Fuel Processing Technology 91 (2010) 1832–1838

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Maximum solid concentrations of coal water slurries predicted by neural network models

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ARTICLE INFO

Article history:
Received 22 August 2009
Received in revised form 31 July 2010
Accepted 9 August 2010

Keywords:
Coal water slurry
Solid concentration
Neural network model
Back-propagation

ABSTRACT

The nonlinear back-propagation (BP) neural network models were developed to predict the maximum solid concentration of coal water slurry (CWS) which is a substitute for oil fuel, based on physicochemical properties of 37 typical Chinese coals. The Levenberg–Marquardt algorithm was used to train five BP neural network models with different input factors. The data pretreatment method, learning rate and hidden neuron number were optimized by training models. It is found that the Hardgrove grindability index (HGI), moisture and coalification degree of parent coal are 3 indispensable factors for the prediction of CWS maximum solid concentration. Each BP neural network model gives a more accurate prediction result than the traditional polynomial regression equation. The BP neural network model with 3 input factors of HGI, moisture and oxygen/carbon ratio gives the smallest mean absolute error of 0.40%, which is much lower than that of 1.15% given by the traditional polynomial regression equation.

1. Introduction

Energy (especially liquid fuels) shortage and environmental pollution are serious problems all over the world. Due to the rapid development of Chinese economy and society, the total energy consumption will be 2.5–3.3 billion tons of standard coal in China in 2020. The liquid fuel consumption will be 0.43–0.48 billion tons and the crude petroleum shortage will be 0.23 billion tons (about 50%). It is very urgent and important to promote energy utilization efficiency, reduce pollutant emissions and develop substitute fuels, so as to support sustainable development of China and be responsible for global environment. Coal water slurry (CWS) composed of 60–70 wt.% pulverized coal (40–50 μm), 30–40 wt.% water and <1 wt.% chemical dispersant is a non-Newton fluid fuel with a high viscosity of 800–1200 mPa s (at a shear rate of 100 s^{-1}). CWS fuel emits less pollutants of ash, SO_2 and NO_x in combustion than coal fuel, because its ash content is generally lower than 7 wt.%, sulfur content is generally lower than 0.5 wt.%, combustion flame temperature is lower by 100–150°C than pulverized coal. CWS fuel can be stored in tanks, transported through pipelines, atomized and burned like oil fuel, so it is a suitable substitute for heavy oil and residue oil used in boilers and gasifiers. About 2.2 tons of CWS can substitute for 1 ton of oil fuel based on the same calorific value, but the price for 2.2 tons of CWS is only about 50% of the price for 1 ton of oil fuel. Therefore, CWS fuel has been popularized in many industries such as electric power, coal, petroleum, chemical, metallurgy, glass and ceramic. CWS fuel has been widely applied in over 20 power station boilers (65–670 t/h), over 300 industrial furnaces (<35 t/h) and hundreds of various kilns in China [1,2]. The CWS production potential is 23 million tons per year in China, in which 15 million tons are for combustion and 8 million tons are for gasification. Based on a preliminary statistical report issued by National Coal Water Slurry Engineering and Technology Center of China, about 8 million tons of CWS fuel was actually burned to substitute for about 3.6 million tons of oil fuel in various boilers and kilns in China in 2007.

It is necessary to volume produce high-quality CWS fuel with a high solid concentration, a low viscosity, a good rheological behavior and a longtime stability. Although coal production and consumption in China are foremost in the world, the various coals including lignite, bituminous coal and anthracite have quite different properties. The physicochemical properties of parent coals such as coalification degree, chemical compositions (viz. moisture, ash, volatile, oxygen, carbon, oxygenic function groups, etc.), surface chemistry (viz. wettability, adsorption, Zeta potential, etc.) and particle size distribution have important impacts on CWS properties [3–7]. The various chemical dispersants and stabilizers have been developed to improve CWS properties [8–10]. It is difficult to prepare CWS fuel from the coals with high moisture, high oxygen and low Hardgrove grindability index (HGI). The maximum solid concentration, which is the weight ratio of pulverized coal in the CWS fuel, is a very important quality index. The various coal properties give different maximum solid concentrations even with the same chemical dispersants in the CWS fuel preparation. If the weight ratio of pulverized coal is higher than

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doi:10.1016/j.fuproc.2010.08.007

the maximum solid concentration, the CWS property will sharply deteriorate with an increased viscosity, a worsened fluidity and an accelerated particle deposition. On the other hand, it is very difficult to ignite CWS fuel with a low solid concentration and a low calorific value, which results in an unstable combustion condition and a low burnout efficiency. The estimation of CWS solid concentration from physicochemical properties of parent coal is a complex problem characterized by many interacting factors. Based on the experimental properties of 37 typical Chinese coals and their CWS maximum solid concentrations, a polynomial regression equation was summarized as follows [11]:

$$\begin{aligned}\text{CWS solid concentration} = {} & 67.848 + 0.061366\,\text{HGI} \\ & - 0.267763\,\text{moisture} \\ & - 0.030864\,\text{oxygen}^2\,(\%)\end{aligned}$$

This regression equation has been widely used to estimate CWS maximum solid concentrations in China. However, it is a tough task with a limited precision to develop empirical relationships to predict CWS solid concentrations.

Because there are nonlinear relationships which are not precisely known between physicochemical properties of parent coals and their CWS properties, it is a challenging problem to predict CWS maximum solid concentrations. The data-based modeling using machine-learning methods such as artificial neural network has been proposed to solve complex nonlinear problems without requiring exhaustive theoretical knowledge in the clean coal technology field. It was reported that artificial neural networks were used to model and predict coal grindability [12–15], chemical compositions (such as hydrogen) [16,17], heating value [18], ash fusion temperature [19,20], combustion characteristics [21–23] and pollutant emissions (such as mercury and NO_x) [24–26]. However, the application modeling of artificial neural networks in the CWS field has not been reported in the literatures until now. In this paper, the neural network models were developed to predict CWS maximum solid concentrations from various coal properties.

2. Topological structure of neural network models

The artificial neural network technique is very effective to realize nonlinear mapping and solve black-box or grey-box problems, which have unclear relationships between input and output factors. It has many advantages over conventional regression approaches, including the increased tolerance to noise and uncertainty, reduced need for theoretical knowledge on the modeled phenomenon, and relative ease of developing and updating the model. The back-propagation (BP) learning algorithm is a generalization of the delta learning rule for single-layer artificial neural network. It is now the most popular learning algorithm for multilayer feedforward neural networks because of its simplicity, power to extract useful information from examples, and capacity of storing information implicitly in the connecting links in the weights form. The BP neural network with three layers can approximate any continuous function with any precision, when the neurons in the hidden layer can be freely regulated according to the requirements. Therefore, the BP neural network models with three layers were developed to predict CWS maximum solid concentration from parent coal properties, as shown in Fig. 1. The CWS solid concentration is a strong nonlinear problem codetermined by the HGI, moisture, oxygen, carbon, volatile, ash and

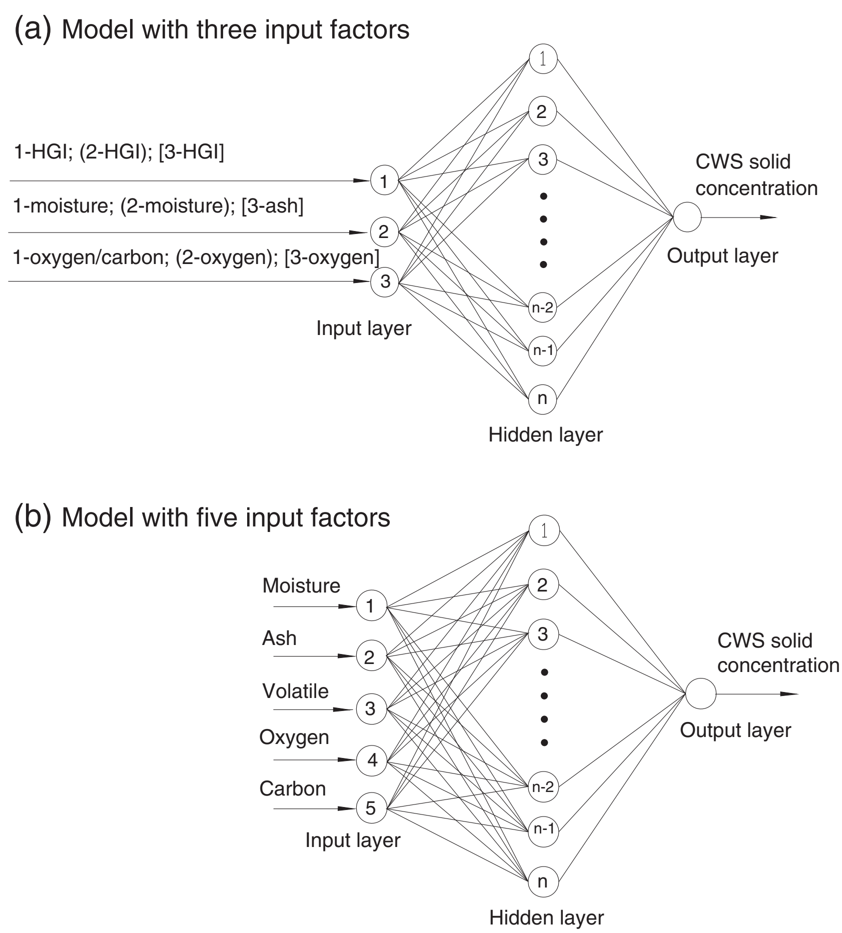

Fig. 1. BP neural network models for CWS maximum solid concentration.