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Original Research Paper

Development and analyses of data-driven models for predicting the bed depth profile of solids flowing in a rotary kiln

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ABSTRACT

Soft computing data-driven modeling (DDM) techniques have attracted the attention of many researchers across the globe as they do not require deep knowledge of the complex physical process. In the present research, data-driven based models have been developed using support vector regression (SVR), multilayer perceptron neural network (MLP), radial basis function neural network (RBFNN) and general regression neural networks (GRNN) techniques for predicting the bed depth profile of solids flowing in a rotary kiln. The performances of the developed models were compared and evaluated against the experimental results in terms of statistical measures such as coefficient of determination (R^2), and average absolute relative error (AARE). The obtained results and findings from this research have revealed that data-driven models can predict the bed depth profile of solids flowing in a rotary kiln quite accurately. The SVR-based model exhibited the lowest AARE value of 1.72% and highest R^2 value of 0.9981 while GRNN, RBFNN, and MLP models gave corresponding values of AARE as 3.69%, 55.13%, 98.15% and those of R^2 as 0.9898, 0.0052 and 0.0081, respectively. Moreover, the developed DDM-based models i.e. GRNN, RBFNN, and MLP models overcame the limitations of the existing solutions which involved iterative numerical procedure entailing high degree of computational complexity.

1. Introduction

The rotary kiln has a wide range of applications such as burning and roasting, reduction of oxide ores, calcination of petroleum coke and reclamation of hazardous waste. Rotary kiln is a long inclined horizontal cylinder rotating slightly about its axis. It works as a co-current and counter-current heat exchanger and is used to heat the material to a high temperature in which energy from a hot gas phase is transferred to the bed material. The heat transferred to the solid is mainly dependent upon the residence time of the solids in the kiln which in turn depends on the solid bed depth profile. The solid bed depth profile is a function of various parameters such as kiln dimensions (radius R, length L, dam height h_o), operating conditions (rotation speed n, solids mass feed rate $\dot{m}$, slope β), and properties of the solids (bulk density ρ, repose angle θ). The schematic representation of a typical rotary kiln is shown in Fig. 1.

In the past, researchers have tried to predict the solid bed depth profile of the rotary kiln [1–4]. A steady-state model for the transport of granular material of an inclined rotating cylinder was given by Saeman [1] and Kramers and Croockewit [2]. Kramers and Croockewit for the first time [2] performed the experiments in a rotating cylinder with an inner diameter 0.197 m, length 1.78 m, kiln slope 0.5–5° and rotational speed 0.04–0.25 r.p.s. The constant feed material was maintained as the steady condition was achieved, the cylinder hold-up was calculated by weighing its contents. Gupta et al. [3] presented a model which is a modified version of the single-particle trajectory model of Saeman for the axial transport of solids in a horizontal rotating cylinder. They compared their model predictions with Hehl's [5] experiment and a sound match between the theory and the experimental data for the axial velocity v, and the maximum deviation of the trajectory from Saeman model δ was obtained. Sai et al. [4] measured the axial bed depth profile of solids in a rotary kiln under steady-state and transient conditions. The variation of axial velocity of the kiln was measured using the independent variables feed rate of solids, kiln inclination, rotational speed of the kiln and the dam height. The mean residence time of solids was also determined from fractional hold-up.

One such experiment was performed by Lebas et al. [6] in the pilot rotary furnace of 0.6 m diameter and a length of 6 m with coal and coke particles. Various equations were used to estimate the experimental results. The equation of Kramers and Croockewit [2] best predicted the bed depth profile. Furthermore, Spurling

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