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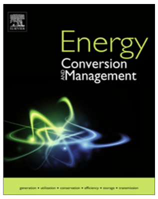

Dynamic modelling of biomass gasification in a co-current fixed bed gasifier

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ABSTRACT

Existing technical issues related to biomass gasification process efficiency and environmental standards are preventing the technology to become more economically viable. In order to tackle those issues a lot of attention has been given to biomass gasification process predictive modelling. These models should be robust enough to predict process parameters during variable operating conditions. This could be accomplished either by changes of model input variables or by changes in model structure. This paper analyses the potential of neural network based modelling to predict process parameters during plant operation with variable operating conditions. Dynamic neural network based model for gasification purposes will be developed and its performance will be analysed based on measured data derived from a fixed bed biomass gasification plant operated by Technical University Dresden (TU Dresden). Dynamic neural network can predict process temperature with an average error less than 10% and in those terms performs better than multiple linear regression models. Average prediction error of syngas quality is lower than 30%. Developed model is applicable for online analysis of biomass gasification process under variable operating conditions. The model is automatically modified when new operating conditions occur.

1. Introduction

The process of biomass gasification is a high-temperature partial oxidation process in which a solid carbon based feedstock is converted into a gaseous mixture (H_2, CO, CO_2, CH_4, light hydrocarbons, tar, char, ash and minor contaminants) called 'raw syngas', using gasifying agents [1]. Gasification products are mostly used for separate or combined heat and power generation [2], for hydrogen production [3], methanol production [4] and production of other chemical products [5]. A more detailed overview of available biomass gasification technologies is published by Kirkels and Verbong [5].

Although, gasification is a relatively well known technology, the share of gasification in overall energy demand is small due to current barriers concerning biomass harvesting and storage [6], biomass pre-treatment (drying, grinding and densification), gas cleaning (physical, thermal or catalytic), process efficiency and syngas quality issues [7]. The performance of biomass gasification processes is influenced by a large number of operational parameters, among them: biomass quality, fuel and air flow rate, composition and moisture content of the biomass, gasifier design, reaction/residence time, gasifying agent, biomass particle sizes, gasification temperature and pressure [8]. Process temperature is considered as one of the most important process parameters which influences syngas quality, reaction rate and tar concentration [9]. Furthermore, gasification operating conditions have tendency to change during a long term facility operation due to ash sintering, agglomeration and deposition on reactor walls which could cause bed sintering and defluidisation [10].

To improve process efficiency or to guarantee constant process quality during operation, plant operation simulation models that enable parameter prediction as a function of various operating conditions, are needed. Large scale experiments could be used for this purpose on pilot plants [11] or laboratory scale setups [12] but they are often too expensive or problematic in terms of safety. Most of the available models for biomass gasification simulation

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Nomenclature

Main symbols

$mair$	air flow rate, m^3/h
$mair_{av}$	average air flow rate, m^3/h
mb	biomass flow rate, kg/h
mb_{av}	average biomass flow rate, kg/h
mb_{freq}	fuel injection frequency, –
$error_{av}$	average error, –
β_{1-10}	regression coefficients, –
i	measurement number, –
N	number of measurement samples, –
T	temperature, °C
t	time

Abbreviations

ANN	artificial neural networks
APE	average prediction error
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
H_2	hydrogen
MFB	mean fractional bias
MLR	multiple linear regression
NMBF	normalised mean bias factor
NNM	neural network model
O_2	oxygen
R^2	coefficient of determination
RMSE	root mean square error

are based on equilibrium models for Gibbs free energy minimisation [13], CFD analysis [14] or kinetic reactions [15]. A more detailed review of available models for biomass gasification process can be found in the research done by Baruah and Baruah [16] or in comparative analysis performed by Mikulandric et al. [17]. From this point of the state of the art, it can be concluded that the most of available models are well capable to describe stationary process behaviour under constant operating conditions but they are not suitable for on-line process analysis where process dynamics under changeable operating conditions is considered.

Adaptable/evolutionary models and optimisation methods have potential to become a powerful methodology for gasification systems analysis, control and optimisation [18]. Artificial intelligence systems (such as neural networks) are widely accepted as a technology that is able to deal with non-linear problems, and once trained can perform prediction and generalisation at high speed. Artificial neural network (ANN) based prediction models use a non-physical modelling approach which correlates the input and output data to develop a process prediction model. ANN is a universal function approximator that has the ability to approximate any continuous function to an arbitrary precision even without a priori knowledge about the structure of the function that is approximated [19]. Dynamic neural networks with feedforward or recurrent feedback connections are used for systems with large delays like activated sludge processes [20], vapour-compression liquid chillers [21], chemical process systems [22] or energy related prediction processes [23]. Once trained ANN can predict process parameters in circulating and bubbling fluidised bed gasifiers [24], fluidised bed gasifiers with steam as gasifying agent [25] or in fixed bed gasifiers [26] with reasonable speed and accuracy. However, the prediction quality of trained ANN is highly dependent on the quantity and quality of training data related to the process. Changing process operating conditions can cause large prediction errors if the ANN models have not been modified for those particular conditions. The importance of dynamic modelling has been elaborated for the case of flexible operation and optimisation of carbon dioxide capture plants [27]. To encounter issues related to changeable operating conditions and to obtain reasonable model prediction accuracy Wang and Hu [28] proposed a dynamic parameter estimation approach using genetic algorithms to predict thermal behaviour of buildings with changeable thermal capacitance. For prediction of the lead-acid battery state of charge during operation Fendri and Chaabene [29] proposed dynamic recursive estimation Kalman filter algorithms. However, performance of a dynamic modelling approach for changeable operating conditions in biomass gasification has still not been analysed.

In this paper a dynamic ANN based modelling approach will be utilised to describe the process behaviour in a 75 kW_{th} fixed bed gasifier, operated by TU Dresden. The ANN model needs to be able to predict process parameters with reasonable speed and accuracy in a gasification process with large delays and changing operating conditions. In order to guarantee prediction accuracy for changing operating conditions a dynamic modelling approach with automatic ANN re-training sessions will be utilised and its performance will be compared with a dynamic multiple linear regression based model. Reasonable prediction speed is required in order to enable on-line parameter prediction for process analysis. Model performance has been analysed using statistical error analysis.

2. Gasification plant and operating conditions

In order to develop a neural network based model (NNM), the neural network has to be trained using observed/measured data to predict process parameters. Neural network based models generally require a large number of measurement data to form input and output data sets for neural network training. Results from NNM could differ significant if different sets of input and output data have been used for training purposes. Due to their nature NNMs are used to describe particular processes that occur in the observed system during stable operating conditions. However, if something changes in the process due to changes in operating conditions, design changes, biomass quality or other unexpected process variables the NNM structure has to be modified (NNM has to be re-trained) to preserve prediction quality for this particular condition. For the purpose of NNM modelling 2 sets of experiments (9 experiments in total), with different operating conditions, were conducted to form a database for NNM training. The object of modelling is a co-current fixed bed gasifier with thermal input of 75 kW_{th}, located in Pirna (Germany), operated by TU Dresden. Biomass wood chips, distributed from a local provider, are used as fuel in the gasification process. The facility scheme is presented in Fig. 1.

During facility operation the biomass is firstly injected manually in a small storage room with a manually controlled valve. Once the valve opens, the whole amount of biomass from the storage room is injected into the biomass shredder and consequently injected into the gasification reactor. Gasification air is distributed by fans and injected in the process from the upper side of the gasifier, leading to a co-current flow system. Ash is removed manually by opening ash removal valves. The biomass quality could be determined offline by dedicated laboratory tests, however it is hard to determine biomass quality for modelling purposes online due to variability between batches of distributed wood chips.

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