Effect of Twisted Tape Baffles on Pressure Drop, Fluctuation and Expansion Ratios in gas - Solid Fluidized Bed

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ABSTRACT: *In the present work an attempt has been made to study the effect of the twisted tapes as bed internals, on the performance of the gas-solid fluidized beds. Experimental investigation has been carried out in cylindrical column with and without twisted tapes. Twelve numbers of twisted tapes of three different widths with four values of the twist ratios for each width were studied at different static bed heights. Twist ratio (y) is the ratio of axial distance for* 180^0 *rotation of the tape (H) and the width (W) of the twisted tape. By using twisted tape the change in pressure drop, fluctuation ratio and expansion ratio have been studied as compared to "without twisted tape". Incorporation of twisted tapes as baffle decreases the fluctuation ratio and expansion ratio thereby improving the fluidization quality as compared to the "without twisted tape". However the increase in pressure drop due to presence of twisted tape is only marginal and of the order of, 5.25 to 14.9 percent over that of without twisted tapes. The maximum decrease in fluctuation ratio (r) for the tapes of various twist ratio has been found to be 11.6 to 20.5 percent based on the case of "without twisted tape", thereby indicating a corresponding improvement in the quality of fluidization with reduced degree of bubbling and slugging. Quantitatively the maximum decrease in R for the twisted tapes of various twist ratios has been found to be 17 to 23 percent based on the case of "without twisted tapes". However, the pressure drop, fluctuation and expansion ratio were in general found to decrease with decrease in twist ratio of a twisted tape. Different correlations have been developed for pressure drop, fluctuation ratio and expansion ratio and compared with their corresponding experimental values.*

KEY WORDS: *Twisted tape , Gas-solid fluidization, Pressure drop, Fluctuation and expansion Ratios.*

INTRODUCTION

Fluidization as an established fluid-solid contacting technique has found extensive application in unit operation like drying, adsorption and in chemical processes like solid catalyzed reactions, carbonization, gasification and combustion. In most fluidized bed applications a gas is contacted with catalytic or reacting solid particles.

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In all such cases, the technique of fluid-solid contact is very essential and developments to increase the efficiency of this contact are always desirable. The gas fluidized beds suffer from certain inherent drawbacks like channeling, bubbling and slugging which results in poor gas-solid contact, lower diffusion and heat transfer rates by affecting the quality of fluidization. It is observed that by providing different bed internals, fluidization becomes smoother. One way to reduce the problem and thereby improve the quality of fluidization includes the incorporation of baffles in the bed, imparting vibrations to the column, operation in a multistage unit and use of semi fluidized bed. Baffles of various geometry have been tried and it was found that vertical rods served as the best ones in the improvement of performance without creating any additional problem like segregation in the beds. The quality of fluidization can be quantitatively expressed by a factor called fluctuation ratio under conditions of high gas flow, the top of fluidized bed may fluctuate considerably. Quantitatively the fluctuation ratio is defined as the ratio of the highest and the lowest levels which the top of the bed occupies for any particular gas flow rate. The fluctuation ratio is designated as ‘r’. A lower value of fluctuation ratio indicates lesser fluctuation at the top of the bed and hence smoother fluidization and better bed performance without bubbling and slugging.

Incorporation of vertical baffles in large diameter beds prevents the development of very large bubbles and thereby improve the uniformity and general quality of fluidization. It has been seen that in the fluidized bed with vertical baffles, the fluid velocity varies from zero at the wall to the maximum at the center of all the compartments formed by the insertion of the baffles. This variation in fluid velocity in the bed leads to improved gas-solid contacting. Inspite of many advantages of fluidized beds, the efficiency and quality of fluidization in large scale and deep gas-solid, cylindrical fluidized bed are seriously affected by bubbling, slugging and channeling which results in poor gas-solid contact, lower diffusion and heat transfer rates.

In order to determine the quality of fluidization there are two methods such as Uniformity Index method and Fluctuation Ratio [1] .*Moarse & Ballou* [2] expressed fluidized bed densities by means of the dielectric properties of the elements of a fluidized system. Quantitatively the fluctuation ratio may be defined by the ratio of the highest and lowest levels which the top of the bed occupies, for any particular gas flow rate. This has been termed as the fluctuation ratio. *Lewis et al.* [3] correlated their data for Fluctuation ratio as $r = e^{m}$ $[(G_f - G_{mf})/Gmf]$, where the slope 'm' is related to particle diameter .

The systematic investigation of the effect of baffles on the expansion behavior of gas fluidized systems was reported by *Massimilla & Bracale* [4]. *Volk et al.* [5] suggested that vertical tubular surfaces should be inserted into large diameter beds to prevent the development of very large bubbles and thereby improving the uniformity and general quality of fluidization. They indicated that these types of baffled reactors are useful for roasting and other chemical reactions.

Krishnamurty et al. [6] suggested that vertical baffles of circular cross-section are suitable for improving the quality of fluidization. *Yogesh Chandra, et al.* [7] studied the effect of vertical baffles on bed expansion characteristics and the pressure drop in continuous gas-solid fluidization. It was observed that in fluidized beds with vertical baffles, the fluid velocity varies from zero at the walls to the maximum at the center of all the compartments formed by the insertion of the baffles. *Agarwal et al.* [8] have studied the effect of stirrer type baffles on fluidization quality and proposed a correlation for the prediction of fluctuation ratio in terms of bed, gas solid and baffle properties. The following correlation has been proposed.

$$r = 2.49\left(\frac{G_f}{G_{mf}}\right)^{1.75}\left(\frac{D_p}{D_o}\right)^{-0.07}\left(\frac{D_p}{h_s}\right)^{-0.29}\left(\frac{\rho_s}{\rho_f}\right)^{-0.25} \tag{1}$$

Rao et al. [9] have studied pressure drop in batch fluidized beds in the presence of helical tape promoter. The effects of void fraction, tape pitch and tape width on pressure drop were studied. *Kumar et al.* [10] studied the minimum fluidizing velocity and the pressure peak for gas-solid fluidization in conical beds. *Kumar & Roy* [11], studied the effect of different rod type promoters in a gas solid fluidized bed and found that the use of the above promoters are effective in reducing the bed expansion and fluctuation ratios. *Sahoo & Roy* [12] studied the effect of rod and disc type of promoters in a squared gas solid fluidized bed and found that the incorporation of promoters have significant effect on Euler’s number. Few qualitative explanation and expression relating to the effect of promoters and bed fluctuation in cylindrical bed have been studied by *Kumar & Roy* [13], but the effect of twisted tape in gas solid fluidized bed as baffle remains un-explored. *Mohanty et al*. [14] investigated the effect of rod and disc promoters on fluctuation and expansion ratios and in this case, the rod promoters were found to be more effective in reducing bed fluctuation, and in increasing bed expansion at high gas mass velocities. *Mohanty et al.* [15] studied a new technique for augmenting mixing of particles, expressed through the mixing index and it is found that the best mixing performance is achieved under conditions of simultaneous primary and secondary air supply. In case of a well fluidized dense phase bed, local temperatures and solids distributions are much more uniform. This is important in many chemical and catalytic processes for a better control and higher yield. Particle size in a fluidized bed is of a smaller order of magnitude then in a fixed bed. So the resistance to diffusion through the particle is smaller in the fluidized bed which results in better reaction rates in case of solid catalyzed reactions. Additions to or withdrawal from the bed is possible by controlling the fluid velocity in case of fluidization. This is important when rapid-active losses are involved. Thus the fluidized bed offers a great advantage where highly exothermic or endothermic reactions are involved. Fluidization eliminates catalyst pelleting, an important cost in many catalytic processes. Inspite of the above advantages, the gas fluidized beds suffer from certain inherent drawbacks like channeling bubbling and slugging which results in poor gas-solid contact, lower diffusion and heat transfer rates by affecting the quality of fluidization. Phenomenon of gas-solid fluidization changes drastically when scaling up is done from laboratory setup to industrial units. Incorporation of twisted tape as baffles in large diameter beds prevents the development of very large bubbles and there by improve the uniformity and general quality of fluidization. It has been seen that in the fluidized bed with Twisted tape (vertical) baffles, the fluid velocity varies from zero at the wall to the maximum at the center of all the compartments formed by the insertion of the baffles. This variation in fluid velocity in the bed leads to improved gas-solid contacting.

The twisted tapes have long been known to significantly improve forced convection heat transfer coefficients, especially for laminar flow through a tube, by introducing secondary flow and improving the degree of turbulence. In the present work an attempt has been made to study the effect of twisted tapes as bed internals, on the performance of the gas-solid fluidized bed. Twelve numbers of twisted tapes of three different widths with four values of the twist ratios (y) for each width, were studied. By using twisted tape the change in pressure drop fluctuation ratio and expansion ratio have been studied as compared to “without twisted tape” condition. Different correlations have been developed for pressure drop, fluctuation ratio and expansion ratio and compared with their corresponding experimental values. Effects of the static bed height have also been investigated.

EXPERIMENTAL SECTION

The experimental set-up is shown in Fig. 1. Twelve numbers of twisted tapes shown in Fig. 2 are used. The twisted tapes are of three different widths and four twist ratio(y) values for each width. The details of twisted tapes are given in Table 1. These twisted tapes are used as baffle for better fluidization and are inserted vertically into the cylindrical bed. The different bed parameters used are given in Table 2. The known amount of bed material is charged to the column slowly from the top to get the desired bed height. The surface of the bed material is made smooth by fluidizing the bed gradually and allowing it to settle slowly. The compressed dry air was admitted to the column from the constant pressure tank. The corresponding static bed height is noted. As the compressed dry air was admitted to the column the bed pressure drop and the bed heights were recorded against the gradual change of flow rate till fluidization condition is attained. In the fluidized state, as the top layer of the bed was fluctuating, both levels (maximum and minimum) and the pressure drop across the bed (with and without twisted tapes) are noted against flow rate. The procedure is repeated with various static bed heights and different twisted tapes.

Development of correlations

The correlations for pressure drop, fluctuation and the expansion ratio have been developed with the help of relevant dimensionless groups involving interacting parameters like, the inlet diameter of fluidizer, the superficial fluid mass velocity in fluidized state, fluid

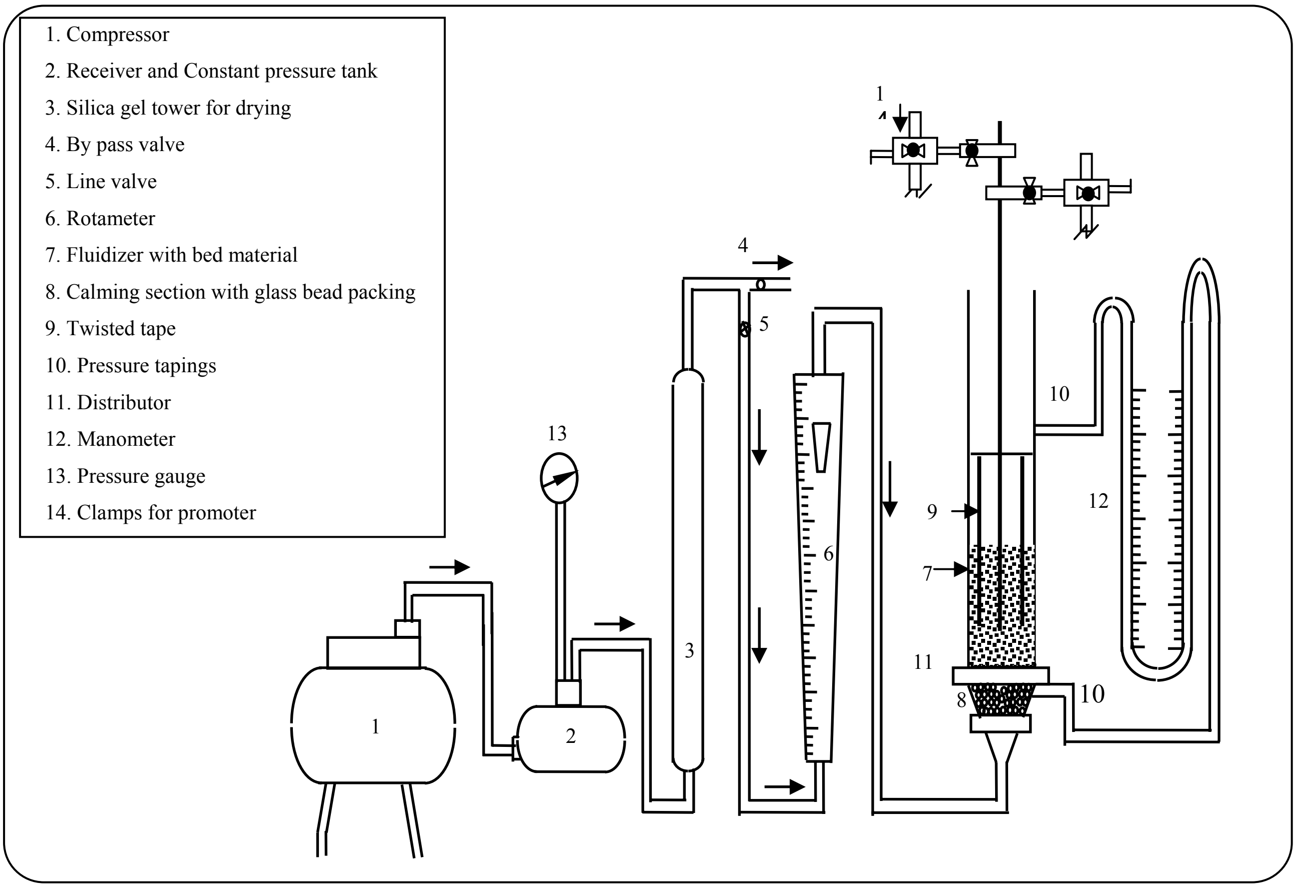
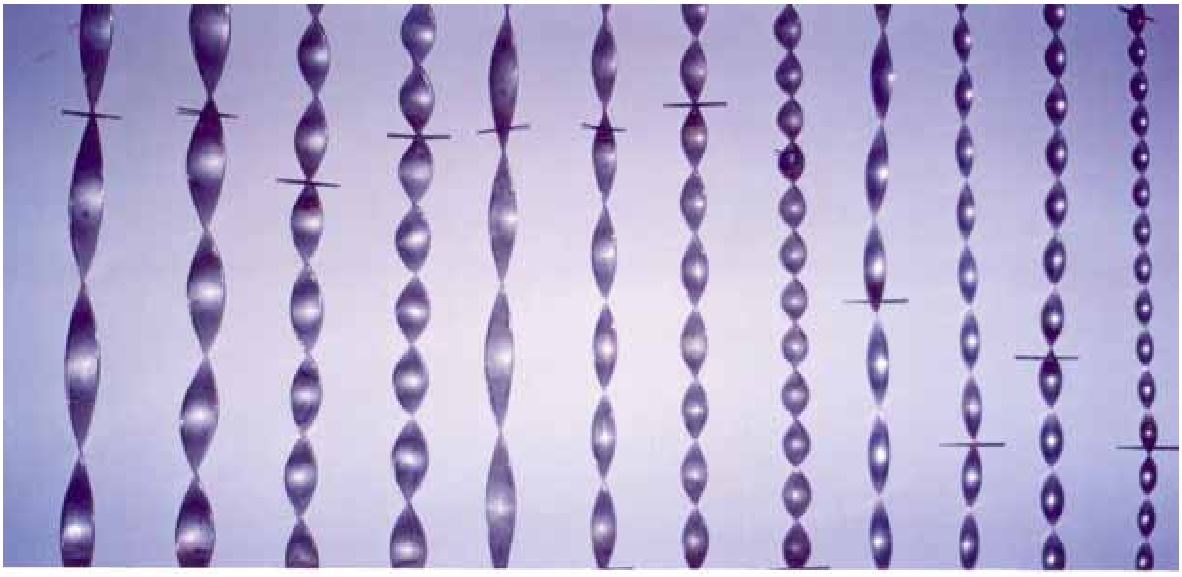


Fig. 1: Schematic diagram of the experimental set-up.



W in cm	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5
y (H/W)	**6.84**	**5.40**	**3.55**	**3.05**	**6.54**	**5.46**	**3.78**	**2.51**	**6.30**	**4.21**	**3.23**	**2.92**

Fig. 2: Twisted Tapes.

Table 1: The detail of twisted tapes.

W in cm	Thickness in mm	Twist Ratio			
		y_1	y_2	y_3	y_4
2.5	2.0	6.84	5.4	3.55	3.05
2.0	1.6	6.54	5.46	3.78	2.51
1.5	1.0	6.3	4.21	3.23	2.92

Table 2: The Different parameter used.

Bed	Cylindrical
Bed Material	Dolomite
Mesh Size	(-22 + 30) B.S.S (British Standard Shieve)
hs/Do	1.5, 2, 3, 4
Do	5 cm
Dp	0.605 mm

mass velocity at minimum fluidization, static bed height, and width of twisted tape and height of twisted tape.

For dimensional analysis, the pressure drop can be related to the system parameters as follows:

$$\Delta P = f\left(\frac{h_s}{D}\right)^a \left(\frac{H}{W}\right)^b \left(\frac{G_f}{G_{mf}}\right)^c \tag{2}$$

$$\Delta P = k_1\left(\frac{h_s}{D}\right)^a \left(\frac{H}{W}\right)^b \left(\frac{G_f}{G_{mf}}\right)^c \tag{3}$$

Where, twist ratio y = H / W, k1 is the coefficient and a, b, c are the exponents.

The effect of the individual group on the pressure drop has been separately evaluated. Following correlation have been developed for pressure drop through dimensional analysis as:

$$\Delta P = 956.07\left(\frac{h_s}{D}\right)^{0.8760} (y)^{0.0753}\left(\frac{G_f}{G_{mf}}\right)^{-1.5049} \tag{4}$$

Similar procedure is adopted to obtain the correlation for fluctuation and expansion ratio as follows;

$$r = 0.9926\left(\frac{h_s}{D}\right)^{0.1806} (y)^{-0.0072}\left(\frac{G_f}{G_{mf}}\right)^{0.3686} \tag{5}$$

$$R = 1.4549\left(\frac{h_s}{D}\right)^{0.02356} (y)^{-0.0029}\left(\frac{G_f}{G_{mf}}\right)^{0.1868} \tag{6}$$

RESULTS AND DISCUSSION

The variation of pressure drop, fluctuation ratio and expansion ratio plotted at different values of fluid mass velocity (G_f) are shown in Figs. 3, 4 and 5. The variation of pressure drop, fluctuation ratio and expansion ratio plotted at different values of reduced fluid mass velocity (G_f / G_{mf}) are shown in Fig. 6, 7 and 8.

The different values of pressure drop were plotted against the corresponding fluid mass velocity for a typical case (W=2.0 cm; h_s/Do =3.0 and y=2.51, 3.78 and 5.46) with and without twisted tape, as shown in Fig. 3. In the fluidized bed region the pressure drop is found minimum in the case of "without twisted tape". In case of twisted tapes it is higher because of the presence of additional surface area as well as because of higher degree of turbulence created by the swirling motion, induced by the presence of twisted tape .The pressure drop is found to be maximum for the case of twisted tape with y value of 5.46 and reduces for y values of 3.78 and 2.51, in that order. However the increase in pressure drop due to presence of twisted tape is only marginal and of the order of, 5.25 to 14.9 percent over that of without twisted tapes.

Similarly, as for the case of pressure drop, the results for the corresponding fluctuation ratio values were plotted and are as shown in Fig.4. Though at the beginning of fluidization there is not much difference in the values of the fluctuation ratio r, as the fluid mass velocity is increased the difference becomes more and more prominent. The fluctuation ratio is seen to decrease in the following order; without twisted tape, with twisted tape of y = 5.46, 3.78 and 2.51. The maximum decrease in fluctuation ratio (r) for the tapes of various twist ratio has been found to be 11.6 to 20.5 percent based on the case of "without twisted tape", thereby indicating a corresponding improvement in the quality of fluidization with reduced degree of bubbling and slugging.

Expansion ratio is useful in deciding the height of the fluidized bed columns. The trend for the variation of expansion ratio is qualitatively almost similar to that of fluctuation ratio Fig. 5. Quantitatively the maximum decrease in R for the twisted tapes of various twist ratios (for W=2.0, and h_s/Do=3) has been found to be 17 to 23 percent based on the case of "without twisted tapes".

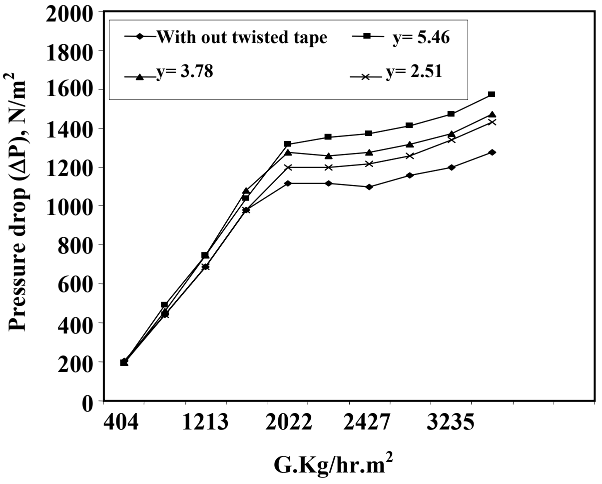


Fig 3: Variation of pressure drop with fluid mass velocity.

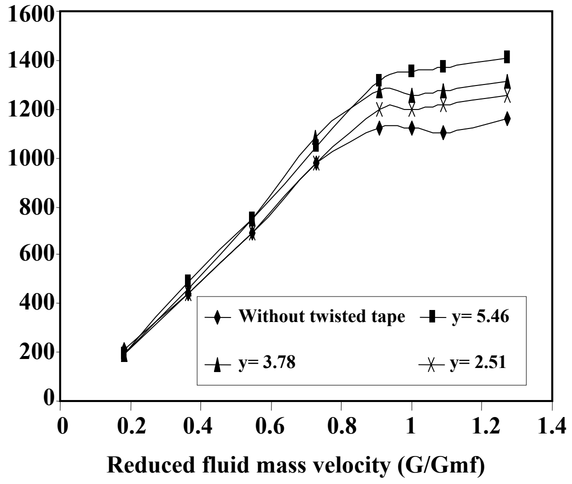


Fig. 6: Variation of pressure drop with reduced fluid mass velocity.

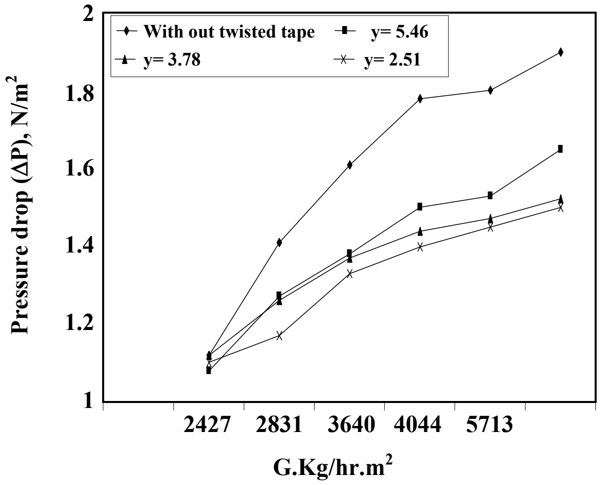


Fig. 4: Variation of fluctuation ratio with fluid mass velocity.

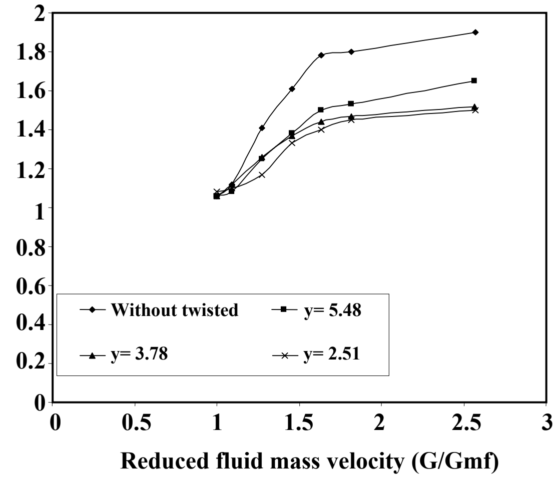


Fig. 7: Variation of fluctuation ratio with reduced fluid mass velocity.

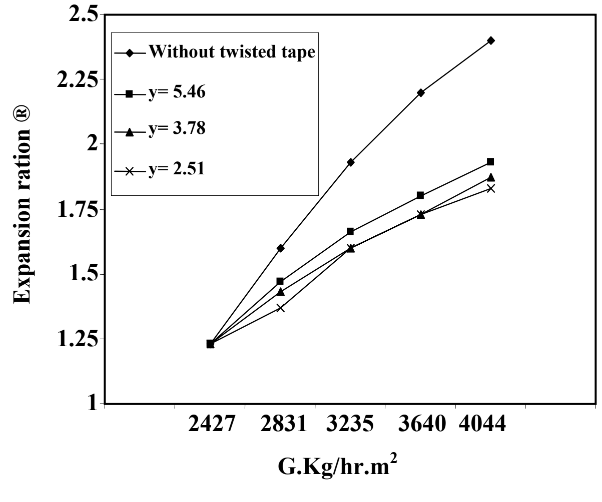


Fig 5: Variation of Expansion ratio with fluid mass velocity.

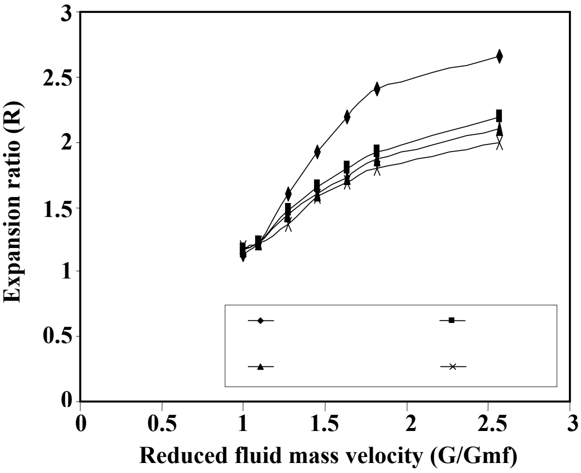


Fig. 8: Variation of Expansion ratio with reduced fluid mass velocity.

Table 3: The deviation of Pressure drop, Expansion and Fluctuation ratio from their experimental value.

Fuidization Characteristics	Pressure Drop (ΔP)		Expansion Ratio (R)		Fluctuation Ratio (r)	
Types of Deviation	Mean Deviation	Standard Deviation	Mean Deviation	Standard Deviation	Mean Deviation	Standard Deviation
Deviation in %	0.79	13.23	- 4.909	12.67	- 0.87	5.17

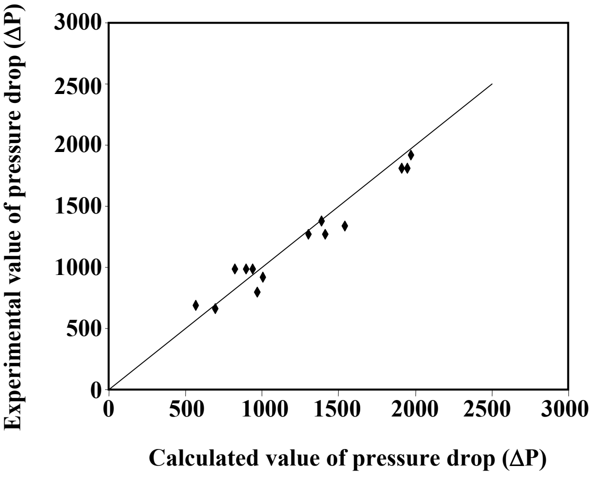


Fig. 9: Comparison of calculated values of pressure drop (ΔP) with their corresponding experimental value.

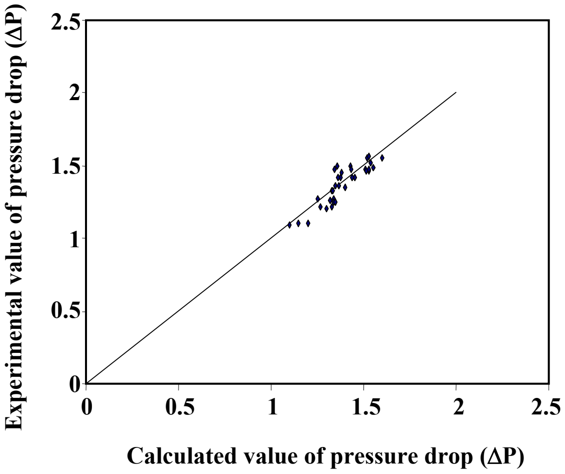


Fig. 10: Comparison of calculated values of fluctuation ratio (r) with their corresponding experimental.

Pressure drop at the same reduced fluid mass velocity (G_f / G_{mf}) was found to be higher with the introduction of twisted tape into the column Fig.6. For the same value of reduced fluid mass velocity (G_f / G_{mf}), fluctuation ratio(r) and the expansion ratio (R) were found to be lower for the case of fluidization with twisted tape Figs.7 and 8 . Pressure drop, fluctuation and expansion ratio were in general found to decrease with decrease in twist ratio of a twisted tape, for almost all widths of the tape and for all hs/D_0 ratios. It may be noted that a lower twist ratio indicates a higher degree of twist and a lower value of H, thereby inducing higher degree of turbulence in the central part of the fluidized bed. Therefore, twisted tape having a lower ratio is desirable to achieve lower pressure drop and lower fluctuation ratio as well as the expansion ratio. The rate of change of the pressure drop, fluctuation ratio and expansion ratio with “y” were all different for the various cases. Pressure drop, Fluctuation and Expansion ratio are calculated by equation 4, 5 and 6, respectively, and have been compared with their experimental values in Figs. 9, 10 and 11 respectively. The mean deviation and standard deviation are given in Table 3.

CONCLUSIONS

The introduction of twisted tapes as baffles in a gas-solid fluidized bed decreases the fluctuation ratios, thereby indicating a corresponding improvement in the fluidization quality. The expansion ratio (R) is also found to be reduced when a twisted tape is used in a fluidized bed. However, pressure drop is found to increase marginally when compared at the same fluid mass velocity G_f. The pressure drop, fluctuation and expansion ratio were in general found to decrease with decrease in twist ratio of a twisted tape.

Nomenclature

a, b, c	Exponents for variables
D_p	Particle diameter, (m)
D	Inlet diameter of fluidizer, (m)
f	Function
G	Superficial fluid mass velocity, (kg/h-m^2)
G_f	Superficial fluid mass velocity in fluidized state, (kg/h-m^2)
G_{mf}	G_f at minimum fluidization mass velocity, (kg/h-m^2)

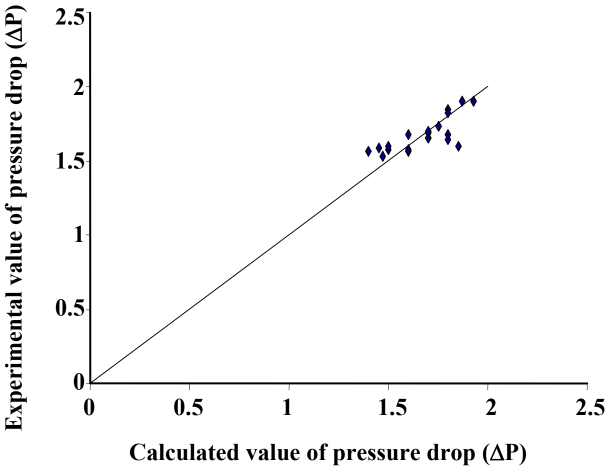


Fig. 11: Comparison of calculated values of expansion ratio (R) with their corresponding experimental values.

h_l	Lowest levels at which the top of the bed occupies (m)
h_2	Highest levels at which the top of the bed occupies (m)
h_s	Initial Static Bed Height (m)
H	Axial distance for 180^0 rotation of the twisted tape (m)
r	Fluctuation ratio ($r = h_2/h_1$, dimensionless)
R	Expansion Ratio ($R = (h_2 + h_1) / 2h_s$, dimensionless)
ΔP	Pressure Drop across the bed (N/m^2)
Y	Twist ratio (H/W.Dimensionless)
W	Tape width (m)

Greek letters

ρ_s	Density of fluidized solid (kg/m^3)
ρ_f	Density of fluid (kg/m^3)

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