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Biomass Characteristics Index: A Numerical Approach in Palm Bio-Energy Estimation

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Oil palm industry contributes a huge amount of valuable crude palm oil, also directly produces large quantity of plantation waste or biomass if it will be utilized as a fuel. In order to give a clear insight of the energy output estimation from the biomass, a comprehensive study on the physical properties of the biomass: bulk density and moisture content is crucial. In conventional approach, these properties are obtained through empirical methods on individual sample basis. There are several drawbacks from the conventional empirical methods: (i) need a huge amount of experimental results to construct biomass properties' curve (ii) data variation affects the accuracy of analysis result. These create a limitation in properties estimation and then further affect the optimum biomass utilization. To tackle this issue, there is a need to search for a direct representation of the properties. A Biomass Characteristics Index (BCI) is proposed to represent the relationship between bulk density and moisture content. A numerical framework is developed to determine the BCI. This index is used to estimate the biomass bulk density and moisture content before the calorific value calculation. A regression graph is plotted to illustrate the relationship among those values with respect to different appearance shapes of biomass. The result shows that different size and shape of biomass has its own specific BCI. The classification of biomass according to its specific BCI can forecast the related bulk density and moisture content. Therefore, it reduces the hassle and time constraint to get those values through conventional empirical method. This will increase the overall biomass operational management efficiency.

1. Introduction

In Malaysia, palm oil mill left over a huge amount of waste after the fresh fruit bunches have been processed for the oil extraction. Among those residues, most reusable matter are empty fruit bunch (EFB) and palm kernel shell (PKS) (Lam et al., 2012). The factor that determines the usefulness of these biomass is the calorific value. Higher calorific value indicates it is more efficient as an energy source (Everard et al., 2012). Before biomass can be sent into the plant for conversion or power generation, storage and transportation issues of raw feedstock have to be taken into account. The questions of where to store and how to send are related to physical characteristics of biomass. Biomass physical characteristics include its moisture content and bulk density. Both properties are interrelated and linked to the structure and physical shape of biomass. Moisture content is the quantity of water that contains in the biomass material. Bulk density is defined as the ratio of biomass mass over its volume. Limitations to raw biomass are high moisture content, low bulk density and therefore lower calorific value. Low bulk density leads to the difficulties of material handling, storage, transportation (Wu et al., 2011). While the higher moisture contents decrease the calorific value of biomass (Chiew et al., 2011). For instance, oil palm empty fruit bunch (EFB) bulk density is lower when it has more moisture within. High moisture content empty fruit bunch is more difficult to be compacted, thus occupies more spaces which increase the total volume. The final bulk density will get lower and this will increase the difficulties of storage and transportation (Miccio et al, 2011). Besides this, bulk density changes with types, size and shape of the

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biomass itself. Therefore, a dry raw empty fruit bunch bulk density is definitely lower than shredded empty fruit bunch because smaller particle size of biomass occupies lesser space with same weight of mass.

Besides moisture content, air volume also influences bulk density. Free air space (FAS) is measured on solid organic waste during composting process. The distribution of air in the waste will affects the performance of composting (Druilhe et al., 2013). Free air space represents the ratio of air volume over global volume (air, water, solid). A pycnometer will be used for free air space measurement. At higher bulk density, the air voids will be displaced as the solid becomes more compacts. This shows a linear relationships between free air space and bulk density for manure compost (Agnew et al., 2003). There are various studies related air porosity to bulk density (Ruggieri et al., 2009) and the relationships are established on different biomass types. Therefore, it is possible that biomass have air voids trap inside the material itself especially fibrous biomass like empty fruit bunch. The space in between the particle of biomass material is a perfect spot for air voids.

Moisture content and bulk density have been studied separately depends on the application area either the pre-treatment process or end product (mostly is pellet). The focus of the research is target on the performance of final product rather than the raw biomass itself. There is no integration on both properties to indicate the initial biomass appearance and shape before the biomass pre-treatment stage. Raw biomass form has essential information that determines the handling, transportation and storage issues (Lam et al., 2013). These information can be feed into biomass supply chain for the purpose of optimized resource planning (Lam et al., 2011). A well planned supply chain design plays an important role to achieve the efficiency in cost and energy utilization (Klemeš et al., 2013).

Secondly, acquisition of bulk density and moisture content are obtained through empirical methods such as the British Standard (British Standard, 2010). Results from those methods may varied from sample to sample and limit by handling procedures. There is no standard or reference value of bulk density and moisture content for one particular biomass such as empty fruit bunch (EFB). In certain analysis, either one of the characteristics - bulk density, moisture content or component breakdown of biomass is involved. This shows the lack of overall coverage of the material’s physical. In Chevenan’s (2010) paper, the characterization of bulk density is focused on switchgrass, wheat straw and corn stover and each gives a different relationships model. Lack of generalized characterization on various biomass impacts on the time constraint and reduces the efficiency in biomass management design and process.

In this paper, Biomass Characteristics Index is proposed to correlate the physical appearance of biomass to its properties, bulk density and moisture content.

2. Methodology

Numerical method is chosen to analyze the biomass physical properties.

2.1 Relationships between bulk density and moisture content

Sims (2005) provided an intuitive formulae for this study,

$$Bulk\ Density\ (\frac{kg}{m^3}) = \frac{13600}{(100-\%m.c.w.b.)} \quad (1)$$

However from his study, this is only applicable for wood chips. In order to provide a generalize characteristics for biomass, this formulae can be enhanced by getting a constant value of k for various types of biomass to replace the value of 13,600. The new modified formulae is,

$$Bulk\ Density\ (\frac{kg}{m^3}) = \frac{\kappa}{(100-\%m.c.w.b.)} \quad (2)$$

In this study, this constant k is a reference index for various appearance shapes of biomass and is proposed as Biomass Characteristics Index (BCI).

2.2 BCI calculation

A systematic numerical approach propose:

a) Database construction

To obtain a series of BCI, a complete biomass database is needed. Various forms of biomass bulk densities and moisture contents are constructed to provide a comprehensive coverage on various appearance shapes of biomass.

b) BCI calculation

From the above database, BCI can be obtained by using the bulk density and moisture content values into this formulae,

$$BCI = Bulk\ Density \times (100 - \%m.c.w.b.) \qquad (3)$$

c) Relationships among BCI, bulk density and moisture content

After the whole set of BCI is obtained, a graph is plotted to show the relationships between BCI and bulk density. From the graph, linear regression is best fitted on the plots. A new regression equation is obtained through the fit.

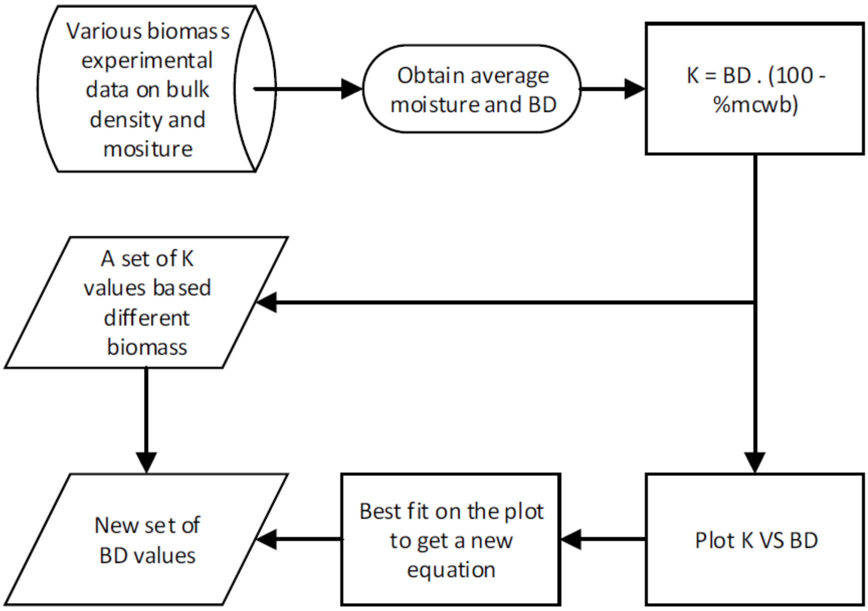

Figure 1: Flow chart of BCI calculation

3. Case study

A case study is demonstrated on a set of different appearance shapes biomass. The database includes most of the common found biomass and few types of oil palm biomass.

Table 1 shows the related bulk density and moisture content for all the common available types of biomass. Average value of bulk density and moisture content are calculated for the proposed BCI Eq(3). BCI value are based on average bulk density and moisture content. As discussed in section 2, the values of BCI from Table 1 are calculated using Eq(3).

By using the BCI values and average bulk densities, a graph is plotted to show the relationships. Figure 2 shows the linear regression fit on the plotted data. The best fit linear regression equation is y = 90,977x-6,115.1 with R-squared value of 0.8675.

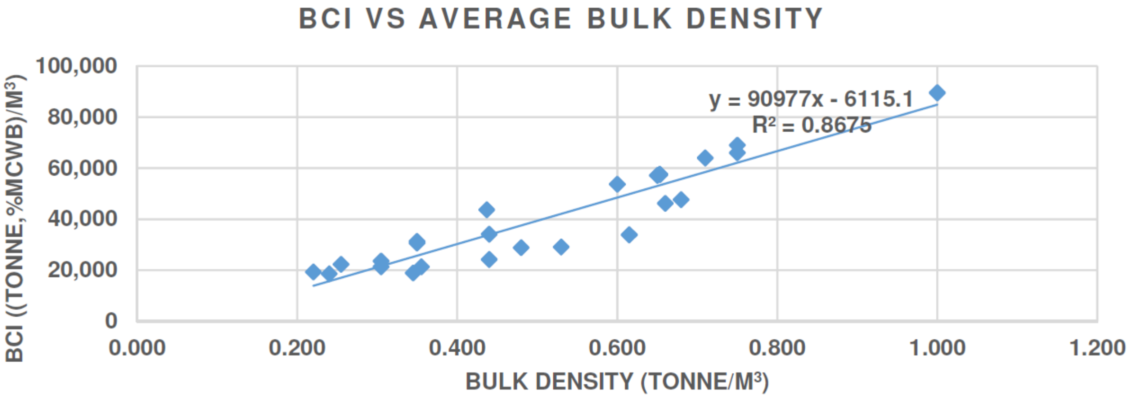

Figure 2: BCI vs bulk density

Table 1: Biomass characteristics

Biomass Types	Moisture (Min)	Moisture (Max)	Average Moisture	Bulk Density (t/m^3, Min)	Bulk Density (t/m^3, Max)	Average Bulk Density (t/m^3)	BCI
Air dry wood chips	20.00 %	25.00 %	22.50 %	0.190	0.290	0.240	18,600
Green wood chips	40.00 %	50.00 %	45.00 %	0.280	0.410	0.345	18,975
Kiln dry wood chips	10.00 %	15.00 %	12.50 %	0.190	0.250	0.220	19,250
Empty Fruit Bunch	15.00 %	65.00 %	40.00 %	0.160	0.550	0.355	21,300
Kiln dry wood chunks	10.00 %	15.00 %	12.50 %	0.200	0.310	0.255	22,313
Air dry wood chunks	20.00 %	25.00 %	22.50 %	0.240	0.370	0.305	23,638
Green wood chunks	40.00 %	50.00 %	45.00 %	0.350	0.530	0.440	24,200
Mesocarp Oily Fiber	30.00 %	N/A	30.00 %	N/A	N/A	0.305	21,350
Kiln dry sawdust	10.00 %	15.00 %	12.50 %	0.240	0.370	0.350	30,625
Fresh Fruit Bunch	40.00 %	N/A	40.00 %	N/A	N/A	0.480	28,800
Green sawdust	40.00 %	50.00 %	45.00 %	0.420	0.640	0.530	29,150
Straw bales	7.00 %	14.00 %	10.50 %	0.200	0.500	0.350	31,325
Green roundwood	40.00 %	50.00 %	45.00 %	0.510	0.720	0.615	33,825
Air dry roundwood	20.00 %	25.00 %	22.50 %	0.350	0.530	0.440	34,100
Ash	0.00 %	N/A	0.00 %	N/A	N/A	0.437	43,700
Sterilized Fruit	30.00 %	N/A	30.00 %	N/A	N/A	0.660	46,200
Fruitlets	30.00 %	N/A	30.00 %	N/A	N/A	0.680	47,600
Wood pellets	7.00 %	14.00 %	10.50 %	0.500	0.700	0.600	53,700
Press expelled cake	12.00 %	N/A	12.00 %	N/A	N/A	0.650	57,200
Palm Nuts	12.00 %	N/A	12.00 %	N/A	N/A	0.653	57,464
Cracked mixture	12.00 %	N/A	12.00 %	N/A	N/A	0.653	57,464
Dry EFB Cut Fiber	10.00 %	N/A	10.00 %	N/A	N/A	0.710	63,900
Shell	12.00 %	N/A	12.00 %	N/A	N/A	0.750	66,000
Coal	6.00 %	10.00 %	8.00 %	0.700	0.800	0.750	69,000
Wood briquettes	7.00 %	14.00 %	10.50 %	0.900	1.100	1.000	89,500

4. Analysis

The validity of BCI can be verified through comparison between the calculated data and actual on field data. From Table 4, the error differences are relatively small. The highest differences are observed on empty fruit bunch (EFB) and fresh fruit bunch (FFB) which are 0.327 and 0.196 respectively. This is mainly due to the nature of these two materials which have a large range of moisture content.

The main advantage of BCI is to perform a cluster forecast on multiple biomass materials. Classification on biomass type can be used on its potential industrial application (Lam et al, 2013). Figure 3 shows BCI and bulk density values are lined up on a bar chart to reflect its dependency. There is step liked clustering on the different biomass and so does the bulk density values. Refer to Figure 3, all the chips materials have a similar range of BCI, from 18,600 to 19,250. So does the chunks, it exhibits the same behaviour. This proposes that similar shapes biomass have a relatively similar bulk density values which reflects on BCI value. Therefore, BCI is capable of forecasting the types and physical appearance of biomass based on a narrow BCI range. From there, bulk density and moisture content are predictable.

Table 2: Comparison of collected and BCI forecast bulk density

Oil Palm Biomass	Collected data (t/m^3)	Forecast from BCI (t/m^3)	Difference (t/m^3)
Empty Fruit Bunch	1. 0.628	2. 0.301	3. 0.327
4. Mesocarp Oily Fibre	5. 0.257	6. 0.302	7. 0.045
8. Fresh Fruit Bunch	9. 0.580	10. 0.384	11. 0.196
12. Ash	13. 0.550	14. 0.548	15. 0.002
16. Sterilized Fruit	17. 0.640	18. 0.575	19. 0.065
20. Fruitlets	21. 0.640	22. 0.590	23. 0.050
24. Press expelled cake	25. 0.550	26. 0.696	27. 0.146
28. Palm Nuts	29. 0.653	30. 0.699	31. 0.046
32. Cracked mixture	33. 0.535	34. 0.699	35. 0.164
36. Shell	37. 0.650	38. 0.793	39. 0.143

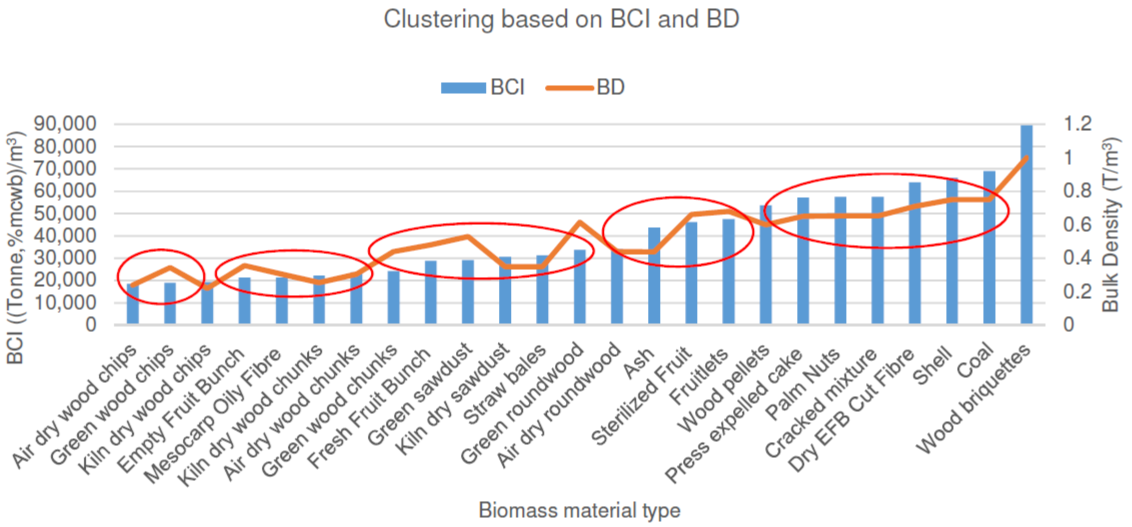

Figure 3: Clustering on similar biomass shapes

5. Case study

For certain biomass management planning, a specific bulk density or moisture content is needed for the ease of transportation or maximum output in the power plant. Therefore, by referring to the BCI, the desired value of bulk density or moisture content can be obtained without difficulties. For example, a biomass power generation plant is running low of existing fuel - straw bales. The management is trying to procure a similar fuel source for replacement. Refer to BCI, straw bales is 31,325. Green sawdust, kiln dry sawdust, air dry roundwood and green roundwood are possible candidates which fall under BCI range of 30,000. Obviously, kiln dry sawdust is the most suitable replacement as the bulk density (350 kg/m^3) and moisture content (12.50 %) are closer match to straw bales (350 kg/m3, 10.50 %). If this material is not available in the nearby area, air dry roundwood will be next suitable substitution (440 kg/m3, 22.50 %). In terms of management, the procurement of the correct material can be done in an accurate manner without further delays.

6. Conclusion and future works

A numerical framework of BCI is developed to represent the appearance and shapes of different biomass materials. By referring to the correct BCI of biomass material, forecast bulk density and moisture contents are obtained without running any time consuming empirical method. These values are critical to the amount of biomass fuel being transfer and the generated output power from the plant. Thus, it improves the overall biomass management process design and development. An efficient design means more output, less waste.

This paper proposes a preliminary framework for BCI in forecasting the physical properties of various biomass. In future, the framework can be enhanced by taking account into more types of biomass and larger sets of data on each biomass type. Nevertheless, the analysis on BCI can be done by using multivariate regression to provide a comprehensive model on the relationships of bulk density and moisture contents. This will improve the accuracy of BCI prediction on biomass appearance properties. All these estimated biomass values can be applied in sustainable and life cycle studies and energy total site analysis (Kostevšek et al., 2014)

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