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Prediction Heating Values of Lignocellulosics from Biomass Characteristics

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Abstract**—**The paper provides biomasses characteristics by proximate analysis (volatile matter, fixed carbon and ash) and ultimate analysis (carbon, hydrogen, nitrogen and oxygen) for the prediction of the heating value equations. The heating value estimation of various biomasses can be used as an energy evaluation. Thirteen types of biomass were studied. Proximate analysis was investigated by mass loss method and infrared moisture analyzer. Ultimate analysis was analyzed by CHNO analyzer. The heating values varied from 15 to 22.4MJ kg^{-1}. Correlations of the calculated heating value with proximate and ultimate analyses were undertaken using multiple regression analysis and summarized into three and two equations, respectively. Correlations based on proximate analysis illustrated that deviation of calculated heating values from experimental heating values was higher than the correlations based on ultimate analysis.

Keywords**—**Heating value equation, Proximate analysis, Ultimate analysis.

I. Introduction

BIOMASS is renewable, sustainable and environmental friendly. It is an abundant renewable energy resource in several countries. It appears now attractive as is a potentially valuable source of thermochemical conversion for sustainable bioenergy, biofuel, chemical products and co-fire systems. In recent years, a number of researchers have conducted studies on the agricultural biomass issues as its thermal decomposition process is now relevant to the production of charcoal, activated carbon, pyrolytic liquid fuels and fuel gases. Biomass is commonly a lignocellulosic material whose major constituents are hemicellulose, cellulose and lignin. Pyrolysis of biomass containing these three constituents has been widely studied [1]-[4]. Recent reviews on cofiring stated that 16 countries have already used some major biomasses combusted with some types of coal in boiler [5].

The aim of the present work is to model the heating value of 13 types of biomass by the proximate and ultimate analyzes. Satisfactory equations are summarized and reported and discussed.

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II. Experimental

A. Preparation of Various Biomasses

Thirteen types of biomass (Narrowleaf cattail, Rice straw, Lawn grass, Jackfruit leaf, Mango leaf, Bamboo leaf, Mast tree leaf, Banana leaf, Coconut leaf, Coconut coir, Sugarcane bagasse, Water hyacinth, Corncob) were obtained locally, then washed, and dried at temperature of 100ºC for 12h in order to reduce the moisture content and stored in desiccator before tests.

B. Characterization of Biomasses

For proximate analysis, the data of moisture content, volatile matter and ash were obtained by weight loss method. For moisture content, a comparison of mass loss method by oven and the infrared moisture analyzer was done. The biomass was air-dried in an electrical oven (MEMMERT Model UL 40) at temperature of 107^{o}C for 12h (ASTM E 790-92). The mass loss of moisture content measurement was determined every hour for 12h to ensure that its mass loss became steadily. By the infrared moisture analyzer, METTLER TOLEDO INFRARED DRYER Model LJ16 LP16 was used. For volatile matter, the biomass was heated and burnt in an electrical furnace (Model NABER 2804 Lilienthal/Bremen Program Controller C8) at temperature of 950ºC for 7min (ASTM E 897-93). For ash content, the biomass was heated and burnt in furnace at temperature of 500 ºC for 30min and then 815ºC for 1h (Australian Standards 1038.3-1989). For ultimate analysis, carbon (C), hydrogen (H), nitrogen (N) and oxygen (O) content were analysed by CHNO analyzer (ASTM D 5373-93). Heating value was measured by bomb colorimeter (SANYO GALLENRAMP (AUTO BOMB) Model CBA-350-K).

III. Results and Discussion

A. Properties of the Biomasses

The high contents of volatile and carbon are the major properties of starting materials for the heating value. Physical and chemical properties by proximate and ultimate analyses of the thirteen types of biomass studied were first determined and presented in Tables I and II. Since coconut shell, sugarcane bagasse and corncob are used as solid fuels in many countries, therefore, the heating value and proximate and ultimate analyzes of them by previous investigators with biomasses in this work are also compared in Tables I and II [6], [7]. The results show that biomasses studied give either higher or lower volatile content than coconut shell, sugarcane bagasse and corncob. The biomasses contain volatile matter in the range 63.61 to 91.30%. However, all biomasses studied give lower fixed carbon than coconut shell. Ultimate analysis shows that the biomasses contain carbon in the range 34.81-50.60% where coconut shell contains lower carbon at 26.68%. Conversely, coconut shell has higher amount of hydrogen at 16.26%, where all biomasses studies have hydrogen in the range 3.30-6.19%.

TABLE I
PROXIMATE ANALYSIS OF BIOMASS (AS-RECEIVED BASIS)

Biomass	Proximate Analysis (%wt, dry basis)			Experimental HHV (kJ/kg, dry basis)
	Volatile Matter	Fixed carbon	Ash	
Narrowleaf cattail	79.19	10.39	10.42	16267.5
Rice straw	63.61	6.88	29.51	15069.1
Lawn grass	74.94	12.39	12.67	17664.1
Jackfruit leaf	70.05	13.67	16.28	17025.4
Mango leaf	73.87	14.75	11.38	18834.5
Bamboo leaf	71.67	8.31	20.02	17760.8
Mast tree leaf	84.00	10.74	5.26	22365.3
Banana leaf	80.35	9.34	10.31	19178.5
Coconut leaf	80.75	12.92	6.33	20828.8
Coconut coir	79.23	17.85	2.92	19082.4
Sugarcane bagasse	75.87	17.97	6.16	18202.6
Water hyacinth	76.85	12.17	10.98	16646.2
Corncob	88.25	9.51	2.23	18762.8
Coconut shell¥	70.72	21.22	0.90	19417.2
Sugarcane bagasse*	73.78	14.95	11.27	17330.0
Corncob*	80.1	18.54	1.36	18770.0

¥ From [6]
* From [7]

TABLE II
ULTIMATE ANALYSIS OF BIOMASS (AS-RECEIVED BASIS)

Biomass	Ultimate Analysis (%wt, dry basis)			
	C	H	N	O
Narrowleaf cattail	39.66	5.18	0.93	43.81
Rice straw	34.81	4.41	1.21	30.07
Lawn grass	37.79	5.46	2.34	41.74
Jackfruit leaf	42.33	4.70	3.12	33.57
Mango leaf	43.89	4.57	1.59	38.57
Bamboo leaf	39.81	5.68	3.26	31.32
Mast tree leaf	50.60	5.93	2.69	35.52
Banana leaf	44.54	5.74	1.90	37.52
Coconut leaf	47.89	6.19	1.66	37.93
Coconut coir	46.33	3.74	1.46	45.56
Sugarcane bagasse	44.05	4.50	0.75	49.06
Water hyacinth	37.42	3.30	2.04	46.27
Corncob	43.77	4.67	1.17	48.16
Coconut shell¥	48.09	7.68	0.55	43.68
Sugarcane bagasse*	44.80	5.35	0.38	39.56
Corncob*	46.58	5.87	0.47	45.47

A comparison between the moisture content with the mass loss method by electrical oven and the infrared moisture analyzer is given in Table III. The results show that the moisture content by infrared analyzer gives higher values of moisture than by oven at around 1.99-4.21%.

TABLE III
COMPARISON OF MOISTURE CONTENT BY MASS LOSS METHOD USING OVEN AND THE INFRARED MOISTURE ANALYZER

Biomass	Moisture Content (%wt, as received)		The difference (%)
	Oven	Infrared	
Narrowleaf cattail	8.10	10.68	2.58
Rice straw	6.77	9.23	2.46
Lawn grass	6.67	8.83	2.16
Jackfruit leaf	8.39	11.24	2.85
Mango leaf	6.69	8.60	1.91
Bamboo leaf	4.55	7.96	3.41
Mast tree leaf	5.27	7.70	2.43
Banana leaf	5.27	8.40	3.13
Coconut leaf	4.77	7.44	2.67
Coconut coir	7.13	11.34	4.21
Sugarcane bagasse	4.34	6.59	2.25
Water hyacinth	8.53	12.31	3.78
Corncob	7.63	9.62	1.99

B. Calculation of the Heating Value

Predicting heating value of biomasses from proximate analysis was also studied in Cordero et al. [8]. As previously stated, this present work is aimed at determining the heating value of biomasses as a function of proximate and ultimate analyses. Five different correlation equations were examined to obtain optimized equation either with proximate or ultimate analysis. Three different equations were obtained with the proximate analysis and two different equations were obtained with ultimate analysis. The calculations of heating value with the proximate analysis are given as follows:

$$HHV = 199.28VM + 241.25FC \quad (1)$$

$$HHV = 157.34(VM + FC) + 4243.97 \quad (2)$$

$$HHV = 14441.82(X) + 7018.311 \quad (3)$$

where $X = VM/(VM + FC + A)$

where VM, FC and A are the volatile matter, fixed carbon and ash, respectively. HHV is the higher heating value and calculated by dry basis in kJ/kg. The calculated results showed that the heating values

In the case of the calculated heating value equation with ultimate analysis, the two equations can be obtained as:

$$HHV = 342.15C + 446.13H + 351.98N + 25.57O - 13.05A \quad (4)$$

$$HHV = 343.08C + 424.92H + 261.98N + 27.76O \quad (5)$$

where HHV in (5) was calculated by dry-ash-free-basis in kJ/kg.

The validity of each calculated heating value equation was estimated by fitting the calculated equation to the experimental data. The normalised standard deviation (Δq_e) was calculated using the following equation:

$$\Delta q_e(\%) = \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{q_{e,\exp} - q_{e,cal}}{q_{e,\exp}}\right)^2}{N-1}} \times 100 \qquad (7)$$

where N is the number of experimental data points.

The calculated heating value with proximate analysis data by (1) to (3) are listed in Table IV. The calculated heating value with ultimate analysis data by (4) and (5) are given in Table V. The results show that the experimental heating values vary from 15 to 22.4MJ kg^{-1}. It can be seen that the calculated heating values by (1), (2), and (3) vary between 14.3-20.01MJ kg^{-1}, 15.3-19.7MJ kg^{-1} and 14.4-20.1MJ kg^{-1}, respectively.

TABLE IV
COMPARISON OF HEATING VALUES WITH PROXIMATE ANALYSIS

Biomass	$q_{e,\exp}$	$q_{e,cal}$ (kJ/kg)		
	(kJ/kg)	(1)	(2)	(3)
Narrowleaf cattail	16267.5	18287.6	18338.5	18324.5
Rice straw	15069.1	14336.0	15334.9	14419.4
Lawn grass	17664.1	17923.1	17984.5	17864.2
Jackfruit leaf	17025.4	17257.5	17416.5	17125.8
Mango leaf	18834.5	18279.3	18187.4	18128.1
Bamboo leaf	17760.8	16287.2	16828.0	16360.7
Mast tree leaf	22365.3	19330.5	19150.4	19380.0
Banana leaf	19178.5	18265.4	18355.8	18347.0
Coconut leaf	20828.8	19208.8	18982.0	19161.1
Coconut coir	19082.4	20095.3	19518.5	19858.7
Sugarcane bagasse	18202.6	19895.1	19718.4	20118.5
Water hyacinth	16646.2	18250.7	18250.4	18209.9
Corncob	18762.8	19880.7	19625.5	19997.8

TABLE V
COMPARISON OF HEATING VALUES WITH ULTIMATE ANALYSIS

Biomass	$q_{e,\exp}$ (kJ/kg, dry basis)	$q_{e,cal}$ (kJ/kg, dry basis)	
		(5)	(6)
Narrowleaf cattail	16267.5	17185.2	17267.4
Rice straw	15069.1	15094.6	14968.3
Lawn grass	17664.1	16720.0	17056.8
Jackfruit leaf	17025.4	17813.0	18269.0
Mango leaf	18834.5	18273.2	18486.9
Bamboo leaf	17760.8	17386.6	17795.1
Mast tree leaf	22365.3	21075.1	21570.4
Banana leaf	19178.5	18992.8	19259.1
Coconut leaf	20828.8	20285.9	20548.2
Coconut coir	19082.4	18799.3	19131.3
Sugarcane bagasse	18202.6	18394.3	18583.2
Water hyacinth	16646.2	15707.9	16059.2
Corncob	18762.8	17185.2	17267.4

Comparison of the value of the R^2 and Δq_e from (1) to (5) are listed in Table VI. For the correlation of the heating value with proximate analysis, it can be concluded that data by (2) (Δq_e = 7.39%) gave better results than other equations. However, from the values of R^2 in (4) and (5) in Table VI, which are the calculated heating value with ultimate analysis, results described better correlation (R^2 = 0.91 and 0.83) than results with proximate analysis by equations 1 to 3, which are calculated with proximate analysis (R^2 = 0.38, 0.41 and 0.32).

TABLE VI
COMPARISON OF R^2 AND Δq_e OF CALCULATED HEATING VALUE WITH EXPERIMENTAL HEATING VALUE

Equation	R^2	Δq_e (%)
(1)	0.38	7.80
(2)	0.41	7.39
(3)	0.32	7.61
(4)	0.91	3.82
(5)	0.83	3.40

IV. CONCLUSION

Thirteen types of biomass were used to study the correlation of the heating value with proximate and ultimate analyses. The results showed that the heating value varied from 15 to 22.4MJ kg^{-1}. Correlations of the calculated heating value with proximate and ultimate analyzes were undertaken by using multiple regression analysis and summarized into three and two equations, respectively. The results showed that correlations with proximate analysis gave higher deviation of calculated heating values from experimental heating values than ultimate analysis used.

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