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(RESEARCH ARTICLE)

Investigation of Hydrodynamics Characteristics of Fluidized Bed with back propagation Artificial Neural Network (BPANN)

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Abstract

Correlations have also been developed with system parameters by using dimensional analysis and an artificial neural network approach. The paper describes an investigation for the thermal design of a fluidized bed cooler and prediction of heat transfer rate among the media categories. It is devoted to the thermal design of such equipment and their application in the industrial fields. In the present work, an extensive ANN by using back propagation (BP) has been carried out to correlate the expansion ratio, fluctuation ratio in gas-solid fluidized bed. Back propagation network is the most well-known and widely used among the current types of neural network system, several applications of ANN for modeling of nonlinear process systems and subsequent control were reported. In back-propagation, different ANN structures (I×H×O) with varying number of neurons in the hidden layer were used as a tool for training input and output data for prediction value of hydrodynamic characteristics of the bed system. It was noted that ring models are the best ones in reducing bed expansion ratio and fluctuation ratio around (25%) and (23.22%).

Keywords: Fluidized Bed; Ring-Promoted; bed expansion ratio; Intelligent Systems

1. Introduction

Fluidization is a process in which solids are caused to behave like a fluid by blowing gas or liquid upwards through the solid-filled reactor[1]. Fluidization phenomenon of an inclined fluidized bed systems have not been well understood and receive less research attention as compared with vertical fluidized bed[2]. The inclined fluidized bed has been applied in the cracking of heavy oils; coal gasification and reactors [3]. An artificial neural network based model is defined as a computing system made up of a number of simple, highly interconnected processing elements, which processes information by its dynamic state response to external inputs. An artificial neural network (ANN) is a computational model or a mathematical model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connection approach to computation. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data [4]. 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 nonlinear relationship. An artificial neural network based model is defined as a computing system made up of a number of simple, highly interconnected processing elements, which processes information by its dynamic state response to external inputs. Neural Network consists of a number of interconnected processing elements, commonly referred to as neurons or nodes as shown in fig.1.

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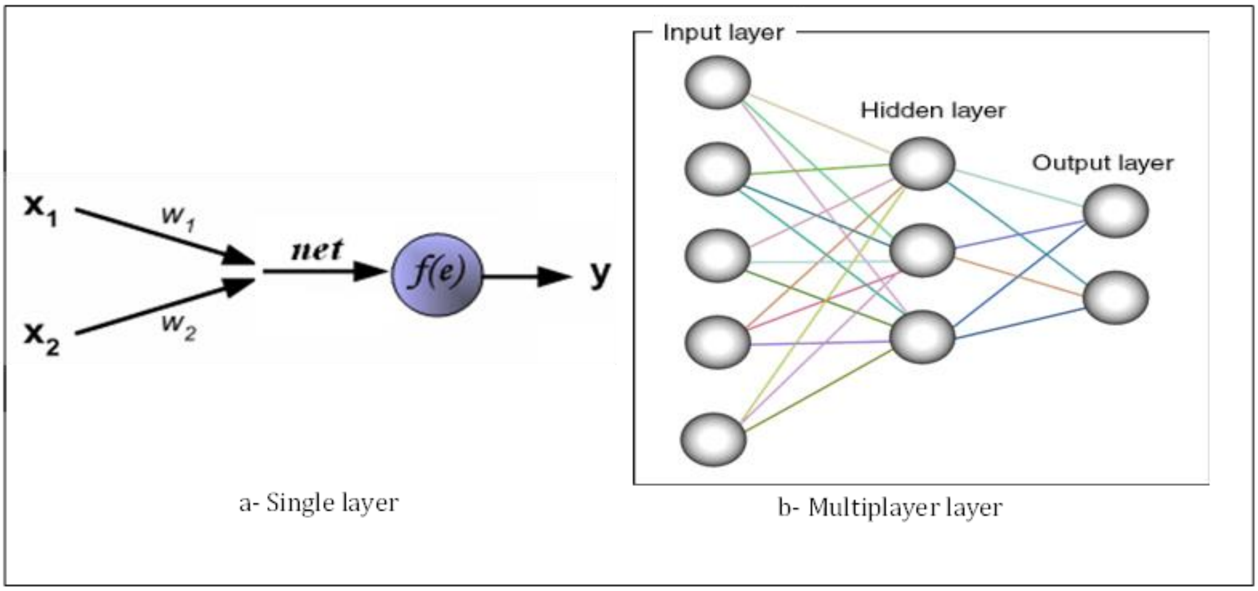

Figure 1 Structure of neural and ANN

Mohd [6] investigated the effect of inclination angle, particle size and particle composition to the minimum fluidization velocity in the range within 0 to 30 degree of inclination with vertical. The experimental results showed that the minimum fluidization velocity *(Umf)* of the particles is lower at higher angle of inclinations. Watcharop [7] developed a mathematical model to investigate the mixing behaviors of solid particles within an inclined fluidized bed from 0 ∘ , 10 ∘ , 20 ∘ to 30 ∘ . The simulations results show that an increase in angle of inclination leads to a decrease in the fraction of the bed. Bachtiyar et al. [8] investigated experimentally the dynamics and structure of a fluidized bed in inclined columns from 0º to 90º with vertical and the fluidizing agent is water. For inclined columns (10°and 45°) the escape flow rate initially increases with the bed height, but in the case of a vertical pipe (90°) the behavior is different and the escape flow rate generally decreases with statics bed height. A.Kumar, G.K. Roy [9] obtained the bed expansion data for unpromoted and promoted bed (coaxial rod and blade type) for varying operating parameters: fluid mass velocity, particle size, density and initial static bed heights. Correlations have been developed for the prediction of bed expansion.

In the present work, an extensive ANN by using back propagation (BP) has been carried out to correlate the expansion ratio, fluctuation ratio in gas-solid fluidized bed for unpromoted as well as promoted beds with ring type, where fluidizer in both cases is inclined in range of (45º, and 90º) from horizontal. In back-propagation, different ANN structures (I×H×O) with varying number of neurons in the hidden layer were used as a tool for training input and output data for prediction value of hydrodynamic characteristics of the bed system.

2. Experimental Setup

The experimental setup manufacturing consists of an air compressor, constant pressure tank, orifice meter, column, 46mm I.D. glass column (fluidizer) as shown in (fig.2). The particle used in this work was Alumina with average large diameter (1.18mm) and bulk density is (1888 kg/m^3) with porosity (0.446). The distributor plate is manufactured with total open area of (1.74%) of the column section. Three types of ring promoters are manufactured from Perspex material; the details are shown in table (1). The rings of each promoter have been fixed to brass support rod with (2) mm diameter and (20) pieces with equal spacing of (38.6) mm (center to center) and at an inclination of 10º with the horizontal alternatively in the opposite directions to minimize the accumulation of bed materials over the ring. The diameter of orifice was selected according to free area ($\alpha = D^2o/D^2c$). Free area was taken (0.25).

A known amount of the bed material was charged to the column from the top to a static bed (8cm) was obtained after fluidizing the bed gradually and allowing it to settle slowly. The experimental plot of bed pressure drop versus incipient fluidizing velocity was used to obtain the value of minimum fluidization velocity in each case. Steps were repeated with the column in a position of inclination of (45º, and 90º) without and with ring promoted.

Table 1 Ring- promoter characteristics

Properties of bed material	**Material**		
	Alumina	Sand	Coal
Diameter (mm)	0.71, 1.18, 1.7, 2	0.71, 1.18, 1.7, 2	0.71, 1.18,1.7,2
Density (kg/m^3)	1904	2425	1617
Ring promoter details			
	Outer diameter D_k of ring (mm)	Inner diameter D_o of ring (mm)	Ring thickness t_k of ring (mm)
	28 28 38	8 12 8	14 14 19
Angle of inclination			
θ	90º, 45º		

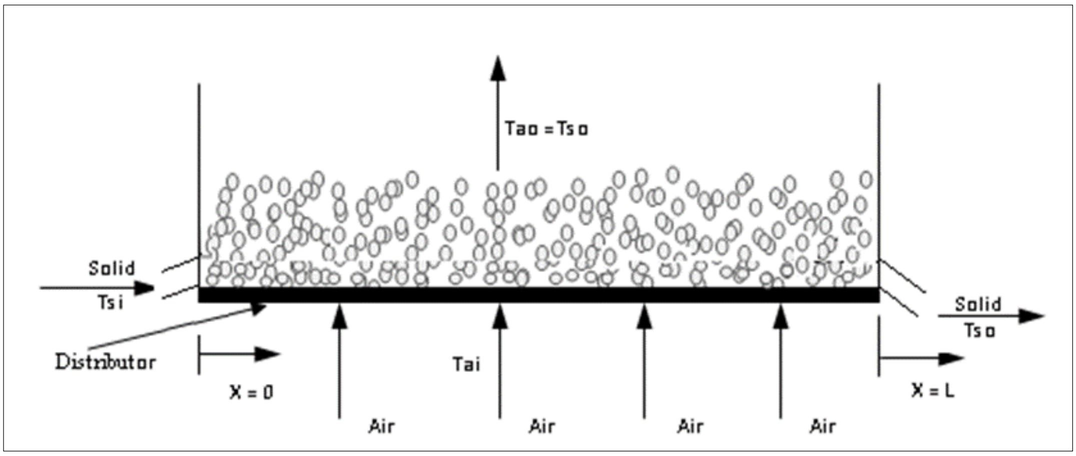

Figure 2 Schematic diagram of the gas-solid fluidized bed

3. Artificial Neural Network (ANN) Approach

In the present investigation, multilayered feed-forward back propagation neural networks are used, which are implemented using neural network toolbox that is available in MATLAB version (6.5). This program implements several different neural network algorithms, including back propagation algorithm. The total experimental data are divided into two sets models using mean square error back-propagation algorithm: one each for unpromoted bed and bed with ring type of promoter. The training set is used for computing the gradient and updating the network weights and biases to diminish the training error, and thus finding the relationship between the input and output parameters.

In each case, different ANN structures (input, hidden, and output) with varying number of neurons in the hidden layer were tested at constant epochs (cycles), and learning rates, as in fig. 3 and table 2. The training of the network using input and output data for particular type of bed resulted in a system (model) which was used as a tool for prediction of the bed expansion ratio, and fluctuation ratio for the corresponding bed.

Parameters: $G_R, Sin\theta, \frac{\rho_s}{\rho_f}, \frac{d_p}{d_o}, \frac{h_s}{D_c}, \frac{d_p}{D_c}, \frac{D_o}{D_c}, \frac{t}{D_c}, \frac{D_k}{D_c}$ have been considered as the input parameters.

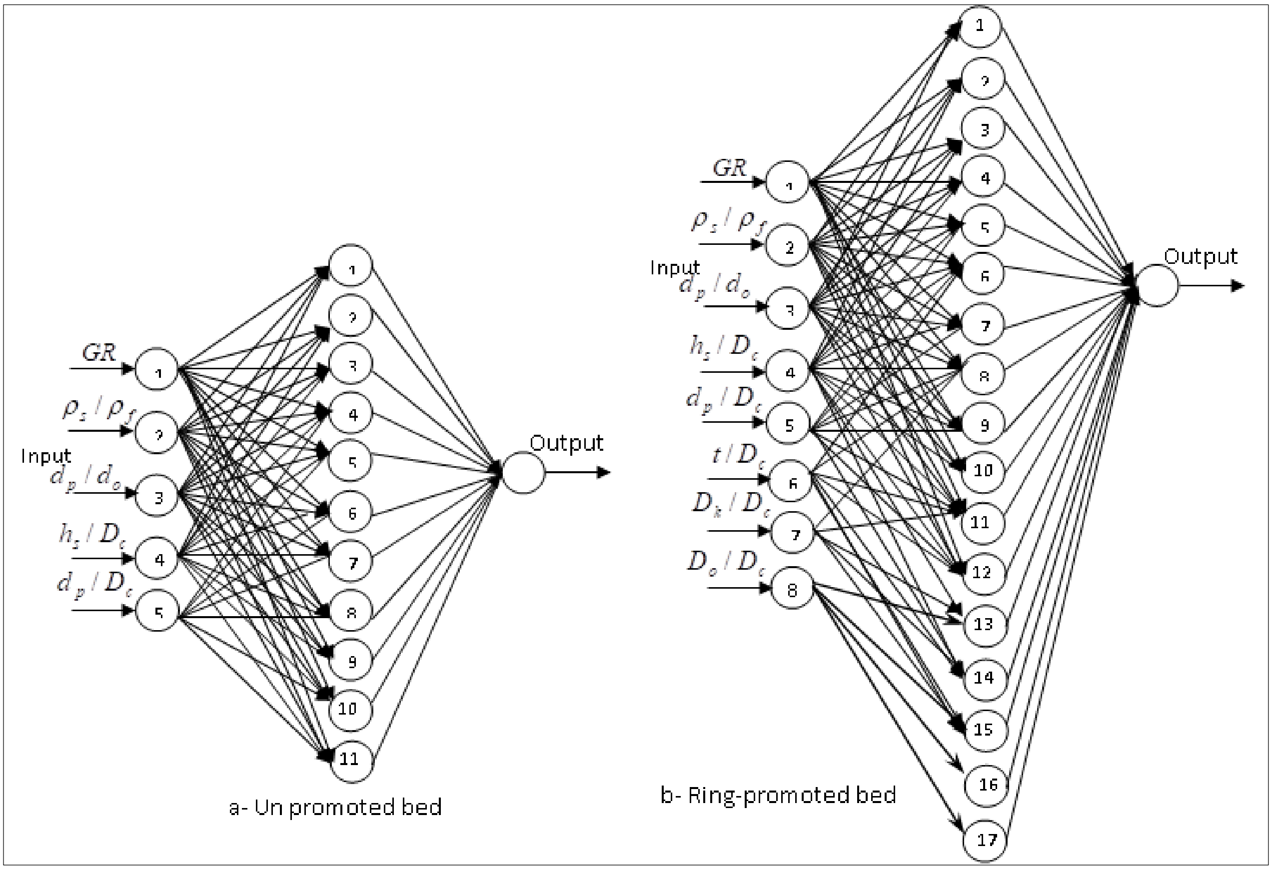

Figure 3 The proposed neural network architecture

Table 2 Selected structures of neural network models for test problems undertaken

Bed type	**BP**	**BP dimension**
	Range of initial weight and biases	
UP	[-1,1]	68
Ring	[-1,1]	155

The size and dimension of ANN using PSO and BP for unpromoted bed and beds promoted with rod, disk, and ring type of promoter are presented in table 3.

Table 3 The size and dimension of ANN using BP for unpromoted bed and bed promoted

Learning rate = 0.1 , MSE = 10^{-7}				
Bed particular	Input nodes I	Hidden nodes H	Output nodes O	No. of epoch training
Unpromoted bed	5	11	1	500
Bed with ring promoter	8	17	1	500

4. Accuracy of ANN

Error plot for learning of the data using BP is presented in fig.4. The training process continues until the slop conditions are met the minimum error (10^{-7}) or maximum number of iteration. So, for different types of beds (unpromoted and ring promoted bed, the maximum numbers of iteration (met the lowest learning error) using BP are 113 and 145 epoch respectively.

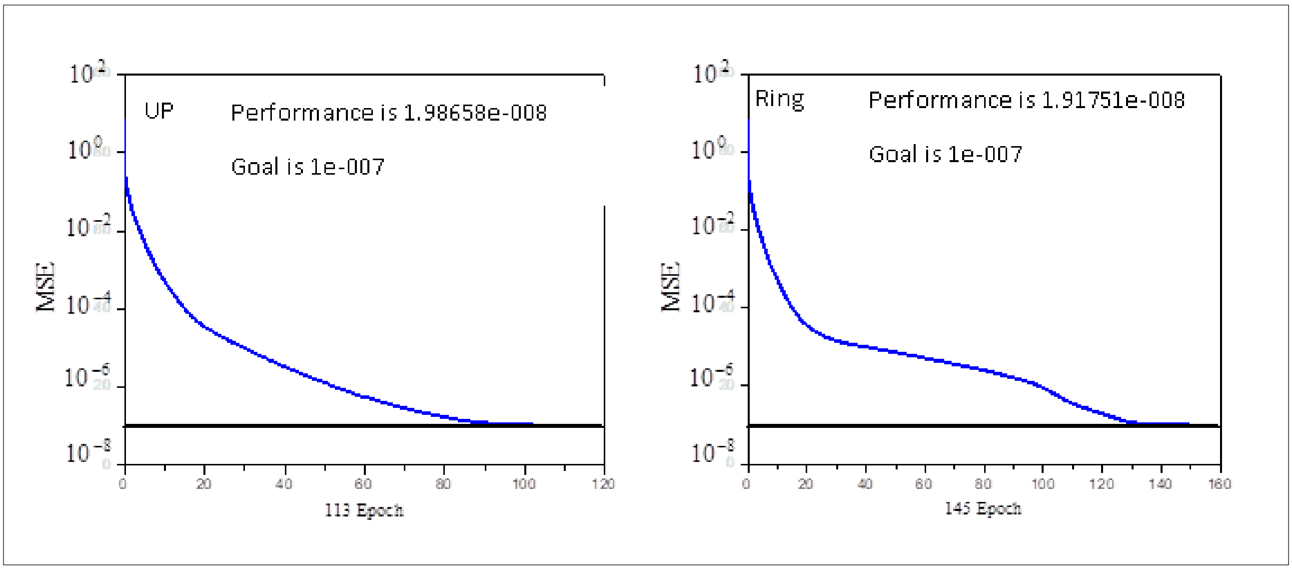

Figure 4 Mean square error against the number of epoch for different beds

The network structure together with the learning rate was varied to obtain an optimum structure with a view to minimize the mean square error at the output. The accuracy for ANNBP of different beds is listed in table 4.

Table 4 Accuracy of ANNBP of different beds

Unpromoted	
Learning Iteration	113
Error Convergence	1.98658e-008
Convergence Time	19 sec
No. of initial weights	1 set
Accuracy (%)	93.1
Ring promoted	
Learning Iteration	145
Error Convergence	1.91751e-008
Convergence Time	51sec
No. of initial weights	1 set
Accuracy (%)	94.6

5. Developed correlation by ANN approach

In the present work, the network is trained for each type of fluidized bed. The network structure together with the learning rate was varied to obtain an optimum structure with a view to minimize the mean square error at the output. Bed expansion (R) and fluctuation ratio (r) is a function of static and dynamic properties of the fluidized bed.

$$Z = f\left[Sin\theta, G_R, \frac{\rho_s}{\rho_f}, \frac{d_p}{d_o}, \frac{h_s}{D_c}, \frac{d_p}{D_c}, \frac{D_o}{D_c}, \frac{t_k}{D_c}, \frac{D_k}{D_c} \right] \quad \ldots (1)$$

Unpromoted bed:

$$Z = K\left(Sin\theta (G_R)^a \left(\frac{\rho_s}{\rho_f}\right)^b \left(\frac{d_p}{d_o}\right)^c \left(\frac{h_s}{D_c}\right)^d \left(\frac{d_p}{D_c}\right)^e \right)^n \quad \ldots (2)$$

Ring promoted bed:

$$Z = K\left(Sin\theta (G_R)^a \left(\frac{\rho_s}{\rho_f}\right)^b \left(\frac{d_p}{d_o}\right)^c \left(\frac{h_s}{D_c}\right)^d \left(\frac{d_p}{D_c}\right)^e \left(\frac{t_k}{D_c}\right)^g \left(\frac{D_k}{D_c}\right)^h \left(\frac{D_o}{D_c}\right)^m \right)^n \quad \ldots (3)$$

Parameters: $R, r, G_R, Sin\theta \frac{\rho_s}{\rho_f}, \frac{d_p}{d_o}, \frac{h_s}{D_c}, \frac{d_p}{D_c}, \frac{D_e}{D_c}, \frac{t}{D_c}, \frac{D_k}{D_c}, \frac{D_o}{D_c}$

have been considered as the input parameters. K and n (overall coefficient and exponent of the correlation, respectively), and *a, b, c, to m* (individual exponents of these parameters) have been considered as the output for the ANN training of the data. The value of *K,n, a, b, c, to m* are presented in table 5.

Table 5 Experimental exponent

Bed expansion ratio										
Bed prediction	Method	Constant	Exponents							
		K	a	b	c	d	e	g	h	m	n
Unpromoted bed	DA	0.62	0.754	0.36	0.28	0.58	0.018	-	-	-	0.38
	BP	0.611	0.751	0.37	0.28	0.56	0.019				0.377
Ring promoted bed	DA	0.41	0.39	0.266	0.2	0.533	0.004	0.007	0.204	0.235	0.63
	BP	0.406	0.38	0.263	0.17	0.531	0.0038	0.0072	0.20	0.231	0.62
Bed fluctuation ratio										
Unpromoted bed	DA	0.64	1.03	0.42	0.61	2.1	0.019	-	-		0.261
	BP	0.637	1.032	0.41	0.6	2.11	0.0188	-	-		
Ring promoted bed	DA	0.37	0.263	0.197	0.12	0.34	0.0043	0.0076	0.153	0.142	0.911
	BP	0.36	0.261	0.195	0.12	0.338	0.0041	0.0077	0.152	0.141	0.91

6. Result and discussion

The values of the bed expansion ratio and fluctuation ratio calculated with the help of the developed correlation for unpromoted and ring-promoted beds with inclination were compared with the corresponding experimental ones and found to be in good agreement. Comparison between the calculated values of bed expansion ratio, and bed fluctuation ratio, by (DA) approach, and Bp against the experimental data for unpromoted, and ring promoted as shown in figures 5 and 6. The reduction of bed expansion and fluctuation with increase the blockage volume by the ring promoter in terms of increase in outer and inner ring diameter/thickness is due to the increase in the effectiveness of the promoter element in controlling the bubble behavior viz. hindering the formation and growth of bubbles, limiting their size. Also, it has been observed that the pressure drop ratio increases with increase in blockage volume due to enhanced secondary flow. The ring promoter was found effective for large particle in reducing the bed expansion and fluctuation to (1.33, 1.26) respectively nearest to value (1.34, 1.27), respectively for small particle for unpromoted. It is found that the use of a ring promoter gives good mixing.

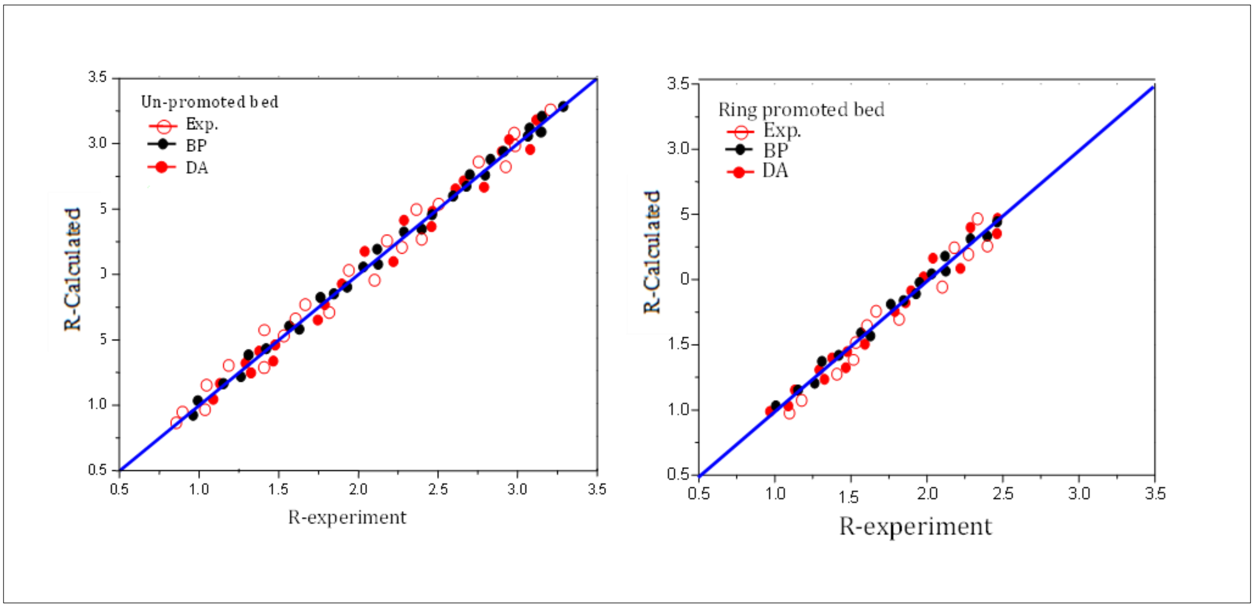

Figure 5 Comparison between the calculated values of bed expansion by Exp. , Bp and DA approach against the experimental data

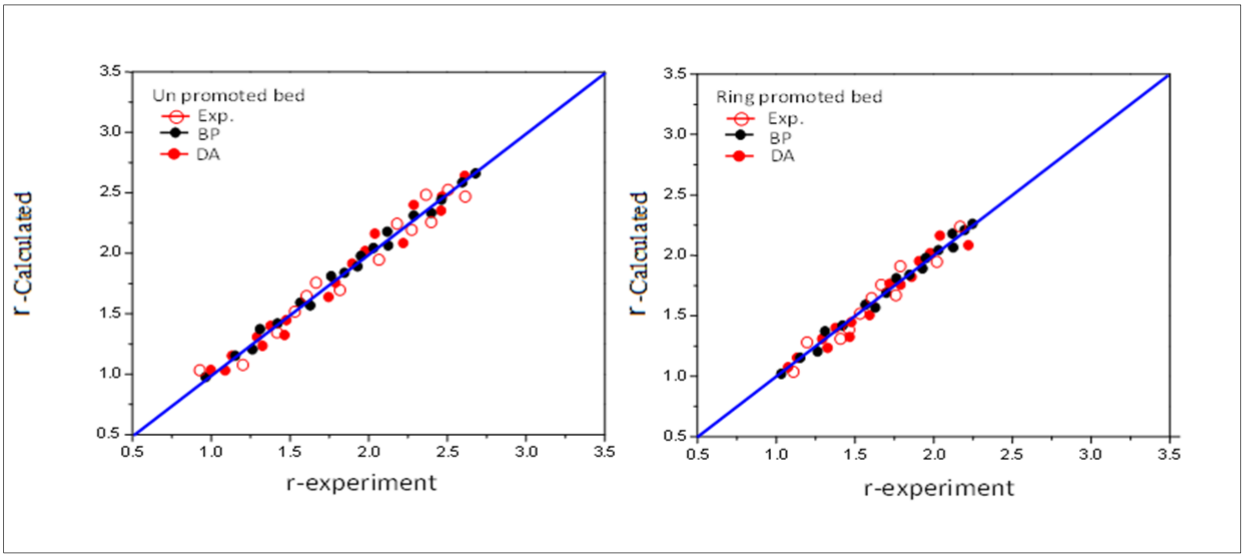

Figure 6 Comparison between the calculated values of bed fluctuation ratio by Exp. , Bp and DA approach against the experimental data

7. Conclusion

An experimental study was carried out to investigate the structure and dynamics of a fluidized bed in inclined pipes. The bed dynamic is significantly influenced by the particle size, particle density, promoter with different open area, and bed inclination. The following conclusions are drawn:

- It has been seen that ring promoter are more effective in improving the quality of fluidization by reducing expansion and fluctuation over unpromoted bed.
- It has been found that the expansion and fluctuation ratio reduces with decreasing bed inclination from (90º to 45º) for all bed types (unpromoted and promoted bed).
- The ring promoter has been found effective for large particle in reducing bed expansion and fluctuation ratio to value (1.33, 1.26), respectively, nearest to value (1.34, 1.27), respectively of small particle for unpromoted.
- It can be observed that the pressure drop ratio increases rapidly with increase in particles size, i.e. increase in fluidization velocity; ring promoter has the highest fluidization velocity.
- It was observed that ring models is best in reducing bed expansion ratio and fluctuation ratio around (23.5%) and (21.87%), respectively at angle (45º).

The bed expansion and fluctuation decreases with decrease bed angle. The bed pressure drop and minimum fluidization velocity decreases with decrease in bed angle. As the inclination is decreased, the gravity effect on the bed is reduced (The effective gravitational force becomes the product of sin (θ) and the normal gravitational force). So that, the bed pressure drop across the bed will be decreased (822 to 750 Pa), and the gas velocity for fluidization decrease (0.4 to 0.325 m/s) with decreasing bed angle.

Correlations have been developed with the help of relevant dimensionless groups, involving interacting parameters by using dimensional analysis (DA).

Nomenclature

Latin Symbol	Meaning	Unit
a,b..,m	Constants	-
D_c	column diameter	m
D_k	Disk diameter	m
D_o	orifice of ring diameter	m
dp	Particle diameter	m
d_o	orifice diameter	m
GR	fluid mass velocity ratio GR= $(G_f - G_{mf})/G_{mf}$	-
G_f	fluid mass velocity	kg/ m²s
G_{mf}	min.fluidization mass velocity	kg/ m²s
g	Gravitational acceleration	m/s²
h_s	static bed height	m
R^2	Coefficient of determination for correlation	-
R	Bed expansion ratio	-
r	Bed fluctuation ratio	-

t_k	Disk thickness	m
U_{mf}	min. fluidization velocity	m/s

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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