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Separation of binary solid mixtures by fluidization

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ABSTRACT:
The process of fluidization involves bringing granular materials into contact with a fluid, which causes them to change into a fluid-like state. The Ergun equation can be used to measure the pressure drop by passing a liquid or gas through a bed, created with the help of solid particles at a very low velocity. Since the solid particles remain stationary, the drag and the pressure drop on each of the particles grow as the fluid velocity is gradually raised, causing the particles to become suspended and move in the fluid.
Screening, flotation, jigging, wiley tables, cyclone separators, and other methods are used to separate mixtures of materials. The solid mixes of various sizes and densities are attempted to be separated in this work via fluidization. The literature on this separation procedure is scarce.
Based on dimensional analysis and experimentation, equations are created to determine the separation amount. These equations have an error rate of under 15%. This approach is beneficial for using cylindrical columns to separate vast amounts of solid mixes in businesses and industries.

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I. INTRODUCTION:

Free granular solids are converted into a fluid-like condition by the process of fluidization, which takes place when they come into contact with a fluid. There would be an increment in the drag and the pressure drop on independent particles when there is a gradual increment in the fluid velocity, and after a period of time, the particles start to move and become suspended in the fluid.

The main benefits of fluidization are ensuring complete fluid contact with all solid particle surfaces, preventing particle segregation through vigorous bed agitation, reducing temperature differences even in large reactors, and ensuring rapid heat and mass transfer rates. Fluidization is used in synthesis operations, drying and sizing of crystals, conveying solids, covering metal surfaces with plastic compounds, and catalytic cracking reactors in the petroleum sector.

The drawbacks of fluidization include higher power needs, significant solid particle leakage, severe pipe and container erosion, and the demand for larger reactors. The binary solid mixtures are attempted to be separated in this work via fluidization. On the basis of dimensional analysis and a number of operational variables, equations are built.

FORMULATION OF EQUATIONS:

The various variables involved are: 1-size of the small size particles(d_s),2-size of the big size particle (d_b),3-density of small size particles(ρ_{ss}),4-density of big size particle(ρ_{sb}),5-minimum fluidization velociy(G_{mf}),6-operating fluidization velocity(G),7-total height of bed(h_t) and 8-diameter of the column (D_c).h_s is the height of small size particles(1,2,3,4,5).

$$h_s = f(h_t, d_s, d_b, G_{mf}, G, \rho_{ss}, \rho_{sb}, D_c) \text{-----} \quad \text{-(1)}$$

Applying Rayleigh's method of dimensional analysis, equation (1) can be written as:

$$h_s = k\, h_t^a\, d_s^b\, d_b^c, G_{mf}^d, G^e \rho_{ss}^f, \rho_{sb}^g, D_c^h \text{------} \quad (2)$$

Putting dimensions on both sides (L, M, and T), equating the dimensions and collecting powers gives,

$$h_s/D_c = k1\, [(h_t/D_c)^a (d_s/D_c)^b (d_b/D_c)^c (G_{mf}/G)^e (\rho_{sb}/\rho_{ss})^g]^m \text{----} \quad (3)$$

The values of k1, a, b, c, e, g, and m are found by conducting the experiments.

Using the same equations (1) and (2) and applying Rayleigh's method using dimensional analysis, another form of equation obtained is:

$$h_s/h_t = k2\, [(d_s/h_t)^b (d_b/h_t)^c (D_c/h_t)^h (G_{mf}/G)^e (\rho_{sb}/\rho_{ss})^g]^n \text{------} \quad (4)$$

The values of b, c, d, e, g, n, and k2 are obtained by the experiments.

Experimentation:

The experimental set-up consists of a blower for air, a heating system that is not in use, a flow control valve for air, a U-tube manometer for measuring air flow, a switch board with indicators for temperatures, voltage, and current, a fluidization column, and a screen to catch solids in the column.

For Example to find the "a" value in equation 3, h_t/D_c is only varied and the rest on the right side of equation 3 are kept as constants. The observations of the left side, h_s/D_c are noted. Plotting log values of h_s/D_c and h_t/D_c gives the value (a) as a slope (Straight line relation). This procedure is repeated for b, c, e, g values. Lastly the values of k1 and m are obtained by experiments (6).

II. Results and Discussion:

For Equation 3:The observations for power of 'a' are shown in the table-1. The observations for power of 'c' are shown in the table-2. The observations for power of 'b' are shown in the table-3. The observations for power of 'e' are shown in the table-4. The observations for power of 'g' are shown in the table-5. The observations for power of 'k1' and 'm' are shown in the table-6. Finally the comparison of equation values and observed values of h_s/D_c are shown in table – 7.

The values obtained for equation 3 are: a=1.07,b=-0.35,c=-0.30,e=-0.43,g=0.08,k1=0.07 and m=0.93.

The final correlated equation is (for equation 3):

$$h_s/D_c=0.07\,(h_t/D_c)^{0.995}\,(d_s/D_c)^{-0.325}\,(d_b/D_c)^{-0.279}\,(G_{mf}/G)^{-0.399}\,(\rho_{sb}/\rho_{ss})^{0.074} \quad \text{---(5)}$$

Table – 1: Power of "a"(h_s Vs. h_t,Equ.3)

S.no	h_{t*100}	h_{s*100}	G_{mf}/G	h_s/d_c	h_t/d_c
1	14.0	6.9	0.67	3.63	7.36
2	18.0	7.6	0.67	4.00	9.47
3	22.0	8.6	0.67	4.47	11.5
4	26.0	9.5	0.67	5.00	13.6
5	30.0	10.4	0.67	5.47	15.78
6	34.0	12.6	0.67	6.63	17.80

D_c=0.019,d_s=0.00068,d_b=0.001107, ρ_{ss} =1600,ρ_{sb}=1600,Material:Sand,a=0.567

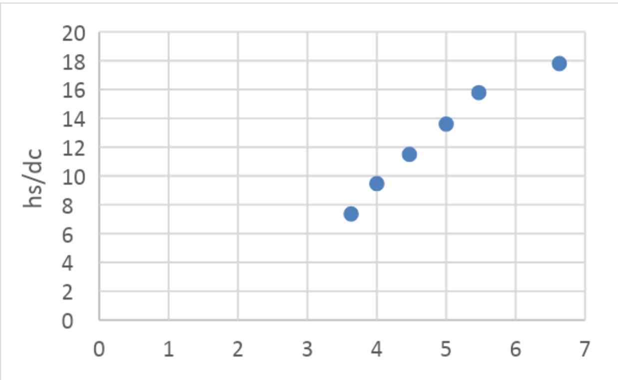

Fig 1: Power of "a"(h_s Vs. h_t,Equ.3)

Table – 2: Power of "c"(h_s Vs.d_b,Equ.3)

S.no	h_{t*100}	h_{s*100}	d_{b*100}	G_{mf}/G	h_s/d_c
1	8.0	3.0	0.356	0.67	1.57
2	8.0	3.5	0.21	0.67	1.84
3	8.0	4.0	0.1107	0.67	2.10
4	8.0	4.3	0.068	0.67	2.31
5	8.0	4.7	0.045	0.67	2.48
6	8.0	4.9	0.039	0.67	2.57

D_c=0.0190, d_s=0.00032, ρ_{ss}=1600, ρ_{sb}=1600,Material:Sand,c=-0.2457

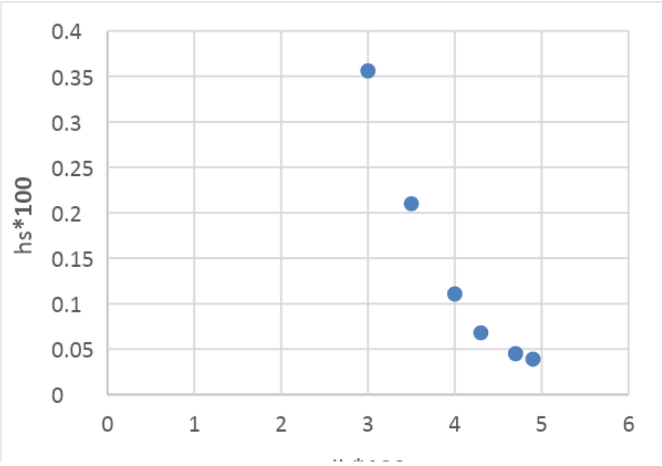

Fig 2: Power of "c"(h_s Vs.d_b,Equ.3)

Table – 3: Power of "b"(h_sVs. D_c,Equ.3)

S.no	h_{t*100}	h_{s*100}	d_{s*100}	G_{mf}/G
1	8.0	4.0	0.21	0.67
2	8.0	4.4	0.1107	0.67
3	8.0	4.8	0.068	0.67
4	8.0	5.0	0.045	0.67
5	8.0	5.3	0.039	0.67
6	8.0	5.5	0.032	0.67

D_c=0.0190, d_b= 0.00356, ρ_{ss} = 1600, ρ_{sb} = 1600,Material:Sand,b=-0.1682

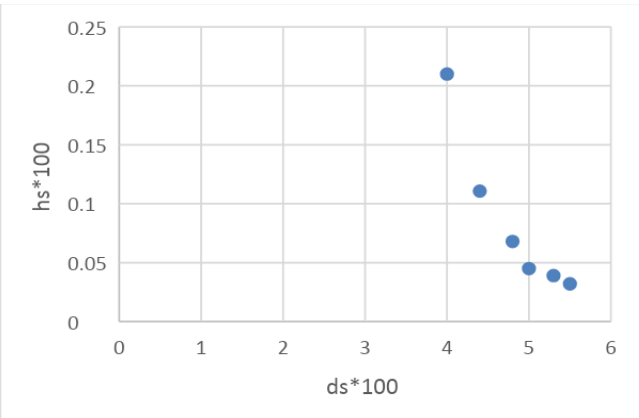

Fig 3: Power of "b"(h_sVs. D_c,Equ.3)

Table – 4: Power of "e"(h_sVs.G_{mf}/G,Equ.3)

S.no	h_{t*100}	h_{s*100}	G_{mf}/G	h_s/d_c
1	8.0	3.5	0.67	1.84
2	8.0	3.7	0.50	2.10
3	8.0	3.8	0.4	2.00
4	8.0	4.1	0.33	2.15
5	8.0	4.3	0.28	2.26
6	8.0	4.5	0.25	2.31

D_c=0.0190, d_s = 0.00378, d_b= 0.00462, ρ_{ss} =7630, $\rho_{sb=}$7630,Material:Sand, e=-0.238

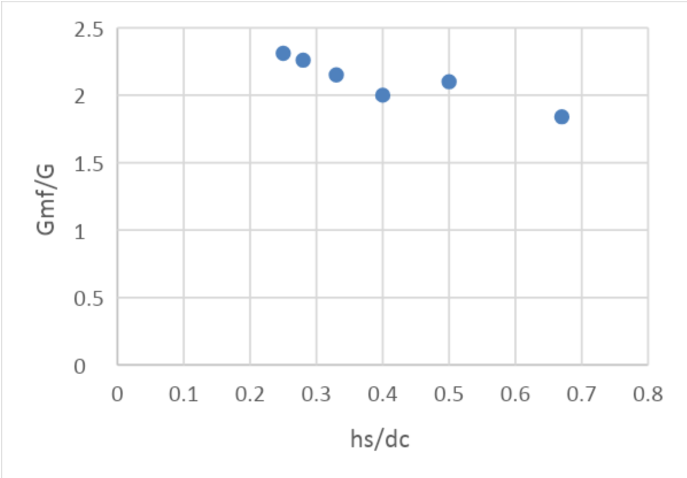

Fig 4: Power of "e"(h_sVs.G_{mf}/G,Equ.3)

Table – 5: Power of "g"(h_s vs. ρ_{sb},Equ.3)

S.no	h_{t*100}	h_{s*100}	$\rho_{ss}/1000$	$\rho_{sb}/1000$	h_s/D_c	ρ_{sb}/ρ_{ss}
1	10.0	4.5	2.15	7.63	2.36	3.548
2	10.0	5.4	2.15	2.15	2.84	1.00
3	10,0	5.7	2.15	2.15	3.00	1.004
4	10.0	5.8	2.15	1.40	3.05	0.651
5	10.0	6.0	2.15	1.10	3.15	0.511
6	10.0	6.40	2.15	0.60	3.36	0.279
7	10.0	6.8	2.15	0.43	3.57	0.200

D_c=0.0190, G_{mf}/G = 0.67, d_b= 0.0021,d_s=0.00112,Materials:Steel,dolamite,Bengal gram, Berry seeds, sodium chloride; g=-0.141.

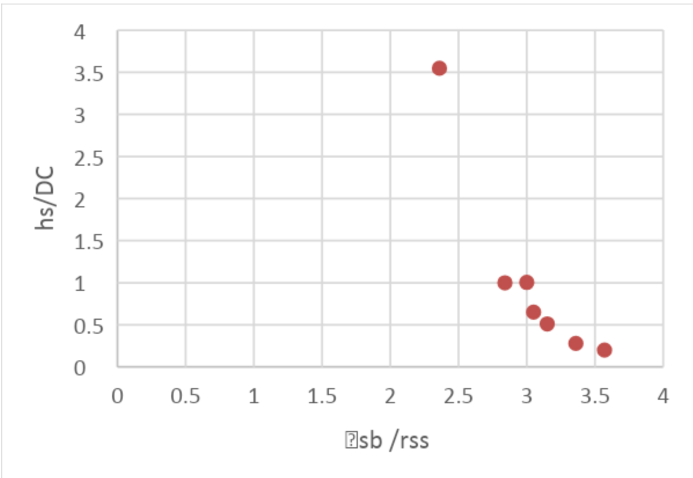

Fig 5: Power of "g"(h_s vs. ρ_{sb},Equ.3)

Table – 6: k1 and m values(Equ.3)

S no	h_s/D_c	$[(h_t/D_c)^a (d_s/D_c)^b (d_b/D_c)^c (G_{mf}/G)^e (\rho_{sb}/\rho_{ss})^g]$
1	2.08	4.46
2	2.68	5.00
3	3.38	5.75
4	3.54	6.02
5	3.71	6.76
6	1.90	3.68
7	3.80	7.58
8	3.89	7.94
9	4.07	8.10
10	4.26	8.40
11	4.46	8.59
12	4.57	8.99
13	4.78	9.52

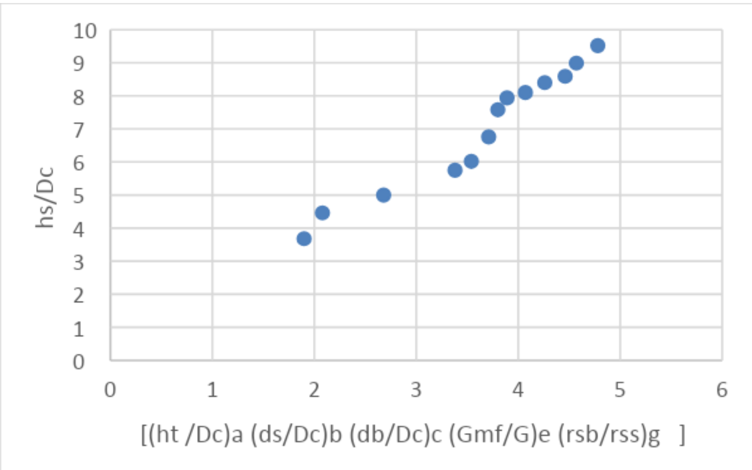

Fig 6: k1 and m values(Equ.3)

Table – 7: Comparison (Equ.3)

S. No	$d_{s}*100$	$d_{b}*100$	$\rho_{sb}/1000$	$\rho_{ss}/1000$	G_{mf}/G	$h_{s}*100$	$h_{t}*100$	$(h_s/D_c)_{equ}$	$(h_s/D_c)_{obs}$	% error
1	0.356	0.589	1.1	1.6	0.83	5.0	10	2.72	2.63	-3.42
2	0.3075	0.462	7.63	2.51	0.66	9.8	18.2	2.69	2.52	-6
3	0.3075	0.462	7.63	2.57	0.83	4.6	10.0	2.5	2.4	-7.0
4	0.45	0.68	7.63	2.51	0.83	5.8	12.0	2.46	3.05	19.3
5	0.45	0.68	7.63	2.57	0.66	5.9	12.0	2.6	3.1	16.0

6	0.3075	0.462	7.63	2.51	0.83	6.8	14.0	3.0	3.57	16.0
7	0.3075	0.378	7.63	2.57	0.83	6.5	14.0	3.15	3.42	14.4
8	0.45	0.68	7.63	2.51	0.83	3.4	7	1.53	1.8	16.3
9	0.45	0.68	7.63	2.51	0.66	6.3	13.0	2.9	3.3	12.1
10	0.45	0.68	7.63	2.51	0.83	4.9	11	2.2	2.57	14.3
11	0.45	0.68	7.63	2.51	0.83	4.0	8.0	1.8	2.1	14.2
12	0.45	0.68	7.63	2.51	0.83	3.7	7.5	1.7	2.0	16.0

Arithmetic mean absolute error = 14.3

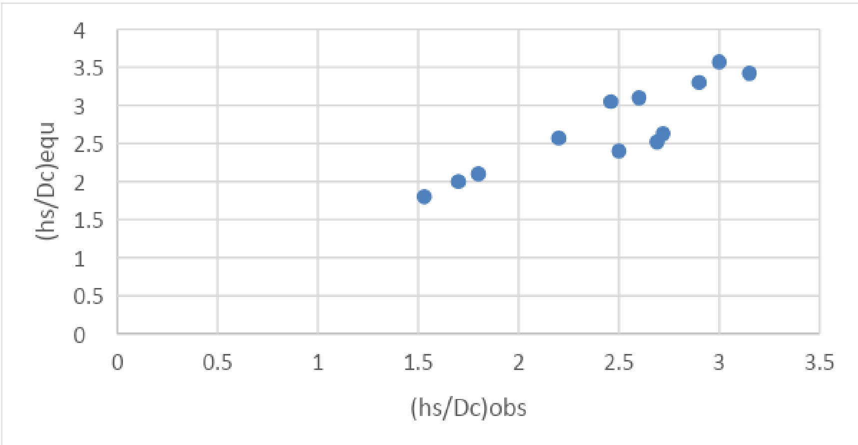

Fig 7: Comparison (Equ.3)

For Equation 4:The observations for power of "b"are shown in the table-8.The observations for power of "c"are shown in tabe-9.The observations for power of "e" are shown in tabe-10.The observations for power of"h"are shown inable-11.The observations for power of"g" are shown in table-12.The observations for "n" and "k2" are shown in table-13.The comparion of "(h_s/h_t)obs. Versus (h_s/h_t)cal. are shown in table-14.

Table – 8: Power of "b"(h_s vs.d_s,Equ.4)

S. NO	h_{s*100}	h_{t*100}	d_{s*100}
1	6.0	10.5	0.613
2	5.5	10.5	0.462
3	4.0	10.5	0.378
4	3.5	10.5	0.290

D_c=0.0190,d_b= 0.00774,G_{mf}/G = 0.67,ρ_{sb} =7813,ρ_{ss}=7813,b=-0.75,Material:Steel

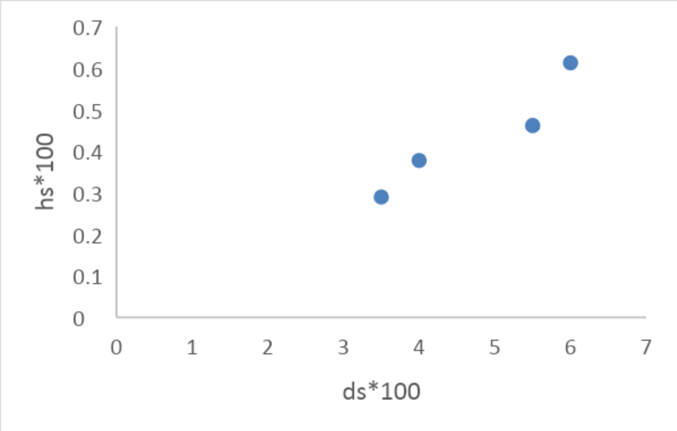

Fig - 8: Power of "b"(h_s vs.d_s,Equ.4)

Table – 9: Power of "c"(h_s vs.d_b,Equ.4)

S no	h_{s*100}	h_{t*100}	d_{b*100}
1	5.2	10.5	0.774
2	6.0	10.5	0.613
3	6.5	10.5	0.460
4	6.7	10.5	0.370
5	7.3	10.5	0.290

D_c=0.0190, d_s =0.0027,G_{mf}/G =0.67, ρ_{sb} =7813,ρ_{ss}=7813,Material:Steel,c=0.32

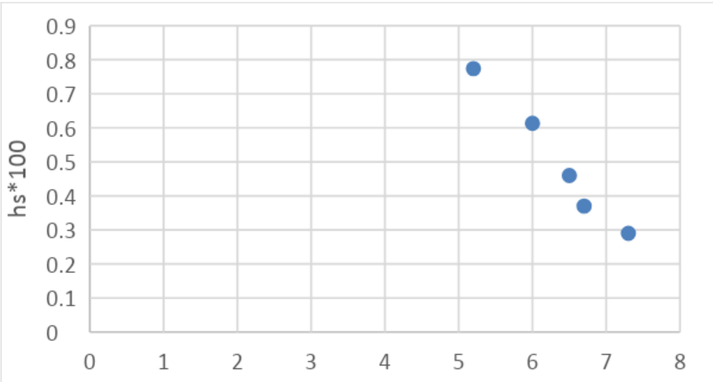

Fig-9: Power of "c"(h_s vs.d_b,Equ.4)

Table – 10: Power of "e"(h_s vs.G_{mf}/G,Equ.4)

S no	h_{s*100}	h_{t*100}	G_{mf*100}	G*100	G_{mf}/G
1	11.5	25.0	2.9	4.35	0.66
2	11.9	25.0	2.9	5.80	0.50
3	12.3	25.0	2.9	7.25	0.40
4	12.5	25.0	2.9	8.70	0.33
5	12.7	25.0	2.9	10.10	0.28
6	12.9	25.0	2.9	12.0	0.25

D_c=0.0190,d_s =0.0057,d_b= 0.0084,ρ_{sb}=1050,ρ_{ss}=1050,Material:Berry seeds, e=0.116

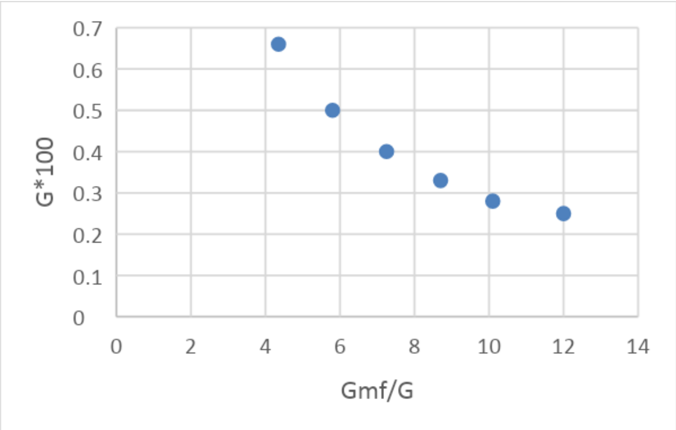

Fig-10: Power of "e"(h_s vs.G_{mf}/G,Equ.4)

Table – 11: Power of "h"(h_s vs.D_c,Equ.4)

S NO	h_{s*100}	h_{t*100}	D_{c*100}
1	6.8	10.5	1.0
2	5.9	10.5	1.5
3	4.9	10.5	1.9
4	4.2	10.5	2.5

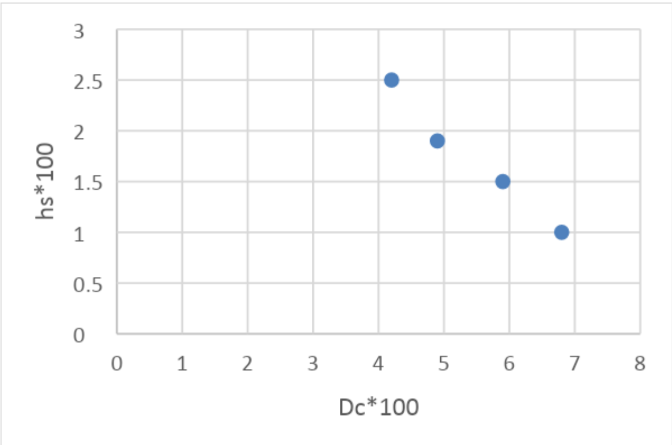

Fig – 11: Power of "h"(h_s vs.D_c,Equ.4)

d_b=0.0055,d_s=0.0011,G_{mf}/G=0.67, ρ_{sb} =2620, ρ_{ss} =2620,Material:Glass, h=0.77

Table – 12: Power of "g"(h_s vs.ρ_{sb}/ρ_{ss},Equ.4)

S.no	h_{t*100}	h_{s*100}	$\rho_{sb/1000}$	$\rho_{ss/1000}$
1	13.0	8.80	2.62	1.052
2	13.0	10.5	7.813	1.052
3	13.0	10.5	7.813	2.62
4	13.0	9.00	7.813	2.40
5	13.0	8.00	2.62	2.40

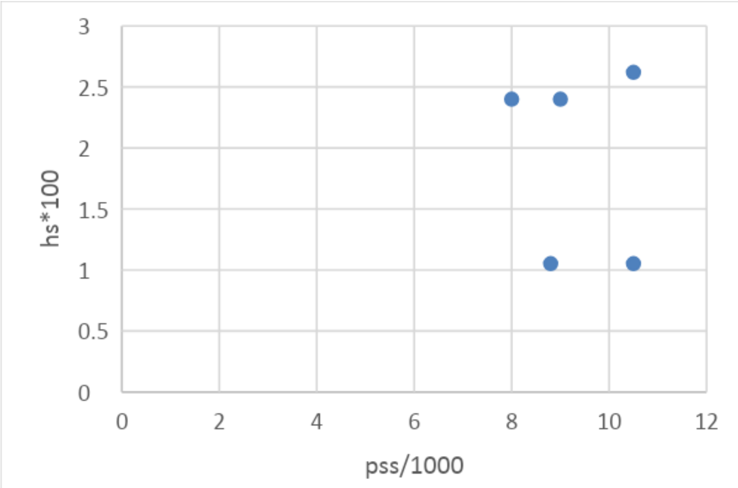

Fig 12: Power of "g"(h_s vs.ρ_{sb}/ρ_{ss},Equ.4)

D_c=0.025, d_s = 0.0030, d_b=0.00775, G_{mf}/G=0.67,g=0.14

Table – 13:Power of k2 and n values(Equ.4)

S NO	d_s/h_t	d_b/h_t	D_c/h_t	G_{mf}/G	ρ_{sb}/ρ_{ss}	h_s/h_t
1	0.031	0.073	0.20	0.44	3.26	0.52
2	0.038	0.070	0.21	0.33	3.00	0.20
3	0.043	0.046	0.19	0.26	7.40	0.65
4	0.050	0.100	0.41	0.22	2.80	0.41
5	0.060	0.050	0.16	0.18	1.13	0.66
6	0.020	0.035	0.19	0.16	1.08	0.57
7	0.060	0.110	0.50	0.14	1.12	0.40
8	0.031	0.068	0.22	0.13	2.47	0.272
9	0.018	0.031	0.11	0.12	2.50	0.18
10	0.035	0.098	0.22	0.11	2.28	0.23

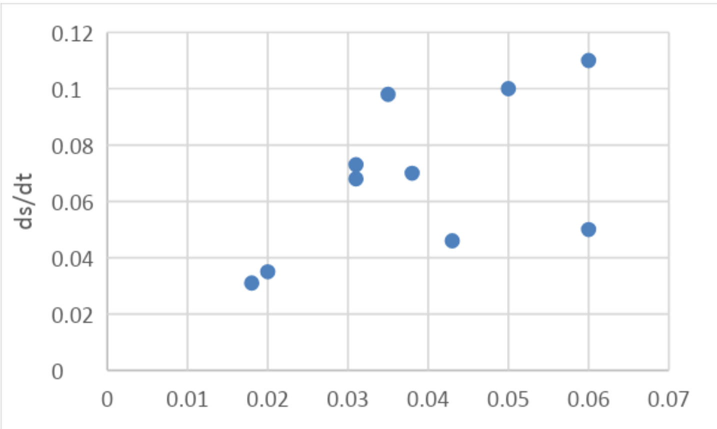

Fig 13: Power of k2 and n values(Equ.4)

n=1.08,k2=0.205

Table – 14: Comparison(Equ.4)

S no	h_s/h_t (Equ)	h_s/h_t obs	% Error 100x{(obs-Equ)/obs}
1	0.91	0.76	18.7
2	0.36	0.43	16.3
3	0.32	0.40	20.0
4	0.48	0.45	6.7
5	0.63	0.66	4.5
6	0.26	0.30	13.0
7	0.36	0.38	5.0
8	0.36	0.33	6.5
9	0.37	0.33	11.0
10	0.31	0.37	16.0
			Arithmetic absolute Mean Error= 11.8

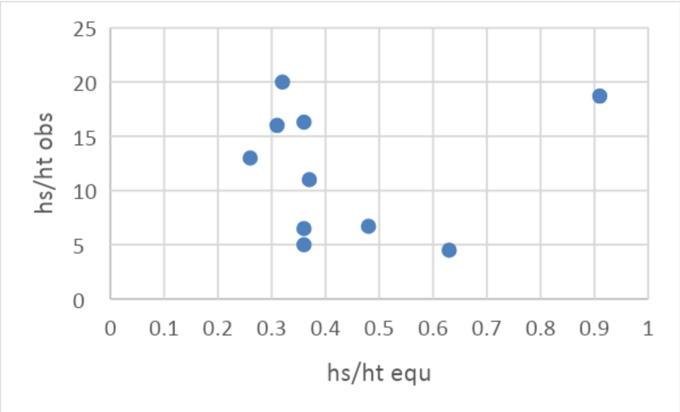

Fig 14: Comparison(Equ.4)

The values obtained for equation (4) are: b=-0.75, c=0.32, h=0.77, e=0.116, g=0.14, k2=0.205 and n=1.08.
The final form of equation (4) is:
$h_s/h_t = 0.205\,(d_s/h_t)^{0.81}\,(d_b/h_t)^{0.346}\,(D_c/h_t)^{0.832}\,(G_{mf}/G)^{0.125}\,(\rho_{sb}/\rho_{ss})^{0.151}$---(6)

The comparison of experimental values and equation values for h_s / D_c and h_s / h_t are shown in Figures 1 and 2.The absolute arithmetic mean error for h_s / D_c and h_s / h_t are 14.3% and 11.8 % respectively.

The scope of experiments is shown in Tabe-15.

Table – 15: SCOPE OF EXPERIMENTS

S.no	BED MATERIAL	PARTICLE SIZE*100	PARTICLE DESNSITY /1000	PARTICLE SHAPE
1	Sand	0.21 to 0.032	1.40 to 1.70	Non-Spherical
2	Bengalgram	0.21 to 0.039	1.10 to 1.20	N0n-Spherical
3	Dolamie	0.308 to 0.024	2.7 to 2.90	Non-Spherical
4	Mustard Seeds	0.155 to 0.513	0.43	Spherical
5	Steel Balls	0.774to0.21	7.30 to 7.80	Spherical
6	Berry Seeds	0.84 to 0.57	1.05 to 1.10	Spherical
7	Glass Beeds	0.786 to 0.051	2.10 to 2.60	Spherical
8	Sodium Chloride	0.308 to 0.032	2.163	Non-Spherical

III. CONCLUSIONS:

Fluidization technique is successfully used to for separate the solid mixtures of different sizes and dimensions to some extent. Equations are formulated to predict the heights of small solids and big solids in a cylindrical column after fluidization for a binary mixture of solids .This work can be extended to multi component solid mixtures and other conduits.

Nomenclature:

$a,b,c,d,e,f,g,h,k,k_1.k_2,m,n$ = Constants
D_c = Diameter of the Column, m
d_s = Diameter of small solids, m
d_b = Diameter of big solids, m
h_s = Height of small diameter solids, m
h_b = Height of big diameter solids, m
h_t = Height of total bed of solids, m
G_{mf} = Minimum Fluidization velocity, Kg/(m^2.sec)(proportional to level difference in manometer)
G = Operating Fluid velocity, Kg/(m^2.sec)(proportional to level difference in manometer)
ρ_{ss} = Density of small solids, Kg/Cub.m.
ρ_{sb} = Density of big solids, Kg/Cub.m.
ρ_{ss}/ρ_{sb}, h_s/d_c, d_s/D_c, h_t/d_c, d_b/D_c, G_{mf}/G=dimensionless
X (in Equ 3) = $(h_t/D_c)^a\,(d_s/D_c)^b\,(d_b/D_c)^c\,(G_{mf}/G)^e\,(\rho_{sb}/\rho_{ss})^g$
X (in Equ 4) = $(d_s/h_t)^b\,(d_b/h_t)^c\,(D_c/h_t)^h\,(G_{mf}/G)^e\,(\rho_{sb}/\rho_{ss})^g$

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