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Effect of Co-Axial Promoters (Rod and Disc Type) On Pressure Drop in Squared Gas-Solid Fluidized Bed.

A. Sahoo and G. K. Roy*
Department of Chemical Engineering
National Institute of Technology
Rourkela-769008, Orissa,
India.

E-Mail: abantisahoo@hotmail.com
Correspondence to be made
*gkroy@nitr.ac.in

*gk_roy@hotmail.com
Fax: 0661-2472926 (attn. – Prof. G. K. Roy)

Abstract:

This paper deals with the experimentation conducted to obtain pressure drop in a squared gas-solid fluidized bed under varying conditions. The flow rate, the initial static bed height, particle size and density have been altered; and the bed pressure drops under fluidizing conditions have been measured. The data have been correlated in terms of Euler Number. Correlations relating Euler Number with the system parameters have been developed for the unpromoted bed and beds with rod and disc promoters. Developed correlations have been authenticated by an ANN-model. The values of Euler Number thus predicted as well as the bed pressure drop values calculated there-of have been compared with the experimental values and have been found to agree fairly well.

Author Keywords: co-axial promoters, squared gas-solid fluidized bed, ANN-model, Euler Number.

Article Outline

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1. Introduction

Improvement of the quality of gas-solid fluidization can be well achieved by the introduction of a suitable turbulence promoter to the conventional bed. Many investigations have already been carried out to study the effect of turbulence promoters of different shape, size, roughness and configuration on various aspects of bed dynamics for both gas-solid [1-8] and liquid-solid [9-10] systems in case of columnar fluidized beds. Takami et al [11] have reported that enhanced conversion of hydrogen chloride to chlorine can be achieved in a fluidized catalyst bed with internal baffles (in the present case "promoters"). Hartholt et al [12] have also studied the effect of baffles on mixing and segregation of binary group B mixture in a gas-solid fluidized bed. However available information on the above aspects in case of non-cylindrical beds is almost negligible. Here attempt has been made to study the effect of co-axial rod and disc promoters of different configuration on pressure drop in case of a squared gas-solid fluidized bed.

2. Literature Review

There are several well-recognized correlations which permit the prediction of pressure drop for gas-solid fluidized bed of spherical or non-spherical particles in cylindrical conduits. These are of Blake et al. [13], Carman et al. [14], Chilton and Colburn [15] and Oman and Watson, Leva and Coworkers, Happel, Ergun, Rose and Rizk mentioned in 'Fluidisation and Fluid- particle System' by Zenz an Othmer [16]. Prediction of pressure drop in terms of a dimensionless group (as pressure drop ratio) for a gas-solid fluidized bed is developed by Kumar [17] as given below.

$$\frac{\Delta P_d}{\Delta P} = 1.29 \times 10^{-4} (G_{mrf})^{1.14} \left(\frac{\rho_s}{\rho_f}\right)^{0.48} \left(\frac{A_{do}}{A_C}\right)^{-1.83} \left(\frac{d_p}{d_o}\right)^{0.89} \left(\frac{Hs}{D_C}\right)^{-1.02} \quad \ldots\ldots\ldots (1)$$

Kumar et al. [17] also gave the following relation between pressure drop ratio and system variables including promoter parameters for a gas-solid rod promoted fluidized bed as under,

$$\frac{\Delta P_d}{\Delta P} = 8.66\times10^{-5}\left(G_{mrf}\right)^{1.26}\left(\frac{\rho_s}{\rho_f}\right)^{0.53}\left(\frac{A_{do}}{A_c}\right)^{-2.01}\left(\frac{d_p}{d_o}\right)^{0.94}\left(\frac{Hs}{D_C}\right)^{-1.18}\left(\frac{D_E}{D_C}\right)^{-0.21} \quad \text{.................} \quad (2)$$

While sufficient information is available for measuring pressure drop in conventional gas-solid fluidized beds information for non conventional conduits is very limited. Singh et al. [18] have developed the following correlation for measuring pressure drop in squared gas-solid fluidized bed.

$$\Delta P = 150 + 3.5\times\left(\frac{N_{\text{Re}}}{1-\varepsilon}\right) \quad \text{....................} \quad (3)$$

3. Experimentation

The experimental set-up (Fig-1) consists of an air compressor, a rotameter, a manometer and a fluidizer (8.2 × 8.2 × 100cm) with a conical calming section and a multiorifice distributor. The disc promoter consists of six numbers of stars of perspex material spaced at 10 cm gaps with a central rod of 120cm long. The rod promoter consists of three 6mm dia and 60cm long steel rods which are placed at the vertices of an equilateral triangle with the fourth rod of 120cm length placed at its centre. (Fig-1)

For a particular run the variation of pressure drop was noted with the gradual increase of air flow rate. Experimental runs were repeated with varying initial static bed height, bed material and its particle size. The scope of the experiment is given in Table-1.

4. Development of Correlations

Pressure drop in terms of Euler Number under fluidization condition has been correlated to various system parameters from a Dimensional Analysis approach. The following three correlations have been developed for unpromoted and the two promoted beds:

The values of Correlation Coefficients and overall exponents have been obtained through Fig-2, Fig-3 and Fig-4 respectively. The final correlations are as under.

For unpromoted bed,

$$Eu = 17.817 \times \left[\left(\frac{H_S}{D_C} \right)^{1.25} \times \left(\frac{d_P}{D_C} \right)^{-0.45} \times \left(\frac{\rho_S}{\rho_f} \right)^{0.23} \times \left(\frac{U_f}{U_{mf}} \right)^{-1.88} \right] \qquad \text{----------- (4)}$$

For disc-promoted bed,

$$Eu = 2.85 \times 10^{02} \times \left[\left(\frac{H_S}{D_E} \right)^{0.045} \times \left(\frac{d_P}{D_E} \right)^{-0.224} \times \left(\frac{\rho_S}{\rho_f} \right)^{-0.025} \times \left(\frac{U_f}{U_{mf}} \right)^{-0.184} \right] \qquad \text{----------- (5)}$$

For a rod-promoted bed,

$$Eu = 31.223 \times \left[\left(\frac{H_S}{D_E} \right)^{-0.234} \times \left(\frac{d_P}{D_E} \right)^{-0.273} \times \left(\frac{\rho_S}{\rho_f} \right)^{0.222} \times \left(\frac{U_f}{U_{mf}} \right)^{-0.821} \right] \qquad \text{--------- (6)}$$

5. Development of ANN-Model

An ANN-based model has been defined in literature by several authors Wasserman et al., Chitra et al., Rumelhart et al., Bhatt et al. and Scott et al. [19 – 23] as a computing system made up of a number of simple and highly interconnected processing elements which processes information by its dynamic state response to external inputs. The Back Propagation Network corrects its weights to decrease the observed error as reported by Dayhoff et al. [24].

An attempt has been made to authenticate the developed correlations by means an ANN-package written by Rao and Rao [25] in the Supervised Learning framework. A three layered feed forward Neural Network is considered for this problem. The network is trained for a given set of input and target data sets. These sets were obtained from the experimental observations. The network is trained with 60 sets of data sets, where each set consists of four system parameters (viz; Hs/Dc, dp/Dc, ρ_s/ρ_f and U_f/U_{mf}) and the corresponding value of experimental Euler Number (calculated from measured pressure drop) .These system parameters are the input and the experimental Euler Numbers are the output respectively. The data were normalized and then the network was exposed to these normalized sets. These normalized input and output data are known as the training data. The same sets or the other sets of input data are taken as the verification or testing data for which the target or output data are to be calculated. The network weights were updated using the Back Propagation algorithm.

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 optimum parameters of ANN-model obtained for the data set for different systems are listed in **Table-3** and the schematic ANN- structure is shown in **Fig.5-A**. This has 4 input nodes, 25 hidden nodes and 1 output nodes for all the three systems which are shown in **Fig-5-B**.

6. Results and Discussion

Calculated values of Euler Number obtained through the equations (4), (5) and (6) have been authenticated with the help of the above ANN-model. Calculated values of Euler Number by both the approaches (i.e. by Dimensional analysis and ANN-model) for the unpromoted, disc-promoted and rod-promoted beds have been compared with their corresponding experimental values in Fig-6, Fig-7 and Fig-8 respectively.

Standard and mean deviations of the calculated values with respect to the experimental ones for Euler Number in case of all types of beds and by both the approaches are given in **Table-2**. With the help of equations (4), (5) and (6), bed pressure drop values have been calculated for the unpromoted and promoted beds respectively and presented in **Fig-9**. It is observed that the bed pressure drop is higher for the promoted bed in comparison with the unpromoted bed. Hoffmann [26] has shown that the fluidization index (F.I.) thereby the pressure drop is more for the baffled bed than the bed without baffles. Chung Lim Law et al [27] have discussed the effect of vertical baffles on the group D mixture where the fluctuation of pressure drop is not significant. The same thing has also been observed here. The Pressure drop deviation in case of rod-promoted bed is not as significant as with the disc-promoted bed. This may be attributed to the break up of channels and slugs which may be due to the combined effect of channel and slug breakage by the vertical elements of the rod promoter.

Disc promoter offers resistance in the horizontal plane. The wakes of rising bubbles loose their wake particles due to the presence of promoters and there after new wakes form above the disc/baffle. This decreases the upward particle transport in the bed as explained by Hartholt et al., 1997 [12]. But the denser particles may flow upward in the wakes of the bubbles in between two discs. Because of which pressure drop/ Euler No. is inversely proportional to the density parameter in Eq-5 of the revised manuscript. Whereas in Eq-4 and 6 of the manuscript, the pressure drop is proportional to the density parameter as usual since particles get space for vertical movement in the column.

For all types of beds the pressure drop is inversely proportional to the fluidization velocity. That is with the increase of fluidization velocity the pressure drop decreases. Similarly the pressure drop is inversely proportional to the particle size parameter because of more void spaces with large size particles in a fluidized bed. For the static bed height parameter it is found that pressure drop increases with the increase in bed height in case of un-promoted and disc-promoted bed. But for rod-promoted bed its effect is reverse. Reason might be attributed to the breakage of channeling due to the presence of rod promoter.

Further work is being carried out to compare the values of Euler No. for non-cylindrical and cylindrical gas-solid fluidized beds under the similar process conditions.

7. Conclusion

The system parameters like bed height, particle size and density as well as the presence of promoters significantly influence the Euler Number. On comparison of the calculated values of Euler Number with the experimental values for all types of beds it is observed that the developed correlations are in good agreement with the measured values which is also authenticated by the ANN-model. Therefore, the developed correlations can be used over a wider range of variables with reasonable accuracy for unpromoted and promoted beds. Rod type promoters can be used for better mixing thus improving the quality of fluidization with bed pressure drop values very much closer to that of an unpromoted bed which does not alter the operating economics in a significant way.

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NOMENCLATURE:

a, b, c, d	: exponents for variables
Ac	: Cross sectional area of the fluidizer, m^2
A_{do}	: Open area of the distributor, m^2
D_C	: Column Diameter of the fluidizer, m
D_E	: Equivalent Column Diameter for Promoted Bed, Squared Bed, m
d_P	: Particle Diameter, m
do	: Orifice Diameter, m
Eu	: Euler Number, $(\Delta P/(\rho U_f^2))$, Dimensionless
F.I.	: Fluidization Index, $\Delta P/(W/Ac)$, Dimensionless
Gf	: operating fluidization mass velocity, $kg/hr\text{-}m^2$
Gmf	: Minimum fluidization mass velocity, $kg/hr\text{-}m^2$
Gmrf	: Reduced fluidization mass velocity, (Gf/Gmf) Dimensionless
Hs	: Initial Static Bed Height, m
N_{Re}	: Reynolds Number, Dimensionless
ΔP	: Pressure Drop across the bed, N/m^2
ΔP_d	: Pressure Drop across the distributor, N/m^2
U_f	: Superficial Velocity of fluid (air) under fluidization condition, m/s
U_{mf}	: Superficial velocity of fluid under minimum fluidization condition, m/s
W	: Weight of fluidized solid, kg
ε	: Void fraction of the bed
ρ_S	: Density of fluidized solid, kg/m^3
ρ_f	: Density of fluid, kg/m^3

Abbreviations used:

D A	: Dimensional Analysis
ANN	: Artificial Neural Network
UP-Bed	: Unpromoted bed
DP-Bed	: Disc- promoted Bed
RP-Bed	: Rod- promoted Bed
Rhos	: Density of solid, kg/m^3

Rhof : Density of fluid, kg/m^3

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TABLE-1:

Sl. No.	Bed material	Particle diameter, $dp\times10^3$,m	Density of fluidized solid, ρ_s, kg/m^3	Initial Static Bed Height, $Hs\times10^2$,m
1	Dolomite	1.700	2855	8.00
2	Dolomite	1.125	2855	8.00
3	Dolomite	0.725	2855	8.00
4	Dolomite	0.550	2855	8.00
5	Dolomite	1.700	2855	6.00
6	Dolomite	1.700	2855	8.00
7	Dolomite	1.700	2855	10.00
8	Coal	1.700	1524	12.00
9	Coal	1.125	1524	8.00
10	Coal	0.725	1524	8.00
11	Coal	0.550	1524	8.00
12	Limestone	1.700	2245	8.00
13	Limestone	1.125	2245	8.00
14	Limestone	0.725	2245	8.00
15	Limestone	0.550	2245	8.00

TABLE-2:

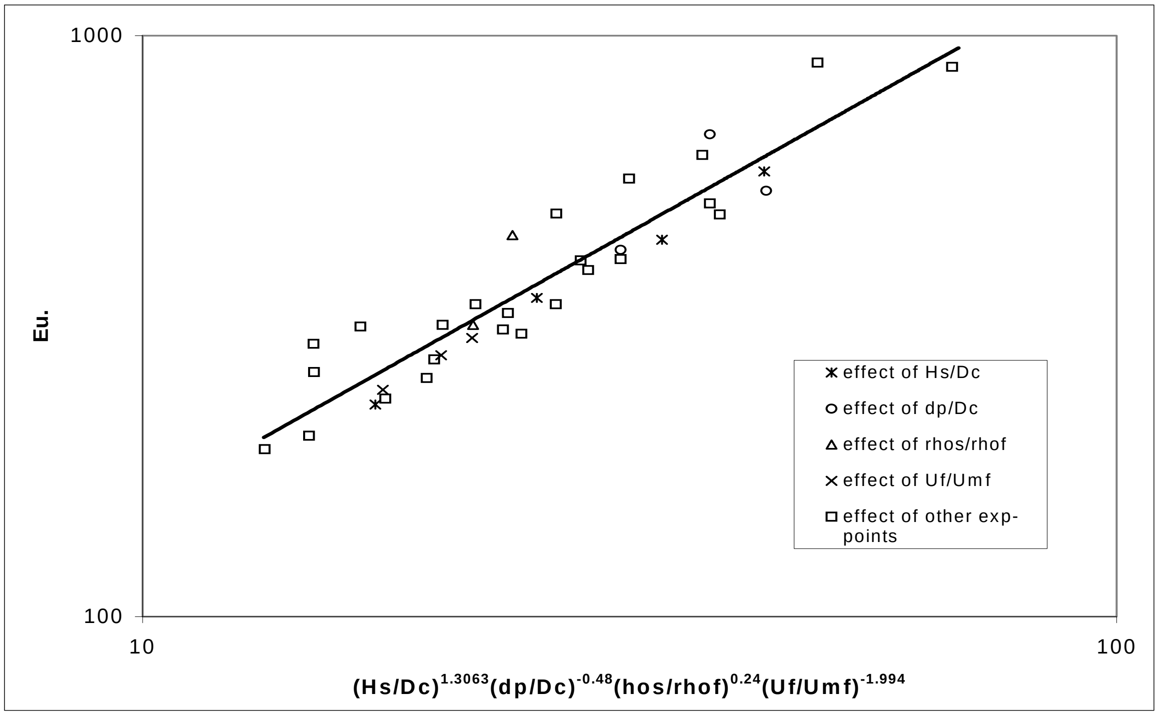
Sl.No	Types of Bed	Percentage Deviation			
		Dimensional Analysis approach		Artificial Neural Network approach	
		Standard	Mean	Standard	Mean
1	UNPROMOTED	12.841	12.690	12.754	12.607
2	DISC PROMOTED	13.485	13.308	13.526	13.350
3	ROD PROMOTED	11.686	11.437	11.697	11.448

TABLE-3:

Sl. No.	ANN-Parameters for (Three layered Back Error Propagation)	Unpromoted Bed	Disc Promoted Bed	Rod Promoted Bed
1	Error tolerance, (0.001-100)	0.001	0.001	0.001
2	Learning parameter, (0.01-1.0)	1.0	0.5	1.0
3	Momentum parameter, (0.01-1.0)	0.01	0.01	0.03
4	Noise factor, (0.0-1.0)	0.0	0.0	0.0
5	Slope, (0.1-1.0)	0.9	0.4	0.9
6	Maximum cycles	50000	50000	50000
7	Input units	4	4	4
8	No. of hidden layer	1	1	1
9	No. of hidden layer Neurons	25	25	25
10	No. of output unit	1	1	1

FIGURE CAPTIONS:

1. Experimental Set-Up
2. Variation of Euler Number with system parameters (Unpromoted bed).
3. Variation of Euler number with system parameters (Disc-promoted bed).
4. Variation of Euler number with system parameters (Rod-promoted bed).
5. ANN-Symbol
6. Comparison of Calculated Values of Euler Number By Both The Approaches (Dimensional Analysis / D.A. and ANN-model) with the experimental values for Unpromoted bed.
7. Comparison of calculated values of Euler Number by both the approaches (Dimensional Analysis / D.A. and ANN-model) with the experimental values for Disc-promoted bed.
8. Comparison of calculated values of Euler Number by both the approaches (Dimensional Analysis / D.A. and ANN-model) with the experimental values for Rod-promoted bed.
9. Comparison of calculated pressure drop for promoted bed with unpromoted bed.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Eu.
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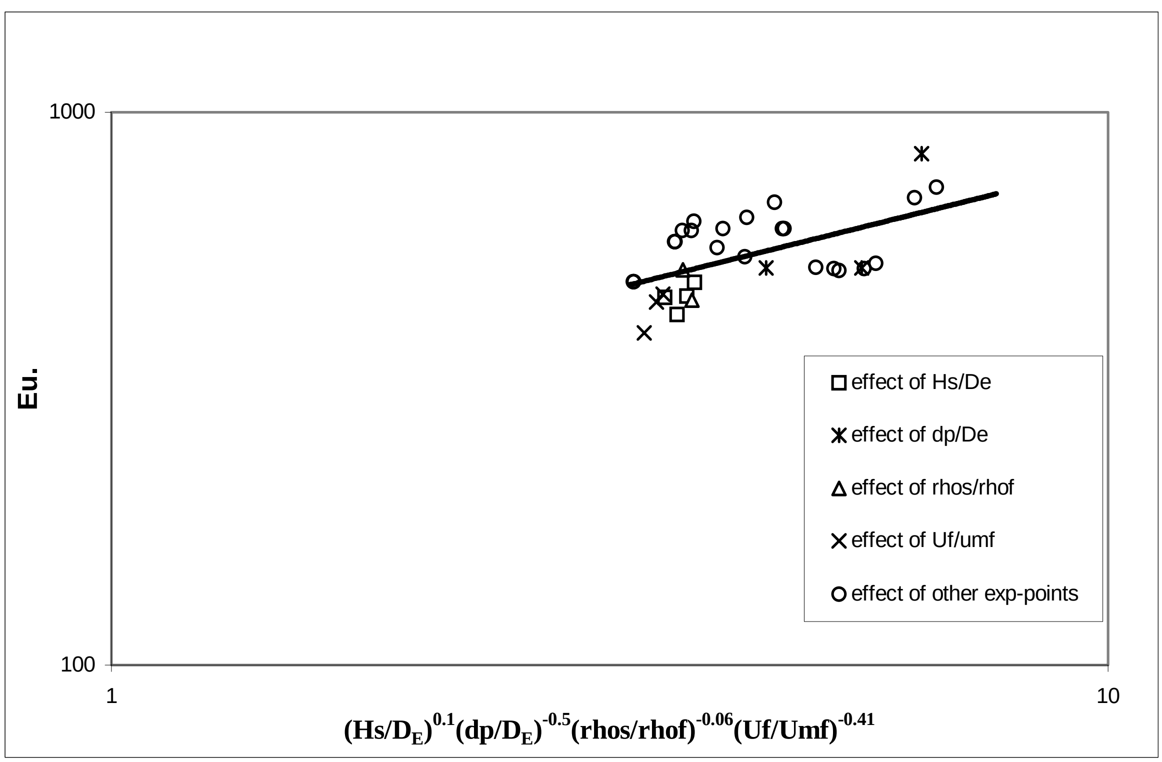
effect of dp/Dc
effect of rhos/rhof
effect of Uf/Umf
effect of other exp-points

Fig-2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effect of dp/De
effect of rhos/rhof
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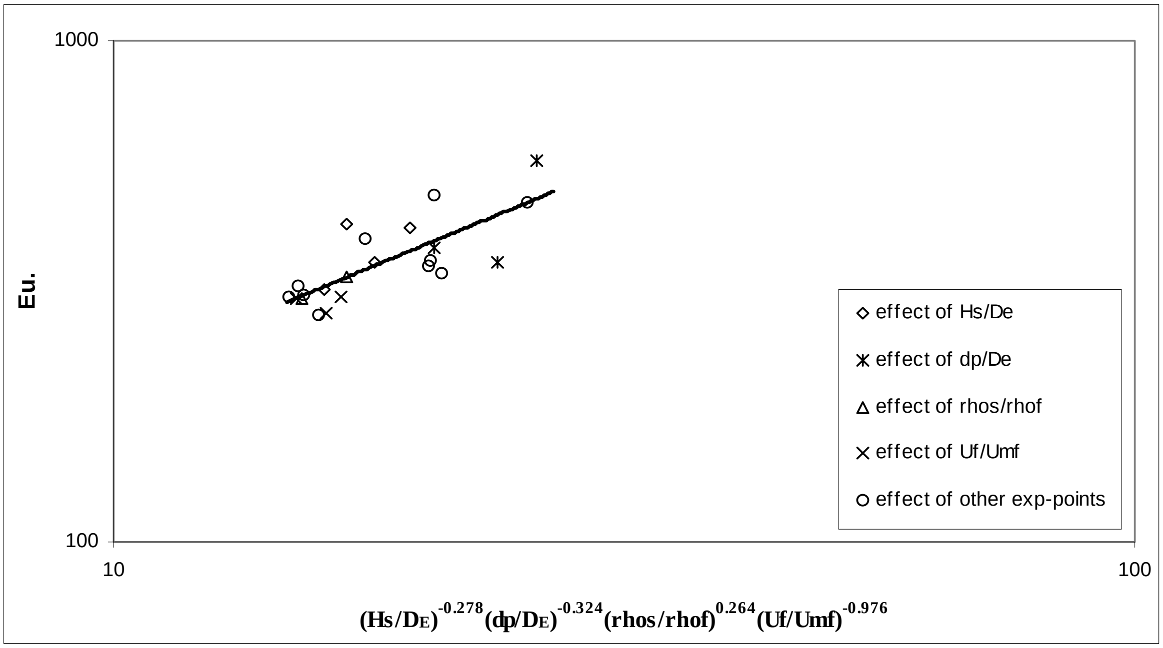
effect of other exp-points

Fig-3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Eu.
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effect of dp/De
effect of rhos/rhof
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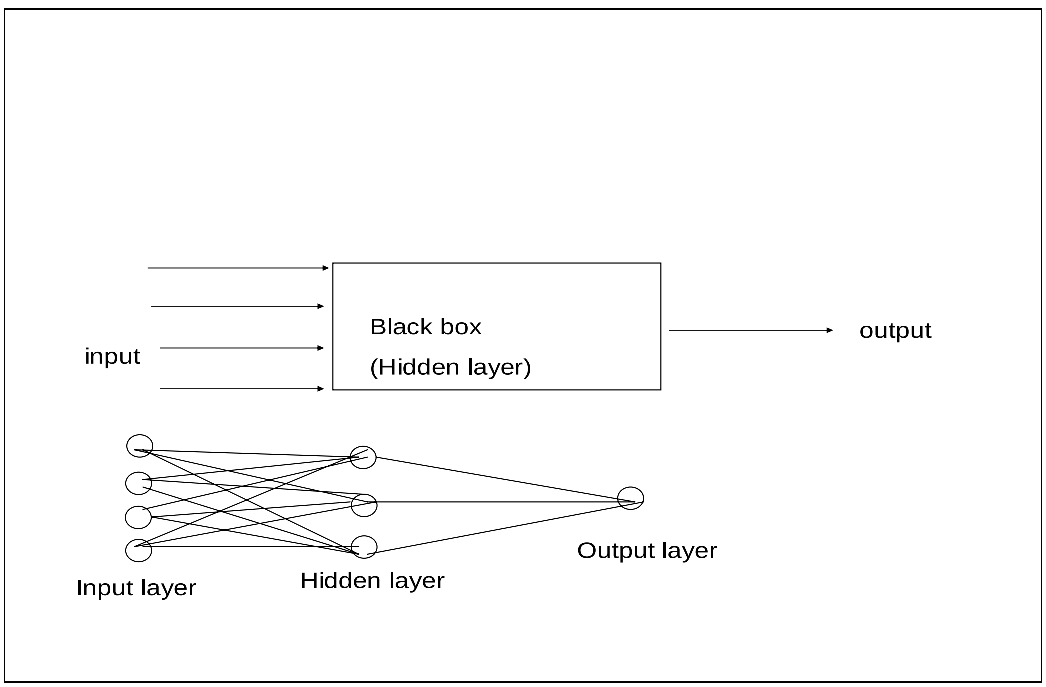
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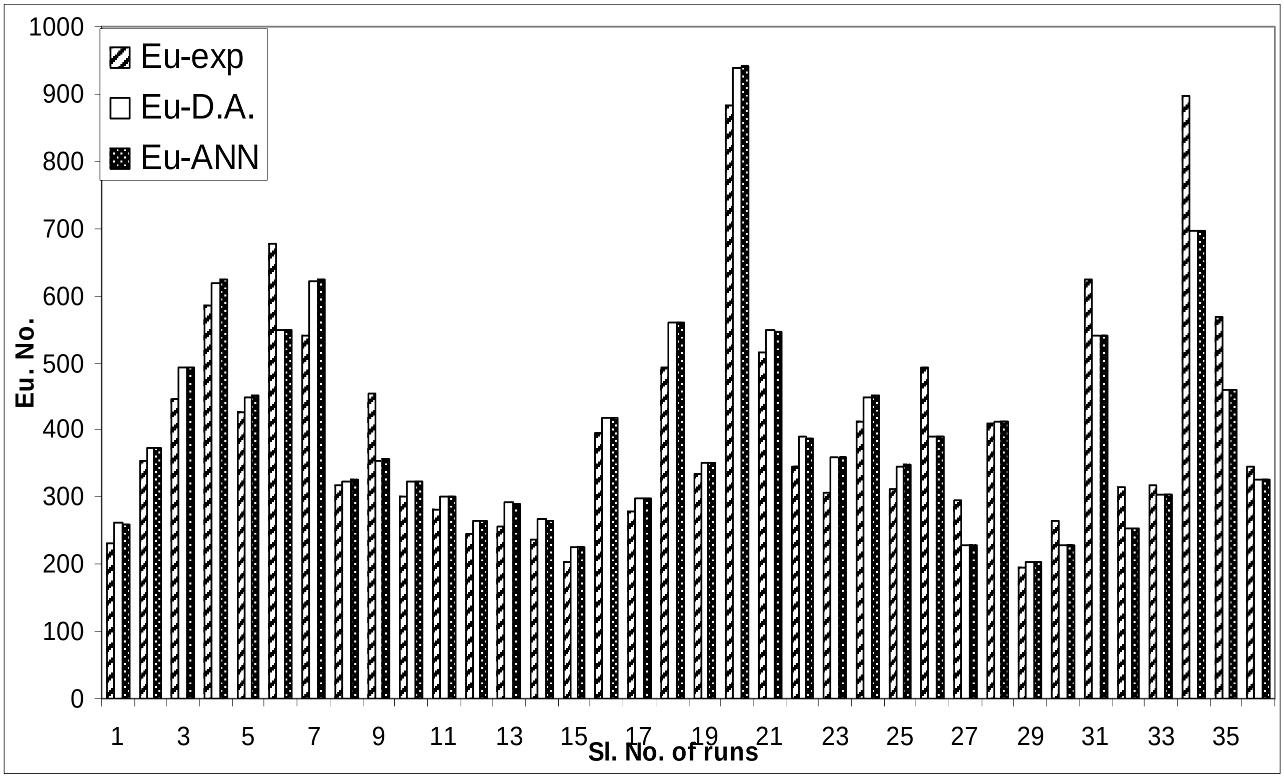
output
Input layer
Hidden layer
Output layer

Fig-5-A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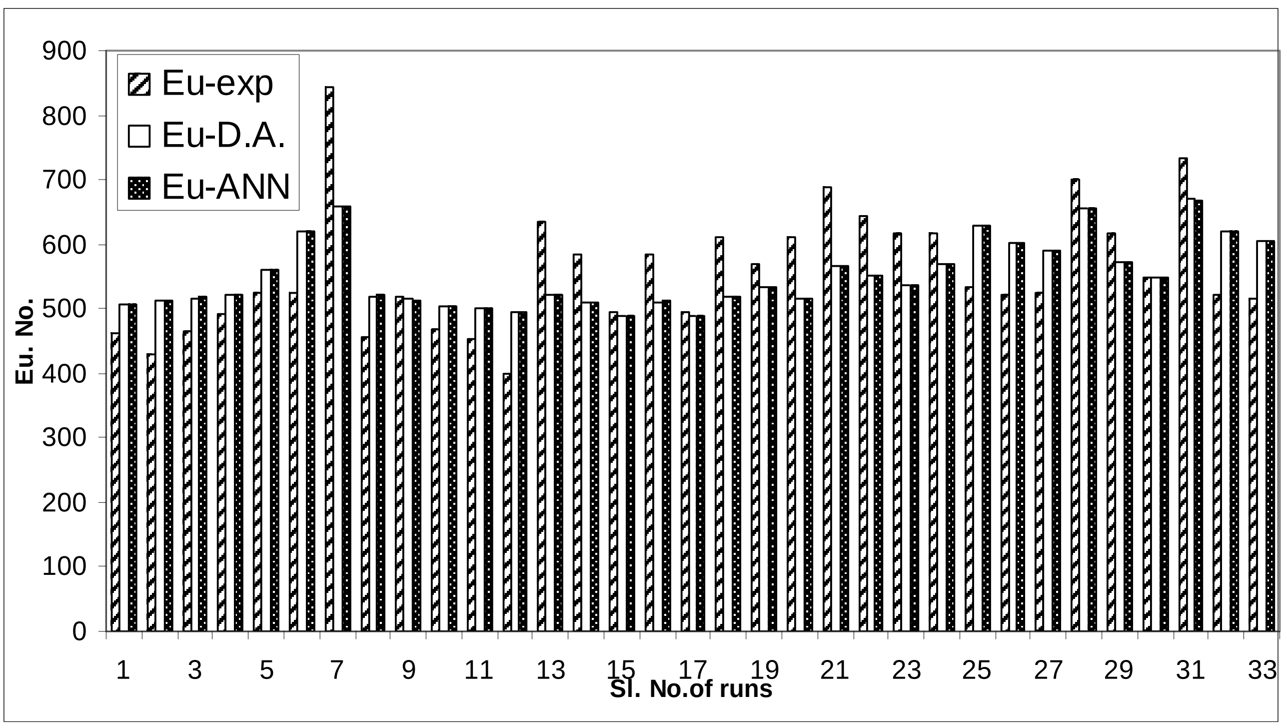
Eu-D.A.
Eu-ANN
Eu. No.
Sl. No. of runs

Fig-6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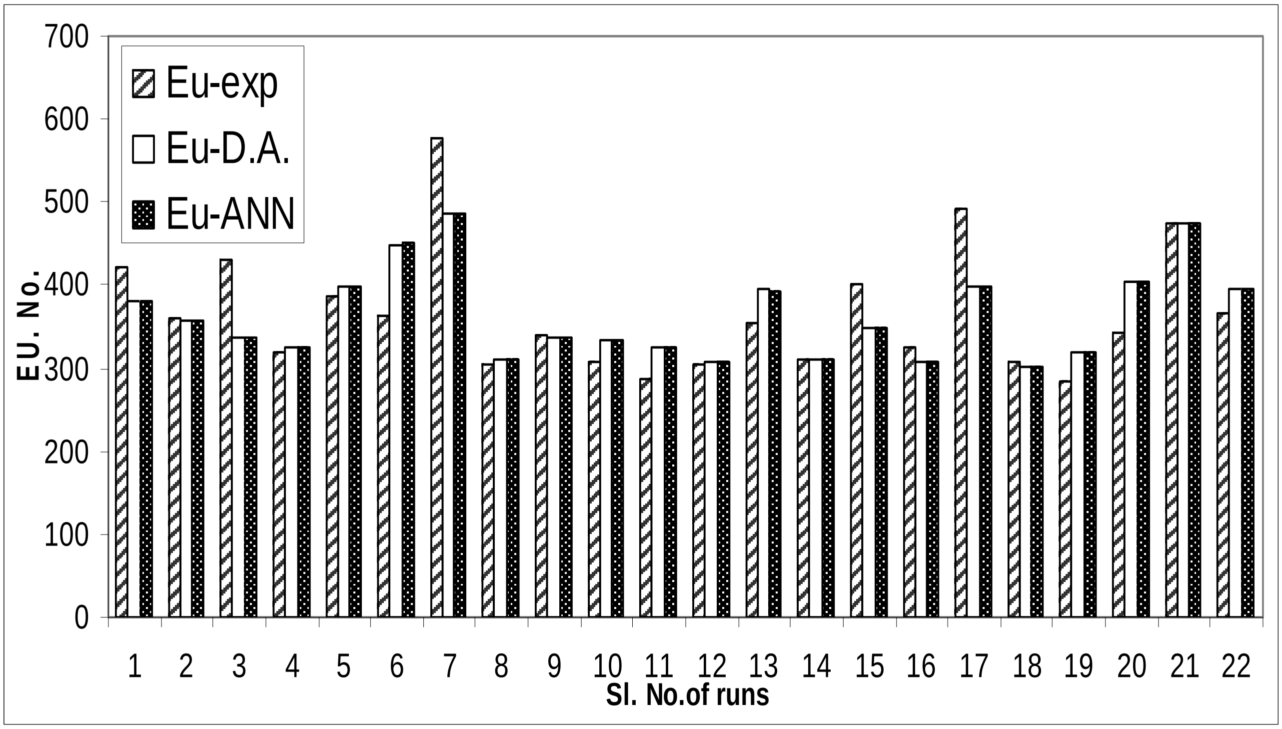
Sl. No.of runs

Fig-7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600
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400
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200
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Eu-D.A.
Eu-ANN
EU. No.
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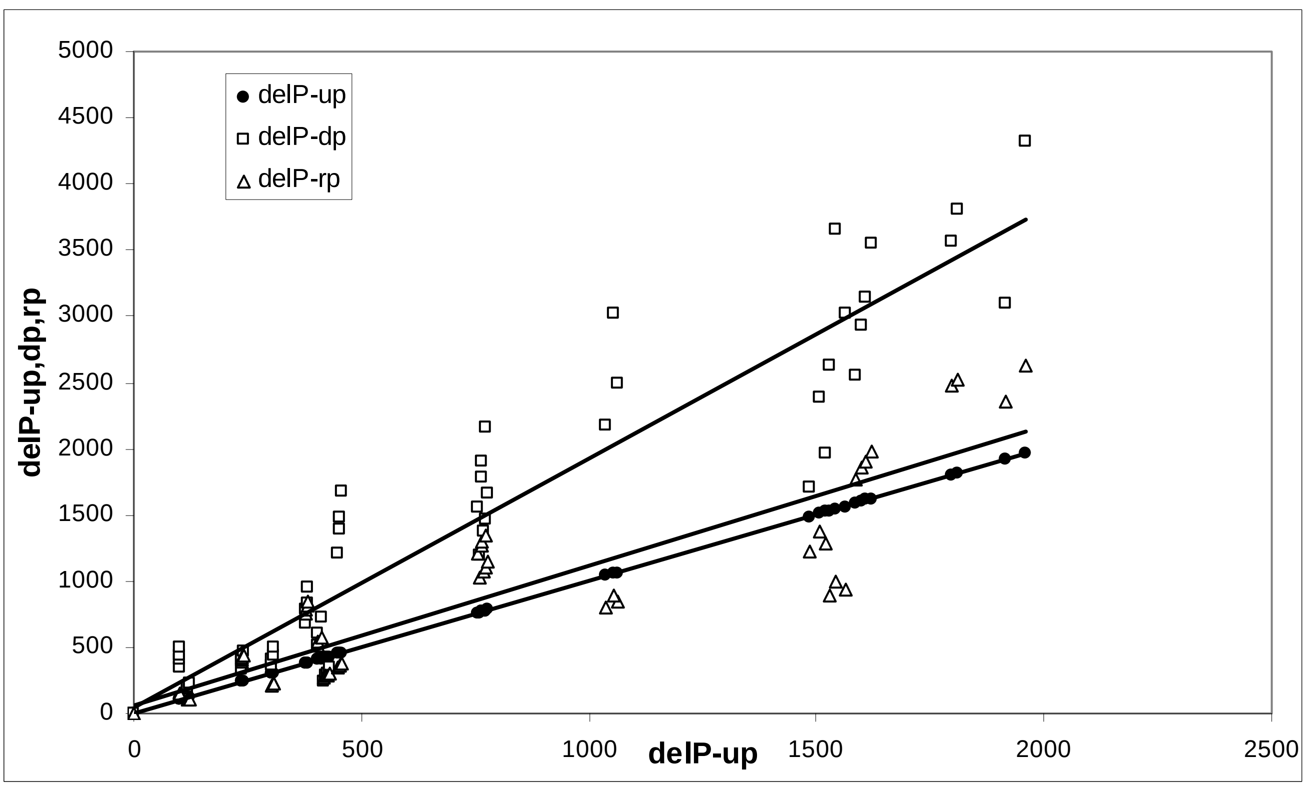
Sl. No.of runs

Fig-8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3500
3000
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2000
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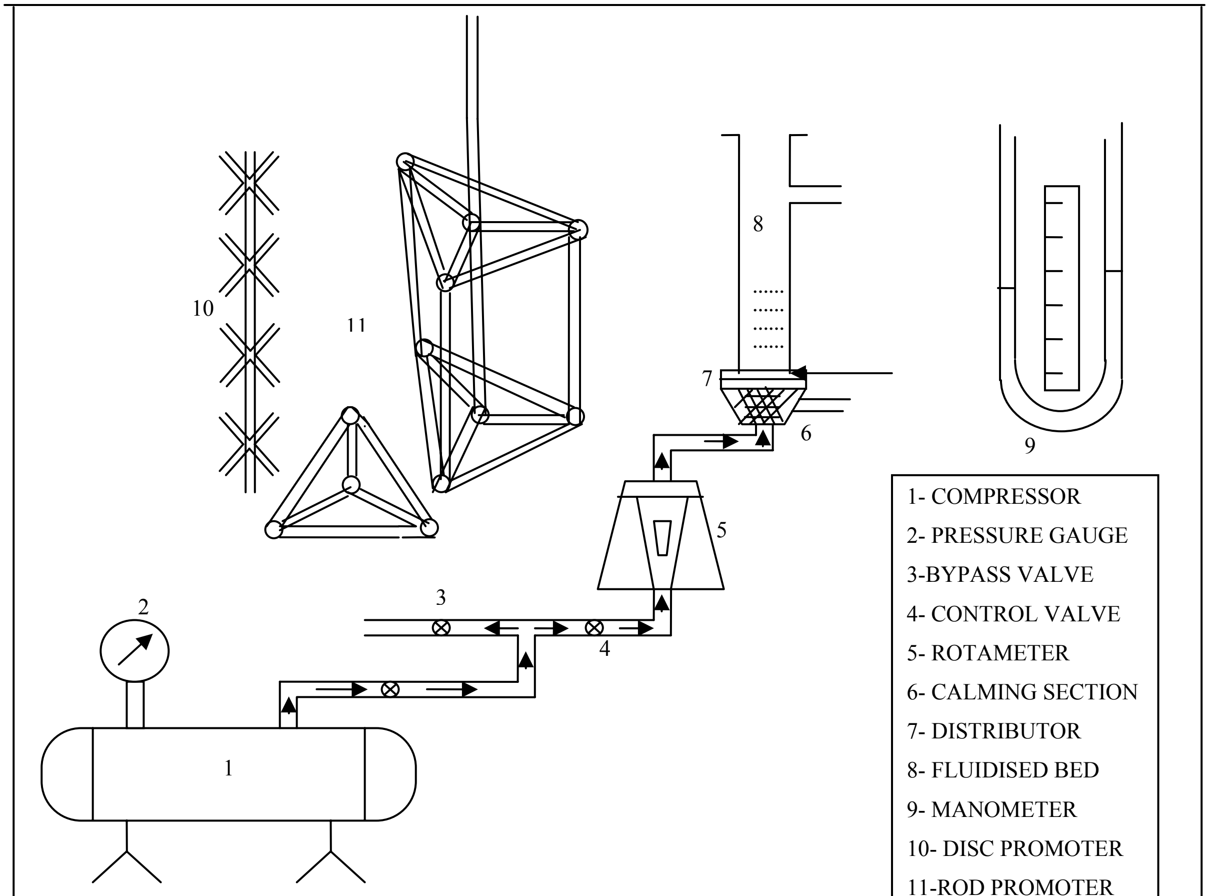
delP-up

Fig-9



10
11
8
7
6
9
5
3
2
4
1
1- COMPRESSOR
2- PRESSURE GAUGE
3-BYPASS VALVE
4- CONTROL VALVE
5- ROTAMETER
6- CALMING SECTION
7- DISTRIBUTOR
8- FLUIDISED BED
9- MANOMETER
10- DISC PROMOTER
11-ROD PROMOTER

Fig. 1

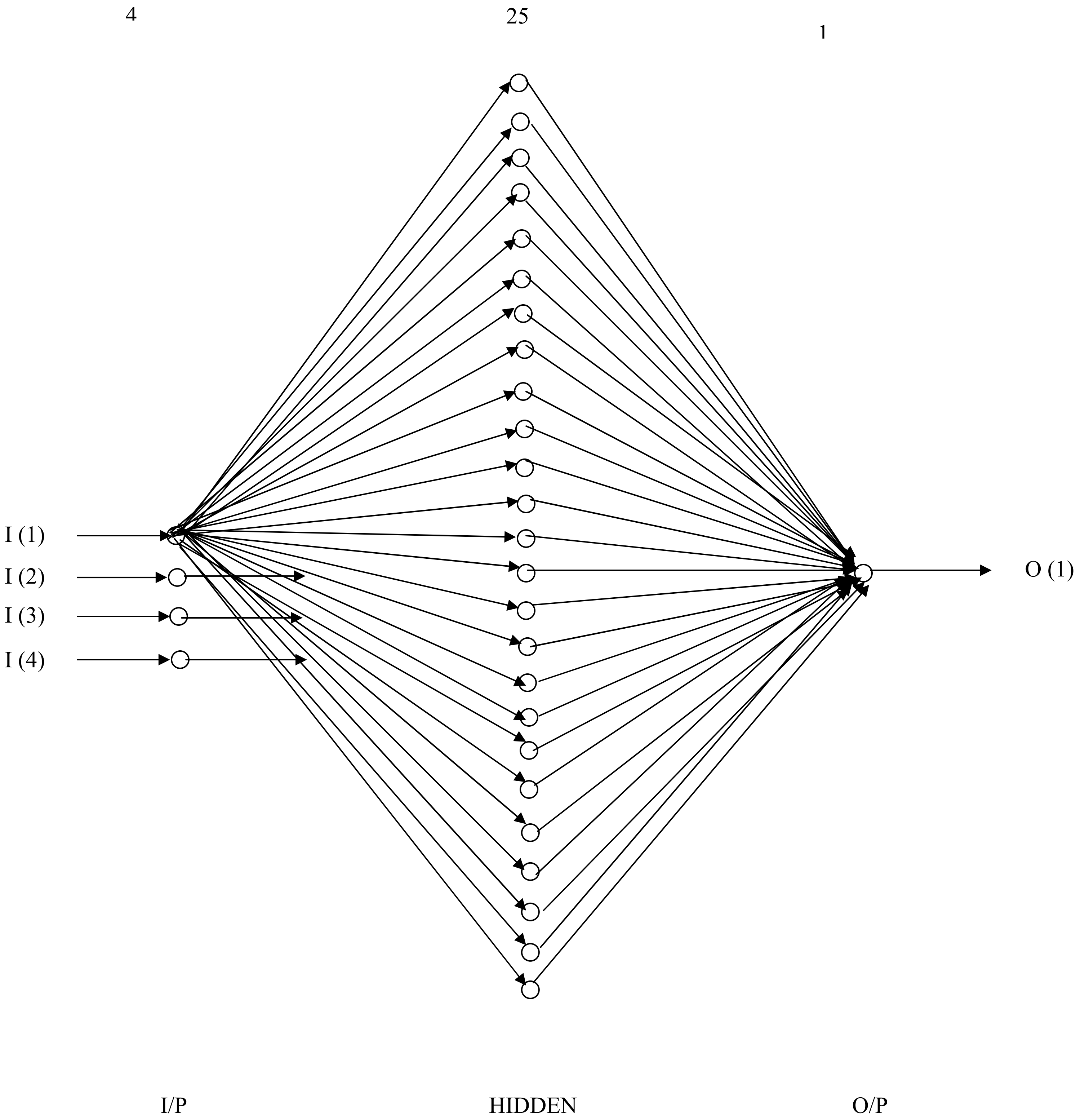


Fig-5B