Archives of Waste Management and Environmental Protection

Archiwum Gospodarki Odpadami i Ochrony Środowiska

ISSN 1733-4381, vol. 17, issue 1 (2015), p. 141-148

http://awmep.org

The Influence of Compositions of Alternative Fuels on Higher Heating Values - A Review

ShashankSAKLESHPUR NAGARAJA [1], Lucyna CZARNOWSKA [2], Magdalena BOGACKA [3]

[1] *MSc Student, Clean Fossil and Alternative Fuels Energy, Silesian University of Technology, e-mail: shashank.sn92@gmail.com*

[2] *Department of Technologies and Installations for Waste Management, Silesian University of Technology, e-mail: lczarnowska@polsl.pl*

[3] *Department of Technologies and Installations for Waste Management, Silesian University of Technology, e-mail:magdalena.bogacka@polsl.pl*

Abstract

Heating value of a fuel is an important parameter in selection of fuel. Higher Heating value (HHV) is the enthalpy of complete combustion of a fuel, including the condensation enthalpy of formed water. Numerous empirical correlations are available in the open literature to obtain the HHV of the fuel from its elementary composition. In the present study, these correlations are used to obtain HHV of few alternative fuels and the value of HHV for each fuel is compared with experimental values and mean absolute error % is calculated. It was found that *Dulong* model had the least mean error percentage for alternative fuels considered in the present study.

Keywords: Higher heating value (HHV), Composition of alternative fuel, Empirical correlations

Streszczenie

Wpływ składu paliw alternatywnych na ciepło spalania

Ciepło spalania (Q_w) jest ważnym parametrem charakteryzującym paliwa, a określane jest jako entalpia całkowitego spalania paliwa, z uwzględnieniem entalpii kondensacji skroplonej pary. Liczne korelacje empiryczne są dostępne w literaturze, na podstawie których można oszacować ciepło spalania Q_w paliwa znając jego skład pierwiastkowy. W artykule, zestawiono 10 różnych wzorów empirycznych i na ich podstawie określono Q_w dla wybranych paliw alternatywnych o różnym składzie. Dodatkowo obliczono średni błąd procentowy w odniesieniu do wyników eksperymentalnych. Stwierdzono, że użycie wzoru Dulonga w przypadku rozważanych paliw alternatywnych jest obarczone najmniejszym średnim błędem procentowym.

Słowa kluczowe: ciepło spalania (Q_w), skład paliw alternatywnych, korelacje empiryczne

1. Introduction

Dwindling fossil fuel reserves and long lead times in creation of conventional fuels have increased the fear of energy crisis in the near future. Moreover, increased concern about the environment has led to a debate on the use of alternative fuels based on renewable sources. Renewable alternative fuels like biomass, reduce greenhouse gas emissionsand particulate matter and promotes energy independence, whereas NOx emissions of biomass are comparable with conventional solid fuels. Biomass fuels are considered to maintain overall CO_2 balance in the atmosphere. Use of agricultural waste as fuels also solves the problem of solid waste disposal partially. Thus, knowing the potential of alternative fuels, it is important to study the properties of such fuels.

One of the important properties is the Higher Heating Value (HHV) or Gross Heating Value (GHV). HHV is the amount of heat produced by the complete combustion of a unit quantity of fuel when all products of the combustion are cooled down to the temperature before the combustion and also, the water vapour formed during combustion is condensed.

Lower Heating Value (LHV) is then determined by subtracting the heat of vaporization of the water vapour from the higher heating value. The relation between LHV and HHV is shown in Equation 1.1. When advanced combustion units having secondary or tertiary condensers are designed, the appropriate fuel value to use in the design process is the HHV, whereas in normal processes, water vapour released by fuel combustion is passed into the surrounding with flue gases and the latent heat of vaporization is irreversibly lost to the environment. In these cases, it is essential to use LHV for the design of such plants. Generally, HHV is obtained experimentally using a bomb calorimeter and LHV is calculated. Even though the procedure is simple, the device is not always available for the researchers.

A better solution to circumvent this problem is to carry out ultimate analysis of the fuel and subsequently use the composition data in established empirical correlations to obtain the HHV. However, not all correlations give good results for alternative and non-conventional fuels. Therefore, in the present study an attempt is made to compare the HHV obtained using numerous correlations with the experimental value measured by bomb calorimeter according to the ASTM D2015 standard method which is presented in [1] and an error analysis is carried out.

$$HHV = LHV + h_v \times (9H + W) \tag{1.1}$$

where

h_v latent heat of vapourization of water in kJ/kg,

H weight% of Hydrogen in the fuel,

W weight% of Water vapour in the fuel.

2. Literature Review

Several empirical correlations for determining HHV of solid fuels have been proposed since late 1800s. Over the past decade, with the gaining popularity of renewable fuels, researchers have attempted to find empirical correlations for HHV of biomass fuels. Few of the correlations are summarized in the following subsections. In the correlations, C, H, O, N and S represents the carbon, hydrogen, oxygen, nitrogen and sulphur percentages (by weight in dry biomass) in the fuel respectively.

2.1. Boie's correlation

This correlation is one of the oldest and was often used to obtain HHV of coal [2]. It was obtained by Boie in the 1953. The correlation is shown in equation 2.1.

$$HHV = 83.2\mathrm{C} + 224.2\mathrm{H} + 25\mathrm{S} + 15\mathrm{N} - 25.8\mathrm{O}\ (kcal/kg) \tag{2.1}$$

2.2. Tillman's correlation

In 1978, Tillman suggested correlation for HHV of biomass material on the phenomenon that heating value is a strong function of the carbon content of the fuel[3]. This correlation, shown in equation 2.2 was suggested after estimating HHV of wood and wood bark.

$$HHV = 0.4373C - 1.6701\ (MJ/kg) \tag{2.2}$$

2.3. Lloyd and Davenport's correlation

In 1980, Lloyd and Davenport developed a regression model with 138 compounds representative for substances found in fossil fuel liquids[4]. This correlation, shown in equation 2.3 has been used for biomass fuels for past two decades.

$$HHV = 357.77\mathrm{C} + 917.58\mathrm{H} - 84.51\mathrm{O} - 59.38\mathrm{N} + 111.87\mathrm{S}\ (kJ/kg) \tag{2.3}$$

2.4 Jenkins' correlation

This correlation was developed in 1985[5]. Heating value and fuel proximate analyses were determined for 62 kinds of biomass. Ultimate analyses were determined for 51 kinds of biomass. Biomass samples were selected from 6 categories: (1) field crop residues, (2) orchard prunings, (3) vineyard prunings, (4) food and fibre processing wastes, (5) forest residues and (6) energy crops. The following correlation shown in equation 2.4 was obtained.

$$HHV = -0.763 + 0.301C + 0.525H + 0.064O\ (MJ/kg) \tag{2.4}$$

2.5. Demirbas' correlation

In this study carried out in 1996, the author estimated HHV of fuels from lignocellulosic materials using their ultimate analysis data [1]. The correlation shown in equation 2.5 was derived using the oxidation heats of Cand H and the reduction heat of O, assuming that the effectof the N content of a biomass fuel on its HHV was negative

$$HHV = \{33.5[\mathrm{C}] + 142.3[\mathrm{H}] - 15.410] - 14.5[\mathrm{N}]\} \times 10^{-2}\ (MJ/kg) \tag{2.5}$$

2.6. Channiwala and Parikh's correlation

The authors used 225 data points to develop this correlation in the year 2002 and validated it for additional 50 points [6]. The entire spectrum of fuels including solids, liquids and gases were considered to derive this correlation. Equation 2.6 gives the correlation.

$$HHV = 0.3941C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211\ \mathrm{Ash}\ (MJ/kg) \tag{2.6}$$

2.7. Friedl et al's correlation

In 2004, the authors developed a regression model to predict HHV of biomass fuels using database of elemental compositions of 122 samples of plant origin [7]. In this study, it was found that HHV also depends on square of C and product of C x H. The correlation is shown in equation 2.7.

$$HHV = 3.55\mathrm{C}^2 - 232\mathrm{C} - 2230\mathrm{H} + 51.2\mathrm{C} \times \mathrm{H} + 131\mathrm{N} + 20,600\ (kJ/kg) \tag{2.7}$$

2.8. Sheng and Azevedo correlation

Sheng and Azevado concluded that correlations based on ultimate analysis of fuel were more accurate [8]. In their work in the year 2005, correlation shown in equation 2.8 was obtained statistically based on a large database of biomass samples obtained from open literature. HHV of biomass was found to be function of main elements of the fuel (C, H and O).

$$HHV = -1.3675 + 0.3137C + 0.7009H + 0.0318O\ (MJ/kg) \tag{2.8}$$

2.9.Chun-Yang Yin's correlation

In 2010, Chun – Yang Yin developed correlations via step-wise linear regression method by using data of biomass samples from different geographical locations [9]. In this study, it was found that HHV of biomass material is function of carbon and hydrogen percentage in the fuel. The correlation is shown in equation 2.9.

$$HHV = 0.2949C + 0.8250H\ (MJ/kg) \tag{2.9}$$

2.10 Dulong's correlation

One of the oldest formulas for calculating HHV of coal is given by Dulong. This formula is used ubiquitously and a mention of this is made by Szargut [10]. The correlation is shown in equation 2.10

$$HHV = (33900\mathrm{C} + 10500\mathrm{S} + 121400(\mathrm{H} - (\mathrm{O}/8)) - 2500\mathrm{W} + (\mathrm{W} + 9\mathrm{H})2257)/100000 \ \ (\mathrm{MJ/kg}) \quad (2.10)$$

3. Methodology

In the present study, alternative fuels shown in Table 3.1 were chosen to study the behavior of the above equations. A tool, shown in Figure 3.1 was developed using MATLAB, a commercial software package. HHV values for each fuel are obtained using various correlations and are compared with the experimental value. Absolute values of error percentage are obtained in individual cases and a mean absolute value of error percentage is calculated and the correlation having lowest mean absolute value of error percentage is chosen as the best correlation for alternate fuels. The equations 3.1 and 3.2 show the relations.

Table 3.1 Alternative fuels and their compositions in weight % [1]

Fuel	C	H	N	S	O
Olive Husk	49.9	5.5	0.7	0	42.0
Hazelnut Shell	52.8	5.6	1.4	0	37.8
Softwood	52.1	6.1	0.2	0	41.0
Hardwood	48.6	6.2	0.4	0	41.1
Wheat Straw	45.5	5.1	1.8	0	34.1
Corn Cob	49.0	5.4	0.4	0	44.6
Tea Waste	48.6	5.5	0.5	0	39.5
Saw Dust	46.9	5.2	0.1	0.04	37.8
Corn Stover	42.5	5.0	0.8	0.2	42.6
Poplar	48.4	5.9	0.4	0.01	39.6
Rice Husk	47.8	5.1	0.1	0	38.9
Cotton Gin	42.8	5.4	1.4	0.5	35.0
Bagasse	44.8	5.4	0.4	0.01	39.6
Peach Pit	53.0	5.9	0.3	0.05	39.1
Alfafa Stalk	45.4	5.8	2.1	0.09	36.5
Switchgrass	46.7	5.9	0.8	0.19	37.4
Red Oak Wood	50.0	6.0	0.3	0	42.4
Beech Wood	49.5	6.2	0.4	0	41.2
Spruce Wood	51.9	6.1	0.3	0	40.9

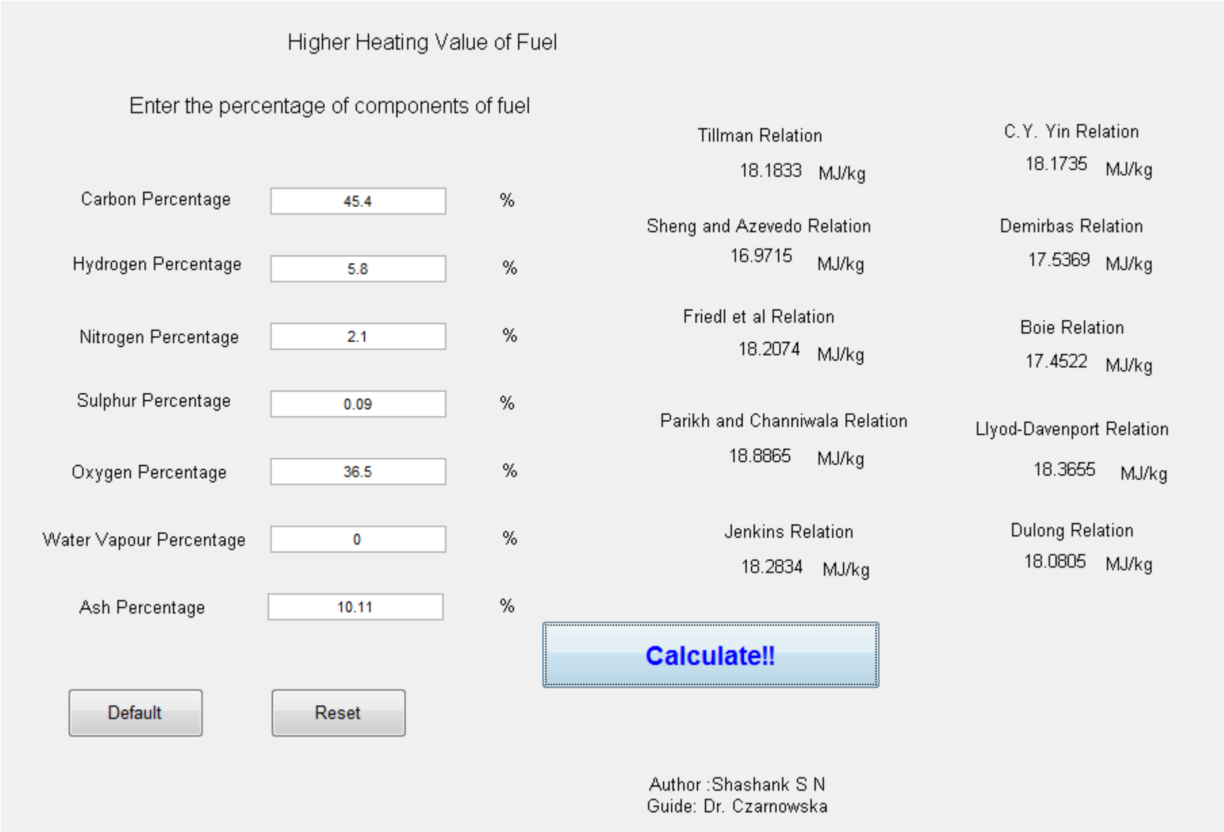

Fig 3.1 MATLAB application developed for the HHV calculation

$$(Error\,\%)_{abs} = \frac{(HHV)_{correlation} - (HHV)_{experiment}}{(HHV)_{correlation}} \times 100 \tag{3.1}$$

$$(Error\,\%)_{abs,mean} = \frac{\sum_{i=1}^{n}(Error\,\%)_{abs,i}}{n} \tag{3.2}$$

4. Results and Discussions

Experimental values of HHV of seven alternative fuels were taken from literature and compared with the HHV obtained from previously mentioned correlations. The HHV of the fuels obtained from different correlations are shown in Table 4.1. All higher heating values are in MJ/kg.

Table 4.1. Comparison of HHV in MJ/kg

Fuel	Expt	Boie	Tillman	Lloyd	Jenkins	Demirbas	Channiwala	Friedl	Sheng	Yin	Dulong
Olive Husk	19	18.8	20.2	19.9	20.2	18.8	20.4	20.1	18.7	19.9	19.3
Hazelnut Shell	19.3	19.1	21.5	20.3	20.8	18.9	20.6	21.1	19.2	20.2	19.4
Softwood	20	19.5	21.1	20.8	20.7	19.8	21.1	20.8	19.3	20.4	20.1
Hardwood	18.8	18.4	19.6	19.6	19.8	18.7	20	19.4	18.3	19.4	19
Wheat Straw	17	17	18.2	18	17.8	17	18.3	18.1	16.5	17.6	17.5
Corn Cob	17	17.3	19.7	18.6	19.7	17.1	18.8	19.3	17.8	18.9	17.5
Tea Waste	17.1	17.9	19.5	19.1	19.3	17.9	19.4	19.2	17.7	18.7	18.3
Saw Dust	17	17.1	18.8	18.4	18.5	17.3	18.6	18.4	17	18.1	17.5
Corn Stover	17.8	15	16.9	16.2	17.4	14.7	16.3	17	15.5	16.6	15
Poplar	19	18.1	19.5	19.4	19.4	18.5	19.7	19.2	18	19.1	18.7
Rice Husk	17.7	17.2	19.2	18.5	18.8	17.3	18.7	18.7	17.2	18.3	17.5
Cotton Gin	16.9	16.3	17	17.3	17.2	16.4	17.7	17.1	15.9	17	16.9
Bagasse	17.7	16.4	17.9	17.6	18	16.5	17.9	17.7	16.5	17.7	16.8
Peach Pit	19.4	19.8	21.5	21	20.8	20.1	21.4	21.2	19.4	20.5	20.4
Alfafa Stalk	18.6	17.5	18.2	18.4	18.3	17.5	18.9	18.2	17	18.2	18.1
Switch Grass	18.6	17.8	18.8	18.9	18.8	18.2	19.4	18.6	17.4	18.6	18.5
Red Oak Wood	19.7	18.5	20.2	19.8	20.1	18.7	20.1	19.9	18.5	19.7	19
Beech Wood	19.4	18.6	20	19.7	20	18.7	20.2	19.9	18.5	19.7	19.1
Spruce Wood	20.3	19.4	21	20.7	20.7	19.7	21	20.8	19.2	20.3	20

HHV of the alternative fuels considered for the study varied between 16.9 MJ/kg and 20.3 MJ/kg. Among the fuels considered, Spruce wood has the highest HHV and Cotton gin has the lowest HHV. All the correlations considered in the study, show highest deviation for corn stover. It can be noted from the above table that few correlations show negative deviation and few others show positive deviation. Hence, an absolute value of error percentage was calculated and is shown in Table 4.2.

Table 4.2 (Error %)$_{abs}$for different fuels from correlations

Fuel	Boie	Tillman	Lloyd	Jenkins	Demirbas	Channiwal a	Friedl	Sheng	Yin	Dulong
Olive Husk	1.1	5.9	4.5	5.9	1.1	6.9	5.5	1.6	4.5	1.6
Hazelnut Shell	1	10.2	4.9	7.2	2.1	6.3	8.5	0.5	4.5	0.5
Softwood	2.6	5.2	3.8	3.4	1	5.2	3.8	3.6	2	0.5
Hardwood	2.2	4.1	4.1	5.1	0.5	6	3.1	2.7	3.1	1.1
Wheat Straw	0	6.6	5.6	4.5	0	7.1	6.1	3	3.4	2.9
Corn Cob	1.7	13.7	8.6	13.7	0.6	9.6	11.9	4.5	10.1	2.9
Tea Waste	4.5	12.3	10.5	11.4	4.5	11.9	10.9	3.4	8.6	6.6
Saw Dust	0.6	9.6	7.6	8.1	1.7	8.6	7.6	0	6.1	2.9
Corn Stover	18.7	5.3	9.9	2.3	21.1	9.2	4.7	14.8	7.2	18.7
Poplar	5	2.6	2.1	2.1	2.7	3.6	1	5.6	0.5	1.6
Rice Husk	2.9	7.8	4.3	5.9	2.3	5.3	5.3	2.9	3.3	1.1
Cotton Gin	3.7	0.6	2.3	1.7	3	4.5	1.2	6.3	0.6	0
Bagasse	7.9	1.1	0.6	1.7	7.3	1.1	0	7.3	0	5.4
Peach Pit	2	9.8	7.6	6.7	3.5	9.3	8.5	0	5.4	4.9
Alfafa Stalk	6.3	2.2	1.1	1.6	6.3	1.6	2.2	9.4	2.2	2.8
Switch Grass	4.5	1.1	1.6	1.1	2.2	4.1	0	6.9	0	0.5
Red Oak Wood	6.5	2.5	0.5	2	5.3	2	1	6.5	0	3.7
Beech Wood	4.3	3	1.5	3	3.7	4	2.5	4.9	1.5	1.6
Spruce Wood	4.6	3.3	1.9	1.9	3	3.3	2.4	5.7	0	1.5

It isobserved from Table 4.2 that maximum absolute error in calculating HHV was from Demirbas correlation whenused for Cornstover. Mean of absolute error percentageshelps to compare the correlations and select the bestcorrelation for calculating HHV of alternativefuelsconsidered in thisstudy. The values of mean of absolute error percentages for eachcorrelationissummarized in Table 4.3.

Table 4.3 Mean of (Error %)$_{abs}$ for different correlations

Correlation	Mean Value (%)
Boie	4.2
Tillman	5.6
Lloyd	4.4
Jenkins	4.7
Demirbas	3.8
Channiwala	5.8
Friedl	4.5
Sheng	4.7
Yin	3.3
Dulong	3.2

5. Conclusions

The authors arrive at the following conclusions from the above results:

1. Dulong correlation gives better results than all other correlationsfor the alternative fuels considered in this study.
2. Based on Table 4.3, a mean value of absolute error less than 6 % shows that all the correlations are applicable for alternative solid fuels considered in the study.
3. From different correlations available to calculate HHV of biomass, this study suggests that HHV is a strong function of Carbon and Hydrogen composition (wt %) in the fuel and a weak function of Nitrogen and Oxygen in the fuel.

Acknowledgements

The paper has been prepared in the frames of the project: "A review study on *Influence of Compositions of Alternative Fuels on Higher Heating Values* ", funded by the KIC InnoEnergy program

6. References

1. Demirbaş, A. (1997). Calculation of higher heating values of biomass fuels.Fuel, 76(5), 431-434.
2. Boie, W. (1953). Fuel technology calculations. Energietechnik, 3, 309-316.
3. DA, Tillman. (1978). Wood as an energy resource.
4. W.G. Lloyd, D.A. Davenport, J. Chem. Educ. 57 (1980) 56–60.
5. Jenkins, B. M., Baxter, L. L., Miles Jr, T. R., & Miles, T. R. (1998). Combustion properties of biomass. Fuel processing technology, 54(1), 17-46.
6. Channiwala, S. A., & Parikh, P. P. (2002). A unified correlation for estimating HHV of solid, liquid and gaseous fuels. Fuel, 81(8), 1051-1063.
7. Friedl, A., Padouvas, E., Rotter, H., &Varmuza, K. (2005). Prediction of heating values of biomass fuel from elemental composition. AnalyticaChimicaActa, 544(1), 191-198.
8. Sheng, C., &Azevedo, J. L. T. (2005). Estimating the higher heating value of biomass fuels from basic analysis data. Biomass and Bioenergy, 28(5), 499-507.
9. Yin, C. Y. (2011). Prediction of higher heating values of biomass from proximate and ultimate analyses. Fuel, 90(3), 1128-1132.
10. Szargut, J. (1998). Thermodynamic (in Polish: Termodynamika), WydawnictwoNaukowe PWN