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Assessment of producer gas composition in air gasification of biomass using artificial neural network model

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ABSTRACT

Energy generation from renewable and carbon-neutral biomass is significant in the context of a sustainable energy framework. Hydrogen can be conveniently extracted from biomass through thermo-chemical conversion process of gasification. In the present work, an artificial neural network (ANN) model is developed using MATLAB software for gasification process simulation based on extensive data obtained from experimental investigations. Experimental investigations on air gasification are conducted in a bubbling fluidised bed gasifier with different locally available biomasses at various operating conditions to obtain the producer gas. The developed artificial neural network consists of seven input variables, output layer with four output variables and one hidden layer with fifteen neurons. The multi-layer feed-forward neural network is trained employing Levenberg–Marquardt back-propagation algorithm. Performance of the model appraised using mean squared error and regression analysis shows good agreement between the output and target values with a regression coefficient, $R = 0.987$ and mean squared error, $MSE = 0.71$. The developed model is implemented to predict the producer gas composition from selected biomasses within the operating range. This model satisfactorily predicted the effect of operating parameters on producer gas yield, and is thus a useful tool for the simulation and performance assessment of the gasification system.

Introduction

Concerns about energy security and environmental apprehensions have compelled the policymakers in the energy sector to consider renewable and sustainable energy options to satisfy ever-growing energy demands. Biomass, a naturally available renewable carbon resource, is considered for energy extraction in the sustainable energy framework. It is the fourth largest source of energy which is abundantly available, renewable and potentially sustainable [1]. A wide variety of biomasses ranging from wood transformation industry residues to industrial wastes and energy crops are abundantly available. A major part of biomass is made up of ligno-cellulosic material consisting of cellulose, hemicellulose, and lignin [2] which is the vital element for creating biomass cell structure. Balat et al. [3] and Hosseini et al. [4] presented a detailed review of the possible conversion methods of biomass into hydrogen, a clean energy carrier. Hydrogen has been projected as a promising source of energy with multitude

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uses with less pollution on the environment [5,6]. As a fuel, hydrogen finds wide application in transportation, heating and power generation sectors. It is expected that hydrogen has the potential to eventually replace coal, oil and natural gas. Biomass can be efficiently converted into producer gas, a mixture of gaseous products consisting of hydrogen, carbon monoxide, methane and carbon dioxide through a thermochemical conversion process called gasification [7]. Gasification occurs at sub-stoichiometric oxidizing conditions, at high temperatures (above 700 °C) in a reactor. Gasification of biomass has been identified as one of the possible sources for bio-hydrogen which can be used in fuel cells. Among the various types of fuel cells, proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) have received most attention [8]. Integrated power generation system coupling solid oxide fuel cells (SOFCs) with gasifiers is now being considered as one of the promising technologies [9,10]. Research activities in the performance of SOFCs through the improvement of anode, cathode, and electrolyte materials, and contaminant tolerance limitations are being actively studied [8–11]. Investigations on gasification process operations to improve producer gas yield and composition is also a matter of concern. The producer gas composition and associated hydrogen yield depend on the feedstock characteristics, moisture content, gasifier design, gasification medium and the operating conditions of the gasification process [12,13]. A detailed review of the factors influencing biomass gasification has been reported [13–17].

Among the different gasification media (air, steam, oxygen, etc.) available for biomass gasification, air gasification is considered in this work. Being an autothermal gasification process, it makes use of heat produced in exothermic combustion reactions to sustain the endothermic gasification reactions. Air gasification process provides a gas mixture with lower calorific value in the range 4–7 MJ/Nm^3 and hydrogen yield varying from 8 to 14% [18]. Though different types of gasifiers [19,20] are available, bubbling fluidised bed gasifiers (BFB) are widely used for biomass gasification. BFB gasifiers can conveniently accommodate a wide variety of biomasses. They provide excellent heat transfer between biomass and bed materials and have approximately constant temperature distribution all over the reactor [5]. Further, BFB gasifiers are also capable of generating consistent producer gas composition with a low content of unconverted carbon and tar [14]. Experimental investigations on air gasification with fluidised bed gasifiers have been reported in the literature [21–26]. The effect of feedstock characteristics, gasifier design, gasification medium and the operating parameters on producer gas yield and compositions have been discussed.

Researchers have also formulated different mathematical models – thermodynamic equilibrium, kinetic, computational fluid dynamic (CFD) and artificial neural network (ANN) [27–29] to evaluate the performance of biomass gasification based on product gas yield and composition and for predicting the quantity and quality of product gas. An equilibrium model, applied to reacting systems, is developed on the concept of chemical reaction equilibrium grounded on the second law of thermodynamics [30]. The transfer phenomena among phases and the reaction kinetics of the primary reactions in biomass gasifier are taken into consideration in kinetic models [31]. In CFD models, a set of simultaneous equations for conservation of energy, momentum, mass, and species are resolved over a distinct region of the gasifier to predict the distribution of different parameters like temperature and concentration [27]. Artificial neural networks rely on a large number of experimental data and make use of mathematical regression in order to correlate between input and output streams [28].

Among the different mathematical modelling approaches, development of an artificial neural network model is considered in this study. ANN model is developed based on experimental investigations on air gasification of locally available biomasses in BFB gasifier to assess the producer gas composition. The effect of operating parameters – temperature and equivalence ratio on producer gas composition is investigated in detail. ANN is a useful tool for simulation when interactions of complex non-linearities are present in the process. Biomass gasification which is a complex thermochemical process can thus be conveniently simulated using an appropriately designed ANN.

ANN modelling concepts were extensively used in the arena of signal processing, pattern recognition, process simulation and function approximation [32]. Kalogirou [33] identified the importance of artificial neural networks as a tool in renewable energy system prediction and modelling. Applications of ANN models for biochemical and thermochemical conversions of biomass are now being reported. Development of ANN models have been reported for the prediction and optimization of hydrogen yields [34–37] in biochemical conversions of biomass. The application of ANN to analyse the biomass pyrolysis and gasification process have also been reported [32,38–47]. Guo et al. [32] developed a hybrid model incorporating multilayer ANNs to predict the product yield and gas composition in an atmospheric steam blown biomass fluidised bed gasifier. Xiao et al. [38] predicted the gasification characteristics of municipal solid wastes with an ANN model. Souza et al. [39] modelled a biomass gasification process in a fluidised bed gasifier based on the concepts of ANN to correlate between the composition of the produced gas and the characteristics of different biomasses for several operating conditions. Sreejith et al. [40] emphasised the prediction capacity of ANN models over corrected equilibrium models. Puig-Arnavat et al. [41] have used ANN models to predict producer gas composition in the case of bubbling and circulating fluidised beds. Karaci et al. [42] developed an ANN model to estimate hydrogen yield from pyrolysis of waste materials. Sun et al. [43] reported the development of a ANN model to predict the selectivity and yield of gaseous products from the pyrolysis of industrial waste biomass. Pandey et al. [44] developed ANN based modelling approach to estimate lower heating value of gasification products. Aydinli et al. [45] attempted to predict the energy potential and pyrolysis process products from biomass using ANN. Sunphorka et al. [46] reported the prediction of kinetic parameters of biomass from its constituents with ANN model. Baruah et al. [47] developed an ANN model to assess product gas composition in fixed bed downdraft gasifier. ANN applications in coal gasification have also been reported [48–50]. Off late, Li et al. [51] have proposed a back propagation neural network optimized by particle swarm optimization to predict gas