

# FLUIDIZATION CHARACTERISTICS OF ION EXCHANGE RESINS

<sup>1</sup>Rajesh S. Sanap, <sup>2</sup>Praful S. Bhosale, <sup>3</sup>Shabnam K. Tadv & <sup>4</sup>Manoj B. Mandake

<sup>1-3</sup>Undergraduate Students at Bharati Vidyapeeth College of Engineering

<sup>4</sup>Assistant Professor at Bharati Vidyapeeth College of Engineering,

<sup>1</sup>Department of Chemical Engineering,

<sup>1</sup>Bharati Vidyapeeth College of Engineering, Navi Mumbai, India.

**Abstract:** Ion exchange is the most common process for public water supplies in the United States. There are certain characteristics of water that indicate the quality of the water such as hardness, salinity, alkalinity, etc. To make the water safer for consumption, it is passed through a packed bed of ion exchange resins to remove hardness. In this process of ion exchange, the resins become saturated and have to be regenerated. For regeneration of resins, backwashing takes place. Here, fluidization plays a vital role. Fluidization is a process by which a bed of particulate materials exhibits fluid-like behaviour as a result of fluid flowing through it. For regeneration of resins, fluidization properties of the resins such as minimum fluidization velocity, pressure drop across the bed, porosity of the bed are required. Ion exchange resins is also one of the best methods to reduce heavy metals concentration in waste streams down to levels fulfilling the everyday stricter regulations on the disposal of waste waters.

**Keywords:** Ion exchange resin, fluidization, minimum fluidization velocity.

## Fluidization:

Fluidization is the phenomenon of imparting the properties of a fluid to a bed of particulate solids by passing a fluid (liquid or gas) through the material (Escudero, 2010). Fluidized beds are reactors in which fluidization of particulate solids takes place. Fluidized beds are an important asset in many industrial processes because they present several advantages that include a high rate of heat and mass transfer, low pressure drops, and uniform temperature distribution (Cranfield & Geldart, 1974).

A fluidized bed is a packed bed through which fluid flows at such a high velocity that the bed is loosened and the particle-fluid mixture behaves as though it is a fluid. Thus, when a bed of particles is fluidized, the entire bed can be transported like a fluid, if desired. Both gas and liquid flows can be used to fluidize a bed of particles. The most common reason for fluidizing a bed is to obtain vigorous agitation of the solids in contact with the fluid, leading to excellent contact of the solid and the fluid and the solid and the wall (Subramanian, 2002).

Fluidization is widely used in commercial operations; the applications can be roughly divided into two categories, i.e.

- Physical operations, such as transportation, heating, absorption, mixing of fine powder, etc.
- Chemical operations, such as reactions of gases on solid catalysts and reactions of solids with gases etc.
  1. The fluidized bed is one of the best known contacting methods used in the processing industry (Dechsiri, 2004).
  2. Among its chief advantages are that the particles are well mixed leading to low temperature gradients (Kunii & Levenspiel, 1991), they are suitable for both small and large scale operations and they allow continuous processing of materials having a wide particle size distribution (Cocco, Karri & Knowlton, 2014).

## Important terms in fluidization:

Minimum fluidization velocity ( $V_{mf}$ ):

- The minimum fluidization velocity ( $V_{mf}$ ), defined as the superficial gas velocity at which the drag force of the upward moving liquid becomes equal to the weight of the particles in the bed, is one of the most important parameters associated with a fluidized bed system (Hilal, Ghannam & Anabtawi, 2001).
  - The  $U_{mf}$  value is important because it dictates the onset of fluidization and phenomena like the extent of segregation in bubbling fluidized beds.
  - Generally,  $U_{mf}$  is expressed as a function of particle properties (e.g., particle diameter ( $d_p$ ), particle density ( $\rho_p$ ), particle sphericity ( $\phi$ )), and bed properties (e.g., bed voidage at minimum fluidization ( $\epsilon_{mf}$ )).
1. At  $Re < 1$ , the equation for minimum fluidization becomes,

$$V_{mf} = \frac{g(\rho_p - \rho)\phi^2 D_p^2 \epsilon^3}{150\mu(1 - \epsilon)} \quad (1)$$

2. The equation for  $Re > 1000$  is,

$$V_{mf} = \sqrt{\frac{g(\rho_p - \rho)\phi D_p \epsilon^3}{1.75\rho}} \quad (2)$$

- $\phi$  - sphericity of the particles
- $\rho_p$  - density of particle
- $\rho$  - density of fluid
- $\epsilon$  - porosity of the bed
- $D_p$  - diameter of particle
- $g$  - acceleration due to gravity
- $\mu$  - viscosity of fluid

Terminal settling velocity ( $V_t$ ):

- Terminal velocity is the highest velocity attained by an object as it falls through a fluid.
- It occurs when the sum of the drag force ( $F_D$ ) and the buoyancy is equal to the downward force of gravity ( $F_G$ ) acting on the object. Since the net force on the object is zero, the object has zero acceleration.

- In fluid dynamics, an object is moving at its terminal velocity if its speed is constant due to the restraining force exerted by the fluid through which it is moving.
- As the speed of an object increases, so does the drag force acting on it, which also depends on the substance it is passing through. At some speed, the drag or force of resistance will equal the gravitational pull on the object. At this point the object ceases to accelerate and continues falling at a constant speed called the terminal velocity.
- An object moving downward faster than the terminal velocity (for example because it was thrown downwards, it fell from a thinner part of the atmosphere, or it changed shape) will slow down until it reaches the terminal velocity.
- Drag depends on the projected area, here, the object's cross-section or silhouette in a horizontal plane. An object with a large projected area relative to its mass, such as a parachute, has a lower terminal velocity than one with a small projected area relative to its mass, such as a bullet.

Terminal settling velocity can be expressed as,

$$V_t = \frac{g D_p^2 (\rho_p - \rho)}{18 \mu} \quad (3)$$

Where,

- $D_p$  - diameter of particle
- $g$  - acceleration due to gravity
- $\rho_p$  - density of particle
- $\rho$  - density of fluid
- $\mu$  - viscosity of fluid

Superficial velocity ( $V_s$ ):

Superficial velocity in porous media, is a hypothetical flow velocity calculated as if the given phase or fluid were the only one flowing or present in a given cross sectional area. Other phases, particles, the skeleton of the porous medium, etc. present in the channel are disregarded (Liang et al., 1997).

Superficial velocity is used in many engineering equations because it is the value which is usually readily known and unambiguous, whereas real velocity is often variable from place to place, its mean not readily available in complex flow systems, and subject to assumptions.

Superficial velocity can be expressed as:

$$V_s = \frac{Q}{A} \quad (4)$$

Where,

- $V_s$  - superficial velocity of a given phase, m/s
- $Q$  - volume flow rate of the phase,  $m^3/s$
- $A$  - cross sectional area,  $m^2$

**Packed bed:**

- A packed bed is a hollow tube, pipe, or other vessel that is filled with a packing material (Subramanian, 2002).
- The packing can be randomly filled with small objects like Raschig rings or else it can be a specifically designed structured packing.
- Packed beds may also contain catalyst particles or adsorbents such as zeolite pellets, granular activated carbon, etc.
- The purpose of a packed bed is typically to improve contact between two phases in a chemical or similar process.
- Packed beds can be used in a chemical reaction, a distillation process, or a scrubber, but packed beds have also been used to store heat in chemical plants.

From a fluid mechanical perspective, the most important issue is that of the pressure drop required for the liquid or the gas to flow through the column at a specified flow rate. To calculate this quantity we rely on a friction factor correlation attributed to Ergun. Other fluid mechanical issues involve the proper distribution of the liquid across the cross-section, and developing models of the velocity profile in the liquid film around a piece of packing material so that heat/mass transfer calculations can be made. Design of packing materials to achieve uniform distribution of the fluid across the cross-section throughout the column is an important subject as well. Here, we only focus on the pressure drop issue.

Pressure drop in packed bed:

The Ergun (1952) equation that is commonly employed is given below

$$\frac{\Delta p}{l} = \frac{150(1-\epsilon)^2 \mu V_s}{\phi^2 d_p^2 \epsilon^3} + \frac{1.75 \rho V_s^2}{\phi d_p \epsilon^3} \quad (5)$$

Where,

- $\Delta p$  : pressure drop
- $l$  : length of the bed
- $\epsilon$  : porosity of the bed
- $\mu$  : viscosity of fluid
- $V_s$  : superficial velocity
- $\phi$  : sphericity of the particles
- $d_p$  : diameter of particle

By using the Ergun equation we can calculate the pressure drop across packed bed.

Application:

- To catalyse gas reactions
- Removal of color from dye waste water
- Water filtration
- Ammonia synthesis

- Sulphuric acid production
- In continuous bio-diesel production

At the beginning of a new filter run, the filter efficiency increases simultaneously with the number of captured particles in the medium. This process is called filter ripening. During filter ripening the effluent might not meet quality criteria and must be re-injected at previous steps in the plant. Regeneration methods allow the reuse of the filter medium. Accumulated solids from the filter bed are removed. During backwashing, water (and air) is pumped backwards through the filter system. Backwash water may partially be re-injected in front of the filter process and generated sewage needs to be discarded. Backwashing is done by using fluidization process.

#### **Backwashing of filter media:**

Backwashing refers to pumping water backwards through the filters media, sometimes including intermittent use of compressed air during the process. Backwashing is a form of preventive maintenance so that the filter media can be reused. Water treatment filters that can be backwashed include rapid sand filters, pressure filters and granular activated carbon (GAC) filters. Diatomaceous earth filters are backwashed according to the proprietary arrangement of pumps, valves and filters associated with the filtration system. Slow sand filters and self-cleaning screen filters employ mechanisms other than backwashing to remove trapped particles. To keep water treatment filters functional, they have to be cleaned periodically to remove particulates. Ineffective backwashing is one of the main reasons that water treatment filters fail.

#### **Procedure:**

Backwashing of granular media filters involves several steps. First, the filter is taken off line and the water is drained to a level that is above the surface of the filter bed. Next, compressed air is pushed up through the filter material causing the filter bed to expand breaking up the compacted filter bed and forcing the accumulated particles into suspension. After the air scour cycle, clean backwash water is forced upwards through the filter bed continuing the filter bed expansion and carrying the particles in suspension into backwash troughs suspended above the filter surface. In some applications, air and water streams are simultaneously pushed upwards through the granular media followed by a rinse water wash. Backwashing continues for a fixed time, or until the turbidity of the backwash water is below an established value. At the end of the backwash cycle, the upward flow of water is terminated and the filter bed settles by gravity into its initial configuration. Water to be filtered is then applied to the filter surface until the filter clogs and the backwash cycle needs to be repeated.

#### **What are ion exchange resins?**

Ion exchange resins are polymers that are capable of exchanging particular ions within the polymer with ions in a solution that is passed through them. This ability is also seen in various natural systems such as soils and living cells. The synthetic resins are used primarily for purifying water, but also for various other applications including separating out some elements. In water purification the aim is usually either to soften the water or to remove the mineral content altogether. The water is softened by using a resin containing  $\text{Na}^+$  cations but which binds  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  more strongly than  $\text{Na}^+$ . As the water passes through the resin the resin takes up  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  and releases  $\text{Na}^+$  making for a 'softer' water. If the water needs to have the mineral content entirely removed it is passed through a resin containing  $\text{H}^+$  (which replaces all the cations) and then through a second resin containing  $\text{OH}^-$  (which replaces all the anions). The  $\text{H}^+$  and  $\text{OH}^-$  then react together to give more water. The process has some disadvantages in that there are substances occurring in some water (such as organic matter or  $\text{Fe}^{3+}$  ions) which can foul the resin, but in general the advantages of the process (long life of resins, cheap maintenance etc.) outweigh the disadvantages. In addition, the process is very environmentally friendly because it deals only with substances already occurring in water.

#### **Uses:**

A bed of resin can be used either to remove unwanted ions from a solution passed through it or to accumulate a valuable mineral from the water which can later be recovered from the resin. Examples of the removal of unwanted ions are the removal of heavy metals from metal trade wastes, the demineralisation of the whey used to manufacture specialized dairy products and the removal of salts from fruit juices. Strong cation resins in the hydrogen form are used for the hydrolysis of starch and sucrose. Resins also find many uses in the laboratory where the chemists' ingenuity is less constrained by economic considerations. They can be used to remove interfering ions during analysis or to accumulate trace quantities of ions from dilute solutions after which they can be concentrated into a small volume by elution. A cation resin in the hydrogen form can be used to determine the total concentration of ions in a mixture of salts. The sample passing through a column is converted to the equivalent quantity of acid and the amount readily found by titration.

#### **Water Treatment:**

Far more resin is used for water purification than for any other purpose. It is therefore appropriate to discuss water treatment examples when outlining the application of the principles of ion exchange technology. Industrial ion exchange units are produced in sizes ranging from a few litres up to vessels holding several tonnes of resin. Service runs between regenerations usually range from 12 to 48 hours. The two major types of treatment applied to water are water softening - the replacement of 'hard' ions such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  by  $\text{Na}^+$  - and demineralisation - the complete removal of dissolved minerals. Both of these treatments are outlined below.

#### **Water softening:**

In water softening a cation resin in the sodium form is used to remove hard metal ions (calcium and magnesium) from the water along with troublesome traces of iron and manganese, which are also often present. These ions are replaced by an equivalent quantity of sodium, so that the total dissolved solids content of the water remains unchanged as does the pH and anionic content. At regular time intervals the resin is cleaned. This involves passing influent water back up through the resin to remove suspended solids, passing a regenerant solution down through the resin to replace the ions that have bound to the resin and then rinsing again with water to remove the regenerant solution. In water softening the regenerant is a strong solution of sodium chloride.

#### **Demineralisation**

Virtually all the dissolved matter in natural water supplies is in the form of charged ions. Complete deionization (i.e. demineralisation) can be achieved by using two resins. The water is first passed through a bed of cation exchange resin contained in a vessel similar to that described for softeners. This is in the hydrogen ion form brought about by the use of a strong acid regenerant (either hydrochloric or sulphuric). During service, cations in the water are taken up by the resin while hydrogen ions are released. Thus the effluent consists of a very weak mixture of acids. The water now passes through a second vessel containing anion exchange resin in the hydroxide form for which sodium hydroxide is used as the regenerant. Here the anions are exchanged for

hydroxide ions, which react with the hydrogen ions to form water. Such twin bed units will reduce the total solids content to approximately 1-2 mg L<sup>-1</sup>. With larger units it is usual to pass water leaving the cation unit through a degassing tower. This removes most of the carbonic acid produced from carbon dioxide and bicarbonate in the feed water and reduces the load on the anion unit. Without degassing the carbonic acid would be taken up by the anion bed after conversion to carbonate.

#### Advantages and disadvantages in the use of ion-exchange resins

The advantages of ion exchange processes are the very low running costs. Very little energy is required, the regenerant chemicals are cheap and if well maintained resin beds can last for many years before replacement is needed. There are, however, a number of limitations which must be taken into account very carefully during the design stages. When itemized, these limitations appear to represent a formidable list and the impression can be given that ion exchange methods might have too many short comings to be useful in practice. However, this is not the case as the advantages mentioned above are very great and compensation can readily be made for most restrictions.

#### Regeneration of resin:

Regeneration is a process that takes ion exchange resin beads that are exhausted (fully loaded), and removes ions that have been picked up during the in-service cycle so the resin can continue to be used. An ion exchange system consists of a bed of resin beads with the ability to pick up hardness or other elements by ion exchange. The resin beads can then be regenerated by a high concentration (10% brine) of salt or other regenerant chemical to restore the resin's capacity, enabling the system to be used over and over for many years. Regeneration of an ion exchange resin bed involves multiple processes, including:

- Backwash
- Chemical injection
- Slow rinse
- Fast rinse

The first step in regeneration is to backwash the system by running water backwards through the bottom of the bed. This lifts the bed and dislodges dirt, debris and other insoluble material that is in the bed. It also helps to remove air pockets in the resin bed and reclassifies the resin. Backwash is essential to minimize pressure drop and ensure even flow in the bed. Regular backwash is only carried out in co-flow systems. In counter-flow systems, backwash is done only when required.

The bed is then settled and regenerated with a brine solution or other regenerant chemical. This step drives off the hardness or other ions and restores the resin back to the required starting form for beginning a new service cycle.

After regeneration, the slow rinse step continues to push regenerant through the bed to continue conversion and remove the regenerant from the system. The fast rinse is a final rinse with raw water to ensure that water quality is being met after regeneration. In counter-flow systems, there can be a recycle step as an alternative to the fast rinse. Recycling between cation resin and anion resin will remove any remaining regenerant chemical.

When a resin system regenerates, only about 60% – 80% of the total ion exchange resin capacity is restored. Some hardness or elemental ions are left on and in the resin. When next in service, some of these residual compounds will leach off the resin and pass into the effluent, and this is called "leakage."

#### Characteristics of packed bed:

Sphericity of particles ( $\phi_s$ ):

Sphericity is a measure of the roundness of a shape. A sphere is the most compact solid, so the more compact an object is, the more closely it resembles a sphere. Sphericity is a ratio and therefore a dimensionless number. It has applications in geology, where it is important to classify particles according to their shape. Sphericity may be calculated for any three-dimensional object if its surface area and volume are known.

$$\phi_s = \frac{6V_p}{D_p S_p} \quad (6)$$

Where,

- $V_p$  – volume of particle
- $S_p$  – surface area of particle
- $D_p$  – diameter of particle

Equivalent diameter of particle ( $D_{eq}$ ):

Equivalent diameter of irregularly shaped particle is the diameter of a sphere of equivalent volume. The equivalent diameter of non-spherical particle is equal to a diameter of a spherical particle that exhibits identical properties to that of the investigated non-spherical particle.

$$D_{eq} = 4 \left( \frac{\varepsilon}{1-\varepsilon} \right) \frac{V_p}{S_p} \quad (7)$$

Where,

- $\varepsilon$  – porosity of packed bed
- $V_p$  – volume of particle
- $S_p$  – surface area of particle

Effective size of particle ( $D_{10}$ ):

It is the size of particle below which 10 percent particles are finer or smaller in size.

Bed porosity ( $\varepsilon$ ):

Bed porosity is defined as the fraction of the bed volume that is occupied by the voids.

$$\varepsilon = \frac{\text{volume of voids}}{\text{total volume (particle+voids)}} \quad (8)$$

Porosity plays an important role in the operations related to the packed bed.



## LIQUID SOLID FLUIDIZATION

**Objective:** To study the fluidization characteristics of liquid solid fluidized bed

**Equipments:** Transparent column, manometer, filter media, manometer, rotameter, pump, tank.

**Theory:** When a liquid or gas is passed up through a bed of solid particles at very low velocity, the particles do not move, and the pressure drop is given by Ergun equation. If the fluid velocity is steadily increased, the pressure drop and drag on individual particle increases. With further increase in velocity, a stage is reached when the drag force on the particles equals the gravity minus the buoyancy force and the particles start moving away from one another. This is called fluidization. The terms fluidization and fluidized bed are used to the condition of fully suspended particles, since the suspension behaves as dense fluid. An equation for minimum fluidization velocity can be obtained by settling the pressure drop across the bed equal to weight of the bed per unit area of cross section, allowing for the buoyant force of the displaced fluid:

$$\frac{\Delta p}{l} = g(1 - \varepsilon)(\rho_p - \rho). \quad (9)$$

The Ergun equation can be written as,

$$\frac{\Delta p}{l} = \frac{150(1-\varepsilon)^2 \mu V_s}{\phi^2 d_p^2 \varepsilon^3} + \frac{1.75 \rho V_s^2}{\phi d_p \varepsilon^3}. \quad (10)$$

Equating above equations to the point of minimum fluidization gives a quadratic equation for minimum fluidization velocity

$$\frac{150 \mu V_{mf}(1-\varepsilon)}{\phi^2 D_p^2 \varepsilon^3} + \frac{1.75 \rho V_{mf}^2}{\phi D_p \varepsilon^3} = g(\rho_p - \rho) \quad (11)$$

For very small particles, only the laminar flow term of the Ergun equation is significant. With  $Re_e < 1$ , the equation for minimum fluidization becomes

$$V_{mf} = \frac{g(\rho_p - \rho) \phi^2 D_p^2 \varepsilon^3}{150 \mu (1-\varepsilon)}. \quad (12)$$

In the limit of very large sizes, the laminar term becomes negligible, and  $V_{mf}$  varies with the square root of the particle size. The equation for  $Re_e > 1000$  is

$$V_{mf} = \sqrt{\frac{g(\rho_p - \rho) \phi D_p \varepsilon^3}{1.75 \rho}}. \quad (13)$$

For low Reynolds number,  $V_t$  and  $V_{mf}$  both vary with  $D_p^2$ ,  $(\rho_p - \rho)$  and  $\frac{1}{\mu}$  so the ratio  $\frac{V_t}{V_{mf}}$  depends mainly on the void fraction at minimum fluidization.

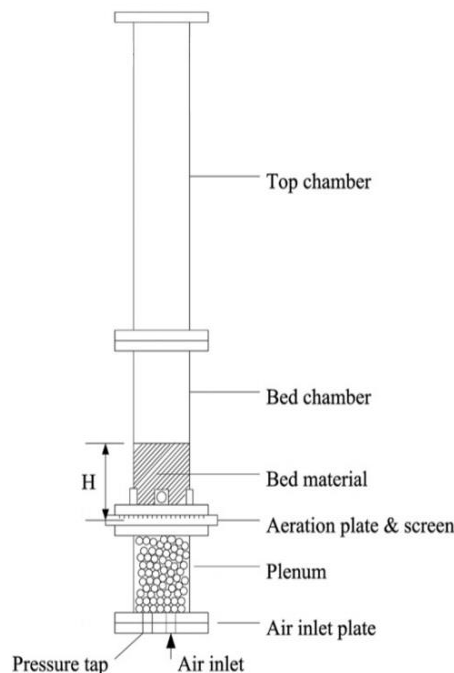
$$V_t = \frac{g D_p^2 (\rho_p - \rho)}{18 \mu} \quad (14)$$

Dividing equation 14 by equation 12,

$$\frac{V_t}{V_{mf}} = \frac{150 D_p^2 g (\rho_p - \rho) \mu (1-\varepsilon)}{18 \mu g (\rho_p - \rho) \phi^2 D_p^2 \varepsilon^3} \quad (15)$$

$$\frac{V_t}{V_{mf}} = \frac{8.33(1-\varepsilon)}{\varepsilon^3 \phi^2} \quad (16)$$

Equation 16 expresses the ratio of terminal settling velocity to minimum fluidization velocity.



**Figure 1: Experimental Setup of fluidized bed reactor (not to scale). The static bed height is identified by H.**

### Methodology:

1. Start the pump and adjust the valve for constant flow rate.
2. Increase the flow rates in gradually. For each value of liquid flow rate note down the mean height of the packed bed and the liquid levels in the two manometric limbs.
3. After attaining the maximum flow rate, start decreasing the flow rate and again measure the mean height of the bed and the fluid levels in the two manometric limbs.

4. Calculate  $\frac{\Delta p}{l}$  and superficial velocity in the bed voidage using eq. 1
5. Plot a graph of  $\Delta p$  versus liquid velocity. From the graph, find the minimum fluidization velocity and compare with that calculated from Ergun equation.
6. From the particles diameter, calculate the terminal settling velocity of the particles.
7. For bed in the fluidized state, plot appropriate graphs between bed voidage and the ratio of superficial velocity and terminal velocity of the particle. Compare the observed bed expansion with that predicted theoretically. (McCabe, Smith & Harriott, 2001)

**Graphs:**

TABLE I. Pressure drop v/s superficial velocity:

TABLE II. Bed porosity v/s  $\frac{V_s}{V_t}$ 

Compare observed bed expansion v/s predicted (from porosity)

**Sample calculations:**

1. Data from experiment:

Flow rate(Q), pressure drop( $\Delta p$ ), bed height(l).

2. Superficial velocity ( $V_s$ ):

$$V_s = \frac{Q}{A} \quad (17)$$

Where,

Q- Volumetric flow rate

A- Cross-sectional area of the column

3. Terminal settling velocity of particle( $V_t$ ):

$$V_t = \frac{g D_p^2 (\rho_p - \rho)}{18 \mu} \quad (18)$$

Where,  $D_p$  -diameter of particle

g -acceleration due to gravity

 $\rho_p$  -density of particle $\rho$  -density of fluid $\mu$  -viscosity of fluid

4. Ratio of superficial velocity to the terminal settling velocity  $\frac{V_s}{V_t}$

5. Bed porosity( $\epsilon$ ):

At minimum fluidization,

$$\frac{\Delta p}{l} = g(1 - \epsilon)(\rho_p - \rho). \quad (19)$$

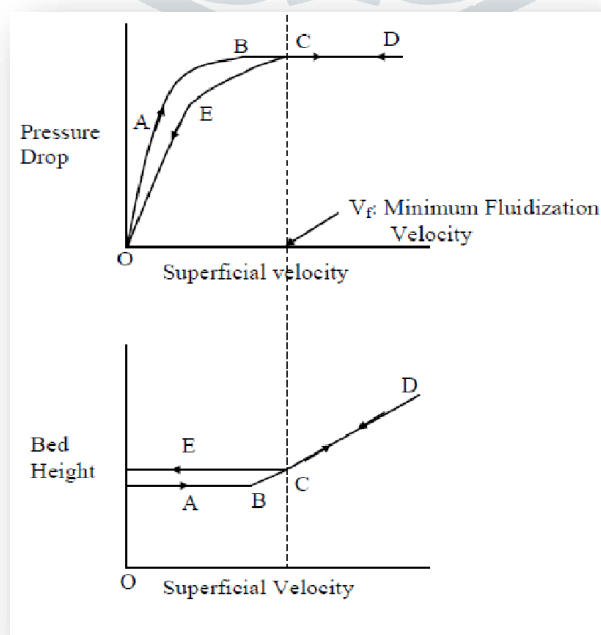
From above equation we can calculate the porosity of the bed.

6. Plot a graph between pressure drop( $\Delta p$ ) v/s superficial velocity( $V_s$ ):

(The graph of pressure drop v/s superficial velocity will show how pressure drop gets affected by changing superficial velocity)

From this graph we will get the minimum fluidization velocity (the velocity at which bed start to fluidize)

Expected graph:

**Figure 2:**

## (a) Pressure drop v/s superficial velocity

## (b) Bed height v/s superficial velocity

Now compare the minimum fluidization velocity obtained from graph with the calculated minimum fluidization velocity by using Ergun's equation.

7. Plot graph between bed porosity( $\epsilon$ ) and the ratio of superficial velocity and terminal velocity of the particle ( $\frac{V_s}{V_t}$ ):

(The graph between bed porosity and the ratio of superficial velocity of particle and terminal settling velocity of particle gives an idea about how bed porosity increases along with the superficial velocity of particle).

From the graph we will get the relation between bed porosity and ratio of superficial velocity and terminal velocity of the particle, this relation calculate the bed porosity and then the predicted bed expansion. Now compare the actual bed expansion and the predicted bed expansion.

### FLUIDIZATION CHARACTERISTICS OF ACTIVATED FILTER MEDIA (AFM)

**Properties of media:** AFM is an amorphous aluminosilicate manufactured by up-cycling post-consumer green glass bottles in a dedicated factory designed and operated specifically to produce activated glass water filtration media. The particle shape of AFM is controlled to maximize surface area and to minimize pressure differential and bed lensing effects.

**Table 1: Characteristics of AFM**

Specifications	Grade 1	Grade 3
Particle size	0.4 to 1.0mm	2.0 to 4.0mm
specific gravity (grain)	2.4 kg/l	2.4 kg/l
Maximum effective size	0.46 mm	2.6 mm
Bulk bed density	1.25 kg/l	1.22 kg/l
Embodied energy	< 65 kW/tonne	< 50 kW/tonne
Colour	>95% green	>95% green

**Data:** Grades of AFM used: grade 1 and grade 3

Total bed height: 60 cm (grade 3- 15cm + grade 1- 45cm)

Column diameter: 10 cm

Density of water: 1000 kg/m<sup>3</sup>

Manometric fluid: mercury

Density of manometric fluid: 13600 kg/m<sup>3</sup>

Viscosity of water: 0.00089 Pa.s

**Table 2: Observations and calculations for Activated Filter Media (AFM)**

Observations				Calculations			
Flow rate $Q$ (m/hr)	bed length $L$ (m)	$\Delta h$ (m)	$\Delta p$ (kg/ms <sup>2</sup> )	Superficial velocity $V$ (m/s)	$\Delta p/l$	Bed porosity $\epsilon$	$V_s/V_t$
0	0.46	0.005	618.03	0	1343.543478	0.902173913	0
0.04	0.46	0.006	741.63	0.0014	1612.23913	0.882609645	0.008064516
0.067	0.46	0.008	988.84	0.00237	2149.652174	0.843479527	0.013652074
0.08	0.46	0.01	1236.06	0.00283	2687.086957	0.804347826	0.016301843
0.144	0.465	0.013	1606.87	0.0051	3455.634409	0.748388349	0.02937788
0.163	0.47	0.014	1730.48	0.0057	3681.87234	0.731915513	0.032834101
0.24	0.488	0.014	1854.09	0.0084	3799.364754	0.723360656	0.048387097
0.3	0.51	0.015	1854.09	0.0106	3635.470588	0.735294118	0.061059908
0.36	0.533	0.015	1977.09	0.0127	3709.362101	0.729913929	0.073156682
0.4	0.557	0.016	1977.09	0.0141	3549.533214	0.74155139	0.081221198
0.5	0.622	0.016	1977.06	0.0176	3178.553055	0.768563197	0.101382488
0.6	0.685	0.016	1977.06	0.0212	2886.218978	0.789848625	0.122119816
0.7	0.735	0.016	1977.06	0.0247	2689.877551	0.804144637	0.142281106
0.6	0.69	0.016	1977.06	0.0212	2865.304348	0.791371461	0.122119816
0.5	0.62	0.016	1977.06	0.0176	3188.806452	0.767816627	0.101382488
0.4	0.565	0.016	1977.06	0.0141	3499.221239	0.745214705	0.081221198
0.36	0.54	0.016	1977.06	0.0127	3661.222222	0.73341909	0.073156682

0.3	0.51	0.015	1854.09	0.0106	3635.470588	0.735294118	0.061059908
0.24	0.49	0.015	1854.09	0.0084	3783.857143	0.724489796	0.048387097
0.2	0.465	0.014	1730.48	0.00707	3721.462366	0.729032884	0.040725806
0.09	0.455	0.006	741.63	0.0032	1629.956044	0.881319641	0.01843318
0.041	0.455	0.005	618.03	0.00145	1358.307692	0.901098901	0.008352535
0.025	0.455	0.004	496.42	0.0088	1091.032967	0.920559708	0.050691244
0	0.455	0.004	496.42	0	1091.032967	0.920559708	0

### FLUIDIZATION CHARACTERISTICS OF 225 NA RESINS

**Properties of resin:** INDION 225 is a strongly acidic, unfunctional, cation exchange resin containing sulphonic acid groups. It is based on cross linked polystyrene and has a gel structure. The resin is extremely robust and has excellent physical and chemical characteristics.

**Table 3: Characteristics of 225Na resin**

Specifications	Characteristics
Appearance	Golden yellow beads
Ionic form as supplied	Sodium
Particle size range	0.3 to 1.2 mm
> 1.2 mm	5.0% maximum
< 0.3 mm	1.0% maximum
Max. Effective size	0.45 to 0.55 mm
Maximum operating temperature	140 °C
Operating pH range	0 to 14
Resistance to reducing agents	Good
Resistance to oxidizing agents	Generally good, chlorine should be absent

**Data:** Total bed height: 60 cm

Column diameter: 10 cm

Density of water: 1000 kg/m<sup>3</sup>

Manometric fluid: mercury

Density of manometric fluid: 13600 kg/m<sup>3</sup>

Viscosity of water: 0.00089 Pa.s

**Table 4: Observations and calculations for 225Na resins**

Observations				Calculations			
Flow rate Q (m/hr)	bed length L (m)	Δh (m)	Δp (kg/ms <sup>2</sup> )	Superficial velocity V (m/s)	Δ p/l	Bed porosity ε	Vs/Vt
0	0.6	0	0	0	0	0	0
0.02	0.61	0.005	618	0.00070771	1013.115	0.6851	0.0139
0.034	0.62	0.006	741.6	0.00120311	1196.129	0.6282	0.0239
0.048	0.65	0.007	865.2	0.00169851	1331.077	0.5863	0.0239
0.2	0.665	0.007	865.2	0.00707714	1301.053	0.5956	0.1394
0.24	0.87	0.007	865.2	0.00849257	994.4828	0.69	0.1692
0.3	0.96	0.013	1606.8	0.01061571	1673.75	0.4798	0.2111
0.36	1.03	0.014	1730.4	0.01273885	1680	0.4778	0.253
0.4	1.14	0.014	1730.4	0.01415428	1517.895	0.5282	0.28
0.5	1.28	0.012	1483.2	0.01769285	1158.75	0.64	0.3525
0.48	1.24	0.012	1483.2	0.01698514	1196.129	0.63	0.3366
0.4	1.03	0.012	1483.2	0.01415428	1440	0.55	0.28
0.36	0.99	0.012	1483.2	0.01273885	1498.182	0.53	0.253
0.3	0.91	0.012	1483.2	0.01061571	1629.89	0.49	0.2111
0.24	0.82	0.009	1112.4	0.00849257	1356.585	0.57	0.17



0.2	0.75	0.008	988.8	0.00707714	1318.4	0.59	0.14
0.12	0.705	0.008	988.8	0.00424628	1402.553	0.56	0.0836
0.075	0.64	0.008	988.8	0.00265393	1545	0.52	0.0517
0.06	0.63	0.008	988.8	0.00212314	1569.524	0.51	0.0418
0.05	0.6	0.007	988.8	0.00176929	1648	0.48	0.0338
0.011	0.59	0.007	865.2	0.00038924	1466.441	0.54	0.0077
0	0.58	0	0	0	0	0	0

### FLUIDIZATION CHARACTERISTICS OF 236H RESINS

**Properties of resin:** INDION 236 is a weak acid, unfunctional cation exchange resin containing carboxylic acid groups. It is based on cross-linked polyacrylic acid and is supplied as moist white beads in the hydrogen form. INDION 236 is recommended for the reduction of alkalinity in boiler feed water. It is also widely used in the treatment of water for many industrial processes.

**Table 5: Characteristics of 236H resin**

Specifications	Characteristics
Appearance	Moist ,white to pale yellow spherical opaque beads
Particle size range	0.3 to 1.2 mm
> 1.2 mm	5.0% maximum
< 0.3 mm	2.0% maximum
Effective size	0.40 - 050 mm
Operating pH range	0-14
Maximum operating temperature	1200 °C
Resistance to reducing agents	Good

**Data:** Total bed height: 60 cm

Column diameter: 10 cm

Density of water: 1000 kg/m<sup>3</sup>

Manometric fluid: mercury

Density of manometric fluid: 13600 kg/m<sup>3</sup>

Viscosity of water: 0.00089 Pa.s

**Table 6: Observations and calculations for 236H resins**

Observations				Calculations			
Flow rate <b>Q</b> (m/hr)	bed length <b>L</b> (m)	$\Delta h$ (m)	$\Delta p$ (kg/ms <sup>2</sup> )	Superficial velocity <b>V</b> (m/s)	$\Delta p/l$	Bed porosity $\epsilon$	<b>Vs/Vt</b>
0	0.6	0.013	1606.878	0	2678.13	0.3058734	
0.033	0.71	0.029	3584.574	0.00116773	5048.69577	-0.308538	0.0261003
0.087	0.84	0.029	3584.574	0.00307856	4267.35	-0.106026	0.0688099
0.12	0.915	0.029	3584.574	0.00424628	3917.56721	-0.015368	0.0949102
0.144	0.965	0.029	3584.574	0.00509554	3714.58446	0.0372417	0.1138923
0.156	0.99	0.029	3584.574	0.00552017	3620.78182	0.0615538	0.1233833
0.19	1.085	0.029	3584.574	0.00672328	3303.75484	0.1437219	0.1502746
0.32	1.3	0.029	3584.574	0.01132343	2757.36462	0.2853371	0.253094
0.2	1.07	0.029	3584.574	0.00707714	3350.06916	0.131718	0.1581837
0.13	0.92	0.029	3584.574	0.00460014	3896.27609	-0.00985	0.1028194
0.12	0.88	0.029	3584.574	0.00424628	4073.37955	-0.055752	0.0949102
0.083	0.81	0.029	3584.574	0.00293701	4425.4	-0.14699	0.0656463
0.075	0.785	0.02	2472.12	0.00265393	3149.19745	0.1837806	0.0593189
0.04	0.68	0.019	2348.514	0.00141543	3453.69706	0.1048593	0.0316367
0	0.6	0.013	1606.878	0	2678.13	0.3058734	

**Results:****Table 7: Comparisons between the experimentally determined (actual) bed height to the mathematically predicted bed height.**

AFM		225Na		236H	
Actual bed height (m)	Predicted bed height (m)	Actual bed height (m)	Predicted bed height (m)	Actual bed height (m)	Predicted bed height (m)
0.46	0.46	0.6	0.6	0.6	0.6
0.46	0.460000669	0.61	0.610004047	0.71	0.6808246
0.46	0.460002902	0.62	0.620018645	0.84	0.7643161
0.46	0.46000476	0.65	0.650019547	0.915	0.8092067
0.465	0.465024863	0.665	0.667744017	0.965	0.8369165
0.47	0.470034269	0.87	0.876179989	0.99	0.850515
0.488	0.488104926	0.96	0.972715139	1.085	0.9083607
0.51	0.510209812	1.03	1.052800676	1.3	0.9960958
0.533	0.533363074	1.14	1.173726165	1.07	0.8892426
0.557	0.557508001	1.28	1.353935171	0.92	0.8069479
0.622	0.623053545	1.24	1.302538622	0.88	0.7782535
0.685	0.686951773	1.03	1.060471886	0.81	0.7396749
0.735	0.738211678	0.99	1.011915213	0.785	0.7221019
0.69	0.69196602	0.91	0.922052892	0.68	0.6472481
0.62	0.621050157	0.82	0.825902495	0.6	0.6
0.565	0.565515297	0.75	0.753132198	-	-
0.54	0.540367842	0.705	0.705696932	-	-
0.51	0.510209812	0.64	0.640165524	-	-
0.49	0.490105356	0.63	0.630090064	-	-
0.465	0.46506182	0.6	0.600047432	-	-
0.455	0.455006632	0.59	0.590000754	-	-
0.455	0.455000729	0.58	0.58	-	-
0.455	0.455111384	-	-	-	-
0.455	0.455	-	-	-	-

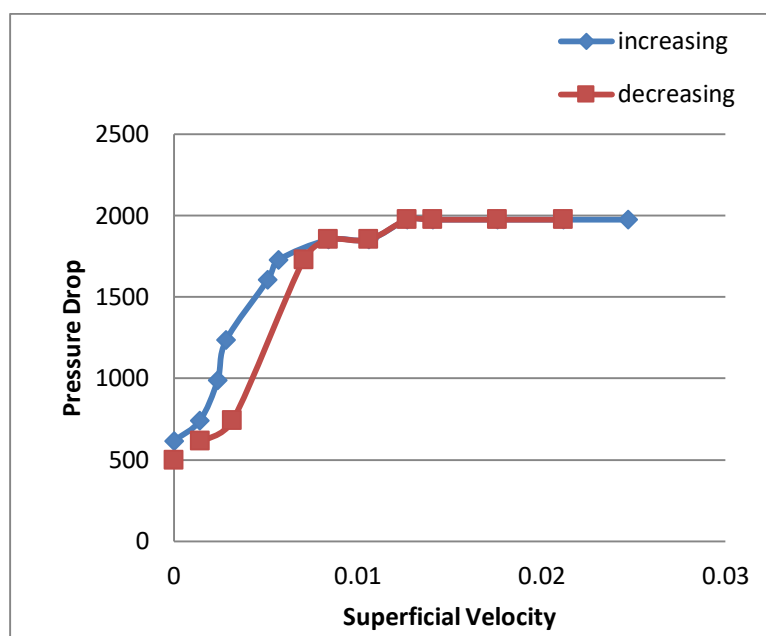


Figure 3: Pressure drop across the resin bed at various values of superficial velocities for AFM

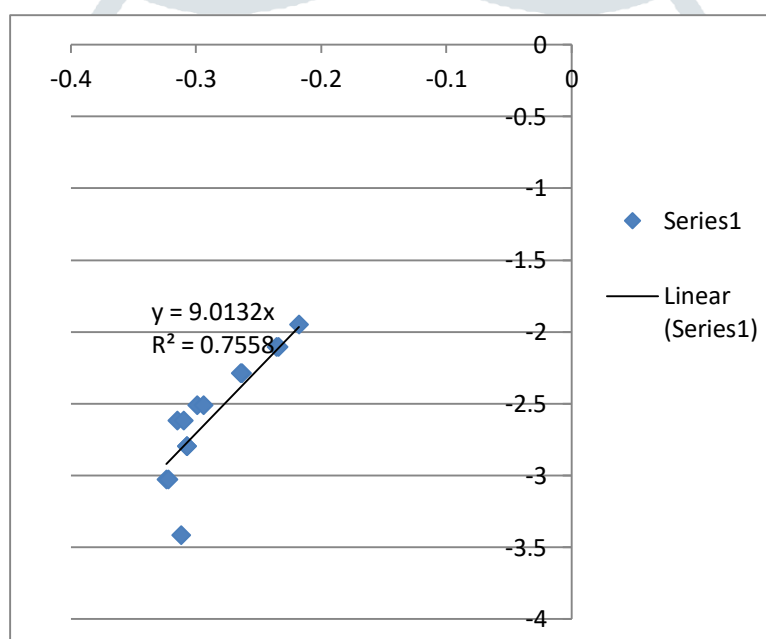


Figure 4: Porosity (y-axis) v/s ratio of superficial velocity to terminal settling velocity (x-axis) for AFM

Minimum fluidization velocity for AFM from graph = **0.0127 m/s**

Minimum fluidization velocity for AFM from Ergun's equation = **0.00955 m/s**

Pressure drop at the minimum fluidization velocity = **1977.09 kg/ms<sup>2</sup>**

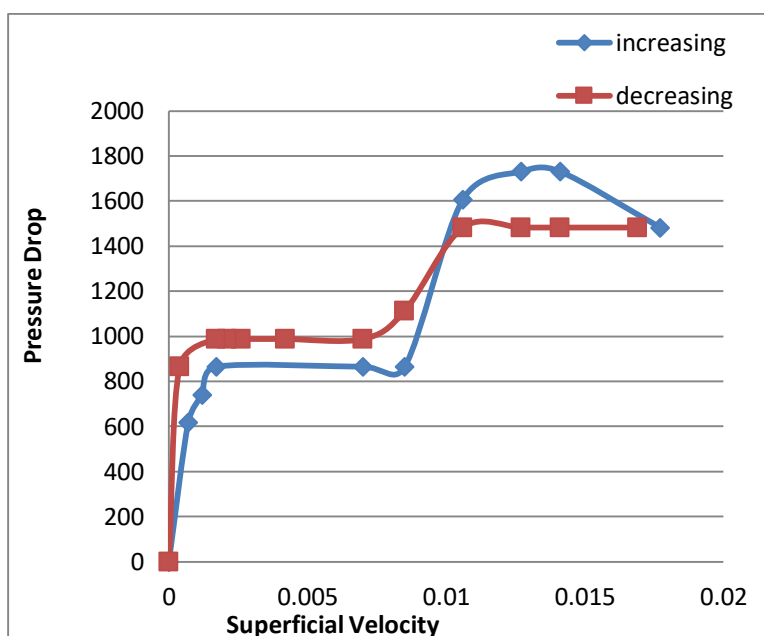


Figure 5: Pressure drop across the resin bed at various values of superficial velocities for 225Na resin

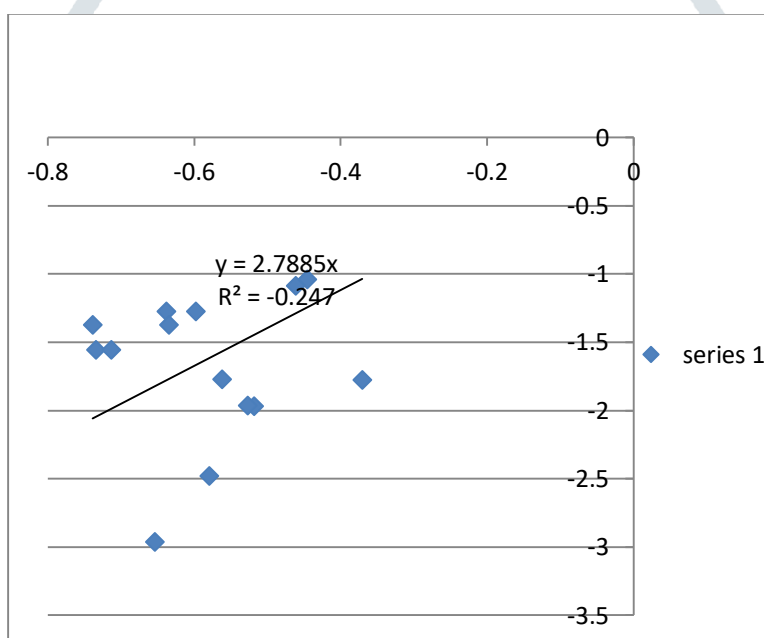


Figure 6: Porosity (y-axis) v/s ratio of superficial velocity to terminal settling velocity (x-axis) for 225Na resin

Minimum fluidization velocity for resin 225Na from graph = **0.0017 m/s**

Minimum fluidization velocity for resin 225Na from Ergun equation = **0.001366 m/s**

Pressure drop at the minimum fluidization velocity = **1483.2 kg/ms<sup>2</sup>**

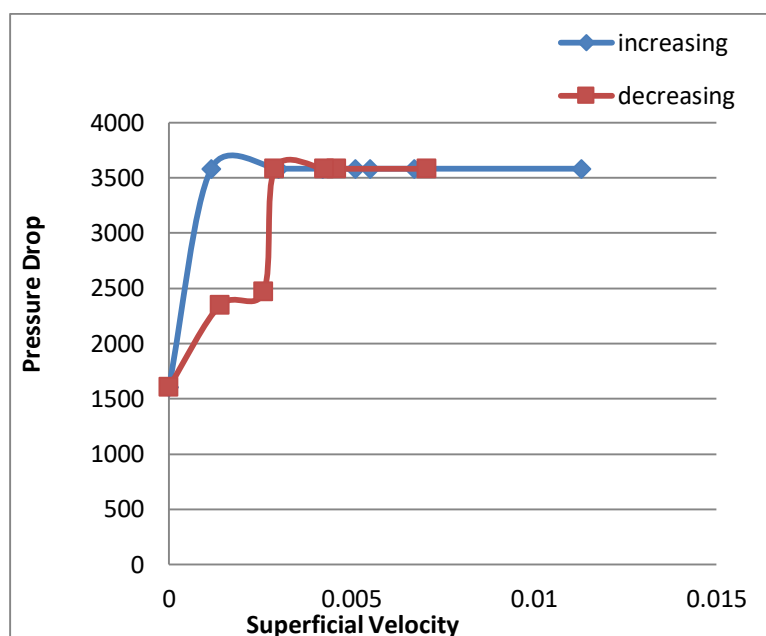


Figure 7: Pressure drop across the resin bed at various values of superficial velocities 236H resin

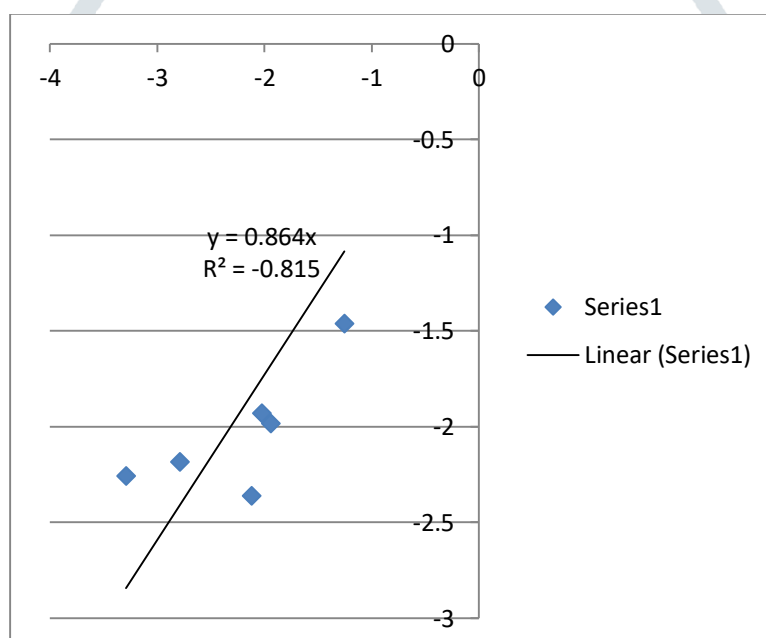


Figure 8: Porosity (y-axis) v/s ratio of superficial velocity to terminal settling velocity (x-axis) for 236H resin

Minimum fluidization velocity for resin 236H from graph = **0.0051 m/s**

Minimum fluidization velocity for resin 236H from Ergun equation = **0.0049 m/s**

Pressure drop at the minimum fluidization velocity = **3584.57 kg/ms²**

#### Discussions:

1. The graphs of pressure drop v/s superficial velocity (Fig. 3, 5 & 7) depict the pressure drop across the resin bed at varying values of superficial velocities.
2. Two graphs are plotted, first with increasing and next with decreasing superficial velocity.
3. When the bed gets fluidized, pressure drop across bed become constant. It shows the balance between resistance forces offered by the bed and the forces by the flow.
4. In Figure 5, the 225Na resin shows the damping effect in graph as there is a sudden spike in pressure drop after remaining constant for a small period of time. This happens due to size of the resin, which is very small. It also affects the fluidization due to less porosity.
5. The graphs of porosity v/s ratio of superficial velocity to the terminal settling velocity (Figures 4, 6 & 8) assist to predict the height of the bed at varying values of superficial velocities. The following equations are obtained from the graphs described in the Figures 4, 6 & 8 respectively.

$$\log(\varepsilon) = \log(V_s/V_t)^{9.0132} \quad (20)$$

$$\log(\varepsilon) = \log(V_s/V_t)^{2.7885} \quad (21)$$

$$\log(\varepsilon) = \log(V_s/V_t)^{0.864} \quad (22)$$

Using the above equations, bed height can be predicted.

6. The fluidization velocity can be affected by the porosity of the bed, superficial velocity, sphericity of the particles, density of the resins & height of the column.



**Conclusion:**

For the regeneration of ion exchange resins the fluidization characteristics of ion exchange resins are useful. The pressure drop indicate the minimum differential pressure required for pumping the regenerating solution used for regeneration. Minimum fluidization velocity indicates the fluidization of resin bed, and to avoid resin loss during the regeneration it is necessary to keep superficial velocity of fluid close to minimum fluidization velocity.

**REFERENCES:**

- [1] Cocco, R., Karri, S., & Knowlton, T. (2014). Introduction to Fluidization. Chemical Engineering Progress. 110. 21-29.
- [2] Cranfield, R., & Geldart, D. (1974). Large particle fluidisation. Chemical Engineering Science, 29(4), 935-947. doi: 10.1016/0009-2509(74)80085-0.
- [3] Dechsiri, C. (2004). Particle Transport in Fluidized Beds: Experiments and Stochastic Models. Groningen: s.n.
- [4] Ergun, S. (1952). Fluid flow through packed columns.
- [5] Escudero, D. (2010). Bed height and material density effects on fluidized bed hydrodynamics. Graduate Theses And Dissertations. 11656, 7. doi: 10.31274/etd-180810-1789
- [6] Hilal, N., Ghannam, M., & Anabtawi, M. (2001). Effect of Bed Diameter, Distributor and Inserts on Minimum Fluidization Velocity. Chemical Engineering & Technology, 24(2), 161-165. doi: 10.1002/1521-4125(200102)24:2<161::aid-ceat161>3.0.co;2-s.
- [7] Kunii, D., & Levenspiel, O. (1991). Introduction. Fluidization Engineering. doi: 10.1016/b978-0-08-050664-7.50007-x.
- [8] Liang, W., Zhang, S., Zhu, J., Jin, Y., Zhiqing Yu, & Wang, Z. (1997). Flow characteristics of the liquid-solid circulating fluidized bed. Powder Technology, 90(2), 95-102. doi: 10.1016/s0032-5910(96)03198-1.
- [9] McCabe, W., Smith, J., & Harriott, P. (2001). Unit operations of chemical engineering (pp. 165-177). Boston: McGraw-Hill.
- [10] Subramanian, R.S. (2002). Flow through Packed Beds and Fluidized Beds.

