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Production of charcoal briquettes from biomass for community use

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Abstract. This article reports of a study on the production of charcoal briquettes from biomass for community use. Manufacture of charcoal briquettes was done using a briquette machine with a screw compressor. The aim of this research was to investigate the effects of biomass type upon the properties and performance of charcoal briquettes. The biomass samples used in this work were sugarcane bagasse (SB), cassava rhizomes (CR) and water hyacinth (WH) harvested in Udon Thani, Thailand. The char from biomass samples was produced in a 200-liter biomass incinerator. The resulting charcoal briquettes were characterized by measuring their properties and performance including moisture content, volatile matter, fixed carbon and ash contents, elemental composition, heating value, density, compressive strength and extinguishing time. The results showed that the charcoal briquettes from CR had more favorable properties and performance than charcoal briquettes from either SB or WH. The lower heating values (LHV) of the charcoal briquettes from SB, CR and WH were 26.67, 26.84 and 16.76 MJ/kg, respectively. The compressive strengths of charcoal briquettes from SB, CR and WH were 54.74, 80.84 and 40.99 kg/cm^2, respectively. The results of this research can contribute to the promotion and development of cost-effective uses of agricultural residues. Additionally, it can assist communities in achieving sustainable self-sufficiency, which is in line with our late King Bhumibol's economic sufficiency philosophy.

1. Introduction

Biomass is clean, renewable and environmentally friendly energy. It has very much less sulfur, nitrogen and ash, which cause SO_2 and NO_x formation, compared to fossil fuels [1]. Biomass is a huge energy resource since there are so many raw materials that can be used for energy such as wood slivers, agricultural residues, manure, food residues, garbage and wastewater, among others. Biomass is renewable energy as it is replenished on a shorter timescale than fossil fuels [2]. Moreover, Thailand is endowed with large biomass resources. Generating energy from biomass could not only reduce the need for imported fossil fuels, but also increase job opportunities for the population.

Thailand is an agrarian country. There are many agricultural residues produced. According to data from the Department of Agricultural Economics in 2015, Thailand's economic crops were sugarcane, rice, cassava and corn. Annual production of these crops totaled 171.7 million tonnes. This was comprised of 106.3 million tonnes of sugar cane, 28.4 million tonnes of rice, 32.4 million tonnes of cassava and 4.6 million tonnes of corn [3]. The residue to product ratios of sugarcane bagasse, sugarcane leaves and tops, rice husks, rice straw, cassava stalk, cassava rhizomes and corn stalks are 0.291, 0.302, 0.230, 0.447, 0.088, 0.490 and 0.250, respectively [4]. Thus, total crop residues amounted to 102.1

million tonnes per year. Some residues were used as fuel for power generation. For example, sugar mills burn sugarcane bagasse and rice mills burn rice husk as power plant fuels, while other materials are use as livestock feed. However, less than a half of total residues were taken. The remaining were disposed of through incineration, which aggravates air pollution. Using agricultural residues as energy is an attractive option. There are three types of biomass thermal conversion technologies. These include direct combustion, pyrolysis, and gasification [5-7]. Direct combustion is a process of burning biomass at low temperatures for long durations. The product gained from direct combustion is a solid called char that can be used as fuel. Pyrolysis is a process of converting biomass into energy under controlled temperatures (400-500°C) without oxygen. The pyrolysis product is liquid called bio-oil. Generating energy by pyrolysis has been researched and is currently economically infeasible in Thailand. Gasification, which similar to pyrolysis, is the conversion of biomass by burning it at a high temperature (800°C) in the absence of oxygen to produce a syn-gas. Manufacturing syn-gas is quite complicated and is also still under research and development. Each technology has its own advantages and disadvantages. Selection of the most appropriate technology depends on how the end products will be used. In Thailand, the most widely used technology at a community level is direct combustion owing to its simplicity, convenience and worthiness. As discussed above, direct combustion produces a solid material. Its particle size varies depending on the type of raw material used. However, to increase the efficiency of biomass fuel, making charcoal briquettes is a favored technique. At present, charcoal briquettes are made from small sized traditional charcoal. Small charcoal is ground to a powder and then mixed with binders, flour and water. All the ingredients are mixed together and then mechanically pressed into the desired shape. Moisture is removed from the briquettes either by sun drying or in a heated drier. Briquetted charcoal has better quality than the traditional charcoal. It is suitable for cooking and widely used in both noodle and grill restaurants. According to restaurant owners interviewed in the Udon Thani area, the cost of charcoal briquettes is 10 THB per kilogram and there is high demand for it.

This research aimed at sustainably introducing charcoal briquetting at the community level while using agricultural residues. Making charcoal briquettes in this setting requires simple techniques using a single machine. This will help agriculturists increase their income. Pressed charcoal briquettes must be dried to less than 8% moisture according to the community product standard. Charcoal briquette quality is competitive with traditional charcoal both in terms of its heating value and burning time. The raw materials used in this research were locally harvested sugarcane bagasse, cassava rhizomes, and water hyacinth. Charcoal briquette properties were compared with traditional charcoal. The results of this research will be shared with local communities to encourage them to sustainably use biomass in accordance with the philosophy of a sufficiency economy.

2. Experimental method and analysis

2.1. Biomass samples

The biomass studied in this research consisted of sugarcane bagasse (SB), cassava rhizomes (CR) and water hyacinth (WH). They are commonly found in Udon Thani. The samples were sun dried before being burned in a 200 liter incinerator in the absence of oxygen. All three types of samples were subjected to proximate analysis (moisture, volatile matter, ash and fixed carbon), ultimate analysis (carbon, hydrogen, nitrogen, sulfur and oxygen) and calculated heating value analysis.

2.1.1. Proximate analysis. Proximate analysis is the determination of the percentages of moisture, volatile matter, ash and fixed carbon of a substance. Moisture, volatile matter and ash determinations followed ASTM E1756-01, E872-82 and E1755-01 standards, respectively. The apparatus used consisted of a ceramic cup with a cover, metal bottom plate, desiccators, a four decimal digital scale and a high temperature incinerator. Fixed carbon was determined as the remaining portion of the sample after measuring moisture, volatile matter and ash.

2.1.2. Ultimate analysis. Ultimate analysis was used to determine the carbon, hydrogen, nitrogen, sulfur and oxygen contents of biomass samples. The oxygen content was calculated as the portion that remained after accounting for the other elements. A Leco Carbon Hydrogen Nitrogen & Sulfur analyzer, Model Carbon 628,628 S, was used. The analysis was done at the Center for Scientific and Technological Equipment, Suranaree University of Technology.

2.1.3. Heating values. Heating values were obtained by calculation. The higher heating values (HHV) were calculated using Sheng and Azavedo's equation (1) [8], while the lower heating values (LHV) were obtained using ECN's equation (2) [9], in which the results of ultimate analysis are required inputs.

$$HHV\left(\frac{MJ}{kg}\right) = -1.3675 + 0.3137C + 0.7009H + 0.0318O^{*} \quad (1)$$

where C and H are percentages of carbon and hydrogen (dry basis), respectively.

$$LHV\left(\frac{MJ}{kg}\right) = HHV - 2.442 \times 8.936\left(\frac{H}{100}\right) \quad (2)$$

2.2. Incinerating biomass
The biomass samples were burnt with a controlled amount of air in a 200 liter incinerator, as shown in figure 1. This was done to find the appropriate time to close the air inlets for each biomass sample.

Figure 1. Biomass incinerator used in this study.

2.3. Char grinding
After the biomass was converted to char, the char were ground to a smaller size, less than 0.5 cm. This promoted easy mixing with binders and a smooth surface of the desired shape. Char from cassava rhizomes is hard. Therefore it required mechanical grinding. Char from sugarcane bagasse and water hyacinth was soft enough to be ground by hand.

2.4. Mixing and pressing
Cassava starch and water were used as binders to agglomerate the ground charcoal. These materials were mixed and mechanically stirred. The machine used for this purpose was equipped with both stirring and pressing mechanisms, as shown in figure 2. The ratio of char particles: cassava starch : water were determined in previous research. The mixing ratio for cassava rhizomes, sugarcane bagasse, and water hyacinth were 5 kg: 0.5 kg: 6 liter, 2 kg : 0.1 kg : 2 liter, and 2 kg : 0.1 kg : 2 liter, respectively [10].

Figure 2. Charcoal briquette machine with a screw compressor.

2.5. Drying charcoal briquettes
According to the community product standard, the moisture content of charcoal briquettes must be less than 8%. However, the moisture content of the freshly pressed charcoal briquettes was 30-40%. So, drying was needed to remove moisture.

2.6. Charcoal briquette properties testing and analysis
The basic properties of biomass charcoal briquettes were analyzed in accordance with ASTM standards as follows.

2.6.1. Heating value. Heating value was determined following the ASTM D 5865 standard using an oxygen bomb calorimeter or calculation. For calculations, the higher heating values (HHV) and lower heating values (LHV) from ultimate analysis are required inputs. The higher heating value can be determined using equation (3) [11]. The lower heating value and hydrogen content can be determined using equation (2) [9].

$$HHV_{dry}\left(\frac{MJ}{kg}\right) = 0.3491C + 1.1783H + 0.1005S - 0.10340O - 0.0151N - 0.0211A \quad (3)$$

where C, H, S, O, N and A are the percentages of carbon, hydrogen, sulfur, oxygen, nitrogen and ash (dry basis), respectively.

2.6.2. Bulk density. Bulk density was determined using equation (4).

$$\rho = \frac{m}{V} \quad (4)$$

where m and V are mass and volume of charcoal briquettes, respectively.

2.6.3. Moisture content. Moisture content was analyzed following the ASTM D 3173 standard.

2.6.4. Volatile matter content. Volatile matter content was determined following the ASTM D 3175 standard.

2.6.5. Ash content. Ash content was analyzed following the ASTM 3174 standard.

2.6.6. Fixed carbon. Fixed carbon was determined following the ASTM 3172 standard.

2.6.7. The elemental composition. The elemental composition of charcoal briquettes was analyzed using the same method as for biomass

2.6.8. The compressive strength. The compressive strength of briquettes was determined using a Compression Testing Machine, STYE-2000. All three types of biomass charcoal briquettes with external diameter, internal diameter and length were 40, 16 and 80 mm, respectively were subjected to compressive strength testing.

2.6.9. Extinguishing time testing Extinguishing time testing is a method to determine how long the charcoal briquettes burn compared to traditional charcoal. The test was done by burning charcoal briquettes in a community gasifier stove.

2.7. Technology transfer and passing on knowledge
The innovation and technology from this research have been shared with people who interested in biomass charcoal briquette manufacturing. This was done through a new entrepreneur launch as part of a university knowledge-based project.

3. Results and discussion

3.1. Characteristic of biomass samples
Table 1 shows results of proximate analysis, ultimate analysis, and heating value calculations of three biomass types, i.e., sugarcane bagasse (SB), cassava rhizomes (CR), and water hyacinth (WH). The results show that percentages of volatile matter in cassava rhizomes and sugarcane bagasse were similar but cassava rhizomes had less ash. From the ultimate analysis, it was seen that cassava rhizomes and sugarcane bagasse had almost the same percentage of carbon. This value has a direct impact on the heating value. For water hyacinth, the percentage of carbon and heating values were less, while the ash content was greater than the other two types of biomass.

Table. 1 Characteristic of biomass samples.

Analysis	CR	SB	WH
Proximate Analysis (wt.%, dry basis)			
Moisture[a]	8.03±0.05	7.24±0.10	9.08±0.12
Volatile matter	77.63±0.56	77.70±0.26	55.53±0.38
Fixed carbon*	14.53±0.71	8.65±0.27	11.33±0.53
Ash	7.20±0.16	13.13±0.13	32.31±0.23
Ultimate Analysis (wt.%, dry basis)			
Carbon	46.63±0.11	47.05±0.02	37.11±0.12
Hydrogen	7.79±0.02	7.33±0.02	6.53±0.07
Nitrogen	0.59±0.02	0.39±0.01	1.25±0.02
Sulfur	0.07±0.01	0.29±0.07	0.37±0.01
Oxygen*	37.68±0.13	31.74±0.08	22.16±0.37
H/C molar ratio	2.00±0.01	1.87±0.00	2.11±0.02
O/C molar ratio	0.61±0.00	0.57±0.00	0.45±0.01
Molecular formula	$CH_{2.00}O_{0.61}$	$CH_{1.87}O_{0.57}$	$CH_{2.11}O_{0.45}$
Heating value by calculation (MJ/kg, dry basis)			
HHV	19.94±0.03	19.56±0.02	15.61±0.07
LHV	18.24±0.03	17.97±0.02	14.18±0.06

*Calculated by difference.
[a] wet basis.

3.2. Optimization of biomass burning

Figure 3 illustrates yield of char product obtained from burning three different types of biomass in a 200 liter incinerator with a controlled amount of air. The results showed that percentages of charcoal obtained from cassava rhizomes (CR), sugarcane bagasse (SB) and water hyacinth (WH) were 47.08, 26.08 and 58.33, respectively. The burning times before closing the air inlets were 20, 10 and 15 minutes, respectively.

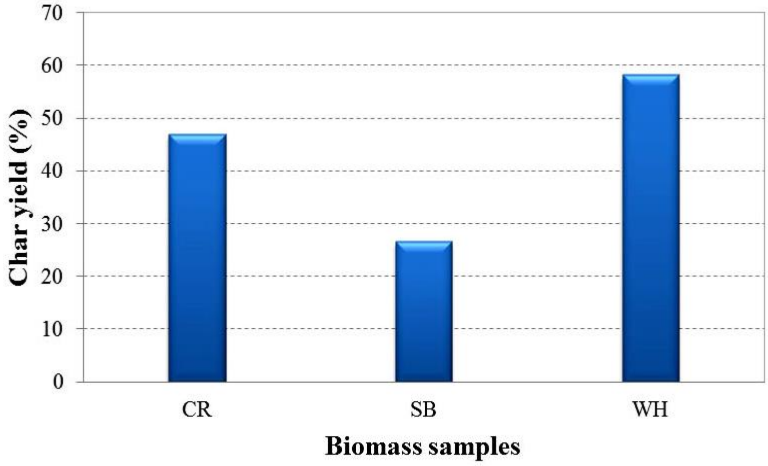

Figure 3. Yield of char product obtained after burning biomass samples.

3.3. Properties of biomass charcoal briquettes

The shape of the charcoal briquette is a hollow cylinder with a 10 mm inner diameter, a 40 mm outer diameter, and a 100-120 mm length, as shown in figure 4. Table 2 describes properties of three types of biomass charcoal briquettes. The moisture contents of all types of biomass charcoal complied with the community product standard (less than 8%). The CR charcoal briquettes gave the highest lower heating value (by calculation) at 26.84 MJ/kg followed by SB charcoal briquettes, 26.67 MJ/kg, and WH charcoal briquettes, 16.67 MJ/kg. According to the community product standard, the lower heating value must not less than 20 MJ/kg. The CR and SB charcoal briquettes met this standard. This result is consistent with the results of Phutteesakul et al. [12]. The CR charcoal briquettes had the highest density. Additionally, the CR, SB and WH briquettes could withstand applied loads of 80.84, 54.74 and 40.99 kg/cm^2, respectively. CH and SB charcoal briquettes cracked through the vertical axis, from top to bottom (figure 5). WH charcoal briquettes homogeneously cracked the whole briquette. Comparison of the three biomass charcoal briquettes revealed that CH charcoal briquettes had the best properties, followed by SB charcoal briquettes.

Figure 6 shows extinguishing times of biomass charcoal briquettes compared with traditional charcoal. The CR charcoal briquettes had the longest extinguishing time, followed by SB charcoal briquettes. The WH charcoal briquettes not only had a low extinguishing time but also a high ash content. Thus, when manufacturing WH charcoal briquettes, more charcoal particles should be added to improve its properties, especially the heating value.

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Table 2. Properties of biomass charcoal briquettes.

Analysis	CR	SB	WH
Proximate analysis (wt.%, dry basis)			
Moisture[a]	5.04±0.07	6.15±0.08	4.57±0.04
Volatile matter	20.96±0.39	19.53±0.34	13.33±0.37
Fixed carbon*	70.37±0.52	66.59±0.27	56.77±0.25
Ash	8.41±0.19	13.50±0.09	29.70±0.47
Ultimate analysis (wt.%, dry basis)			
Carbon	71.01±0.23	70.23±0.10	46.72±0.75
Hydrogen	4.07±0.05	3.82±0.03	3.14±0.11
Nitrogen	0.30±0.03	0.54±0.01	1.00±0.06
Sulfur	0.02±0.01	0.01±0.01	0.36±0.03
Oxygen*	16.16±0.40	11.84±0.07	19.01±0.62
H/C molar ratio	0.69±0.01	0.65±0.01	0.81±0.03
O/C molar ratio	0.17±0.00	0.13±0.00	0.31±0.01
Molecular formula	$CH_{0.69}O_{0.17}$	$CH_{0.65}O_{0.13}$	$CH_{0.81}O_{0.31}$
Heating value by oxygen bomb calorimeter (MJ/kg)			
HHV	24.25±0.64	22.66±0.46	15.74±0.45
Heating value by calculation (MJ/kg, dry basis)			
HHV	27.73±0.13	27.50±0.03	17.44±0.39
LHV	26.84±0.12	26.67±0.03	16.76±0.37
Bulk density (kg/m^3)	1,494±10.1	1,146±23.7	696.2±6.0
Compressive strength (kg/cm^2)	80.84±5.62	54.74±1.23	40.99±1.12

*Calculated by difference.
[a] wet basis.

Figure 4. Finished biomass charcoal briquettes.

(a) CR charcoal briquette (b) SB charcoal briquette

Figure 5. Cracking characteristic of biomass charcoal briquettes after compressive strength testing.

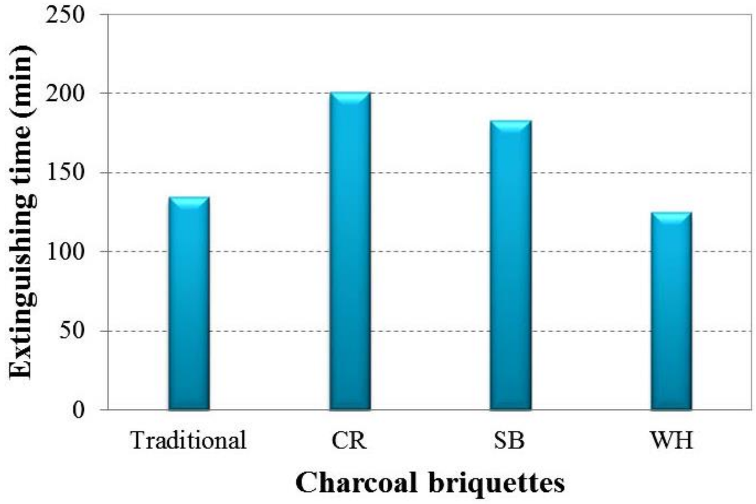

Figure 6. Extinguishing time of biomass charcoal briquettes compared with traditional charcoal.

3.4. Technology transfer and passing on knowledge

The innovation and technology from this research have been shared with people interested in manufacturing charcoal briquettes from biomass through a new entrepreneur launch as part of a university knowledge-based project. The project was held on 27-29 March 2017 at Udon Thani Rajabhat University (figure 7).

Figure 7. Technology and knowledge transfer for biomass charcoal briquetting.

4. Conclusions

Three biomass types commonly found in Udon Thani were tested for their suitability for making charcoal briquettes, sugarcane bagasse (SB), cassava rhizomes (CR), and water hyacinth (WH). Fresh biomass samples were sun dried and then burnt in a 200 liter incinerator with a controlled amount of air. The resulting char particles were mechanically pressed into a hollow-cylindrical shape. It was found that the CR charcoal briquettes had the best properties in terms of heating value, compressive strength, and extinguishing time. The innovation and technology from this research have been shared with people who are interested in manufacturing biomass charcoal briquettes to encourage them to use biomass sustainably.

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