Thimmannagari, M. and Dutta, A. 2018. Hydrothermal carbonization of fruit wastes: A promising technique for generating hydrochar. *Energies.* 11(8) : 2022.