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Effect of Flow Rate, Temperature and Shape of packed bedon The Pressure Drop in Multi-Phase Flow Systems

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Abstract

The aims of the present research study the pressure drop and the parameter that effect on it in the two type of multi-phase upward flow system (fixed bed and fluidized bed) and used the solids as dense phase such as glass beads with diameter 6 mm and Rashing ring with 6 mm equivalent diameter and distilled water as moving phase with change in temperature of moving phase for four-level (20, 30, 40 and 50)℃.

Used design of experimental to give the all conditions of the experimental runs and carried out in experimentally in the cylindrical column made from Perspex with 5 cm ID and 6 cm OD and 1m length with two holders one put in the basic of packed bed and another used to prevent the particles from carried out with moving phase in the fluidized bed and used to make the bed in stationary state in the fixed bed. Where fixed on the wall of the column six pressure sensor transducer put the first at the basic of the packed bed and each 10 cm put the other one for six sensors and connected to the Arduino cart and used LabVIEW program to display and save the data of pressure sensors readings.

And the experimental result of fluidized bed comparewith the fixed bed and it was observed the pressure drop effect by the change in the shape of dense phase and temperature of moving phase, where the pressure drop decrease with increase in diameter of dense phase also decrease with change in the shape from sphere to Rashing ring and increase with increase in temperature.

To make sure the data taken from the experimental work makes validation with many theoretical equations and empirical design model and gives a good agreement.

Keyword: pressure drop, shape, and temperature, multi-phase

1 Introduction

The multi-phase flow system was discovered in the early 1920s and used first one in 1923 by Germany in gasification industrial and after that used in different fields of industrial such as used for catalytic cracking and refinery process because it gives high surface area for contact between dense and moving phase and good heat transfer to prevent the catalyst from coke by effect of heat and used in this flied in 1926 [1][2],in 1937 also used to produce the gasoline from petroleum refinery and from other sources such as natural gases[3],and used in other sectors such as heat exchanger, ion exchange, synthesis reactions[4][5].

The fluidized bed system has special advantage not available in fixed bed is moving bed to give more surface area and good heat transfer coefficient and used this advantage for more applications such as separation of particles in the binary mixture of packed bed and, the particles separate when the bed start to moving and use for mixing processes and also illustrate from the moving of packed bed to use in the dray process and remove the wet from bed

March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

[5][6][7][8].Fluidization is not limitedto use for engineering industrial also using in the Pharmaceutical Industries where used for purifications and decontaminations [6][7][8]. Used in German, united states and chainindustries [9].

because of the increase in the industrial areas which used the fluidized bed system push the researchers toward search and developments of fluidized bed system design, scale-up, control procedures, and operating measurements. Fluidized bed system has more advantage such as give minimum energy consumption from another type of two-phase packed bed systems such as fixed bed, maximum product quality, easy for operation condition and low impact environment [10]. **Sabbiergun, el at.** [11]studied the effect of porosity and viscosity and superficial velocity if liquid on pressure drop, shown the pressure drop increase with increase in liquid superficial velocity and decrease with increase in liquid viscosity and porosity.**Mogan, el at.**[12]studied the effect of velocity on porosity and the effect of porosity on pressure drop in a fluidized bed. It was observed the increase in liquid velocity leads to increase in porosity and increase in porosity leads to decrease in the pressure drop.**Murch, el at.**[13]studied the effect of Reynolds number on the pressure drop in spherical packed bed in fixed system with used different correlation equations and show the pressure drop increase with increase in Reynolds number, and this increase linearly experimentally and theoretically for some correlations such as Ergun, Hanley, Heggs. **Foscolo, el at.**[14]studied the tortuosity in the randomly packed bed and show experimentally the tortuosity for random packed bed mono-size system it is a function of porosity were increasing in porosity leads to a decrease in tortuosity. observed the pressure drop increase with increase in tortuosity $\Delta p \; \alpha \; \tau$.**Mamoru Ozawa, el at.** [15]studied the effect of particles size on drag force, showexperimentally the effect of particle size on the drag force and proved the drag force increases with an increase in the particle size. **Wugeng Liang, el at.**[5]studied the circulating fluidized bed and proved this system is cannot be assumed as a homogenous bed because there is more change in the radial flow.**Dong Hyun Lee** [7] **studied** the effect of liquid superficial velocity on pressure drop in fluidized bed and it was observed the pressure drop increase with increasing in liquid superficial velocity until reach the maximum value of pressure drop when the buoyancy force of water equal to the weight of bed and the superficial velocity called minimum fluidization velocity and after this point the pressure drop decrease with increase in liquid superficial velocity and become nearly constant.**Guadalupe Ramos Caicedo, el at** [16]studied the minimum fluidization velocity with a different experimental condition such as a change in the height of the bed and used different particles sizes. Observed the minimum fluidization velocity was found to be a function of bed weight and particles diameter or $(\frac{D}{d_p})$ ratio.**Makkawi, el at.** [17]studied the drag force in two conventional fluidized bed systems difference in diameter of packed bed by using electrical capacitance technology and show the drag forces depend on the particle Reynolds number and special the drag force a function of the weight of the particles.**Bing Du, el at.** [18]studied the effect of temperature on the multi-phase flow system and show the system becomes more homogenously with an increase in temperature from the ambient temperature because the time hold up of particles in the emulation decrease so that leads to more mixing and improve the quality of fluidization process with an increase in temperature of the system. Also, the bubble size decreases with increase in temperature for the gases system.

1.1 Hydrodynamic Properties

1.1.1 Pressure Drop

The source of pressure drop in this system isan interaction that occurs between the working fluid and packed bed and particle with a particle inside the packed bed as well as the interaction of particles with the wall of the column.

TEST Engineering & Management
March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

Pressure drop in two-phase packed bed systems calculated in the fixed state by the Ergun equation(1)[9]and Levenspiel [2]equation(3) as shown below consecutively

$$\frac{\Delta p}{l_m} = 150\frac{(1-\epsilon_m)^2}{{\epsilon_m}^3}\frac{\mu_f u_s}{(\emptyset p\, d_p)^2} + 1.75\frac{(1-\epsilon_m)}{{\epsilon_m}^3}\frac{\rho_f {u_s}^2}{\emptyset_p d_p} \quad (1)$$

$$\frac{\Delta p_{fr}}{l_m} = 150\frac{(1-\epsilon_m)^2}{{\epsilon_m}^3}\frac{\mu\, u_s}{(\emptyset p\, d_p)^2} + 1.75\frac{(1-\epsilon_m)}{{\epsilon_m}^3}\frac{\rho_f {u_s}^2}{\emptyset_p d_p} \quad (2)$$

$$\Delta p_{\text{calculated}} = \Delta p_{fr} \pm \frac{\rho_f\, l_m}{g_c} \quad (3)$$

And there are many research used another form for Ergun equation such as Akhil Rao el at.[22]used the formula

$$-\frac{\Delta p}{l_m} = bu_s + a{u_s}^2 \quad (4)$$

Where

$$a = 1.75\frac{(1-\epsilon_m)}{{\epsilon_m}^3}\left(\frac{\rho_f}{\emptyset_p d_p}\right)(5) \qquad b = 150\frac{(1-\varepsilon_m)^2}{{\epsilon_m}^3}\left(\frac{\mu_f}{{\emptyset_p}^2{d_p}^2}\right) \quad (6)$$

And Robert K. Niven[23]used the Ergun equation un another term by the sum of two terms: a vicious energy loss term, proportional to the fluid velocity, and an inertial loss (kinetic energy) term, proportional to the velocity squared,

$$\frac{\Delta p}{l_m} = au_s + b^2{u_s}^2 \quad (7)$$

Where for monosized spheres the viscous and inertial regime coefficients become

$$a = 150\frac{\mu_f}{{d_p}^2}\frac{(1-\epsilon_m)^2}{{\epsilon_m}^3}(8), \qquad b = \sqrt{1.75\frac{\rho_f}{d_p}\left(\frac{1-\epsilon_m}{{\epsilon_m}^3}\right)} \quad (9)$$

for fluidization state by the fluidization equation as shown below[2]

$$\frac{\Delta p}{l_{mf}} = (1-\epsilon_{mf})[(\rho_p - \rho_f)\, g] \quad (10)$$

1.1.2 *Average Porosity*

calculated the porosity experimental by using the method of the two measuring cylinders and in theoreticalmethodcalculate the porosity by using the equation below [24].

$$\epsilon_m = \frac{volume\ of\ the\ voidge}{volume\ of\ the\ inter\ bed} \quad (11)$$

And this equation become

$$\epsilon_m = \frac{\pi\ R^2 l_m - \frac{weight\ of\ all\ particales}{particle\ density}}{\pi\ R^2 l_m} \quad (12)$$

2 Experimental Work

The date of pressure drop and of the velocities taken experimentally by using a system made from two-part first called ring part where consist from tank, heater, pump flow meter, test section, and second called electrical part where consist from pressure sensors transducer,Arduino cart,andLabVIEW programs. as shown in the description below.

March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

Figure 1 Experimental rig

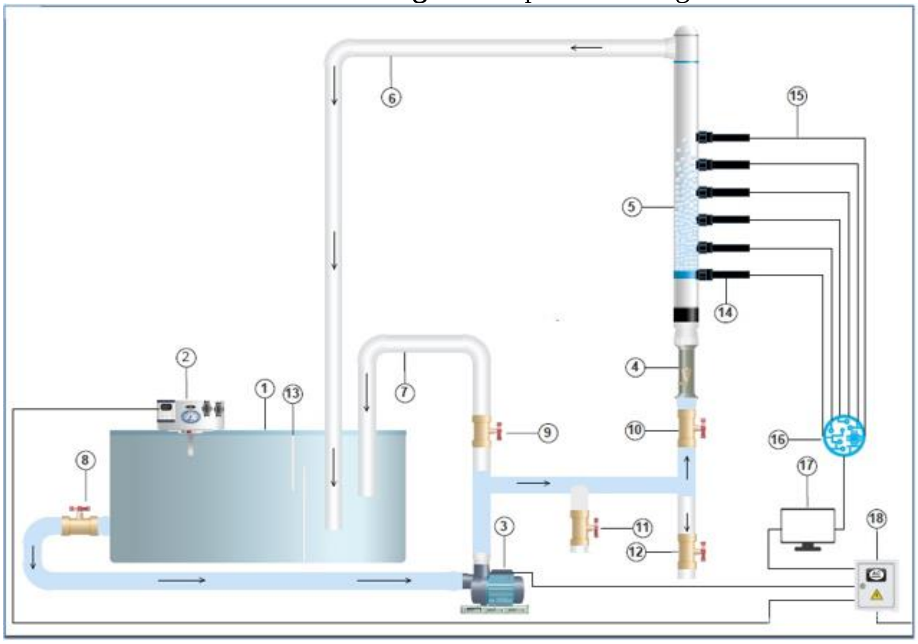

Figure 2 Schematic diagram of the experimental rig

Table 1 Definition of the parts of the experimental ring

NO	name	NO	name
1	Recycle tank controller	10	Flow rate controller valve
2	Heater controller	11	Drain valve
3	pump	12	Drain valve
4	Flowmeter	13	baffle
5	Test section	14	Pressure sensor transducer
6	Main recycle	15	Wire connection
7	Secondary recycle	16	Arduino cart
8	Feed valve	17	computer
9	Recycle controller valve	18	Electrical source

2.1 The Experimental Procedure

Fill the Recycle tank controller with water and a just the working temperature by heater controller and after reach the study state pumped the water from recycle tank controller to flow meter by pump and a just the working flow rate by the Flowmeter and inter the water to the test section and running the Lab View to display the data of pressure drop that take form pressure sensors and began to save this data in computer and the recycle controller valve using to control on the water excess that pumped by pump and return to the tank and the two drain valves using to empty the system at end of experimental work.

3 Result and Conclusion

3.1 Average Porosity

3.1.1 Effect of Different particles Shape on Average Porosity

In order to study the effect of particles shape on average porosity, chose two different packed bed sphere and Rashing ring and equal in the otherparameters such as material, diameter, and height of bed, it is has been observed the Rashing ring packed bed has more porosity from sphere packed bed, that due to the shape of Rashing ring give more voidages and spaces at packing than the sphere packing.

Packed bed	Fixed state	Fluidization state
6 mm sphere	0.4	0.433
6 mm Rashing ring	0.5	0.63

3.2 pressure Drop

3.2.1 Effect of Water Flow Rate on Pressure Drop

Two packed bed were selected (6mm Rashing ring and 6 mm sphere) for study the effect of water flow rate on the pressure drop as shown below.

March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

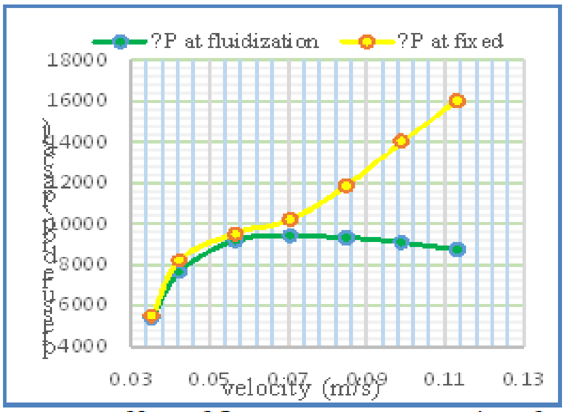

Figure 1 Effect of flow rate on pressure drop for 6 mm sphere

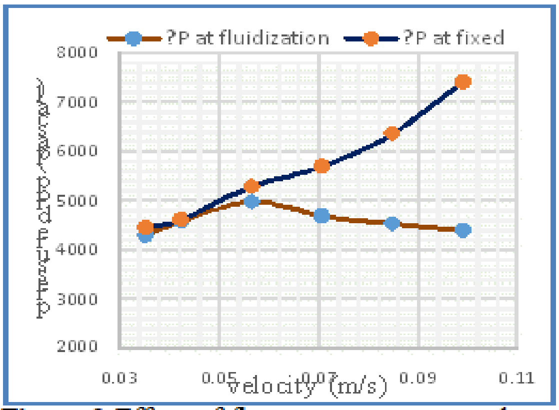

Figure 2 Effect of flow rate on pressure drop for 6 mm Rashing ring

Figure 2 and 3 show the effect of water flow rate on pressure drop, it has been observed the pressure drop increase with increase in water flow rate in fixed bed and that due to the sources of pressure drop increase with increasing in water flow rate such as the interaction between the water flow rate and particles of bed, particles with particle and makes more eddy, and all this leads to increase in pressure drop

And in fluidized bed the behavior of pressure drop differs from than fixed bed, the pressure drop increase with increase in water flow rate in the two states fixed and expansion state when the buoyancy force of water less or equal to the weight of bed and the reason of increase in pressure drop as mentions above. When the buoyancy force become more than the weight of bed and inter in the fluidization state the pressure drop decreasing and increase in the decreasing with increase in the water flow rate until become nearly constant and that due to the porosity of fluidized bed increase in the fluidization state and increase in porosity leads to reduce the main source of pressure drop (friction factor) and that mean the water passes through more voidage and spaces between the particles and leads to decrease in pressure drop.

3.2.2 Effect of Water Temperature on Pressure Drop

Four levels of water temperature were selected(20, 30, 40, 50°C)to known the effect of temperature on pressure drop.

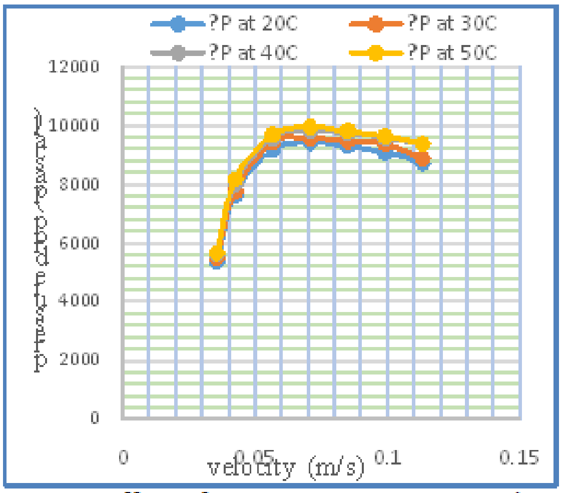

Figure 1effect of temperature on pressure drop for 6 mm sphere at fluidized bed

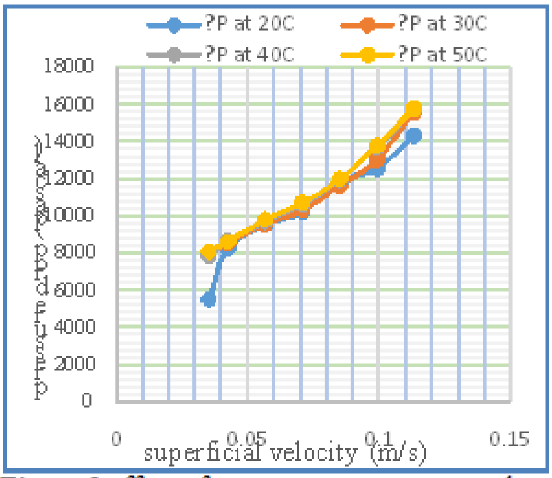

Figure 2 effect of temperature on pressure drop for 6 mm sphere at a fixed bed

March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

Figure 4 and 5display, in general, the pressure drop increase with increase in level of water temperature for fixed and fluidized bed, the physical properties of water viscosity and density affected by change in temperature and decrease with increase in temperature and the reduce in this physical properties leads to reduce in the buoyancy force of water . so need to increase in water flow rate to compensate for the loss in buoyancy force and that leads to increase in sources of pressure drop. As shown in figures above the change in pressure drop low with change in temperature because the change in temperature has low effect on the physical properties of water.

3.2.3 Effect of Particles Shape on the Pressure Drop

In order to study the effect of shape on pressure drop, it has been chosen 6 mm glass Rashing ring and 6 mm glass sphere at 20°C water temperature

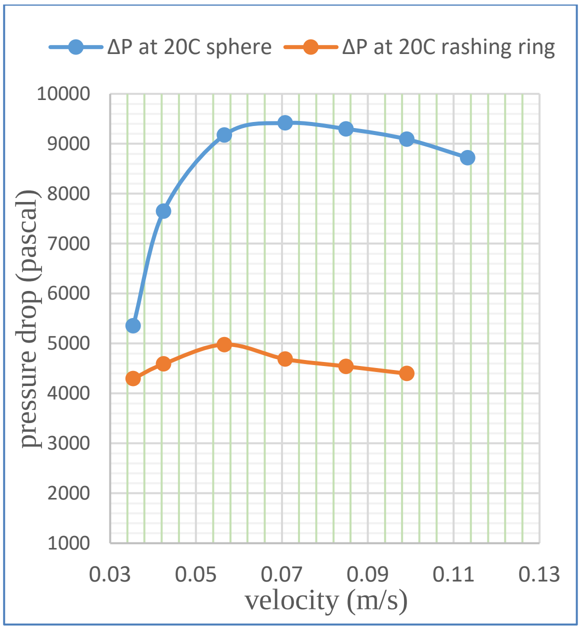

Figure 3 effect of different shape on pressure drop at fluidized bed at 20°C

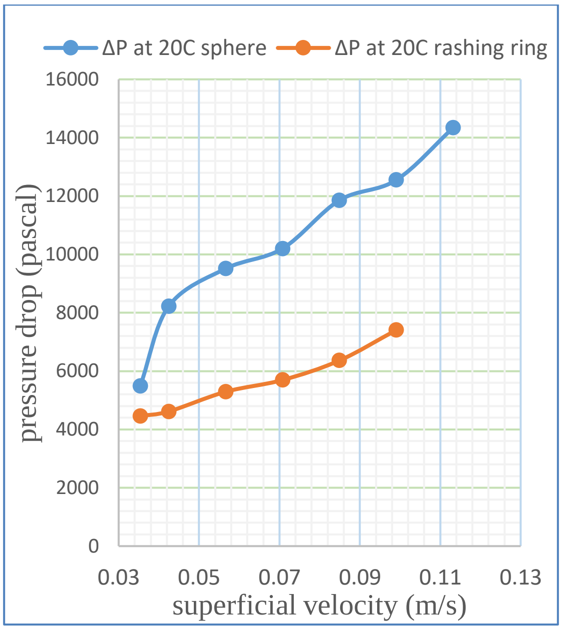

Figure 4 effect of different shape on pressure drop at a fixed bed at 20°C

Figure 6 and 7 show the pressure drop increase with change in shape from Rashing ring to sphere that due to the Rashing ring has more voidage and spaces and has more tortuosity and packing from sphere packing and that allows for water to passes through more porosity and that means the Rashing ring has less friction factor and interaction and eddy and that leads to decrease in pressure drop. In fluidized bed the maximum pressure drop in Rashing ring shape packed bed was (4979.597 Pascal) will in spherical shape packed bed was (9418.012 Pascal). In fixed bed, the maximum pressure drop for Rashing ring (7408.443 Pascal) and for spherical packed bed at the same flow rate is(12551.03 Pascal).

4 Validation

To determine the accurse of the data which take off from the experimental work make validation with the other source can be given the data such as theoretical equations, analysis programs or by simulation programs, and make the error percentage must be in the acceptable range where below 25%[2].

TEST Engineering & Management
March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

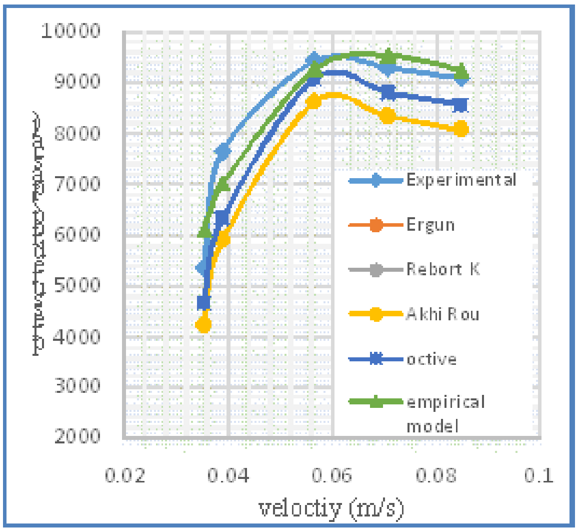

Figure 1 Validation of pressure drop for 6mm at 20?

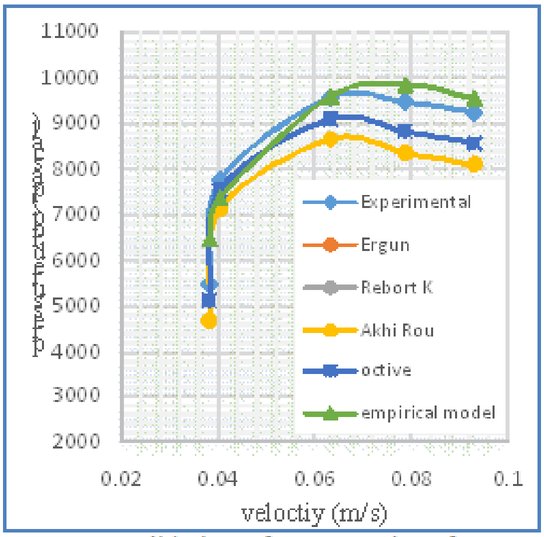

Figure 2 Validation of pressure drop for 6mm at 30?

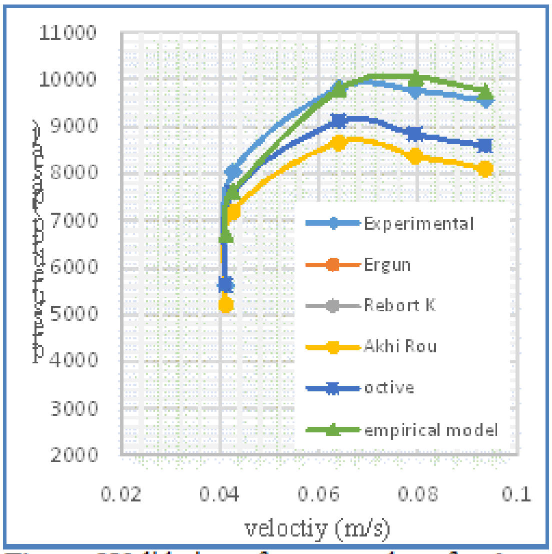

Figure 1 Validation of pressure drop for 6mm at 40?

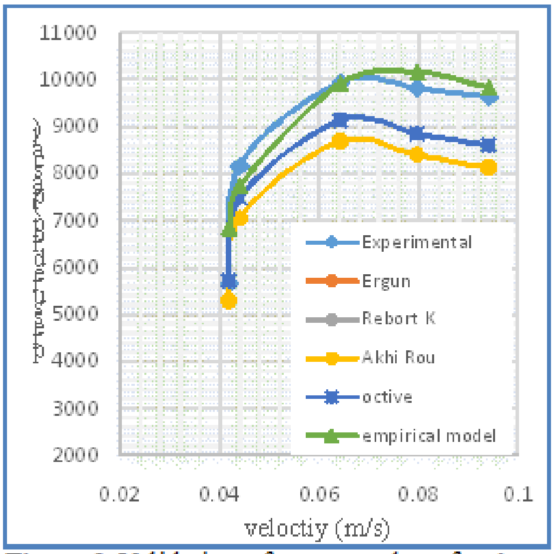

Figure 2 Validation of pressure drop for 6mm at 50?

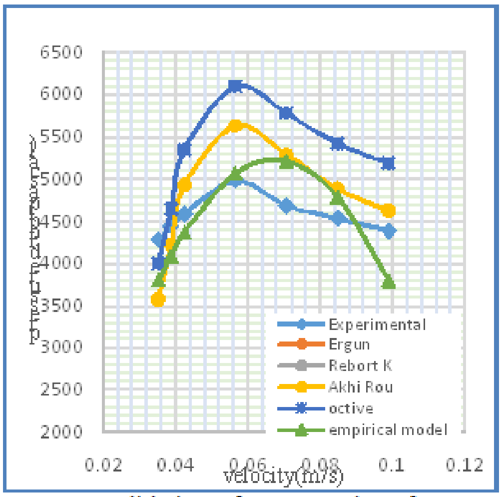

Figure 1 Validation of pressure drop for 6mm Rashing ring at 20?

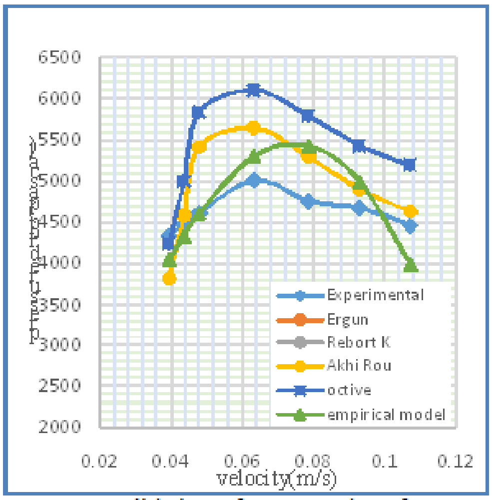

Figure 2 Validation of pressure drop for 6mm Rashing ring at 30?

March - April 2020
ISSN: 0193-4120 Page No. 7256 - 7266

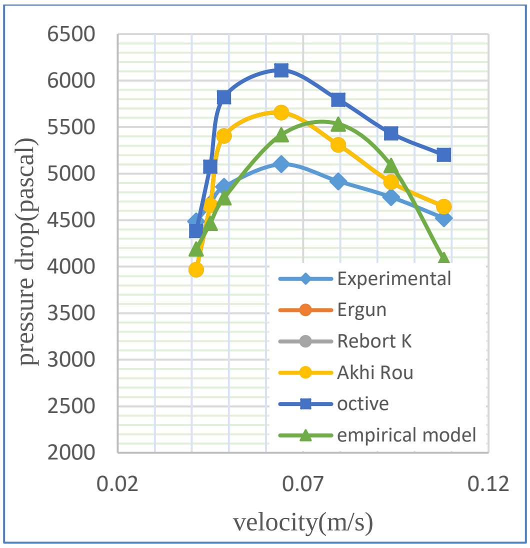

Figure 5 Validation of pressure drop for 6mm Rashing ring at 40℃

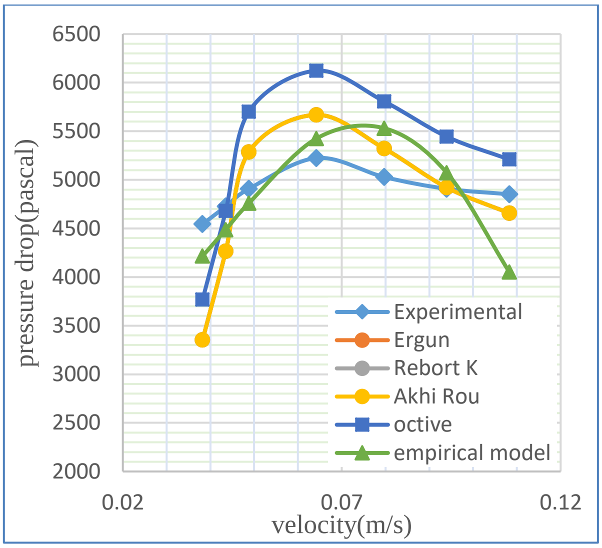

Figure 6 Validation of pressure drop for 6mm Rashing ring at 50℃

5 Conclusions

1. Pressure drop in general in the fixed bed system larger than in the fluidized bed system.
2. Pressure drop increases with the increase in flow rate at the fixed bed and also increase in a fluidized bed at the fixed state and reach the maximum value at the expansion state and after that decrease with increase in flow rate.
3. Pressure drop decrease with the change in the shape of packed bed at on case of the second shape has more spacing from the first shape at packing in the column.
4. Pressure drop has low increase with the change in temperature of the water.

Notation

Symbols	**notations**	**units**
Δp	= Pressure drop	[Pascal]
Δp_{fr}	= Frictional pressure drop	[Pascal]
l_m	= Fixed bed initial height	$[m]$
l_{mf}	= Expansion bed height	$[m]$
ϵ_m	= Average Fixed bed porosity	…
ϵ_{mf}	= Average Fluidized bed porosity	…
d_p	= particle diameter	$[m]$
$d_{p,eqv.}$	= Equivalent particle diameter	$[m]$
μ_f	= Working fluid viscosity	$[{}^{kg}/_{m\ s}]$
ρ_f	= Working fluid density	$[{}^{kg}/_{m^3}]$
ρ_p	= Particle density	$[{}^{kg}/_{m^3}]$
u_s	= Working fluid superficial velocity	$[{}^{m}/_{s}]$
u_{mf}	= Minimum fluidization velocity	$[{}^{m}/_{s}]$
$Q^{\cdot}$	= Working fluid Volumetric flow rate	$[{}^{m^3}/_{s}]$
A_c	= Test section Cross sectional area	$[m^2]$
D	= Diameter of test section	$[m]$
V_P	= Volume of particle	$[m^3]$
Re	= Reynolds number	…

Re_p	= Particle Reynolds number	...
$Re_{p,mf}$	=Particle Reynolds number at minimum fluidization condition	...
g	= Gravity	$[^m/_{s^2}]$
$\emptyset_p$	= Sphericity	...

6 References

[1] R. Di Felice and L. G. Gibilaro, “Wall effects for the pressure drop in fixed beds,” *Chem. Eng. Sci.*, vol. 59, no. 14, pp. 3037–3040, 2004.

[2] D. Kunii and O. Levenspiel, *fluidization engineering*. London, 1991.

[3] C. Tang, M. Liu, and Y. Li, “Experimental investigation of hydrodynamics of liquid-solid mini-fluidized beds,” *Particuology*, vol. 27, pp. 102–109, 2016.

[4] T. T. Hansen and S. B. A. Y. Jorgensen, “Optimal Control of Binary Batch Distillation in Tray or Packed Columns,” *Chemical Erzgrneerzng J.*, vol. 33, pp. 151–155, 1986.

[5] W. Liang *et al.*, “Flow characteristics of the liquid-solid circulating fluidized bed,” *Powder Technol.*, vol. 90, no. 2, pp. 95–102, 1997.

[6] S. Khan *et al.*, “Expansion Behaviour of a Binary Solid-Liquid Fluidised Bed with Different Solid Mass Ratio,” *Adv. Powder Technol.*, vol. 28, no. 12, pp. 3111–3129, 2017.

[7] D. H. Lee, “Transition Velocity and Bed Expansion of Two-Phase (Liquid-Solid) Fluidization Systems,” *Korea Adv. Inst. Sci. Technol.*, vol. 18, no. 3, pp. 347–351, 2001.

[8] S. Limtrakul, J. Chen, P. A. Ramachandran, and M. P. Dudukovi, “Solids motion and holdup profiles in liquid fluidized beds,” *Chem. Eng. Sci.*, vol. 60, pp. 1889–1900, 2005.

[9] Z. Yongmin, C. Lu, and M. Shi, “A Practical Method to Estimate the Bed Height of a Fluidized Bed of Fine Particles,” no. 12, pp. 1735–1742, 2008.

[10] D. Escudero and T. J. Heindel, “Bed height and material density effects on fluidized bed hydrodynamics,” *Chem. Eng. Sci.*, vol. 66, no. 16, pp. 3648–3655, 2011.

[11] S. Ergun and A. A. Orning, “Fluid Flow through Randomly Packed Columns and Fluidized Beds,” *Ind. Eng. Chem.*, vol. 41, no. 6, pp. 1179–1184, 1949.

[12] J. P. Mogan, R. W. Taylor, and F. L. Booth, “A method of prediction of the porosities of high-pressure gaseous fluidization systems,” *Can. J. Chem. Eng.*, vol. 47, no. 2, pp. 126–130, 1969.

[13] R. E. Murch, “Pressure Drop in Packed Beds of Spheres Different,” vol. 9, no. 3, pp. 500–502, 1970.

[14] P. U. Foscolo, L. G. Gibilaro, and S. P. Waldram, “A unified model for the particulate expansion of fluidized beds and flow in fixed porous media,” *Chem. Eng. Sci.*, vol. 38, no. 8, pp. 1251–1260, 1983.

[15] M. Ozawa, H. Umekawa, T. Matsuda, N. Takenaka, M. Matsubayashi, and A. Tsuruno, “Large Particle Movement and Drag Coefficient in a Fluidized Bed.,” *heat transfer*, vol. 26, no. 1. pp. 54–67, 1997.

[16] G. R. Caicedo, M. G. Ruiz, J. J. P. Marque´s, and J. G. Soler, “Minimum fluidization velocities for gas-solid 2D beds.pdf,” *Chem. Eng. Process.*, vol. 41, no. 9, pp. 761–764, 2002.

[17] Y. T. Makkawi and P. C. Wright, “The voidage function and effective drag force for fluidized beds,” *Chem. Eng. Sci.*, vol. 58, no. 10, pp. 2035–2051, 2003.

[18] B. Du, W. Warsito, and L. S. Fan, “Bed nonhomogeneity in turbulent gas-solid fluidization,” *AIChE J.*, vol. 49, no. 5, pp. 1109–1126, 2003.

[19] D. C. Sau, S. Mohanty, and K. C. Biswal, “Minimum fluidization velocities and maximum bed pressure drop for gas-solid tapered fluidized

beds," *Chem. Eng. J.*, vol. 132, no. 3, pp. 151–157, 2007.

[20] M. K. Karmakar, C. Loha, S. De, and P. K. Chatterjee, "Hydrodynamics of Circulating Fluidized Bed Systems," *Coal Biomass Gasif.*, vol. 13, pp. 93–114, 2018.

[21] W. Zhong, B. Jin, Y. Zhang, X. Wang, and R. Xiao, "Fluidization of biomass particles in a gas-solid fluidized bed," *Energy and Fuels*, vol. 22, no. 6, pp. 4170–4176, 2008.

[22] A. Rao, J. S. Curtis, B. C. Hancock, and C. Wassgren, "The Effect of Column Diameter and Bed Height on Minimum Fluidization Velocity," *Alche*, vol. 56, no. 9, pp. 2304–2311, 2010.

[23] R. K. Niven, "Physical insight into the Ergun and Wen and Yu Equations for Fluid Flow in packed," *Chem. Eng. Sci.*, vol. 57, pp. 527–534, 2002.

[24] C. J.geankoplis, *transport process and unit operations*, Third. Canada, 1993.