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Prediction of Higher Heating Value Bioorganic Fraction of Municipal Solid Waste from Proximate Analysis Data

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***Abstract*— This paper provides proximate analysis data (moisture content, volatile matter, ash, and fixed carbon) bioorganic fraction of municipal solid waste (MSW) and their calorific values. Samples were collected from waste sorting facilities located in the landfill Temesi Gianyar and Bengkala Singaraja. The moisture content was determined by the standard ASTM D 3173-87, volatile matter by the standard ASTM D 3175-89, ash content by the standard ASTM D 3174-89, and fixed carbon content is calculated by difference with reference to ASTM D 3172-73. The HHV was determined based on the standard ASTM D 5865-85 by using Bomb Calorimeter. Furthermore, nine empirical correlations between the calorific value and proximate analysis data were developed to estimate the heating value from proximate analysis data base on linear regression. The validity of calculated heating value from each equation was conducted by using the experiment heating value. The performance of each model was compared too with the models were developed by other researcher based on the coefficient of determination between calculated and the experiment heating value. The results showed that the volatile matter of samples at a range from 64.95 to 74.58%, fixed carbon from 14.74 to 19.57%, and ash from 10.44 to 16.79%. The experimental heating values vary from 14.53 to 17.07 MJ/kg. Based on the correlations confirmed that ash showed negative influence on the calorific value while the volatile matter and fixed carbon showed positive influence. However, none of which showed a coefficient of determination greater than or equal to 0.90.**

Keywords*— *Municipal Solid Waste, Biorganic Fraction, Proximate Analysis, Calorific Value

I. INTRODUCTION

Municipal solid waste (MSW) is an integral part of people's lives. MSW is generated as a result of human activity. If this waste management planning is not done in accordance, it will lead to problems such as serious environmental pollution of water, soil and air. Recently, landfilling is the waste management practices are generally widely applied in Indonesia. Given the increasingly limited availability of land for landfill location and some environmental problems associated with landfilling processes such as gas emissions and the resulting leachate, necessary alternatives that in addition to reducing the land for landfilling, waste to energy is one of them. This is important, because basically waste is entropy or energy that is not utilized.

Attractive option that can be considered in the management and energy recovery from waste is thermal conversion based processing method such as incineration, gasification, and pyrolysis. This method, besides being able to recovery the energy from waste, it could also reduce the volume of waste reached 85% [1], then, it will reduce the land need for landfilling. In an effort to evaluate the feasibility of energy recovery from waste as an integral part of the waste management system, it is important to determine the energy content or the calorific value. The calorific value is the amount of heat released when a unit mass of material burned completely. Calorific values are generally expressed in two terms, higher heating value (HHV) or gross heating value and lower heating value (LHV) or net heating value. HHV represents the enthalpy change of reactants and products in a stoichiometric when a compound is burned at reference temperatures and the water produced is considered in the form of liquid, whereas, in LHV, water is considered in the form of vapor [2-3].

The calorific value of a fuel can be determined either by measurements or by empirical correlation approach. Measurement method was conducted with use a bomb calorimeter [2] that measures the change in enthalpy between reactants and products. Generally, the empirical approach used mathematical models based on linear regression [4-6]. The models were developed to predict the heating value based on attributes as fuel material such their proximate and ultimate analysis data [5-7]. Proximate analysis data of solid fuel included moisture content, volatile matter, ash, and fixed carbon, while the ultimate analysis data included carbon, hydrogen, oxygen, nitrogen, and sulfur. However, given the determination of ultimate analysis data is relatively expensive, therefore, for the practice purpose correlation based on proximate analysis data will be more profitable. This data is the easiest and most widely used in the characterization of fuels mainly solid fuel. With reference to the idea that the calorific value is proportional to the carbon content and hydrogen in the sample, then, HHV is assumed as a function of the fixed carbon (FC, % by weight) and volatile matter (VM, % by weight) in which the main components are carbon and hydrogen. However, the influence of mineral or ash is also often considered in correlation.

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There are various correlation models that have been developed previously to prediction gross calorific value (higher heating value, HHV) of solid fuels including biomass waste from their proximate analysis data [3,4, 5,8,9]. However, given the extremely heterogeneous of MSW and their rate of production as well as the physical composition varies between one and the other in accordance with the socio-economic level, cultural, and climatic conditions, the characteristics of MSW in one city will be different from the other city. Therefore, the suitability assessment of developed correlations with characteristic MSW in Indonesian were needed.

In Indonesia, especially in Bali, MSW is dominated by bioorganic fraction, it is up to 68.78% [10]. Therefore, the energy content will be more influenced by these components. In this, in addition to susceptibility variations on the season, it is important to determination the calorific value of these components due the possibility of changes in composition with respect to time as a result of related policies such as 3R (reduce, reuse, and recycle) program.

This paper focused on the development of linear regression-based correlation to predicting HHV of bioorganic fraction from their proximate analysis data. The accuracy of its predictions compared with developed correlation and data experiment.

II. MATERIALS AND METHODS

A. Sample Preparation

Bioorganic fraction of MSW samples in this study were collected from the 2 manually waste sorting facility in Temesi Gianyar and Bengkala Singaraja landfill. In both location, sorting facility aims to separate the bioorganic components to be composted. Sampling was performed in 4 months ie. in May, June, July, and August on 2011. Total 24 samples were collected. Samples were taken at some point and mixing it well to get a suitable representation. Approximately five (5) kg of waste as the sample size taken from the points specified in the mounds of bioorganic fraction separated. Furthermore, it was divided into four equal parts and one quarter of its parts was taken and dried under sun for 1-2 days before characterization were conducted.

B. Sample Characterization

Sample characterization included the determination of the HHV and their proximate analysis (moisture content, volatile matter, ash, and fixed carbon). Sample preparation prior to the characterization performed referring to [11]. This procedure requires that samples be used in the form of small pieces up to a maximum size of 2.5 cm. The water content was determined by the standard [12], volatile matter was determined by the standard [13], ash content was determined by the standard [14], and a fixed carbon content was calculated by difference with reference to [15]. The HHV was determined based on the standard [16] by using Bomb Calorimeter. All these laboratory testing were carried out in the Laboratory of Mineral and Coal Technology Bandung.

C. Developments of Models

The HHV and proximate analysis data were used to generate multiple linear regression correlations. These correlations showed the influence of proximate analysis data on the HHV. Some possible combinations of dependent variables (proximate analysis data) that contribute to the energy content were developed and evaluated to produce the mathematical models. In general, the correlation was written as follows.

HHV = f(M, A, VM, FC)

Where HHV = Higher heating value (MJ/kg), M = moisture content (%), A = ash (%), VM = volatile matter (%), and FC = fixed carbon (%).

D. Choosing the Best Correlatin

To select the most appropriate correlations, determined based on the coefficient of determination (R^2). In this, SPSS 17 was used to calculate the R^2. R^2 had been widely used in statistical and regression analysis which was applied as a comprehensive parameter for quantifying the accuracy of the correlation. A correlation with higher R^2 value indicate better estimate (perfect correlation has a value of $R^2 = 1$). Therefore, the models with the high value of R^2 were selected for estimating HHV and the results were compared with the data obtained from the experiments and previously models were developed. The models chosen were based on the analysis of the average absolute error (AAE) and average refractive errors (ABE). Both of these parameters were expressed by the following equation:

$$AAE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{HHVe - HHVm}{HHV}\right| 100\%$$

$$ABE = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{HHVe - HHVm}{HHVm}\right] 100\%$$

Where, subscript e and m indicate the estimated value from model (calculation) and from the result of measurement respectively.

The average absolute error indicates the average correlation error. The lower average absolute error mean correlation error is smaller and vice versa. The average bias error indicates the average bias error correlation. A positive value of average bias error implies estimation goes beyond measurement, while a negative value indicates an overall estimate below the measurement results. The lower value of average absolute error show average bias error of the correlation is also lower. Those parameters were fundamental statistical criteria which were used widely in the error analysis and also had been used to assess the correlation value of empirical model [3-4]. Therefore, these parameters were also adopted in this paper as an evaluation of the model parameters.

However, it was important to note here that the correlation that had been published only valid for the fuel from which the equation were derived. Therefore, the comparison was done solely for the academic concern. In comparing the correlations generated in this study with the already existing, the seven equations had been selected from the literature as shown in Table 1.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Table 1. Empirical correlations between HHV and Analysis Proximate Data from Other Authors

References	Model	Unity of HHV
[17]	HHV =10,81408 + 0,3133 (VM + FC)	MJ/kg
[3]	HHV=19,914-0,2324 A	MJ/kg
[3]	HHV=-3,0368+0,2218VM+0,2601FC	MJ/kg
[18]	HHV=0,196FC+14,119	MJ/kg
[8]	HHV=0,312FC+0,1534VM	MJ/kg
[9]	HHV=0,3543FC+0,1708VM	MJ/kg

III. Results and Discussion

A. Solid Waste Characteristics

Twenty two of the twenty four collected data were used to generate empirical correlation which showing the influence of proximate analysis data to the calorific value. The two other data released after normalization test. Table 2 shows the characteristics data bioorganic fraction of MSW in area study. Volatile matter is the main composition at a range 64.95 to 74.58% and with the average 69.41%, followed by ash at a range 10.44 to 16.79% and with the average 13.50%, fixed carbon at a range 14.74 to 19.47% and with the average 17.09% in dray basis, and moisture content at a range 9.13 to 12.23% and with the average 10.43%. The water content is relatively low because it were dried prior to analysis in the laboratory. The experimental heating values vary from 14,53 to 17,07MJ/kg and with average 15.96 MJ/kg in dry basis. This result is not much different from the characteristics of waste in Bhopal India as reported by [19]. In [19] were reported that MSM in Bhopal, containing an average of 64.82% volatile matter, 21,7 % ash, and 13.21% fixed carbon in dry basis, and the average moisture content is 28.1%. On average the HHV of waste, it was reported about 2200 to 2400 kcal/kg or 9.2 to 10.08 MJ/kg in wet basis (12.80 to 14.02 MJ/kg in dry basis).

Table 2**.** Proximate Analysis Data and Calorific Value Bioorganic Fraction of Municipal Solid Waste

No Sample	Proximate Data (%)				HHV MJ/kg
	Moisture Content	Ash	Volatile Matter	Fixed Carbon	
1	11.95	17.31	64.95	17.74	15.42
2	11.87	13.04	70.41	16.56	16.64
3	12.23	13.93	66.90	18.32	15.80
4	10.67	11.94	70.57	18.27	17.00
5	11.20	13.81	68.18	18.02	15.77
6	11.59	14.08	70.09	15.82	15.82
7	11.37	15.30	67.30	17.40	15.43
8	11.08	13.34	68.76	17.90	15.92
9	11.78	12.64	69.74	17.63	15.90
10	10.82	16.79	66.56	16.65	15.19
11	9.43	10.44	74.58	14.97	15.76
12	9.51	13.38	71.59	15.03	15.26
13	10.53	16.53	68.10	15.37	14.53
14	9.13	14.50	68.25	17.24	15.27
15	9.58	12.38	70.66	16.97	15.58
16	9.51	12.95	72.31	14.74	15.56
17	9.49	11.78	72.19	16.03	16.80
18	9.59	10.85	71.41	17.74	17.07
19	9.36	13.43	68.51	18.06	16.60
20	9.43	13.54	68.16	18.31	16.52
21	9.62	13.47	68.81	17.73	16.48
22	9.66	11.55	68.98	19.47	16.92
Average	10.43	13.50	69.41	17.09	15.96

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B. Model Developed

Although, collecting the proximate analysis data of solid fuels is relatively easy but, not many researchers developed correlation models between calorific value and proximate analysis data. In this paper, at first, simple correlation with the emphasis on the correlation between calorific value with each proximate analysis data were focused. It was done by plotting HHV as a function of moisture content, ash, volatile matter, and fixed carbon (Figure 1). It is intended to demonstrate quantitatively the correlation between HHV with each proximate analysis data. Obviously, the tendency can be seen in Figure 1a and 1b that HHV down with increasing moisture content and ash in bioorganic fraction of MSW. This result is consistent with the observations were done by [3, 20].

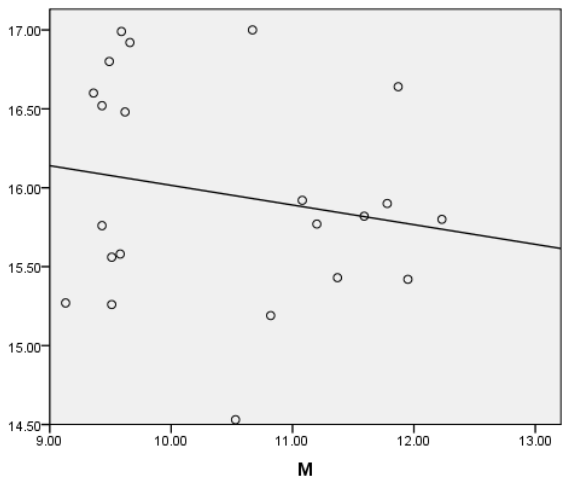

Figure 1a. Plot between HHV and Moisture Content

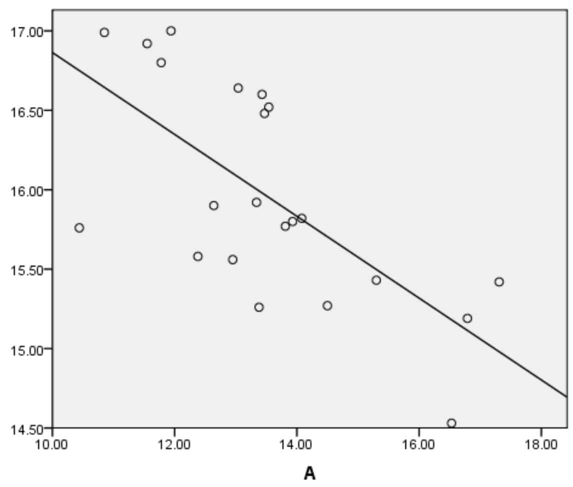

Figure 1b Plot between HHV and Ash Content

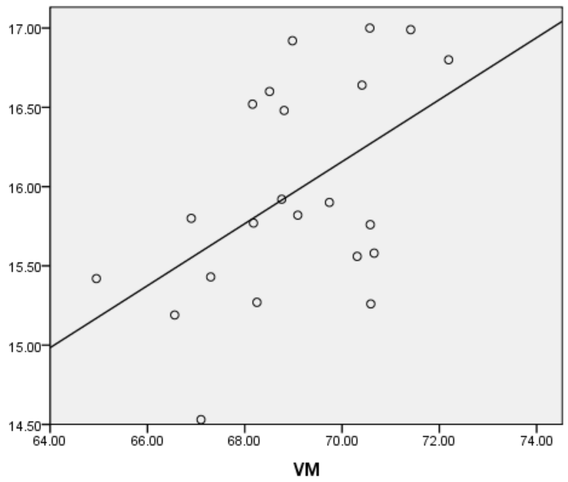

Figure 1c. Plot Between HHV and Volatile Matter

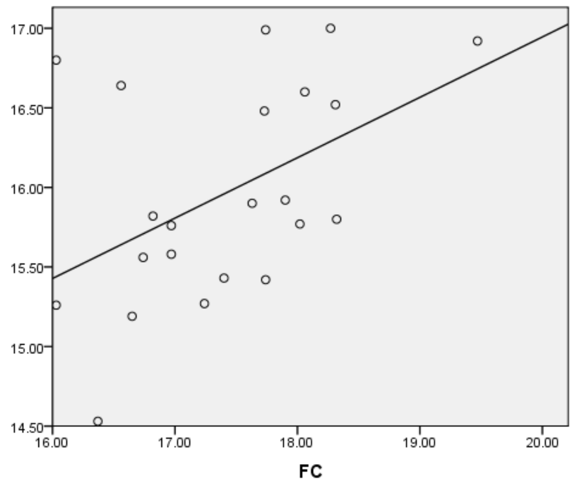

Figure 1d. Plot Between HHV and Fixed Carbon

Figure 1. Plot Between HHV and Proximate Analysis Data

The moisture content of the solid fuel is highly dependent on the drying process and the drying process is an integral part in the utilization of biomass fuels. Thus, the moisture content is less precise represented in the equation because it depends on the preparation process, so it can vary widely. It is directly affected by physical and chemical properties of material which enable it to absorb the exiting water in the environment. Therefore, by using mathematical models the involvement of the moisture content can result in a significant error in the determination of calorific values. This explanation is confirmed that taking into account the moisture content in the sample, giving a weak correlation to the calorific value (Figure 1a). Equation (1) in Table 3 shown also very small (0.04) the coefficient of determination between HHV calculated and experimental results. Therefore, in an effort to eliminate the influence of water content on the determination of the calorific value, the variable M is not represented in the correlation in a model of multiple linear regression analysis-based correlation.

As the moisture content, the ash also contributes negatively to HHV (Figure 1b). It means, the higher of ash content in the fuel, the energy content will be lower. Unlike the case with the moisture content, ash can be applied to estimate HHV due it is the characteristics of a specific solid fuel. However, the correlation between calculated HHV with

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Vol. 5 Issue 02, February-2016

the experiment results as shown by equation (2) is also relatively small (Table 3).

Table 3. The Performance of Developed Equations in This and Previous Study

No.	Researchers	Models	R^2	Error Analysis	
				AAE	ABE
(1)	This Study	HHV = -0.125M+17.251	0.04	3.00	0.00
(2)	This Study	HHV=19.440-0.258A	0.46	3.00	0.00
(3)	This Study	HHV=2.467+0.196VM	0.26	4.00	1.00
(4)	This Study	HHV=9.355+0.380FC	0.23	3.00	-1.00
(5)	This Study	HHV=-9.509+0.259(VM+FC)	0.56	19.00	-19.00
(6)	This Study	HHV=-30.727+0.459VM+0.716FC	0.67	16.00	-16.00
(7)	This Study	HHV = 0.192A+0.459VM+0.716FC-30.727	0.69	2.00	0.00
(8)	This Study	HHV=0.185A+0.467VM+0.712FC+0.056M-31.723	0.69	2.00	0.00
(9)	This Study	HHV = 0.226A+0.519(VM+FC)-31.916	0.59	3.00	0.00
(10)	[17]	HHV =10,81408 + 0,3133 (VM + FC)	0.30	137.8	137.8
(11)	[3]	HHV=19,914-0,2324 A	0.978	5.01	5.01
(12)	[3]	HHV=-3,0368+0,2218VM+0,2601FC	0.399	43.5	43.50
(13)	[18]	HHV=0,196FC+14,119	0.822	9.60	9.06
(14)	[8]	HHV=0,312FC+0,1534VM	0.623	2.40	0.20
(15)	[9]	HHV=0,3543FC+0,1708VM	0.628	12.30	12.30

Note : HHV in MJ/kg

The relationship between HHV to fixed carbon and volatile matter also gives no significant coefficient of determination between HHV calculation results and the experimental respectively 0.23 and 0.26 for equation (3) and (4) as shown in Table 3. However, both are contributing positively to the HHV (Figure 1c and d). Given the lack of correlation between HHV with water content, ash, volatile matter and fixed carbon separately or in simple linear regression relationship, various combinations of these variables (except moisture) were used to estimate HHV through multiple linear regression.

Based on the consideration that the ash in a dry basis is the residue of volatile matter and fixed carbon (100-VM-FC) then, previous researchers have proposed an equation to correlate HHV with VM and FC or the number of VM and FC content as shown in Table 1. In this paper, the relationship is also used to develop the correlation (Eq. (1) up to (9)). The coefficient of determination, average absolute error, and average bias error of each equation are presented in Table 3.

C. Models Performance Assessment

Table 3 confirmed that the equation (5) to (9) which developed in this study showed a stronger correlation between calculated HHV and the experimental results compared to equation (1) to (5). Among them there are three equations with R^2 values of more than 0.6, namely the equation (6), (7) and (8). Based on the error analysis, the equation (6) showed a tendency to underestimation while equation (7) and (8) shows the tendency of overestimation, as can be seen from the average value of bias errors in a negative and positive sign. In addition, both the value of AAE and ABE from equation (6) exceeding 5%. The measurement values and HHV calculated results from equation (7) and (8) almost the same on all sample. These are indicated by the value of their AAE and ABE less than 5%. Based on this fact (the value of R^2, AAE, and ABE), two correlation (eq. (7) and (8)) resulting from this study were selected.

To compare the models performance (eq. (7) and (8)) with models were developed by previous researchers, data collected in this study were applied to the models and the results are presented in Table 3 (eq. (10) to (15)). When viewed on their statistically performance, only equation (11) was developed by [3] showed a strong correlation between the results of calculations with experiments. In addition the error level is about 5%.

IV. CONCLUSIONS

Based on the fuel characteristics the bioorganic fraction of MSW in area study, the volatile matter is the main composition with the average 69.41%, followed by ash with the average 13.50%, fixed carbon with the average 17.09%, and moisture content with the average 10.43%, while, the experimental heating values with average 15.96 MJ/kg. In the literature, there were a few empirical correlations to estimate HHV of bioorganic fraction of municipal solid waste from their proximate analysis data. However, assuming that the equations are only valid for the data from which is derived, the new correlations between HHV with volatile matter, fixed carbon, and ash from bioorganic component were developed in this study. Accuracy of the models developed and available in the literature were evaluated statistically using proximate analysis data collected in this study. Two of the nine correlations were developed in this study showed a good performance that HHV = 0.192A + 0.459VM + 0.716FC - 30.727 and HHV = 0.185A + 0.467VM + 0.712FC + 0.056M - 31.723 which have the highest accuracy compared to other models have been developed including those from previous studies. However, due $R^2 << 1$ then, there are the effect of variation in the MSW. The main advantage of this correlation is only based on the proximate analysis data that besides fast in provision, more easy and economic than ultimate analysis data.

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