ESTIMATING THE CALORIFIC VALUES OF LIGNOCELLULOSIC FUELS FROM THEIR CONTENT OF HEMICELLULOSE, CELLULOSE AND LIGNIN

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ABSTRACT

Estimating the calorific value of a lignocellulosic fuels can be of practical interest for the design of any power plant. There exists a variety of correlations for the predicting the calorific value of lignocellulosic fuels based on ultimate and proximate analysis. However, the ultimate and proximate analyses are expensive and need special instruments. The proportional composition of cellulose, hemicellulose and lignin plays a significant role in the calorific value of lignocellulosic fuels. This study deals with a new method to calculate the higher heating value (HHV) of lignocellulosic fuels from the content of hemicellulose, cellulose and lignin by using nonlinear regression model.

The mean absolute percentage error (MAPE) was used to show the goodness of the proposed method. A high degree of correlation was observed in this study (MAPE < 10). The results indicate that the regression model offers a high degree of correlation and the correlation can be used during the design stage of any fuel-processing system to estimate the HHV when only the structural content of the linked-lignocellulosic fuel is available.

INTRODUCTION

Energy security have become key issue all around the world [1]. Lignocellulosic fuels are expected to play an important role as a renewable energy source. Physical, chemical and thermodynamic properties of biomass are essential parameters for designing any energy systems[2]. The use of biomass as a biofuel requires the knowledge of higher heating value (HHV) [3]. Lignocellulosic fuels are complex materials that generally consist of 3 major organic fractions: lignin, cellulose, and hemicellulose [4]. Therefore, they are not fully standardized and do not follow any specific, existing normative, though the properties of commercial fossil fuels are usually well known [5].

There are numerous works deal with the use of ultimate and proximate analysis for determining higher heating values of lignocellulosic fuels. However, the estimation of lignocellulosic fuels calorific value based on biomass constitutes was not studied enough in the literature. Unfortunately, there are a few correlations based on biomass constitutes to calculate HHVs of biomass fuels. Table 1 shows a representative list of the correlations for predicting HHV of biomass fuels based on structural composition.

TABLE 1. A REPRESENTATIVE LIST OF THE CORRELATIONS FOR PREDICTING HHV OF BIOMASS FUELS BASED ON STRUCTURAL COMPOSITION

MODEL	Reference
$14.3377 + 0.1228(L) + 0.1353(Ext)$	[6]
$0.17389[Ce] + 0.26629(100 - [Ce])$	[7]
$0.17389[Ce] + 0.26629[L] + 0.32187[E]$	[8]
$(1 - [Ash]/([Ce] + [L] + [E]))(0.17389[Ce] + 0.26629[L] + 0.32187[E])$	[9]

This study aims at providing an alternative method for the calorific value of biomass that is faster, easier to use and less expensive than existing techniques and methods with comparable or enhanced accuracy.

Sample

In this study, a total of 20 biomass samples have been selected from previous studies with their HHVs. Their HHVs were calculated by using the Milne equation. The datasets were divided into training (75%) and testing (25%) that were selected randomly. Table 2 shows the training dataset of calorific values of biomass samples with their measured constitutes.

TABLE 2. THE TRAINING DATASET OF CALORIFIC VALUES OF BIOMASS SAMPLES WITH THEIR HHVS

No	Cellulose	Hemicellulose	Lignin	HHV	Reference
1	25,90	29,90	42,50	19,28	[10]
2	26,80	30,40	42,90	21,05	[11]
3	24,00	23,60	48,40	19,93	[10]
4	48,40	34,60	17,00	19,42	[11]
5	25,60	22,10	52,30	23,14	[11]
6	50,70	28,90	20,40	19,75	[11]
7	38,10	32,90	5,70	19,39	[12]
8	37,90	32,00	6,70	19,22	[12]
9	38,50	32,90	6,00	19,47	[12]
10	50,00	26,00	8,00	17,75	[13]
11	31,50	27,50	24,00	16,21	[14]
12	39,50	17,60	25,20	19,24	[15]
13	36,30	34,40	12,10	19,40	[10]
14	42,40	28,20	27,00	19,40	[10]
15	31,70	30,60	38,20	20,00	[16]

Methodology

Depending upon the physicochemical structure of the lignocellulosic fuels, the heating values may differ [17]. The HHV prediction models for the content of hemicellulose, cellulose and lignin can be introduced as follows:

$$HHV= \gamma 1*He + \gamma 2*Ce + \gamma 3*Li + \gamma 4 \qquad (1)$$

where He, Ce, and Li, are the content of hemicellulose, cellulose, and lignin, respectively, expressed in percentage on dry basis and γi's are the numerical coefficients. The nonlinear regression model was determined using a training dataset. The model equation was solved with the aid of the MATLAB r2014a, based on developing statistical correlations between the training dataset of the HHV and the constitutes of lignocellulosic fuels. The relationship is described by the following equation:

$$HHV=0,16101*He + 0,093833*Ce + 0,11323*Li + 8,57 \qquad (2)$$

The mean absolute percentage error (MAPE) as a statistical parameter was used to measure the performance of the regression model (Eq. 3). The MAPE is defined as follows:

$$MAPE=\frac{1}{n}\sum_{i=1}^{n} \frac{|c_i-m_i|}{m_i} \times 100 \qquad (3)$$

Where m_i is the measured value for the ith testing dataset, c_i is the calculated value for the ith testing dataset.

RESULTS

The correlation was verified for accuracy using the testing dataset. The testing dataset was not utilized at any point during the training of the development of the correlation. Table 3 shows the testing dataset of higher heating values of biomass samples with their measured constitutes.

TABLE 3. THE TESTING DATASET OF BIOMASS CONSTITUTES WITH THEIR HHVS

No	Cellulose	Hemicellulose	Lignin	HHV	Reference
1	24,70	27,00	27,20	19,50	[15]
2	41,10	20,90	28,00	19,26	[15]
3	24,20	24,70	34,90	20,56	[15]
4	29,60	15,70	53,00	18,92	[10]
5	30,00	28,00	37,00	20,80	[18]

Table 4 shows the model estimation results with relative errors.

TABLE 4. THE HHVS ESTIMATIONS AND THEIR RELATIVE ERRORS

HHV (MJ/kg)	Predicted (MJ/kg)	Relative Error (%)
19,50	18,31	6,08
19,26	18,96	1,55
20,56	18,77	8,71
18,92	19,88	5,06
20,80	20,08	3,45

Overall, the results in Table 4, show that a high degree of correlation was observed in this study. The MAPE of the HHV prediction model was 7.03%. This is the indicator of the precision of the developed correlation.

CONCLUSION

The value of lignocellulosic fuels' HHVs strongly depends on the content of hemicellulose, cellulose and lignin. In this study, a correlation has been developed to determine the HHVs of various lignocellulosic fuels. The developed model in this work for lignocellulosic fuels gives a clear view of the change of HHV at various the content of hemicellulose, cellulose and lignin. The main advantage of this correlation is, based on only biomass constitutes' data, it provides a rapid and easy estimation of the HHV.

NOMENCLATURE

HHV: Higher Heating Value.
MAPE: The mean absolute percentage error.

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