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Characterization of Rice Husk for Cyclone Gasifier

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Abstract: The characterization of rice husk from local rice mills has been studied and evaluated to determine its potential utilization as a biomass fuel for a cyclone gasifier. The raw rice husk was pre-treated throughout a grinding process into smaller sizes of particles which is within a range of 0.4 to 1 mm and the sample of ground rice husk was analyzed for its fuel characteristics. The result of proximate analysis shows that the ground rice husk with size distribution within 0.4 to 1 mm contains 13.4% of fixed carbon, 62.95% of volatile matter and 18.5% of ash on dry basis. The moisture content of the sample was measured and determined as 10.4% (wet basis) and the calorific value was found to be approximately 14.8 MJ kg^{-1} with bulk density of 91.46 kg m^{-3}. The result of ultimate analysis validates both ash and moisture content which are found to be 18.15 and 10.4%, respectively. Other elemental compositions determined by the ultimate analysis are carbon (37.9%), hydrogen (5.2%), nitrogen (0.14%), sulfur (0.61%) and oxygen (27.7% by difference). The study has identified that the fuel characteristics of the ground rice husk is comparable with other types of biomass and thus, making it another potential source of fuel for the cyclone gasification system.

Key words: Biomass, rice husk, fuel characteristics, ash content, characterization, cyclone gasifier

INTRODUCTION

In the future, our energy systems will need to be renewable and sustainable, efficient and cost effective, convenient and safe (Helena and Ralph, 2001). Biomass is seen as an interesting energy source for several reasons. The main reason is that bioenergy can contribute to sustainable development. Resources are often locally available and conversion into secondary energy carriers is feasible without high capital investments. In addition, the importance of biomass as fuel has increased during the last decades for two main reasons. The first reason is the oil crisis and the second one is the effort to control the greenhouse effect caused by the emissions of CO_2 increases (Monique *et al*., 2003). There are several ways of reducing the CO_2 emissions and the use of biomass as fuel is one of them.

Biomass represents large quantities of residues, associated with agricultural production and processing industries. The main utilizations of biomass are energy production and thermal applications. And for the worldwide energy production, biomass contributes 14% of the total energy supply. Extensive studies have been done on various forms of biomass for converting them into fuel. One of the most potential biomass energy sources which are widely available in the Asia-Pacific region is rice husk. Rice husk is referred to an outer cover of the rice grain and is in the form of hull. The husk accounts for 22% of the weight of paddy and 78% of the weight is received as rice, broken rice and bran throughout the milling process (Umamaheswaran and Batra, 2007). In Malaysia, rice husk and paddy straw have become a major potential for Biomass-Based Power Generation after wood and palm oil residues. Mazlina (2005) reported that the rice husk generated in Malaysia in year 2000 has reached up to 471 thousand tones and the potential power generated from the utilization of rice husk was about 72.07 MW. And for paddy straw, the residue generated in year 2000 was 856 thousand tones and the potential power generated from paddy straw was about 83.86 MW. This trend is expected to continue increasing every year.

Recently, there are few appealing methods of converting the rice husk to a useful form of product that fulfills both thermal and energy requirements. Maiti *et al*. (2006) conducted both physical and thermochemical characterization on rice husk char yielded from a fixed bed pyrolysis of rice husk. The rice husk char is palletized and combusted under certain parameters. The results of analysis show that the rice husk char is potential to be utilized as one of the biomass energy sources.

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Umamaheswaran and Batra (2007) determined high silica content with negligible amounts of volatile oxides or salts in rice husk ash via physico-chemical characterization process. It is found that the rice husk ash can be ground into powder and further processed for ceramic products.

Apparently, the studies associated with the conversion of rice husk to useful forms of energy are tend to focus on the processing of end products like ash and char obtained from the rice husk gasification process. The tendency might be due to an inefficient gasification process from conventional gasifiers such as fixed bed gasifiers to produce a clean and hot producer gas without tar and particulate matter for further applications such as thermal and power generation. The latest development of cyclone gasification technique might change the scenario. The recent studies show that a cyclone gasifier is capable to maintain the fuel temperature at a level where ash vaporization will not occur and the corrosive ashes would remain solid in the char particles. Thus, an efficient gasification of biomass with high ash content like rice husk can be realized using the cyclone gasification system. As a result, the utilization of rice husk will not only concentrate on its end products throughout the gasification process but also as a useful source of fuel for the cyclone gasifier.

For few decades, cyclones were studied to be as an alternative to gasify smaller particles of biomass. Since its original function is to separate solid particles from clean gas/air, it can increase the efficiency of gasification process if used as a gasifier where cyclone gasifier can be dual-functional gasifier, meaning that it gasifies the biomass and separate the harmful particles from the producer gas.

Fredriksson (1999) reported the experimental investigation of cyclone gasifier using commercial Swedish wood powder as a biomass fuel. Based on his experiment, the exit temperature of cyclone was able to be increased up to 820°C with the increasing equivalence ratio. The calorific value of producer gas was approximately 4.4 MJ m^{-3} with H_2 concentration of 8%.

Gabra *et al*. (2001a) studied the performance of a cyclone gasifier using sugarcane residue (bagasse) as a source of fuel. Two forms of bagasse had been tested which are crushed and palletized and the injection medium used is steam. The fuel characteristics were improved by palletizing the crushed bagasse, followed by grinding process. The moisture content of the tested fuel was found to be 5.90 (wt. %).

Gabra *et al*. (2001b) also studied the performance of a cyclone gasifer using sugarcane residue with air as an injection medium. The test results show that the gas temperature can be controlled within a range of 820 to 850°C. And the heating value of the producer gas was in the range of 4.5 to 4.8 MJ m^{-3}.

Gabra *et al*. (2001c) also performed a comparison study of alkali separation using bagasse as a source of fuel between fluidized bed and cyclone gasifier. The bulk density of bagasse has significantly increased from 128 to 485 kg m^{-3} after they were palletized and ground. The cyclone gasification process was found stable after 15 min of fuel injection at the temperature of 850°C and the range of equivalence ratio within 0.21 to 0.25.

Syred *et al*. (2004) developed an inverted cyclone gasifier to gasify pulverized biomass with larger sizes of fuel particles extending from 2 to 3 mm. In particular, the performance tests of the inverted cyclone gasifier had been conducted using commercial Austrian sawdust and commercial Swedish wood powder with the size distribution of 0.063 to 3 mm. The experimental results show that there was a significant improvement in cyclone gasification process where the operating temperature can be increased from 850 to 1250°C, the air flow rate increased from 550 to 880 L min^{-1}, a good quality of the producer gas was yielded with a maximum calorific value of 5.91 MJ m^{-3}.

Azman (2007) discussed the experimental study of a cyclone gasifier using wood sawdust from Malaysian furniture industries. The sawdust was ground to a particle size distribution within a range of 0.25 to 1 mm. The low heating value of the ground sawdust was determined to be approximately 16.54 MJ kg^{-1} with a moisture content of 8.25%. From both proximate and ultimate analysis, the sawdust was found to have high volatile matter and low ash content and that were about 76.23 and 1.49%, respectively. And the carbon content (dry basis) of the sawdust was found to be comparable with other biomass wood fuels which were approximately 42.38%. Based on the performance test, the heating value of the producer gas was determined to be 3.9 MJ kg^{-1} with the air flow rate of 0.01471 m^3 sec^{-1}. The efficiency of the cyclone gasifier was able to be increased with the increasing equivalence ratio from 0.19 to 0.47. The maximum efficiency of the cyclone gasifier achieved in the experiment was about 73.4% which was comparable with other research works (36-76%).

This study describes the characterization of rice husk from local rice mill to determine its fuel characteristics and suitability to be utilized as a source of fuel for cyclone gasifier. Each of the characterization process for the rice husk was performed and discussed.

The main objective of this study is to pre-treat the raw rice husk throughout grinding process and to characterize the ground rice husk for determining its potential use as a biomass fuel in the cyclone gasification system. The purposes of performing the characterization process were to:

- Study the fuel characteristics of the ground rice husk in order to determine its thermo-chemical properties. This was realized throughout several tests and analyses.
- Compare the fuel characteristics of the ground rice husk with other typical biomass fuels for cyclone gasification system. This is to determine the suitability of the ground rice husk as a source of fuel for a newly developed cyclone gasifier at University Science of Malaysia, Penang.

MATERIALS AND METHODS

This study was done at Universiti Sains Malaysia, Pinang where the sample of raw rice husk was collected from a local rice mill factory. The design and development of USM cyclone gasifier is based on work by Fredriksson, 1999 with few modifications on cyclone geometry, fuel feeding system and injection system. And the utilization of other types of biomass such as rice husk for the cyclone gasifier operation is an interesting aspect to be explored. The sample of rice husk will be characterized in order to determine its fuel characteristics throughout particle size analysis, thermal analysis and chemical composition analysis. The fuel characteristics of rice husk will be compared to other typical biomass fuels which had successfully been used in the gasification process.

FUEL CHARACTERISTICS

Pre-treatment: The first step in the characterization process was to pre-treat the raw material. In particular, the raw rice husk were ground, sieved and classified to obtain fractions of uniform particle size. The major sizes obtained are 1, 0.6 and 0.45 mm. Sawdust with 0.6 mm was selected to become a sample for the experiments (Table 1, Fig. 1).

The grinding and sieve-shaking processes were done to cater for the size requirement of the biomass fuel to be used in the cyclone gasifier system that ranges from 0.4 to 1 mm. To counter-check the grinding capability, sieving of the ground rice husk was done using automatic sieve shaker to determine its size distribution (Fig. 2).

The result from the sieving process is as shown in Table 2. It shows that a higher percentage of particle sizes were coming from both 0.45 and 0.6 mm, followed by the particle size of 0.25 and 1 mm. This indicates a good agreement between the machine grinding capability of the raw rice husk and the sieve test. Majority of the particle sizes after grinding, fall within the range of the desired size requirement for the cyclone gasifier which is from 0.4 to 1 mm.

Moisture content: The sample of ground rice husk was tested using moisture content determinant balancing. A

Table 1: Sieve shaker analysis for ground rice husk

Sieve size	Amount (g)	Percentage (%)
Less than 0.05 (mm)	0.70	3.37
0.06 (mm)	0.50	2.40
0.13 (mm)	1.30	6.25
0.25 (mm)	3.80	18.28
0.45 (mm)	5.80	27.88
0.60 (mm)	5.80	27.88
1 (mm)	2.70	12.98
More than 1 (mm)	0.20	0.96
Total sample	20.80	100.00

Table 2: Result of proximate analysis for ground rice husk

Operating command	Proximate analysis	Value (%)
Moisture content	Heat from 50 to 110°C by constant heating rate of 60°C min^{-1}	5.41
Volatile matter	Held 2 min at temperature 110°C	62.95
Fixed carbon content	Heat from 110 to 900°C by constant heating rate of 100°C	13.49
Ash content	Held 5 min at temperature 900°C	18.15

Fig. 1: Raw rice husk (left), ground rice husk (right)

Fig. 2: Grind machine (left) Automatic sieve shaker (right)

Fig. 3: Moisture content determinant balancing

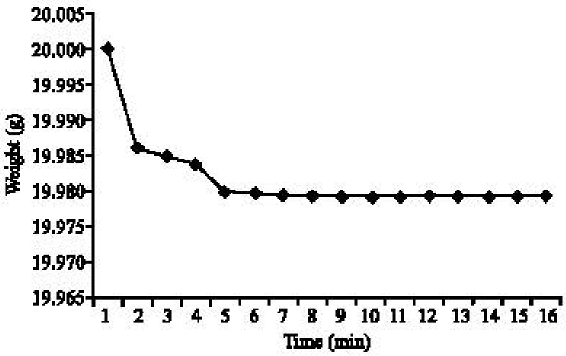

Fig. 4a: Weight losses (g) versus time (min)

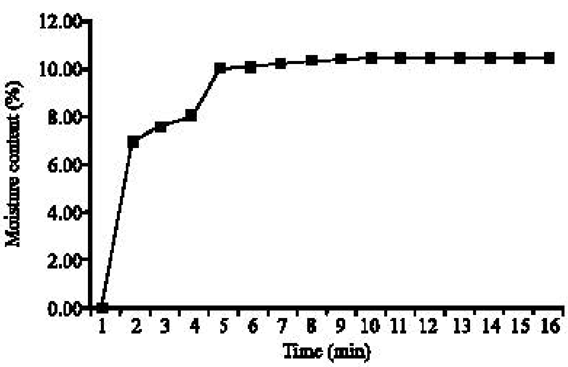

Fig. 4b: Moisture content (%) versus time (min)

20 g sample of rice husk was weighed. First, put the sample into the plate. Switch on the balancing and select a temperature and duration of heating. The temperature for drying process is 110°C in 30 min. Take a reading of weight losses in every two minutes passed. After finished 30 min, switch off the balancing and take out the sample (Fig. 3). Calculate moisture driven out and plot graph moisture content (%) and weight losses versus time. The formula of moisture content is as follow;

Fig. 5: Equipment for bomb calorimeter testing

$$\text{Moisture content (\% on wet basis)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \tag{1}$$

The trends of weight losses and moisture content of the sample with respect to time variation are shown in Fig. 4a and b. The moisture content of the ground rice husk was determined to be 10.4% on wet basis.

Calorific value: Bomb calorimeter test was used to determine the heating value of the sample material. In this case, the test was performed to check the calorific value of the ground rice husk. For the measurement of calorific values, Beckmann's thermometers were used (Fig. 5).

The sample must be placed in the crucible by wrapping the sample tightly and tied it with nickel wire. The length of nickel wire was measured. Then, crucible with sample was placed in bomb and the bomb was filled up with oxygen. Capacity of oxygen is 300 cm^3. Then, bomb was positioned in inner cylinder and immerse in 2100 mL of water. The outer jacket was kept at a constant temperature of the calorimeter water in the inner vessel was changed. The change in temperature was measured of the heat content of sample. The experiment was done in almost 15 min. The calorific value of the test sample can be determined using the following expression,

$$\text{Calorific value} = \frac{\begin{array}{l}\text{(Equivalent calorimeter water} \\ \text{+ Mass of water in cylinder)}\end{array}}{\begin{array}{l}\times\text{(Correction temperature / Mass of sample)} \\ \times\text{(Latent heat of water}\end{array}}$$

Referring to Fig. 6, data of temperature and time can be obtained and the calorific value of the ground rice husk was determined to be 14.8 MJ kg^{-1}.

Bulk density: Moisture content determinant balancing machine as in Fig. 3 was again used to weigh the sample

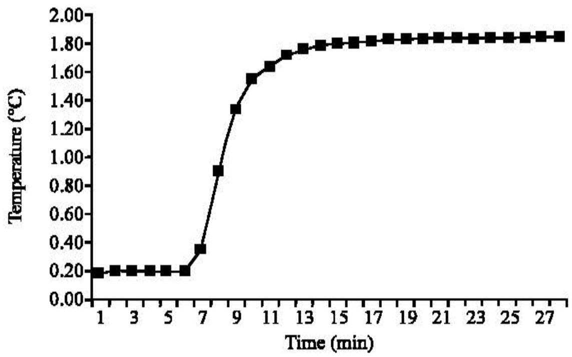

Fig. 6: Water temperature (C) versus time (min)

of raw rice husk which was placed inside the container for determining its bulk density in kg m^{-3}. The weight of the ground rice husk was found to be 3.04 g and the volume of the container was measured and determined as 3.324×10^{-5} m^3. Thus, the bulk density of the sample was calculated as 91.46 kg m^{-3}.

Proximate analysis or Thermal Gravimetric Analysis (TGA): Proximate analysis was carried out using TGA7 together with TG controller. The TGA system interfaced to a computer for data acquisition and control task. The operation was fully automatic. The TGA consist of sample pan that was suspended from the weighing mechanism with wire. The weighing balance accuracy is 0.1% and the sensitivity is 0.1 µg which are accurate enough to analyze the sample ground rice husk in few milligrams. The furnace can withstand up to 1150°C and the reactor temperature was measured by a chromel-alumel thermocouple located exactly below the sample pan (Fig. 7).

This system considers the weight of the sample as 100% and accordingly any loss of weight will be given by the system as percentage of sample weight. About 5 mg sample of ground rice husk was heated from 50 to 110°C by constant heating rate of 60°C min^{-1} and the temperature was held constant at that temperature for 2 min to determine the moisture content. This is followed by a constant heating rate of 100°C min^{-1} to the maximum temperature of 900°C under the inert atmosphere (100% of nitrogen) to measure the percentage of volatile matters were expelled. The purge gas was then switched to oxygen, for burning the remaining residue. The residue left after the combustion was called ash and the weight loss on combustion was referred as fixed carbon. Each analysis was repeated to ensure repeatability in data.

At the end of operation, the ash content of the ground rice husk was weighed and determined as 18.15% (Table 3).

Table 3: Result of ultimate analysis for ground rice husk

Elements	Percentage of content (%)
Carbon	37.85
Hydrogen	5.20
Nitrogen	0.14
Sulfur	0.61
Oxygen	27.65
Ashes	18.15
Moisture content	10.40

Fig. 7: TGA7 for proximate analysis

Fig. 8: PE 2400 elemental analyzer for ultimate analysis

Ultimate analysis: Basically, it is important to conduct the ultimate analysis using the elemental analyzer for the determination of carbon, hydrogen, nitrogen and sulfur content in organic and fine chemistry samples, sources of energy from agriculture, food, geological, biological, synthetic material, metallurgy and new material such as carbon fiber, conductive polymers and alloy. And for this particular project, the ultimate analysis was conducted on the sample ground rice husk in order to determine its chemical composition.

The ultimate analysis was carried out using PE 2400 Elemental Analyzer (Fig. 8). There is a good agreement between both proximate and ultimate analysis for the ash content measurement of the sample which was about 18.15%. Similar trend observed on the moisture content which was approximately 10.4% measured via the ultimate analysis and the manual weighing using the moisture content determinant balancing machine (Table 4).

RESULTS AND DISCUSSION

Table 4 shows a comparison of proximate analysis between the tested sample of ground rice husk and typical rice husk used in conventional gasifiers. In terms of size of particle, the ground rice husk for cyclone gasifier is finer than the ground rice husk for conventional gasifiers. The particle size requirement for cyclone gasifier is within a range of 0.4 to 1 mm compared to conventional gasifier which is within a range of 1 to 10 mm.

There is no significant difference between the sample rice husk from the experiment and the reference. The percentage difference for volatile matter is below 10% and the rest are all below 5%. High Heating Value (HHV) of round rice husk from the experiment is found to be 14.80% on dry basis and it differs only 0.8% from the reference data. Ash content is very important parameter that affects the composition and calorific value of the producer gas. The ash content for the tested sample is found to be 10.40% on wet basis and it is only 0.4% difference with the reference data.

Table 5 shows the proximate analysis of typical biomass fuels for conventional gasification system including rice husk. From the given data, it shows that the fuel characteristics of rice husk are corresponding to other types of biomass except for its high ash content. The percentage difference for ash content between rice husk and bagasse is about 11%, with sawdust is about 15% and with coffee grounds is about 13%.

Table 6 shows the ultimate analysis of ground rice husk from the experiment and the ultimate analysis done by Fredriksson(1999) on wood powder. There is a significant difference in terms of percentage between the ground rice husk and wood powder on ash content which is about 17%, followed by oxygen content which is about 15% and carbon content which is approximately 12%. The percentage differences of the rest of elements are all below 10%.

Table 4: Proximate analysis of the ground rice husk

	Proximate analysis					
Rice husk	Fixed carbon (% dry basis)	Volatile matter (% dry basis)	Ash (% dry basis)	Moisture (% wet basis)	HHV MJ kg^{-1} (% dry basis)	Bulk density (kg m^{-3})
Experiment	13.49	62.95	18.15	10.40	14.80	91.46
Reference (Sanchez, 1994)	12.00	72.20	15.80	10.00	15.60	86.00 to 114.00
Percentage difference	1.49	9.25	2.35	0.40	0.80	min. of 5.46

Table 5: Proximate analysis and heating values of typical biomass fuels

	Proximate analysis				
Biomass	Fixed carbon (% dry basis)	Volatile matter (% dry basis)	Ash (% dry basis)	Moisture (% wet basis)	HHV MJ kg^{-1} (% dry basis)
Rice husk	12.00	72.20	15.80	10.00	15.60
Bagasse	9.20	86.40	4.40	6.40	16.70
Sawdust	15.20	84.20	0.60	12.90	18.00
Spent coffee grounds	13.90	83.50	2.60	5.70	21.80

Table 6: Comparison of ultimate analysis for ground rice husk and wood powder

Ultimate analysis (dry wt. %)	Experimental data (ground rice husk)	Fredriksson (1999) (wood powder)	Percentage difference (%)
C	37.90	50.10	12.20
H	5.20	6.30	1.10
N	0.14	< 0.10	0.04
S	0.61	< 0.20	0.41
O (diff.)	27.70	42.60	14.90
Ash	18.15	0.80	17.35
Moisture content	10.40	4.30	6.10

CONCLUSIONS

The pretreatment process of raw rice husk helps to improve its fuel characteristics especially for the potential use as a biomass fuel in the cyclone gasification system. The ground rice husk with particle sizes of 0.45 and 0.6 mm had been selected for further characterization process because these particle sizes fall within the required range of fuel size for the cyclone gasification system which is from 0.4 to 1 mm. Based on the literature study, other sizes of particles will contribute to a clogging problem to the cyclone gasifier especially at both feeding and injector systems.

Based on the experimental results, it is shown that the ground rice husk with almost 70% of particle size distribution within 0.4 to 1 mm, moisture content of 10.4%, bulk density of 91.46 kg m^{-3} and calorific value of 14.8 MJ kg^{-1} is potential to be utilized as a source of fuel for the existing cyclone gasifier. The fuel characteristics of rice husk are comparable to other typical biomass fuels. There are two major elements from the rice husk that requires a careful attention if it is used as a biomass fuel for the cyclone gasification system. The first element is ash content. Critical operating parameters of the cyclone gasifier such as gasification temperature, combustion residence time and air to biomass fuel ratio must be properly set-up to ensure that the ash vaporization will not occur during the cyclone gasification process and the corrosive ashes would remain solid in the char particles. The second element is moisture content. But the control of moisture content of rice husk is easier than the ash content since it can be done during the pre-treatment process.

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