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Application of general regression neural network to model a novel integrated fluidized bed gasifier

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ABSTRACT

In order to better understand gasification performance, a general regression neural network (GRNN) was developed to model a novel integrated fluidized bed (IFB) gasifier to research the correlative relationship between the input and output parameters of the IFB gasifier. Additionally, the prediction accuracy of the GRNN model was compared with the multivariate nonlinear regression (MNR) method. The performances of the two methods were evaluated using the mean relative error (MRE), the root mean square error (RMSE) and the coefficient of determination (R^2). The GRNN model simulated the IFB gasifier with a higher R^2, a lower RMSE and a lower MRE demonstrating the prediction accuracy of the GRNN model over the MNR method. Furthermore, the effects of the oxygen to coal ratio, the steam to coal ratio, the oxygen to fly ash ratio and the steam to fly ash ratio on gasification performance were analyzed using the proposed GRNN model.

Introduction

Coal gasification is a clean and efficient process [1] to convert coal into syngas [2], which has already been extensively applied to the production of hydrogen, liquid fuels, ammonia, synthetic natural gas [3], acetic acid and many other substances. Three different approaches have been developed for coal gasification: entrained flow [4,5], fixed bed [6] and fluidized bed [7]. As one of the fluidized bed gasifiers, the ash agglomerating fluidized bed (AFB) gasifier has the advantages of lower costs, moderate operating temperatures and higher adaptability. However, the carbon conversion (~90%) of the AFB gasifier has the potential to be enhanced.

To increase the carbon conversion, a novel pressurized integrated fluidized bed (IFB) gasifier which consists of a fluidized bed section and an entrained flow section has been developed by Institute of Coal Chemistry, Chinese Academy of Sciences. The IFB gasifier can handle coal with a higher efficiency in the fluidized bed section and further gasify fly ash in the entrained flow section to improve the overall carbon conversion. However, existing problems regarding its complex structure and interactive reactions prevent the IFB gasifier from becoming more technologically and economically feasible.

In order to solve these problems, several methods have been developed to research the IFB gasifier. Wu et al. [8] used experimental methods to research the IFB gasifier. The results

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showed that the fluidized bed section had the capacity to handle the fly ash from the entrained flow section. Jia [9] researched the effects of the operating conditions of the IFB gasifier on carbon conversion, gas composition and the gasification temperature. However, pilot-scale experiments to perform gasifier analysis are time consuming, cumbersome and expensive [10].

As a direct consequence, various predictive models have been employed to study the IFB gasifier. Liang [11] used computational fluid dynamics (CFD) to research the distribution of particles, solid-gas flow areas and mutual influences between the fluidized bed section and the entrained flow section. Chen [12] modeled the IFB gasifier using the kinetic based Chemkin to research the effect of fly ash on gasification performance. Although the CFD model of the IFB gasifier can achieve better prediction accuracy, it has the disadvantages of being time consuming, with software restrictions and uncertain parameters [13]. The kinetic based Chemkin model must take into account the structural parameters of the IFB gasifier, the kinetics constants and reaction coefficients. However, literature often offers different kinetics constants and reaction coefficients. Therefore, an appropriate approach is needed to study the IFB gasifier to offer a better understanding of the nonlinear, complex and interactive relationships between input parameters and output variables.

The general regression neural network (GRNN) is a novel method that is capable of solving highly non-linear problems and correlates input and output parameters to establish a prediction model. GRNN approximates arbitrary functions between input parameters and output variables [14,15] and does not require iterative training [16,17]. Recently, GRNN has increasingly attracted attention. Zhou et al. [18] used a GRNN model to predict regional $PM_{2.5}$. Chelgani et al. [14] employed the GRNN model to predict inorganic and organic sulfur reduction in a coal desulfurization plant. Antanasijević et al. [16] proposed using the GRNN model to estimate greenhouse emissions and energy consumption in European countries. However, to the best of the author's knowledge, there is no application using the GRNN model for the prediction of the pressurized IFB gasifier.

In this paper, a GRNN model with six input parameters was proposed to predict gas composition (H_2 (y_1, %), CO (y_2, %), CO_2 (y_3, %), CH_4 (y_4, %)), gas yield (y_5, Nm^3/kg), and gasification temperature (y_6, °C) in a pilot-scale pressurized IFB gasifier. The six input parameters are the flow rate of oxygen in the fluidized bed section (x_1, Nm^3/h), the flow rate of steam in the fluidized bed section (x_2, kg/h), the flow rate of coal in the fluidized bed section (x_3, kg/h), the flow rate of oxygen in the entrained flow section (x_4, Nm^3/h), the flow rate of steam in the entrained flow section (x_5, kg/h) and the flow rate of fly ash in the entrained flow section (x_6, kg/h). Additionally, the multivariate nonlinear regression (MNR) method which has the same input variables as the GRNN model was simultaneously employed to predict y_1-y_6 and the prediction results of the GRNN model were compared with the results from the MNR method.

Description of the IFB gasifier

As a novel and promising gasification technology, a pilot scale pressurized IFB gasifier has been systematically studied many times. A wide variety of Chinese coals were successfully tested. The types of Chinese coals include Yangcheng anthracite, Jincheng anthracite, Tianxi anthracite, Houlinhe lignite, Wenshan lignite, Xiaolongtan lignite, Shenmu bituminous and Xiangyuan bituminous. The test results showed that the platform could process 4.5 t/h of coal in the operating temperature range of 850–1100 °C, and a pressure of 0.3–2.5 MPa, with effective gas (H_2 + CO) content of 60%–75% and a gas yield of 1.4–2.9 Nm^3/kg.

Fig. 1 shows the schematic diagram of the IFB gasifier in detail. The primary feature of the IFB gasifier is that the fluidized bed section is coupled with the entrained flow section. The fluidized bed section is a stepped tapered cylinder with a diameter of 1200 mm in the top zone and 800 mm in the bottom zone. The fluidized bed section consists of a center tube and a conical distributor at the bottom. Meanwhile, the entrained flow section is a cylinder with a diameter of 800 mm. The aim of the entrained flow section is to enhance the carbon conversion of fly ash. The reaction products of the entrained flow section are fed into the fluidized bed section. In the bottom of the fluidized bed section, the local region of high temperature is caused by the injection of high concentration oxygen, which is injected through the center tube. Thus the ash becomes larger and the particles heavier due to the effects of high concentration oxygen and high temperature and then separates from semi-char. These characteristics make the IFB gasifier suitable for many kinds of coal.

General regression neural network

GRNN, which was first established by Specht, has been successfully and extensively developed by researchers. GRNN is

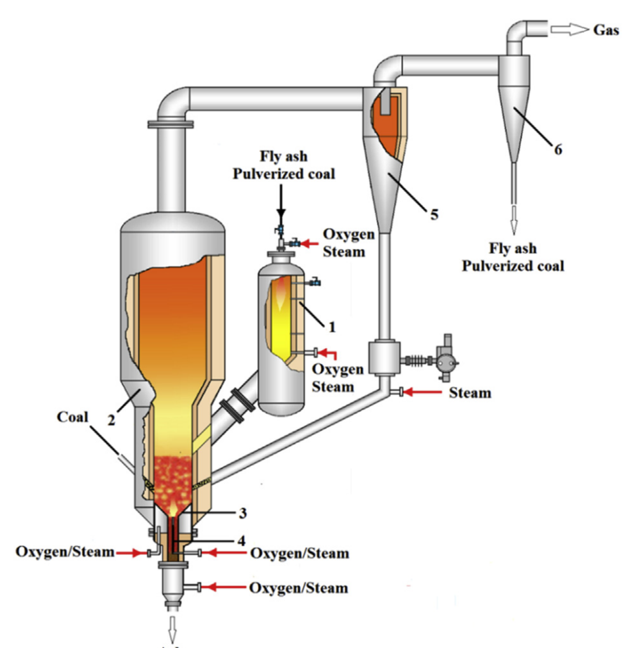

Fig. 1 – Schematic of the IFB gasifier. The main parts: (1) entrained flow section, (2) fluidized bed section, (3) conical distributor, (4) center tube, (5) the first cyclone, (6) the second cyclone.