Energy Content Estimation in Waste Saw Dust, Maize Cobs and Rice Husks Using Multiple Regression Analysis

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Abstract: *Solid wastes are produced and accumulated due to human activities. Energy recovery from the wastes is considered a sound waste management practice. Energy recovery process can be anaerobic digestion, incineration, pyrolysis and gasification among others. It is important to estimate the theoretical energy content of the wastes in order to accurately determine system performances and process efficiency. This is important during planning of waste to energy strategies. Saw dust, maize cobs and rice husks waste were sampled from dumpsites, dried and stored in contamination free environment. Samples were analyzed for the concentration of moisture, Carbon (C), Nitrogen (N), Hydrogen (H), oxygen (O) and sulfur (S). Saw dust contained 49.08±0.07% C, 6.04±0.05% H, 40.89±0.18% O, 0.25±0.06%N and 0.078±0.01% S, while rice husk contained 42.9±0.71% C, 4.06±0.07% H, 35.98±0.11% O, 1.02±0.02% N and 0.2±0.01% S .A model for estimation of municipal solid waste energy content was developed using input parameters of the waste composition. Based on the results of regression analysis, a mathematical model equation was developed which was used to predict the higher heating value (HHV). The results of this model compares well with experimental data and the Du Long formula. The model provides a quick and accurate method of higher heating value determination where the elemental composition of the wastes is known and can be applied for segregated wastes and mixed waste.*

Keywords: Wastes, Energy content, saw dust, maize cobs, rice husks high heating value

1. Introduction

Due to human activities in the cities municipal solid waste (MSW) is produced which may result in various environmental and public health problems [1, 2]. Recovering energy from municipal solid waste is considered a good practice in waste management [2]. This can be achieved through processes such as combustion, anaerobic digestion, pyrolysis and gasification [1].

Design and operation of such energy systems based on municipal solid waste are highly related to heating value of the used municipal solid waste materials. Thus, determining heating value (HHV) of solid waste is a key work to perform the efficient design and operation of the waste to energy conversion based technologies. It is also important when planning a WtE facility.

The high heating value/ calorific value is normally determined experimentally in a bomb calorimeter which is difficult especially when the equipment are not available [3]. An alternative method due to the availability of instrumental packages for ultimate analysis, HHV can be obtained via a mathematical relation using the deduced chemical composition of the fuel which employs empirical correlations to compute this HHV. These correlations are based on limited or investigator's own data points, and their application to a wider spectrum of fuels result in large errors in HHV estimations [4]. Other equations are based on the fact that fuel HHV can be estimated by summing the weighted combustion enthalpies of the constituent elements;- however, when oxygen is present in the fuel, it occupies a fraction of carbon or hydrogen bond sites.

The purpose of this work is to develop and validate a mathematical model for HHV prediction from elemental composition of a fuel. This is an empirical model for estimation of energy content, which is represented by higher heating value, of municipal solid waste using their contents of water, carbon, hydrogen, nitrogen, oxygen, and sulfur. In order to determine the equation coefficients of the developed model equation, the method of multiple nonlinear regression analysis has been used.

2. Materials and Methods

2.1 Area of Study

This study was carried out in Thika Municipality of Kiambu County. The study site lies between latitudes 3°53′ and 1°45′ south of Equator and longitudes 36°35′ and 37°25′ east [12]. Kang'oki dumpsite is the major dumpsite in the municipality where this study was carried out.

2.2 Sample Collection

Rice husks, maize cobs and saw dust samples were collected in pre cleaned polyethene bags, screened to remove large particles and sun dried to a constant weight before storage.

2.3 Sample Treatment

Rice husks, maize cobs and saw dust samples were dried by spreading them outside sunlight to reduce the moisture content. Samples of this waste were taken and tested to determine their elemental composition.

2.4 Elemental characterization of waste from Thika municipality

Ultimate analysis test methods were executed according to ASTM established procedures (ASTM, 2003) [5] at the Kenya Industrial Research and Development Institute (KIRDI) instrument laboratory in Nairobi Kenya. This was done using different instruments that include: UV/Visible Spectrophotometer, bomb calorimeter and a pH meter. This test was used to determine the ratio of combustible elements (Carbon, Hydrogen, Nitrogen, Sulfur, Oxygen), to incombustible constituents like inorganic ash residue of a sample. The composition of the sample was important to define the energy content and to determine how clean and efficient it was for use.

2.5 Data Analysis

Analysis was through the use of descriptive statistics, covariate correlation and cross tabulation. The data was summarized into frequencies and percentages and presented in tables, and figures. Frequencies and percentages were adopted to present, discuss and interpret findings obtained. The findings obtained were used to develop a model that can be used to predict the higher heating values of different waste to determine the best combination of different wastes to achieve optimum power generation from the waste.

2.6 Model Development

Data from the ultimate analysis formed the data points which were fed to simulation software developed by Oakdale University in USA [6]. Composite 32 wastes samples were analyzed. The ultimate analysis for Carbon (C), hydrogen (H), nitrogen (N), oxygen (O), sulfur (S) (mass percentages on a dry weight basis), and moisture (H_2O) were used as input data parameters/ variables.

Experimental higher heating values (MJ/kg) were determined and used to validate the empirical model as described by Meraz *et al* (2003) [7]

2.6.1 Model HHV equations
The fuel elemental composition as mass percentage (on a dry basis) of carbon (%C), oxygen (%O), hydrogen (%H), nitrogen (%N), and sulfur (%S) is used in calculations. According to Dulong's formula, the heat of combustion of a sample equals the heat of combustion of its elements regardless of whether it passes through one or more oxidation states as shown in equation1.

$$HHV = 0.0336\%C + 1.418\%H + 0.094\%S - 0.145\%O \dots\dots\dots\dots\dots\dots\dots 1$$

The HHV is then calculated through a linear combination of these variables. Boie, (1953), developed a model as indicated in equation 2

$$HHV = \left(1 - \frac{H2O}{100}\right)(-0.3517\%C - 1.1625\%H + 0.1109\%O - 0.0628\%N - 0.1109\%S \dots\dots\dots\dots 2$$

Another mathematical correlation that is widely used in combustion technology was developed by Lloyd and Davenport [9] when he subjected 138 liquid fossil fuels to a multiple regression analysis; a least squares fit of the enthalpy of combustion as a function of elemental composition was found by forcing the fit through the origin. The resulting model is illustrated by equation 3 below:

$$HHV = \left(1 - \frac{H2O}{100}\right)(-0.3578\%C - 1.1357\%H + 0.0845\%O - 0.0594\%N - 0.1119\%S \dots\dots\dots\dots 3$$

Wilson [10] developed another equation shown in equation 4 below.

$$HHV = \left(1 - \frac{H2O}{100}\right)(-0.3279\%C - 1.153\%H + 0.1668\%O + 0.0242\%N - 0.0928\%S \dots\dots\dots 4$$

Meraz et al (2003) [7] developed a similar equation as indicated by equation 5.

$$HHV = \left(1 - \frac{H2O}{100}\right)(-0.3708\%C - 1.1124\%H + 0.1391\%O - 0.3178\%N - 0.1391\%S \dots\dots\dots 5$$

Ebru and Demir, 2009 [11] in their work, Energy content estimation of municipal solid waste by multiple regression analysis developed the following mathematical model.

$$HHV = \left(1 - \frac{H2O}{100}\right)(0.327\%C + 1.241\%H - 0.089\%O - 0.26\%N + 0.074\%S \dots\dots\dots\dots\dots\dots 6$$

The units of all HHV quantities in this report are MJ/kg.

3. Results and Discussion

3.1 Elemental characterization of sample waste

Ultimate analysis of the sample waste collected from the waste stream was

Table 3.1: Results of ultimate analysis (mass on dry basis) conducted that gave the following results with their typical calorific values (HHV) as tabulated in Table 3.1.

Waste type	%H_2O	%C	%H	%O	%N	%S	Ash	HHV (MJ/Kg)
Rice husks	8.21± 0.18	42.9± 0.71	4.06± 0.07	35.98± 0.11	1.02± 0.02	0.2± 0.01	8.04± 0.06	12.69± 0.10
Maize combs	10.21± 0.45	43.06± 0.85	4.04± 0.07	36.14± 0.28	1.13± 0.06	0.25± 0.01	7.98± 0.11	12.34± 0.20
Wood	15.89± 0.11	49.08± 0.07	6.04± 0.05	40.89± 0.18	0.25± 0.06	0.078± 0.01	16.23± 0.28	16.12± 0.18

These results compares well with reported by Meraz *et al.,* 2003[7], Tchobanoglous *et al.,* 1993 [13], and Themelis *et al.,* (2003) [14]. Where for instance Meraz *et al* reported for wood C 49.05%, H 5.99%, O 41.13%, N 0.29% and S 0.08% while Tchobanoglous *et al* had C 44.0%, H 5.9%, O

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1502

44.6%, N 0.3% and S 0.2% and Themelis *et al* C 49.5%, H 6.0%, O 42.7%, N 0.2% and S 0.1% .

3.2 Model development for estimating the higher heating value (HHV) in waste

Experimental higher heating values (MJ/kg) are taken into account as output (target) variable in the empirical model development. The data ranges and statistical analysis of both ultimate analysis and HHV of the 32 considered samples formed the input variable. The summary of this input of the model is shown in Table 3.2 below

Table 3.2: Summary of the data statistics of the modeled equation

Variables	Minimum	Maximum	Mean	Std. Dev
Input variables				
H_2O (%)	0.00	78.29	16.87	22.37
C (%)	15.81	84.54	49.49	13.44
H (%)	2.24	14.13	6.60	2.11
O (%)	0.00	47.84	30.29	13.43
N (%)	0.00	10.00	1.30	2.00
S (%)	0.0	15	0.78	2.66
Output variable				
HHV (MJ/Kg)	4.17	45.88	17.83	8.7

Each independent (input) variable (x) is related to value of the dependent variable (Y). The fundamental equation for the multiple regressions for observation is given in equation 7.

$$y = a + b.x1 + c.x2 + \cdots ... + zxp + \alpha ... ... 7$$

Where *a, b, c* and *z* are the regression coefficient.

The investigated equation for higher heating value estimation of solid waste is given in equation 8

$$y = \left(1 - \frac{x1}{100}\right)(a.x2 + b.x3 + c.x4 + d. + e.x6) ... ... .8$$

where, x_1, x_2, x_3, x_4, x_5 and x_6 represent the input variables, water (H2O), carbon (C), hydrogen (H), nitrogen (N), oxygen (O), sulfur (S)

3.3 Regression Coefficients

Upon input of the parameters to the software the following regression coefficients were obtained as tabulated in table 3.3.

Table 3.3: Regression coefficients results

Variable	Value	Standard error	t-ratio	Prob (t)
A	-0.2557	0.1081	2.3666	0.02568
B	-1.6530	0.7673	2.1544	0.04065
C	0.1439	4.2320E-02	-3.4006	0.00218
D	-0.9314	0.3993	-2.3324	0.02769
E	-.04406	0.3011	-1.4634	0.15532

From these coefficients Carbon, Hydrogen, nitrogen and oxygen represented by a, b, c, and d contribute significantly to the value of higher heating value (HHV) since their probability value is less than 0.05 (at 95 % confidence level). However sulfur represented by e is not significant in

the calculation of HHV since its probability value (0.15532) is greater than 0.05.

Carbon and Hydrogen contribute positively to increase the value of HHV since their coefficients are positive whereas Oxygen, Nitrogen and Sulfur decreases the HHV predicted since their coefficients are negative.

Fitting these coefficient values in the HHV prediction equation 8, equation 9 shown below was obtained.

$$y = (1 - x1/100)(-0.2557 \quad 0.108\,x2 - 1.653$$
$$0.7673x3 + 0.1439 \quad 0.0423x4$$
$$- 0.9314 \quad 0.3993x5 - 0.4406$$
$$0.3011x6) ... ... 9$$

Where y = HHV.

When this is fitted in the equation 8 the final model equation 10 is expressed as;

$$HHV = (1 - \frac{H2O}{100})(-0.2557 \quad 0.108(\%C) - 1.653$$
$$0.7673(\%H) + 0.1439$$
$$0.0423(\%O) - 0.9314$$
$$0.3993(\%N) - 0.4404$$
$$0.3011(\%S) ... ... 10$$

3.4 Statistical Parameters

Some descriptive statistic coefficients of the model used in analyzing the performance criteria of the model are tabulated in the Table 3.4.

Table 3.4: Model equation statistical parameters

Residual statistics	Observed value
Coefficient of multiple determination(R^2)	0.7836
Standard Error of the Estimate(SEE)	4.3477
Sum of square Error(SSE)	491.47
Average absolute errors (AAE)	0.177
Sum of residuals	5.4959

Figure 1 shows the coefficient of multiple determinations R^2 as 0.7836 which shows the percentage variation on the data explained in the model and the regression between the considered model outputs corresponding targets has a good correlation.
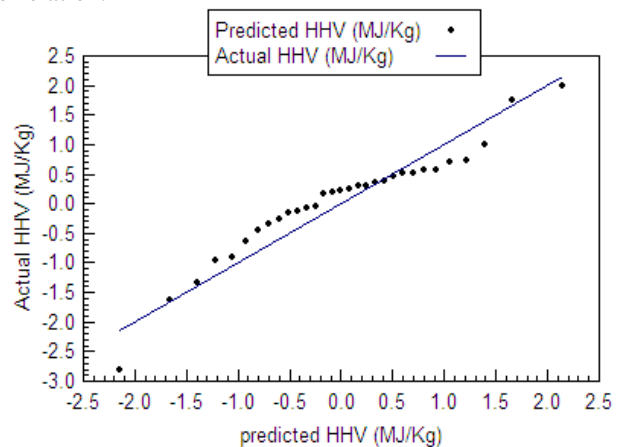

Figure 1: Correlation between the actual and estimated higher heating value of municipal solid waste.

Figure 2 shows the modeled equation estimation output being plotted against the actual higher heating value data.
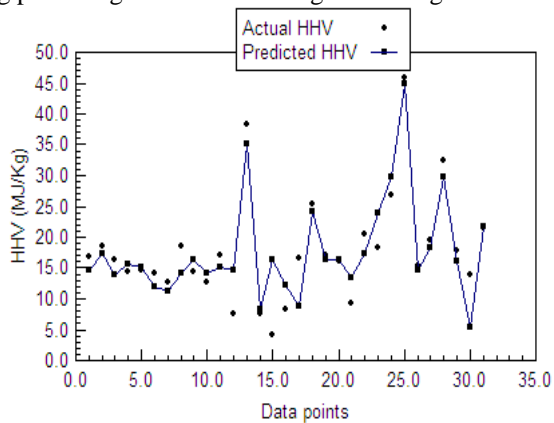

Figure 2: Comparison of predicted higher heating value in the model to the actual higher heating value.

Figure 3 Shows residuals between model prediction results and the corresponding actual data for the sample of the municipal solid waste considered in this study.
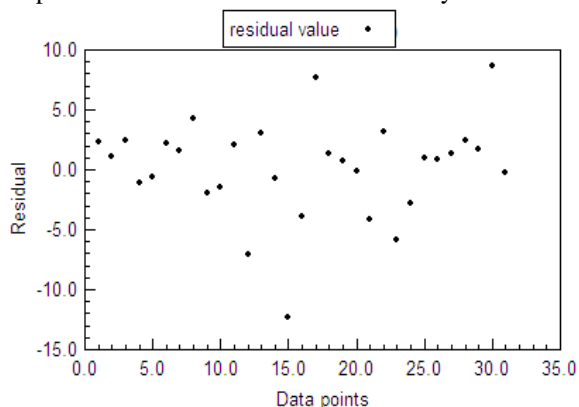

Figure 3: Residual errors between the predicted and the actual higher heating values.

In determination of the potential of designing and implementing a waste to energy conversion facility, the estimation of the higher heating value of municipal solid waste can be done using this modeled equation. This will be time saving and also lead to cost saving since no laboratory tests would be required. The observed higher heating values compared with those calculated by the developed formula as well to those developed by Dulong and Boie.

4. Conclusion

The result gave a good multiple determination coefficients R^2 of 0.7835 and an average absolute error of the estimated value as 0.177 MJ/Kg is an indication that the model can thus be said to be a good prediction tool for higher heating value of the municipal solid waste. The accuracy of the equation developed is dependent on the data points used while developing the equation. The more the data points the higher the correlation thus will predict the HHV value of the waste with high accuracy. The similarities between the Du long equation and the modeled equation shows a remarkable consistency. The higher heating values can thus be predicted reasonably well from elemental composition by using this modeled equation. The Du long and the modeled formula gave the best agreement with the measured heating values and predicted. The uncertainty of the higher heating value calculated by formula is not much different than that measured by bomb calorimeter. Therefore, reliable data on the elemental composition should give accurate higher heating values.

5. Acknowledgement

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