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Effect of promoters on dynamics of gas–solid fluidized bed—Statistical and ANN approaches

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Abstract

In this study, a bubbling fluidized bed column, 99 mm in inside diameter and 960 mm in height, was used to investigate the effect of rod and disc promoters on fluctuation and expansion ratios. Factorial design (statistical approach) and artificial neural network (ANN) models were developed to predict the fluctuation and expansion ratios in this gas–solid fluidized bed with varying gas flow rates, bed heights, particle sizes and densities. The fluctuation and expansion predicted using these statistical and ANN models, for beds with and without promoters, were found to agree well with corresponding experiments. The statistical model was found to be superior to the ANN model due to its ability to take into account both individual and interactive effects. The rod promoters were found to be more effective in reducing bed fluctuation, and in increasing bed expansion at high gas mass velocities.

Keywords: Gas–solid fluidized bed; Fluctuation ratio; Expansion ratio; Promoter; Factorial design; Artificial neural network

1. Introduction

Under gas flow exceeding the minimum fluidization velocity, the top of a fluidized bed may fluctuate considerably leading to instability in operation. For fine or sticky bed material, the bed will be cohesive, tending to form channels through which the gas will escape rather than being dispersed through the interstices supporting the particles. In the other extreme, if the particles are large and heavy, the bed will not fluidize properly, but tend to be turbulent and to form a spout.

The formation of bubbles and their ultimate growth to form slugs, and the collapsing of bubbles cause erratic bed expansion with intense bed fluctuation. Out of the three methods, viz., uniformity index, fluctuation ratio and expansion ratio, the latter two have widely been used to quantify fluidization quality and have been found to be inter-related to each other. The extent of fluctuation and its estimation are important for specifying the height of the fluidizer, and consistent efforts have been made to reduce bed fluctuation and increase bed expansion, and to correlate them with dynamic parameters of the system.

Kumar and Roy (2002a, 2002b, 2004a) studied the effect of co-axial rod, disk and blade promoters on bed fluctuation and expansion in a gas–solid fluidized bed with varying distributor open areas, and found that both bed fluctuation and bed expansion decrease significantly with increase in the blockage area due to the rod or disk promoter, which can be attributed to the breakup of bubbles and controlling their sizes and growth. Mohanty and Singh (2001) predicted the fluctuation ratio for a baffled bed in a 15 cm internal diameter column and found that the use of circular and rod promoters can reduce the fluctuation ratio. In the present case, the effect of rod and disc promoters has been used to predict fluctuation and expansion ratios.

Stewart and Davidson (1967) stated that at superficial gas velocity below the bubble rise velocity, slugging would not take place and the bed would be sufficiently deep for coalescing bubbles to attain the size of a slug. Davis (1978) explained the statistical approach as one of the important methods for processing experimental data due to its interactive effects among the variables and less data are required for the development of model equations. Jin, Shen, and Zhang (1980), Jin, Zhang, Shen, and Wang (1982) observed improvement in breakup of bubbles and circulation of solid particles in a fluidized bed with pagoda-shaped promoters. Chandra, Rao, Paneser, and Gopalkrishna

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Nomenclature

d_p	diameter of particle (m)
D_c	diameter of column (m)
G_f	mass velocity corresponding to fluidization (kg/m^{2}s)
G_{mf}	mass velocity corresponding to minimum fluidization (kg/m^{2}s)
h_S	static bed height (m)
h_1	lower height of the expanded bed (m)
h_2	upper height of the expanded bed (m)
r	fluctuation ratio
r_c	fluctuation ratio for disc promoted bed
r_r	fluctuation ratio for rod promoted bed
r_{exp}	fluctuation ratio obtained from experiment
r_{cal}	fluctuation ratio obtained from factorial design model equations
R	expansion ratio obtained from factorial design model equations
R_r	expansion ratio for rod promoted bed
R_c	expansion ratio for disc promoted bed
R_{exp}	expansion ratio obtained from experiment
R_{cal}	expansion ratio obtained from model equations
Re_p	particle Reynolds Number, dimensionless
$X_1, \ldots, X_4$	factorial design symbols

Greek letters

ρ_f	density of fluid (kg/m^3)
ρ_s	density of solid particle (kg/m^3)

(1981) compared multi-baffled and concentric-baffled fluidized beds, finding that the latter is less uniform. Kono and Jinnai (1983) reported that bubble size in baffled fluidized beds can be significantly reduced, remaining almost constant regardless of bed height. Tsuchiya, Miyahara, and Fan (1989) reported that in gas–liquid or gas–liquid–solid contacting devices bubble coalescence and breakup play a crucial role in determining the bubble size, their rise velocity and gas–liquid interfacial area. Hoffmann (2000) studied the manipulation of fluidized beds by using internals for fine powders.

Wasserman (1989) defined the artificial neural network model as a computing system made up of a number of simple, highly inter-connected nodes or processing elements, which processes information by its dynamic system response to external inputs.

Singh and Singh (2003) suggested the following equations for predicting the expanded bed height for the lower and upper sections of a fluidized column:

$$R_{\text{lower}} = 4.7 \times 10^{-2} \left[(Re_p)^{0.58} \left(\frac{d_p}{D_c} \right)^{1.25} \left(\frac{\rho_s}{\rho_f} \right)^{-0.49} \right], \quad (1)$$

$$R_{\text{upper}} = 5.166 \times 10^{-3} \left[(Re_p)^{0.782} \left(\frac{d_p}{D_c} \right)^{-1.407} \left(\frac{\rho_s}{\rho_f} \right)^{0.39} \right]. \quad (2)$$

Kumar (2003) compared the minimum bubbling velocities in the case of promoted and un-promoted beds and found that bubble formation is delayed in the case of beds having more peripheral contacts with the fluid flow. Kumar and Roy (2004b) found further that correlations involving dimensional analysis and ANN models can satisfactorily be used for predicting bed expansion ratio, and that the ANN method represents the system behaviour more accurately than dimensional analysis. Kumar and Roy (2005) also proposed the following model equation by using the statistical approach for bed fluctuation ratio:

$$r = 1.668 + 0.309\, X_1 + 0.173\, X_2 - 0.114\, X_3 + 0.112\, X_4 + 0.079\, X_1 X_2. \quad (3)$$

Singh and Roy (2006) predicted the bed fluctuation ratio for gas–solid fluidization in cylindrical and non-cylindrical beds and found that under similar operating conditions, the square bed has the maximum and the semi-cylindrical bed has the minimum. Mohanty, Biswal, and Roy (2007) found that a distributor plate having 10% open area gives a better result in terms of fluctuation and expansion as compared to 6%, 8% and 12% open areas. Kumar and Roy (2007) studied the effect of distributor open area (12.9–1.43%) and the number of rod promoters on bed pressure drop ratio, finding that the ratio increases with mass velocity, interference of promoters, and decreases with an increase in open area of distributor.

The objective of the present work is to find a suitable promoter for improving the quality of fluidization, expressed in terms of fluctuation and expansion ratios, and to develop a mathematical model for determining the fluctuation and expansion ratios. Current literature deals but little with fluctuation and expansion ratios. In the present case, a software package for artificial neural network in MatLab is used for back propagation algorithm. Three typical layers, viz, (i) input, (ii) hidden and (iii) output, have been chosen. Fig. 1 shows four nodes in the input layer, three neurons in the hidden layer and one node in the output layer.

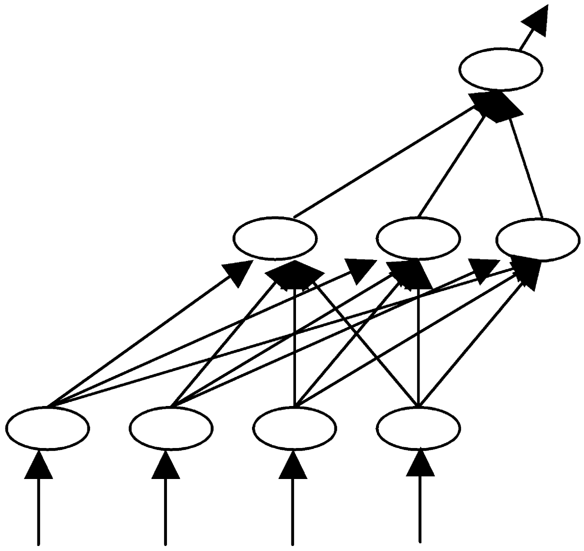

Fig. 1. A typical three layer neural network.