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Artificial neural network modeling of thin layer drying behavior of municipal sewage sludge

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ABSTRACT

The back-propagation (BP) and generalized regression neural network models (GRNN) were investigated to predict the thin layer drying behavior in municipal sewage sludge during hot air forced convection. The accuracy of the BP model to predict the moisture content of the sewage sludge thin layer during hot air forced convective drying was far higher than that of the GRNN model. The GRNN models could automatically determine the best smoothing parameters, which were 0.6 and 0.3 for predicting the moisture content and average temperature, respectively. The model type for predicting the average temperature of the sewage sludge thin layer was selected for different sample groups by comparing their MSE values or R^2 values. The GRNN model was suitable for predicting the average temperature corresponding to the sample groups at hot air velocity of 0.6 m/s, and drying temperatures of 100 °C, 160 °C; hot air velocity of 1.4 m/s, and drying temperatures of 130 °C, 140 °C; hot air velocity of 2.0 m/s, and drying temperatures of 150 °C, 160 °C. The average temperature for the other sample groups was best predicted by the BP model.

1. Introduction

With the development of industries, the sewage sludge is largely generated from waste water treatment [1]. Sludge treatment methods include usually land-filling, incineration, compost and incorporation in building materials. In order to improve efficiency of transporting and processing, it is necessary to reduce moisture content of sewage sludge from waste treatment [2]. Moisture content of sludge may determine performance of the incinerators. Mechanical dewatering including filtration and centrifugation is firstly applied to make the moisture content reduced to about 80%, thermal drying also needs to be conducted in order to yield low moisture content [3]. The heat and mass transfer occur simultaneously during the thermal drying process. The thin layer drying is an important and popular approach for investigating thermal behavior in wet porous media. Moisture content and average temperature of the sewage sludge in the thin layer drying process impact its heat conductivity, specific heat capacity, densities and diffusion coefficient, which dominate the heat and mass transfer characteristics in the sewage sludge [4–6]. In sole experimental research, a large number of experiments under various operating conditions are required for identifying the moisture content and average temperature of the sewage sludge thin layer. Because of the complexity of sludge composition, the nonlinear and time-varying of drying process, there are some limitations for the traditional heat and mass transfer models in applicability, convergence and prediction accuracy of heat and mass transfer in the sewage sludge. Neural networks method, which has the ability of self-organizing, adaptive, self-learning, are powerful tools that can be used to model and investigate various highly complex and nonlinear problems [7].

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Nomenclature

m	moisture content
MR	moisture content ratio
MSE	Mean Square Error
n	total number of data observation
o	actual value
t	time (s)
T	temperature (°C)
X	input vector
Y	output vector
z	prediction value

Greek letter

σ	smoothing parameter

Subscripts and superscripts

a	average
e	equilibrium
0	initial
i	observation number

The neural networks method has been widely used in many fields. Cheng et al. [8] utilized the nonlinear back-propagation (BP) neural network models into predicting the maximum solid concentration of coal water slurry. Each BP neural model can provide a more accurate prediction result than the traditional polynomial regression equation. Chelgani et al. [9] compared the multivariable regression method with the artificial neural network method (ANN) for predicting the free-swelling index of a wide range of the American coal samples. The ANN model can be further employed as a reliable and accurate method in the free-swelling index prediction. Vasseghian et al. [10] developed a prediction model of the ash and sulfur removals in the pitch using the artificial neural networks, in order to predict the best operating condition. Duchesne et al. [11] predicted the slag viscosity over a broad range of temperatures and slag compositions based on the artificial neural networks. Stamenković et al. [12] predicted the ethanolysis reaction of the sunflower oil catalyzed by sodium hydroxide based on the ANN method, and found that the ANN was a better choice over the least squares methods. Jensen et al. [13] used neural networks (NN) to investigate the complex relationships between mercury speciation emissions associated with coal-fired utility boilers and their air pollution control systems. The neural networks are successfully applied to predict many nonlinear problems. However, the application of the neural networks in the drying mainly concentrates in the food engineering. The artificial neural networks can be used for the on-line state estimation and control of drying processes of cassava and mango [14]. Kerdpiboon et al. [15] used the ANN method to predict the shrinkage and rehydration of the carrot in the drying. Nikbakht et al. [16] revealed that the training algorithm of the BP model was suitable to predict the drying parameters of thin-layer drying of sour pomegranate arils. Khazaei et al. [17] developed an ANN model to predict the moisture content of grapes in a hot air dryer. Guiné et al. [18] developed a neural network model to predict the antioxidant activity and phenolic compounds contents of banana with different drying methods. Some literatures are available on the food thin layer drying using the neural networks; however, there is a real shortage of published data on the prediction model of the sewage sludge during the thin layer drying process based on the neural networks. Developing the sewage sludge thin layer drying model is essential for predicting, controlling and optimizing the drying process.

The objective of this work was to develop suitable prediction models for modeling sewage sludge thin layer drying based on the BP and GRNN models. The models were used for predicting the heat and mass transfer of the sewage sludge thin layer during the hot air forced convective drying. Assessments of prediction accuracy for two models were determined according to the mean square error and the coefficient of determination. Prediction values of the model were compared with experimental data of the sewage sludge thin layer drying.

2. Methods

2.1. Experimental facility and test samples

The municipal sewage sludge sample was collected from a water recycling plant at Beijing (in China), which was after mechanical dewatering and natural drying. The sample was placed in a closed container for 24 h after being fully stirred, in order to get homogenization sample. The experiments were carried out in a laboratory convective dryer as shown in Fig. 1.

The system consisted of a tunnel, a fan, a heater, a drying chamber, a dehumidification unit and a set of temperature data acquisition. The drying air was introduced by the frequency conversion fan and heated by the 3000 W heater. The hot air was dehumidified through the dehumidification unit containing calcium oxide drying agent and circulated about 15 min before sample was placed the drying chamber. About 52 g of the prepared sewage sludge sample was uniformly spread as a thin layer on a square steel tray (80 mm × 80 mm × 10 mm). The samples had initial moisture content of 0.93–0.98 kg/kg (d.b.). The thickness of the thin layer was about 10 mm. The sewage sludge thin layer on the tray over a digital balance was placed in the drying chamber and dried by the convective heat exchange of the hot air. Then the hot air was dehumidified through the dehumidification unit. During the drying process, the weight of the samples was recorded at an interval of 90 s by a computer connected to the digital balance (OHAUS; CP413, China) with an accuracy of 0.0001 g. Three thermal resistances (Pt100) were used to measure the surface temperature and center temperature