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Experimental study and CFD simulation of multi – phase (two and three) flow in fluidized bed column

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ABSTRACT

Background: fluidization is a process in which the solid particles are suspended in a pipe containing flowing one or multi component fluid. **Objective:** the objective of this paper is to study influence of superficial inlet velocity and the ratio of initial height of solid particles to the diameter of the bed (H/D ratio) on the bed expansion for the two (water – solid) and three phase (water – gasoline – Solid) fluidized bed experimentally and numerically. **Results:** pressure of the bed and the expansion of the solid particles increased as the superficial velocity increased (water, gasoline), it also increased as (H/D) increased. A correlation was derived, using the computer program (STATISTICA 10) to predict the pressure drop of the bed. **Conclusion:** both water and gasoline superficial velocity has influence on the pressure of the bed as well as on the expansion of the solid particles inside the bed. H/D ratio has influence on both pressure and the expansion of the particles.

KEYWORDS: Fluidization Two phase Three phase Pressure distribution Pressure drop Bed expansion

INTRODUCTION

Fluidization is a process in which the solid particles are suspended in a pipe containing flowing one or multi component fluid. The reason to that is the drag force which opposes the buoyancy force or the gravitational force on the solid particles. This process can be used to extract or discard a certain component from the liquid phase without any treatment or a change in the properties of the liquid phase [27, 3]. Three phase fluidized beds have been widely used in many environmental, chemical, pharmaceutical, refining, food, biotechnology, and petrochemical industries, because of their desirable characteristics such as large fluid-particles contact area, high heat and mass transfer rates between phase, temperature homogeneity, easy holding, relatively low axial mixing of the fluid, and good mixing of particles [21,19,3]. Almost all the designs and developments of the fluidized beds have been experimental because of the complexity of the flow behavior of liquid-liquid solid fluidized beds. Which are difficult systems to be modeled and still not entirely well understood and are complicated to predict. Chiu *et al*. [11], experimentally investigated the axial mixing, mass transfer, and holdup of dispersed phase for three phase fluidized bed. Kerosene acetic acid was used as a solute while NaOH was used as a solution. Sarkar *et al*. [23], studied the flow of solids from a fluidized bed through inclined pipes. The effect of variables such as fluidization velocity in the bed, diameter and length of the pipe, shape of the pipe at the entry, gas flow through the pipe and inclination of the pipe were investigated. Bandaru *et al*. [10], experimentally investigated the inverse three phase fluidized bed hydrodynamics using particles with low density. Razzak *et al*.

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[22], studied the phase holdups axial distribution in a circulating fluidized bed having three phase (solid-liquid-gas). They used optical fiber probe and electrical resistance tomography to study the circulation rate of solids and the superficial velocity of liquid and gas, and its effect on the phase holdups axial distribution. Nguyen and Huang [21], studied the three phase gas-liquid-solid fluidized bed hydrodynamics by using computational fluid dynamics. Fluent 6.2 modeling multiphase flow Euler-Euler model and they used Gidaspow model to simulate the drag model. Tandon and Karnik [27], studied the dependability of the granular model kinetic theory in expecting the flow of gas – solid hydrodynamics. They used STAR-CCM+ to simulate the granular Euler-Euler model. Habeeb and Al –Turhee [17], investigated two phase flow in vertical pipe experimentally and numerically for steady and unsteady flow. Sheikhi *et al*. [24], studied a conventional three phase (gas-liquid-solid) fluidized bed hydrodynamics by means of pressure fluctuation and vibration signature analysis. Three different regions in the bed were shown which were pre fluidization, bubble coalescing, and bubble disintegrating. Shrivastava *et al*. [25], experimentally performed three phase (solid-liquid-gas) fluidized bed. They found that as the superficial velocity of gas and size of particles increased, the pressure drop increased while the liquid minimum fluidization velocity decreased. Mohammed *et al*. [20], performed an experiment to investigate the three phase fluidized bed hydrodynamics characteristics, they found that the holdup of solid phase decreased with the increase in the velocity of dispersed and continuous phases and particles size. Al – Turhee and Oleiwi [2], studied the two phase fluidized bed experimentally and numerically using Ansys Fluent 15.0 with water and stainless steel particles as the two phase. In this work, two and three phase fluidized beds were studied. The results were compared with the results found by a CFD model. A pressure drop correlation was developed for the two and three phase fluidized bed that depended on the geometrical and physical variables.

1. The Experimental Work

The experimental work consists of two parts, which are the two phase and the three phase fluidized bed.

1.1 Two Phase Flow Experiment Setup Components:

Components used to perform the experiment work of the two phase fluidized bed consists of the following parts. This can be seen in figure (1)

- Main pipe: The fluidized bed main pipe column is a transparent Perspex pipe, with a circular cross section (0.0254 m) diameter and (1m) length.
- Distributor: As a distributer for the fluidized bed a square holes, and rectangular pitch net was used with (0.33 mm) mesh spaces.
- Water flow meter: A flow meter (float type) was used. The flow meter has a flow rate ranged from (5 l/min) to (35 l/min).
- Water centrifugal pump: The centrifugal pump (2″ × 2″) used to supply water into the test pipe. The pump has a maximum discharge of (500 l/min), and a maximum head of (5 m).
- Water tank: A circular cross section tank was used to store the water used in the experiment. The tank is made of aluminum with a capacity of (760 l).
- Pressure sensor: Four pressure transducer sensors were used to measure the pressure. The pressure sensors were located at the pipe side (0.2 m) apart from each other with a pressure measuring range of (0 – 1) bar and accuracy of (0.1 %).
- Pressure interface: An interface was used to connect the pressure sensor a personal computer. The interface transforms the voltage (analog) signal from the sensors into a digital signal that can be read through a software program (DaLi08) run on the personal computer.
- AOS high speed camera: A high speed camera was used to monitor and record the flow behavior in the bed column with high speed (500 frames/sec). The output formats of the camera are optional with active resolution of (720 × 480) and image frequency of (29.97 Hz) (59.94 Hz interlaced).

1.2 Three Phase Flow Experiment Setup Components:

In order to transform the two phase fluidized bed rig into three phase fluidized bed, the following equipment were added. This is shown in figure (2)

- Gasoline flow meter: To measure the volume flow rate of gasoline in the fluidized bed column, a flow meter (float type) was used. The flow meter has a flow rate ranged from (10 l/min) to (70 l/min).
- Gasoline centrifugal pump: The centrifugal pump used to supply the gasoline into the test pipe from the gasoline tank has a maximum discharge of (500 l/min) and it gave a maximum head of (22.5 m).
- Gasoline tank: The gasoline used in the experiment was stored in a tank made of aluminum. The tank has a capacity of (530 l).
- Separation tank: The mixture of water and gasoline coming out of the test column were collected into a tank and left there for a day or so until the gasoline and water separate. The separation tank was made from plastic material with a capacity of (400 litter).

1.3 Experimental Procedure:

The procedure for these experiments is as follows:-

1. The first quantity of the spherical solid particles was placed inside the fluidized bed column, which is the initial static height of the solid particles as shown in table (1) by the ratio H/D.
2. Water was pumped from the tank into the bottom of the bed. The water valve was adjusted until the volume flow rate in the flow meter reached the first value of the water flow rate.
3. The pressure was measured by the sensors, for all process. And images for the process were taken by AOS high speed camera.
4. The water valve was closed.
5. The above steps repeated for the five different values of water flow rates which are shown in table (1).
6. The above steps were repeated for the five different values of H/D ratio which are shown in table (1).

For the three phase fluidized bed the following procedure is followed:-

1- The first quantity of the spherical solid particles was placed inside the fluidized bed column.

2- Water was pumped from the water tank into the bottom of the bed with the first value of the water flow rate.

3- Gasoline was pumped from the gasoline tank into the bottom of the bed with the first value of the gasoline flow rate.

4- The pressure being measured by the sensors, for all the process. And images for the process were taken by AOS high speed camera.

5- The gasoline and water valves were closed respectively.

6- The above steps were repeated for the five different values of gasoline volume flow rates, see table (1).

7- The above steps were repeated for the five different values of water flow rates which are shown in table (1).

8- The above steps were repeated for the five different values of H/D ratio which are shown in table (1).

Table 1: Variables of the Experiments

H/D ratios	Water volume flow rate (l/min)	Gasoline volume flow rate (l/min)
0.59	5	10
0.79	10	12.5
0.98	15	15
1.18	20	17.5
1.38	25	20

1.4 Superficial Velocity:

Superficial velocity was found for water and gasoline and used in the graphs to show the effect of increasing it on the pressure profile and bed expansion. According to equation (1).

$$Q = UA \quad (1)$$

Where

Q = Liquid flow rate (m^3/s).

A = Column cross sectional area (m^2).

U = Liquid superficial velocity (m/s).

2. Numerical Method

2.1 The Geometry:

The geometry of the problem was modeled as a 2D structure for the two and three phase fluidized bed using Designmodeler combined with Ansys Workbench 15.0 by drawing a rectangle on the X-Y plan with (0.0254 m) horizontal dimension and (1 m) vertical dimension.

2.2 The Mesh:

The geometry of the two phase fluidized bed was divided into small square element (Quadrilateral structured grid) using the Meshing combined with Ansys Workbench 15.0 with maximum and minimum size equal to (0.002 m) which produced (6500) elements, (7014) nodes and maximum aspect ratio equal to (1.45187). Quadrilateral mesh (Hybrid grid) was used for the three phase fluidized bed model with maximum and minimum element size equal to (0.002 m) and (0.000314 m) respectively which produced (6648) elements, (7183) nodes and maximum aspect ratio equal to (16.4135).

2.3 Two Phase Fluidized Bed Boundary Conditions:

The inlet of the bed, which is the bottom edge of the geometry, was divided into (13) sections, the superficial velocity of primary phase (water) entered the bed through these edges symbolizing the distributor net that was used experimentally. The outlet of the bed, which is the top edge of the geometry, was set to be outlet pressure, then was given a value of mixture gage pressure taken from the experimental data.

2.4 Three Phase Fluidized Bed Boundary Conditions:

The bottom edge of the geometry was divided into (81) sections which is the inlet of the bed. The superficial velocity of primary phase (water) and dispersed phase (gasoline) enter the bed through these edges and this was done to symbolize the distributor action. The outlet of the bed, which is the top edge of the geometry, was set to be outlet pressure, given a value of mixture gage pressure taken from the experimental data.

2.5 Problem Assumptions:

In order to simulate the fluidized bed model, the following assumptions were made.

1. Unsteady state flow
2. Turbulent flow
3. Planer two dimensional space
4. Pressure based solver
5. Incompressible flow
6. The gravity in Y direction is (-9.81 m/s^2)

2.6 Simulation Models:

Eulerian – Eulerian multiphase model were chosen to simulate the two phase fluidized bed. The continuous phase, which is water, was set to be the primary phase whereas the solid particles were set to be granular secondary phase with. Syamlal-O'Brien drag coefficient was set for the interaction between solid and water. Eulerian- Eulerian multiphase model was used with dense discrete phase model parameter to simulate the three phases in the fluidized column. The gasoline phase was set to be a dense discrete phase.

2.7 Governing Equations:

Eulerian model solves the conservation equations of continuity and momentum for each phase. The general equations used by Ansys Fluent 15.0 software were (Fluent User's Guide).

I. Continuity Equation:

The continuity equation was used to calculate the phase volume fraction, eq. (2).

$$\frac{1}{\rho_{rq}}\left(\frac{\partial}{\partial t}\left(\alpha_q\rho_q\right)+\nabla.\left(\alpha_q\rho_q\vec{v}_q\right)=\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right)\right) \quad (2)$$

Where the subscripts q and p represent the primary and secondary phases which makes $\dot{m}_{pq}$ is the mass transfer from the phase p to the phase q and $\dot{m}_{qp}$ the mass transfer from the phase q to the phase p. The phase velocity is $\vec{v}$, ρ is the density of phase, and α is the volume fraction.

II. Momentum Equation:

The equation general form for a liquid – solid granular flow is as eq. (3)

$$\frac{\partial}{\partial t}\left(\alpha_s\rho_s\vec{v}_s\right)+\nabla.\left(\alpha_s\rho_s\vec{v}_s\vec{v}_s\right)=-\alpha_s\nabla p-\nabla p_s+\nabla.\bar{\bar{\tau}}_s+\alpha_s\rho_s\vec{g}+\sum_{l=1}^{N}\left(K_{ls}\left(\vec{v}_l-\vec{v}_s\right)+\dot{m}_{ls}\vec{v}_{ls}-\dot{m}_{sl}\vec{v}_{sl}\right)+\left(\vec{F}_s+\vec{F}_{lift,s}+\vec{F}_{vm,s}\right) \quad (3)$$

2.8 Turbulence Model:

Turbulence RNG (Re-Normalization Group) mixture model was set for the two and three phase fluidized bed model which can be defined through these equations, eq. (4, and 5) (Fluent User's Guide).

$$\frac{\partial}{\partial t}\left(\rho_m k\right)+\nabla.\left(\rho_m\vec{v}_m k\right)=\nabla.\left(\frac{\mu_{t,m}}{\sigma k}\nabla k\right)+G_{k,m}-\rho_m\in \quad (4)$$

$$\frac{\partial}{\partial t}\left(\rho_m\in\right)+\nabla.\left(\rho_m\vec{v}_m\in\right)=\nabla.\left(\frac{\mu_{t,m}}{\sigma_\in}\nabla\in\right)+\frac{\in}{k}\left(C_{1\in}G_{k,m}-C_{2\in}\rho_m\in\right) \quad (5)$$

Where $\in$ is the turbulent dissipation rate, μ is the viscosity, G is the energy, and σ is the surface tension.

3. RESULTS AND DISCUSSIONS

3.1 Two Phase Fluidized Bed Results:

For the two phase fluidized bed, the influence of increasing water superficial velocity from (0.16 m/s) to (0.82 m/s) and the influence of increasing H/D ratio from (0.59) to (1.38) on the pressure profile of the bed and the expansion of the solid particles were studied.

3.1.1 The Influence of Water Superficial Velocity on the Pressure Profile:

Figure (3) show the effect of increasing water superficial velocity on the pressure profile. It can be seen that the pressure profile increased with increasing water superficial velocity at each H/D ratio. When the water superficial velocity increased, the turbulence inside the test column is increased and the mixing between phases being high leading to increase in the pressure over the walls of the test column. The volume of the test column was constant and it was already occupied by the solid particles and water, so any increase in the amount of water would increase the pressure over the walls of the bed. This figure also illustrates a comparison amid the experimental results and the results originated with Ansys Fluent 15.0. The deviation amid these two results was found to be (16 %).

3.1.2 The Influence of H/D Ratio on the Pressure Profile:

Influence of H/D ratio on the pressure profile for varied values of water superficial velocity at four points on the test column side were shown in figure (4). A comparison between the experimental results and the computational fluid dynamic results are also shown in this figure. The simulation results seemed to have approximately the same influence of that the experimental results. These figures illustrated that when H/D ratio increased the pressure profile increased. As the mass of solid particles inside the bed increased by increasing H/D ratio, the resistance of the particles over the flow of water increased leading to an increase in the pressure of the bed. A deviation amid the experimental data and the computational fluid dynamics results was (16 %).

3.1.3The Influence of Water Superficial Velocity on the bed expansion:

Figures (5,6) demonstrate the solid particles expansion inside the test column experimentally and numerically for five varied values of water superficial velocity at constant values of H/D ratio. As the superficial velocity of water increased, the elevation of solid particles inside the test column increased over the value that originally pumped into the bed as well as the spaces between the particles increased. The increase that happened in the elevation of solid particles was due to the increase in the amount of water pumped into the test column as the water superficial velocity increased which pushed the particles into farther places within the column.

A visual comparison between the experimental test column photographs and the simulated solid volume fraction images are made in these figures. The values of the volume fraction that were represented by contours can be shown by the color rule on the left side of the numerical images.

3.1.4The Influence of H/D Ratio on the bed expansion:

Influence of H/D ratio on the expansion of solid particles for the two phase fluidized bed are shown in figures (7,8) for various values of water superficial velocity. When the value of H/D ratio was increased, the elevation of particles rose and the spaces amid the solid particles increased as well, but not as high as when the value of water superficial velocity rose. These figures show the experimental fluidized bed behavior through the photographs that were taken for test column and compared them with the solid volume fraction found numerically with Ansys Fluent 15.0. A close similarity was seen between the expansion of solid particles between the experimental photos and the images of solid volume fraction found with Ansys Fluent 15.0.

3.2 Three Phase Fluidized Bed Results:

Influence of increasing gasoline superficial velocity from (5.26 m/s) to (10.53 m/s), water superficial velocity from (0.16 m/s) to (0.82 m/s), and H/D ratio from (0.59) to (1.38) on the pressure and the expansion of the three phase fluidized bed were studied.

3.2.1 The Influence of Gasoline Superficial Velocity on the pressure profile:

Figure (9) show the effect of increasing gasoline superficial velocity on the fluidized bed pressure measured at four points along the test column. It also show a comparison between the experimental measured results and the numerical results found at a surface point created with the same coordinate where the pressure sensors situated experimentally. The simulation results seemed to have the same influence as the experimental results with a deviation of about (22 %) found between the experimental and the numerical data. The pressure of the test column increased due to the increase in the energy and circulation of the test pipe as a result of the turbulence motion. As far as the tube volume is concerned, it was noticed that although gasoline flowed inside the tube and occupied the same volume as water.

3.2.2 The Influence of Water Superficial Velocity on the pressure profile:

Influence of water superficial velocity on the pressure along the fluidized bed pressure for the changed values of gasoline superficial velocity and H/D ratio can be seen in figure(10).The pressure inside the fluidized bed increased with the increase in the water superficial velocity with respect to the gasoline superficial velocity and H/D ratio. The pressure over the walls of the test column increased as the water superficial velocity increased due to the increase in the amount of water inside the test column which had a constant volume that already filled with gasoline, water, and solid particles. Increasing the amount of water, increased the pressure over the walls of the bed. The experimental results were compared with the numerical results in this figure.

The computational fluid dynamics gave a simulation results varied up and down the experimental results with a deviation of about (22 %) found amid the experimental and the numerical results.

3.2.3 The Influence of H/D Ratio on the pressure profile:

Figure (11) demonstrate the effect of H/D ratio on the pressure profile for diverse values of water and gasoline superficial velocities. This figure illustrate that the pressure in the fluidized bed increased with the increase in the ratio of H/D at definite value of water superficial velocity and gasoline superficial velocity. This came to be adequate with the fact that the amount of solid particles in the fluidized bed increased by increasing H/D ratio. Increasing of H/D ratio, increased the resistance over the coming flow of the water and gasoline mixture which was the reason for the solid particles being suspended in the flow. Increasing the resistance led to an increase in the pressure of mixture on the walls of the bed. The numerical influence for increasing H/D ratio was the same as the experimental one with a deviation of about (22 %) found amid the experimental and the numerical results.

3.2.4 The Influence of Gasoline Superficial Velocity on the bed expansion:

Figures (12, 13) demonstrate the solid particles expansion inside the test column experimentally and numerically. As the gasoline superficial velocity increased, the solid particles would be driven into further places increasing by the height of solid particles and the spaces between them. The energy put into the fluidized bed increased as the gasoline superficial velocity increased which also increased the expansion of the solid particles by increasing the movement inside the bed. A visual compassion between the experimental photographs and the solid volume fraction images were made in these figures.

3.2.5The Influence of Water Superficial Velocity on the bed expansion:

Figures (14, 15) show the influence of water superficial velocity on the expansion of solid particles in the test column at various values of gasoline superficial velocity and H/D ratio, experimentally and numerically. The fluidized bed activity increased as the water superficial velocity increased which produced an increase in the turbulence of the bed and the circulation as well causing by that an increase in the expansion and separation of the bed solid particles.

3.2.6The Influence of H/D Ratio on the bed expansion:

Influence of H/D ratio on the expansion of solid particles for the three phase fluidized bed are shown in figures (16, 17) for various values of gasoline superficial velocity and water superficial velocity. When the value of H/D ratio rose, the altitude of particles and the spaces amid the solid particles rose as well. Since the diameter of the test column was constant, the ratio H/D increased through increasing the initial elevation of solid particles inside the test column, so as the gasoline and water superficial velocity increased, it drove the particles into higher elevation increased by the expansion of solid particles. These figures show the experimental fluidized bed behavior through the photographs that were taken for test column and visually compared it with the solid volume fraction found by numerical simulation. A close similarity for the expansion of solid particles between the experimental photos and the images of solid volume fraction found with Ansys Fluent 15.0.

3.3 Pressure Drop Correlations for two and Three Phase Fluidized Beds:

A pressure drop correlation for the two and three phase fluidized beds was suggested according to the experimental data took the following form, eq. (6) & (7).

$$\Delta P = C\left(Lr\right)^{a_1}\left(Re_c\right)^{a_2}\left(d_p*(H/D)\right)^{a_3}\left(Ar\right)^{a_4} \quad (6)$$

For the two phase fluidized bed and

$$\Delta P = C\left(Lr\right)^{a_1}\left(Re_c\right)^{a_2}\left(Re_d\right)^{a_3}\left(d_p*\rho_s*(H/D)\right)^{a_4} \quad (7)$$

For the three phase fluidized bed

Where C and $a_{1,\,2,\,3,\,4}$ are constants determined by a computer program (STATISTICA Version 10) using the least square fit producing the final form of the correlation, eq. (8) & (9).

$$\Delta P = 0.721778\left(Lr\right)^{-0.35855}\left(Re_c\right)^{0.129586}\left(d_p * (H/D)\right)^{-0.350143}\left(Ar\right)^{0.276293} \quad (8)$$

For the two phase fluidized bed and

$$\Delta P = 1.61567\left(Lr\right)^{-1.26263}\left(Re_c\right)^{0.03603}\left(Re_d\right)^{0.28236}\left(d_p * \rho_s * (H/D)\right)^{-0.4836} \quad (9)$$

For the two phase fluidized bed and

The correlation performance for the two phase is shown in figure (18) and for the three phase is shown in figure (19) , a deviation of about (17 %) was found between the experimental and the correlated data for the two phase fluidized bed and (22 %) for the three phase fluidized bed. Reynolds number for continuous phase ranged from (4161) to (20800), Reynolds number for dispersed phase ranged from (8052) to (16100), and H/D ratio ranged from (0.59) to (1.38).

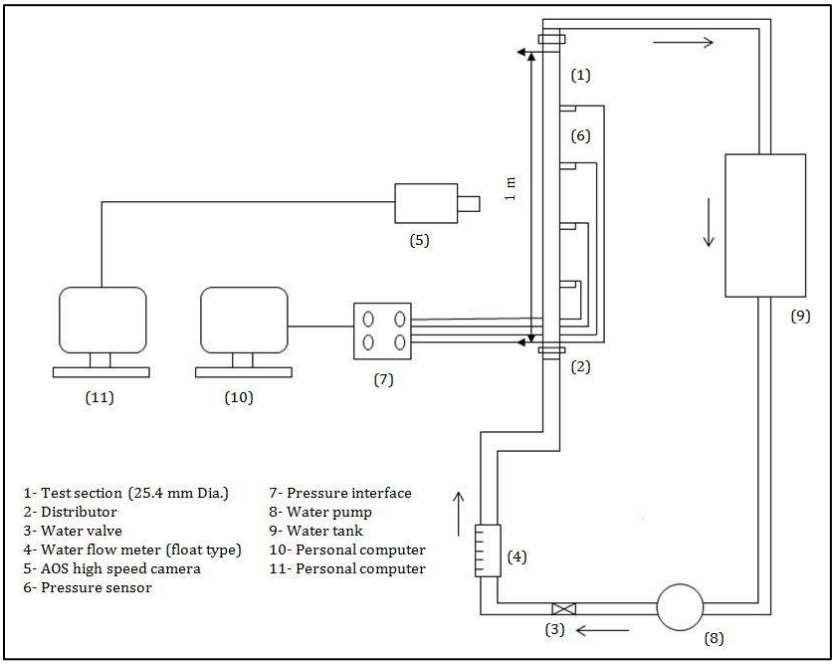


Fig. 1: The two phase fluidized bed schematic diagram

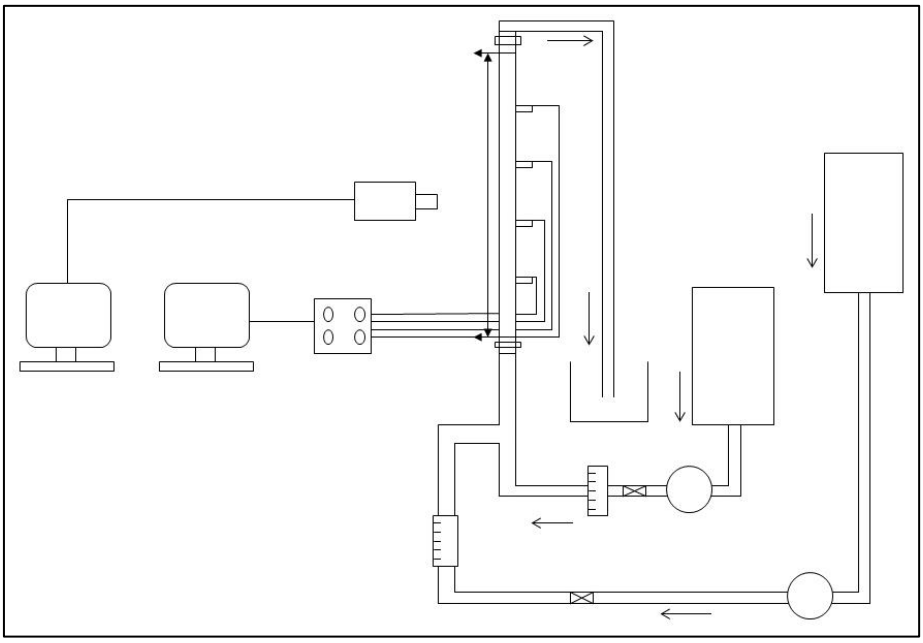


Fig. 2: The three phase fluidized bed schematic diagram

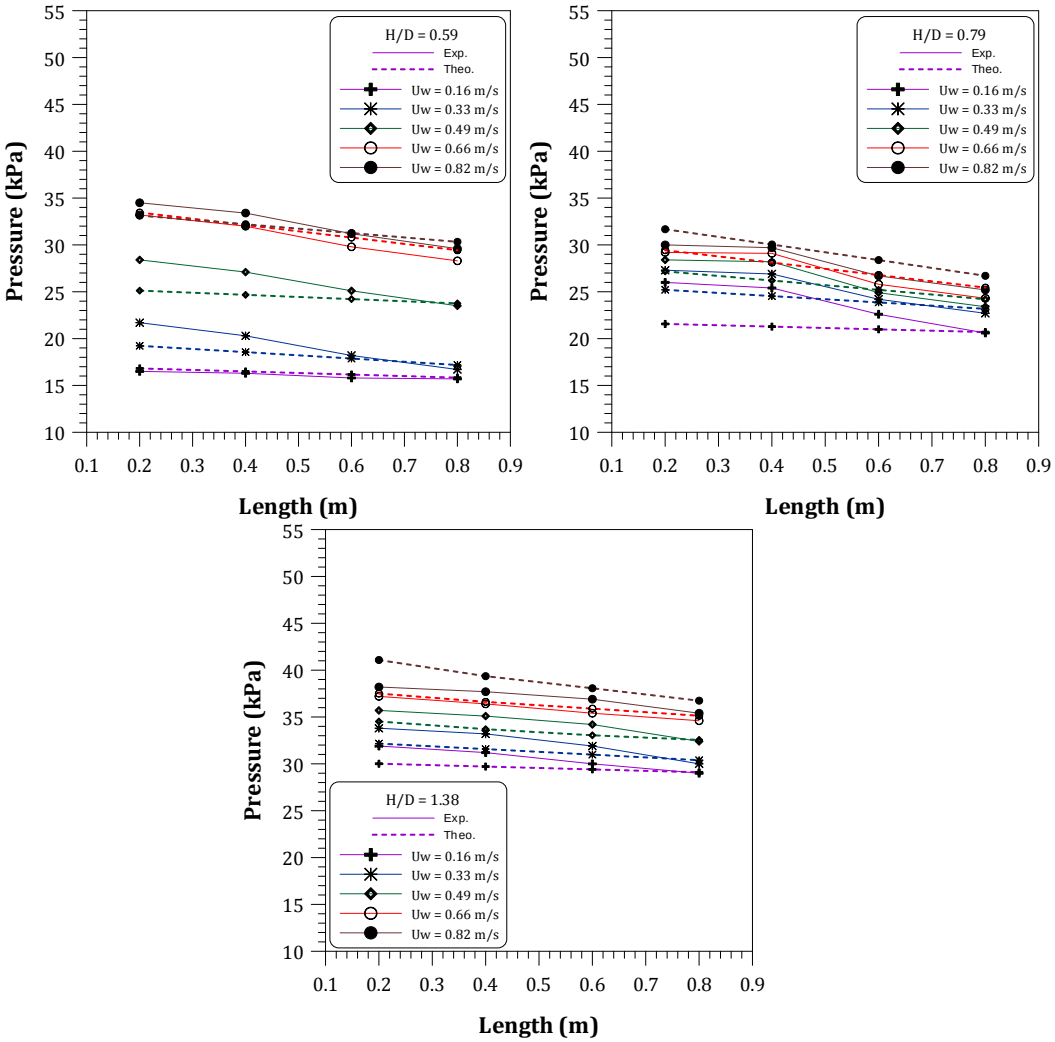


Fig. 3: Effect of Water Superficial Velocity on the Pressure Profile at Different Values of H/D ratio

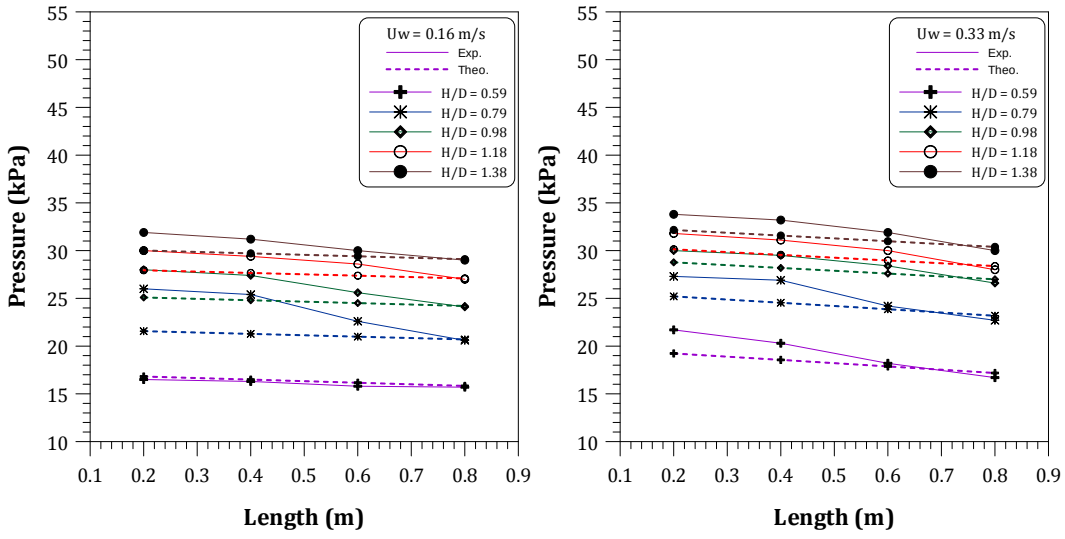
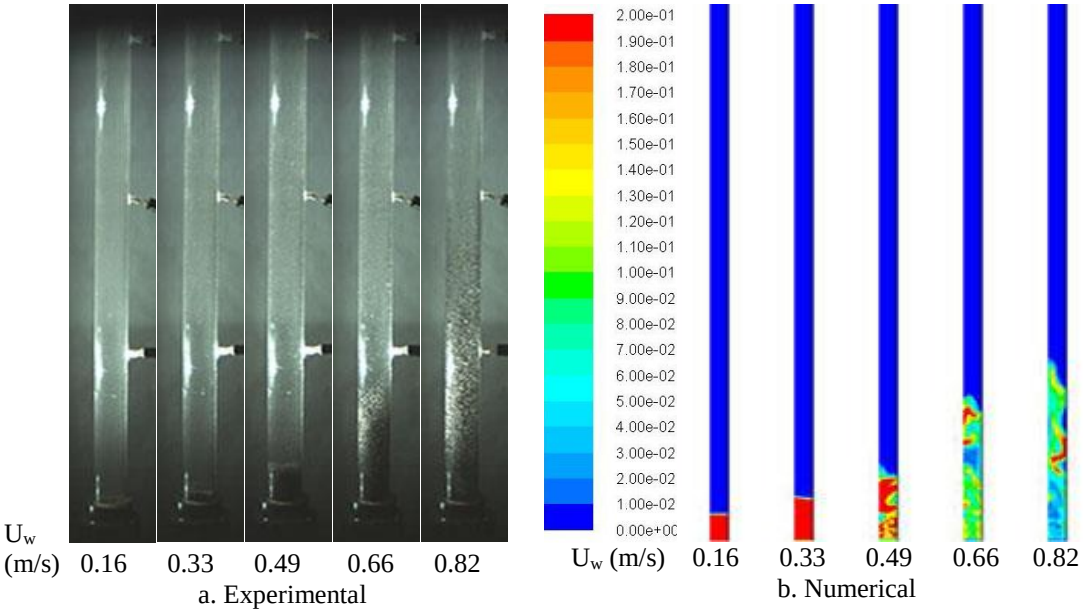
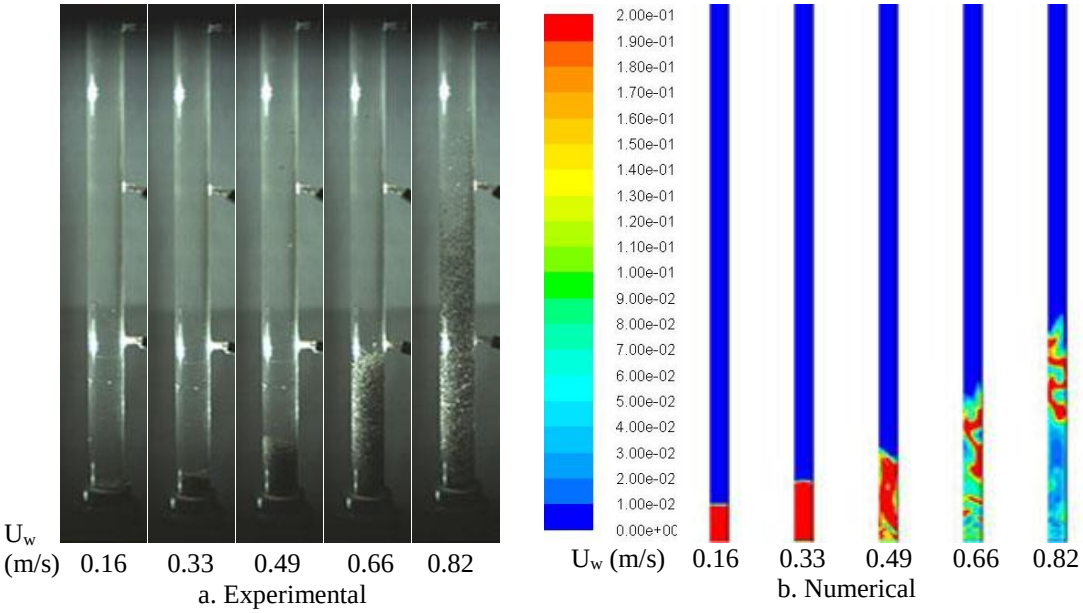


Fig. 4: Effect of H/D Ratio on the Pressure Profile at Different Values of Water Superficial Velocity



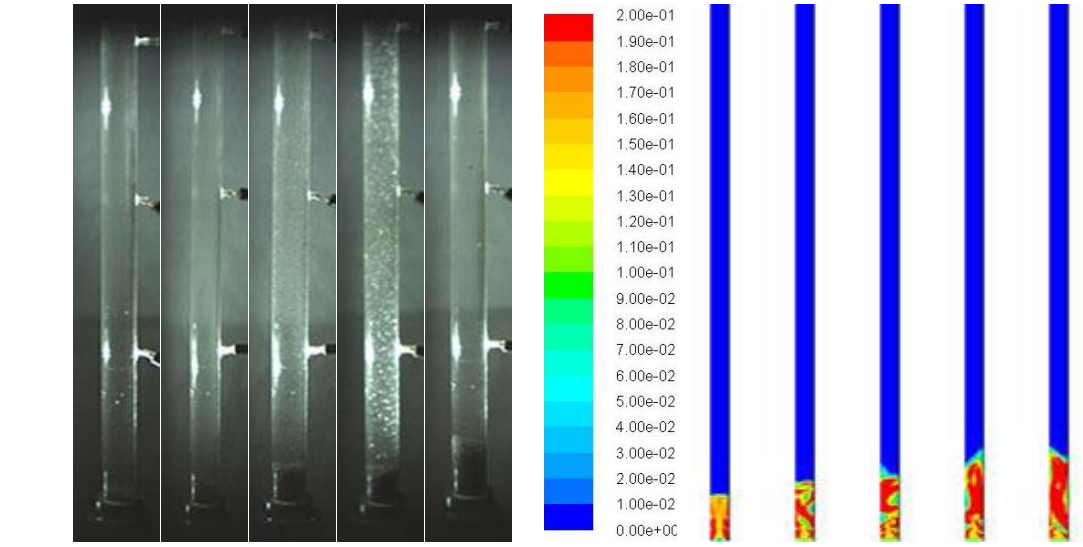
a. Experimental b. Numerical

Fig. 5: The Effect of Water Superficial Velocity on Bed Expansion at H/D = 0.98



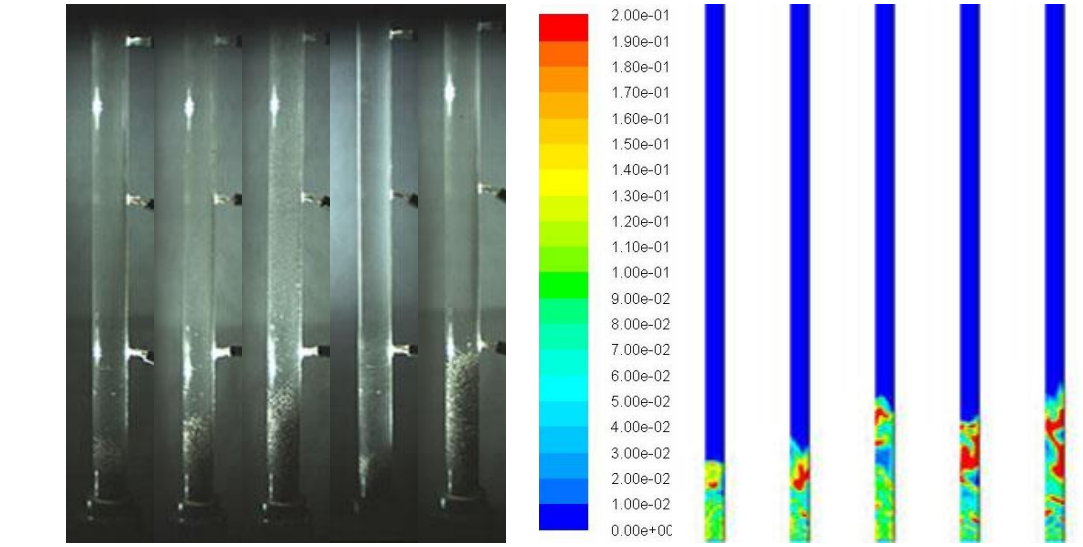
a. Experimental b. Numerical

Fig. 6: The Effect of Water Superficial Velocity on Bed Expansion at H/D = 1.38



a. Experimental b. Numerical

Fig. 7: The Effect of H/D Ratio on Bed Expansion at 0.49 m/s Water Superficial Velocity



a. Experimental b. Numerical

Fig. 8: The Effect of H/D Ratio on Bed Expansion at 0.66 m/s Water Superficial Velocity

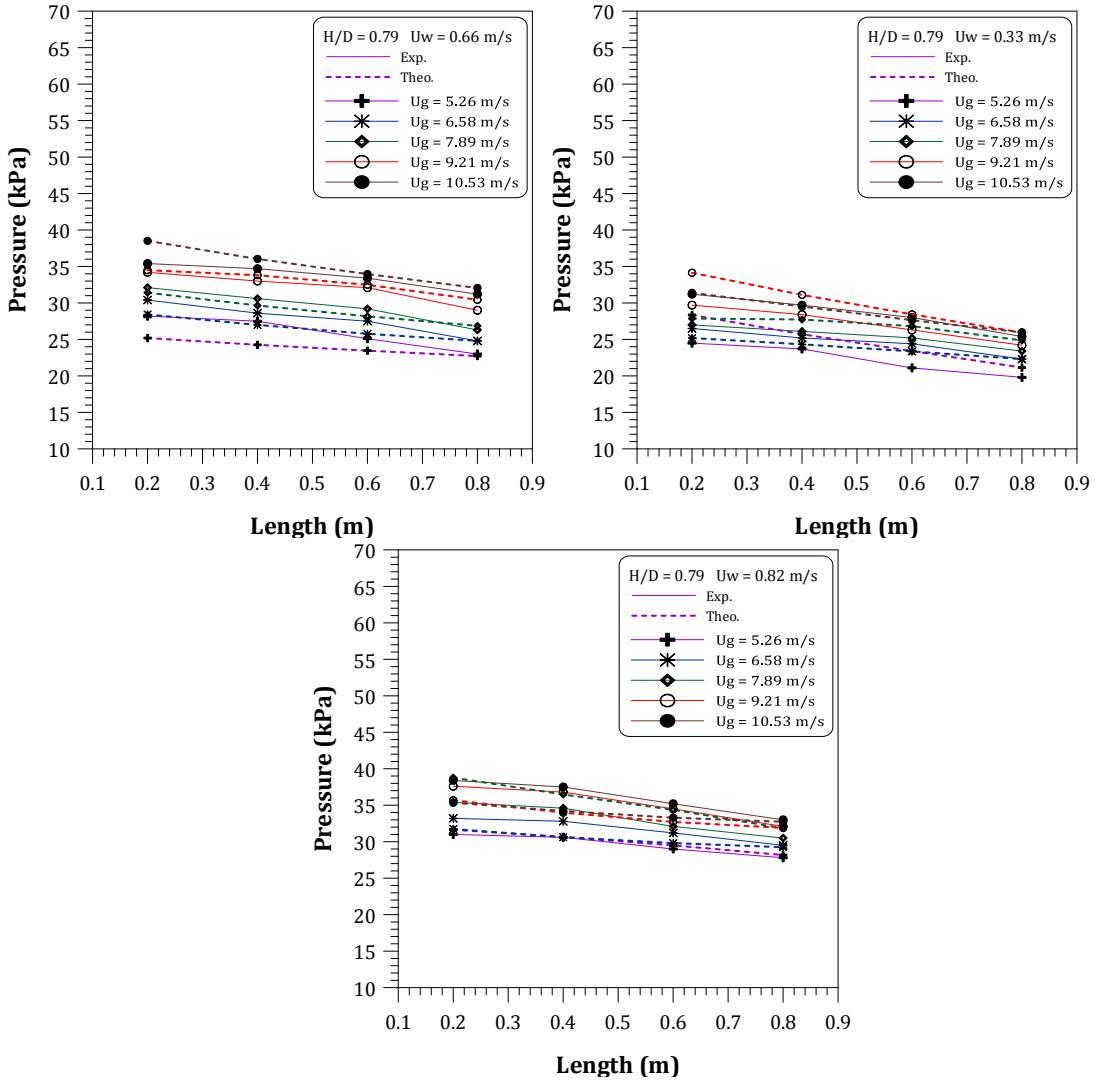
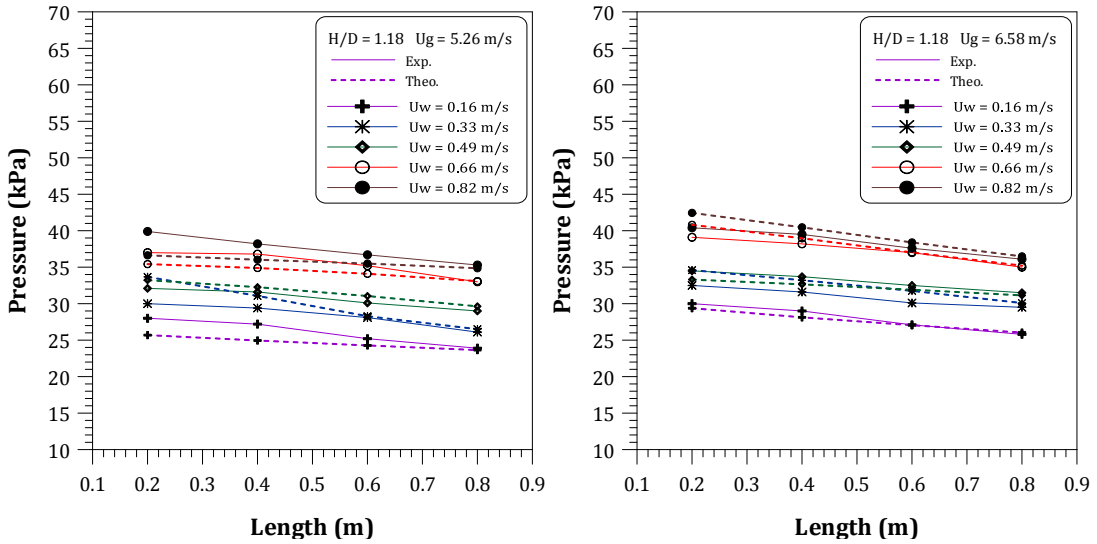


Fig. 9: Effect of Gasoline Superficial Velocity on the Pressure Profile at 0.79 H/D and Different Values of Water Superficial Velocity



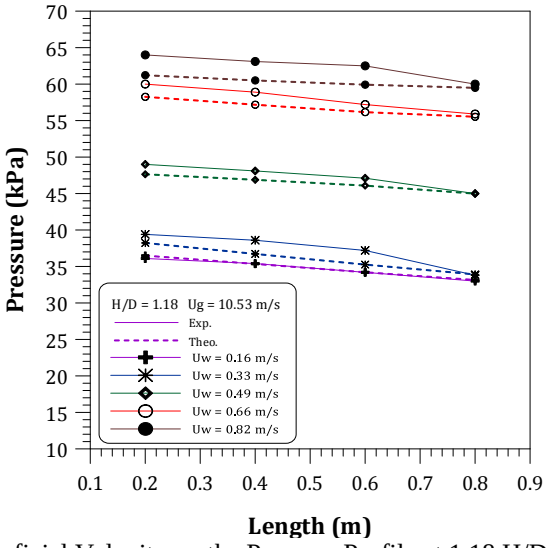


Fig. 10: Effect of Water Superficial Velocity on the Pressure Profile at 1.18 H/D and Different Values of Gasoline Superficial Velocity

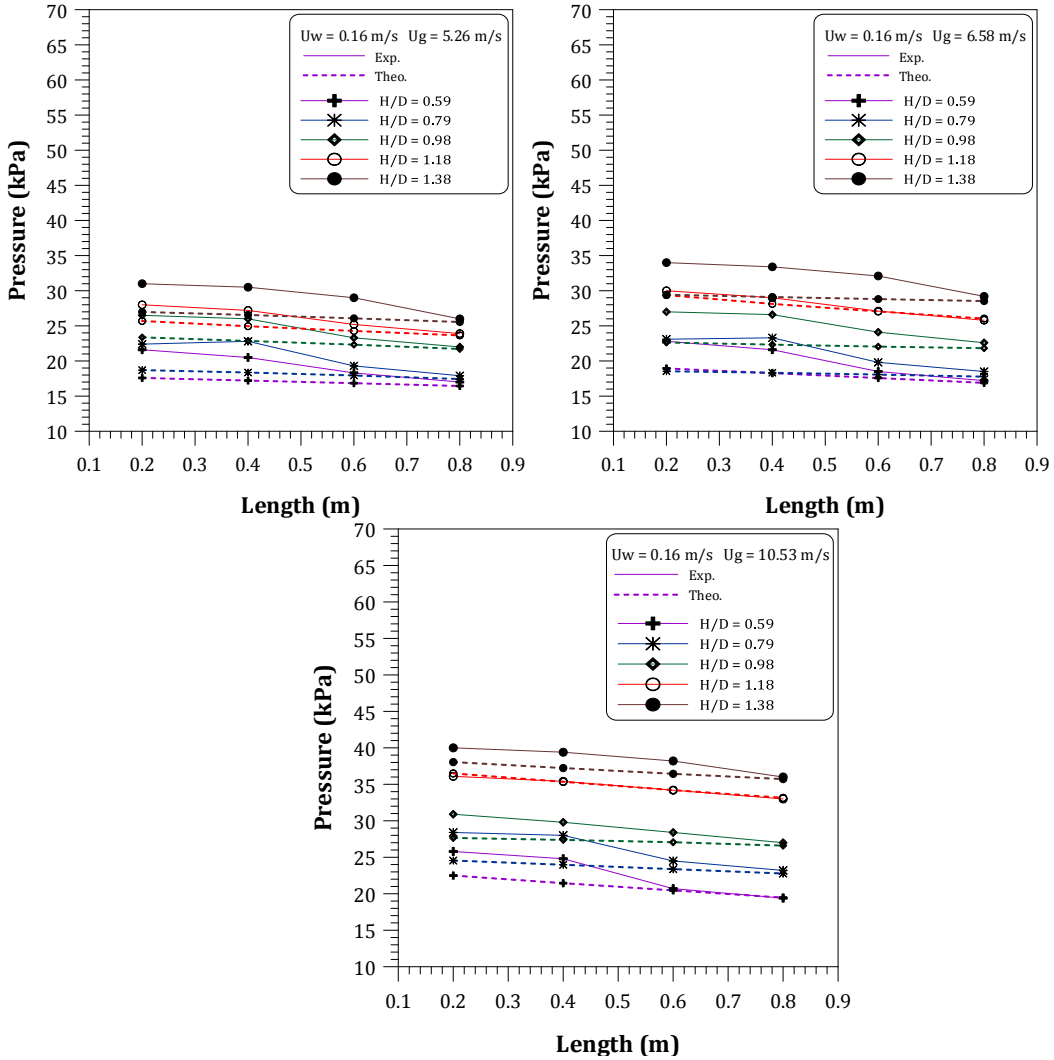


Fig. 11: Effect of H/D Ratio on the Pressure Profile at 0.16 Water Superficial Velocity and Different Values of Gasoline Superficial Velocity

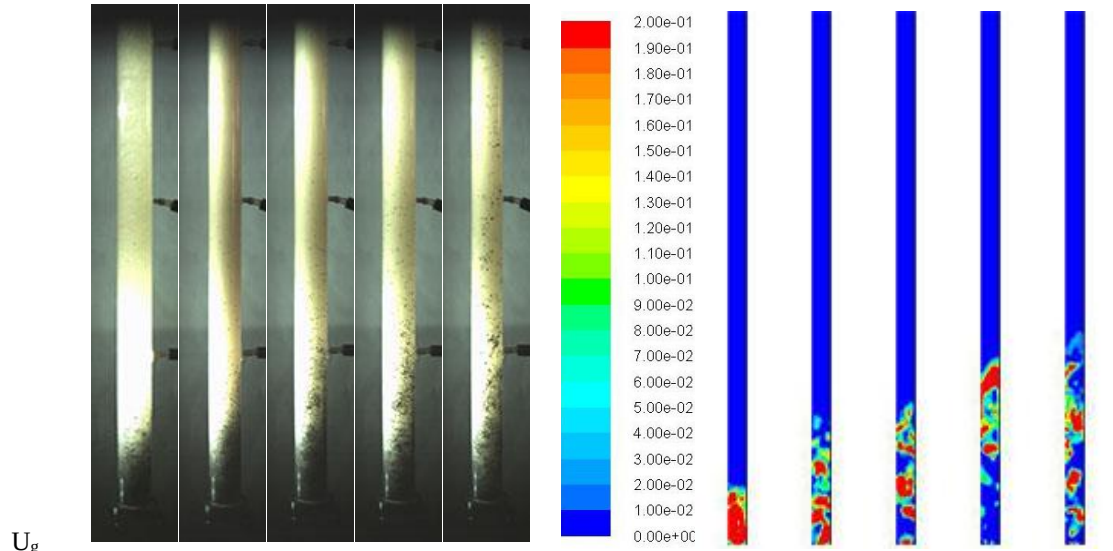


Fig. 12: The Effect of Gasoline Superficial Velocity on Bed Expansion at H/D = 0.98 and 0.33 m/s Water Superficial Velocity

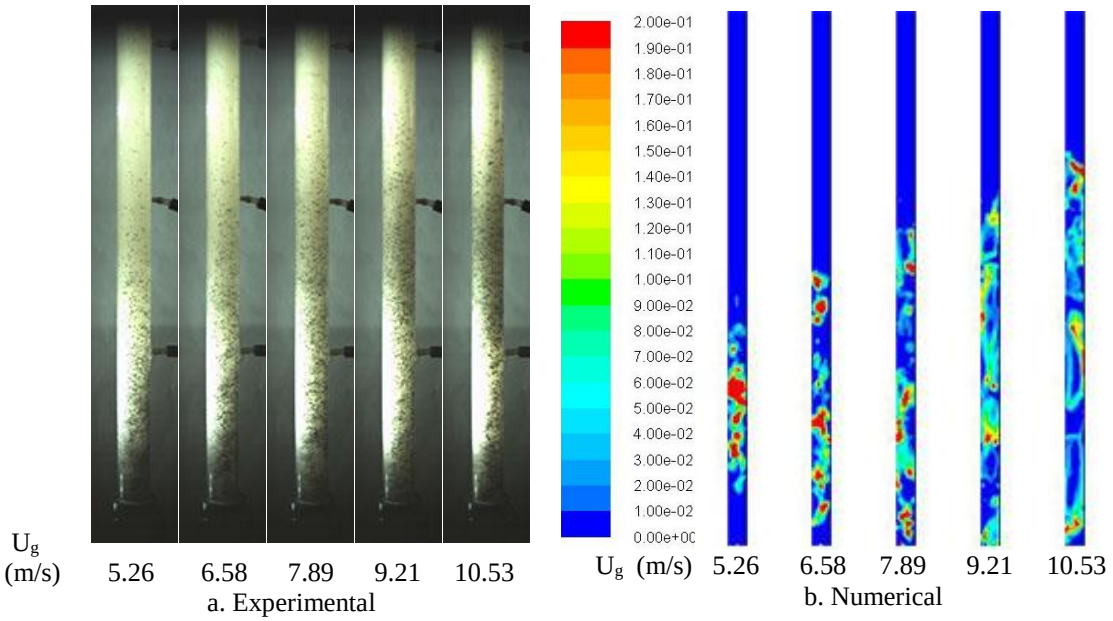


Fig. 13: The Effect of Gasoline Superficial Velocity on Bed Expansion at H/D = 0.98 and 0.49 m/s Water Superficial Velocity

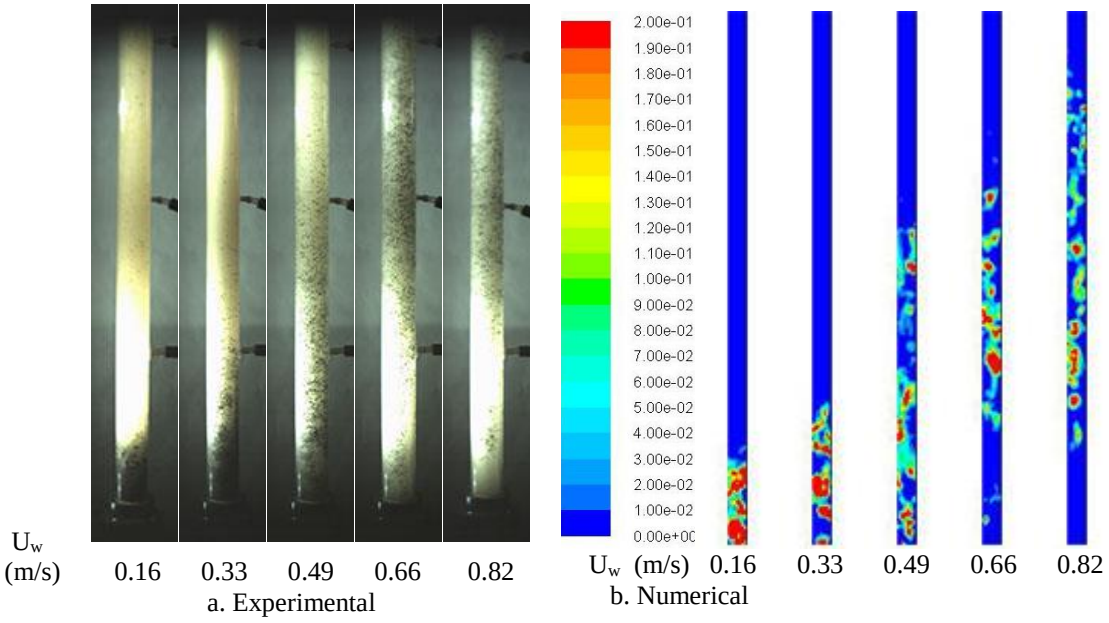


Fig. 14: The Effect of Water Superficial Velocity on Bed Expansion at H/D = 0.98 and 7.89 m/s Gasoline Superficial Velocity

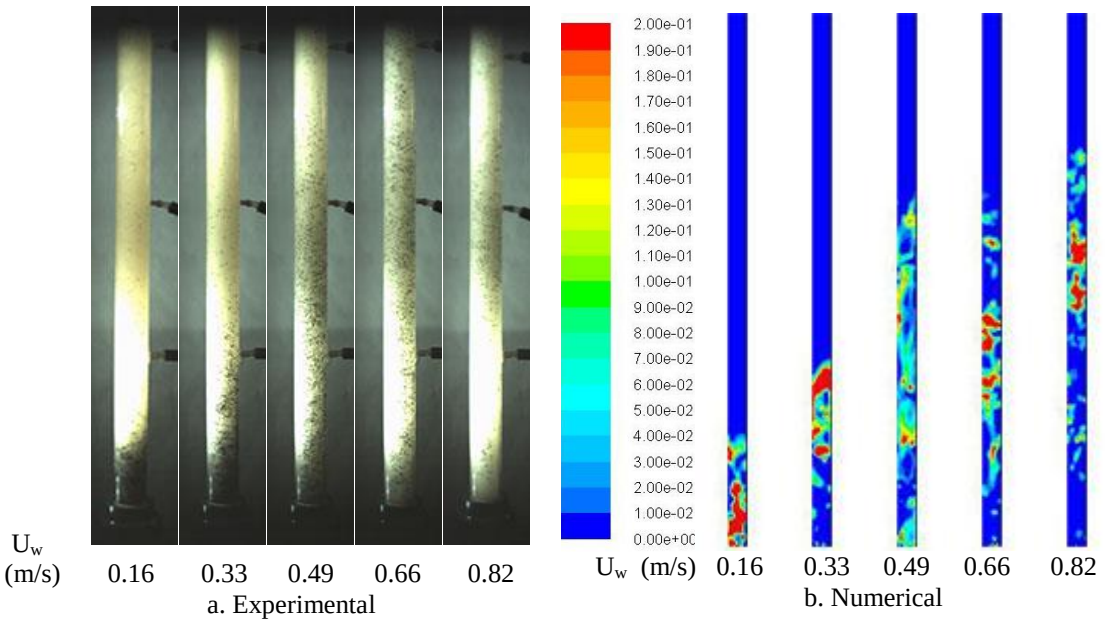
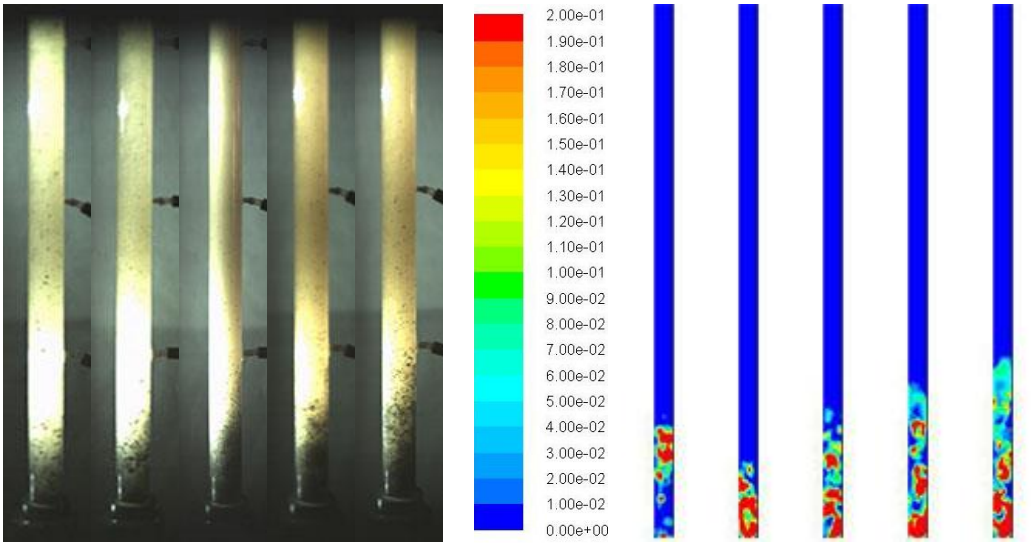
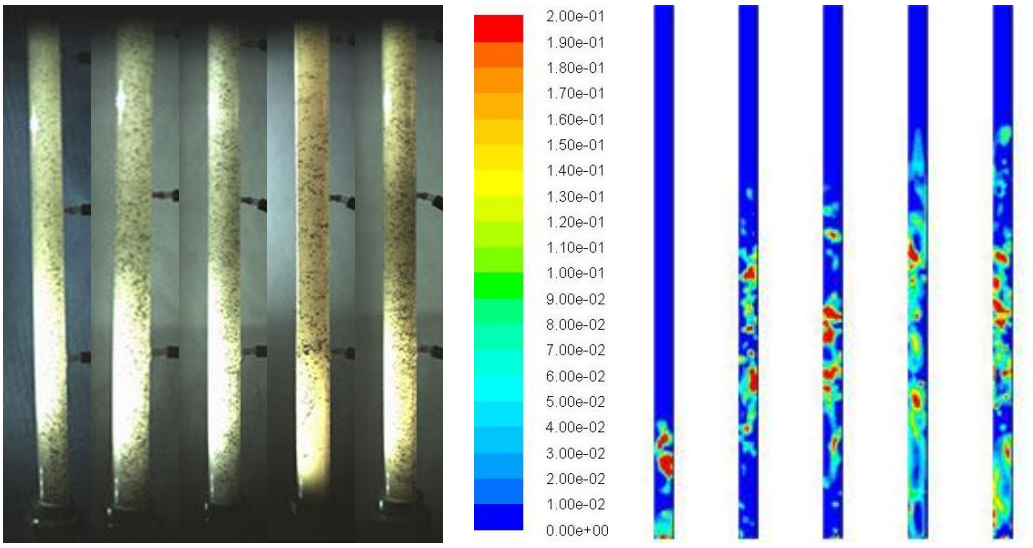


Fig. 15: The Effect of Water Superficial Velocity on Bed Expansion at H/D = 0.98 and 9.21 m/s Gasoline Superficial Velocity



a. Experimental b. Numerical

Fig. 16: The Effect of H/D Ratio on Bed Expansion at 0.33 m/s Water Superficial Velocity and 6.58 m/s Gasoline Superficial Velocity



a. Experimental b. Numerical

Fig. 17: The Effect of H/D Ratio on Bed Expansion at 0.66 m/s Water Superficial Velocity and 9.21 m/s Gasoline Superficial Velocity

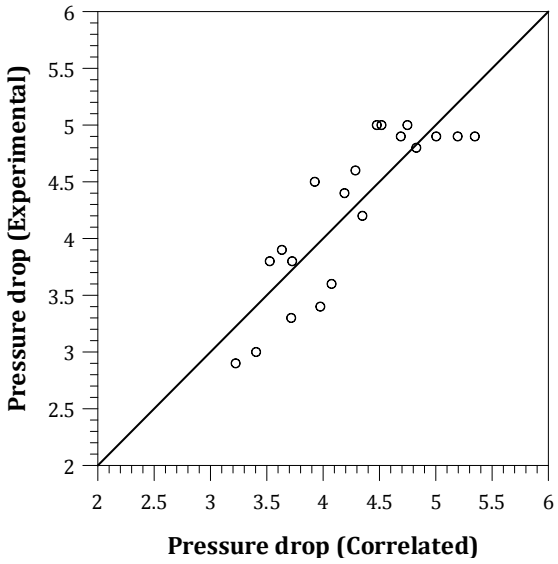


Fig. 18: A Comparison between the Experimental and the Correlated Values of Pressure Drop for Two Phase Fluidized Bed

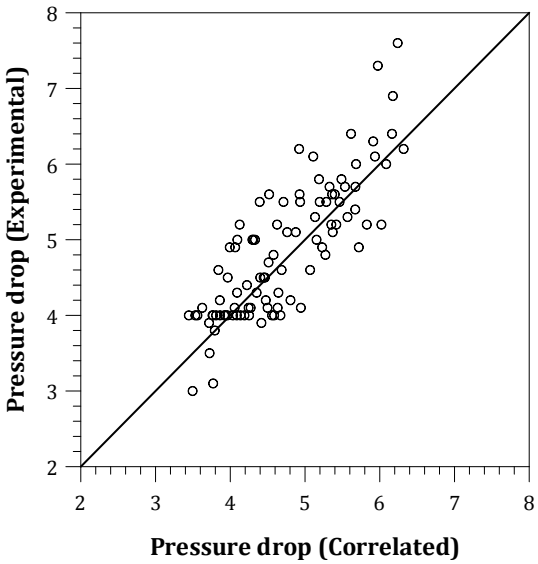


Fig. 19: A Comparison between the Experimental and the Correlated Values of Pressure Drop for Three Phase Fluidized Bed

Conclusions and Future Work:

In this work a two phase flow and three phase flow experiments were performed, the influence of H/D ratio, water superficial velocity, and gasoline superficial velocity were studied. The experimental data was compared with a CFD simulation data found with Ansys Fluent 15.0. A correlation for the pressure drop in the bed was obtained for both two and three phase fluidized bed based on the experimental data and by using a computer program (STATISTICA Version 10). The following conclusions are drowning from this work:

1- H/D ratio and water superficial velocity has a direct proportional influence on the test column pressure along the pipe for the two phase fluidized bed.

2- H/D ratio, water superficial velocity and gasoline superficial velocity have a direct proportional influence on the test column pressure for the three phase fluidized bed.

3- A correlation is reached to estimate the pressure drop for the two phase fluidized bed with deviation of (17 %).

4- A correlation is reached to estimate the pressure drop for the three phase fluidized bed with deviation of (22 %).

5- H/D ratio and water superficial velocity has a direct proportional influence on the expansion of solid particles for the two phase fluidized bed, increasing these variables leads to increase the expansion of the bed

and the spaces between particles.

6- H/D ratio, water superficial velocity, and gasoline superficial velocity have direct proportional influences on the expansion of solid particles for the three phase fluidized bed, increasing these variables lead to increase the expansion of the bed and the spaces between particles.

7- The simulated model gives results comparable to the experimental results with accuracy of (16 %) for the pressure of the two phase model and (22 %) for the pressure of the three phase model.

Some of the future work to add is to study the heat transfer, heat flux and the temperature distribution through the bed by adding heat source to the test column. Also the effect of using different types of fluids and different types and sizes of solid particles can be study for the future to show the effect of it.

Nomenclature:

Ar: Archimedes number
D: Particle diameter (m)
g: Acceleration of gravity (m/s^2); Standard values = 9.80665 (m/s^2)
H/D: Initial height of solid particles to the column diameter
Lr: Pipe Length multiplied by radius of the pipe (m^2)
Re: Reynolds number
U: Superficial velocity (m/s)
ρ : Density (kg/m^3)

Subscripts:

c: Continuous
d: Dispersed
g: Gasoline
m: Mixture
p: Particles of solid phase
vm: Virtual mass
w: Water
s: Solid
l: Liquid

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