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Heat Transfer Analysis for Bare Tube Immersed In Gas-Solid Fluidized Bed of Large Particles Using Artificial Neural Network

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Abstract **- This paper presents heat transfer analysis of bare tube arrangement in gas-solid (air-solid) fluidized bed of large particles such as mustard(1.1mm), raagi (1.4mm) & bajara(2.1mm) also predictions are done by using Artificial Neural Network (ANN) based on the experimental data. Within the range of experimental conditions influence of bed particle diameter (D_p), fluidizing velocity (U) were studied, which are significant parameters affecting heat transfer. It is observed that the average heat transfer coefficient increases with the increase in fluidizing velocity. Here, feed-forward architecture and trained by back-propagation technique of Artificial Neural Network (ANN) is adopted to predict heat transfer analysis found from experimental results. The network predictions are found to be in very good agreement with the experimental observed values of bare tube heat transfer coefficient (h_b) and Nusselt number of bare tube (Nu_b).**

Keywords: Fluidized bed; Heat transfer coefficient; Nusselt number.

I Introduction

Fluidized bed provide nearly isothermal environment with high rate of heat transfer to submerged objects due to thorough mixing, turbulent motion and large contact area between the gas and particles. The information available on bare tube in fluidized beds of large particles is relatively very limited. Also the information on heat transfer studies particularly in fluidized bed by artificial neural network is very limited.[1]

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation. An ANN is also called a simulated neural networks or commonly just neural networks is an interconnected group of artificial neurons and that uses a mathematical or computational model for information processing based on a connectionist approach to computation. A typical ANN consists of three layers, an input layer which takes the input variables from the problem under consideration, a hidden layer made up of artificial neurons that transform the inputs, and an output layer that stores the results. The most commonly used method for prediction in engineering is multi layer perceptrons (MLP).[7]

II Experimental set-up

The experimental facility consists of a square fluidizing column designed with provisions to install bare tube in the bed and other associated subsystems. The facility is suitably instrumented for measurement of bed pressure profile, bed temperature, surface temperature of the heat transfer tube, electrical energy supplied to heat transfer tube and air flow rate. Figure 1.1 shows the schematic of the experimental facility whose various subsystems are described in the following sections.
Air supply to the fluidized bed is from a centrifugal blower having a capacity of 850 m3/hr, which is driven by 0.746 electric motor. The blower sucks air from atmosphere and discharges from its spiral casing outlet into the delivery pipe, where a butterfly valve is provided for control of the air flow rate. The diffuser (tapering section) is provided to minimize the acceleration effects and to improve the quality of fluidization. The plenum chamber is made up of 1.5 mm thick mild steel plate and is fixed to a flange at its top end to accommodate the distributor plate.

In the present investigation, a nozzle type distributor is designed and fabricated, made of 4mm thick mild steel plate, having 24 nozzles arranged in a square array.Each nozzle with 4 holes of 3mm diameter giving an open area 1.5%. The test section consists of a square column in side 0.15 x 0.10 meters and height of 0.4 meter. One pair of opposite walls of the column is made out of 3mm thick fibre glass sheets, to facilitate visual observation, while the other two walls are made of 3mm thick mica sheets. In one of the sheets, two openings at the height of 2cm and 30cm above the distributor plate is provided to measure the bed pressure drop. On the same sheet openings are provided to accommodate thermocouples to measure the bed temperature along the bed height.

The heat transfer bare tube of length 110mm and 27.5mm outer diameter is made of brass. A 25.4mm diameter and 12.5mm diameter cartridge heater of length equal to 110mm is inserted inside the bare tube, supplies electrical heat input which is measured and controlled with a wattmeter. The ends of the heat transfer tube are fitted with nylon plugs of outside diameter 25.4mm and a thickness of 3mm to both ends to reduce axial heat loss.The bare tube heat transfer coefficient was computed from the measured heat input and the temperature of the heater tube surface by using the following relations:

hb = Qb/Ab (Tw-Tb), W/m2K

Where,
Q_b = measured bare tube heat input, in watts
A_b =surface area of bare tube, m2
T_w =heat transfer tube surface temperature,
T_b =temperature, K [1]

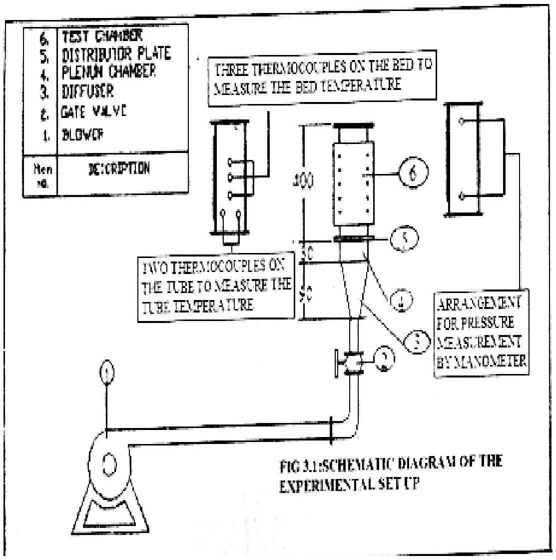

FIG 3.1:SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET UP

III Results

2.0 SINGLE BARE TUBE

PARTICLE : MUSTARD
STATIC BED HEIGHT : 80mm PARTICLE
SIZE : 1.1 mm
DIAMETER OF TUBE : 27.5 mm

Table 2.1

Sr. No.	Approach Velocity (m/s)	Heater Temperature Tw (°C)		Tw Avg. (°C)	Bed Temperature Tb (°C)			Tb Avg. (°C)	Heat Transfer Coefficient Hb (W/m^{2}K)
		T,	T2		Tbl	Tb2	Tb3		
1.	15.8	149	145	147.0	32	37	36	35.0	49.04
2.	16.3	131	28	129.5	32	36	34	34.0	57.52
3.	16.8	111	110	110.5	32	35	34	33.67	71.49
4.	17.3	99	98	98.5	31	34	33	32.67	80.15
5.	17.7	87	86	86.5	31	33	32	32.0	100.78
6.	18.2	84	82	83.0	31	33	32	32.0	107.70

PARTICLE : BAJARA
STATIC BED HEIGHT : 80mm PARTICLE
SIZE : 2.3 mm
DIAMETER OF TUBE : 27.5 mm

Table-2.2

Sr. No.	Approach Velocity (m/s)	Heater Temperature Tw (°C)		Tw Avg. (°C)	Bed Temperature Tb (°C)			Tb Avg. (°C)	Heat Transfer Coefficient Hb (W/m^{2}K)
		T,	T2		Tbl	Tb2	Tb3		
1	17.3	155	150	152.5	37	43	36	38.67	48.254
2	18.2	145	140	142.5	36	42	35	37.67	52.40
3	19.0	111	106	108.5	35	40	34	36.33	76.109
4	19.4	105	103	104	34	39	33	35.33	79.988
5	19.8	95	93	94	354	38	33	35	93.098
6	20.6	92	88	90	33	37	32	34	98.086

PARTICLE : RAAGI
STATIC BED HEIGHT : 80mm
PARTICLE SIZE : 1.3mm
DIAMETER OF TUBE : 27.5 mm

Table -2.3

Sr. No	Approach Velocity (m/s)	Heater Temperature Tw (°C)		Tw Avg. (°C)	Bed Temperature Tb (°C)			Tb Avg. (°C)	Heat Transfer Coefficient Hb (W/m^{2}K)
		T,	T2		Tb^1	Tb^2	Tb^3		
1	17.3	147	143	145	36	47	37	40	52.31
2	18.2	113	111	112	35	46	36	39	75.24
3	19.0	102	101	101.5	34	45	36	38.33	86.95
4	19.4	94	90	92	33	44	35	37.33	100.47
5	19.8	85	82	83.5	33	42	34	36.33	116.44
6	20.6	82	78	80	32	41	33	35.33	122.96

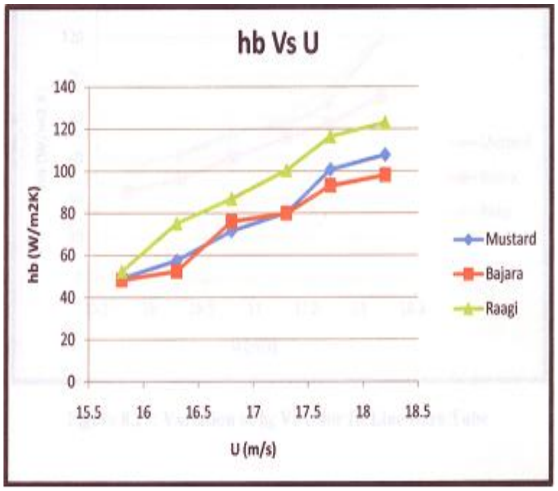

Figure 2.4: Variation of h_b Vs U for Single Tube

3.0 Single bare Tube- Comparison of experimental and predicted values in training large particles, for Heat Transfer Coefficient & Nusselt Number

Table 3.1

h(exp)	h(ann)	% error
49.04	49.0372	0.0057
57.52	57.5241	0.0071
71.49	71.4981	0.0113
80.15	80.1667	0.0208
48.25	48.2621	0.0252
52.4	52.4098	0.0187
76.1	76.1002	0.0002
79.98	79.9806	0.0007
52.31	52.3064	0.0069
75.24	75.2426	0.0034
86.95	86.9559	0.0068
100.47	100.492	0.0218

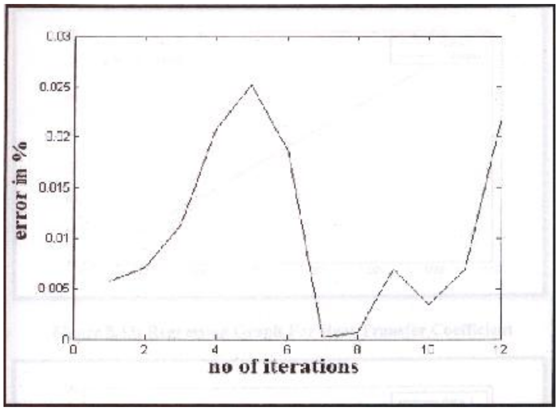

Figure 3.1: Error Graph for Heat Transfer Coefficient

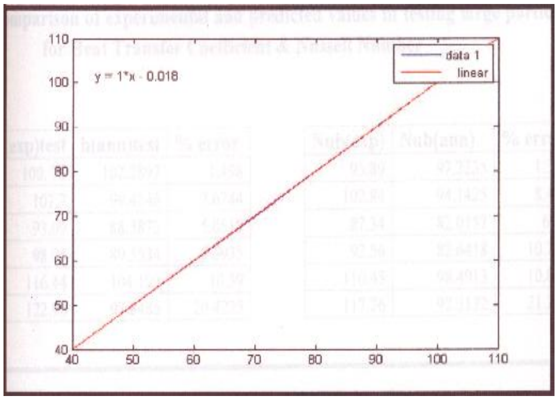

Figure 3.2: Regression Graph For Heat Transfer Coefficient

Table 3.2

Nub(exp)	Nub(ann)	% error
42.97	42.9673	0.0064
51.62	51.6227	0.0053
65.97	65.9747	0.0072
74.97	74.9808	0.0144
41.8	41.7803	0.0471
46.02	46.0129	0.0155
70.11	70.1095	0.0007
74.13	74.1304	0.0005
45.66	45.6567	0.0073
68.64	68.6417	0.0024
80.53	80.5324	0.003
94.23	94.2446	0.0155

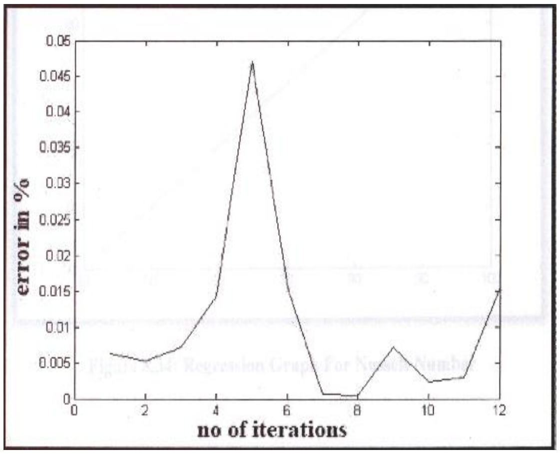

Figure 3.3: Error Graph for Nusselt Number

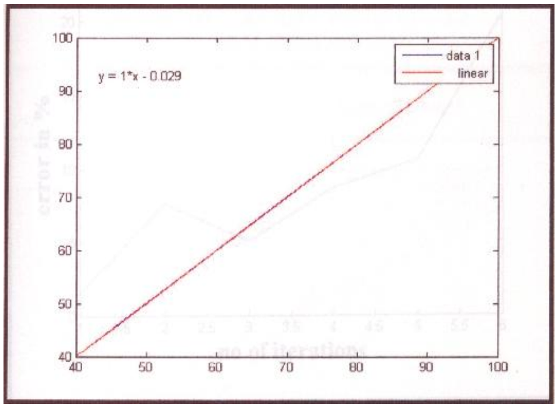

Figure 3.4: Regression Graph For Nusselt Number

4.0 Single bare Tube- Comparison of experimental and predicted values in testing large particles, for Heat Transfer Coefficient & Nusselt Number

Table 4.1

h(exp)test	h(ann)test	% error
100. 78	102.2897	1.498
107.7	99.4346	7.6744
93.09	88.3872	5.0519
98.08	89.5534	8.6935
116.44	104.109	10.59
122.96	97.8485	20.4225

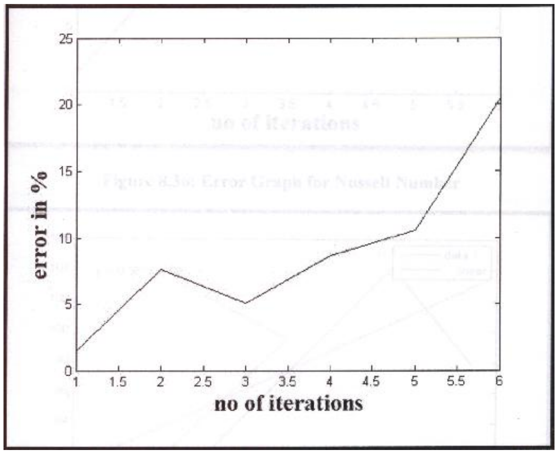

Figure 4.1: Error Graph for Heat Transfer Coefficient

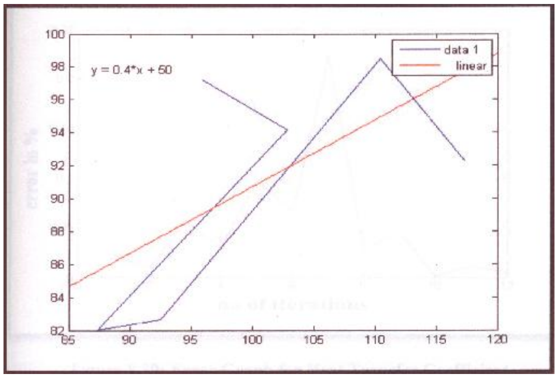

Figure 4.2.: Linear Fitting for Heat Transfer Coefficient

Table 4.2

Nub(exp)	Nub(ann)	% error
95.89	97.2235	1.3907
102.84	94.1425	8.4573
87.34	82.0157	6.096
92.56	82.6418	10.7154
110.45	98.4913	10.8272
117.26	92.3132	21.2748

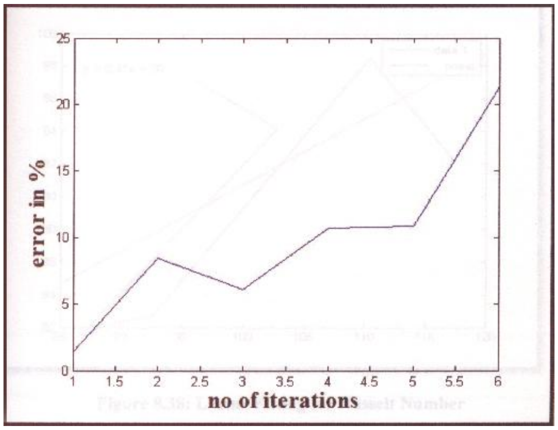

Figure 4.3: Error Graph for Nusselt Number

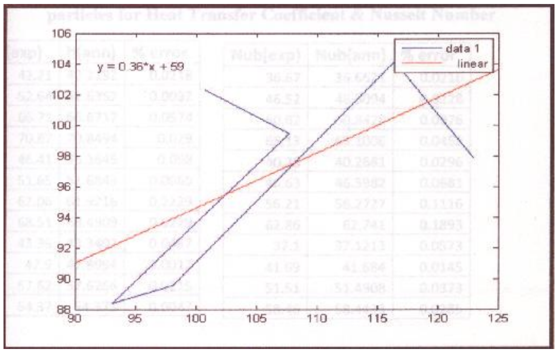

Figure 4.4: Linear Fitting for Nusselt Number

5.0 Single bare Tube- Comparison of experimental and correlated values in large particles, for Heat Transfer Coefficient & Nusselt Number

Table 5.1

h(exp)	h(corr)	% error
49.04	42.04	14.27
57.52	51.34	10.74
71.49	62.45	12.64
80.15	75.46	5.85
100.78	87.44	13.23
107.7	98.15	8.86
48.25	42.11	12.72
52.4	51.24	2.21
76.1	61.15	19.64
79.98	73.12	8.85
93.098	84.04	9.72
98.086	99.59	1.53
52.31	53.7	2.65
75.24	65.67	12.71
86.95	79.812	8.21
100.47	96.433	4.018
116.44	111.75	4.02
122.96	133.75	8.77

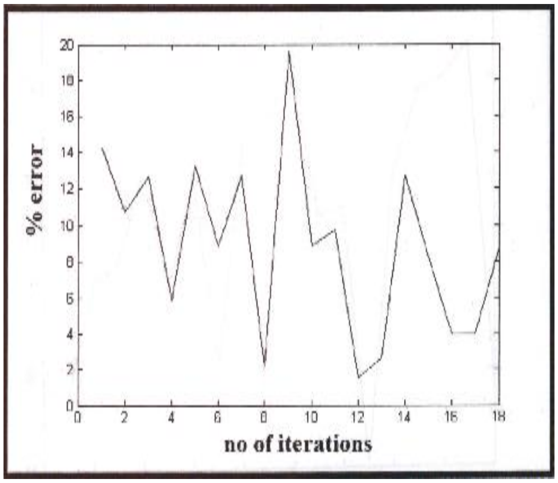

Figure 5.1: Error Graph for Single Tube For Heat Transfer Coefficient

Table 5.2

Nub(exp)	Nub (corr)	% error
42.97	38.81	9.69
51.62	47.44	8.1
65.97	57.65	12.61
74.97	69.66	7.08
95.89	80.72	15.82
102.84	96.61	6.05
41.8	38.416	8.11
46.02	46.7434	0.88
70.11	55.78	20.44
74.13	66.696	10.038
87.3488	76.66	12.236
92.5657	90.84	1.864
45.66	49.73	8.9
68.64	60.8112	11.41
80.53	73.901	8.23
94.23	89.2928	5.24
110.455	103.4834	6.311
117.263	123.8518	5.33

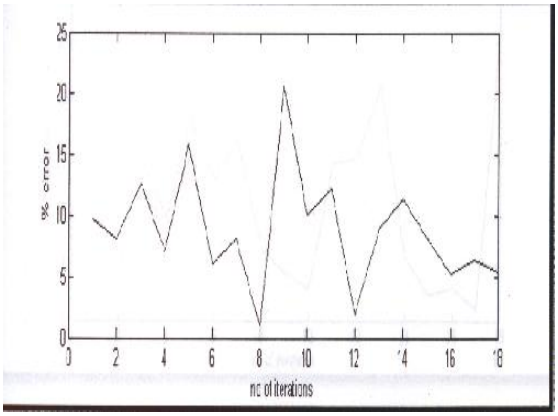

Figure 5.2: Error Graph For Single Tube For Nusselt Number

Conclusion

Heat transfer studies were conducted to obtain heat transfer parameters experimentally for single bare tube immersed in gas solid fluidized bed with air being used as the fluidizing medium at atmospheric condition in the initial stage. Also in the present study 70% of data is used for training and remaining 30% is used for testing. Performance evaluation of the network was done by regression analysis and most of the result obtained; match very well with experimental data in training and testing.

Based on the experimental data & analytical works the following conclusions were drawn:

- Keeping in view the complexity of the bubbling bed, dynamics for modeling & the need to have predictive equation for thermal design of tube bundles immersed in the gas solid fluidized bed it is advantageous to have experimentally based directly usable correlations incorporating physically meaningful & easily measurable process variable. This is true for large particles ($D_{p>}$ lmm) for which the data is scarce.
- It is observed that the average heat transfer coefficient increases with the increase in the fluidizing velocity.
- It is also observed that the curves are more flatter as the particle size increases. This behavior may be due to gradual change over from unsteady conduction mechanism of heat transfer for particle size greater than 1 mm diameter.
- A new direct correlations for Nusselt number using only easily measurable variables are presented as:

SINGLE BARE TUBE -

MUSTARD :

$$Nub = (1.511 * 10^{-7}) * [(U-Umf)/Umf]^{(1.3746)} * [(Pg * u * Dt)/\mu g^{(5.0740)} * [Ar]^{(-39709)} * [Pr]^{0.3}$$

BAJARA :

$$Nub = (7.24 * 10^{-3}) * [(U-Umf)/Umf]^{(-13.7641)} * [(pg * u * Dt)/\mu g]^{(19.8925)} * [Ar]^{(-896139)} * [Pr]^{03}$$

RAAGI:

$$Nub = (9.128 * 10^{-3}) * [(U-Umf)/Umf]^{(4-4270)} * [(pg * u * D,)/ \mu g]^{(2.0200)} * [Ar]^{(-3.8075)} * [Pr]^{03}$$

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