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Method for Screening of Malaysian Biomass Based on Aggregated Matrix for Hydrogen Production through Gasification

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Abstract: Screening and evaluating various biomass for their potential as gasifier feedstocks can be a very complex and time consuming works. To optimize time of screening and selecting a promising fuel for gasifier, a novel method for screening of biomass using an aggregated matrix is introduced. Eleven Malaysian biomass from various resources are characterized and subsequently screened using this method based on their calorific value, O:C and H:C ratios, moisture, ash, volatiles and fixed carbon content. From the results obtained, palm kernel shell, sawdust and coconut shell are the most preferred biomass for gasification as each of these samples obtained 12 points from the aggregated matrix. The least preferred is empty fruit bunch, with only 8 points. Rubber seed kernel and coconut fiber scored 10 points while the other biomass scored 9 points. Through this novel and flexible method, users such as researchers or industrial practitioner who have limitations such as time and equipment availability are able to do an efficient screening of multiple feedstocks for their systems.

Key words: Biomass, characterization, gasifier, fluidized bed, screening method, aggregated matrix

INTRODUCTION

Biomass signifies bulky amount of residues, related to agricultural production and processing industries, where the whole matter that stems from plants are called biomass. It stored energy of sunlight in terms of chemical bonds, where combustion or decomposition will cause the bonds between carbon, hydrogen and oxygen molecules to come apart and discharge their chemical energy (McKendry, 2002a). Utilization of biomass as a renewable energy source is essential for the transition to a more sustainable society. Biomass contributes 40-50% of the energy supply in many developing countries and overall, contributing about 12% of today's world energy supply (Demirbas, 2001). Extensive researches have been done on a variety of biomass for their application as fuel.

Country with huge agricultural resources like Malaysia has great potential to expand its growth by embarking on renewable energy from biomass. Oil palm industries in Malaysia produce various types of residues including palm kernel shells, trunks, fibers, empty fruit bunch and fronds. Oil palm residues in Malaysia give the major biomass crop, which are approximately 68.9 million metric tons between years 2002 to 2007 (Department of Agricultural Malaysia, 2009). From an amount of fresh fruit bunch produced, 7% are kernel shells, 15% are fibers, 23% are empty fruit bunches while the remaining 65% are the palm oil mill effluent (Ropandi *et al*., 2002).

Another highly potential source of biomass fuel in Malaysia comes from paddy residues, which are rice husk and paddy straw. From an amount weight of rice collected, 22% of the weight of paddy is rice husk, while 78% of the weight is received as rice throughout the milling process, while 40% of the total paddy residues accounts for paddy straw (Umamaheswaran and Batra, 2007; Mokhtar, 2005). This biomass has major potential as fuel for biomass-based power generation after wood and palm oil residues (Yusof *et al*., 2008). In year 2000, paddy straw generated was 0.86 million tones and potential power generated from this waste was about 83.86 MW (Mokhtar, 2005; Hashim, 2005). Besides biomass obtained from oil palm and paddy sectors, there are several potential energy producer biomass which are fairly available throughout the country namely, wood chips, bagasse, rubber seed kernel, coconut fiber and shell.

The society and government have realized on the environmental benefits of biomass fuel and has intensely exploring and using biomass fuels in energy production technology. Thermo chemical and elemental characteristics of biomass are very important for utilization of them as fuels as well as in modeling, process designing and analysis of conversion processes and technologies (Liao *et al*., 2004). However, there are still lacks of information and selection basis of the characteristics of various biomass in Malaysia. Extensive researches have been done worldwide in characterizing

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their biomass resources as gasifier fuels. Based on their findings, several most significant properties of biomass are selected and studied.

This research aims to introduce a method of screening suitable Malaysian biomass as gasifier fuels, particularly for hydrogen production based on the selected gasifier properties. Appropriate Calorific Value (CV), fixed carbon, volatiles, O:C and H:C ratios, ash and moisture contents of biomass are essential to produce hydrogen gas with higher CV, promote higher combustion efficiency inside gasifier (Solar Energy Research Institute United States, 1988) and avoid additional operational costs (due to slagging, bridging and rusting).

MATERIALS AND METHODS

Biomass sampling: Various biomass samples were collected from local mills from diverse industries and cultivation sectors in Perak, Kedah and Selangor. Specifically, samples used in this research were oil palm residues (kernel shell, frond and fiber), paddy residues (straw and husks), sugarcane residue, rubber seed kernel, sawdust and coconut (fiber and shell). Samples were collected appropriately to get the most representative portions from the bulk amount, since there are no established standard sampling procedures specified for biomass materials.

Sample preparation and analysis: Biomass were weighed once received from the mill, to measure the moisture content. Note that this content varies with harvesting and planting conditions. Subsequently, biomass were oven dried at 105°C and the weights were noted every 1 h, until the readings became constant. This was the indication that all excessive moisture has vaporized. Besides, this will also enable more accurate relative comparison to be done on the biomass.

Prior to characterization, raw materials were mechanically pre-treated using a disk mill, which is capable of grinding and consecutively sieving the raw materials into less than 250 μm particle size. The samples were prepared in accordance with ASTM D 2013-86, where it required samples to be not more than 250 μm particle size. The intrinsic moistures of the samples were determined following ASTM D 3173-87 method in Mettler Toledo HR73 moisture content analyzer.

For ash content, ASTM D 3174-89 method was used in electric muffle furnace, while ASTM D 3175-89 was followed for volatile matter determination. The fixed carbon content was obtained by difference. For elemental analysis, ASTM D 3176 to 79-89 were applied using Leco CHNS elemental analyzer. For calorific value determination, ASTM E711-87 was referred using IKA C5000 bomb calorimeter.

Criteria selection: Proximate and ultimate analyses were able to provide a very comprehensive data on the biomass properties. Generally, almost any carbonaceous fuels can be gasified and produce combustible gases. However, it is a matter of prioritizing and justifying on which characteristics that was highly significant to the process scheme. Evaluation of fuel characteristics is highly important to create an economically attractive process.

Over the past few decades, biomass gasification technology has shown major advances. As a result, there were intense discussions on the suitable and non-suitable properties or characteristics of the feedstock itself that need to be carefully observed and controlled.

Table 1 shows a range of significant characteristics of biomass as gasifier fuels reported by many researchers. Based on information obtained in Table 1, the characterization works and data collections in this study will focus on these characteristics.

RESULTS AND DISCUSSION

The key material properties of interest of biomass as energy resources are determined through lab analytical instruments. Average characteristics compositions and standard deviations for proximate and ultimate analysis of the fuels are as shown in Table 1 and 2, respectively.

Table 1: Significant fuel characteristics for biomass as gasifier fuel feedstocks

Fuel characteristic	Remarks	References
Calorific value (CV), elemental composition	O:C and H:C ratios indicate energy values of fuel High CV of feedstock gives higher CV of producer gas	[1, 3, 4, 5, 6, 7, 8, 9, 10, 13]
Moisture content	<10 wt% is most preferred >50 wt% is extremely not preferred	[1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 13]
Ash content	No slagging (<3%) Minor slagging (3-6%) Severe slagging (>6%)	[1, 2, 3, 4, 5, 7, 8, 10, 13]
Volatiles, fixed carbon	High contents of these components indicate higher energy stored	[2, 5, 6, 7, 10, 13]

1: Rajvanshi (1986), 2: McKendry (2002b), 3: van Doorn *et al.* (1997), 4: Lijun *et al.* (2008), 5: Liao *et al.* (2004), 6: Orecchini and Bocci (2007), 7: Miskam *et al.* (2009), 8: Yusof *et al.* (2008), 9: Azali *et al.* (2005), 10: McKendry (2002a), 11: Kelly-Yong *et al.* (2007), 12: Ni *et al.* (2006), 13: Solar Energy Research Institute United States (1988)

Table 2: Characteristics of fuels-proximate analysis

Biomass	Moisture (wt.%)	CV (MJ kg^{-1})	Proximate analysis (db, wt.%) Ash (db, wt.%)	Volatiles (db, wt.%)	FC (by diff)
EFB	66.26±1.55	18.60±0.32	5.50±2.11	84.61	9.89
MCF	45.23	18.66	7.10	81.52	11.38
PKS	17.50	20.40	4.10	81.03	14.87
OPF	71.43±1.31	15.59±0.67	3.90±1.26	83.19	12.91
RSK	18.37	15.94	6.10	81.82	12.08
SD	16.30±0.89	18.19±2.02	5.00	78.80	16.20
SCR	52.20±0.41	15.25±0.22	3.90±2.32	80.19	15.91
RH	13.08±0.61	14.79±1.52	22.00±1.44	59.97	18.03
PS	8.47±0.33	13.74±1.12	18.30±2.02	72.48	9.22
CF	24.51	21.17	6.70	80.24	13.06
CS	18.50±0.89	18.18±2.33	5.52	75.00	19.48

Table 3: Characteristics of fuels-ultimate analysis

Biomass	Ultimate analysis (daf, wt.%) C	H	N	S	O (by diff.)
EFB	40.73	5.75	1.40	0.22	92.63
MCF	40.97	5.96	0.77	0.51	92.76
PKS	49.65	6.13	0.41	0.48	92.98
OPF	42.10	5.46	0.70	0.13	93.71
RSK	44.01	6.11	0.58	0.03	93.28
SD	43.68	6.65	0.23	0.04	93.08
SCR	42.93	5.82	0.68	0.06	93.44
RH	38.74	5.83	0.55	0.06	93.56
PS	33.48	6.01	1.46	0.15	92.38
CF	45.51	6.02	0.78	0.09	93.11
CS	43.00	6.30	0.75	0.05	92.90

B. coal: Bituminous coal, PKS: Palm kernel shell, EFB: Empty fruit bunch, CS: Coconut shell, MCF: Mesocarp fiber, OPF: Oil palm frond, CF: Coconut fiber, PS: Paddy straw, RSK: Rubber seed kernel, SCR: Sugarcane residue, SD: Sawdust, RH: Rice husks

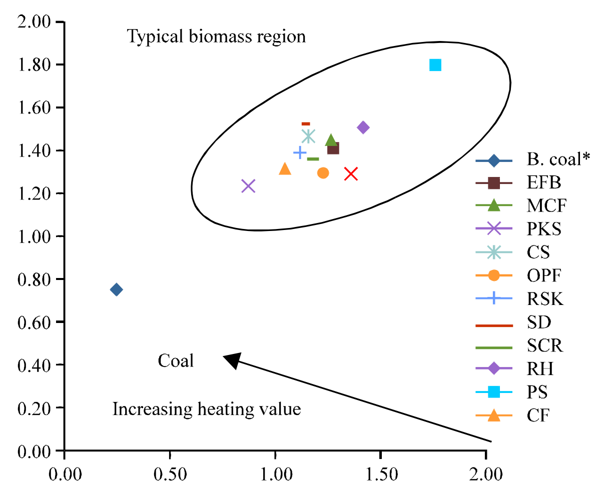

Fig. 1: Van Krevelen diagram for the tested biomass

From data obtained in elemental analysis, Van Krevelen diagram (Fig. 1) is constructed in order to signify the O:C and H:C ratios to the CV of fuels. It illustrates the energy contents of biomass based on oxygen-carbon and hydrogen-carbon bonds contained in the materials (McKendry, 2002a). Lower O:C and H:C ratios resulted in higher energy content of the biomass and positioned the species nearer towards coal, which is used as reference material (Table 3).

Biomass evaluation: To evaluate overall performance of all of the biomass, scores are given for each characteristic according to their percentages that suit the gasification system. For a hydrogen production, highly potential gasifier fuels should have high calorific value, fixed carbon and volatile, but low in ash and moisture content. Scores are assigned according to the justification and how the properties affect the system. The aggregates and the guidelines for each characteristic are as indicated in Table 4.

From above assessment as in Table 4, biomass are sorted accordingly based on scoring from the most preferred to the least preferred gasifier fuels. Based on the aggregated matrix and assessment above, it is found that palm kernel shell, sawdust and coconut shell are among the most potential feedstock for hydrogen production via gasification system as shown in Fig. 2. Compared to other 8 biomass samples, these 3 biomass have the most suitable properties to ensure promising and reliable process.

For a dry biomass conversion, important fuel characteristics are as explained in the following paragraph.

Calorific value and moisture content: High moisture content eventually reduces the calorific value of the fresh fuel and also lowers the heating value of product gas. This is due to the loss of energy in order to evaporate

Table 4: Aggregated matrix

	Characteristics					
Biomass	Calorific value	O:C and H:C ratio	Moisture content	Ash	Fixed carbon and volatiles	Total score
	A	B	C	D	E	
EFB	2	2	0	1	3	8
MCF	2	2	1	1	3	9
PKS	3	2	2	2	3	12
OPF	2	2	0	2	3	9
RSK	2	2	2	1	3	10
SD	3	2	2	2	3	12
SCR	2	2	0	2	3	9
RH	2	2	2	0	3	9
PS	2	1	3	0	3	9
CF	2	2	2	1	3	10
CS	3	2	2	2	3	12

A: 0 for less than 10, 1 for less than 10-14, 2 for between 14 to 20, 3 for higher than 20 MJ kg^{-1}. (Note that typically biomass has 14-20 MJ kg^{-1}), B: 1 if furthest from coal, 2 if near towards coal, 3 if very near towards coal (Fig. 1), C: 0 for more than 50, 1 for between 35-50, 2 for between 10-35, 3 for less than 10 wt.% moisture, D: 0 for more than 15, 1 for between 6-14, 2 for between 3-6, 3 for less than 3 wt.% ash, E: 0 for less than 10, 1 for between 10- 25 wt.%, 2 for between 25 to 50 wt.%, 3 for more than 50 wt.%. (Note that typically almost more than 60 wt.% of biomass is volatiles and fixed carbon)

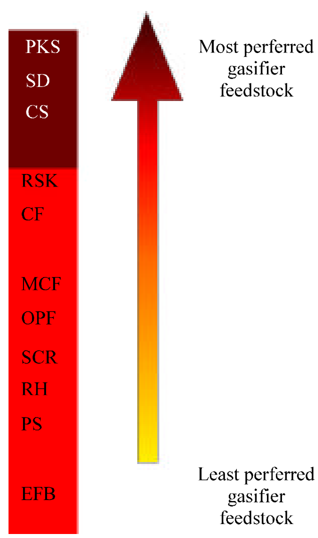

Fig. 2: Biomass ranking

excessive moisture content of the biomass. Low moisture content also promotes better heat recovery and combustion efficiency (McKendry, 2002a; Solar Energy Research Institute United States, 1988). Based on findings by other researches, the most preferred moisture content is as low as 10 wt.% for a gasification process (Table 1), however in nature (without drying), biomass can contain more than this value.

For CV, the typical values for biomass are between 14 to 20 MJ kg^{-1}, which is considered low as compared to bituminous coal which has between 26 to 30 MJ kg^{-1}. With CV between 18 to 20 MJ kg^{-1} and moisture content less than 20 wt.%, PKS, SD and CS are comparable with several types of hardwood such as black alder, cotton wood and eucalyptus which have been utilized as cyclone gasifier feedstocks (Miskam *et al*., 2009; McKendry, 2002a).

Proportions of fixed carbon and volatile matter: According to a study done by Solar Energy Research Institute United States (1988) on various biomass, it was found that more than 70 wt.% of biomass comes from volatiles matter and this value is an advantage for biomass in gasification process compared to coal which usually contained only 30 to 40 wt.% only. However, as a trade off biomass are lack of fixed carbon content while coal have very high content of this.

For all tested biomass in this study, the values of these matters are in agreement with the findings, where most of the biomass have volatiles content of more than 70 wt.% and fixed carbon of less than 20 wt.%, except for rice husk which has slightly low volatiles contents compared to other samples. Energy is stored in fixed carbon and volatiles forms in solid fuels. High content of these forms in biomass indicate that these feedstocks are easy to be ignited and gasified, resulting in a more efficient gasification.

Ash content: The ash content of biomass is typically less than that of coals (which is less than 10 wt.%) except for some forms of biomass (McKendry, 2002a). The results obtained from this study are in agreement with this statement where most of the samples have less than 10 wt.% ash content, except rice husk and paddy straw.

High mineral matter leads to slagging problem in the gasifier system, causing decrease in operation throughput and increase in operating costs. Besides, blockages of airways are highly possible when alkali metal and silica contents in the ash reacted and formed sticky liquid. Nevertheless, this problem can be solved with proper ash removal system.

With high CV, fixed carbon and volatiles, low O:C and H:C ratios, ash and moisture contents, PKS, SD and CS are found to be very potential for hydrogen production via gasification. Properties of these 3 biomass were comparable with sawdust, commercial wood powder and wheat straw used as cyclone gasifier feedstocks (Miskam *et al*., 2009; McKendry, 2002a). With these properties, these 3 samples are able to produce hydrogen gas with higher CV, promote higher combustion efficiency inside gasifier (Solar Energy Research Institute United States, 1988) and avoid additional operational costs (due to slagging, bridging and rusting).

Through this aggregated matrix, researchers are able to do a better screening of feedstocks, especially when there are many samples and characteristics to be screened. This will allow prioritization to be made, especially when subsequent process is time and cost consuming. If there are more characteristics to be considered in evaluating a particular group of samples, the aggregated matrix as in Table 4 can be easily expanded while maintaining the same concept of scoring and justifying.

CONCLUSION

From this study, a screening method using an aggregated matrix has been introduced in evaluating potential Malaysian biomass for hydrogen production via gasification. Based on the findings, PKS, SD and CS have been identified as the most potential gasifier feedstock based on their high total scoring obtained from the aggregated matrix based on their physico-thermochemical properties. The aggregated matrix is useful as a reference for future research utilizing similar multiple feedstocks in which this help to save cost and time for biomass screening.

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