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Hydrodynamic Behaviour of Common Salt Water (NaCl Solution) in a Glass-beads Packed Cylindrical Fluidized Bed

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Authors' contributions

This work was carried out in collaboration between all authors. Author HS designed the study, performed the experiment, wrote the protocol and wrote the first draft of the manuscript. Authors KB, AKB and RM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The research paper focuses on to design a laboratory scale cylindrical fluidized bed column. The column was fabricated successfully having a height of 1.5 m and 5 cm inner diameter. Glass beads of spherical shape are packed up inside the column up to 2.4 cm height having 8 mm size. Sodium Chloride (NaCl) salt water solution of different concentrations (1-5 kg salt + 1.3 m^3 of water) has been implemented to characterize the hydrodynamic properties. Results are compared for each concentration with pure water as normal practice considering flow rate, pressure drop across the bed and distributor plate, bed height, bed void fraction and finally bed expansion ratio as variables prevailing an interesting conclusion which may needful towards engineering literature.

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Keywords: Fluidized column; bed height; pressure drop; void fraction; bed expansion ratio.

1. INTRODUCTION

Fluidization is the operation where a granular material is converted from a static solid like state to a dynamic fluid like state. It is a process whereby solid particles behave like a fluid through suspension in a liquid or gas. One of the most important features of fluidized beds is their ability to mix and segregate. As fluidization possesses many advantages like; good solid mixing; leading to uniform temperature throughout the bed, high mass and heat transfer rates, significantly lower pressure drop, thereby reduce pumping costs and minimizing investments for the same feed and product specifications. On passing fluid (gas or liquid) upward through the bed of fine particles, at a low flow rate, fluid merely percolates through the void spaces between the stationary particles. Under this condition it is called a fixed bed. With an increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted regions and called as expanded bed. At a still higher velocity, the pressure drop through the bed increases. At a certain velocity the pressure drop through the bed reaches the maximum and a point is reached when the particles are all just suspended in the upward flowing gas or liquid. At this moment, the particles at the bottom of the bed begin to fluidize, thereafter the condition of fluidization will extend from the bottom to the top and the pressure drop will decline fairly sharply. Fluidization is an established fluid-solid contacting technique, which finds extensive applications in combustion, gasification, carbonization, drying of solids, coating of particles, and many others.

Extensive research on fluidization has been found from about last five decades. Hydrodynamic study of fluidized bed has quite historic. Still novel works on fluidization is under progress. An experimental work carried out to clarify the density differences between components; that plays an important role in the segregating fluidization process of two solid beds [1]. An experiment was carried out in which liquid-fluidized bed of binary (and ternary) mixtures of Teflon having different shapes like spherical, discs shaped and rod shaped were taken. All particles had the same volume, while sphericity is nearly same in case of discs and rods [2]. When binary mixtures of different size or density are fluidized, segregation can occur by shape, with similar segregated and mixed zones. Another fluidization technique was proposed; that has been taken for particulate material processing operations to control the separation efficiency [3]. During fluidization; the fluid velocity is a significant parameter that controls the dynamic behavior. To analyze simpler particulate systems and later to study a wider range of particulate systems simultaneous scheme was developed. Discrete element method (DEM) incorporates both the solid and hydrodynamic components of the interactive forces, worked as an important tool for understanding the separation behaviour of binary particulate systems in fluidized beds. An experiment was carried out to clarify the component densities and mixture composition by several series of experiments. The term "velocity interval" of fluidized bed is limited by its "initial and final fluidization velocity" [4]. Pressure drop method was used to find and compare the minimum fluidization velocity of a three phase system (gas-liquid-solid) between a conical and a cylindrical fluidized bed [5]. An Experiment was carried out using air as fluidizing medium and segregation was observed experimentally using binary mixture of solid particles of same size as feed having different density [6] with variables like superficial gas velocity, solids feed rate and feed composition. There is physical equilibrium between the evolved float Sam and the residual jetsam at steady state when the granular solids behave like a fluid state. The distribution of the float Sam and jetsam shows the segregation in the fluidized bed and which clarify the analogy with the distillation of the binary mixture of liquid [7]. Equilibrium distribution of the floatsam and jetsam was studied to find the effect of the solids feed rate and feed composition. Hydrodynamic characteristics of liquid-sold fluidization of binary mixtures is available in literature with the size ratios ranging from 1.2 to 5.13; using sand of different sizes in tapered beds of apex angles 50°, 100° and 150° having water as the fluidizing medium [8]. There was a study of the fluctuation ratios for regular and irregular particles in gas-solid tapered fluidized beds and to perform dimensional analysis, to develop models with the system parameters viz. geometry of tapered bed, particle diameter, static bed height, density of solid and gas and superficial velocity of the fluidizing medium [9]. The literature scopes for hydrodynamic characteristics of a co-current gas-liquid-solid semi-fluidized bed using liquid as continuous phase and gas as discrete phase [10].

2. MATERIALS

2.1 Experimental Set Up

A line diagram of the experimental set up has shown in Fig. 1.

The experimental set-up is designed and fabricated at our institute and that the auxiliary instruments are manufactured in India. The set up primarily consists of following parts (As per the numbering in Fig. 1.

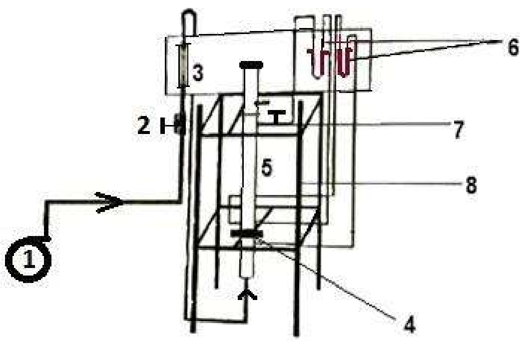


Fig. 1. Outline of experimental set-up

2.1.1 Centrifugal pump

A centrifugal pump (50 Hz, 1 kW) was incorporated to pump the water and salt solution through piping system.

2.1.2 Valves

A 3-way T-shaped ball valve was attached to the pump outlet to further regulate the flow of water from the pump.

2.1.3 Rotameter

A rotameter (up to capacity of 500 lph) is used for the purpose of measuring the flow rate of water.

2.1.4 Distributor plate

In order to support the solid particles (i.e. glass beads) and to distribute the salt water uniformly through bed, a plate was fabricated as per trial and error calculations. The distributor plate made from aluminum sheets and having a diameter of 5 cm was used. 27 holes of 3 mm diameter each were drilled in it using an electric vertical drill and the holes were arranged in rotated square pitch form. Around the distributor plate, a layer of rubber tubing was used to prevent water leakage between two flanges. A snapshot of distributor plate is shown in Fig. 2.

2.1.5 Fluidizing tube

The fluidizing bed is a Perspex pipe of inner diameter 5 cm and having a height of 150 cm above the distributor plate and thickness being 0.5 cm. This column is connected to another pipe of length 50 cm by means of flanges of diameter 10 cm attached to both the sides and distributor plate fixed in between.

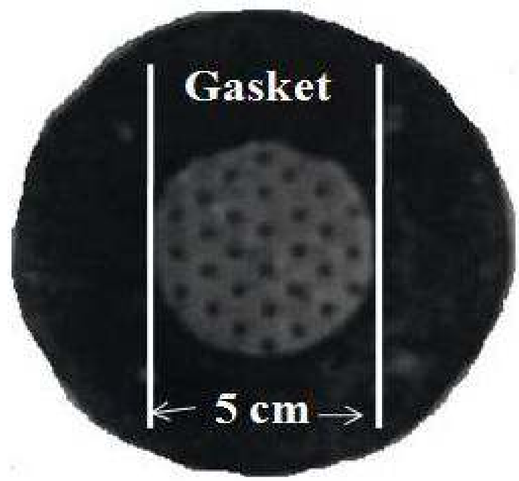


Fig. 2. Image of distributor plate

2.1.6 Manometer

Two manometers; one of 25 cm height for measuring the pressure drop across the fluidizer and another one of 20 cm height for measuring the pressure drop across the distributor were used. Both the manometer were filled with mercury (density =13.6 g cm^{-3}).

2.1.7 Taping valve

Two sets of taping valves, one set across the fluidizer and another set across the distributor and provided for noting the pressure drop across the fluidizer and across the distributor by the help of a manometer.

2.1.8 Fluidizer stand

For the purpose of portability; the set-up stand was designed by welding straight iron rods. It has one end fixed and the other end provided with a clamp.

2.2 Glass Beads

The fluidized bed is packed with glass beads of total 75 gm having a diameter of 8 mm. The beads are fed randomly to the column; up to a static bed height of 2.4 cm from distributor plate.

2.3 Fluidizing Medium

The medium incorporated in this project is water along with dissolved sodium chloride salt in it. For analysis purpose the dynamic characteristics with normal water was studied at first stage. Further the research is extended to study the behavior using different amount of sodium chloride salt dissolved in water. The volume of total amount of water is 1.3 m^3. The salt water solution is differentiated in terms of varying the amount of salt in fixed volume of water at normal atmospheric temperature and pressure. Table 1 shows the characteristics of solution used for the study.

Table 1. Characteristics of solution

Total amount of water	NaCl content in water, kg	Density of solution, $kg.m^{-3}$
1.3 m^3	1	1037.3
	2	1041.4
	3	1044.8
	4	1047.6
	5	1058.2

3. EXPERIMENTAL CALCULATION

3.1 Pressure Drop

Although the pressure drop across the bed could be calculated using Ergun equation [11]. But we have calculated from manometer implemented in the set up. Both the pressure drop across the bed and the distributor plate are calculated using manometer reading from the correlation given by eq-1.

$$\Delta P = (\rho 1 - \rho 2)gh \qquad (1)$$

Where

- ΔP = Pressure drop across the bed and distributor plate, $N.m^{-2}$.
- $\rho 1$ = Density of manometric fluid, $kg.m^{-3}$.
- $\rho 2$ = Density of flowing fluid, $kg.m^{-3}$.
- g = Gravitational force, 9.8 $m.s^{-2}$.
- h = Manometer reading, m.

3.2 Bed Void Fraction (Є)

It is defined as the volume occupied by the fluid phase relative to that of the two-phase mixture. The mathematical correlation is given by eq-2.

$$Є = \frac{vb - vp}{vb} \qquad (2)$$

Where

vb= volume of bed, vp = volume of particles.

3.3 Bed Expansion Ratio (R)

It is a measure of the ability of the bed to expand. It is the ratio of the average of the highest and the lowest bed heights to the static bed height for a particular fluid flow rate; given by eq-3.

$$R = \frac{Average\ bed\ height}{Stagnant\ bed\ height} \qquad (3)$$

All the experiments conducted and data collected are reproducible and repeatable.

4. RESULTS AND DISCUSSION

The variation of pressure drop across the bed with flow rate has been presented in Fig. 3. It is obvious from the figure that the pressure drop across the bed is maximum for pure water. For pure water the value raises up to 57 N/m^2. It is observed that the increase in bed pressure drop for water at incipient stage is time consuming. On focusing the results for salt water; a measurable fall in the pressure drop is visible might be due to increase in density, which significantly affects the bed pressure drop. The minimum pressure drop is found for 5 kg brine solution. It is noteworthy to observe the output for 1 kg salt solution. A most rapid increase in the value is seen as substantial stage then a constant value of pressure drop across the bed. The pressure drop across the bed stabilizes within 50-150 lph for all brine concentration type. Whereas for pure water the pressure drop across the bed regularizes at 260 lph.

The variation of distributor pressure drop with flow rate has been plotted in Fig. 4. It is observed from the results that the distributor pressure drop is quite less compared to bed pressure drop. Similar results are visible as before; with maximum distributor pressure drop for water and subsequently a declined value with salt addition. A steady state in distributor pressure drop is perceived within 50-100 lph for all fluid type.

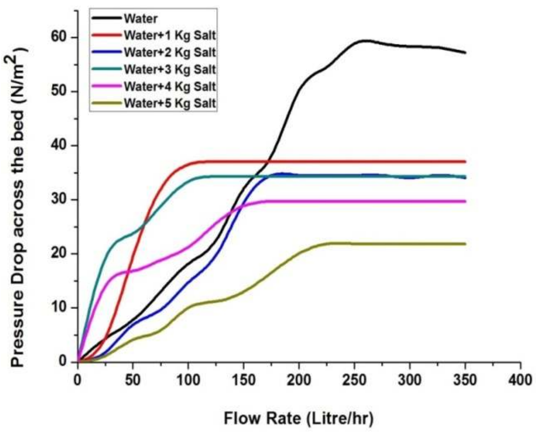


Fig. 3. Variation pressure drop across the bed

The characteristic curves for bed height and bed expansion ratio has been revealed in Fig. 5. The bed height (Fig-5.a) is minimum when fluidized with water. Fluidization starts at 230 lph for water. Whereas at 100 lph fluidization initiates for 2 kg brine solution; which is the lowest observable value. The fluctuating behavior of bed expansion ratio has been reported in Fig 5b.

It is quite captivating to analyze the behavior of void faction of the bed during the entire examination. The behavior is pictured in Fig. 6. The void fraction is calculated according to equation-2. The lowest value of void fraction is observed for water unless the fluidization starts. During the experimentation the volume of the bed (vb) varies as the bed height increases. The "vb" value calculated using the maximum height of the bed corresponding to its fluid flow rate. At incipient the void fraction stays at undeviating value till initiation of fluidization. In most of the time during the process the void fraction has maximum for 2 kg salt water solution.

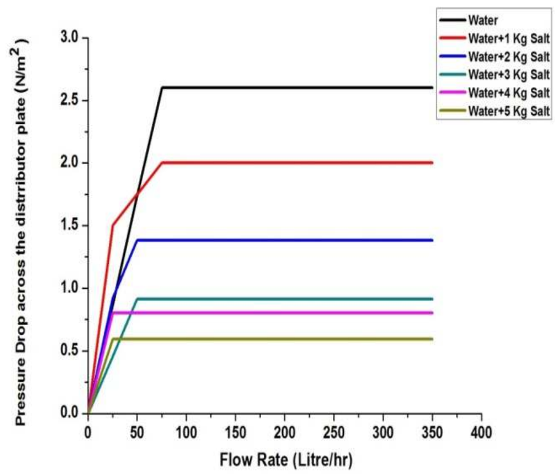
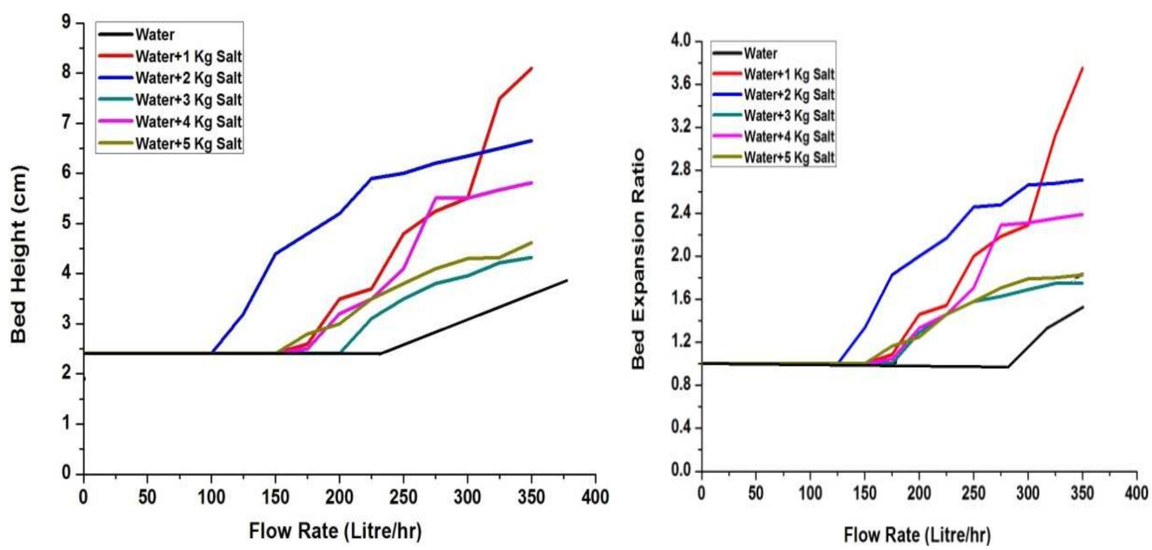


Fig. 4. Variation pressure drop across the distributor plate



(a) **(b)**

Fig. 5. Behavior of (a) bed height and (b) bed expansion ratio with flow rate

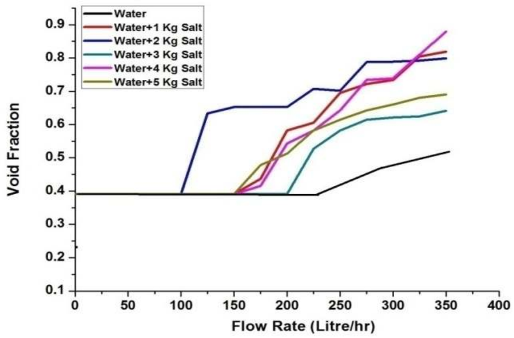


Fig. 6. Variation of void fraction

5. CONCLUSION

Although the research on fluidization is quite matured and may not be superlative, but the focused work is expected to be unconventional and fruitful to the chemical engineering literature. As the study emphasizes the dynamic behaviour of the glass beads bed using salt water media and the results are of acceptable standards. Winding up; salt water as reasonable fluidizing media and can be implemented for innumerable application in engineering for precious products. The present work is a portfolio for future examiners to develop multitudinous research like studying CFD characteristics of bed under motion, mathematical correlation development of parameters, modeling and optimization using statistical analysis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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