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Expansion Characteristics of Polymeric Resins

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Abstract* - Expansion characteristics of polymeric resins have been investigated in a solid-liquid fluidized bed of 100 mm i.d. and 1.2 m in height using water as a fluidizing medium. The effect of solid particle size and density on expansion characteristics has been studied with an emphasis on the swelling characteristics, in particular. The experimental velocity- voidage data have been modeled using Richardson-Zaki equation. It has been observed that the swelling of the resin tend to increase terminal settling velocity of the resin due to an increase in the diameter. The swelling ratio for strong base anion exchange resin (A-36) and strong acid cation exchange resin (T-42) was found to be 1.19 and 1.34, respectively. Moreover, it has also been observed that R-Z represents the experimental velocity- voidage data very well with standard deviation of 0.05%.
***Keywords* - Solid liquid fluidized bed, expansion characteristics, terminal settling velocity, expanded bed.**

I. INTRODUCTION

Solid-liquid fluidized beds (SLFB) are widely used in industry for hydrometallurgical operations, catalytic cracking, chromatographic separation, etc [1]. It is preferred for many advantages over other configuration, like; good solid mixing leading to uniform temperature throughout the bed, high mass and heat transfer rates, easy solids handling, ability to maintain a uniform temperature, significantly lower pressure drops which reduce pumping costs, lower investments for the same feed and product specifications, yielding large axial dispersion of phases, etc [2], [3], [4]. Chromatographic separation has a wide application, it has a major application in fluidized bed. It is based on physical characteristics of the particle i.e., size, density and shape for separation.
A significant amount of work on solid-liquid fluidization has been reported in the literature. Investigators have put forth their study in the form of theoretical and empirical models. Several correlations are available for the velocity-voidage relationship for monosize particle systems. Some of those which are widely used in the literature are Joshi [5], Richardson and Zaki [6], Hanratty and Bandukwala [7], Happel [8], Loeffler and Ruth [9], Bamea and Mizrahi [10], Foscolo [11]. Di Felice [12] and Joshi [5] presented excellent work on the transport phenomena in solid-liquid fluidization. The solid particles considered for hydrodynamic characteristics are light in weight and of small particle size. In this experimental study, special attention is paid to the influence of the characteristics of particles, like density and diameter. In practice, the terminal settling velocity of a solid particle is usually associated with a spherical shape. The purpose of this study is to analyze various correlations from literature for expansion characteristics with the experimental work and study of swelling characteristics of resins.

II. EXPERIMENT AND METHODS

A. Column

A 100-mm-i.d. and 1.2-m- long acrylic pipe was used as the column. The schematic diagram of the experimental setup is as shown in Figure 1 [13]. A reciprocating pump of 120mL/s capacity was provided with a dampener. A calming section packed with sand particles of 0.3-m height was provided below the distributor plate. The distributor plate has 20% fractional opening. A mesh was attached to the distributors at the top and bottom of the column to restrict the movement of resin particles across the distributor plate. Pressure tapings were provided at spacing of 100mm along the column to measure the pressure drop during expansion of the bed. The pressure was measured by a U- tube manometer, with liquid nitrobenzene having specific gravity of 1.2.

B. Liquid and Particles Phases

Tap water was used as liquid phase for all the experiments. The solids phase was polymeric resins manufactured by Thermax Ltd, having the commercial name T-42 (strong acid cation exchange resin) and A-36 (strong base anion exchange resin). The physical properties of resin are given in TABLE I. The polymeric resins were segregated into various sizes and three particle sizes of each resin were selected for experimentation. The particles sizes viz 0.303 mm, 0.428 mm, 0.605 mm (T-42 and A-36) were used to study expansion characteristics.

C. Methodology

The column was filled with water and solid particles were charged to get predetermined fixed bed height (H_0). As water flow was

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started, the bed height of resin increases. For a particular superficial velocity, the bed expands and attains a steady state after a while. This bed voidage was measured using two methods:

1) Solid mass balance method
2) Pressure gradient method

TABLE I
PROPERTY OF RESIN

Property	Tulsion A-36	Tulsion T-42
Type	Strong base anion exchange resin	Strong acid cation exchange resin
Particle size(mm)	0.3-1.2	0.3-1.2
Total exchange capacity (meq/ml resin)	1.2	1.8
Moisture content (%kg water/kg wet resin)	50±3	52±3
Functional group	NH_4^+	$-SO_3^-$
Ionic form	Cl^-	H^+

In the first method, average voidage was calculated by taking the solid-phase balance at the initial and final fluidized state at a given superficial liquid velocity as follows:

$$\frac{\pi}{4}D^2H_0(1-\epsilon_{L0}) = \frac{\pi}{4}D^2H(1-\epsilon_L) \quad (1)$$

Where, the subscript "0" denotes the initial fixed bed condition. In solid-phase balance method, the average voidage is calculated as follows:

$$\epsilon_s = \frac{\epsilon_{so}H_o}{H} \quad (2)$$

In pressure gradient method, the average voidage is calculated as follows by neglecting wall effects and solid accelerations,

$$-\left(\frac{dP}{dz}\right)_Z = (1-\epsilon_{LZ})(\rho_s-\rho_L)g \quad (3)$$

The terminal settling velocity on dry basis is calculated with the equation suggested by Khan and Richardson with the relation of Ga and Re given as:

$$Re_t = (2.33Ga^{0.018} - 1.53Ga^{-0.016})^{13.3} \quad (4)$$

III. RESULTS AND DISCUSSION

A. Swelling characteristics

When water is brought in contact with resins, it swells. Hence the physical properties of resins get altered**.** This also changes the terminal settling velocity of the solid particles**.** The swelling characteristics of the resin were also measured by noting the volume of dry mass (10g) of resin and wet volume (after 12 hrs). The swelling ratio is defined as follows:

$$\text{Swelling ratio} = \frac{\text{Volume of dry resin}}{\text{Volume of wet resin}}$$

Swelling characteristics of the resins is given in TABLE II The increase in diameter of solid particles due to swelling leads to change in terminal settling velocity which also affects the expansion characteristics of bed.

TABLE II
SWELLING CHARACTERISTICS OF RESINS.

Name of resin	Particle size (mm)	Volume of particle (ml)		Swelling ratio	Diameter of particle(mm)		Galileo number (Ga)		Rise in particle diameter
		dry	wet		dry	wet	dry	wet	
T-42	0.605	12	17.8	1.4	0.605	0.68	651.71	1126	1.1
	0.428	12.1	16.2	1.3	0.428	0.44	230.73	506.93	1.1
	0.303	12	16.1	1.34	0.303	0.40	81.86	141.46	1.1
A-36	0.605	19	24	1.2	0.605	0.726	217.23	289.14	1.2
	0.428	22	29	1.2	0.428	0.513	76.91	102.37	1.2
	0.303	22.6	27.5	1.19	0.303	0.360	27.28	36.32	1.2

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B. Expansion Characteristics

Three particles of different sizes (0.303, 0.428 and 0.605mm) were fluidized separately at different superficial liquid velocities to determine their expansion behavior. The terminal settling velocity was determined experimentally by particle drop method. A particle of particular size was dropped in a glass column (50mm i.d and 300mm height) from the top. The particle settled down in the glass column and the time required for the particle to cover a particular distance (200mm) was noted. The corresponding values of terminal settling velocity obtained from solid particle drop method were 10.22 mm.s^{-1},12.45 mm.s^{-1},17.65 mm.s^{-1} and 20.32 mm.s^{-1},33.2 mm.s^{-1},53.9 mm.s^{-1} for the solid particle sizes of 0.303 mm, 0.428mm and 0.605mm for A-36 and T-42 particles respectively. To determine the terminal settling velocity by graphical analysis, the experimental data was put in the form of graph of log superficial velocity versus log of voidage. Richardson-Zaki parameter n was also determined from the above graph. The slope from the Fig 2 and 3 gives R-Z parameter (n) and the intercept is the value of terminal settling velocity. The experimental value of terminal settling velocity and graphical value from the figures are similar. The terminal settling velocities obtained from graphical method of solid particles measured were10.68 mm.s^{-1}, 13.47 mm.s^{-1}, 17.24 mm.s^{-1} and 21.54 mm.s^{-1}, 34.65 mm.s^{-1}, 55.2 mm.s^{-1} for the solid particle sizes of 0.303 mm, 0.428mm and 0.605mm for A-36 and T-42 particles respectively.

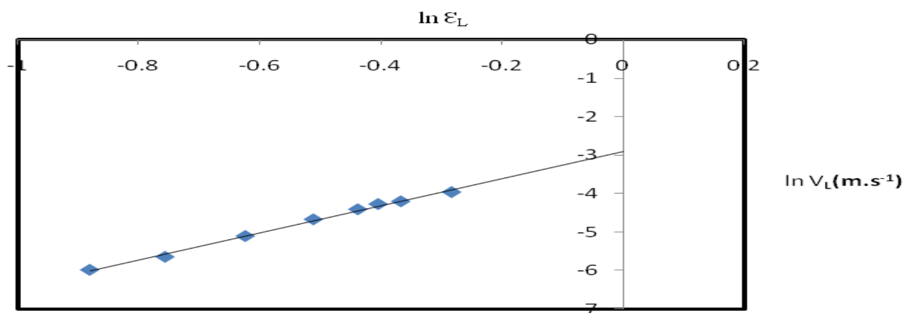

Fig 2: Plot of log superficial velocity versus log voidage for particle size 0.605mm of T-42

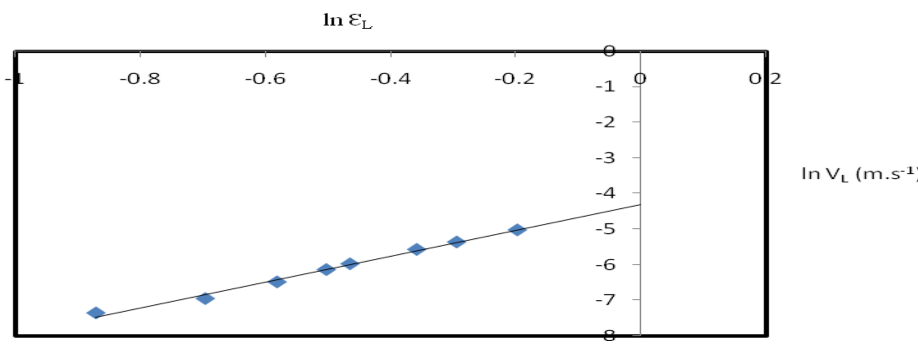

Fig 3: Plot of log superficial velocity versus log voidage for particle size 0.605mm of A-36

Two methods, viz. visual observation and the pressure gradient method, were used to calculate the average voidage. In the 1st method average voidage was calculated by equation (1). In 2nd method, average voidage was calculated by the pressure gradient method using equation (3). A comparison between these two methods is shown in Fig 4 and 5 for particle size of 0.605mm for both resins. The void fraction between these two methods can be seen in good agreement with each other. The Richardson-Zaki parameters for a given particle sizes are reported in TABLE III. It is also observed that as the diameter and density increases, Reynolds number increases which also increases Ga and other physical properties with it. Richardson- Zaki parameter decreases with increase in diameter. The terminal settling velocity of solid particles get significantly affected upon swelling. For example, the terminal settling velocity of 0.605 mm particle is 12.34 mm s^{-1} when this value was calculated on a dry basis. However, when experiments were carried out at a superficial liquid velocity of 17.24 mm s^{-1}, no entrainment was observed. This is due to the swelling of the resin. The voidage estimated by equation (1) at different superficial liquid velocities was compared with various correlations as shown in TABLE IV for 0.605mm particle size. Fig 6 and 7 shows the comparison for T-42 and A-36 resins. It is clear that the models proposed by Richardson-Zaki fits well.

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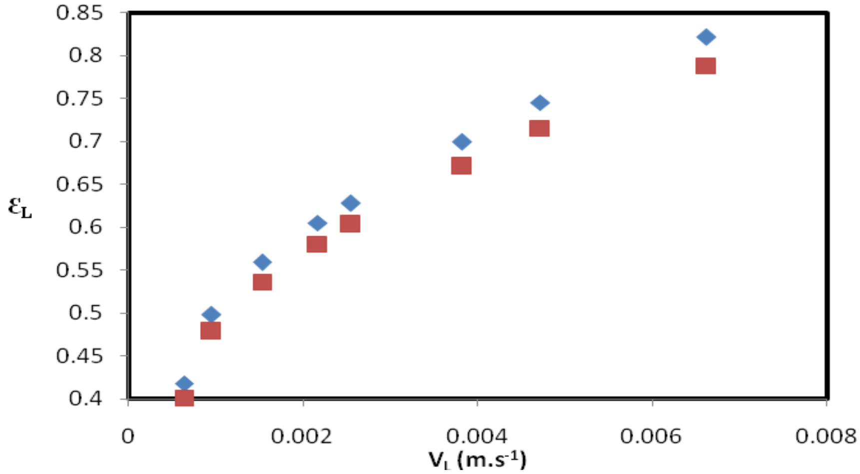

Fig 4: Variation of bed voidage at different superficial velocity for 0.605mm particle of A-36: ( ) Pressure gradient method and ( ) Solid balance method

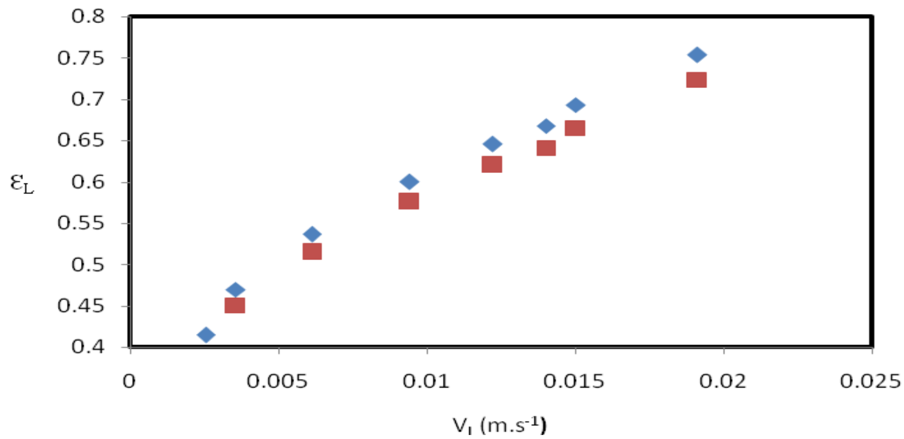

Fig 5: Variation of bed voidage at different superficial velocity for 0.605mm particle of T-42: ( ) Pressure gradient method and ( ) Solid balance method

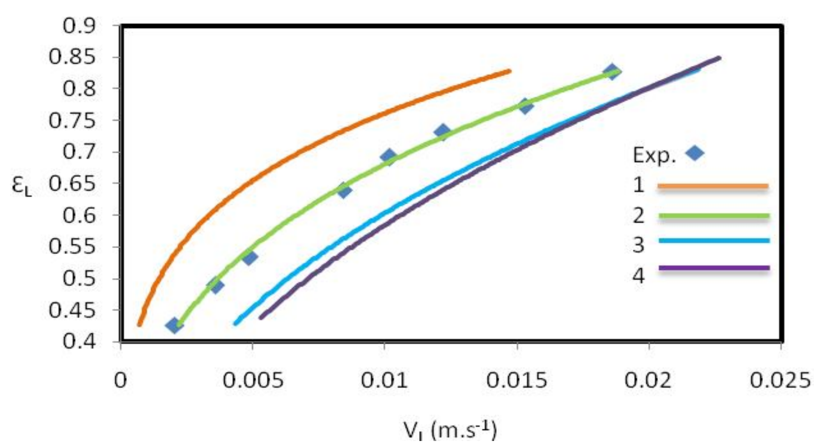

Fig 6: Comparsion of experimental values with various eq for T-42 resin Expt ( ), 1. Hanratty and Bandukwala, 2. Richardson-Zaki, 3. Foscolo, 4.Joshi

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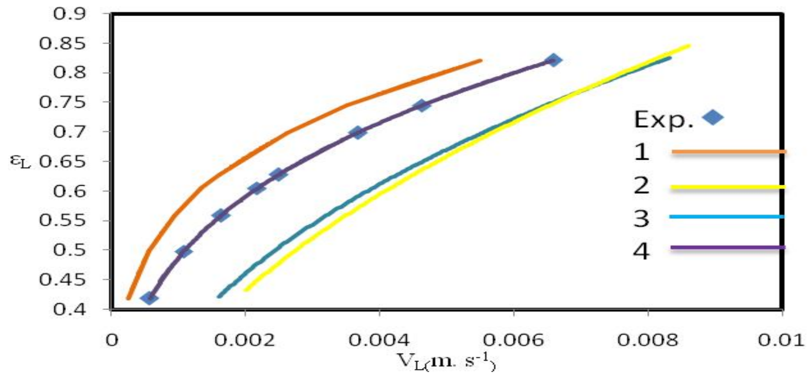

Fig 7: Comparsion of experimental values with various eq for A-36 resin Expt(◆), 1. Hanratty and Bandukwala, 2. Joshi, 3. Foscolo, 4. Richardson-Zaki

TABLE III
SETTLING CHARACTERISTICS OF DIFFERENT SIZE GROUP PARTICLES

Solid	Density of liquid (kg/m^3)	Density of solid (kg/m^3)	Diameter (m)	Terminal velocity (Vt) m/sec	Reynolds number	R-Z(n)
A-36	1000	1100	0.000605	0.0172	10.344	3.092
			0.000428	0.0134	5.7651	3.627
			0.000303	0.0106	3.2360	3.774
T-42		1300	0.000605	0.0552	33.396	3.236
			0.000428	0.0346	14.830	3.396
			0.000303	0.0215	6.5266	3.526

TABLE IV.
VARIOUS VELOCITY-VOIDAGE EQUATIONS FROM LITERATURE

Sr no	Investigator	Equation
1	Richardson and Zaki	$\frac{V_L}{V_{s\infty}} = \epsilon^{n}$
2	Hanratty and Bandukwala	$\frac{V_L}{V_{s\infty}} = (1-\epsilon_s)2exp[\frac{-2.5\,\epsilon_s}{1-\frac{39\,\epsilon_s}{64}}]$
3	Joshi	$\frac{V_L}{V_{s\infty}} = \epsilon_L{}^{n}$ with $\frac{(5.1-n)}{(n-2.7)}0.1Re^{0.9}$
4	Loeffler and Ruth	$\frac{V_L}{V_{s\infty}} = \frac{1}{\frac{1}{\epsilon_L} + 2K\frac{(1-\epsilon_L)}{\epsilon_L{}^{3}}}$ $K = 2.85$
5	Foscolo	$\frac{V_L}{V_{s\infty}} = [\frac{\epsilon_L{}^{4}}{3.55(1-\epsilon_L+\epsilon_L{}^{3})}]^{\frac{1}{2}}$

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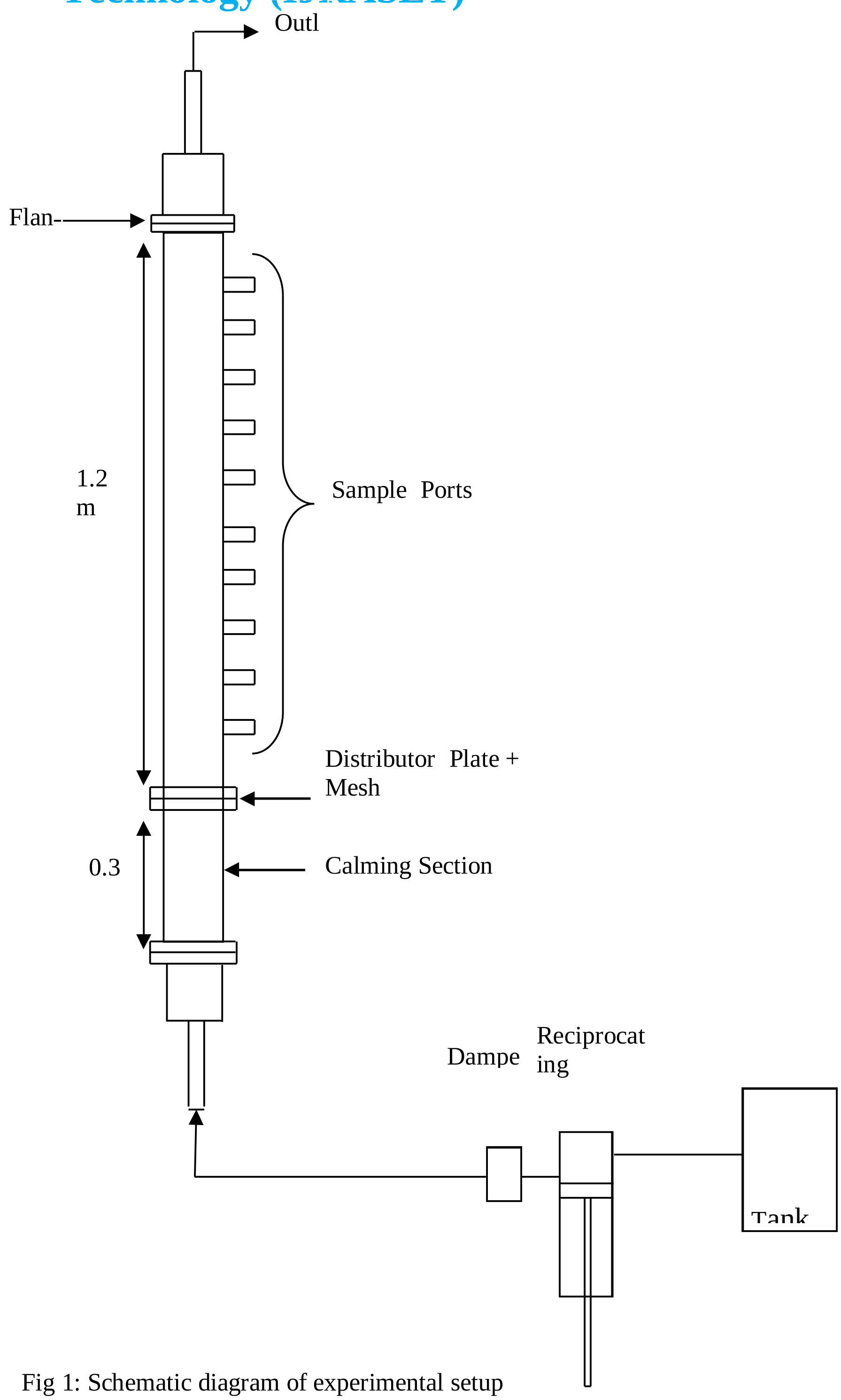

Fig 1: Schematic diagram of experimental setup

IV. CONCLUSION

The swelling ratio for strong base anion exchange resin (A-36) and strong acid cation exchange resin (T-42) was found to be 1.19 and 1.34, respectively. Due to swelling the terminal settling velocity of the particles gets altered from dry resin. Hence all the work is based on swelled diameter. The Richardson- Zaki equation fits well (standard deviation 0.05%) into the velocity-voidage experimental data when compared with the other correlations. The Richardson-Zaki parameters are calculated using experimental velocity voidage data. The experimental and theoretical terminal settling values calculated are similar. It is observed that as the

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particle size increases Reynolds number increases and n parameter decreases. It also has been observed, as the density increases Reynolds number increases.

V. ACKNOWLEDGMENT

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A. NOMENCLATURE

d_p = diameter of solid particle,(m)
g = gravitational acceleration,(m.s^{-2})
Ga= Galileo number,
H = final height of solid bed,(m)
H_0= initial height of solid bed,(m)
N = Richardson-Zaki parameter,
ΔP= pressure drop,(Pa)
V_L= superficial liquid velocity, (m.s^{-1})
V_t = Terminal settling velocity of particle, (m.s^{-1})

B. Greek letters

ρ_L = Liquid density, (kg m^{-3})
ρ_S = liquid density, (kg m^{-3})
$\Delta\rho$= density difference between solid phase and liquid phase, (kg m^{-3})
μ_L= viscosity of liquid, (kg m^{-1} s^{-1})
ε_L = voidage of the bed,

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