

Experimental and Numerical Investigation of Four-Phase Flow (Water–Gasoline–Air–Solid) in a Fluidized Bed Column

Riyadh S. Al-Turaihi

College of Engineering/Babylon University/ Dept. of Mech. Eng.

drriyadhalturaihi@yahoo.com

Abstract:

In this paper four phase fluidized bed is experimentally built and numerically modeled to study the bed characteristics such as ratio (the static bed height of solid particle / the bed diameter (H/D)), air, gasoline, and water superficial velocity. The test pipe for the experimental rig is Perspex pipe with 1 m long and 0.0254 m diameter. The 2D numerical model has been established with Ansys fluent 15.0. Pressure drop equation is found to relate the pressure drop with the bed parameters with deviation of 22%. The Four-phases was represented by air, water, gasoline and solid particle. The results show that the pressure of the bed increases as the ratio H/D increases and air, gasoline, and water superficial velocity increases. As well as the expansion of the bed increases as air, gasoline, and water superficial velocity increases.

Keywords: Four phase, Fluidized bed, Ansys Fluent, CFD, Pressure.

الخلاصة

في هذا البحث تمت دراسة خواص أنبوب التميع رباعي الطور (نسبة ارتفاع المادة الصلبة / قطر الأنبوب (H/D)، سرعه الهواء والماء والغازولين) من خلال بناء أنبوب تميع رباعي الطور عمليا و بناء نموذج نظريا. الأنبوب المستخدم عمليا من مادة (Perspex) بطول 1م وقطر 0.0254 م. تم إنشاء نموذج نظري ثنائي الأبعاد باستخدام برنامج (Ansys fluent 15.0). كذلك تم إيجاد معادلة تجريبية لحساب فرق الضغط للأنبوب بالاعتماد على خواص الأنبوب ونسبة حيود 22 %. الاطوار المستخدمة هي الهواء والماء والغازولين والحبيبات الصلبة. بينت النتائج بان ضغط الأنبوب يزداد بزيادة النسبة (H/D) وسرعة الهواء والغازولين والماء. بالإضافة إلى ذلك فان ارتفاع المادة الصلبة داخل الأنبوب يزداد بزيادة سرعة الهواء والغازولين والماء.

الكلمات المفتاحية: اربع اطوار، تميع، ضغط، CFD

Nomenclature:

CFD: Computational fluid dynamics

D: Bed diameter (m)

d: Particles diameter

F: Force (N)

F_q: External force (N)

g: Gravity acceleration (m/s²)

H: Static bed height (m)

K: Exchange coefficient

L_r: Bed length multiplied by the radius of the bed (m²)

Q: Flow rate (l/min)

q: Number of phases

R: Intraction force

Re: Reynolds number

S: Source term

v: Velocity of phase (m/s)

Greek symbols:

μ: Viscosity

ε: Epsilon

ṁ_n: Interphase mass exchange (kg/m³.s)

α: Volume fraction

Ī: Unity matrix

λ : Bulk viscosity
 ρ : Mixture density (kg/m³)
 τ : Shear stress

Subscripts:

a: Air
g: Gasoline
lift: Lift force
p: Particles
p: Priemary phase
q: Secondary phase
s: Solid
w: Water
vm: Virtual mass force

1.Introduction:

Four phase flow is mostly important in the petroleum industry and untreated reservoir production normally consist of oil, water, gas, and solid usually sand left in the pipes where it's effect on the production rate and sweep efficiency, (Vorobieff *et. al.*,2015;Guler *et. al.*,2001).Minor incidents could happened such as disastrous blowout caused by air pocket that is formed from gas kick and gas cut, shock waves and formidable pressure could generate by the blowout which cause damages and casualties through the drilling process, (Xie *et. al.*,2013). The regimes of the flow through the well must take into account depending on the flow rate, inclination angle, fluids thermo physical properties and diameter the flow regimes for vertical upward flow are slug flow, forth flow, annular mist flow, and bubble flow, (Candia *et. al.*, 2005). Many researchers tried to develop a way that enable the prediction of the oil well hydrodynamics. (Candia and Cruz,2005) presented one-dimensional oil well time dependent mathematical model for three components two phase flow (gas and oil,water), where they determined the distribution of velocity, temperature, and pressure. (Xie *et. al.*,2013) studied how the pressure drop was effected by cuttings for deep wells annulus flow through three phase model (solid, liquid and gas). Hasan and (Kabir ,2010) used the drift-flux approach for a two phase robust model to find the static, kinetic and frictional head in geothermal wells.(Gidaspow *et. al.*,2013) investigated the flow in wild wells through developing a computational fluid dynamics (CFD) code to study the oil production in wild wells using pipes and reservoirs with three phase flow (sand -oil-gas). (Candia *et. al.*,2011) developed a finite difference transient, adiabatic,one dimensional model, which used the conservation equation of energy, momentum, and mass for each phase to simulate the slug flow in oil wells using mixture of gas, water, and oil. (Rundell *et. al.*,1987) studied the fluid dynamics in hydrocarbon research process development unit and compared it with fluidization data found with similar dimension glass pilot cold flow plant. (Pan *et. al.*, 2011) developed analytical solution for wellbore two phase flow by the drift flux model and under isothermal steady state conditions. (Millan *et. al.*, 2014) studied the origin of groundwater sampling by using particle transport modeling and numerical flow under range of pumping rate under ambient vertical head gradients. Tandon and karnik (2014) simulated a rectangular bubbling fluidized bed with two phase flow using Euler-Euler granular model to study the hydrodynamics of the gas solid fluidized bed flow.(Ibrehem,2011)captured the polyethylene production characteristics by using system identification method and based on experimental data that already published. In this paper four phase fluidized bed has investigated experimentally and numerically also an equation for the pressure drop is correlated.

2. Experimental work:

Four phase fluidized bed rig has been built to study the three different phases inside the test pipe as well as, the solid particles has already been placed the pipe. Figure (1) shows the schematic diagram of experimental rig. The equipment used to build experimental rig listed as follows:

- Test pipe made of Perspex material having 1in diameter and 1m height, four holes were made at the side which are used to measure the pressure.
- A aluminum net are placed at the bottom of the test pipe made of square bitch net with 0.333mm side and open area ratio of 25%.
- Water flow meter with measuring range from 5 l/min to 35 l/min.
- Gasoline flow meter with measuring range from 10 l/min to 70 l/min.
- Air flow meter has used to control the air flow rate with range 350 l/hr to 3500 l/hr.
- Air compressor used to provide air, the compressor type is Recomendamos Aceite/Worthington with capacity of 0.5 m³ and maximum pressure of 16 bar.
- Water tank with capacity of 760 l.
- Gasoline tank with capacity of 530 l.
- Pipes and valves with 1in diameter used to control flow.
- AOS high speed camera with active resolution of 720x480, and 29.97 Hz (59.94 Hz interlaced) image frequency with (SDTV 480i).
- Pressure sensor placed at the holes situated at the side of the test pipe with measuring range from 0-1 bar.

The experiments investigation have performed with the following procedure

- 1- The solid particles placed in the test pipe , H/D ratio equals to (0.69) as shown in table (1)
 - 2- The water is inserted into the test pipe with a volume flow rate equals to (12 l/min) as shown in table (1)
 - 3- The gasoline is insert into the test pipe with volume flow rate equals to (5 l/min) as shown in table (1)
 - 4- The air is inserted into the test pipe with volume flow rate equals to (8.33 l/min) as shown in table (1)
 - 5- Measure the pressure distribution by using the pressure sensors along the test pipe
 - 6- Recording the flow pattern by using the high speed camera
- This procedure is repeated for the 3 values of water flow rate , 3values of gasoline flow rate, and 3values of air flow rate each time the value of H/D changes according to table (1).

The pressure of the four phase fluidized bed is drawn with the superficial velocity of air, gasoline, and water. The velocity is found from the flow rate by eq. (1)

$$Q = U * A \quad \dots\dots\dots (1),$$

Yang (2003)

The values of superficial velocities are show in table (2)

Table (1): The experimental values of flow rate

H/D ratio	Water flow rate (l/min)	Gasoline flow rate (l/min)	Air flow rate (l/min)
0.69	12	5	8.334
0.89	14	10	16.667
	16	15	25

Table (2): The experimental values of superficial velocity

Water superficial velocity (m/s)	Gasoline superficial velocity (m/s)	Air superficial velocity (m/s)
0.39	2.63	4.39
0.46	5.26	8.77
0.53	7.89	13.16

3. Mathematical model:

ANSYS fluent 15.0 has used to model and simulate the four phases fluidized bed. A 2D geometry has generated with ANSYS workbench 15.0 with the dimensions 0.0254 x 1 m. The geometry has divided into small element called mesh, quadrilateral mesh type has been used. Transit, Eulerian-Eulerian simulation study has performed with Fluent, the water was set to be the primary phase, the solid set to be granular secondary phase, while the gasoline and air set to be dispersed phase. The bottom of the bed has divided into small edge; the water, gasoline, and air are entered into the bed through this edge with specially set order in order to simulate the distributor in the experimental work.

-The governing equations

The general equations used by Eulerian multiphase model are the conservation of mass and momentum. Mass conservation equation can be written in its general form as (2).

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q) = \sum_{p=1}^n (\dot{m}_{pq} - \dot{m}_{qp}) + S_q \quad \dots\dots\dots (2)$$

The source term S_q is zero as default value or else it can be a set constant value or define by user. Momentum conservation equation can be written in its general form as (3).

$$\frac{\partial}{\partial t}(\alpha_q \rho_q \vec{v}_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q \vec{v}_q) = -\alpha_q \nabla p + \nabla \cdot \vec{\tau}_q + \alpha_q \rho_q \vec{g} + \sum_{p=1}^n (\vec{R}_{pq} + \dot{m}_{pq} \vec{v}_{pq} - \dot{m}_{qp} \vec{v}_{qp}) + (\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}) \quad \dots\dots\dots (3)$$

Where $\vec{\tau}_q$ is the stress - strain tensor.

$$\vec{\tau}_q = \alpha_q \mu_q (\nabla \vec{v}_q + \nabla \vec{v}_q^T) + \alpha_q (\lambda_q - \frac{2}{3} \mu_q) \nabla \cdot \vec{v}_q \vec{I} \quad \dots\dots\dots (4)$$

-Boundary conditions

The inlet of the test pipe set as velocity, the outlet of the test pipe set as pressure, and the two edge on the sides have set as walls. As shown in figure (2)

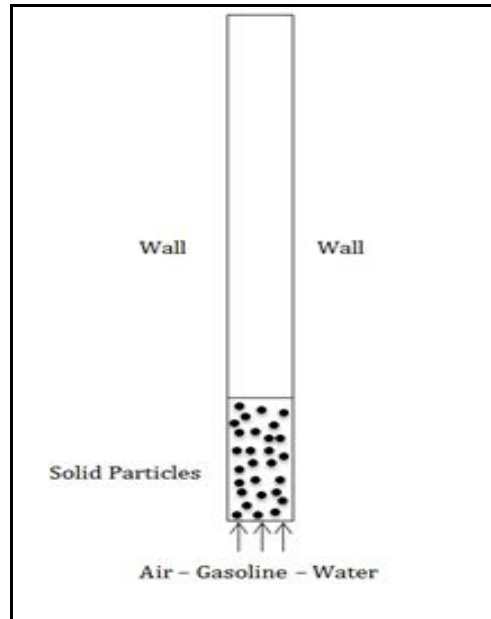


Figure (2) Boundary conditions

At $x=0$ and $x=0.0254$ m the $U_w = U_a = U_g = 0$

The simulation variables inserted into this model are summarized in table (3)

Table (3): The simulation paramters

Description	Value
Particle density	8000 kg/m ³
Water density	998.2 kg/m ³
Gasoline density	800 kg/ m ³
Air density	1.225 kg/ m ³
Mean particle diameter	1.5 mm
Initial solids packing	0.7668
Bed height	1 m
Bed width	0.0254 m
Static bed height (H)	0.0175, 0.0225 m
Time steps	0.0005 sec
Maximum iteration	20
Pressure under relaxation	0.3
Momentum under relaxation	0.2
Volume fraction under relaxation	0.5

4. Results and discussion

In this paper 54 experiments has done to find the effect of fluid phases superficial velocity and H/D ratio on the bed characteristic. Numerical model has been developed for the experimental tests. It has been found a good agreement between the experimental and numerical result. Pressure drop equation has generated for the four phase fluidized bed.

4.1. Expansion of the bed:

Figure (5) to (16) show the effect of superficial velocity and H/D on the flow behavior. The values of solid volume fraction are shown by the color counter on the side of the figure.

I.Effect of air superficial velocity

Air velocity inserted into the fluidized bed pipe is increased from (4.39 m/s) to (13.16 m/s) which leads to increase in the expansion of the bed and this can be shown in figure (3) and figure(4), respectively. Figure (3&4) show the effect of air superficial velocity with constant values of H/D, water superficial velocity, and gasoline superficial velocity. As air velocity increases the expansion of bed is increase with H/D equal to 0.69, gasoline superficial velocity equal to 2.63 m/s, and water superficial velocity changes from 0.39 m/s to 0.46 m/s. The increase in the expansion is due to the increase in the velocity as that will increases turbulence and pushes the solid particles.

II. Effect of gasoline superficial velocity

Figures (5,6,7, and 8) show the effect of superficial velocity of gasoline versus the other velocities. As superficial velocity of gasoline increases the expansion of the test pipe increases. Figure (5) shows the effect of gasoline superficial velocity at constant value of H/D equals to 0.69 and water, air superficial velocities equals to 0.39, and 4.39, respectively. The increase is because the quantity of gasoline in the pipe is increased, due to the resistance of the flow that push over the walls of the pipe and in return it will push the solid particles which is leading to this increase in the expansion of bed.

III. Effect of water superficial velocity

The effect of water superficial velocity on the expansion of the test pipe is shown in figures (9, 10, and 11), where in these figures, water superficial velocity increased leads the expansion of the test pipe to increase also. Figure (9) shows the effect of three different values of water superficial velocity on the flow behavior at constant values of H/D, gasoline superficial velocity, air superficial velocity equal to 0.69, 2.63, and 8.77, respectively. The increasing in the velocity of water lead to increase in the turbulence of the test pipe and the flow is pushing over the walls of the test column which increase the expansion of the bed.

IV. Effect of H/D:

In this test, it has used two different values of H/D ratio which is the ratio of solid height in the test pipe to the test pipe diameter. Figures (12, 13, 14, 15, and 16) show the expansion increases as H/D increases. Figure (15) show the effect of changing H/D two times with constant values of water superficial velocity, gasoline superficial velocity, and air superficial velocity equals to 0.46 m/s, 5.26 m/s, and 13.16 m/s, respectively. Since the solid particles in the bed is increased by increasing initial height of solid particles and the expansion in return will increase.

4.2. Pressure distribution of four phase fluidized bed

The pressure distribution of the bed is measured at different points on the bed (0.2, 0.4, 0.6, 0.8 m). The values of both experimental and numerical pressure are plotted versus the length of the bed pipe which is shown in figures from (17) to (20).

I. Effect of air superficial velocity

Air velocity inserted into the fluidized bed pipe is increased from (4.36 m/s) to (13.16 m/s) lead to increase in the pressure of the pipe from (30.2 kPa) to (33.9 kPa) this can be shown in figure (17,a). Figure (17 a, b, c, d, e,f) shows the effect of air superficial velocity as the other velocities remain constant. The numerical values of the pressure are plotted on the same figures gave the same effect as experimental values. Due to the test pipe is previously filled with water, gasoline, and air as well as the solid particles so when the air is increased it increased the pressure to the wall of the test pipe.

II. Effect of gasoline superficial velocity

Figure (18 a, b, c, d, e, f) shows the effect of gasoline superficial velocity versus the other velocities. As gasoline superficial velocity increase the pressure of the test pipe is increased and this effect is also indicated with the numerical simulation. Figure (18,a) shows the gasoline superficial velocity increase from (2.63 m/s) to (7.89 m/s) lead to increase in the pipe experimental pressure from (30.2 kPa) to (42.9 kPa) and pipe numerical pressure from (28.1391 kPa) to (40.3271 kPa) due to the quantity of gasoline in the pipe is increased lead to increase the resistance of the flow that pushes over the walls of the pipe.

III. Effect of water superficial velocity

Effect of water superficial velocity on the pressure of the test pipe is shown in figures (19 a, b, c, d, e, f). The water superficial velocity is increased with increasing of the test pipe pressure, experimentally and numerically. Can be seen that the numerical results shows same effect of the experimental results but less accuracy due to the assumption that made for the model. The increasing in the velocity of water lead to increase in the turbulence of the test pipe and the flow pushing over the walls of the test column which increase the pressure of the test pipe.

IV. Effect of H/D

Two different values of H/D have used which is the ratio of solid height in the test pipe to the test pipe diameter. Figure (20 a, b, c, d, e, f) shows the pressure increase as H/D increased. the height of solid increase the flow of solid particles which increase the pressure in the test pipe. The numerical results gave the same effect for H/D increasing on the pressure of the test pipe as shown in these figures.

4.3. The flow behavior:

The flow behavior in the fluidized bed are monitored and recorded at different variables of air, gasoline, and water superficial velocity. Figures (21,22, and 23) show the behavior of the flow that was recorded. Figure (21) shows the fluidized bed as the air superficial velocity changes from (4.39 m/s) to (13.16 m/s) with constant values of water and gasoline superficial velocity equal to (0.53 m/s) and (5.26 m/s) respectively and H/D ratio equals to 0.69. Figure (22) shows the behavior of the fluidized bed as the gasoline superficial velocity changes from (2.63 m/s) to (7.89 m/s) with constant values of air and water superficial velocity equal to (4.39 m/s) and (0.53 m/s) respectively and H/D ratio equals to 0.69. Figure (23) shows the effect of water superficial velocity on the fluidized bed at constant values of air and gasoline superficial velocity equal to (4.39 m/s) and (5.26 m/s) respectively and H/D ratio equal to 0.69.

4.4. Pressure drop equation:

The equations to predict the pressure drop of the test pipe is established with the experimental values of the fluidized bed and by the assistance of computer program "STATISTICA". The equation relates the drop in the pressure with the constant values in the bed design with the changed values that implanted into the test pipe.

$$\Delta P = C * (Lr)^{a1} (Rea)^{a2} (Reg)^{a3} (Rew)^{a4} (dp * \rho_s * (H/D))^{a5} \dots\dots\dots (5)$$

Where C, a1, a2, a3, a4, a5 are found by using the least square fit method so the final form of the equation is.

$$\Delta P = 1.97467 * (Lr)^{-2.09601} (Rea)^{0.02161} (Reg)^{-0.19416} (Rew)^{0.00626} (dp * \rho_s * (H/D))^{0.39795} \dots\dots\dots (6)$$

The deviation of this equation is 22% and behavior of the correlation is shown in figure (24).

Conclusions:

In this work, experimental and numerical investigation of the four-phase fluidized bed characteristics has been done. The pressure is measured experimentally from the test pipe of the experimental rig and it also has been found numerically with ANSYS Fluent 15.0. The flow behavior has found by the numerical model. As well as, an equation for the pressure drop is established for the four phase fluidized bed. Three different values of air, gasoline, and water superficial velocity have used with two different values of H/D ratio. The conclusion of this work are.

- As the air superficial velocity increases the pressure of the bed increases.
- As the gasoline superficial velocity increases the pressure of the bed increases.
- As the water superficial velocity increases the pressure of the bed increases.
- As H/D increases the pressure of the bed increases.
- As the air superficial velocity increases the expansion of the bed increases.
- As the gasoline superficial velocity increases the expansion of the bed increases.
- As the water superficial velocity increases the expansion of the bed increases.
- As H/D increases the expansion of the bed increases.

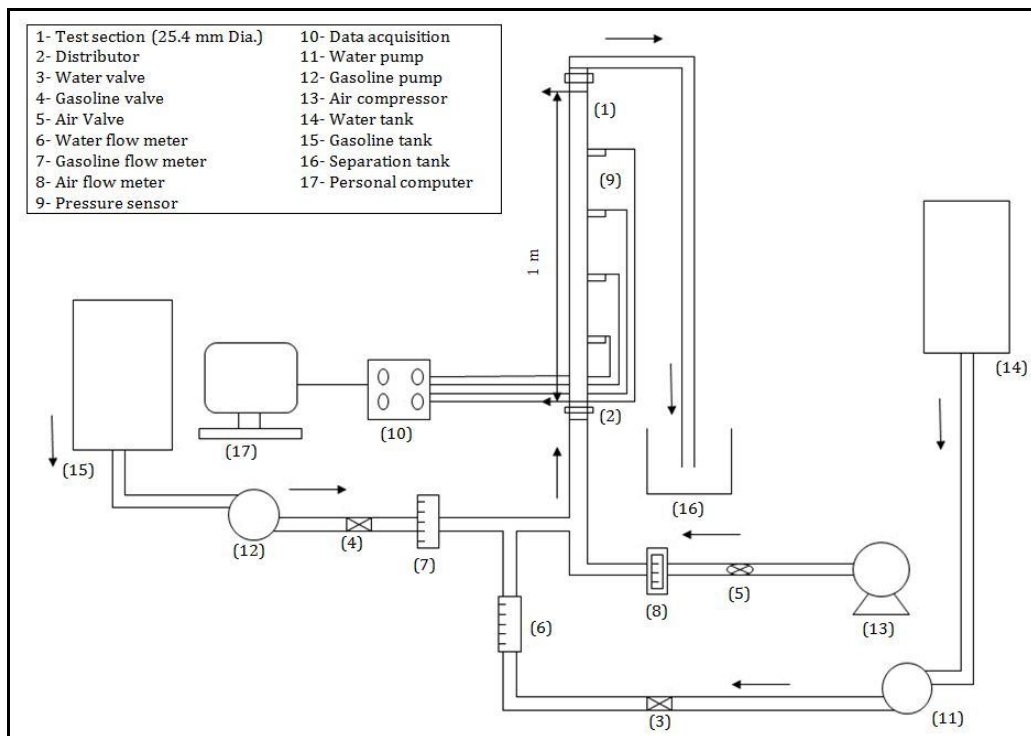


Figure (1) The schematic diagram of the experimental rig

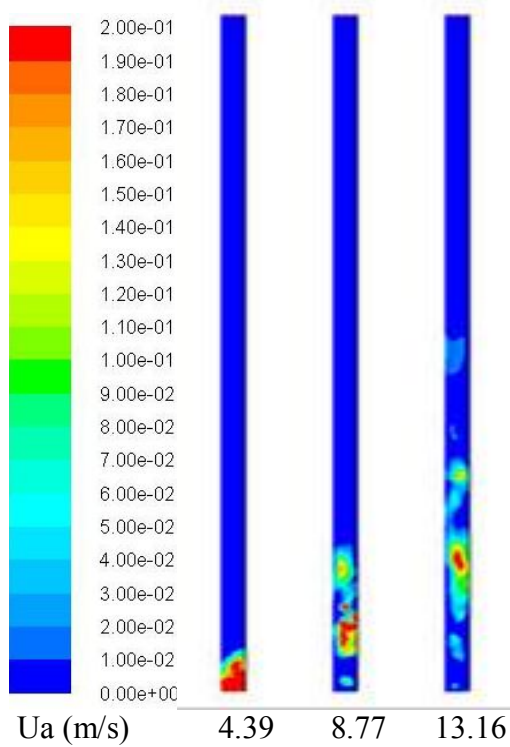


Figure (3) Effect of air superficial velocity on the bed expansion at ($H/D=0.69$), ($U_w=0.39$ m/s), and ($U_g=2.63$ m/s)

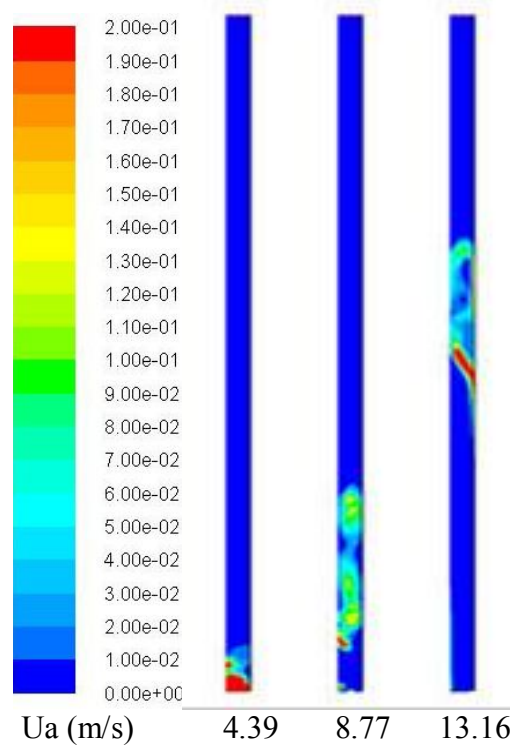


Figure (4) Effect of air superficial velocity on the bed expansion at ($H/D=0.69$), ($U_w=0.46$ m/s), and ($U_g=2.63$ m/s)

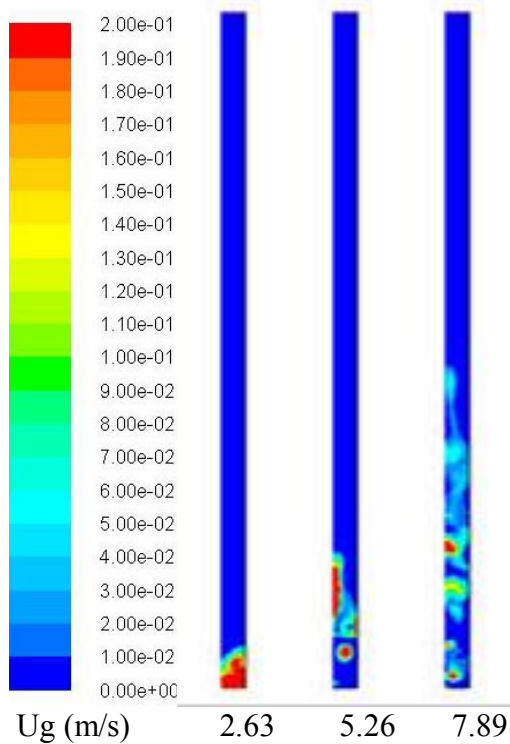


Figure (5) Effect of gasoline superficial velocity on the bed expansion at ($H/D=0.69$), ($U_w=0.39$ m/s), and ($U_a=4.39$ m/s)

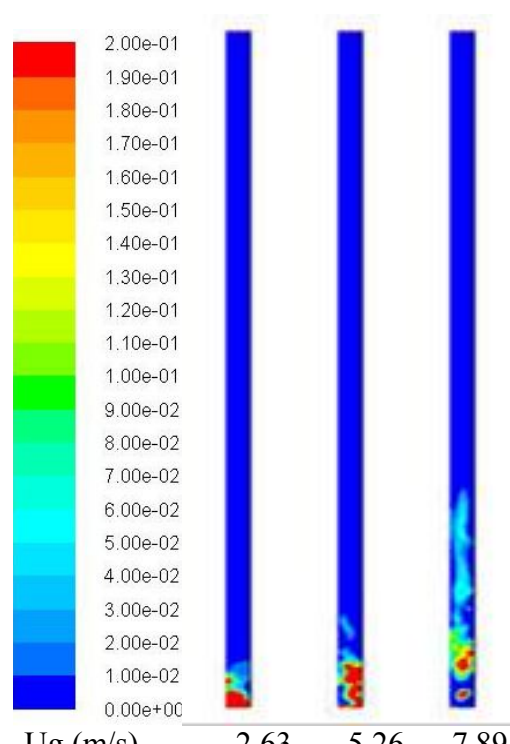


Figure (6) Effect of gasoline superficial velocity on the bed expansion at ($H/D=0.69$), ($U_w=0.46$ m/s), and ($U_a=4.39$ m/s)

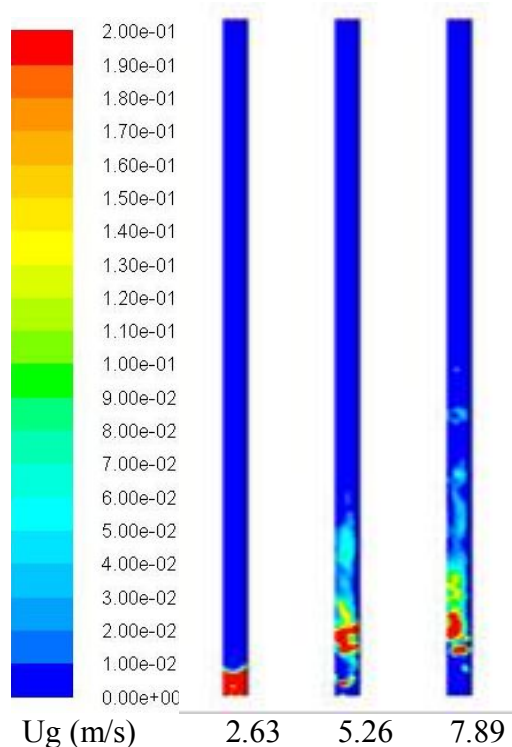


Figure (7) Effect of gasoline superficial velocity on the bed expansion at ($H/D = 0.89$), ($U_w = 0.46$ m/s), and ($U_a = 8.77$ m/s)

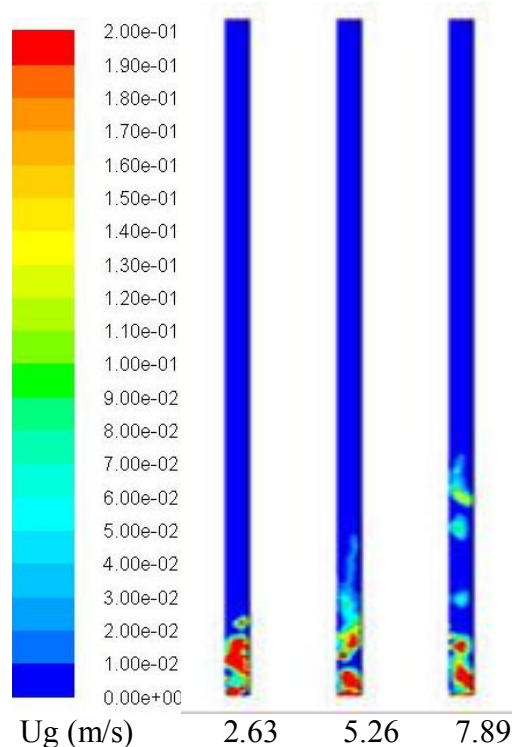


Figure (8) Effect of gasoline superficial velocity on the bed expansion at ($H/D = 0.89$), ($U_w = 0.53$ m/s), and ($U_a = 4.39$ m/s)

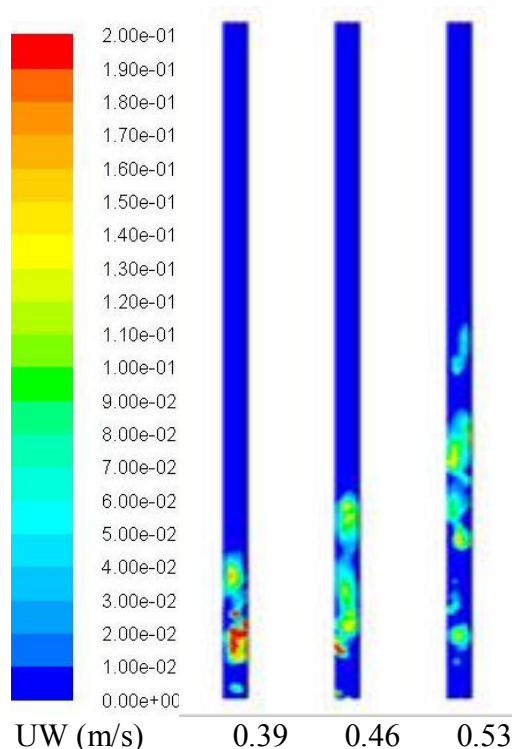


Figure (9) Effect of water superficial velocity on the bed expansion at ($H/D = 0.69$), ($U_g = 2.63$ m/s), and ($U_a = 8.77$ m/s)

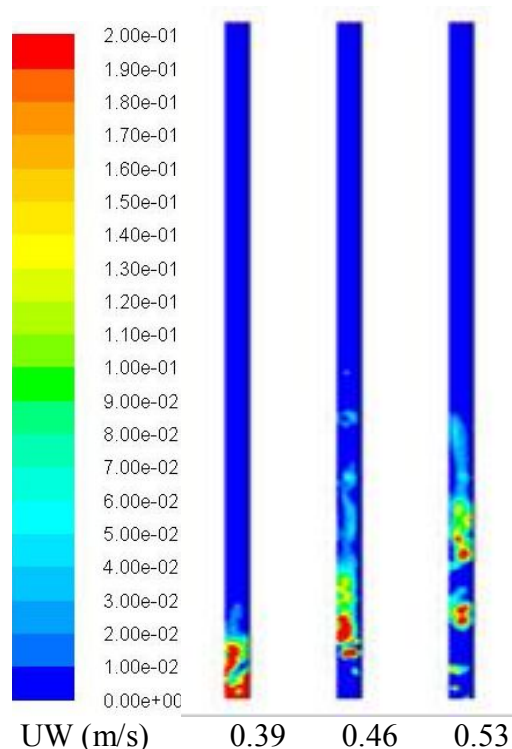


Figure (10) Effect of water superficial velocity on the bed expansion at ($H/D = 0.89$), ($U_w = 0.53$ m/s), and ($U_a = 8.77$ m/s)

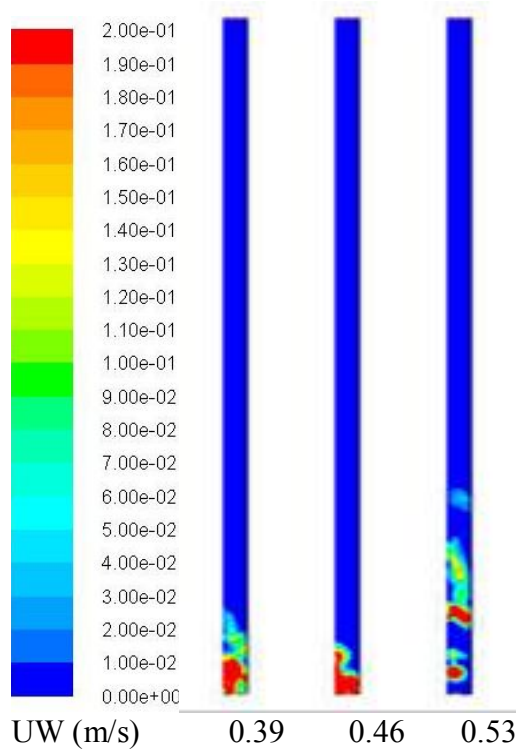


Figure (11) Effect of water superficial velocity on the bed expansion at ($H/D=0.89$), ($U_g=7.89$ m/s), and ($U_a=13.16$ m/s)

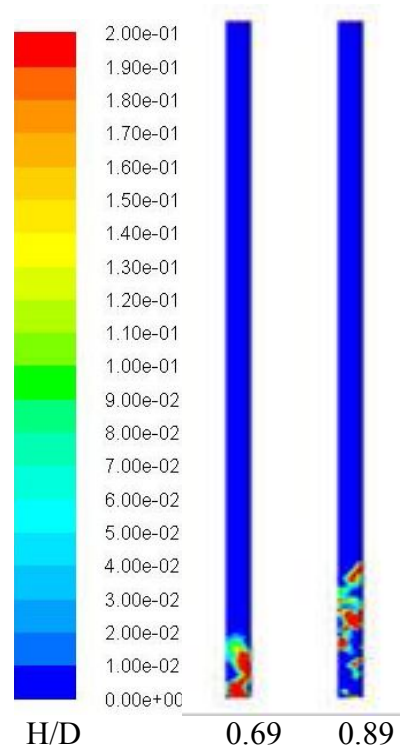


Figure (12) Effect of H/D on the bed expansion at ($U_w=0.39$ m/s), ($U_g=5.26$ m/s), and ($U_a=8.77$ m/s)

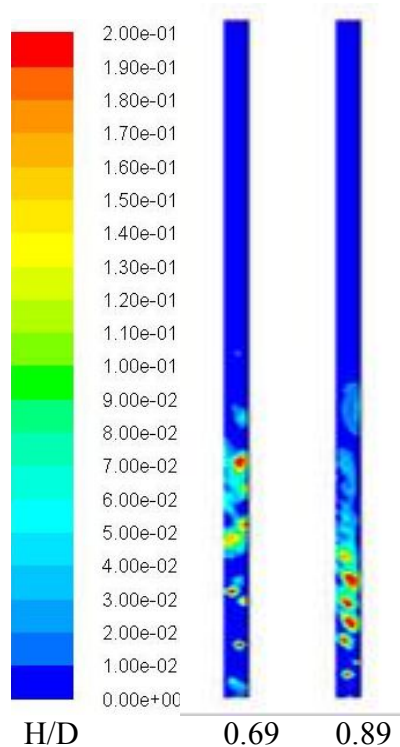


Figure (13) Effect of H/D on the bed expansion at ($U_w= 0.39$ m/s), ($U_g= 5.26$ m/s), and ($U_a= 13.16$ m/s)

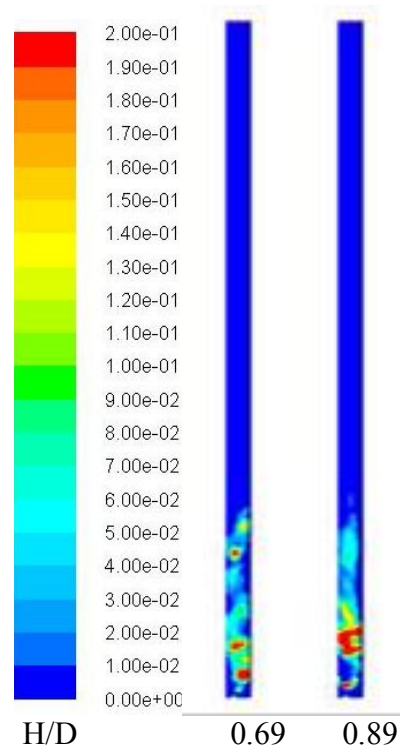


Figure (14) Effect of H/D on the bed expansion at ($U_w= 0.46$ m/s), ($U_g=5.26$ m/s), and ($U_a=8.77$ m/s)

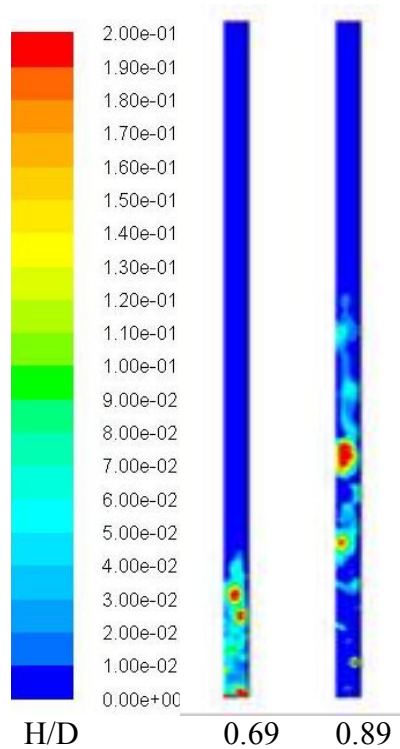


Figure (15) Effect of H/D on the bed expansion at ($U_w=0.46$ m/s), ($U_g= 5.26$ m/s), and ($U_a= 13.16$ m/s)

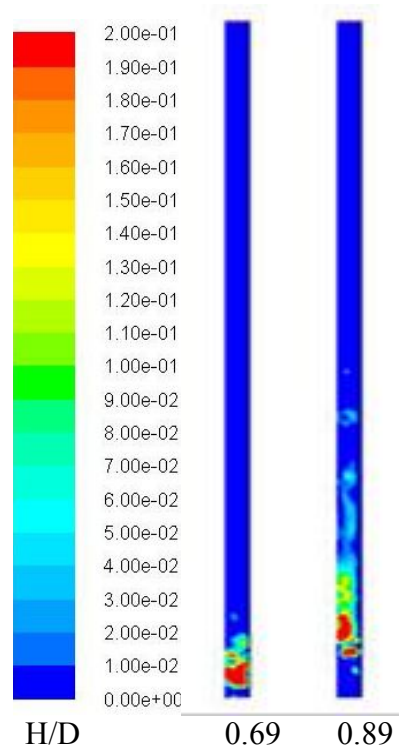
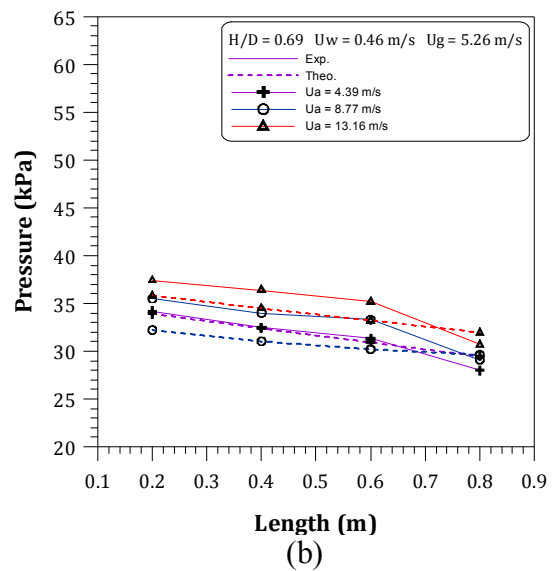
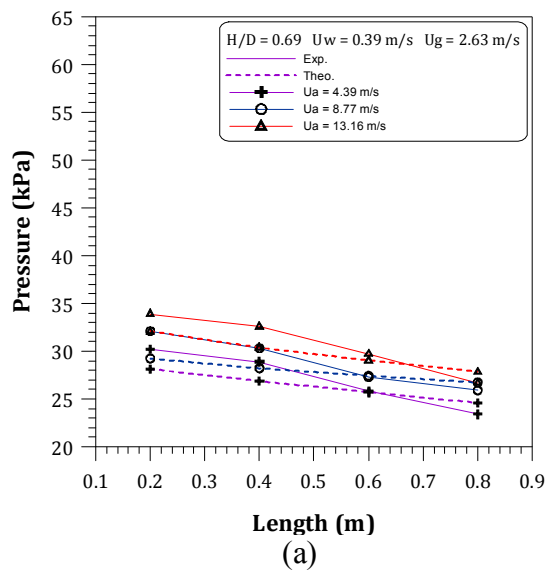


Figure (16) Effect of H/D on the bed expansion at ($U_w=0.46$ m/s), ($U_g= 7.89$ m/s), and ($U_a= 8.77$ m/s)



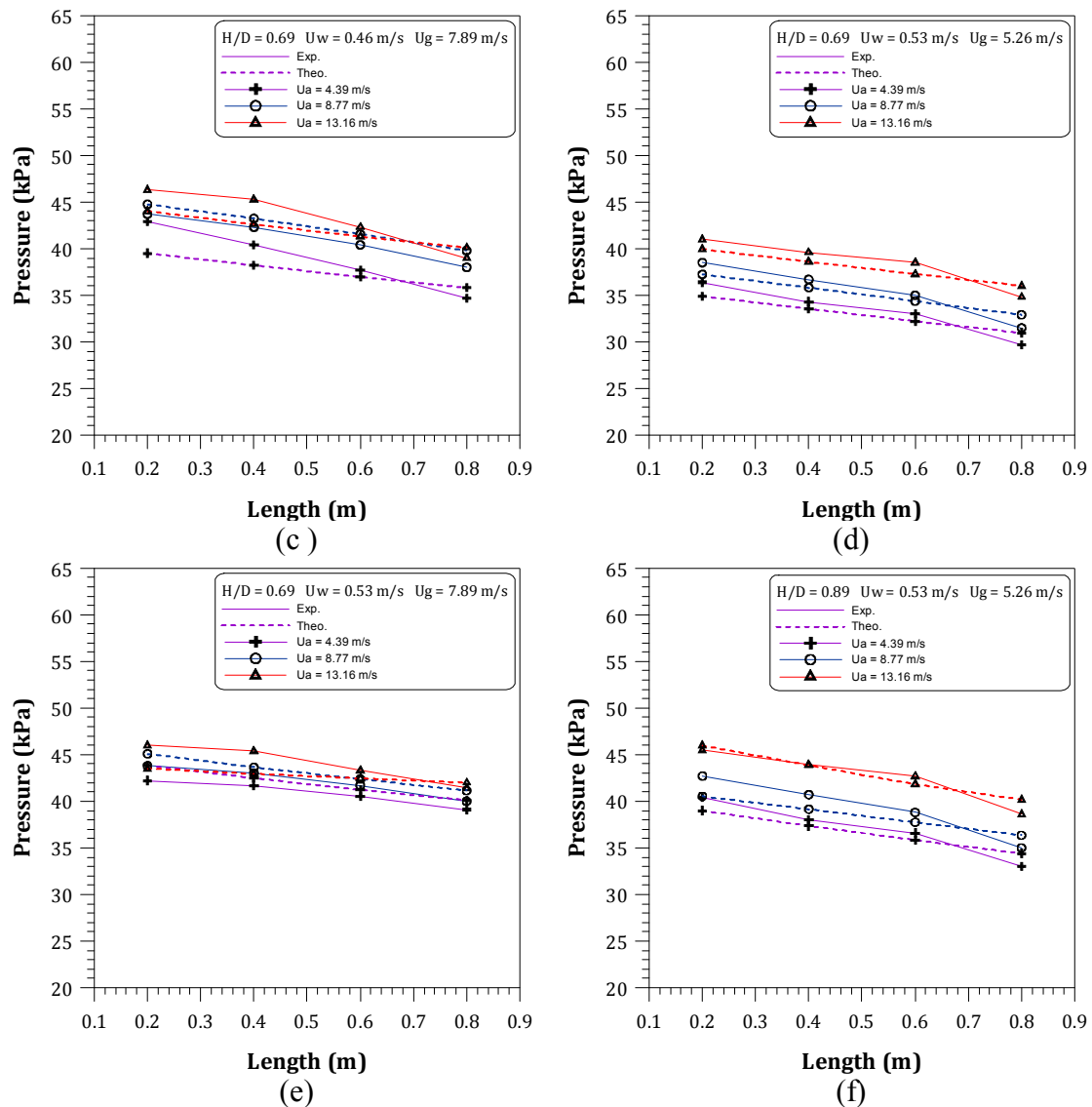
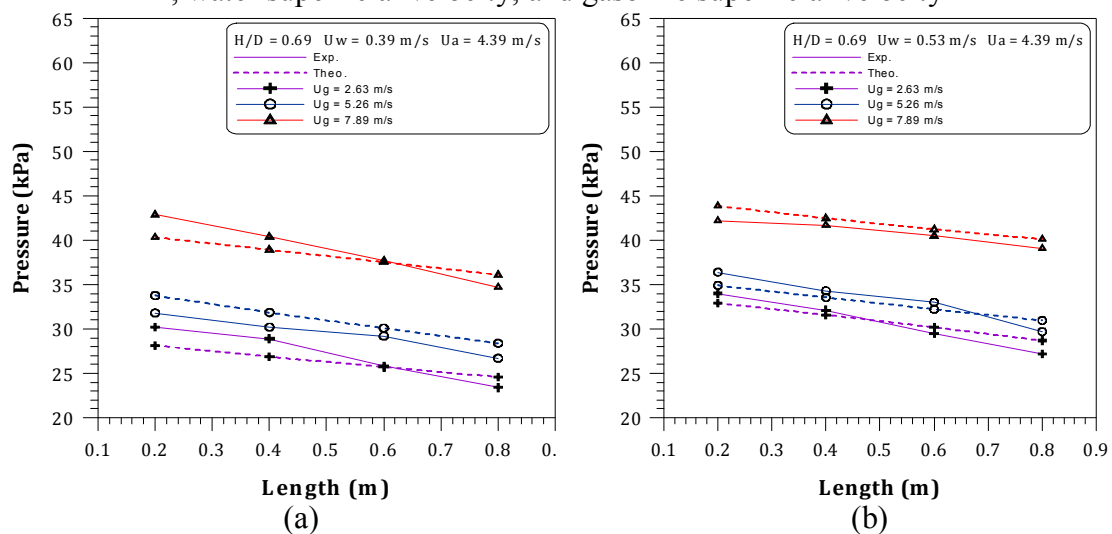


Figure (17) Effect of air superficial velocity on the pressure at different values of H/D , water superficial velocity, and gasoline superficial velocity



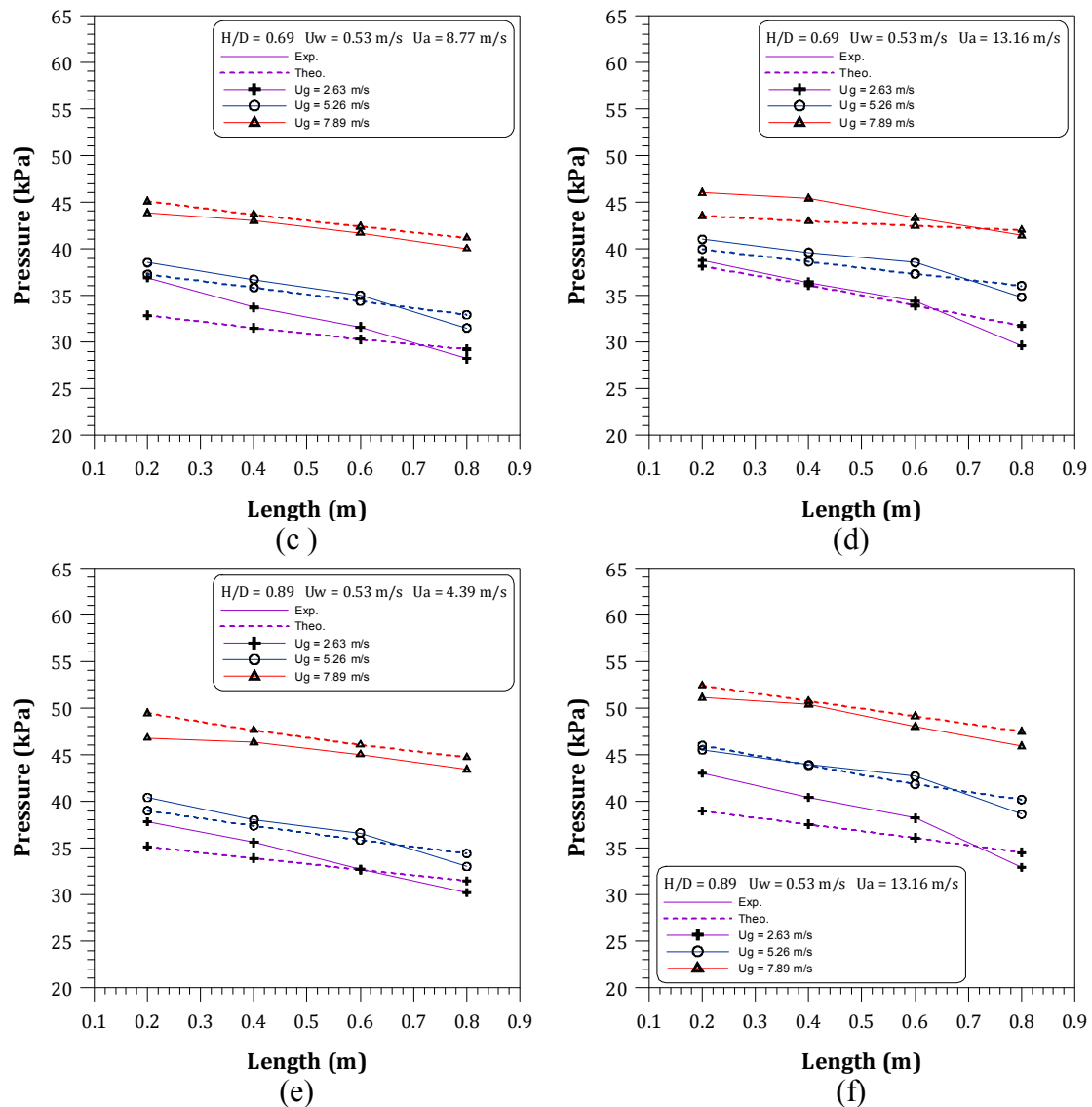
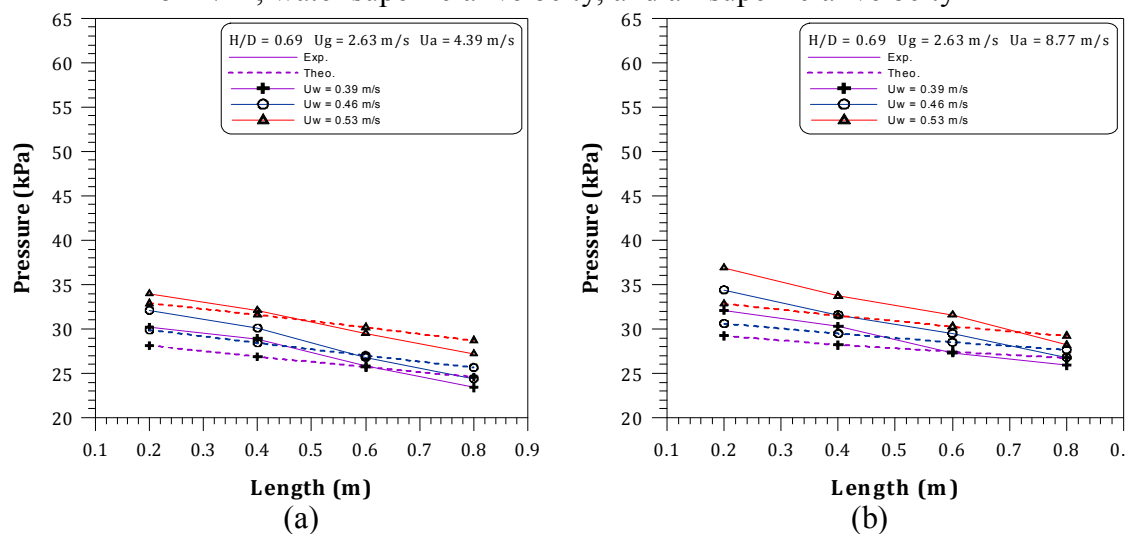


Figure (18) Effect of gasoline superficial velocity on the pressure at different values of H/D , water superficial velocity, and air superficial velocity



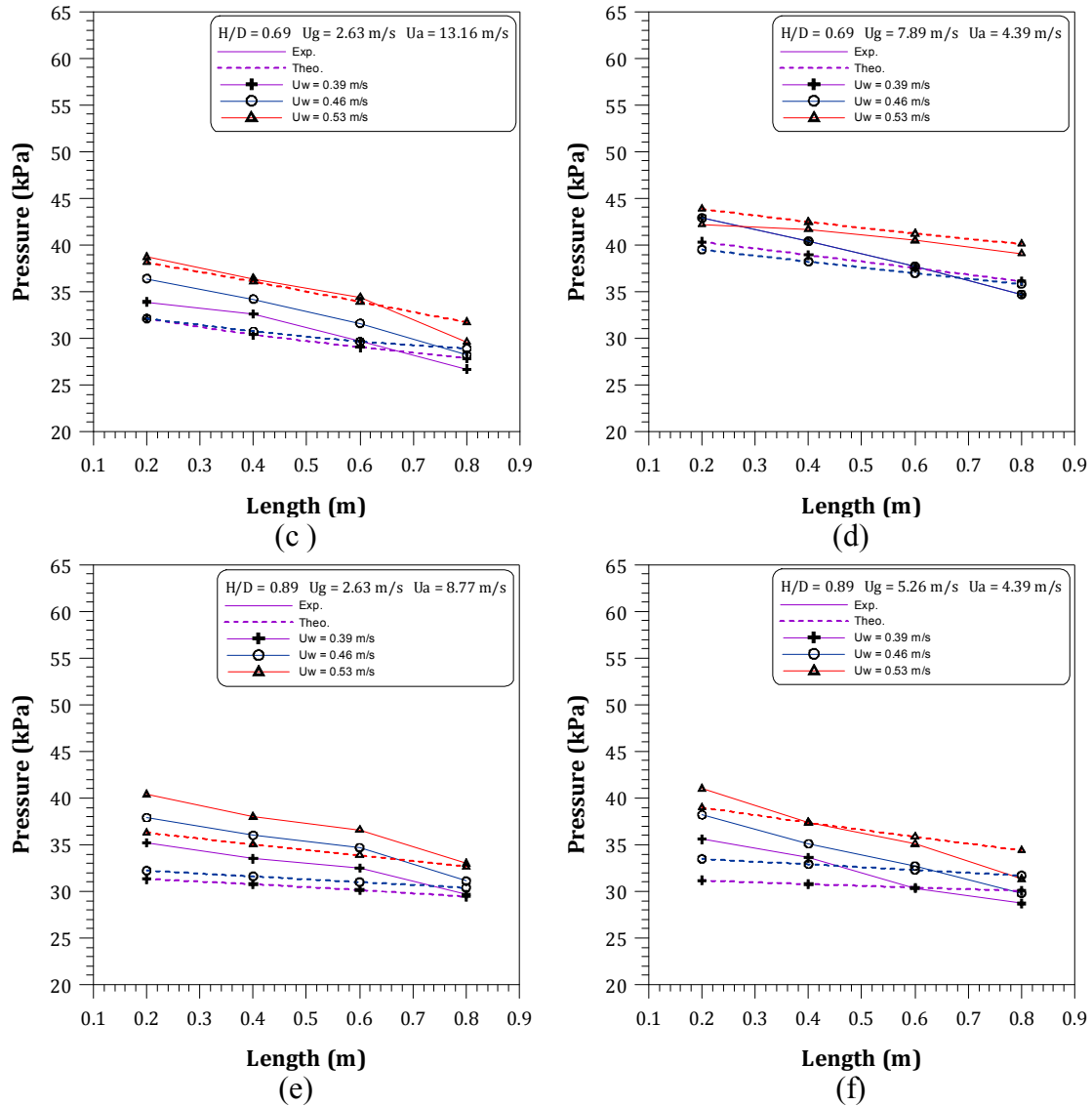
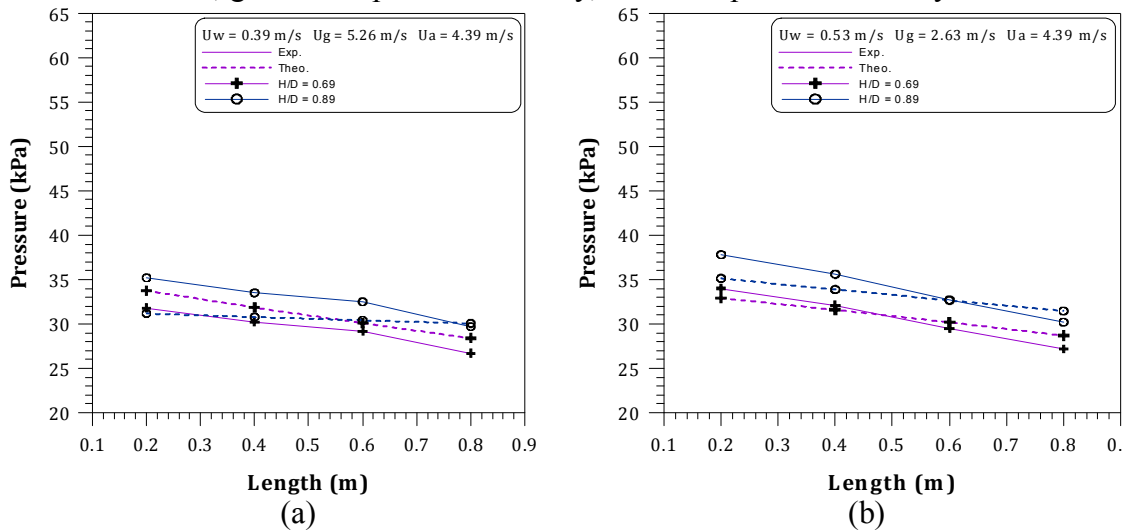


Figure (19) Effect of water superficial velocity on the pressure at different values of H/D , gasoline superficial velocity, and air superficial velocity



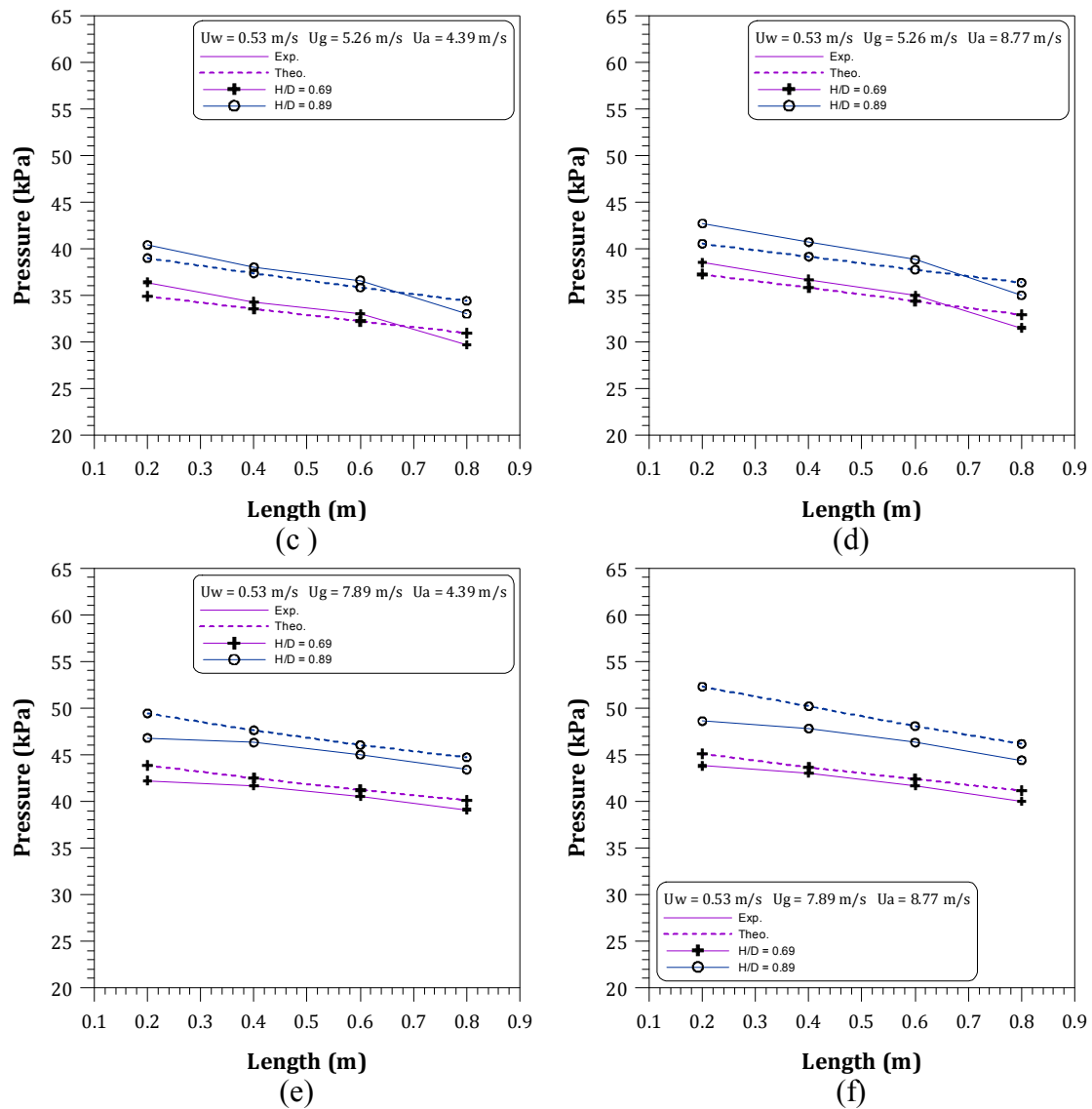


Figure (20) Effect of H/D on the pressure at different values of water superficial velocity, gasoline superficial velocity, and air superficial velocity

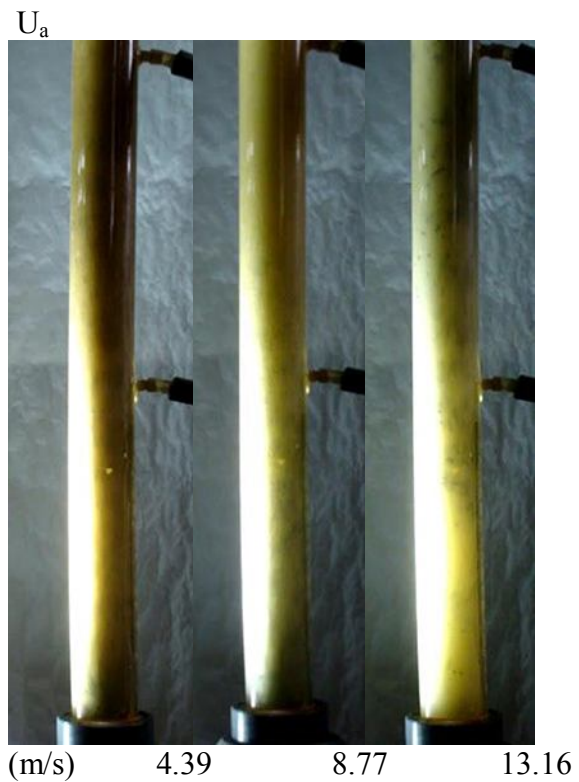


Figure (21) Effect of air superficial velocity on the flow behavior

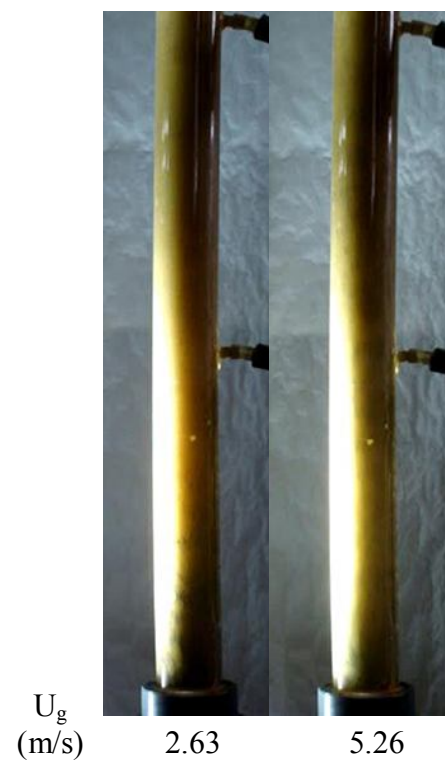


Figure (22) Effect of gasoline superficial velocity on the flow behavior

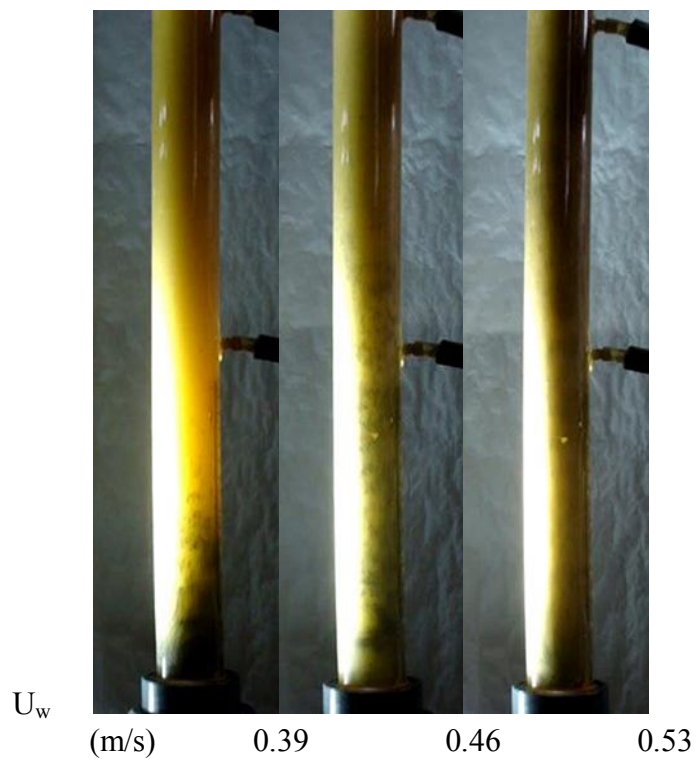


Figure (23) Effect of water superficial velocity on the flow behavior

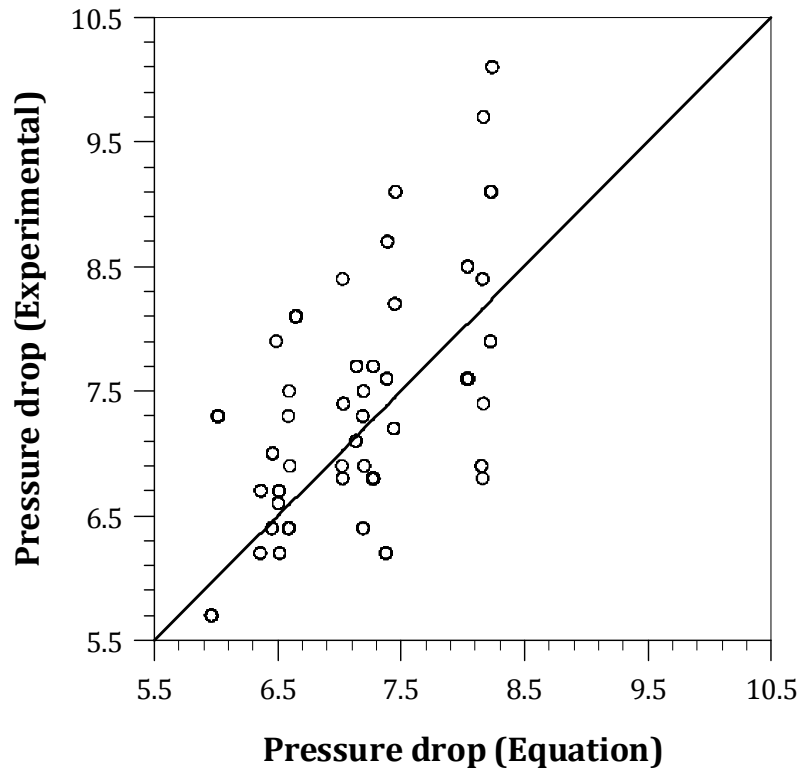


Figure (24) Comparison between the pressure drop experimental values and equation values

References

- Al-Turaihi, R., and Oleiwi, S., 2015, "Experimental and CFD Investigation the Effect of Solid Particle Height in Water-Solid Flow in Fluidized Bed Column", *International Journal of Mechanical Engineering and Applications*, Vol. 3, No. 3, PP. (37-45).
- Al-Turaihi, R., Hussein, A., Al-Kayiem, H., and Mohammed, H., 2013, "Experimental Investigation of Various Solid Particle Materials on the Steady State Gas-Solid Fluidized Bed System", *J. Basic. Appl. Sci. Res.*, Vol. 3, No. 7, PP. (293-304).
- Candia, O., and Cruz, M., 2005, "Prediction of Pressure, Temperature, and Velocity Distribution of Two-Phase Flow in Oil Wells", *Journal of Petroleum Science and Engineering*, Vol. 46, PP.(195-208).
- Candia, O., O.C. Centeno, B., and Paredes, G., 2011, "Two-fluid model for transient analysis of slug flow in oil wells", *International Journal of Heat and Fluid Flow*, Vol. 32, PP.(762-770).
- Gidaspow, D., Li, F., and Huang, J., 2013, "A CFD simulator for multiphase flow in reservoirs and pipes", *Powder Technology*, Vol. 242, PP. (2-12).
- Guler, B., Wang, P., Delshad, M., Pope, G., and Sepehrnoori, K., 2001, "Three- and Four-Phase Flow Compositional Simulations of CO₂/NGL EOR", *Society of Petroleum Engineers*.
- Habeeb, L., and Al-Turaihi, R., 2012, "Simulation and Experiment Study of Gas-Solid Flow Behavior in the Standpipe of a Fluidized Bed", *Proceedings of International Conference on Engineering and Information Technology*, Sep. 17-19 Toronto, Canada.
- Hasan, A., and Kabir, C., 2010, "Modeling two-phase fluid and heat flows in geothermal wells", *Journal of Petroleum Science and Engineering*, Vol. 71, PP. (77-86).

- Ibrehem, A., 2011, "System Identification for Experimental Study for Polymerization Catalyst Reaction in Fluidized Bed", *Bulletin of Chemical Reaction Engineering & Catalysis*, Vol. 6, No. 2, PP. (137-146).
- McMillan, L., Rivett, M., Tellam, J., Dumble, P., and Sharp, H., 2014, "Influence of vertical flows in wells on groundwater sampling", *Journal of Contaminant Hydrology*, Vol. 169, PP.(50-61) .
- Pan, L., Webb, S., and Oldenburg, C., 2011, "Analytical solution for two-phase flow in a wellbore using the drift-flux model", *Advances in Water Resources*, Vol. 34, PP. (1656-1665).
- Rundell, D., Schaefer, R., and Shou, J., 1987, "Hydrodynamics of Four-Phase Fluidization: Comparison of Cold-Flow and Operating Reactor Data for a Gas/Liquid/Coal Slurry Fluidized Bed", *Ind. Eng. Chem. Res.*, Vol.26, PP. (613-617).
- Tandon, M., and Karnik, A., 2014, "Simulation of rectangular fluidized bed with geldart D particles", 10th International Conference on CFD in Oil & Gas, Metallurgical and Process Industries SINTEF, Trondheim, Norway.
- Vorobieff, P., Brebbia, C.A., and Munoz-Cobo, J.L., 2015, "Computational Methods in Multiphase Flow VIII", WIT press Southampton, Boston .
- Xie, J., Yu, B., Zhang, X., Shao, Q., and Song, X., "Numerical Simulation of Gas-Liquid-Solid Three-Phase Flow in Deep Wells", 2013, Hindawi Publishing Corporation *Advances in Mechanical Engineering*, Vol. 2013.
- Yang, W.C., 2003, "Handbook of fluidization and fluid-particle systems", Marcel Dekker, INC..