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Artificial Neural Network-based Prediction of Bed Expansion Ratio in Gas-solid Fluidized Beds with Disk and Blade Promoters

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Artificial Neural Network (ANN) models have been developed to predict bed expansion in gas-solid fluidized bed promoted with blade and disk promoters. To model the above, two systems (eight variables problem in case of bed with disk promoter and six variables problem in case of bed with blade promoters) have been undertaken. For the training of the input-output data, the experimental values of bed expansion ratio collected under different varying conditions of the system parameters have been used. The system variables include seven numbers of disk promoters of varying disk thickness and dia and one blade promoter in addition to five numbers of distributors of varying orifice sizes, four type of bed materials, five sizes of bed material and four initial static bed heights. The values of bed expansion ratio predicted with the help of developed ANN models for respective beds have been found to be closer to the corresponding experimental ones and those obtained using developed correlations[1] on dimensional analysis approach.

Keywords: Neural networks; Promoters; Distributors; Gas-solid fluidized beds; Expansion ratio

NOTATION

A_c : cross-sectional area of column, m^2
A_{do} : open area of distributor, m^2
ANN : artificial neural network
d_o : orifice dia, m
d_p : particle size, m
D_c : column dia, m
D_k : disk dia, m
G_f : fluidization mass velocity, kg/(m^2-h)
G^1_{mf} : minimum fluidization mass velocity in promoted beds, kg/(m^2-h)
G_R : mass velocity ratio, $(G_f - G'_{mf})/(G_t - G'_{mf})$
G_t : terminal mass velocity, kg/(m^2-h)
h_{av} : average bed height, $(h_{max} + h_{min})/2$, m
h_{max} : maximum height of fluidized bed, m
h_{min} : minimum height of fluidized bed, m
h_s : initial static bed height, m
H : hidden nodes
I : input nodes
O : output nodes
R : bed expansion ratio, h_{av}/h_s
R' : modified bed expansion ratio, (R-1)
R^2 : co-efficient of determination
t : thickness of disk plate, m
$w1_{ij}$: weights connecting the input layer nodes to the hidden layer nodes with i indexing the input units and j indexing the hidden units
$w2_{ij}$: weights connecting the hidden layer nodes to the output layer nodes with i indexing the hidden units and j indexing the output units
ρ_f : density of fluid, kg/m^3
ρ_s : density of solid, kg/m^3

INTRODUCTION

Gas-solid fluidized bed, generally of aggregative nature, is marked by occurrence of bubbles of varied sizes. This results in non-uniform bed expansion and a poor fluidization phenomenon. Keeping in view the aforesaid inherent drawbacks, the introduction of promoter in gas-solid fluidized beds has been found effective in smoothening the bed expansion behaviour and improve upon the fluidization quality. Hence, there have been persistent efforts to quantify the bed expansion for proper design of fluidizer. Kumar and Roy[1] developed following correlations for the prediction of modified bed expansion ratio ($R' = R - 1$) using dimensional analysis approach:

$$R' = 0.08(G_R)^{0.75}\left(\frac{\rho_s}{\rho_f}\right)^{0.56}\left(\frac{A_{do}}{A_c}\right)^{0.19}\left(\frac{d_p}{d_o}\right)^{0.26} \times \left(\frac{h_s}{D_c}\right)^{-0.47}\left(\frac{t}{D_c}\right)^{-0.24}\left(\frac{D_k}{D_c}\right)^{-0.48}$$

(for bed with disk promoter) (1)

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$$R' = 0.24(G_R)^{0.73}\left(\frac{\rho_s}{\rho_f}\right)^{0.51}\left(\frac{A_{do}}{A_c}\right)^{0.17}\left(\frac{d_p}{d_o}\right)^{0.22}\left(\frac{h_s}{D_c}\right)^{-0.71}$$

(for bed with blade promoter) (2)

With the view that the artificial neural network model, based on feed forward architecture and trained by the back propagation technique, can represent system behaviour more accurately than the above dimensional analysis approach, attempts have been made to develop two ANN models, one for the bed with blade promoter and the other for the case of bed with disk promoter for the prediction of bed expansion ratio.

LITERATURE REVIEW

Computation through neural networks is one of the recently growing areas of artificial intelligence. Neural networks are promising due to their ability to learn highly non-linear relationship. Wasserman[2] and Chitra[3] defined artificial neural network (ANN) model as a computing system made up of a number of simple, highly interconnected nodes or processing elements, which processes information by its dynamic system response to external inputs. The back propagation algorithm for training has been used in the present study. Several applications of artificial neural networks for modelling of non-linear process system and subsequent control have been reported by Bhat and McAvoy[4] and Singh and Mohanty[5]. In the present case, a softrware package for artificial neural networking developed by Rao and Rao[6], using back propagation algorithm, has been used. A typical three layers, namely, (i) the input layer (I), (ii) the hidden layer (H), and (iii) the output layer (O) neural network with five input nodes, four number of neurons in the hidden layer and one output node, respectively is shown in Figure 1.

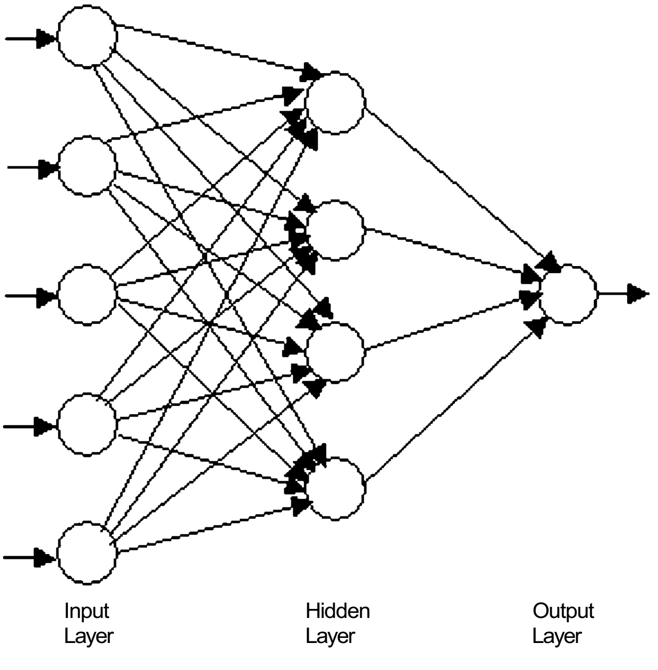

Figure 1 A typical three layer neural network

DATA COLLECTION

Seven disk promoters and one blade promoter with five different distributors of varying open area have been used in the experiment. The disks for the disk promoters have been fixed at an inclination of 10° with the horizontal alternatively in the opposite directions to minimize the accumulation of bed material over the disks. The details of experimental set-up, disk and blade promoters and distributors along with system variables have been given elsewhere[1].

In the fluidized state, the fluctuation for the top of the bed (maximum and minimum levels) has been noted along with the rotameter and manometer readings for each value of the air flow rate. Two scales attached on the opposite sides of the fluidizer have been used to measure the bed height (average value). The same has been repeated with varying particle size, density, static bed height, distributor and promoter.

DEVELOPMENT OF ANN-MODELS

The different dependent and independent variables are normalized so as to lie in the same range group of 0-1. Two different ANN models using back propagation algorithm: one each for bed with disk and the other for bed with blade promoters have been developed. In each case, different ANN structures ($I \times H \times O$) with varying number of neurons in the hidden layer have been tested at constant epochs (cycles), learning rate, error tolerance, momentum parameter, noise factor, and slope parameter. Based on least error criterion, one system (Table 1) is selected for training of the input-output data in each problem. The learning rate is varied in the range of 0.001–0.100 during the training of the input-output data. The number of cycles selected during training is high enough so that the ANN models can rigorously be trained. The weights during the training phase are initialized randomly (from uniform random distribution) between −1 and 1. The training of the network using input and output data for particular type of bed results in a system (model) which has been used as a tool for prediction of the bed expansion ratio for

Table 1 Selected structures of neural network models for test problems undertaken

Learning parameter (β) : 0.001 – 0.100
Error tolerance : 0.001
Momentum parameter (α) : 0.001
Noise factor (NF) : 0.0
Slope parameter for sigmoid function : 0.7
Number of cycles : 50 000

Bed Particulars	Input Nodes	Hidden Nodes	Output Nodes	Number of Cycles used for Training
Bed with disk promoter	7	20	1	50 000
Bed with blade promoter	5	18	1	50 000

Table 2 **Connecting weights between input layer nodes to hidden layer nodes ($w1_{ij}$) for ANN model for bed with disk promoter**

$i \rightarrow$ j $\downarrow$	1	2	3	4	5	6	7
1	0.188	0.670	0.743	0.137	−0.959	−0.342	0.269
2	0.423	0.573	−0.360	−0.626	−1.092	−1.341	0.181
3	0.144	0.281	−1.133	−0.038	−0.048	0.030	0.725
4	−0.473	−0.160	−1.015	1.275	1.267	0.397	−0.147
5	−0.577	−2.174	−0.574	−0.012	0.029	1.095	−1.547
6	−0.440	−0.388	0.292	0.150	0.904	−0.690	−1.231
7	−0.600	−0.634	−0.961	−0.594	0.530	−0.298	−0.762
8	0.100	−0.876	−0.131	−1.147	−0.566	−0.752	−0.871
9	−0.768	0.452	−0.041	−0.073	−0.131	−0.555	−0.208
10	0.704	−1.298	0.924	−1.678	1.324	1.878	−0.388
11	−0.292	0.221	−1.050	−0.359	−0.331	0.236	0.754
12	0.163	1.693	0.681	0.405	−0.464	−0.919	−0.180
13	3.633	0.709	2.157	−0.371	0.291	−0.611	1.502
14	−1.454	−0.157	−0.847	0.221	−1.319	−0.846	0.454
15	−0.458	1.573	0.739	−0.276	0.056	−1.081	0.230
16	−10.877	−2.435	−0.691	−0.293	−1.182	2.975	−0.829
17	−0.477	−1.197	−0.811	−0.013	1.354	0.746	−0.680
18	2.950	0.348	0.651	−3.944	−1.481	−0.875	−1.076
19	−0.189	0.345	−1.024	−0.451	1.141	−0.473	0.005
20	0.400	1.224	0.883	−0.323	−0.935	−1.825	1.532

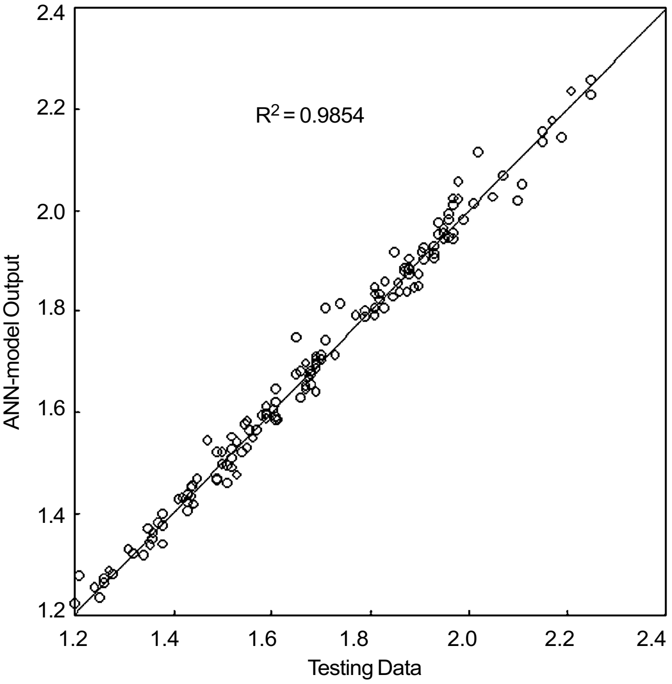

Figure 2 **Comparison between experimental and predicted values of bed expansion ratio corresponding to training data (for bed with disk promoter)**

the corresponding bed. Table 2 represents the weights between input layer nodes and hidden layer nodes and from hidden layer nodes to output layer nodes for ANN-models chosen for beds with disk promoters (Table 3). The comparison plots (Figure 2 and Figure 3 for bed with disk promoter and Figure 4 and Figure 5 for bed with blade promoter) between predicted (output) values of bed expansion ratio using ANN-models and the corresponding experimental ones (input) show that both the ANN-models have been

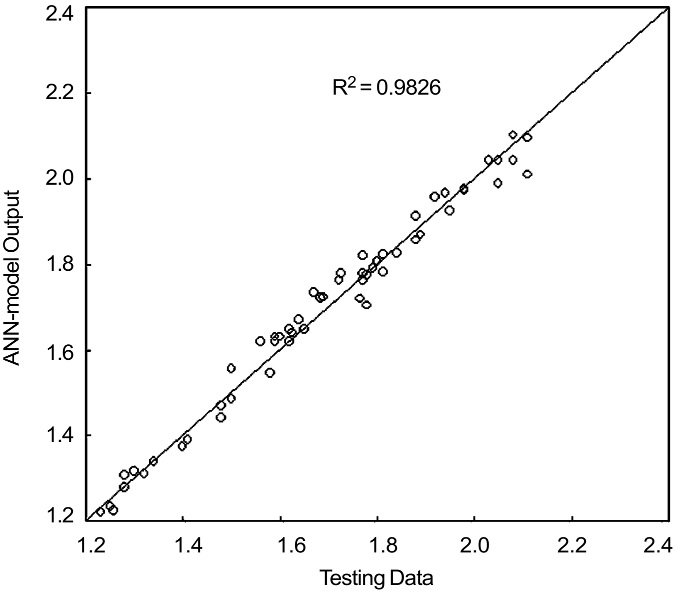

Figure 3 **Comparison between experimental and predicted values of bed expansion ratio corresponding to testing data (for bed with disk promoter)**

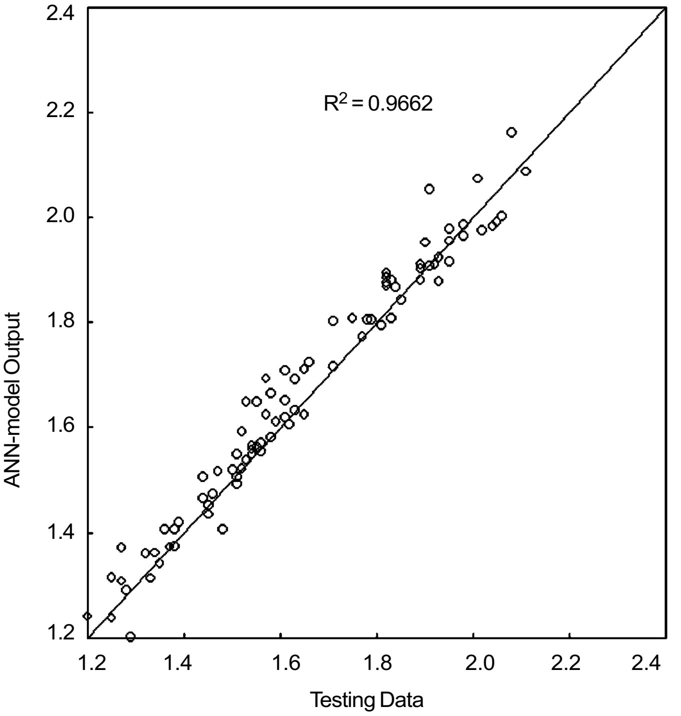

Figure 4 **Comparison between experimental and predicted values of bed expansion ratio corresponding to training data (for bed with blade promoter)**

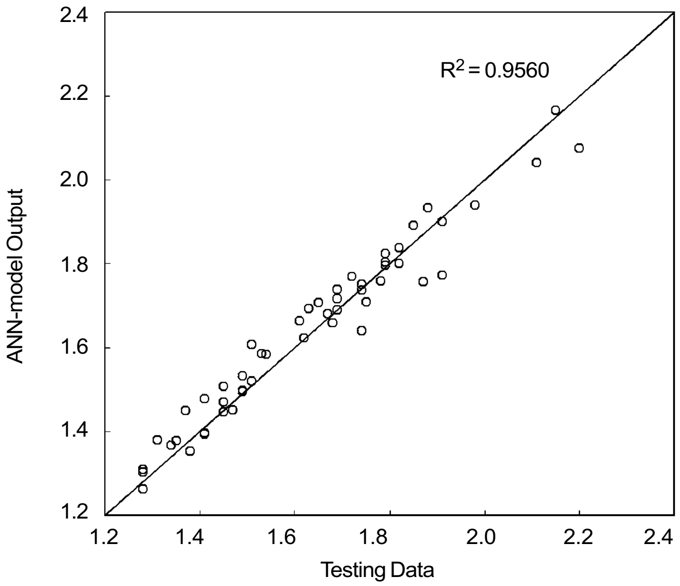

Figure 5 Comparison between experimental and predicted values of bed expansion ratio corresponding to testing data (for bed with blade promoter)

trained to a satisfactory level. Further, the values of the co-efficient of determination (R^2) for training and testing data in case of bed with disk and blade promoters obtained, respectively as (0.9854, 0.9826) and (0.9662, 0.9560) support the above claim.

CONCLUSION

The predicted values of bed expansion ratio using ANN models have been compared with the corresponding experimental ones and those obtained with the help of equation (1) and equation (2) for beds with disk and blade promoters. Figure 6 and Figure 7 show the bed expansion ratio against experiment numbers for three different systems, namely, ANN model, experimental values and dimensional analysis for disk and blade prometer, respectively. These have been shown in Figure 3 and Figure 5 for randomized test data. The mean and standard deviations of the predicted (using the above two methods) values from the experimental ones for bed expansion ratio in case of beds with disk and blade promoters have been given in Table 4.

Further, it can be observed that the developed correlations using dimensional analysis approach as well as ANN-models can satisfactorily be used for the prediction of bed expansion ratio in the respective beds. From Table 3, Figure 3 and Figure 5, it is found that the prediction using ANN-models provide better prediction with reduced standard and mean deviations. Hence, it can be inferred that the artificial neural network model, based on feed forward architecture and trained by the back propagation technique, represents system behaviour more accurately than the dimensional analysis approach.

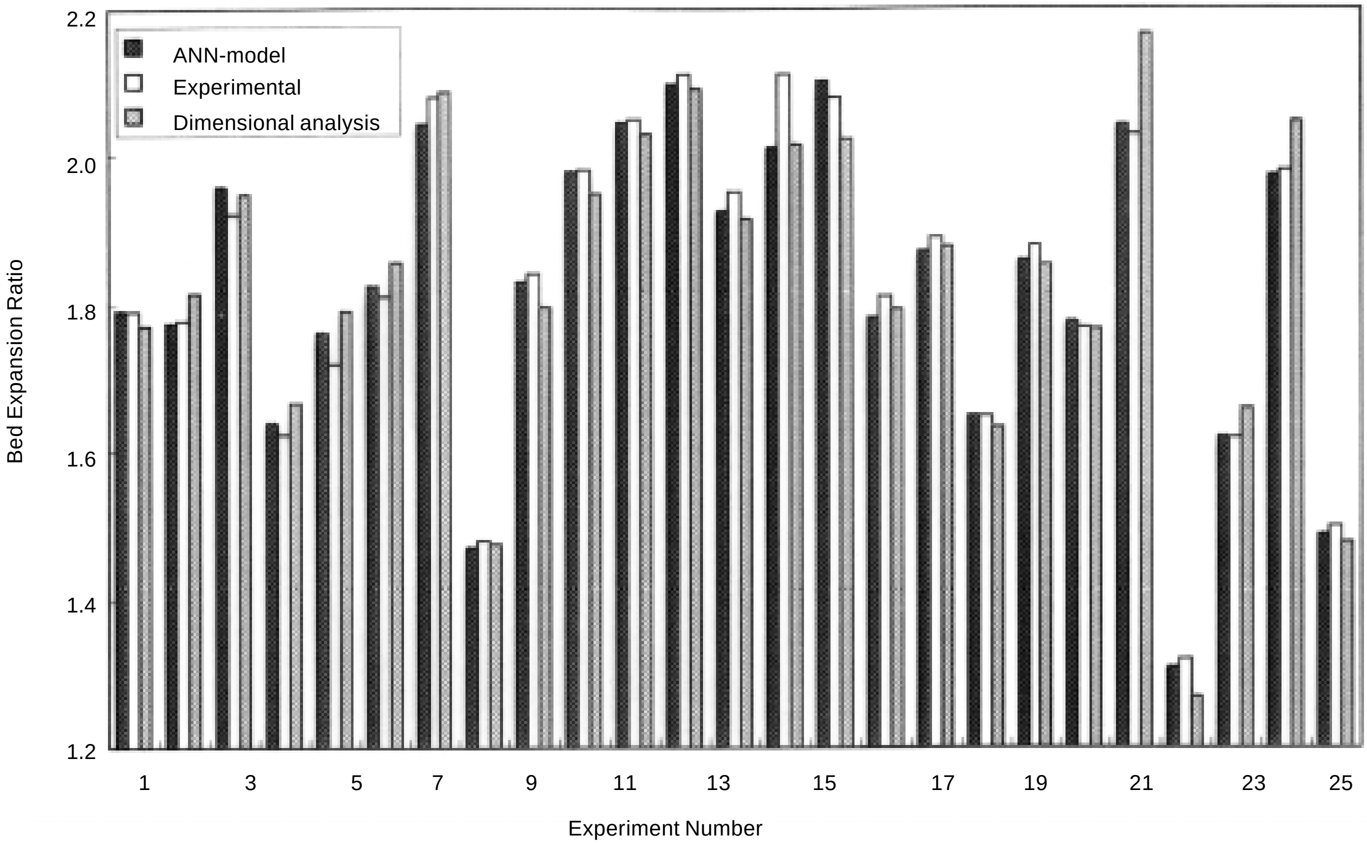

Figure 6 Comparison between experimental and predicted values of bed expansion ratio (by ANN-model and dimensional analysis approach) for bed with disk promoter

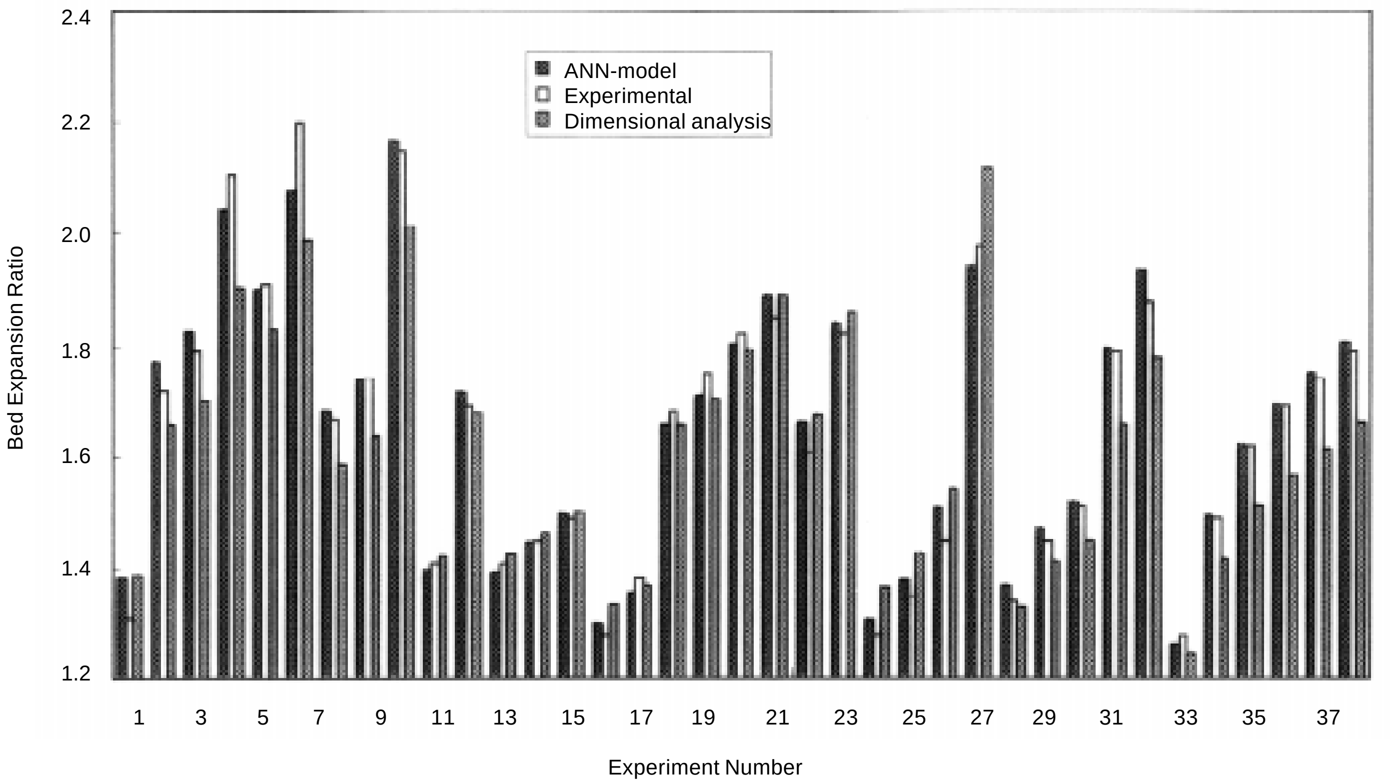

Figure 7 **Comparison between experimental and predicted values of bed expansion ratio (by ANN-model and dimensional analysis approach) for bed with blade promoter**

Table 3 **Connecting weights between hidden layer nodes to output layer nodes ($w2_{ij}$) for ANN model for bed with disk promoter**

$w2_{ij}$	–0.983	–1.153	0.171	1.301	2.427
(i = 1 – 18, j = 1)	0.682	0.897	0.052	–0.251	2.266
	0.196	–1.502	1.397	–0.548	–1.268
	–5.719	2.030	–3.390	0.574	–2.281

Table 4 **Mean and standard deviations**

Bed Particulars	Standard Deviation		Mean		Number of Data
	Dimensional Analysis Method	ANN-Model	Dimensional Analysis Method	ANN-Model	
Bed with disk promoter	2.48	1.828	1.87	1.405	248
Bed with blade promoter	4.48	0.230	3.63	2.269	156

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