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Prediction of Calorific Value of Biomass from Proximate Analysis

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Abstract

Biomass is one of the renewable and sustainable energy sources that does not lead greenhouse gas emissions. Efficient use of biomass energy will help to solve problems resulting from fossil fuels. However, the main concern relevant to use of this energy is mainly related to low calorific value of biomass. Therefore, calorific value is the key parameter to evaluate the fuel quality of a special biomass material in energetic applications. In this context, twenty-seven different biomass species that represent very wide range of biomass materials such as herbaceous and woody biomasses, nut shells, fruit stones, stem and husks, pulps, and agricultural residues have been characterized by proximate analysis (moisture, volatile matter, fixed carbon, and ash contents). Then, various empirical equations which contain linear and nonlinear terms have been tested in order to predict the higher heating values (HHV) of full sample set from the proximate analysis results. It was concluded that since biomasses used in this study have different structures and fuel characteristics, the predicted HHVs for the full sample set were a bit different from the experimental HHVs and the r^2 of these equations varied in the range of 0.812-0.837, while standard deviations were between 1.469 and 1.493 MJ/kg. Nevertheless, considering the number of the biomass species used in this study and their differences in properties, these standard deviations may be regarded in the acceptable limits.

Keywords: Biomass; calorific value; proximate analysis; prediction; correlation.

1. Introduction

Increasing energy need forces societies to find alternative energy sources that are cheap, abundant and have low

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impact on environment. Fossil fuels are highly far from meeting these requirements. From this point of view, biomass is regarded as an energy source which is abundant, easy to find, renewable, and sustainable [1]. On the other hand, in contrast to fossil fuels, biomass is allowed as CO_2-neutral fuel since it does not contribute to the net increase in CO_2 emissions in atmosphere. That is, the amount of CO_2 formed upon burning of biomass is almost equivalent to the CO_2 captured from atmosphere during photosynthesis of green biomass. For these reasons, biomass is of great interest in renewable energy projects worldwide to mitigate greenhouse gases and to lower the share of fossil fuels in energy consumption [2].

The main concern relevant to use of biomass energy resources is that the energy density of biomass is typically lower than that of fossil fuels such as coals and the calorific value of biomass is closely affected from moisture content that it may reach very high levels especially in case of green biomass and waste materials. Besides, the experimental methods to estimate the heating value of a fuel are usually time consuming as well as expensive and have higher possibilities of experimental errors. In addition, the heating value of biomass cannot be calculated merely from the heats of formation of CO_2, H_2O and other products because biomass is a complex mixtures of compounds, and the relevant bond energies cannot be estimated properly [3]. On the other hand, there still exist extra unknown factors that influence the higher heating value (HHV) of biomass and such factors add more difficulty in modeling of this property [3].

In addition, the volatile matter content of biomass reaches up to 90 wt.% in some cases and in turn fixed carbon contents become too low [4]. The fixed carbon content of biomass can be easily connected with the calorific value since it has a positive effect on the energy potential of biomass. On the other hand, this situation is much more complicated for the volatile matter content. Because, high volatile matter content does not guarantee high calorific value since some of the ingredients of volatile matter are formed from non-combustible gases such as CO_2 and H_2O. Besides, ash has not only an inert effect on the calorific value of a fuel but also it shows some detrimental effects on the apparent heat obtained from burning of biomass. That is, the energy need of ash forming inorganics for thermal breakdown and phase transition is taken from the burning energy of biomass and it leads reduction in the calorific value. These relations between the calorific value of biomass and the proximate analysis results (moisture, volatile matter, fixed of carbon, and ash contents) motivates the researchers to develop various mathematical models to predict the calorific value of biomass depending on the proximate analysis results [5-10]. Apart from these studies, several alternative approaches have also been implemented based on ultimate analysis results (C, H, N, S, and O contents), physical or chemical compositions of biomass, and even artificial neural network (ANN) was used for modelling of HHVs [8]. Channiwala and Parikh [11] performed a detailed literature survey on these alternative methods and the systematic development sequence of these procedures for proximate analysis as well as ultimate analysis starting from 1880 can be seen in this paper. However, ultimate analysis and determination of the macromolecular ingredients of biomass such as lignin, cellulose, and hemicellulose require sophisticated equipment with good calibration and very sensitive analytical experiments. Likewise, the methods based on artificial neural network necessitate very large number of experimental data to validate the predicted model and then test it using the existing experimental data. In contrary to these methods, the proximate analysis of biomass only needs a simple oven (for determination of moisture content) and a furnace (for determination of volatile matter and ash contents) which can be easily found in an ordinary laboratory. Consequently, multiple linear regression (MLR) models that can be used for modelling of calorific value of biomass have been developed basing on proximate analysis results of miscellaneous biomass materials and the standard deviation of the predicted values are generally taken into consideration to evaluate the suitability of the predicted models. In this context, the present paper aims to establish various linear and non-linear empirical equations which can be used to predict the HHV values of a number of different biomass species basing on the proximate analysis results, and to check their suitability considering standard deviations and r^2 values that basically measures the goodness-of-fit in the regression analysis.

2. Materials and methods

In this study, twenty-seven different biomass species have been used. All of these biomass samples were Turkish origin and they were collected as residues or by-products from agricultural activities, forestry sector as well as food industry throughout the country. Therefore, these samples represent very wide range of biomass sub-classes. Sample names and codes of these biomasses are as follows: Elaeagnus (1), green bean stem and husk (2), red lentil hull (3),