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A Study of Fluctuation and Expansion Ratios for Gas-Solid Fluidized Columns

Maha. Muhyi Alwan Alhussaini
Lecturer
College of Engineering- University of Baghdad
mahamuhyi@yahoo.com

Hassanain Abbas Hassan
Assistant Lecturer
College of Engineering- University of Baghdad
hassanian.abbas@coeng.uobaghdad.edu.iq

Nada Sadoon Ahmedzeki
Professor
Al-Mustaqbal University College
Nada.Saadoon @mustaqbal-college.edu.iq

ABSTRACT

The fluctuation and expansion ratios have been studied for cylindrical gas-solid fluidized columns by using air as fluidizing medium and Paracetamol as the bed material. The variables were the column diameter (0.0762, 0.15, and 0.18 m), static bed height (0.05, 0.07, and 0.09 m), and air velocity to several times of minimum fluidization velocity. The results showed that both the fluctuation and expansion ratios had a direct relation with air velocity and an inverse one with column diameter and static bed height. A good agreement was between the experimental results and the calculated values by using the correlation equations from the literature.

Keywords: gas-solid fluidized bed, fluctuation and expansion ratios.

دراسة نسب التأرجح و التمدد في الأبراج المميعة نوع غاز- صلب

مها محي علوان الحسيني
مدرس
جامعة بغداد-كلية الهندسة
قسم الهندسة الكيمياوي

حسنين عباس حسن
مدرس مساعد
جامعة بغداد-كلية الهندسة
قسم الهندسة الكيمياوية

ندى سعدون احمد زكي
استاذ
كلية المستقبل الجامعة

الخلاصة

تمت دراسة نسب التارجح و التمدد للابراج المميعة الأسطوانية نوع غاز – صلب لمادة الباراسيتامول باستعمال الهواء ,حيث ان المتغيرات كانت اقطار الأبراج المميعة (0.15,0.0762 و0.18 متر) ,الأرتفاع الأستاتيكي للطبقة المميعة (0.07,0.05 و0.09 متر) و سرعة الهواء لعدة مرات اكبر من سرعة التمييع الدنيا.لوحظ أن كلا من نسبة التارجح والتمدد لها علاقة طردية مع سرعة الهواء وعكسية مع قطر العمود وارتفاع الطبقة. لوحظ تطابق جيد ما بين النتائج العملية مع القيم النظرية .

الكلمات الرئيسة: الأبراج المميعة نوع غاز – صلب ,نسب التأرجح و التمدد.

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*Corresponding author
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1. INTRODUCTION

The fluidized bed is widely used in industrial processes. It is complex to design and operate than the packed type. Several parameters affect the behavior of material the moment it is fluidized. Therefore studying these parameters of different characteristics will help to establish common and other behaviors. (**Singh, 1999)** cleared that in general, the gas-solid beds are of aggregative nature, and bubbles and slug formation mark this behavior. (**Mohanty, et al., 2009)**, mentioned that a particular characteristic of the solid-gas fluidized bed is bubbles formation, which is responsible for the circulation of particles in the bed, the upper and lower limits of the operating range for any fluidization unit is the minimum fluidization and minimum slugging velocities, the gas bypass the bed in bubbles form, the increase in bubbles size causes a bad contact between the gas and the solid, so the overall efficiency decreases, to keep good fluidization condition the gas bubbles should be maintained small in size.

(Sulaymon, et al., 2013) used fluidized bed for heavy metals removal by algal biomass. **(Ebrahim, 2016)** worked on using fluidized beds in Fluoride ions removal from wastewater using blue and green algae biomass. **(Dora, et al., 2016)** mentioned that the fluctuation ratio is one of the essential characteristics in studying the performance of the gas-solid system. It is an inseparable phenomenon to the fluidization of gas-solid columns. Still, the strong fluctuation is undesirable and affects the quality of the system, such as it causes to increase the length of segregation, and that affects the mixing quality and causes the damage of the column after some time. Also, they cleared that bed expansion is an important phenomenon in selecting the size of the fluidization unit. **(Santos, 2018)** commented that the technique of fluidized beds applied for the status of solid fuels as an energy source, these kinds of beds are useful when treating the biomass with high moisture content. **(Marnani, et al., 2019)** explained that the main reason for the increasing use of fluidization processes in industrial processes is the high mass and heat transfer rates because of the increase in the ratio of surface-to-volume(the suspended particles offers a larger surface area than packed beds).

1.1 Fluctuation and Expansion Ratios

(Singh and Roy, 1999) defined the expansion ratio as the ratio between the average heights of the fluidized bed to the static bed height at a certain fluidizing medium velocity above the minimum fluidization velocity:

$$\text{Expansion Ratio} = R = \frac{h_2 + h_1}{2\text{h}_s} \quad (1)$$

Where:

h_2: The highest level of the top of the fluidized bed

h_1: The lowest level of the top of the fluidized bed.

The expansion ratio is a measure of the bed's ability to expand. It can be considered as an important parameter in selecting the static bed height, which is suitable for a particular duty. They concluded that the expansion ratio depends on many parameters such as static bed height, excess gas mass velocity (G_f - G_{mf}), mean particle size, and column diameter. They developed a correlation for expansion ratio as a function of dimensionless groups for cylindrical beds:

$$R = 2.55\left(\frac{dp}{Di}\right)^{0.11}\left(\frac{D_i}{h_s}\right)^{0.31}\left(\frac{\mathrm{Gf-Gmf}}{\mathrm{Gmf}}\right)^{0.18} \quad (2)$$

(Sahoo, and Roy, 2005) mentioned that the reason for expansion occurrence beyond the minimum fluidization velocity is due to bubbles formation. **(Singh, and Roy, 2006)** defined the fluctuation ratio as the ratio of the highest to the lowest level, which can be occupied by the top of a bed for a gas velocity above the minimum fluidization velocity. Experimentally:

$$\text{Fluctuation Ratio} = r = \frac{h_2}{h_1} \quad (3)$$

They cleared that the bed quality and bed fluctuation are interrelated, and the flow of gas is characterized by the prevalence of bubbles. The bubbly flow causes a significant fluctuation and non-uniform expansion for velocities higher than the minimum fluidization velocity, which leads to unstable operating conditions and bad fluidization phenomenon. They used a cylindrical column made of transparent acrylic resign with 0.01 m diameter. The materials used were coal, dolomite, sago, chromite ore, and manganese ore. They predicted a dimensionless correlation to calculate the fluctuation ratio for cylindrical columns:

$$r = 1.95\left[\left(\frac{dp}{Di}\right)^{0.04}\left\{\left(\frac{D_i}{h_s}\right)\left(\frac{\rho_f}{\rho_s}\right)\right\}^{0.04}\left(\frac{\mathrm{Gf-Gmf}}{\mathrm{Gmf}}\right)^{0.05}\right] \quad (4)$$

(Mohanty, 2007) used three cylindrical columns with internal diameters (0.099, 0.125, and 0.15 cm), static bed heights (8, 10, 12, and 14 cm), and air velocities up to 2.5-3 of the minimum fluidization velocity. He mentioned that the fluidization quality depends mainly on column diameter, which can be referred to as wall effect, especially for columns having small diameters. He concluded that both the fluctuation and expansion ratios decrease with increasing static bed height. **(Mohanty, et al., 2009)** used three cylindrical columns to predict the effect of column inside diameter on the fluctuation ratio. They carried out experiments using dolomite of 0.0055 m size. The variables were the column diameter(0.099, 0.127, and 0.1524 m), static bed height of (0.08, 0.1, and 0.12 m), and air velocity up to 3 times of minimum fluidization velocity. They concluded that both ratios had a direct relation with air velocity and an inverse one with static bed height and column diameter; the fluctuation ratio value is small in the range of mass air velocity of $G_f < 2.5\ G_{mf}$. **(Pranati, and Sahoo, 2013)** used a Perspex cylindrical column of 5 cm internal diameter to study the effect of different parameters: the air superficial velocity, static bed height, particle density, and size on the bed fluctuation using fine particles. They concluded that the expansion and fluctuation ratios increased with the increase in gas superficial velocity and decreased with increased static bed height. **(Dora, et al., 2016)** studied the fluctuation ratio of a ternary system using spherical glass beads of three sizes for static bed heights (6, 8,10,12 and 14 cm) and different superficial gas velocities. They observed that increasing the static bed height caused to decrease the fluctuation and expansion ratios, also increasing the superficial gas velocity caused to increase in bed fluctuation. **(Pahadi, et al. 2016)** studied the bed fluctuation with air superficial velocity for static bed height 0.15 cm. They observed that the fluctuation ratio increased with increasing air velocity because the high velocity caused the fluidized bed top to fluctuate considerably**.** They concluded that the bed fluctuation and the quality of fluidization are related, and the fluctuation ratio has been used to quantify the quality of fluidization. Also, they concluded that a direct relation was between static bed height and expansion ratio. **(Yupeng, et al., 2017)**, cleared that the particle wall friction and column diameter are coupled and can not be separated. They are responsible for the fluctuation variation in fluidized beds.

In this study, the fluctuation and expansion ratios have been studied for the gas-solid fluidized system. Three cylindrical columns were used, and the effect of three parameters was considered: air superficial velocity, static bed height, and column inside diameter.

2. MATERIALS and METHOD

2.1 Materials:

The material used was a pharmaceutical material "Paracetamol"**,** its properties are shown in **Table 1.**

This kind of material is considered of type B, according to Geldart classification **(Geldart, D., 1986).** It fluidizes easily with few difficulties**.**

Table1. Bed and material properties.

Inside diameter of cylindrical beds, Di (m)	0.0762, 0.15, 0.18
atic bed heights ,h_s (m)	0.05, 0.07, 0.09
Particle diameter ,d_p (m)	$1.06*10^{-3}$
Particle density, ρ_s (kg/m^3)	600
Air density, ρ_f (kg/m^3)at 25°C	1.18
Name	Paracetamol
Color	White
Shape	spherical

The schematic diagram and a photograph of the experimental set-up are shown in **Fig.1-a and b.** It contains the following parts:

a- Compressor.
b- Silica gel column: A column was filled with blue silica gel; its color changed to pink when it became saturated with humidity.

c- Calming column.
d- Rotameters: Two rotameters were used; they are calibrated at 0.981 bar abs. And 20°C air.
e- U-tube manometer.
f- Fluidization column: A Perspex cylindrical columns of different diameters and 1.0 m height were used. At the entrance of the air to the unit, a calming section filled with Rachig rings was used to get uniform air circulation throughout the bed. An air distributor was fitted at the bottom of the bed.

2.2 Method

A measured quantity of the material was charged from the bed top; the bed was fluidized, and the particles were left to settle freely by the influence of gravity for a few minutes to get the packing state. This procedure was repeated before each experiment. The static bed height was recorded. The compressed air was allowed to pass through the fluidization column, and its velocity was increased until the minimum fluidization velocity was observed experimentally. Then the air velocity increased gradually, and the heights of lowest and highest levels of the fluidized bed top were recorded. This procedure was repeated for the three-column diameters, three times for each bed height.

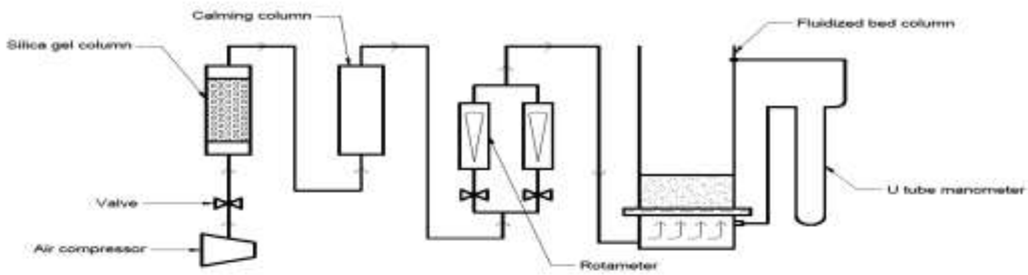

Figure. 1-a The schematic diagram of the experimental set-up.

Figure. 1-b The experimental set-up.

3. RESULTS and DISCUSSION

The experiments were carried out for measuring fluctuation and expansion ratios. The variables were: air superficial velocity (which was raised up to four times the minimum fluidization velocity for Di = 0.0762m, two and half times the minimum fluidization velocity for both Di = 0.15m and 0.18 m) beyond these values, entrainment started, static bed height (0.05, 0.07 and 0.09 m) and column inside diameter (0.0762, 0.15 and 0.18m). The results are shown in **Figs. 2-19 and Tables. 2, 3, and 4.**

The experimental expansion and fluctuation ratios were calculated by using **(Eq.1 and 3)**, their values were agreed well with the calculated ones from the correlation equations **(Eq. 2 and 4)**, the results were plotted for the three static bed heights for each column diameter, as shown in **Figs. 2-7 and Tables. 2, 3, and 4**.

It can be concluded from the **Figs. 2-7** that the best results are for the static bed heights 0.07 and 0.09 for the three-column diameters. As concluded from the results **Tables. 2, 3, and 4**, the fluctuation and expansion ratios decreased with static bed height, so for hs=0.05, there was a high bed fluctuation, which caused difficulty in the experimental readings.

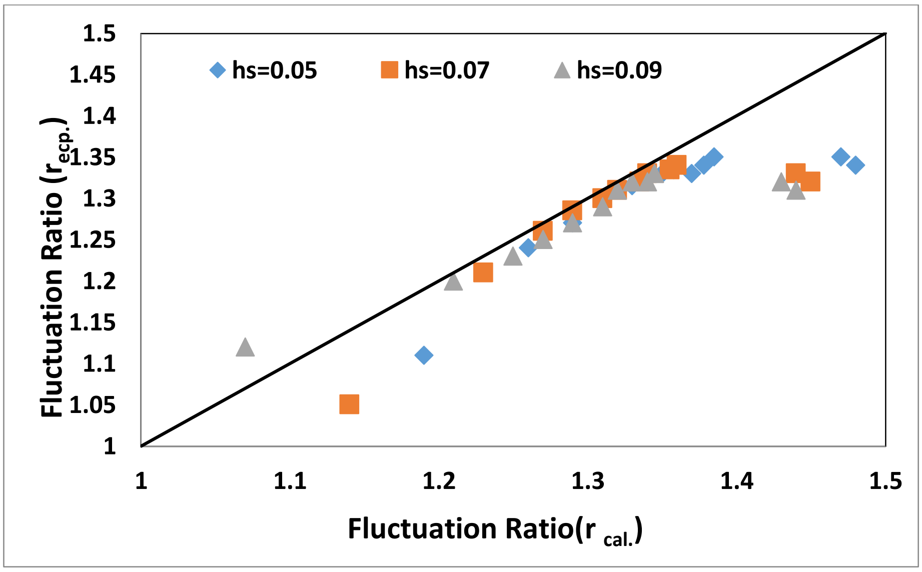

Figure. 2 Comparison between the experimental and calculated values of the fluctuation ratio for column diameter 0.0762.

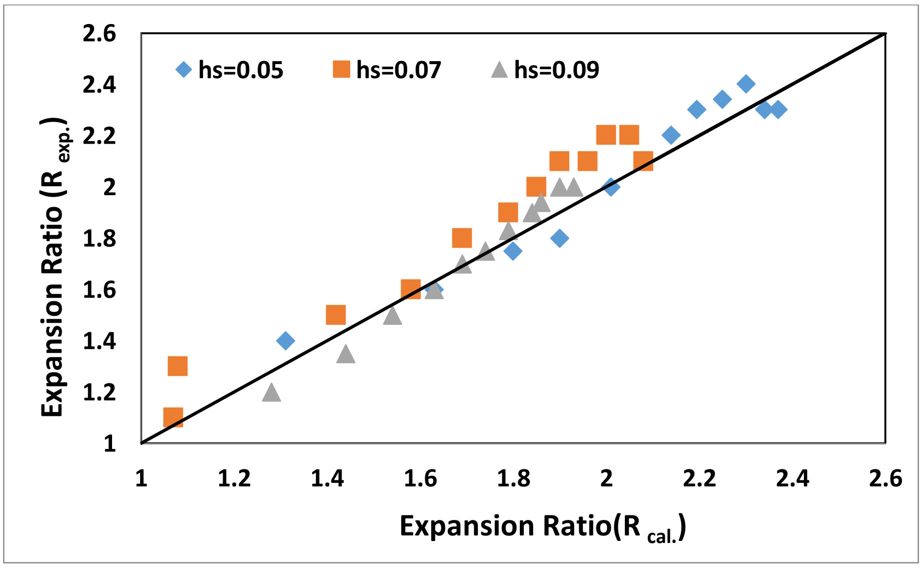

Figure. 3 Comparison between the experimental and calculated values of expansion ratio for column diameter 0.0762m.

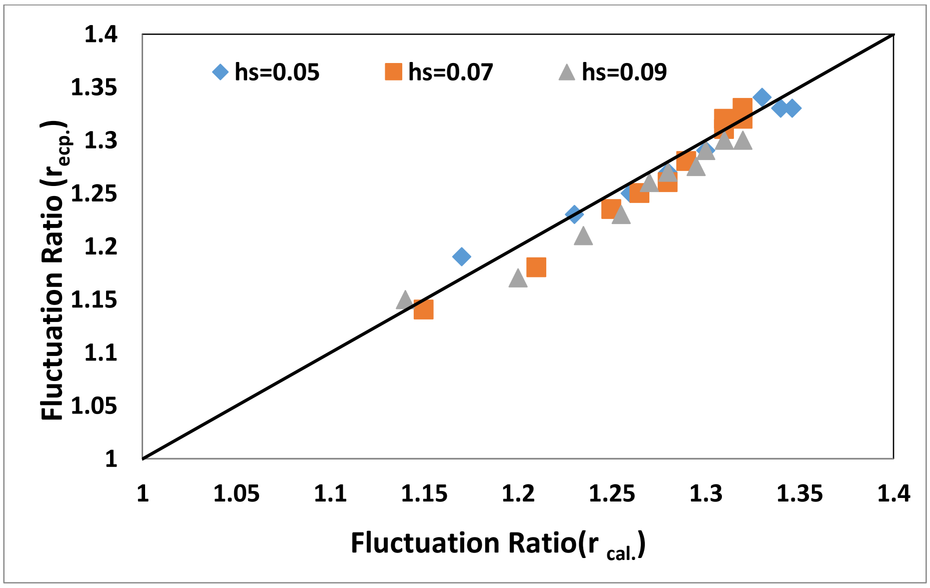

Figure. 4 Comparison between the experimental and calculated values of the fluctuation ratio for column diameter 0.15m.

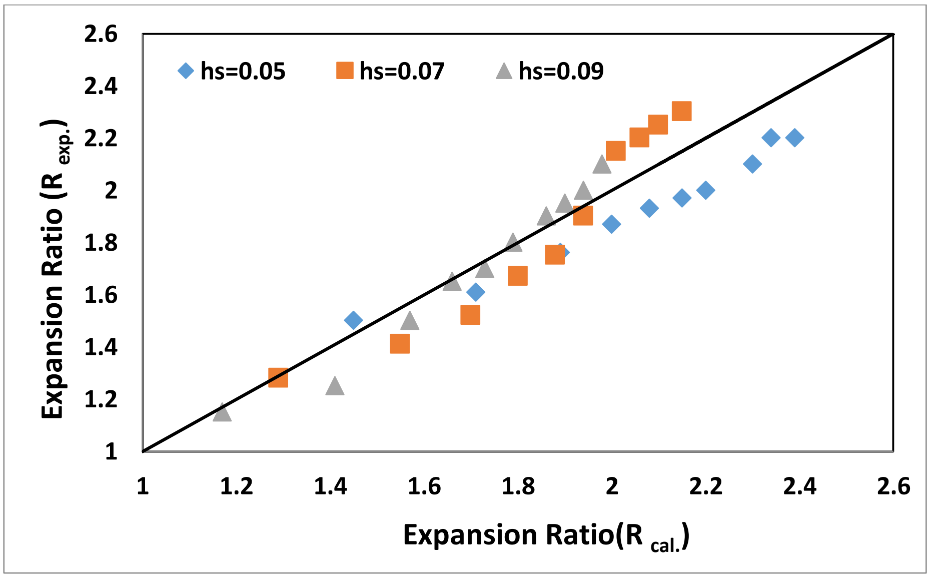

Figure. 5 Comparison between the experimental and calculated values of expansion ratio for column diameter 0.15 m.

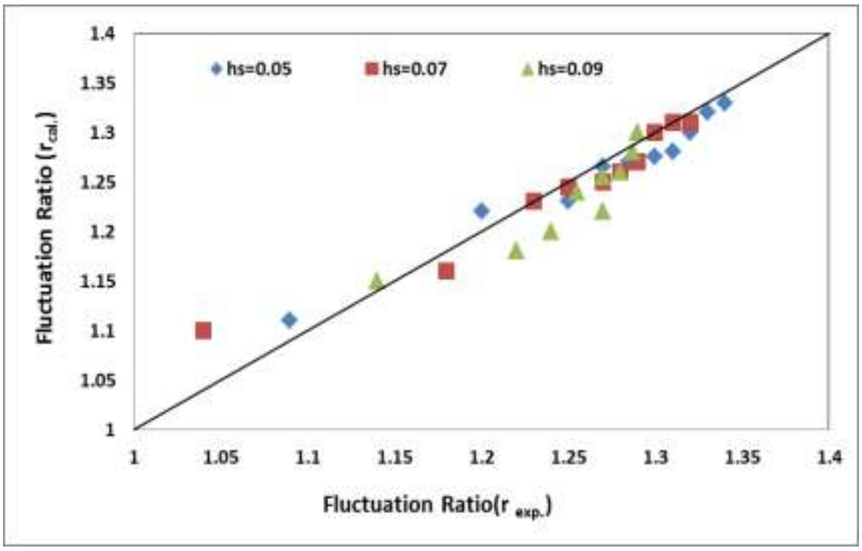

Figure.6 Comparison between the experimental and calculated values of the fluctuation ratio for column diameter 0.18m.

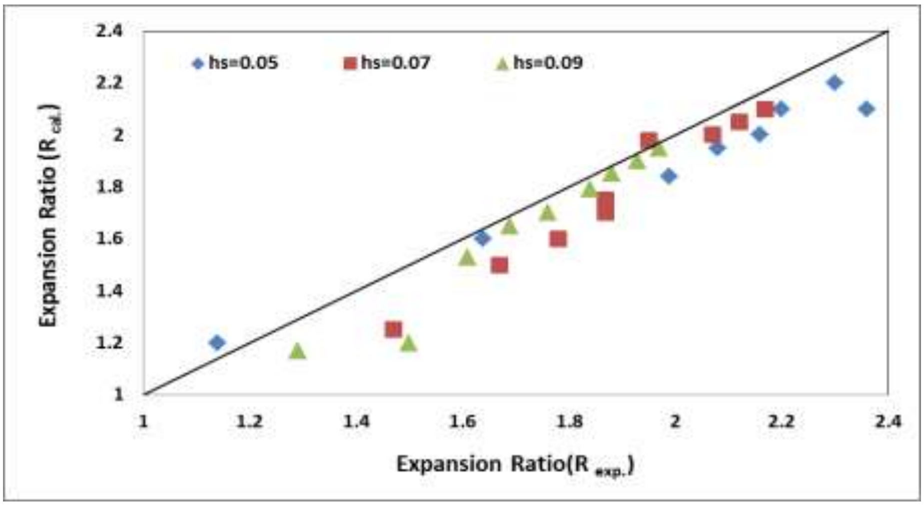

Figure.7 Comparison between the experimental and calculated values of expansion ratio for column diameter 0.18m.

Table. 2 Results and calculations for column diameter 0.0762 m.

d_p / D_i (-)	**D_i / h_s** (-)	**$\rho\rho_{f/s}$** (-) (10^3)	**G_{mf}** ($Kg/m^2.s$) (U_{mf} m/s)	**U_f** (m/s)	**G_f** Kg/m^2s	**$G_f - G_{mf}$ /G_{mf}** (-)	**$r_{cal.}$** (-) Eq.4	**$r_{exp.}$** (-) Eq.3	**$R_{cal.}$** (-) Eq.2	**$R_{exp.}$** (-) Eq.1
h_s=0.05m				0.127	0.15	0.163	1.19	1.11	1.31	1.40
				0.169	0.2	0.55	1.26	1.24	1.63	1.60
				0.212	0.25	0.94	1.29	1.27	1.80	1.75
0.014	1.524	1.967	0.129	0.25	0.3	1.33	1.31	1.3	1.90	1.80
			(U_{mf} =0.1097)	0.3	0.35	1.71	1.33	1.315	2.01	2.0
				0.34	0.4	2.10	1.35	1.33	2.08	2.10
				0.38	0.45	2.49	1.358	1.335	2.14	2.20
				0.42	0.5	2.88	1.37	1.33	2.195	2.30
				0.47	0.55	3.26	1.378	1.34	2.25	2.34
				0.51	0.6	3.65	1.385	1.35	2.30	2.40
				0.55	0.65	4.04	1.47	1.35	2.34	2.30
				0.59	0.70	4.43	1.48	1.34	2.37	2.30
h_s=0.07m				0.127	0.15	0.10	1.14	1.05	1.07	1.10
				0.169	0.20	0.46	1.23	1.21	1.08	1.30
0.014	1.089	1.967	0.1366	0.212	0.25	0.83	1.27	1.26	1.42	1.50
			(U_{mf} = 0.116)	0.25	0.30	1.20	1.29	1.285	1.58	1.60
				0.3	0.35	1.56	1.31	1.30	1.69	1.80
				0.34	0.40	1.93	1.32	1.31	1.79	1.90
				0.38	0.45	2.29	1.335	1.32	1.85	2.0
				0.42	0.50	2.66	1.34	1.33	1.90	2.1
				0.47	0.55	3.03	1.355	1.335	1.96	2.1

				0.51	0.60	3.39	1.36	1.34	2.0	2.2
				0.55	0.65	3.76	1.44	1.33	2.05	2.2
				0.59	0.70	4.12	1.45	1.32	2.08	2.1
h_s=0.09m				0.127	0.15	0.04	1.07	1.12	0.85	1.0
				0.169	0.2	0.39	1.21	1.20	1.28	1.2
0.014	0.85	1.967	0.144	0.212	0.25	0.74	1.25	1.23	1.44	1.35
			(U_{mf} = 0.122)	0.25	0.3	1.08	1.27	1.25	1.54	1.50
				0.3	0.35	1.43	1.29	1.27	1.63	1.60
				0.34	0.4	1.78	1.31	1.29	1.69	1.70
				0.38	0.45	2.13	1.32	1.31	1.74	1.75
				0.42	0.5	2.47	1.33	1.32	1.79	1.83
				0.47	0.55	2.82	1.34	1.32	1.84	1.90
				0.51	0.6	3.17	1.345	1.33	1.86	1.94
				0.55	0.65	3.51	1.43	1.32	1.90	2.0
				0.59	0.70	3.86	1.44	1.31	1.93	2.0

Table. 3 Results and Calculations for column diameter 0.15 m.

d_p / D_i (-) (*10³)	D_i / h_s (-)	$\rho_s \rho_f /$ (-) (*10³)	G_{mf} (Kg/m².s) (U_{mf} m/s)	U_f (m/s)	G_f (Kg/m².s)	$G_f – G_{mf} / G_{mf}$	$r_{cal.}$ (-) **Eq.4**	$r_{exp.}$ (-) **Eq.3**	$R_{cal.}$ (-) **Eq.2**	$R_{exp.}$ (-) **Eq.1**
h_s=0.05m				0.212	0.25	0.14	1.17	1.19	1.45	1.50
				0.25	0.30	0.37	1.23	1.23	1.71	1.61
				0.30	0.35	0.60	1.26	1.25	1.89	1.76
7.07	3.0	1.967	0.2195	0.34	0.40	0.83	1.28	1.27	2.0	1.87
			(U_{mf} = 0.186)	0.38	0.45	1.05	1.30	1.29	2.08	1.93
				0.42	050	1.28	1.31	1.31	2.15	1.97

				0.47	0.55	1.51	1.32	1.33	2.20	2.0
				0.51	0.60	1.74	1.33	1.34	2.30	2.10
				0.55	0.65	1.97	1.34	1.33	2.34	2.20
				0.59	0.70	2.20	1.346	1.33	2.39	2.20
h_s=0.07m 7.07	2.143	1.967	0.222 (U_{mf} = 0.188)	0.212	0.25	0.126	1.15	1.14	1.29	1.28
				0.25	0.30	0.35	1.21	1.18	1.55	1.41
				0.30	0.35	0.58	1.25	1.24	1.70	1.52
				0.34	0.40	0.80	1.265	1.25	1.80	1.67
				0.38	0.45	1.03	1.28	1.26	1.88	1.75
				0.42	0.50	1.25	1.29	1.28	1.94	1.90
				0.47	0.55	1.48	1.31	1.31	2.01	2.15
				0.51	0.60	1.70	1.31	1.32	2.06	2.20
				0.55	0.65	1.93	1.32	1.33	2.10	2.25
				0.59	0.70	2.15	1.32	1.32	2.15	2.30
h_s=0.09m 7.07	1.667	1.967	0.224 (U_{mf} = 0.19)	0.212	0.25	0.116	1.14	1.15	1.17	1.15
				0.25	0.30	0.34	1.20	1.17	1.41	1.25
				0.30	0.35	0.56	1.235	1.21	1.57	1.50
				0.34	0.40	0.79	1.255	1.23	1.66	1.65
				0.38	0.45	1.01	1.27	1.26	1.73	1.70
				0.42	0.50	1.23	1.28	1.27	1.79	1.80
				0.47	0.55	1.46	1.295	1.28	1.86	1.90
				0.51	0.60	1.68	1.30	1.29	1.90	1.95
				0.55	0.65	1.90	1.31	1.30	1.94	2.0
				0.59	0.70	2.125	1.32	1.30	1.98	2.10

Table. 4 Results and calculations for column diameter 0.18m .

d_p/D_i (-) (*10^3)	D_i/h_s (-)	$\rho_s \rho_f$/ (-) (*10^3)	G_{mf} ($Kg/m^2.s$) (U_{mf} m/s)	U_f (m/s)	G_f (Kg/m^2s)	$G_f - G_{mf}$ / G_{mf} (-)	$r_{cal.}$ Eq.4	$r_{exp.}$ Eq.3	$R_{cal.}$ (-) Eq.2	$R_{exp.}$ (-) Eq.1
h_s=0.05m				0.212	0.25	0.03	1.09	1.11	1.14	1.20
				0.25	0.30	0.24	1.20	1.22	1.64	1.60
5.89	3.6	1.967	0.242	0.30	0.35	0.45	1.25	1.23	1.87	1.75
			(U_{mf} = 0.205)	0.34	0.40	0.65	1.27	1.265	1.99	1.84
				0.38	0.45	0.86	1.29	1.27	2.08	1.95
				0.42	050	1.07	1.30	1.275	2.16	2.0
				0.47	0.55	1.27	1.31	1.28	2.20	2.1
				0.51	0.60	1.48	1.32	1.30	2.30	2.20
				0.55	0.65	1.69	1.33	1.32	2.36	2.10
				0.59	0.70	1.89	1.34	1.33	2.40	2. 0
h_s=0.07m				0.212	0.25	0.02	1.04	1.10	0.96	1.0
				0.25	0.30	0.22	1.18	1.16	1.47	1.25
5.89	2.57	1.967	0.246	0.30	0.35	0.42	1.23	1.23	1.67	1.50
			U_{mf}=0.2086)	0.34	0.40	0.63	1.25	1.245	1.78	1.60
				0.38	0.45	0.83	1.27	1.25	1.87	1.70
				0.42	050	1.03	1.28	1.26	1.87	1.75
				0.47	0.55	1.24	1.29	1.27	1.95	1.98
				0.51	0.60	1.44	1.30	1.30	2.07	2.0
				0.55	0.65	1.64	1.31	1.31	2.12	2.05
				0.59	0.70	1.85	1.32	1.31	2.17	2.10
h_s=0.09m				0.212	0.25	-	-	-	-	-

				0.25	0.30	0.16	1.14	1.15	1.29	1.17
5.89	2.0	1.967	0.258	0.30	0.35	0.36	1.22	1.18	1.50	1.20
			U_{mf}=0.2184)	0.34	0.40	0.55	1.24	1.20	1.61	1.53
				0.38	0.45	0.77	1.27	1.22	1.69	1.65
				0.42	0.50	0.94	1.26	1.24	1.76	1.70
				0.47	0.55	1.13	1.27	1.255	1.84	1.79
				0.51	0.60	1.33	1.28	1.26	1.88	1.85
				0.55	0.65	1.52	1.29	1.28	1.93	1.90
				0.59	0.70	1.71	1.29	1.30	1.97	1.95

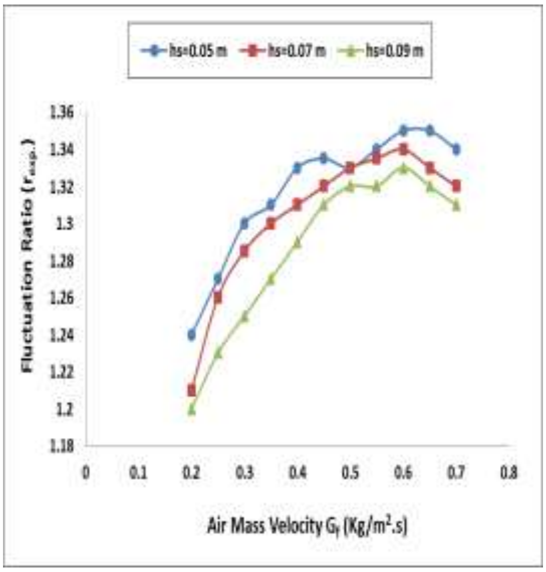

Figure. 8 Effect of static bed height on fluctuation ratio for Di=0.0762m.

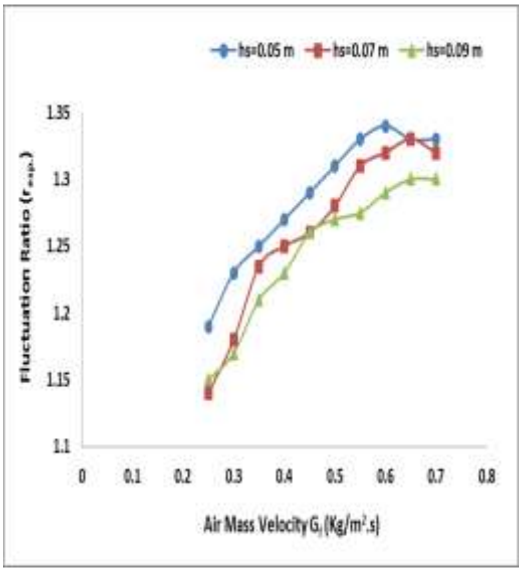

Figure. 9 Effect of static bed height on fluctuation ratio for Di=0.15m.

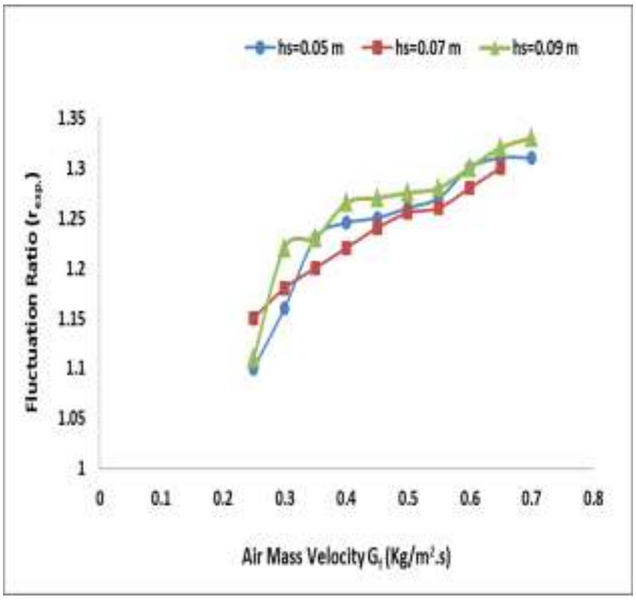

Figure. 10 Effect of static bed height on fluctuation ratio for Di = 0.18m.

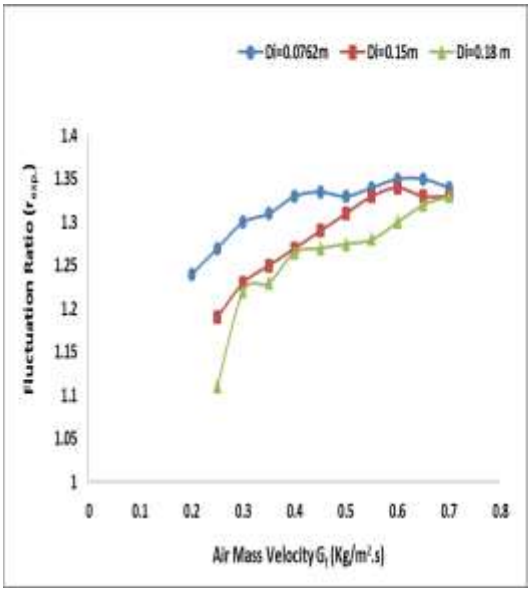

Figure.11 Effect of column diameter on fluctuation ratio for hs=0.05m

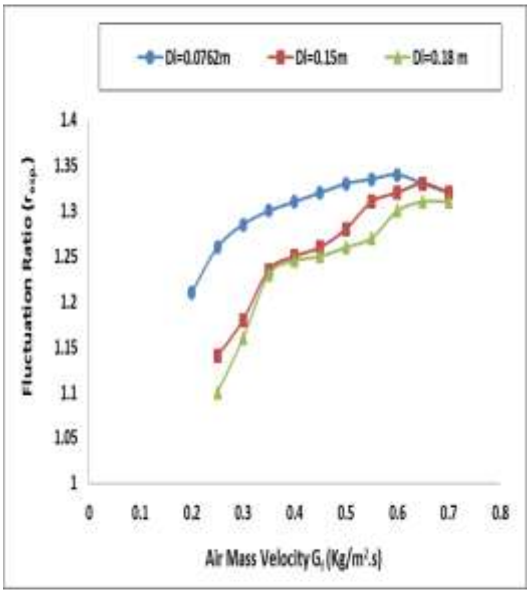

Figure. 12 Effect of column diameter on fluctuation ratio for hs=0.07m.

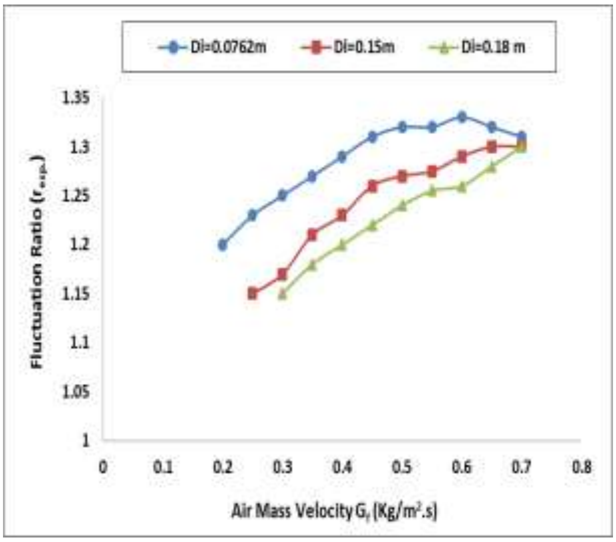

Figure. 13 Effect of column diameter on fluctuation ratio for hs = 0.09 m.

From **Tables. 2, 3,** and **4** and **Figs. 8-13**, it can be concluded that the fluctuation ratio varied directly with air velocity. By increasing the air superficial velocity above the minimum fluidization velocity, bed fluctuation started and increased because above this velocity bubbles started to form and break; "due to collision of bubbles with particles and between them". Also, by increasing gas superficial velocity, the fluctuation ratio increased due to a sharp increase in particle pneumatic conveyance, which caused unstable conditions, and that agreed with **(Dora, et al., 2016)**. By a further increase in the air velocity, the bubbles grew in size and became bigger and caused to increase in the bed fluctuation until it became maximum at a certain gas velocity and then remained constant or decreased at higher velocities because of slug formation and that agreed with **(Singh, and Roy, 2006).** The decrease was associated with bed expansion where the particles separated from each other; this separation increased with increased air velocity and caused to reduce the bed fluctuation.

From **Figs. 8, 9,** and **10,** the fluctuation ratio changed inversely with static bed height. This can be explained due to the drag force affecting the particles during the process of fluidization. The wall friction opposes the weight of the bed, so increasing the bed height means increasing the bed weight, and that increased the friction enhancement, which reduces the bed fluctuation and that agreed with **(Yupeng, et al., 2017).** They explained that the bed height increase causes to increase the contributed wall effects: the boundary wall effect and the particle wall friction**.**

From **Fig. 11, 12, and 13,** the fluctuation ratio decreased with increasing column diameter. This can be explained by increasing column diameter, and for the same bed height, which means a larger weight of the material, the wall friction increased and that increase the resistance to airflow and caused to decrease in the bed fluctuation, and that agreed with **(Mohanty, 2007)**, who concluded that the column diameter greatly affects on fluidization quality which can be referred to wall effect especially for columns having a small diameter, and also agreed with **(Yupeng, et al., 2017).** From **Figs. 8-13**, the fluctuation ratio was less in the case of larger diameters columns compared with columns having smaller diameters because the bubbles grew in size and reached the column diameter and burst, and that caused to increase the ratio. Still, for the columns with larger diameters, the bubbles did not reach the column diameter. When the air velocity reached four times the U_{mf} for Di=0.0762m, two and a half times the U_{mf} for both Di=0.15m and 0.18 m, the fluctuation ratio remained constant or decreased because of channeling effect **(Mohanty, 2007).**

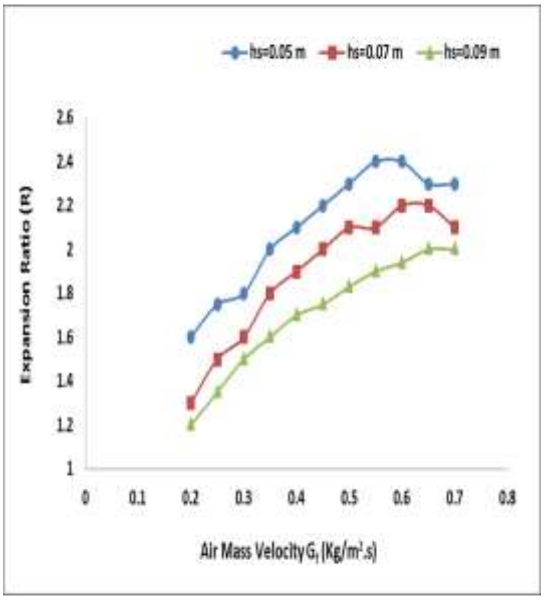

Figure.14 Effect of static bed height on expansion ratio for Di = 0.0762m.

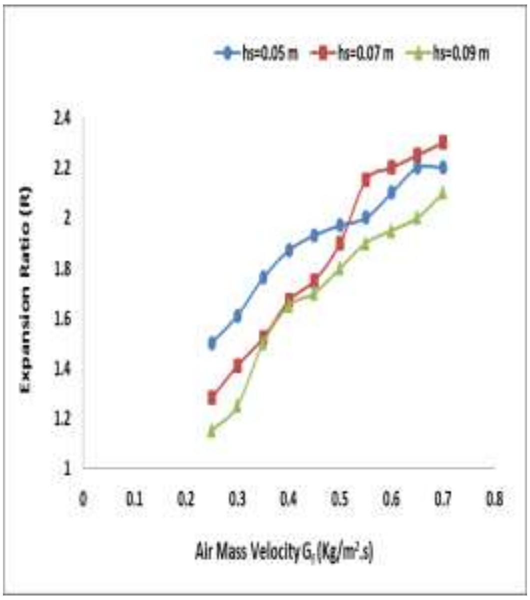

Figure.15 Effect of static bed height on expansion ratio for Di = 0.15m.

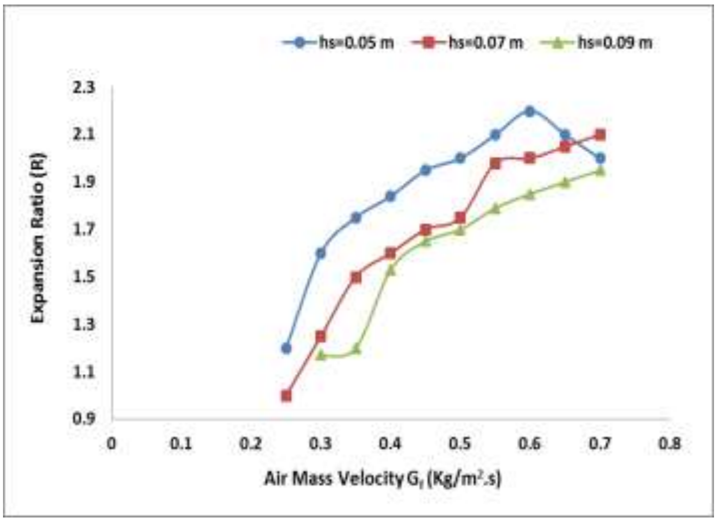

Figure . 16 Effect of static bed height on expansion ratio for Di=0.18m.

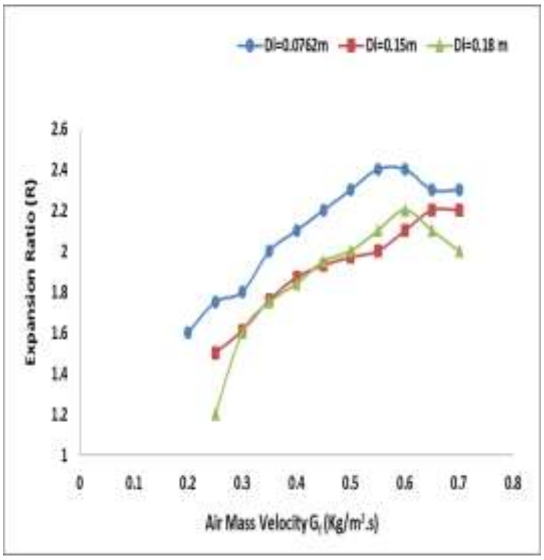

Figure . 17 Effect of column diameter on expansion ratio for hs=0.05m.

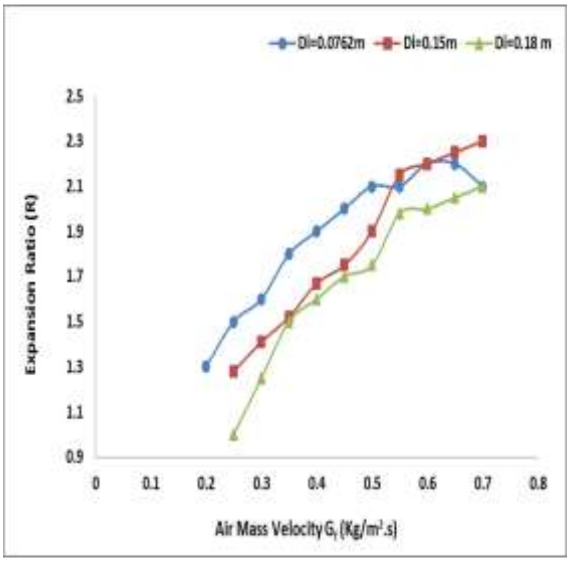

Figure . 18 Effect of column diameter on expansion ratio for hs=0.07m.

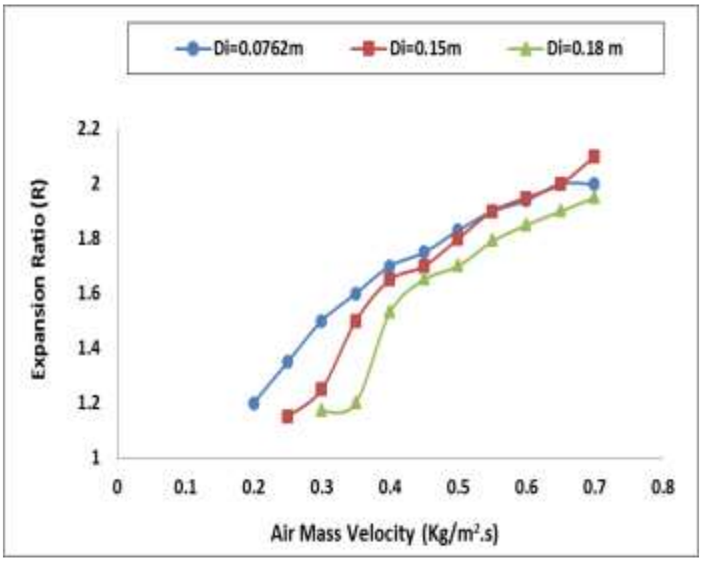

Figure . 19 Effect of column diameter on expansion ratio for hs = 0.09.

From **Tables . 2, 3,** and **4 and Figs. 14-19,** it can be noted that the expansion ratio had a direct relation with air superficial velocity. This is because when the air velocity exceeded the minimum fluidizing velocity, the bubbles started to form, by further increase in the air velocity, the bubbles grew in size and became bigger and that result to increase the bed volume. The bubbles diameter increased until nearly approached the diameter of the bed and that caused the bed to expand.

The expansion ratio had an inverse relation with the static bed height. This can be explained due to the wall friction effect. It is inverse the bed weight, so for higher bed height, the bed weight increased, and the friction effect increased, which caused to reduce the bed expansion. The expansion ratio decreased with increasing column diameter, and this behavior is due to the same reason that mentioned for the fluctuation ratio, the resistance to airflow increased because of the wall friction, which caused the decrease in the bed expansion.

4. CONCLUSIONS

1. The fluctuation ratio varies directly with air superficial velocity and inversely with static bed height and column diameter.
2. The fluctuation ratio is used to quantify the quality of fluidization, which can be improved by lowering the static bed height.
3. The expansion ratio had a direct relation with air superficial velocity and an inverse relation with the static bed height and column diameter.
4. The expansion ratio is a measure of the bed's ability to expand. It should be considered in selecting the static bed height, which is suitable for a particular duty and in choosing the column length.

5. NOMENCLATURE

D_i= column inside diameter, m

d_p = mean particle diameter, m

G_f = air mass velocity, $Kg/m^2.s$

G_{mf} = air mass velocity at minimum fluidization velocity, $Kg/m^2.s$

h_s= static bed height, m

r = fluctuation ratio, dimensionless

R=expansion ratio, dimensionless

U_{mf} = minimum fluidization velocity, m/s

U_f = air Superficial velocity, m/s

ρ_s = density of solid particles, Kg/m^3

ρ_f = density of air, Kg/m^3

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