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Application of real valued genetic algorithm on prediction of higher heating values of various lignocellulosic materials using lignin and extractive contents

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ABSTRACT

The higher heating values (HHVs) of 11 non-wood lignocellulosic materials from Turkey were measured experimentally and calculated incorporating various theoretical models with the values of both lignin and extractive contents. Multiple linear regression (MLR) and real valued genetic algorithm (RVGA) were used to derive the theoretical models. A non-linear RVGA6 model was determined as the best non-linear model considering the experimental results with a regression coefficient of 92% coefficient of determination (R^2), 0.301 sum of squared errors (*SSE*), 0.301 mean squared errors (*MSE*), 0.548 root mean squared errors (*RMSE*) and 0.0187 mean absolute percentage error (*MAPE*) and is proposed as a better alternative for theoretical HHV calculations to the multiple linear modellings such as MLR and RVGA1.

1. Introduction

The studies aimed at finding renewable and environmentally cleaner energy sources grew in importance in order to meet the world's increasing need for energy alongside fossil fuels. One of these renewable sources, the biomass, is quite diverse due to its animal, vegetative and waste content. Lignocellulosic materials can be evaluated in this scope. It is important to know physical, chemical and thermodynamic properties of the material that will be used in the production of biomass energy. For instance, measuring higher heating values (HHVs) of biofuels provides very important data in this sense. The higher heating value (also known as gross calorific value, GCV) of a biofuel is the most important fuel property that reveals whether the fuel can be considered as an economically and environmentally valuable energy source. Thus, rapid and accurate calculation/estimation of this parameter can provide an important advantage in designing for construction process of any biomass conversion plant. However, since these types of materials can exhibit different chemical and structural content in accordance to their origin [1], it is necessary to conduct new measurement for each of the samples. This situation causes the experimental equipment to be complicated and expensive, while testing period takes a lot of time. The researchers trying to overcome this difficulty work on developing different types of models for predicting HHVs based on the properties of lignocellulosic materials that are relatively easier and economically more viable for measurement. Most of the studies conducted until today rely on perennial ligneous biomass materials. However, annual bushes, agricultural waste and other residual forest waste are studied within this scope as well, although rarely. Detailed compilation and evaluation articles that summarize studies conducted on the subject can be found in the literature [1–4].

The results of ultimate analysis [5], proximate analysis [6] and structural analysis [7,8] are generally utilized for predicting the HHVs of lignocellulosic materials. Studies dealing with estimations based on structural analysis data have been found in a lesser number. The one of the reasons of this, the models based on the structural analysis (percentage of lignin, cellulose, holocellulose,

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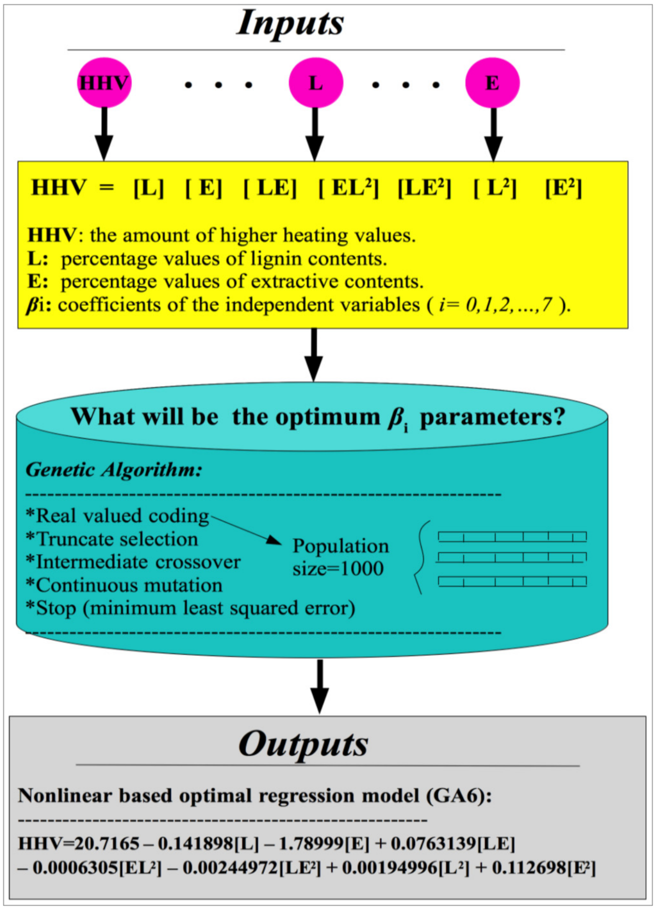

Fig. 1. The general structure of the solution techniques used.

extractives etc.) and obtained from linear regression analysis are less reliable comparing to other models. Another reason in the lacking of studies using structural analysis data is that the structural components can show variability that affect the estimation of HHVs. However, their usages draw interest because of obtaining these types of data using basic laboratory tools-equipment [7,8].

The researchers generally use linear [9] or non-linear [10,11] regression analysis techniques to derive these empirical equations. Some studies for showing significant effects of the interaction of factors or variables are performed by using multi non-linear regression (MNLR) models. The best combination of variables for multi non-linear regression (MNLR) models is determined as a factorial design [12,13]. Different numerical computer-assisted approaches can be found among recent literature. One of these approaches, such as Artificial Neural Network (ANN) model, was used to predict HHVs of urban solid waste and different types of lignocellulosics based on the results of ultimate analysis [14] and proximate analysis [15,16]. Also, this model was successfully used in other study areas, one of them being calculations aimed at obtaining hydrogen rich gas mixture from the pyrolysis of lignocellulosic waste [17]. Two soft techniques called adaptive neuro-fuzzy inference system (ANFIS) and genetic programming (GP) were used to estimate the HHVs of biomass using proximate and proximate/ultimate analyses data, respectively [18,19].

Various approaches based on statistics have been used to predict different responses of variables to obtain optimal conditions of the related systems, and to see the effects of factors on proposed models by researchers [20–22]. Some modern techniques such as Multiple (non-) linear regression (M(N)LR) [23,24], artificial neural networks (ANN) [25–28], response surface methodology (RSM) [12,13,29,30], artificial immune system (AIS) [31], particle swarm optimization (PSO) [32,33], Monte Carlo Simulation (MC) [23,31], and Bayesian approach (Markov Chain-interacted MC) [31,32] have been used by researchers of the modern era. Pros and cons of these techniques have been extensively studied by many researchers [20–32]. A comparison study between techniques of MNLR and ANNs, RSM and PSO is carried out by researchers to lead the selection of relevant techniques [20–32].

In this study, it is attempted to derive useful empirical equations for predicting HHVs based on the percentage of lignin and extractive contents obtained from the results of the structural analysis of 11 different non-wood lignocellulosic wastes from Turkey. The data was first evaluated using multiple linear regression analysis (MLR), then using a numerical technique called real valued genetic algorithm (RVGA). The obtained theoretical HHVs were compared to experimental HHVs.

The main goal of the study is to propose a numerical/intuitive RVGA technique which does not contain complex mathematical calculations for minimizing the error ratio in the estimation of HHVs that is effected by rather variable structural contents of lignocellulosic materials. RVGA regression prediction models based on the different structural analysis can be used to estimate higher heating values (HHVs) and Karadede et al. [33] stated that the proposed algorithm provides more precise results than other conveniently used models such as ANNs, Evolutionary Algorithms and Grey forecasting models. According to Karadede et al. [33], it is possible to estimate the best coefficients for multi linear or non-linear regression models by using the proposed real valued genetic algorithm. The distribution of the data is important for some prediction models, for example, a grey forecasting model works with constantly exponential increasing data, whereas the genetic algorithm works independent of data type because of the ability to quickly search the solution space. This work proposes a solution to this situation where a real valued genetic algorithm uses in order to estimate the best parameter tunning for these models. The best coefficient prediction for variables of the proposed multi non-linear regression models for forecasting higher heating values (HHVs) can be easily estimated by using the real valued genetic algorithm. The proposed genetic algorithm has always evolved with the best candidate solutions and it does not stick to local optimum solution(s). As a result, it can be said that the related feature gives it a superiority to find the optimal or near optimal solutions [33].

2. Material and method

2.1. Sampling and preparation for analysis

Descriptive information about the lignocellulosic materials gathered in the period July–August 2012 is presented in Table 1.

After the samples were collected, they were left on air to dry in order to remove excess moisture. At the end of this period, the samples were ground in an industrial type of mill (Unal Engineering and Machine Industry, Izmir, Turkey). After that, the pieces were sorted by their size by sieving them under 60 Hz intensity for 10 min using Retsch AS 200 model vibrating sieve. The pieces used in the analyses were 125–250 μm in size.

2.2. Original wood analysis conducted on the samples

The analyses and corresponding standards conducted on the ground samples are presented in Table 2.

Analytical grade nitric acid and benzene were purchased from Riedel-de Haën (Seelze, Germany) and sulfuric acid and ethanol were purchased from Merck (Darmstadt, Germany) and were used