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Energy Yield of Torrefied Rice Husk at Atmospheric Condition

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Abstract

Torrefaction is a thermal treatment for lignocellulosic waste biomass at low temperature, which has been found to be effective not only for improving the quality of biomass solid fuels, in terms of higher energy density, longer shelf life and hydrophobic in nature, but also to make them useful as a feedstock for further decomposition such as gasification and liquefaction. In this study, torrefaction of rice husk is carried out in a fixed bed reactor under atmospheric condition at a temperature range of 200 to 300°C, in order to clarify the effect of air on torrefaction of rice husk.

Keywords: Torrefaction, Rice husk, Mass yield, Calorific value ratio, Energy yield.

1. Introduction

Biomass is considered one of the most abundant resources on earth and can be used as feed stock of fuel in its' solid, liquid or gaseous form and chemicals. Lignocellulosic waste biomass is drawing attention worldwide because of its non-edible characteristics. Rice husk is considered to be the best source of biomass energy obtained as milling waste of rice processing centers [1]. In 2009, Bangladesh produced about 9.0 million tonnes of rice husk and it is the fourth largest production of the total world supply of rice husk [2, 3]. Torrefaction is thermal treatment of biomass at 200 to 300° C temperatures under an inert atmosphere is found to be effective for enhancing the energy density and shelf life of the biomass and has been reported for wood and grass biomass over the past few years [4-10].

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Torrefaction can be used to increase the energy content of wood or to facilitate grinding. Couhert et al. confirmed that torrefaction decreased the oxygen carbon ratio [4]. Arias et al. studied torrefied woody biomass (eucalyptus) in order to improve its properties for pulverized systems consisting in a heating treatment at moderate temperature (240, 260, 280 °C) under an inert atmosphere [5]. Torrefaction improves the properties of biomass in relation to energy conversion techniques; e.g., combustion, co-combustion with coal or gasification**.** Bridgeman et al. showed that both volatile and char combustion of the torrefied biomass become more exothermic compared to the raw biomass, and that depending on the degree of the torrefaction. They also reported that torrefied fuel can contain up to 96% of the original energy content on a mass basis and ignites more quickly [6]. After torrefaction the wood briquettes showed an increase of approximately 15 % in heating value, and a decrease of approximately 73% in equilibrium moisture. Torrefied briquettes show hydrophobic nature during storage [7]. The increase of the heating value of the torrefied rice straw and rape seed stalk compared with the raw material are 17% and 15%, respectively [8]. Study results from torrefaction processes of four kinds of biomass materials, including bamboo, willow, coconut shell and wood (Ficus Benjamina L.) show that the biomass torrefied in less than 1 hour with light torrefaction (240°C) is an appropriate operation for producing fuels with higher energy density [9]. Torrefaction or thermal pretreatment of biomass can produce an energy dense and consistent quality solid biomass fuel for combustion and co-firing applications. The results of torrefied pine chips and logging residues showed the improved fuel characteristics and grinding properties closer to coal [10]. There are several research reports on torrefaction of biomass from forest product and some residues however; little information is found on torrefaction of rice husk [28]. Torrefaction process requires heat energy. Then the process could not be energy efficient. Rice husk is produced in rice milling centers of Bangladesh. Rice milling center has a rice husk fired boiler unit [11]. A huge waste heat is liberated from the boiler with temperature ranges of 600 to 700°C. This waste heat can be used to meet up the requirement of heat energy for torrefaction. Most of the torrefaction process is reported under inert (nitrogen) atmosphere. When the waste thermal energy is used for torrefaction, the gas contains some components other than nitrogen such as oxygen, carbon dioxide and water vapor. The oxygen content is thought the worst problem for torrefaction, because there is a possibility of higher oxidation during the process. However, Uemura et al reported that torrefaction can be done without any significant problem in environment with oxygen content in the range of 3 to 15% [24, 25]. The oxygen content in flue gas from boilers used in rice mill is reported in the range of 7-8% [27]. Hence torrefaction under static air would be cost effective and affordable for local condition of rice millers in Bangladesh. A method of comparison study of torrefaction of different varieties of rice husk is reported in Ahiduzzaman [26]. . In this paper, torrefaction of rice husk is carried out in a fixed bed reactor in the presence of static air to answer the question above.

2. Methodology

2.1 Torrefaction

Torrefaction of the rice husk samples is carried out using a crucible as reactor made of ceramic. Four gram of each sample was weighed, and put in a ceramic crucible. The crucible is placed in a muffle furnace having a digital PID controller (jSR Model: JSMF-45T). Time and temperature for torrefaction of each sample is maintained by setting program with PID control of muffle furnace. The temperature of the reactor was raised to desired levels, *i.e.* 200, 250 or 300°C by switching on the furnace. Samples are heated at three different duration of heating for torrefaction, i.e. 10, 20 and 30 min. After finishing the torrefaction, the sample is then removed from furnace and left to cool down at an ambient temperature. The torrefied sample of husk is then weighed and kept in desicator till the characterization. Three replication of each sample are analyzed and an average value is taken.

2.2 Measurements

The moisture content, proximate contents (volatile matter, fixed carbon and ash), mass and the calorific value are measured before and after torrefaction. Volatile matter is determined as per British Standard BS EN 1860 [12]. Fixed carbon and ash content of the samples are determined by following the methods described in Tariq et al. and Rees et al. [13, 17]. The calorific value of rice husk samples are measured using a bomb calorimeter, model CH80b

MAHLER CALORIMETER manufactured by ISI IMPIANTO, ITALIA. Detail description of the method is reported in Ahiduzzaman [26]. From the experimental results, mass yield, calorific value ratio and energy yield are calculated by using the following equations:

$$Mass\ yield = \frac{Mass\ of\ solid\ sample\ after\ torrefaction}{Initial\ mass\ of\ sample} \times 100\% - - - [1]$$

$$Calorific\ value\ ratio = \frac{Calorific\ value\ of\ solid\ sample\ after\ torrefaction}{Calorific\ value\ of\ rice\ husk\ sample\ used} - - - - [2]$$

$$Energy\ yield = Mass\ yield \times Calorific\ value\ ratio\ - - - - - - - [3]$$

3. Results and Discussions

3.1 Proximate analysis of raw husk

The results show that volatile matter, fixed carbon and ash content of husk are 62.84%, 15.09% and 22.07%, respectively. Iyer et al. also reported that the volatile matter of rice husk from different location varied from 65% to 67% while the fixed carbon and ash content varied from 11.2% to 18% and from 13.1% to 22.4% respectively [14]. Kargbo et al. reported that the volatile matter of rice husk is 63.52% [15]. These results are very close to the results of this study although the physical properties of biomass frequently depend on the soil and geographical location of biomass produced. In this study BRRIdhan50 variety of husk is taken for detail analysis of torrefied husk to identify the optimum combination of torrefaction factor in the next section.

3.2 Effect of torrefaction on proximate contents of rice husk

Proximate analysis results of torrefied husk samples at 200, 250 and 300°C for 10, 20 and 30 minutes of heating are shown in Fig. 1, Fig. 2 and Fig. 3. Volatile matter contents decrease in torrefied samples with increase of both temperature and residence time. Whereas, fixed carbon and ash contents increase due to the increasing temperature and duration of heating. Highest volatile matter is found to be 61% at 200°C for 10 min of heating and lowest volatiles matter is found to be 24.68% at 300°C for 30 min heating. Fixed carbon and ash content increase to 32.58% and 42.74% at 300°C for 30 min from their original value of 15.09% and 22.07%, respectively. Sridhar et al. reported that volatile matter decrease and fixed carbon increase with increase in temperature of torrefaction for bamboo [16]. Almeida et al. also reported that an increase in fixed carbon and a decrease in volatile matter with increased temperature and duration of torrefaction reaction occurred for different wood and bark biomass [19].

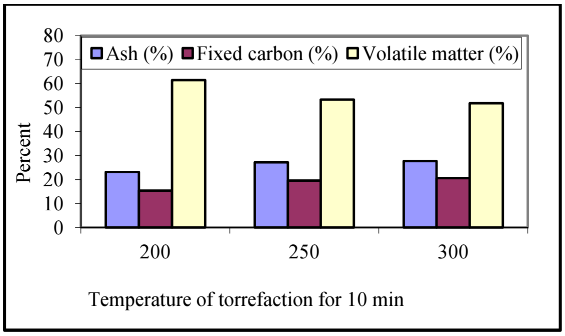

Fig.1. Proximate analysis of torrefied rice husk after 10 minute of residence time

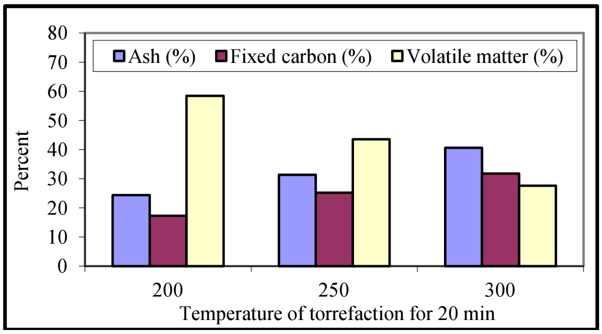

Fig.2. Proximate analysis of torrefied rice husk after 20 minute of residence time

3.3 Effect of torrefaction on mass yield of rice husk

Mass yield of torrefied samples were measured in percent of original mass of sample and presented in Fig. 4. Highest mass yield was 90% at 200°C and 10 min of torrefaction and lowest mass yield was 50% at 300°C and 30 min of torrefaction. This is a genral norm that the rate of mass loss depends on the parameters of torrefaction. In this study it is found that mass loss increases with increase in temperature and reaction time. Similar results for mass loss of torrefied biomass also is reported in previous studies [18, 19].

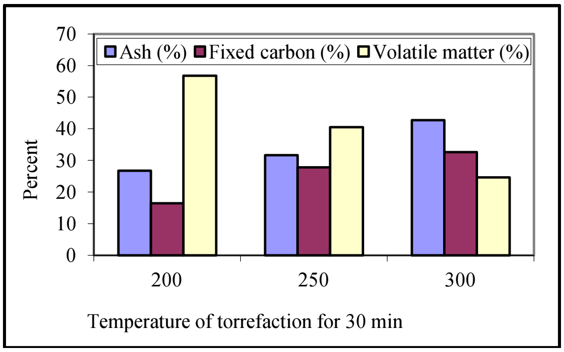

Fig.3. Proximate analysis of torrefied rice husk after 30 minute of residence time

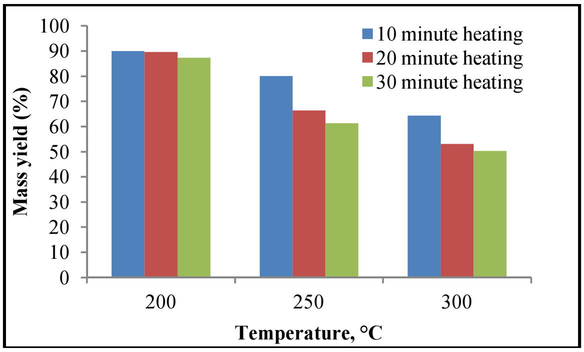

Fig.4. Mass yield of torrefied rice husk at different temperature and residence time

3.4 Effect of torrefaction on calorific value

Calorific value of each sample of torrefied rice husk is measured and presented in Fig. 5. There is an interaction effect of temperature and residence time on calorific value of torrefied rice husk. Calorific value increases remarkly with increasing of heating temperature for a reaction time of 10 min and decreases for a reaction duration of 30 min. Calorific value increases minorly with increasing of temperature of heating under the condition of 20 min of reaction duration. It is reported that calorific value of torrefied wood increases with increase in temperature and duration of reaction [19, 20, 21]. However, for rice husk the calorific value decrease at higher heating time. This phenomenon occured might be due to the increase of mass fraction of ash in torrefied husk. McKendry also reported that the energy of the fuel is reduced in proportion to the magnitude of the ash content [22]. Calorific value ratio of raw husk and torrefied husk are presented in Fig. 6. The highest carific value ratio is found to be 1.33 under the condition of 300°C and 10 min duration of heating. The lowest calorific value ratio is found to be 1.08 under the condition of 300°C and 30 min duration of heating. The results confirm that for obtaining higher energy density, higher heating temperature and lower heating duration is the optimum condition.

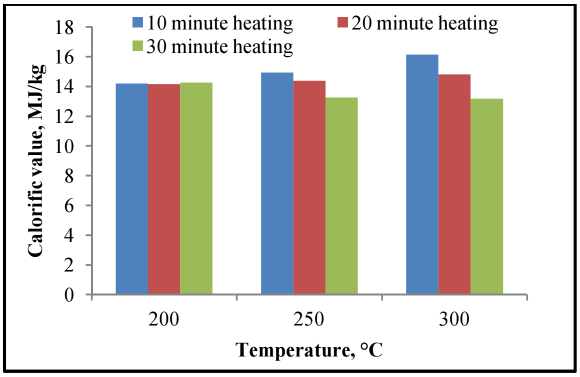

Fig.5. Calorific value of torrefied rice husk at different temperature and residence time

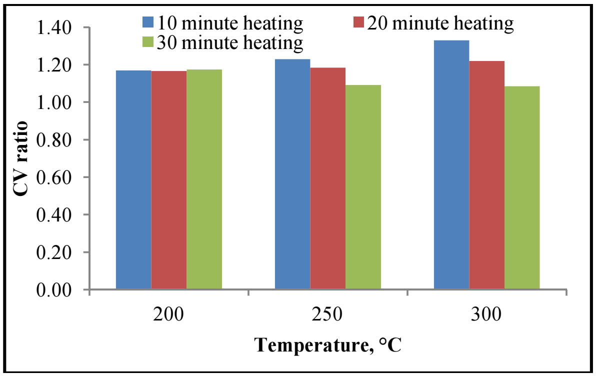

Fig.6. Calorific value ratio of torrefied rice husk and raw husk at different temperature and residence time

3.5 Effect of torrefaction on moisture content of rice husk

During the torrefaction process signifcant amount of moisture is removed. The lowest moisture content is found at 300°C for 30 minutes of heating duration [Table 1]. The results show that the rice husk achieves hydrophobic nature after torrefaction. Thus enhances the maximum energy recovery during the combustion of torrefied biomass.

Table 1. Changes in moisture cotnent of torrefied husk at different time and temperature conditions

Temperature	Moisture content (%) of torrefied product at different condition		
	10 min	20 min	30 min
200°C	2.81	2.31	2.04
250°C	2.28	1.75	1.47
300°C	2.08	1.74	1.46
Control (raw husk)		9.07	

3.6 Effect of torrefaction on energy yield of rice husk

Energy yield indicates the improvement of calorific value of rice husk by torrefaction and it is the key parameter for defining the fuel quality. Fig. 7 shows the relationship between energy yield and temperature at different residence time for 10, 20 and 30 minutres. The energy yield was found in the range of 55% to 105% for torrefied husk. The results show that energy yield decreases with increase in temperature and residence time. The highest energy yield is found at 200°C of heating temperature. Energy yield is found to be 105.3%, 104.5% and 102.5% for 10, 20 and 30 min of residence time, respectively at 200°C. The energy yield at 250°C for reaction period of 10 min was found to be 98%. The energy yield value over 100% means the moisture and some non-energy volatile are significantly removed during torrefaction process. From the results it is recommended that the optimum torrefaction of rice husk should be at a temperature range of 200-300°C for a reaction period of 10-30 minutes. Similar results are reported for other types of biomass such as torrefied wood briquette shows 97% of energy yield for 30 minute of heating duration at 220°C [18] and energy yield of willow is 94.9% at 280°C for 17.5 min reaction time [23]. Uemura et al reported that torrefaction can be done without any significant problem in environment with oxygen content in the range of 3 to 15% [24, 25].

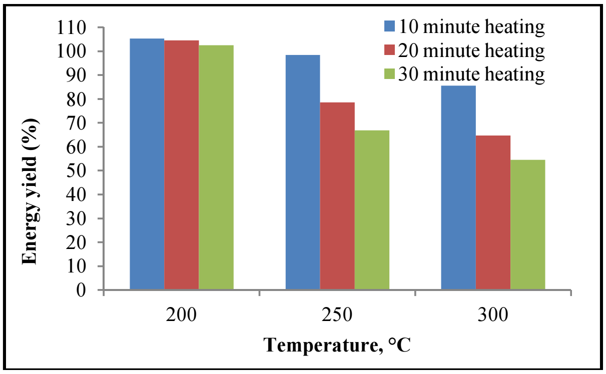

Fig. 7: Energy yield of torrefied rice husk at different temperature and residence time.

4. Conclusion

Torrefaction of rice husk was carried out in the presence of air in order to investigate the effects of various torrefaction conditions, viz., different temperature level (200, 250 and 300°C), different duration of heating (10, 20 and 30 min), on the change in moisture content, mass recovery, calorific value and energy yields. The mass yield decreased noticeably with an increase in temperature and residence time. The results confirm that torrefaction reaction rate is affected by both the temperature and residence time. The calorific value and calorific value ratio show a complex behavior. Caloric value increases considerably with increase in temperature for 10 min of residence time. On the other hand these values decrease with increase in temperature for 30 min of residence time. The energy yield decreases with an increase in temperature and residence time, but all the values fell between 105 and 103% at 200°C for 10 min residence time. It is worthwhile pointing out that torrefaction in the presence of static air can be carried out without any significant problem. Since the temperature of flue gas from rice parboiling boiler contains lower oxygen (7-8% oxygen) compared to air, then the flue gas is more suitable for torrefaction media when it is directly in the reactor.

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