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Effect of Aspect Ratio, Tubular Assembly and Materials on Minimum Fluidization Velocity in 3D-Atmospheric Fluidized Bed

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Keywords: minimum fluidization velocity, minimum bubbling velocity tube bank, biomass, bed height.

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Effect of Aspect Ratio, Tubular Assembly and Materials on Minimum Fluidization Velocity in 3D-Atmospheric Fluidized Bed

Masooma Qizilbash [α] & S. R Malik [σ]

Abstract- Hydrodynamics of fluidized bed is a noteworthy factor in manipulating and analyzing the characteristics of fluidized bed. Minimum fluidization velocity is noteworthy parameter for analyzing the distinctiveness of fluidized bed. Comparison was being done on different Geldart's particles group B (local sand) and A (rice husk) materials having densities of 1490 kg/m^3 and 567 kg/m^3 and same particles sizes i-e 149 μm. In this study different height to diameter (aspect) ratios were used H/D= 0.8, 1, 1.1 along with different tubes banks of two geometries inline assembly and staggered assembly. Diameter of tubes considered to be 1.2" to understand the behavior of minimum fluidization velocity by using these tube banks inside the bed and hydrodynamic parameters were resolute for these three aspect ratios and tube banks assemblies by measuring pressure drop experimentally and theoretically by using Ergun equation. Minimum fluidization velocity reduces by using tubes inside the bed furthermore, fluidization velocity achieves earlier in triangular pitch arrangement of tubes than in square pitch. Minimum fluidization velocity remains unchanged by changing bed height for both the materials. However, pressure drop increases as aspect ratio is incremented.

Keywords: minimum fluidization velocity, minimum bubbling velocity tube bank, biomass, bed height.

I. Introduction

A trend by which fine solids are changed into a fluid-like state through contact with gas or liquid or by both gas and liquid is termed as Fluidization. It is a contacting technique, which has extensive industrial applications and several Investigations concerning range of aspects of fluidization is being carried out and numerous applications have been made based on these techniques like drying, adsorption and chemical processes such as combustion, carbonization, gasification and solid-catalyzed reaction. In order to keep vast variety of review and researches to rational proportion, it has been restricted to gas-solid systems. A number of outstanding reviews have been in print on measurement techniques for fluidized beds by several researchers.

Cylindrical gas-solid fluidized beds have been working in process industries. Apart from the gas-solid advantages of fluidization in cylindrical beds, the efficiency and the quality in large diameter suffer seriously due to certain drawbacks such as channeling, bubbling and slugging behavior at gas velocity higher than the minimum fluidization velocity resulting in poor gas-solid contact. Hence studies have been done by the investigators to improve the quality of gas-solid fluidization. To overcome the above mentioned drawbacks quality techniques such as vibration and rotation of the bed, use of improved distributor and promoter [20] has been studied.

Consideration of non-cylindrical conduits, instead of a cylindrical one is considered to be an striking alternative technique for improved gas-solid fluidization by reference [9] The introduction of vibrational and rotational motion of the bed and distributors promotes turbulence in a gas-solid fluidized bed that increase the fluidization quality by minimizing bubbling, channeling and slugging but the relative demerits of the above technique is increase of pressure drop. The use of non-cylindrical conduits has been found to be more effective in controlling fluidization quality as compared to the other methods [12] Recently the use of non-cylindrical beds has begun to receive much attention for several applications because of a few advantages, like (i) the operation of the fluidizer over a wide range of superficial velocity, (ii) the possibility of fluidizing a wide range of particles of different sizes or densities, and (iii) intensive particle mixing.

Fluidized bed combustion initiated from a flame low grades of variety of fuels. One of the main rewards of fluidized bed is its ability to burn several fuels and is also characterized by following parameters i-e Sulphur removal and low Nox emissions without any particular designed DeSOx or DeNOx equipment [11]. To fluidize biomass is another complicated process Some studies have been done to determine the effect of particle size, shapes and densities of different biomass such as wood chips, mung beans, millets, corn stalks and cotton stalks on minimum fluidization velocity [2]. The effect of tubular assembly on minimum fluidization velocity has not been covered by majority of researchers and is being studied in current paper.

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The purpose of this study is to determine minimum fluidization velocity for local sand and rice husk at different aspect ratios and to investigate the effect of minimum fluidization velocity in presence of tubular assembly of two different arrangements triangular pitch and square pitch having 1.2” diameter of tubes.

II. EXPERIMENTAL SETUP

0.1211 m^2 Atmospheric Fluidized Bed has been fabricated in this study. A schematic diagram of apparatus is shown in Fig1. Rotameter is used to regulate the air flowrate having pressure of 100 psi. Spargers tubes were used as a distributor inserted beneath be for uniform mixing. Local Sand and rice husk has been used both exhibit same diameter of 149µm but different densities 1490 kg/m^3 and 567 kg/m^3 to be familiar with fluidization characteristics for materials having different densities. Tubes inserted having diameter of 1.2 inches and two different assemblies i-e triangular pitch and square pitch. Both arrangements were used on 6 inches above the distributor to keep away from trouble in air distribution.

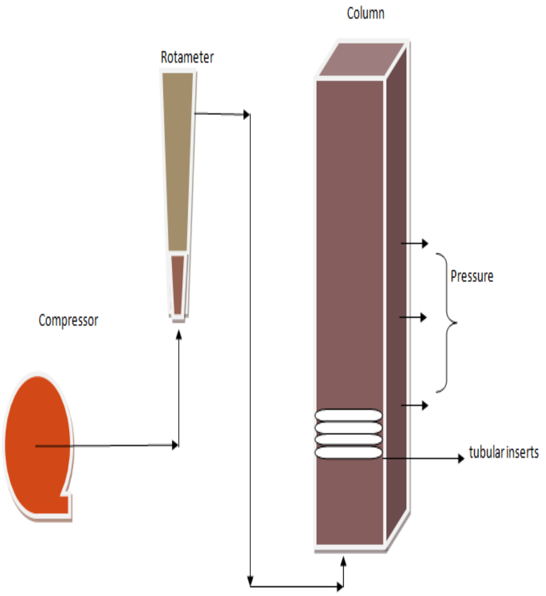

Fig.1 : schematic diagram of 0.348m*0.348m fluidized bed reactor

Table 1 : Properties of bed materials

Materials	Geldart group	dp (µm)	ρp (kg/m^3)	Φ	e
Sand	B	149	1490	$6*10^{-4}$	0.21
Rice husk	A	149	567	0.65	0.79

III. EXPERIMENTAL PROCEDURE

Minimum fluidization velocity was examined experimentally by observing pressure drop across the bed of 0.348m*0.348m fluidized bed reactor. The bed was packed with both solid particles (sand and rice husk) one by one and then vigorously fluidized by introducing air at 100 psi and at particular initial air flow rate to split down the internal structures. Superficial air velocity was varied and at each increment pressure drop was recorded by means of manometer installed. 1.2” diameter tubular geometry (triangular pitch & square pitch) was assembled inside the bed and above the distributor. Pressure drop and minimum fluidization velocity was observed experimentally. Different aspect ratios such as 0.8, 1 and 1.1 then used and Pressure drop and minimum fluidization velocity then evaluated.

IV. OBSERVATIONS AND CALCULATIONS

Density of local sand particle= ρ_s=1490kg/m^3
Density of rice husk=ρ_r=567 kg/m^3
Diameter of both materials=d_p=149μm
Voidage of sand $e_s=1-(\rho_b / \rho_s) = 0.21$
Voidage of rice husk e_r= 0.795 (taken from combustion and gasification in fluidized bed)
Sphericity of sand Φ_s= As/Ap= 0.00006 (taken from combustion and gasification in fluidized bed)
Sphericity of rice husk $\surd_\rho$= 0.65 (taken from combustion and gasification in fluidized bed)
Viscosity of inlet air at 27°C= 1.84*10^{-5}N.s/m^2
Density of inlet air at 27°C=ρa=1.16 kg/m^3
Diameter of tubes inserted=dt=1.2"
Materials of tubes inserted=PVC
Geometry of tubes inserted= triangular pitch and square pitch

Constants C_1 & C_2 for sand and biomass = 27.2 & 0.0408 (taken from Grace, Prabir Basu and used by Basu Paudel, B.t (2011) in experimental study of fluidization biomass, inert particles and biomass/sand mixtures)

a) *Applied equations [9, 10]*

$$\Delta P/L=\{150(1-e)^2/e^3(\mu U)/(\Phi dp)^2\}+\{1.75(1-e)/e^3(\rho g U^2)/(\Phi\ dp) \quad (1)$$

$$F_D=\Delta P=AL\ (1-e)(\rho_p-\rho_g)g \quad (2)$$

$$Ar=\rho_g\ (\rho_p-\rho_g)\ gdp^3/\mu \quad (3)$$

$$Re_{mf}=\{C_1{}^2+C_2 Ar\}^{0.5}-C_1 \quad (4)$$

$$Re_{mf}=U_{mf} d_p \rho_g/\mu_g \quad (5)$$

$$U_{mf}=Re_{mf}\ (\mu_g)/d_p\rho_g \quad (6)$$

Table 2 : Experimental values of pressure drop of different materials at 0.33 m of initial bed height & 1.2''dia tubes

Sr No	Flowrate Q (l/min)	Velocity U (m/s)	Pressure drop ΔP (Cm of water) sand			Pressure drop ΔP (Cm of water) Rice husk		
			Without tubes	Square pitch tubes	Triangular pitch tubes	Without tubes	Square pitch tubes	Triangular pitch tubes
1	0	0	0	0	0	0	0	0
2	20	0.0027	8.2	8.5	8.3	2.5	2.8	2.7
3	40	0.0049	10	11.5	11	3.5	4.2	4
4	60	0.0082	14	15	13.8	4.3	5.8	4.5
5	80	0.0107	19	20	20	5	6	6
6	100	0.0132	22	23	22.5	5.8	4	6.5
7	120	0.0165	22.5	24	23	5	5	5
8	140	0.0189	24	20	23.5	6.1	5.1	5.1
9	160	0.021	25	19.5	18.4	5	5	4.3
10	180	0.024	19	18	20	5.5	5.3	5
11	200	0.027	18.2	20	19.5	5	5	5.5

Table 3 : Experimental values of pressure drop of different materials at 7.1 m of initial bed height & 1.2’’dia tubes

Sr no	Flowrate Q (l/min)	Velocity U (m/s)	Pressure drop ΔP (Cm of water) sand			Pressure drop ΔP (Cm of water) Rice husk		
			Without tubes	Square pitch tubes	Triangular pitch tubes	Without tubes	Square pitch tubes	Triangular pitch tubes
1	0	0	0	0	0	0	0	0
2	20	0.0027	9	9.3	10	2.8	3.7	3
3	40	0.0049	11.5	14	12	3.9	4.3	4
4	60	0.0082	17	22.9	21	4.3	5	4.5
5	80	0.0107	22	24	24	5	5.7	5
6	100	0.0132	23	24.4	24.3	5.9	6	6
7	120	0.0165	24.1	18	24.9	6.8	7	7.1
8	140	0.0189	25.5	19.7	20	7	4.8	7.1
9	160	0.021	19.9	19	19	5	4	3.3
10	180	0.024	18.5	19	18.5	5.9	4.3	4
11	200	0.027	18	19.3	18	5.5	4	4.4

Table 4 : Experimental values of pressure drop of different materials at 6.1 m of initial bed height & 1.2’’dia tc ubes

Sr no	Flowrate Q (l/min)	Velocity U (m/s)	Pressure drop ΔP (Cm of water) sand			Pressure drop ΔP (Cm of water) Rice husk		
			Without tubes	Square pitch tubes	Triangular pitch tubes	Without tubes	Square pitch tubes	Triangular pitch tubes
1	0	0	0	0	0	0	0	0
2	20	0.0027	10	11	10	3	4	3.8
3	40	0.0049	15	17	15.5	4	4.5	4
4	60	0.0082	20	20.5	20	5.5	6	5.7
5	80	0.0107	23	25	25	6	6.7	6
6	100	0.0132	23.8	26.5	25.3	6.9	7	7
7	120	0.0165	25.3	29	29	7.5	5	6.1
8	140	0.0189	26	20	30.2	4	5.1	5
9	160	0.021	26.5	20.2	19.3	2	5	4.3
10	180	0.024	20	19.9	20.1	2.5	5.3	5
11	200	0.027	22	19.9	20	3	5	5.5

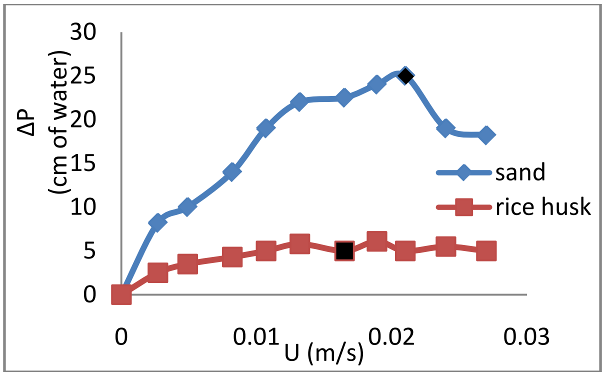

Fig. 2 : Comparison of U_{mf} for sand and rice husk at H/D=0.8 in absence of tubes

Fig 2 represents superficial air velocity as a function of pressure drop for two different particles local sand and rice husk as a bed material at an aspect ratio of 0.8 in the absence of tubular assembly to study the effect of superficial air velocity on pressure drop across the bed in tubes absence to make appropriate comparison with the bed having tubes inserted in it.

Fig 3 and 4 shows the effect of superficial air velocity on pressure drop of two different bed material i-e local sand particles and rice husk particles at an aspect ratio of 1 and 1.1 to estimate the pressure drop variation at different height in the absence of tubes

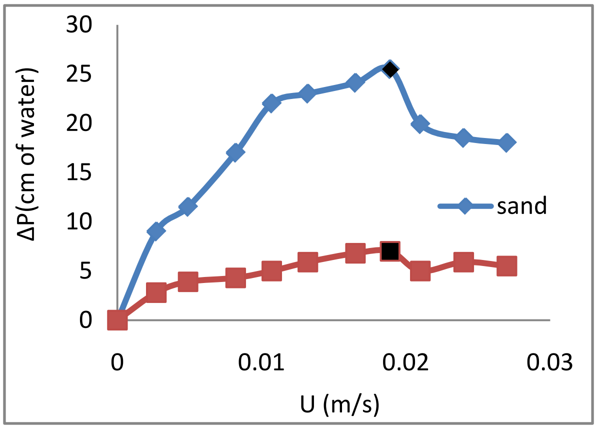

Fig. 3 : Assessment of U_{mf} of sand and rice husk at H/D=1 in absence of tubes

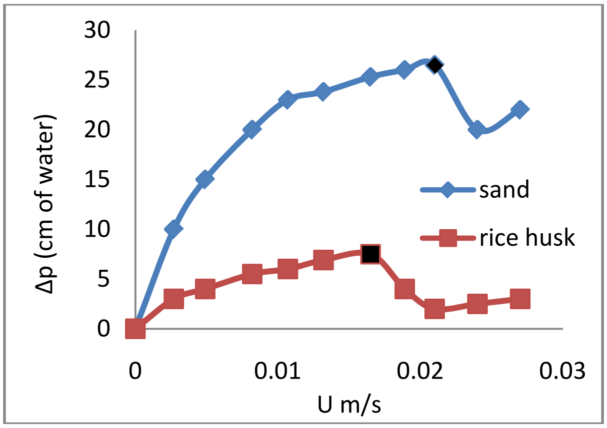

Fig. 4 : Evaluation of U_{mf} for sand and rice husk at H/D=1.1 in absence of tubes

V. RESULTS AND DISCUSSION

a) *Effect of materials and aspect ratios*

Two materials having same diameters and different densities were being studied in the 0.348m*0.348m fluidized bed reactor as a bed material to understand the effect of densities on minimum fluidization velocities and it is observed that rice husk has lower density and so is the minimum fluidization velocity as compared to the local sand having higher density. As well as aspect ratio is concerned pressure drop increases on increasing bed height or aspect ratio but there is no effect of aspect ratio on minimum fluidization velocity hence minimum fluidization velocity for both the material are independent on aspect ratio. fig 5 represents the graph between minimum fluidization velocity for two different materials at three different aspect ratios.

Table 5 : Minimum fluidization velocities and bed weight on increasing height in absence of tubes

H/D	Sand		rice husk	
	U_{mf} (m/s)	Bed weight (kg)	U_{mf} (m/s)	Bed weight (kg)
0.8	0.021	59.6	0.016	22.6
1	0.018	62.5	0.018	23.8
1.1	0.021	68	0.018	26.

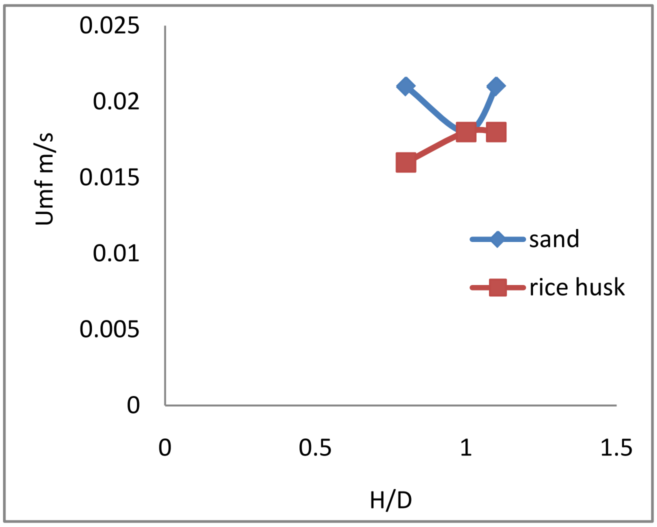

Fig. 5 : H/D vs U_{mf} of sand and rice husk

b) *Effect of tubes inserted*

1.2" diameter of tubes have been used in 3D Atmospheric Fluidized Bed reactor to determined the effect of tubular inserts on minimum fluidization velocity and different arrangements of tubes such as inline arrangement and staggered arrangement were studied to estimate the effect of square pitch arrangement and triangular pitch arrangement on minimum fluidization for both the materials i-e local sand particles and rice husk as observed from fig 6, 7 and 8 which is a comparison plot of superficial air velocity as a function of pressure drop for local sand particles as a bed material in presence of tubes of two different geometries inside the bed at different aspect ratios i-e 0.33 m, 0.35m and 0.38m

Tubes basically confine the air flow and trim down the cross sectional area of fluidized bed reactor, giving higher interestial gas velocity and therefore a lower minimum fluidization velocity U_{mf}

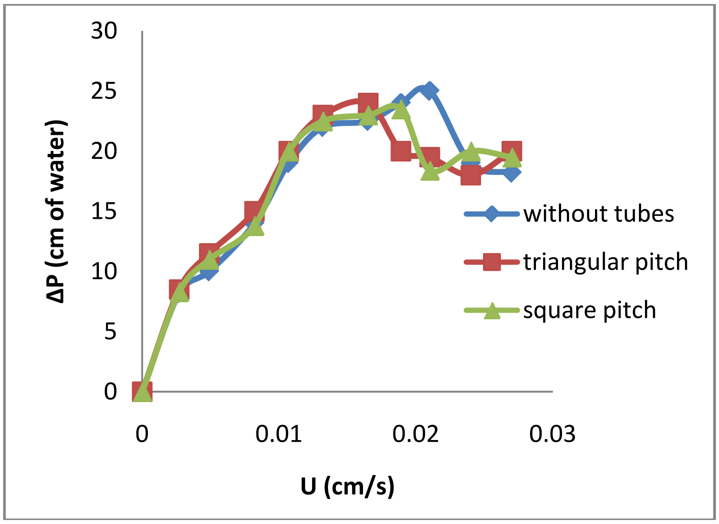

Fig. 6 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2" tubes at 0.33m initial bed height of local sand particles

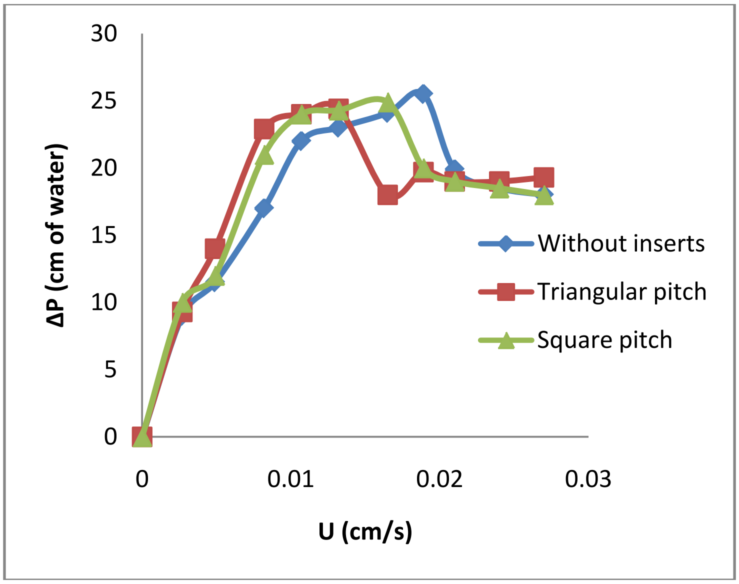

Fig. 7 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2" tubes at 7.1m initial bed height of local sand particles

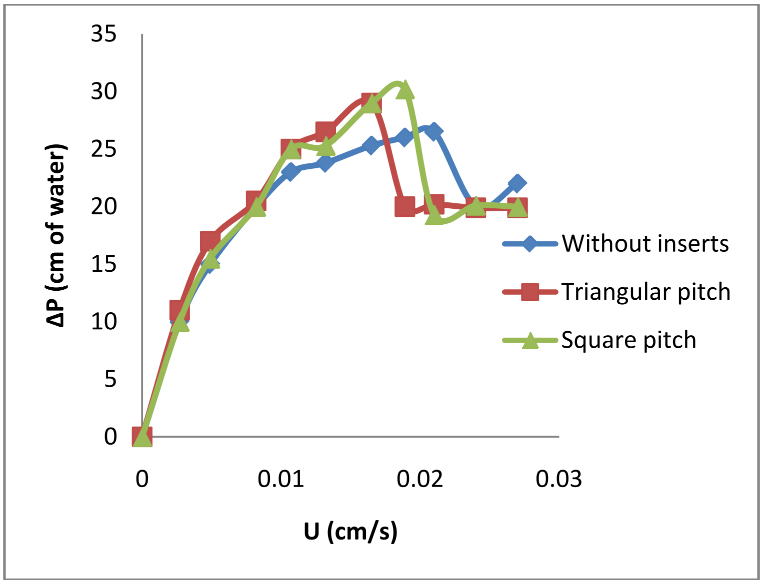

Fig. 8 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2" tubes at 6.1m initial bed height of local sand particles

Fig 9, 10 and 11 represents the graph between superficial air velocity and pressure drop having square pitch arrangement and triangular pitch arrangement of 1.2" diameter tubes inside the reactor at initial bed heights i-e 0.33m, 0.35 and 0.38m. Minimum fluidization of rice husk particles was being studied by determining bed pressure drop experimentally and is being marked in plots.

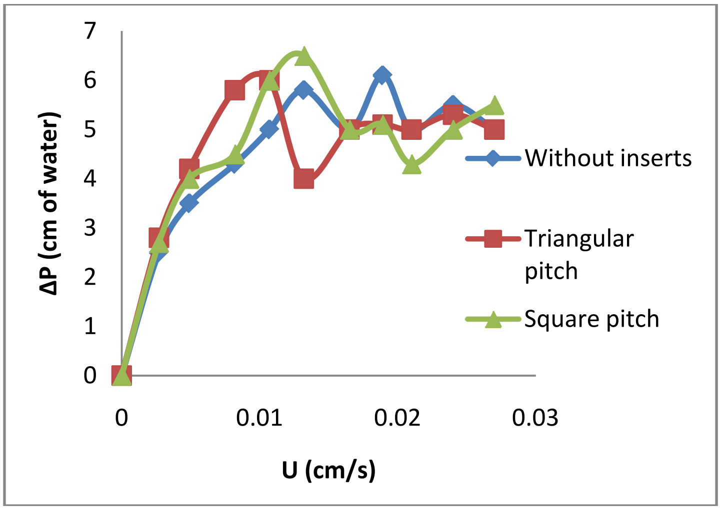

Fig. 9 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2" tubes at 0.33m initial bed height of rice husk particles

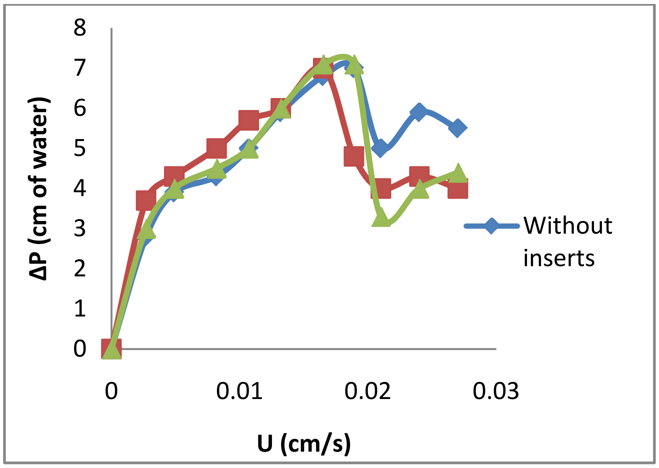

Fig. 10 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2” tubes at 7.1 m initial bed height of rice husk particles

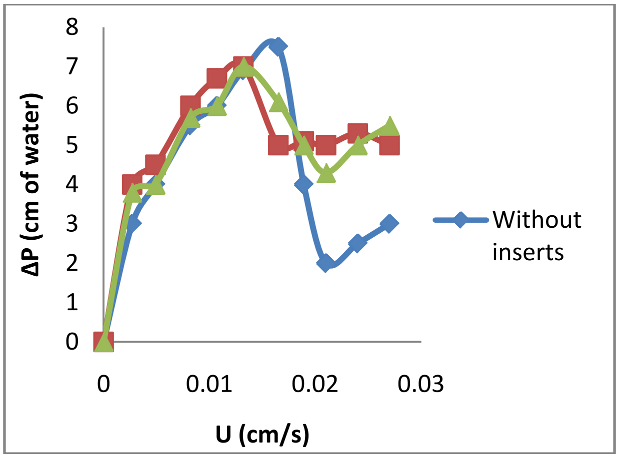

Fig. 11 : Plot between superficial air velocity and pressure drop having square pitch and triangular pitch arrangement of 1.2” tubes at 6.1m initial bed height of rice husk particles

Table 6 : Measured and Calculated Umf with Re_{mf} and Ar

Materials	Particle density ρ_p (kg/m^3)	U_{mf} (woi) (m/s)		Re_{mf}	Ar
		Exp	Pred.		
Sand	1490	0.021	0.015	0.12	165
Rice husk	567	0.018	0.004	0.04	62.07

The force balance in a bed for which the lower part of depth L_1 has no inserts and upper part has inserts of depth L_2

$$\Delta p_1\text{-}\Delta p_2(1\text{-}a_t/a_b)=\prod/6d_g{}^3(\rho_c\text{-}\rho)[(1\text{-}e_1)+(1\text{-}e_2)+(1\text{-}a_t/a_b)L_2]$$

e1=e2=e3 assumption
If mass of particles are constant then

$$M=\prod/6d_g{}^3\rho_c\ (1\text{-}e)[L_1+L_2(1\text{-}a_1/a_b)]$$

Hence at Umf pressure drop is constant so to put side by side different beds with and without inserts one should plot this against true superficial velocity as shown in Fig 14. and showed that Umf is reduced when number of tubes inserted inside the bed.

$$\Delta P'=\ \Delta p\ [L_1/L_1+L_2(1\text{-}a_1/a_b)]$$

$$U'=U[(L_1/L_1+L_2)+(L_2/L_1+L_2)(1/1\text{-}a_t/a_b)$$

Equations for true values obtained from reference [1]

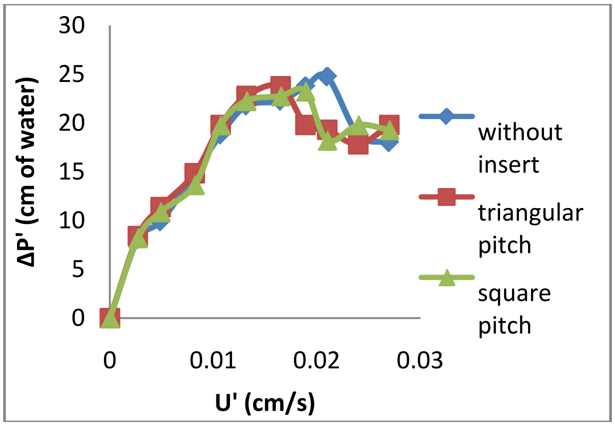

Fig 12 : Graph between true values of pressure drop and superficial air velocity for triangular and square pitch arrangements of tubes inside the bed for sand particles at 0.33m initial bed height

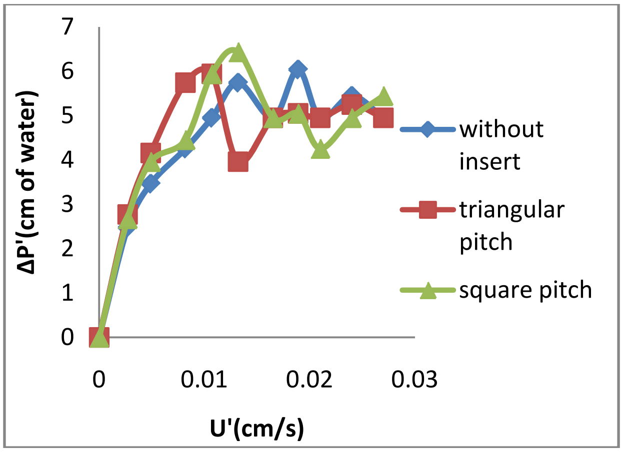

Fig 13 : Graph between true values of pressure drop and superficial air velocity for triangular and square pitch arrangements of tubes inside the bed for rice husk particles at 0.33m initial bed height

VI. CONCLUSIONS

- Minimum fluidization velocity studied in current research in 3D Atmospheric Fluidized Bed increased by increasing the density of the materials.
- The results obtained in current research shows that bed height is independent on minimum fluidization velocity for 0.348m*0.348m Atmospheric Fluidized Bed.
- Pressure drop increased as bed height incremented.
- By using tubes inside bed minimum fluidization velocity reduced.
- Triangular pitch arrangements of tubes enhance turbulence and decrement the fluidization velocity as compared with square pitch arrangements in bed.

Symbols used

d_p=diameter of particles [μm]
H=height of bed [m]
D=diameter of fluidized bed [m]
H/D=height–to-diameter ratio [dimensionless]
U=superficial air velocity [m/s]
Umf=minimum fluidization velocity [m/s]
ΔP=pressure drop across the column [cm of H_2O]
Ar=Archimedes number [-]
ρg= density of gas [kg/m3]
ρp=density of particle [kg/m^3]
g=gravitational constant [m/s^2]
μg=viscosity of gas [Ns/m2]
Remf= Reynolds number [-]
es=voidage of sand[-]
er=voidage of rice husk[-]
Φs=sphericity of sand[-]
Φr=sphericity of rice husk[-]
U'=true velocity [m/s]
ΔP'=true pressure drop[-]
L_1=depth of bed with inserts[m]
L_2=depth of bed without inserts[m]
a_t=cross section area of tubes[m2]
a_b=cross section area of bed[m2]
woi= without inserts

VII. Acknowledgements

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