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Dynamic Modelling and Simulation of a Three-Phase Gravity Separator

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Abstract: Many studies have investigated the crude oil separation process's separation mechanisms, size, and design, employing horizontal 3-Phase Gravity Separators in depth. There are, however, very few articles on their dynamics, modelling, simulation, and control. Understanding its dynamic behaviour will aid in designing and tuning the device that can manage water level, oil level, and gas pressure in response to feeding variations. This Scientific Paper gives a complete mathematical analysis, modelling, and simulation of a crude oil separation process using a horizontal 3-Phase Gravity Separator using Mathworks Matlab R2016b-x64 and Aspen Hysys V10. Bishoy's Equations, which were constructed, will assist in operating this gadget, locating various variables, and observing the effect of modifying variables on the system's variables. The rationale for this study was developed in response to the small number of articles discovered, which may be a covert issue held up by large oil companies, as well as the complicated equations related to this process that remain unsolved, and to monitor what is happening in this complex dynamic process. This paper provides everything related to a three-phase gravity separator, including changing of variables and observing the effect on the system when those variables were modified. The equations determined the following variables: The height of gas, water, oil, the height of oil when it jumped the weir, the pressure of the gas (in and out), water pressure (in and out), oil pressure (in and out), and the effect of increasing α (control valve's stem position) and decreasing Q_{in} (inlet volumetric flowrate) on these variables have all been studied. This article discovered that increasing the control valve stem position and decreasing the inflow volumetric flowrate of both oil and water was highly unsafe and caused significant variations in the system's heights and pressures using Matlab. The Aspen Hysys analysis optimally separates the oil, gas, and water to determine material, energy streams properties, and compositions. As a result, this complex dynamic behaviour was observed, and no additional articles were discovered that addressed this subject. This process monitoring will determine the best conditions for flawless separation, with the selectivity of the desired product or products as the primary goal. This research can revolutionize the way people think about oil and gas extraction and processing and benefit colossal oil and gas firms in Europe, Asia, and Africa.

Keywords: Modeling and Simulation, Matlab, Aspen Hysys, Three-Phase Gravity Separator

1. Introduction

Three-phase gravity separators are an essential component of the petroleum industry's manufacturing process. Because of immiscibility and density differences between the three, they are employed to separate hydrocarbon streams produced at the wellhead into their constituent phases: gas, oil, and water. They are available in both horizontal and vertical formats. As a result, the oil, water, natural gas, and sediment content of produced well fluids varies. The first stage in generating oil and gas is to utilize a separator to split the flow into its constituent components. Much research has been conducted to extensively explore the crude oil separation process's separation mechanisms, size, and design using horizontal 3-Phase Gravity Separators, [1, 4, 8]. There are, however, very few papers about their dynamics, modelling, and simulation. Here are a few examples of such publications:

[4] Grodal, O. and Matthew, R., Optimal design of two- and three-phase separators: A mathematical programming formulation. [8] Monnery, W. D. and Svrcek, W. Y., Successfully specify three-phase separators. Chemical Engineering Progress. [9] N. Al-Hatmi and M. Tham. DYNAMIC MODELLING AND SIMULATION OF A THREE-PHASE GRAVITY SEPARATOR. As a result, this Research Paper is distinct and novel, and it may be compared with the work done by Ref. No: [9] in that those authors did not solve the derived differential equations and did not use Aspen Hysys Modeling and Simulation. This paper covers everything connected to a 3-phase gravity separator, including adjusting variables and observing the effect on the system when those variables were modified.

The rationale for this study was developed in response to the small number of articles discovered, which may be a covert issue held up by large oil companies, as well as the complicated equations related to this process that remain unsolved, and to monitor what is happening in this complex dynamic process. Understanding its dynamic behaviour will aid in designing and tuning a device that may be used to manage water level, oil level, and gas pressure in response to feeding variations. This research aims to create a thorough mathematical analysis, modelling and simulation using Matlab and modelling and simulation using Aspen Hysys of a Crude Oil Separation Process Using a Horizontal 3-Phase Gravity Separator. N. Al-Hatmi and M. Tham are the only authors from the University of Newcastle upon Tyne, UK who have researched significantly on the same subject but not as deep as within this article.

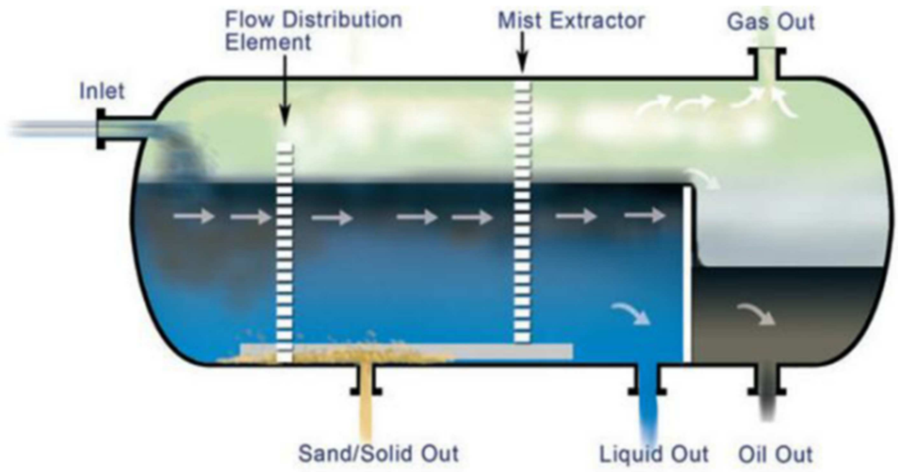

Figure 1. *Horizontal 3-Phase Gravity Separator.*

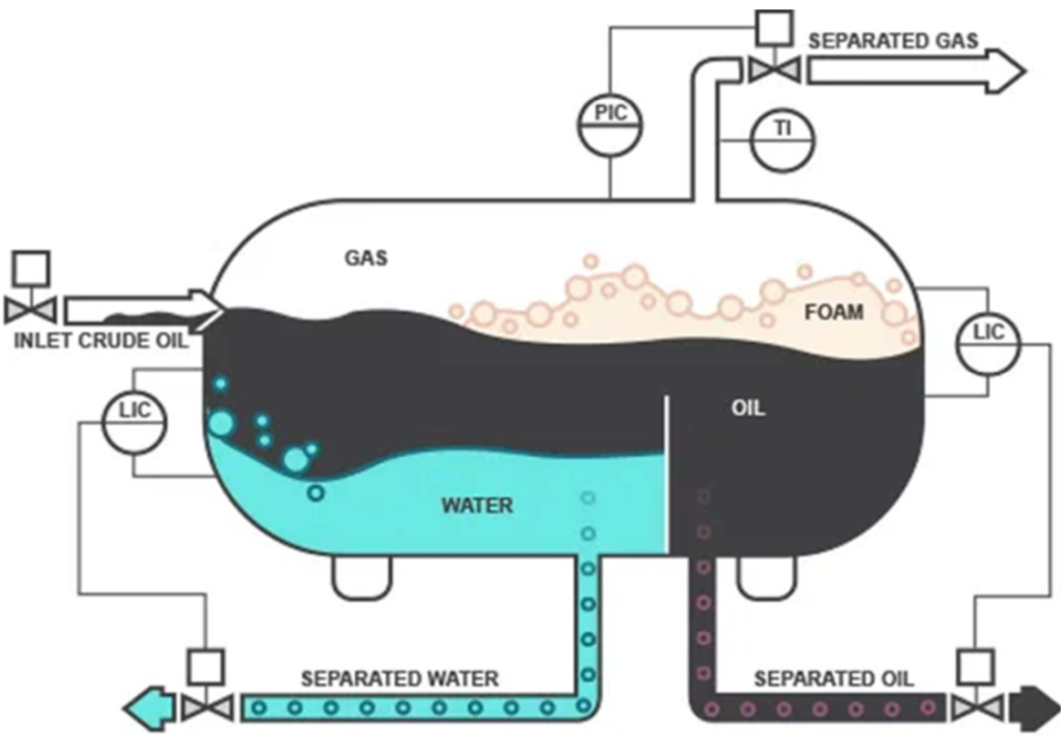

Figure 2. *A Horizontal three-phase separator controllers.*

1.1. Horizontal Three-Phase Separator Operation [7]

Fluid enters the vessel through an entrance and is diverted instantly by an intake diverter in a horizontal three-phase separator. This abrupt impact separates the liquid and vapour and starts the gas-oil separation process. The oil and emulsion separate in the vessel's liquid collection portion, forming a layer or pad above the free water. The oil level is maintained by a weir, while an interface liquid level controller maintains the water level. The oil pours over the top of the weir, and the amount of oil is controlled by a level controller, which runs the oil valve. An interface level controller detects the height of the oil-water interface as well. This controller instructs another valve to discharge as much water as is required to keep the oil-water contact at the predetermined height. Meanwhile, gas rises to the separator's top. It travels horizontally and then through a mist extractor to a pressure control valve, which keeps the vessel pressure constant. A horizontal three phase separator is usually more efficient for the handling of large volume gas. Due to its large interfacial areas, it has better phase separation capability. It does not handle solids [12].

1.2. Oil & Gas Top 50 Companies in the World (2021 Ranking) [11]

1) Shell, Netherlands
2) Saudi Aramco, Saudi Arabia
3) PetroChina, China
4) Sinopec, China
5) BP, United Kingdom
6) Total, France
7) Chevron, United States
8) ExxonMobil, United States
9) Petronas, Malaysia
10) ADNOC, UAE
11) Equinor, Norway
12) Eni, Italy
13) CNOOC, China
14) Gazprom, Russia
15) Valero, United States
16) Pemex, Mexico
17) Lukoil, Russia
18) PTT, Thailand
19) Reliance, India
20) Repsol, Spain
21) Indian Oil, India
22) Esso, United States
23) Phillips 66, United States
24) Enbridge, Canada
25) ConocoPhillips, United States
26) Mobil, United States
27) CNRL, Canada
28) Rosneft, Russia
29) Marathon Petroleum, United States
30) Schlumberger, United States
31) Petrobras, Brazil
32) Exxon, United States
33) Energy Transfer, United States
34) SK Innovation, South Korea
35) Ecopetrol, Colombia
36) ONGC, India
37) Pertamina, Indonesia
38) Baker Hughes, United States
39) Idemitsu Kosan, Japan
40) Bharat Petroleum, India
41) Inpex, Japan
42) Oxy, United States
43) Neste, Finland
44) Enterprise Products, United States
45) OMV, Austria
46) Suncor Energy, Canada
47) Hindustan Petroleum, India
48) S-Oil, South Korea
49) GS Caltex, South Korea
50) Halliburton, United States

2. Methodology

The assumptions for this study were developed in the sections that follow. Four systems then describe the separator: the water sub-system, the left oil sub-system, the right oil sub-system, and the gas sub-system. As a result, the separator model was developed by first creating the relevant unsteady-state mass balance equation for each sub-system. Then, a comprehensive mathematical analysis was built for each sub-system to solve the challenging equations that had remained unsolvable for centuries by using the Matlab Scripts developed. The results were achieved by modelling and simulation using Matlab R2016b, and a discussion summary table was created for the results. Finally, modelling and simulation using Aspen Hysys V10 was performed, and the results were obtained, along with discussions that described the entire process. Following that, the Conclusions and Acknowledgment were written down. In addition, the references utilized were displayed. The biography of the authors can be found at the end of this research article.

2.1. Assumptions

1) The separator has a constant operating temperature. As a result, temperature effects are unnecessary, and constant liquid densities can be assumed further.
2) The separation process is entirely efficient. Other internals such as a diverter, wave breakers, defoaming plates, vortex break, mist extractor, baffle plate, and so on, aside from the weir that divides the two chambers in the separator, should not be considered because they can only improve separation efficiency.
3) Only the suitable flow streams allow liquids to enter and exit the tank (i.e. no evaporation).
4) The vapour phase behaves like an ideal gas, which makes sense given that most real gases obey the general gas laws pretty well at moderate pressures and temperatures substantially higher than their liquefaction point [3].

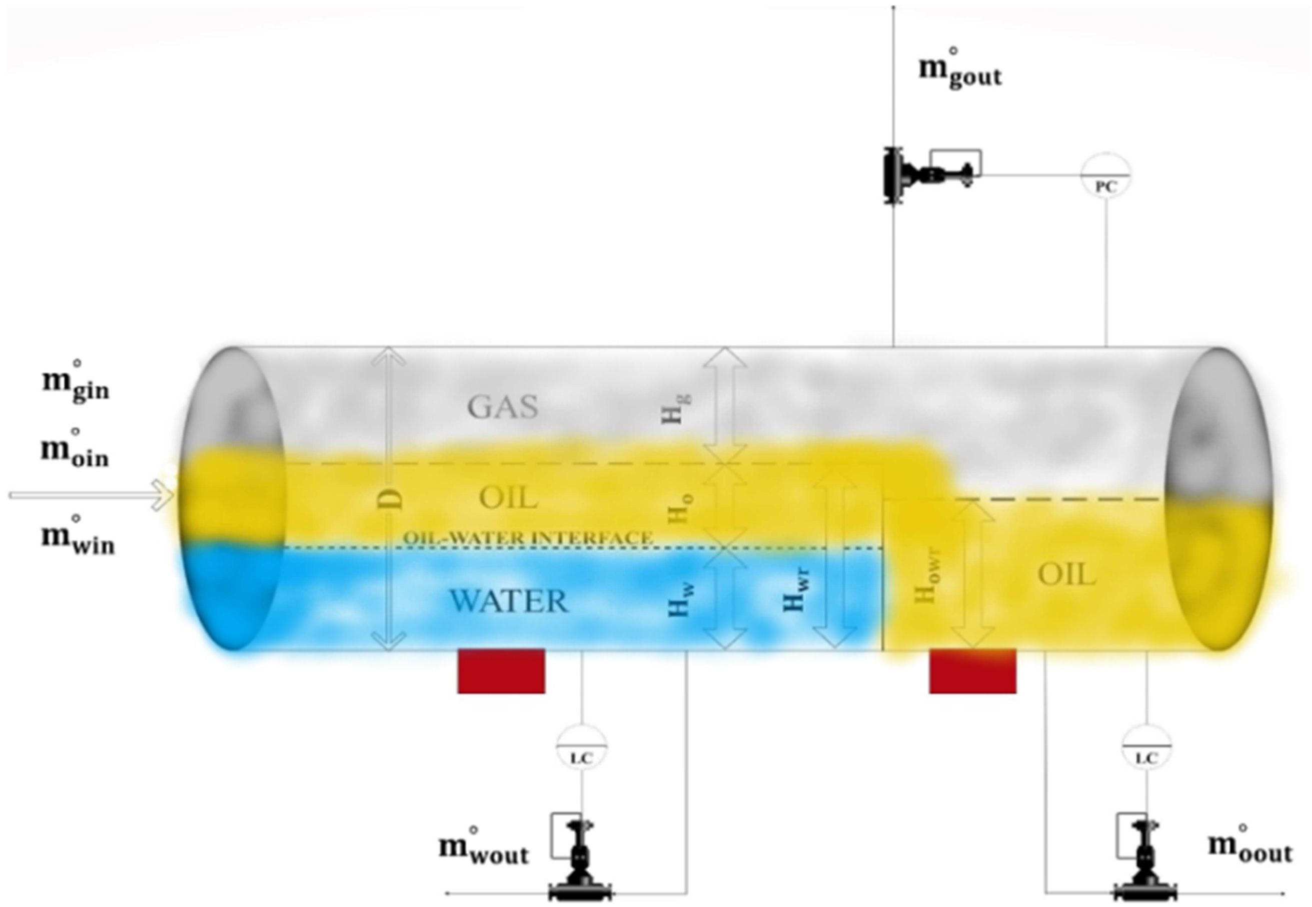

Figure 3. *A horizontal three-phase separator with hemispherical heads was drawn using Edraw Max V9.4.0.*

2.2. Developing the Respective Equations

The Separator is depicted in the above design as having four sub-systems: water, left oil, right oil, and gas. The separator model was developed by creating the respective unsteady-state mass balance equation for each sub-system based on the assumptions provided. According to Ref. No: [9] research resulted in the rise of the following equations; the authors did not solve these obtained differential equations and did not proceed with this Research Project. These were the unsolvable equations:

Water sub-system [5, 14]:

$$Q_{win} = \frac{d\left(\frac{-\pi}{6}H_w^3+\frac{\pi}{4}H_w^2D+\left[L_1\left(\frac{\pi}{2}r^2+r^2\sin^{-1}\frac{H_w-r}{r}+(H_w-r)\sqrt{H_w(2r-H_w)}\right)\right]\right)}{dt} + \frac{\alpha_w}{100}\times C_{vw}\times 6.309\times 10^{-5}\sqrt{\frac{([\rho_w g H_w+\rho_o g H_o]1.45\times10^{-4}+P_g)-P_{wout}}{SG_w}} \quad (1)$$

Left oil sub-system:

$$Q_{oin} = \frac{d\left(\frac{\pi}{12}[-2H_o^3+3H_o^2(D-2H_w)+6H_oH_w(D-H_w)]+L_1\left(\frac{\pi}{2}r^2+r^2\sin^{-1}\frac{H_o-r}{r}+(H_o-r)\sqrt{H_o(2r-H_o)}\right)\right)}{dt} \quad (2)$$

Right oil sub-system:

$$Q_{oin} = \frac{d\left(\frac{-\pi}{6}H_{owr}^3+\frac{\pi}{4}H_{owr}^2D+\left[L_2\left(\frac{\pi}{2}r^2+r^2\sin^{-1}\frac{H_{owr}-r}{r}+(H_{owr}-r)\sqrt{H_{owr}(2r-H_{owr})}\right)\right]\right)}{dt} + \frac{\alpha_o}{100}\times C_{vo}\times 6.309\times 10^{-5}\sqrt{\frac{\rho_o g H_{owr}\times1.45\times10^{-4}+P_g-P_{oout}}{SG_o}} \quad (3)$$

Gas sub-system [6]:

$$\rho_{gin}Q_{gin} = \frac{6894.757\times M_{wt}}{1000\times R\times T_k}\frac{d(P_gV_g)}{dt} + \frac{m}{V_g}\left[962\times\frac{\alpha_g}{100}\times 7.866\times10^{-6}\times C_{vg}\times\sqrt{\frac{P_g^2-P_{gout}^2}{SG_g\times T_r}}\times\frac{P_sT_r}{P_gT_s}\right] \quad (4)$$

2.3. Solving the Unsolved Equations Yielding Bishoy's Equations

What distinguishes this Research Paper is the ease with which it solves the above tricky equations and then changes those variables to see the effect on the system when those variables are altered. As a result, this allows for real-time monitoring of the entire separation process.

Using the Symbolab premium apk mod on an Android phone and arranging:

Water sub-system:

$$\frac{d\left(\frac{-\pi}{6}H_w^3\right)}{dt} = \frac{-\pi}{2}H_w^2\frac{dH_w}{dt}$$

$$\frac{d\left(\frac{\pi}{4}H_w^2 D\right)}{dt} = \frac{\pi}{2}DH_w\frac{dH_w}{dt}$$

$$\frac{d\left(L_1\frac{\pi}{2}r^2\right)}{dt} = 0$$

$$\frac{d\left(L_1 r^2 \sin^{-1}\frac{H_w - r}{r}\right)}{dt} = \frac{L_1 r^2}{\sqrt{2rH_w - H_w^2}}\frac{dH_w}{dt}$$

$$\frac{d\left(L_1(H_w - r)\sqrt{H_w(2r - H_w)}\right)}{dt} = L_1\sqrt{H_w(2r - H_w)}\frac{dH_w}{dt} + \frac{L_1(-H_w + r)(H_w - r)}{\sqrt{H_w(2r - H_w)}}\frac{dH_w}{dt}$$

$$\frac{-\pi}{2}H_w^2\frac{dH_w}{dt} + \frac{\pi}{2}DH_w\frac{dH_w}{dt} + 0 + \frac{L_1 r^2}{\sqrt{2rH_w - H_w^2}}\frac{dH_w}{dt} + L_1\sqrt{H_w(2r - H_w)}\frac{dH_w}{dt} + \frac{L_1(-H_w + r)(H_w - r)}{\sqrt{H_w(2r - H_w)}}\frac{dH_w}{dt} = Q_{win} - \left[\frac{\alpha_w}{100} \times C_{vw} \times 6.309 \times 10^{-5}\sqrt{\frac{([\rho_w g H_w + \rho_o g H_o]1.45\times10^{-4} + P_g) - P_{wout}}{SG_w}}\right]$$

$$\left(\frac{-\pi}{2}H_w^2 + \frac{\pi}{2}DH_w + \frac{L_1 r^2}{\sqrt{2rH_w - H_w^2}} + L_1\sqrt{H_w(2r - H_w)} + \frac{L_1(-H_w + r)(H_w - r)}{\sqrt{H_w(2r - H_w)}}\right)\frac{dH_w}{dt} = Q_{win} - \left[\frac{\alpha_w}{100} \times C_{vw} \times 6.309 \times 10^{-5}\sqrt{\frac{([\rho_w g H_w + \rho_o g H_o]1.45\times10^{-4} + P_g) - P_{wout}}{SG_w}}\right]$$

$$\frac{dH_w}{dt} = \frac{Q_{win} - \left[\frac{\alpha_w}{100}\times C_{vw}\times 6.309\times10^{-5}\sqrt{\frac{([\rho_w g H_w + \rho_o g H_o]1.45\times10^{-4} + P_g) - P_{wout}}{SG_w}}\right]}{\left(\frac{-\pi}{2}H_w^2 + \frac{\pi}{2}DH_w + \frac{L_1 r^2}{\sqrt{2rH_w - H_w^2}} + L_1\sqrt{H_w(2r - H_w)} + \frac{L_1(-H_w + r)(H_w - r)}{\sqrt{H_w(2r - H_w)}}\right)} \tag{5}$$

Left oil sub-system:

$$\frac{d\left(\frac{-2\pi}{12}H_o^3\right)}{dt} = \frac{-\pi}{2}H_o^2\frac{dH_o}{dt}$$

Next one is a total derivative which is Differentiation with indirect dependencies:
For example, the total derivative of $f(x(t), y(t))$ is

$$\frac{df}{dt} = \frac{\partial f}{\partial x}\frac{dx}{dt} + \frac{\partial f}{\partial y}\frac{dy}{dt}$$

Here there is no $\frac{\partial f}{\partial t}$ term since f itself does not depend on the independent variable t directly.

$$\frac{d\left(\frac{3\pi}{12}H_o^2(D - 2H_w)\right)}{dt} = \frac{\pi}{2}H_o(D - 2H_w)\frac{dH_o}{dt} - \frac{\pi}{2}H_o^2\frac{dH_w}{dt}$$

$$\frac{d\left(\frac{6\pi}{12}H_o H_w(D - H_w)\right)}{dt} = \frac{\pi}{2}H_w(D - H_w)\frac{dH_o}{dt} + \frac{\pi}{2}H_o D\frac{dH_w}{dt} - \pi H_o H_w\frac{dH_w}{dt}$$

$$\frac{d\left(L_1\frac{\pi}{2}r^2\right)}{dt} = 0$$

$$\frac{d\left(L_1 r^2 \sin^{-1}\frac{H_o-r}{r}\right)}{dt}=\frac{L_1 r^2}{\sqrt{2rH_o-H_o^2}}\frac{dH_o}{dt}$$

$$\frac{d\left(L_1(H_o-r)\sqrt{H_o(2r-H_o)}\right)}{dt}=L_1\sqrt{H_o(2r-H_o)}\frac{dH_o}{dt}+\frac{L_1(-H_o+r)(H_o-r)}{\sqrt{H_o(2r-H_o)}}\frac{dH_o}{dt}$$

$$\frac{-\pi}{2}H_o^2\frac{dH_o}{dt}+\frac{\pi}{2}H_o(D-2H_w)\frac{dH_o}{dt}-\frac{\pi}{2}H_o^2\frac{dH_w}{dt}+\frac{\pi}{2}H_w(D-H_w)\frac{dH_o}{dt}+\frac{\pi}{2}H_oD\frac{dH_w}{dt}-\pi H_oH_w\frac{dH_w}{dt}+0+\frac{L_1r^2}{\sqrt{2rH_o-H_o^2}}\frac{dH_o}{dt}+L_1\sqrt{H_o(2r-H_o)}\frac{dH_o}{dt}+\frac{L_1(-H_o+r)(H_o-r)}{\sqrt{H_o(2r-H_o)}}\frac{dH_o}{dt}=Q_{oin}$$

$$\left(\frac{-\pi}{2}H_o^2+\frac{\pi}{2}H_o(D-2H_w)+\frac{\pi}{2}H_w(D-H_w)+\frac{L_1r^2}{\sqrt{2rH_o-H_o^2}}+L_1\sqrt{H_o(2r-H_o)}+\frac{L_1(-H_o+r)(H_o-r)}{\sqrt{H_o(2r-H_o)}}\right)\frac{dH_o}{dt}+\left(-\frac{\pi}{2}H_o^2+\frac{\pi}{2}H_oD-\pi H_oH_w\right)\frac{dH_w}{dt}=Q_{oin}$$

$$\frac{dH_o}{dt}=\frac{Q_{oin}-\left[\left(-\frac{\pi}{2}H_o^2+\frac{\pi}{2}H_oD-\pi H_oH_w\right)\frac{dH_w}{dt}\right]}{\left(\frac{-\pi}{2}H_o^2+\frac{\pi}{2}H_o(D-2H_w)+\frac{\pi}{2}H_w(D-H_w)+\frac{L_1r^2}{\sqrt{2rH_o-H_o^2}}+L_1\sqrt{H_o(2r-H_o)}+\frac{L_1(-H_o+r)(H_o-r)}{\sqrt{H_o(2r-H_o)}}\right)}$$

Substitute $\frac{dH_w}{dt}$

$$\frac{dH_o}{dt}=\frac{Q_{oin}-\left[\left(-\frac{\pi}{2}H_o^2+\frac{\pi}{2}H_oD-\pi H_oH_w\right)\frac{Q_{win}-\left[\frac{\alpha_w}{100}\times C_{vw}\times 6.309\times10^{-5}\sqrt{\frac{([\rho_wgH_w+\rho_ogH_o]1.45\times10^{-4}+P_g)-P_{wout}}{SG_w}}\right]}{\left(\frac{-\pi}{2}H_w^2+\frac{\pi}{2}DH_w+\frac{L_1r^2}{\sqrt{2rH_w-H_w^2}}+L_1\sqrt{H_w(2r-H_w)}+\frac{L_1(-H_w+r)(H_w-r)}{\sqrt{H_w(2r-H_w)}}\right)}\right]}{\left(\frac{-\pi}{2}H_o^2+\frac{\pi}{2}H_o(D-2H_w)+\frac{\pi}{2}H_w(D-H_w)+\frac{L_1r^2}{\sqrt{2rH_o-H_o^2}}+L_1\sqrt{H_o(2r-H_o)}+\frac{L_1(-H_o+r)(H_o-r)}{\sqrt{H_o(2r-H_o)}}\right)} \quad (6)$$

Right oil sub-system:
This is derived in the same manner as for the water sub-system and is given by:

$$Q_{oin}=\frac{d\left(\frac{-\pi}{6}H_{owr}^3+\frac{\pi}{4}H_{owr}^2D+\left[L_2\left(\frac{\pi}{2}r^2+r^2\sin^{-1}\frac{H_{owr}-r}{r}+(H_{owr}-r)\sqrt{H_{owr}(2r-H_{owr})}\right)\right]\right)}{dt}+\frac{\alpha_o}{100}\times C_{vo}\times 6.309\times10^{-5}\sqrt{\frac{\rho_ogH_{owr}\times1.45\times10^{-4}+P_g-P_{oout}}{SG_o}}$$

$$\frac{dH_{owr}}{dt}=\frac{Q_{oin}-\left[\frac{\alpha_o}{100}\times C_{vo}\times 6.309\times10^{-5}\sqrt{\frac{\rho_ogH_{owr}\times1.45\times10^{-4}+P_g-P_{oout}}{SG_o}}\right]}{\left(\frac{-\pi}{2}H_{owr}^2+\frac{\pi}{2}DH_{owr}+\frac{L_2r^2}{\sqrt{2rH_{owr}-H_{owr}^2}}+L_2\sqrt{H_{owr}(2r-H_{owr})}+\frac{L_2(-H_{owr}+r)(H_{owr}-r)}{\sqrt{H_{owr}(2r-H_{owr})}}\right)} \quad (7)$$

Gas sub-system:
Case 1:

$$\rho_{gin}Q_{gin}=\frac{M_{wt}}{1000\times R\times T_k}\frac{d\left(P_{g(Pa)}V_g\right)}{dt}+\frac{m}{V_g}\left[962\times\frac{\alpha_g}{100}\times 7.866\times10^{-6}\times C_{vg}\times\sqrt{\frac{P_g^2-P_{gout}^2}{SG_g\times T_r}}\times\frac{P_sT_r}{P_gT_s}\right]$$

$P_{g(Pa)}V_g=nRT_k$ [2]

$$\rho_{gin}Q_{gin}=\frac{M_{wt}}{1000\times R\times T_k}\frac{d(nRT_k)}{dt}+\frac{m}{V_g}\left[962\times\frac{\alpha_g}{100}\times 7.866\times10^{-6}\times C_{vg}\times\sqrt{\frac{P_g^2-P_{gout}^2}{SG_g\times T_r}}\times\frac{P_sT_r}{P_gT_s}\right]$$

$$\rho_{gin}Q_{gin}=\frac{M_{wt}nRT_k}{1000\times R\times T_k}\frac{d(1)}{dt}+\frac{m}{V_g}\left[962\times\frac{\alpha_g}{100}\times 7.866\times10^{-6}\times C_{vg}\times\sqrt{\frac{P_g^2-P_{gout}^2}{SG_g\times T_r}}\times\frac{P_sT_r}{P_gT_s}\right]$$

$$\rho_{gin}Q_{gin} = 0 + \frac{m}{V_g}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]$$

$$\rho_{gin}Q_{gin} = \frac{m}{V_g}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]$$

$$m = \frac{P_{g(Pa)}V_g M_{wt}}{1000 \times R \times T_k} = \frac{P_g V_g M_{wt} \times 6894.757}{1000 \times R \times T_k}$$

$$\therefore \frac{m}{V_g} = \frac{P_g M_{wt} \times 6894.757}{1000 \times R \times T_k}$$

$$\rho_{gin}Q_{gin} = \frac{P_g M_{wt} \times 6894.757}{1000 \times R \times T_k}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]$$

$$(\rho_{gin}Q_{gin}) - \left(\frac{P_g M_{wt} \times 6894.757}{1000 \times R \times T_k}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]\right) = 0 \quad (8)$$

Solving for P_g will give us the gas pressure which occurs inside the separator P_g and which will be out of the separator going into the Valve P_{gin} i.e., $P_g = P_{gin}$

Case 2:

V_g is constant

$$\rho_{gin}Q_{gin} = \frac{6894.757 \times M_{wt} \times V_g}{1000 \times R \times T_k}\frac{dP_g}{dt} + \frac{m}{V_g}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]$$

$$\rho_{gin}Q_{gin} = \frac{6894.757 \times M_{wt} \times V_g}{1000 \times R \times T_k}\frac{dP_g}{dt} + \frac{P_g M_{wt} \times 6894.757}{1000 \times R \times T_k}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]$$

$$\frac{dP_g}{dt} = \frac{(\rho_{gin}Q_{gin}) - \left(\frac{P_g M_{wt} \times 6894.757}{1000 \times R \times T_k}\left[962 \times \frac{\alpha_g}{100} \times 7.866 \times 10^{-6} \times C_{vg} \times \sqrt{\frac{P_g^2 - P_{gout}^2}{SG_g \times T_r}} \times \frac{P_s T_r}{P_g T_s}\right]\right)}{\frac{6894.757 \times M_{wt} \times V_g}{1000 \times R \times T_k}} \quad (9)$$

The preceding equations (5, 6, 7, 8, 9) were called Bishoy's equations, which were implicit and difficult to solve. They were solved using the Matlab scripts developed.

3. Results and Discussion

3.1. Modeling and Simulation Using Matlab

By changing the inputs $\alpha_g, \alpha_w, \alpha_o, Q_{gin}, Q_{win}, Q_{oin}$, the outputs $H_w, H_o, H_{owr}, P_g, H_g$ were also changed.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

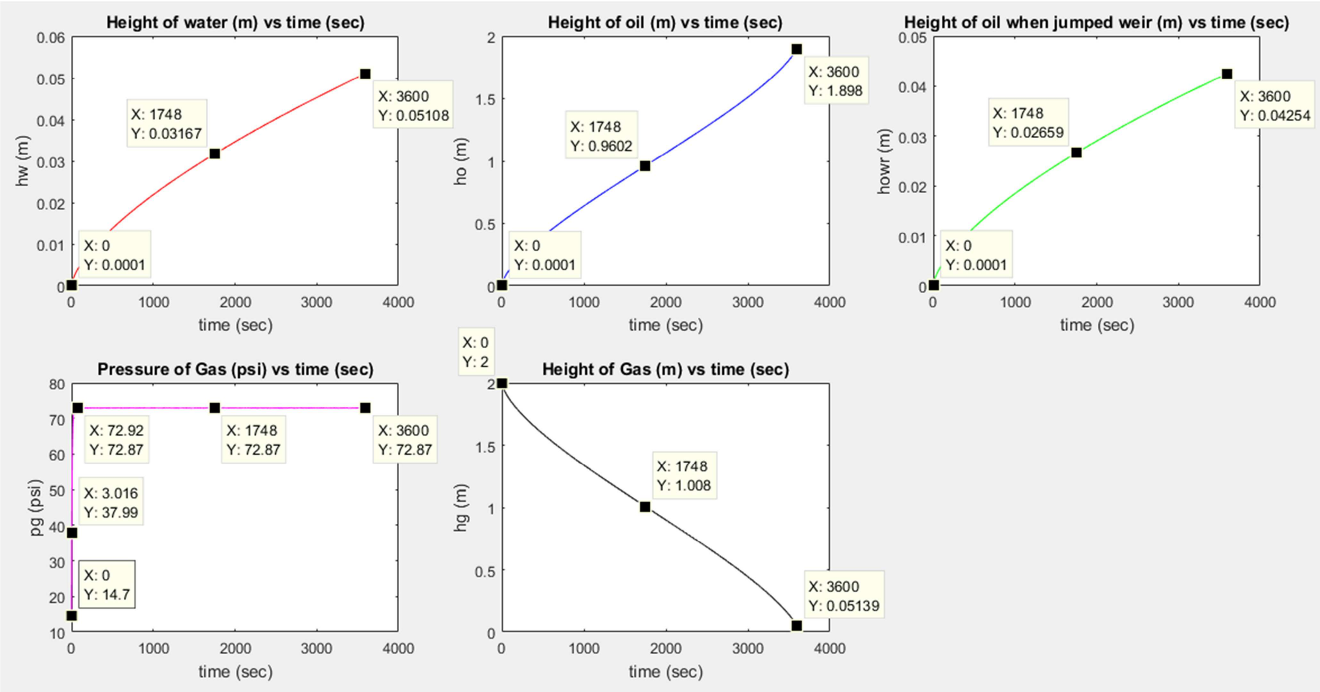

Figure 4. *The system is operating normally.*

$$\alpha_g = 80, \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

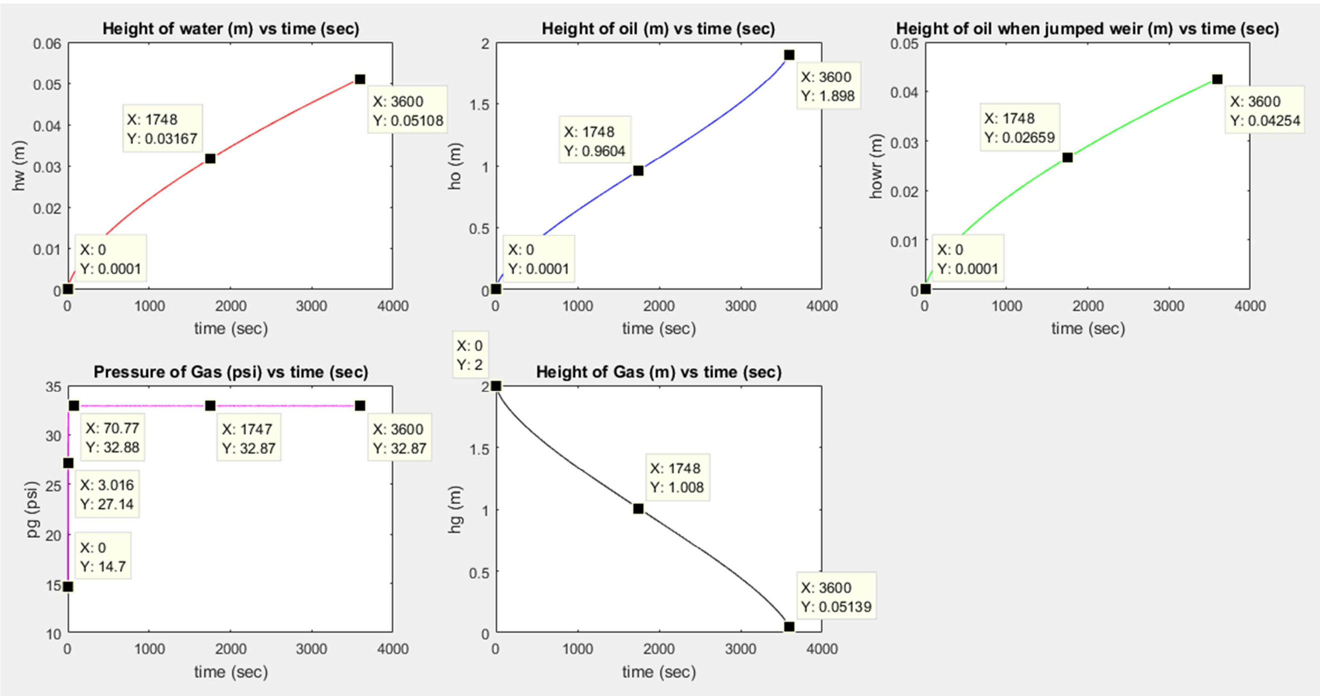

Figure 5. *Control valve's stem position of Gas was increased.*

Increasing α_g will not affect the heights but will decrease the pressure inside.

$$\alpha_w = 80, \alpha_g = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

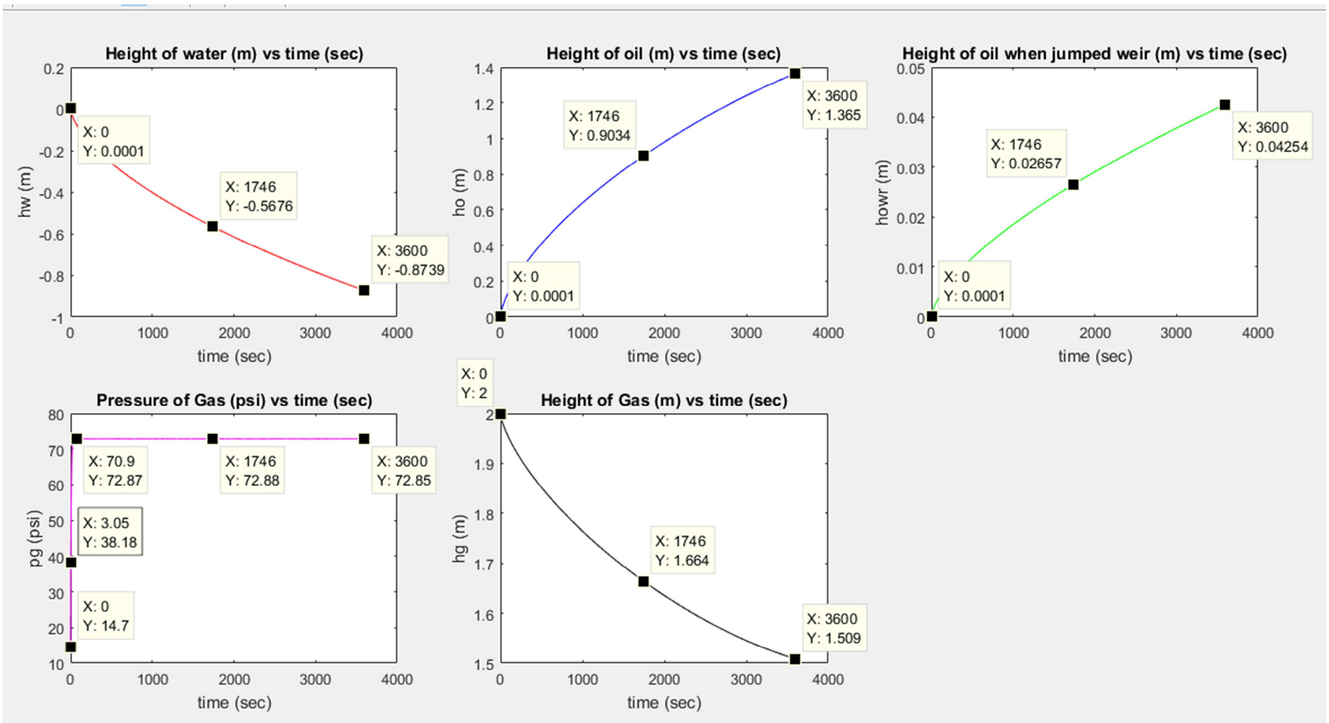

Figure 6. *Control valve's stem position of Water was increased.*

Increasing α_w will not affect right chamber (H_{owr}) and will not affect P_g but H_w will begin decreasing, hence H_o will decrease by a small amount, hence making H_g to increase but keeping P_g constant with no effect on it.

$$\alpha_o = 80, \alpha_w = \alpha_g = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

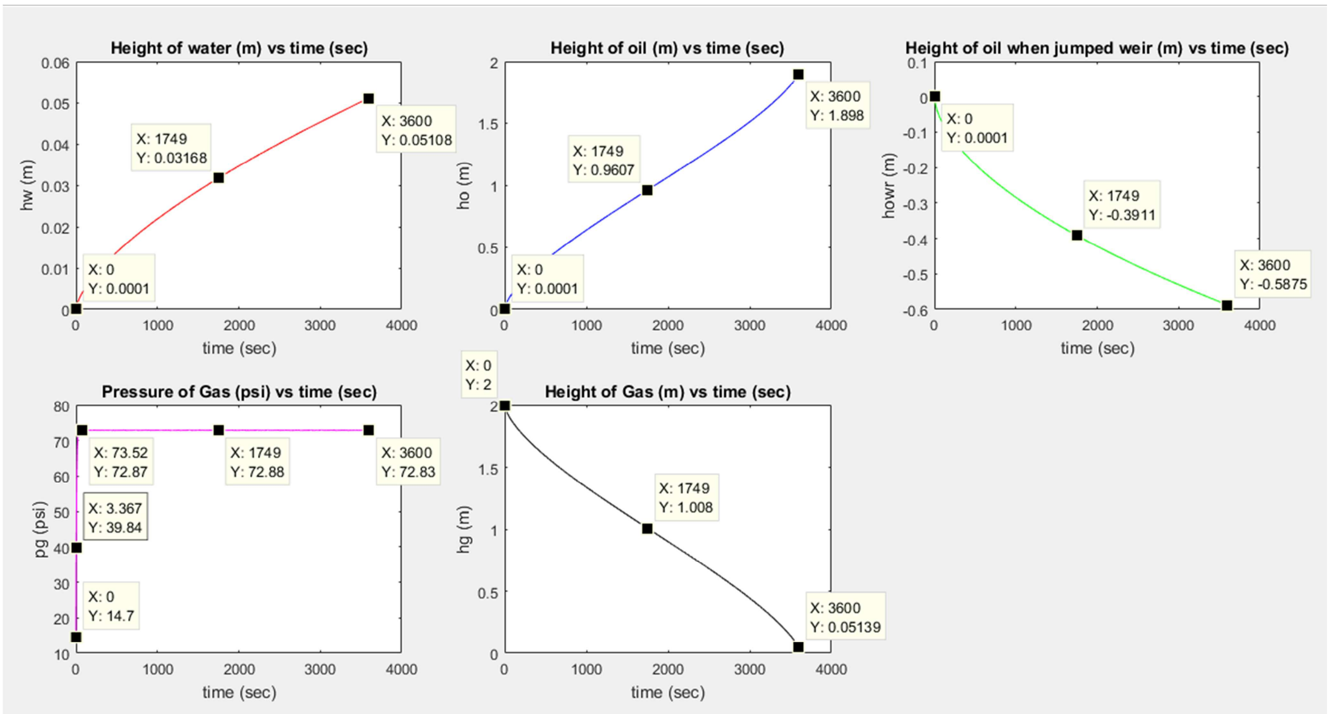

Figure 7. *Control valve's stem position of Oil was increased.*

Increasing α_o will not affect left chamber (H_w) and (H_o), hence no effect on H_g and keeping the pressure constant (no effect on P_g) but of course right chamber is affected and H_{owr} begin decreasing.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 1.655 \frac{m^3}{sec}, Q_{win} = 0.0131 \frac{m^3}{sec}, Q_{oin} = 0.0044304 \frac{m^3}{sec}$$

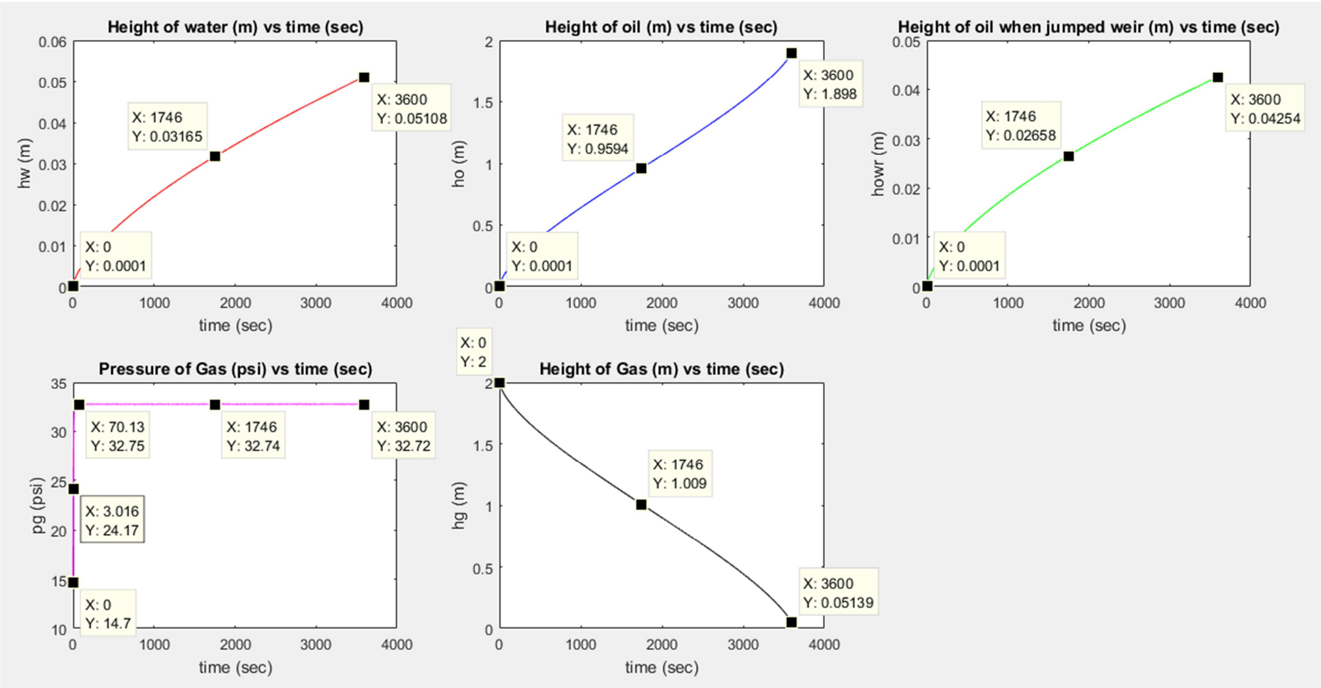

Figure 8. *Inlet volumetric rate of Gas was decreased.*

Decreasing Q_{gin} means decreasing the natural gas inlet volumetric rate entering to the separator which means decreasing the natural gas volumetric rate inside the separator which will be going out of the separator to the valve and this will not affect the heights but will decrease the pressure inside since there will be less natural gas inside which means low gas pressure.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655 \frac{m^3}{sec}, Q_{win} = 0.0120 \frac{m^3}{sec}, Q_{oin} = 0.0044304 \frac{m^3}{sec}$$

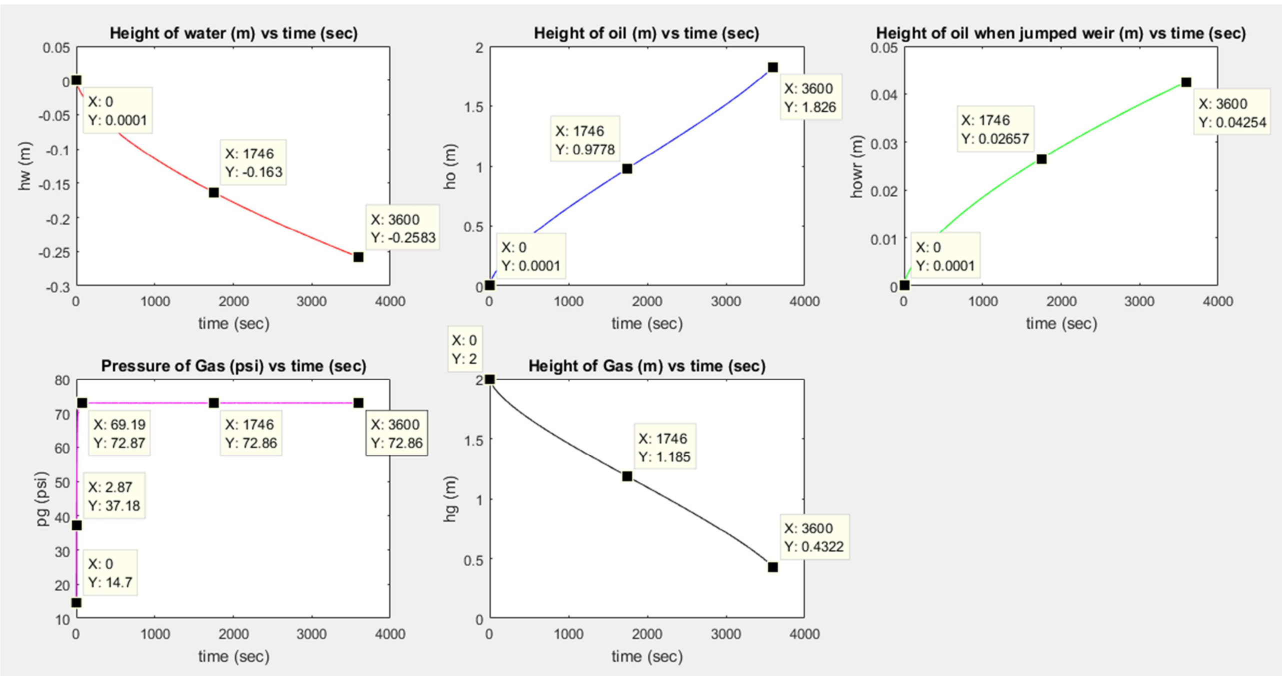

Figure 9. *Inlet volumetric rate of Water was decreased.*

Decreasing Q_{win} means decreasing the water inlet volumetric rate entering to the separator which means decreasing the water volumetric rate inside the separator which will be going out of the separator to the valve and this will not affect right chamber (H_{owr}) and will not affect P_g but H_w will begin decreasing, hence H_o will decrease by a small amount, hence making H_g to increase but keeping P_g constant with no effect on it.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0034304\frac{m^3}{sec}$$

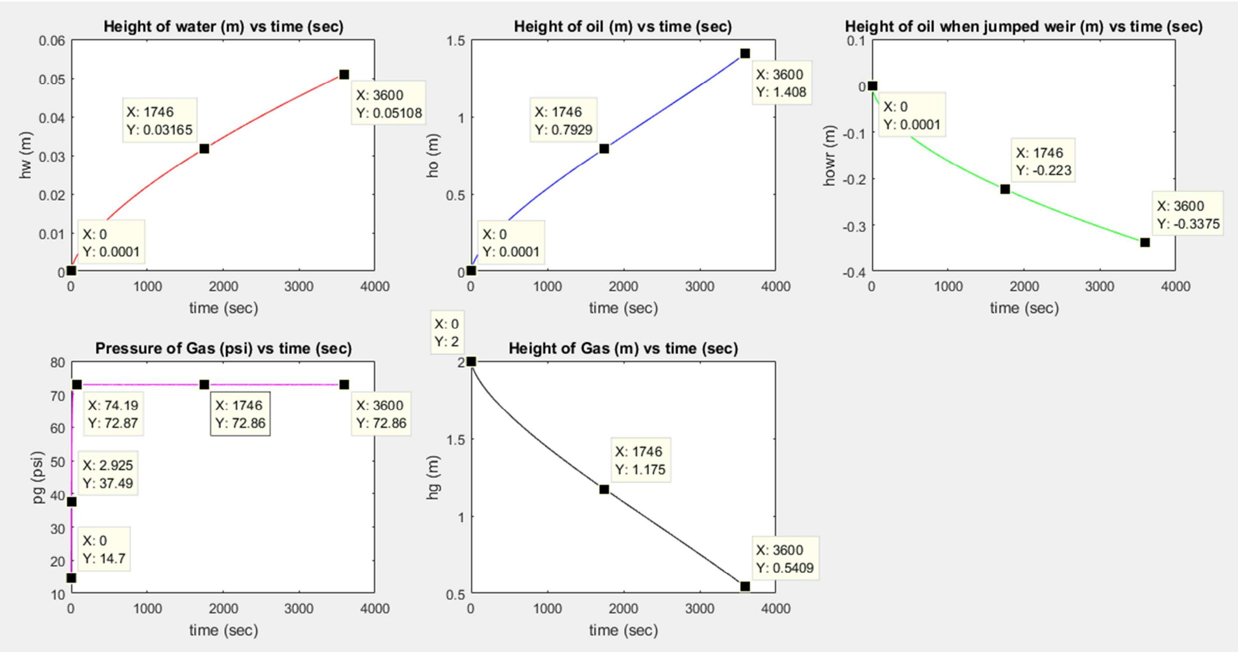

Figure 10. *Inlet volumetric rate of Oil was decreased.*

Decreasing Q_{oin} means decreasing the oil inlet volumetric rate entering to the separator which means decreasing the oil volumetric rate inside the separator which will be going out of the separator to the valve and this will effect left chamber (H_o only which will decrease) with no effect on H_w, hence effecting on H_g which will increase but keeping the pressure constant (no effect on P_g) but of course right chamber is effected and H_{owr} begin decreasing since H_o was decreased.

Table 1. *Discussion summary on the Results of the Modeling and Simulation using Matlab.*

Compared to $\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$ (Normal)						
In t = 3600 sec		**H_w(m)**	**H_o(m)**	**H_{owr}(m)**	**P_g(psia)**	**H_g(m)**
Increasing α	$\alpha_g = 50$	Normal	Normal	Normal	Normal	Normal
	$\alpha_g = 80$	No effect	No effect	No effect	Decreases	No effect
	$\alpha_g = 100$	No effect	No effect	No effect	Decreases	No effect
	$\alpha_w = 50$	Normal	Normal	Normal	Normal	Normal
	$\alpha_w = 80$	Decreases	Small Decrease	No effect	No effect	Increases
	$\alpha_w = 100$	Decreases	Small Decrease	No effect	No effect	Increases
	$\alpha_o = 50$	Normal	Normal	Normal	Normal	Normal
	$\alpha_o = 80$	No effect	No effect	Decreases	No effect	No effect
	$\alpha_o = 100$	No effect	No effect	Decreases	No effect	No effect
Decreasing $Q_{in}\left(\frac{m^3}{sec}\right)$	$Q_{gin} = 2.655$	Normal	Normal	Normal	Normal	Normal
	$Q_{gin} = 1.655$	No effect	No effect	No effect	Decreases	No effect
	$Q_{gin} = 1.3$	No effect	No effect	No effect	Decreases	No effect
	$Q_{win} = 0.0131$	Normal	Normal	Normal	Normal	Normal
	$Q_{win} = 0.0120$	Decreases	Small Decrease	No effect	No effect	Increases
	$Q_{win} = 0.0105$	Decreases	Small Decrease	No effect	No effect	Increases
	$Q_{oin} = 0.0044304$	Normal	Normal	Normal	Normal	Normal
	$Q_{oin} = 0.0034304$	No effect	Decreases	Decreases	No effect	Increases
	$Q_{oin} = 0.0024304$	No effect	Decreases	Decreases	No effect	Increases

By changing the inputs $\alpha_g, \alpha_w, \alpha_o, Q_{gin}, Q_{win}, Q_{oin}$, the Pressures $P_{win}, P_{wout}, P_{oin}, P_{oout}, P_{gin}, P_{gout}$ were also changed.

P_{win} is the Pressure of water inside the separator going to the valve.

P_{wout} is the Pressure of water going out from the valve.

P_{oin} is the Pressure of Oil inside the separator going to the valve.

P_{oout} is the Pressure of Oil going out from the valve.

P_{gin} is the Pressure of Gas inside the separator going to the valve.
P_{gout} is the Pressure of Gas going out from the valve.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

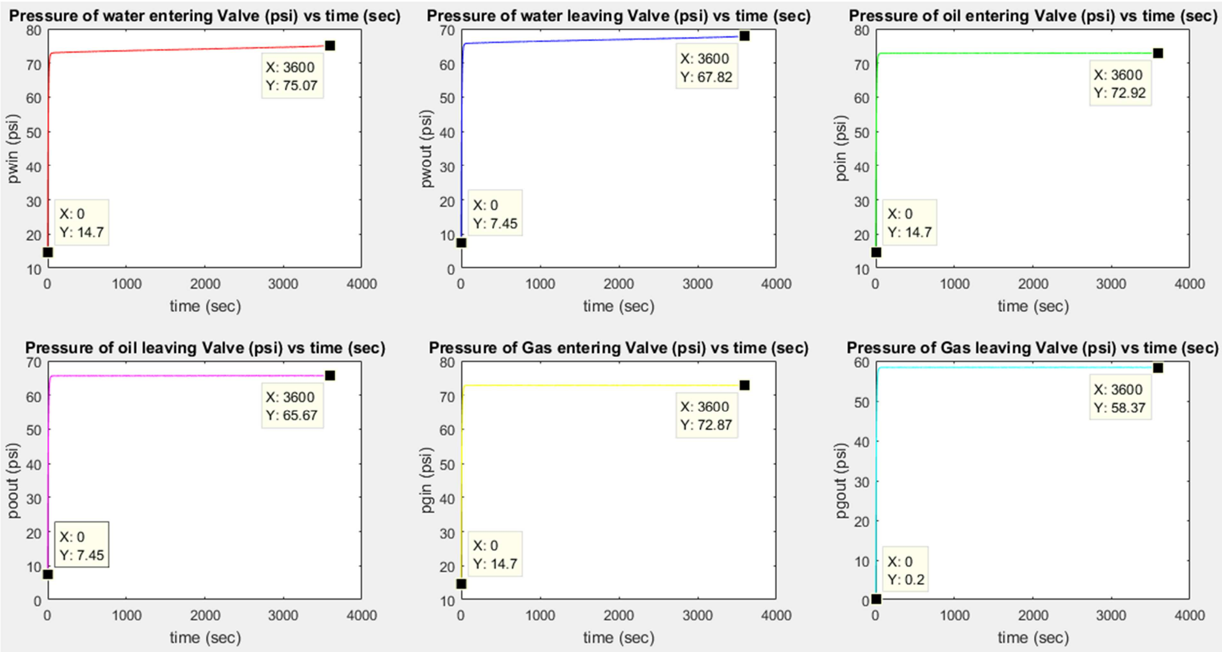

***Figure 11.** The system is operating normally.*

$$\alpha_g = 80, \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

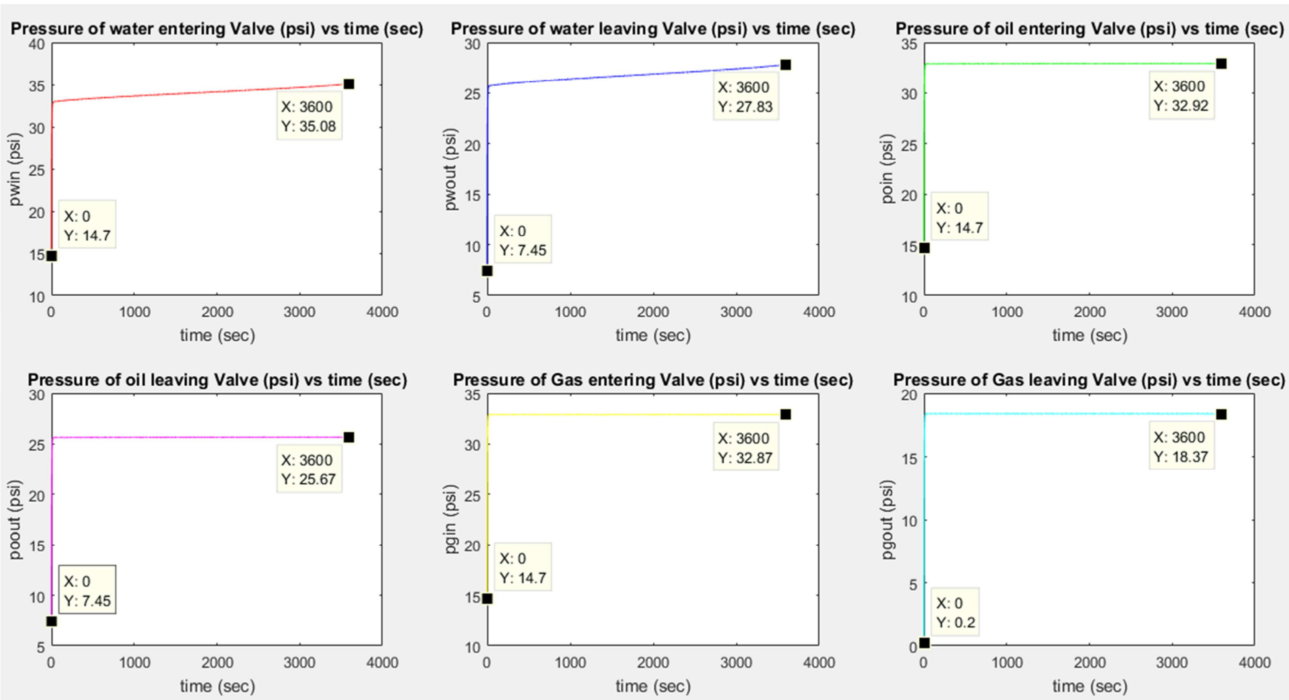

***Figure 12.** Control valve's stem position of Gas was increased.*

Increasing α_g will affect all pressures to decrease (in and out of the valves), hence maintaining all system at low pressures which are not dangerous.

$$\alpha_w = 80, \alpha_g = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

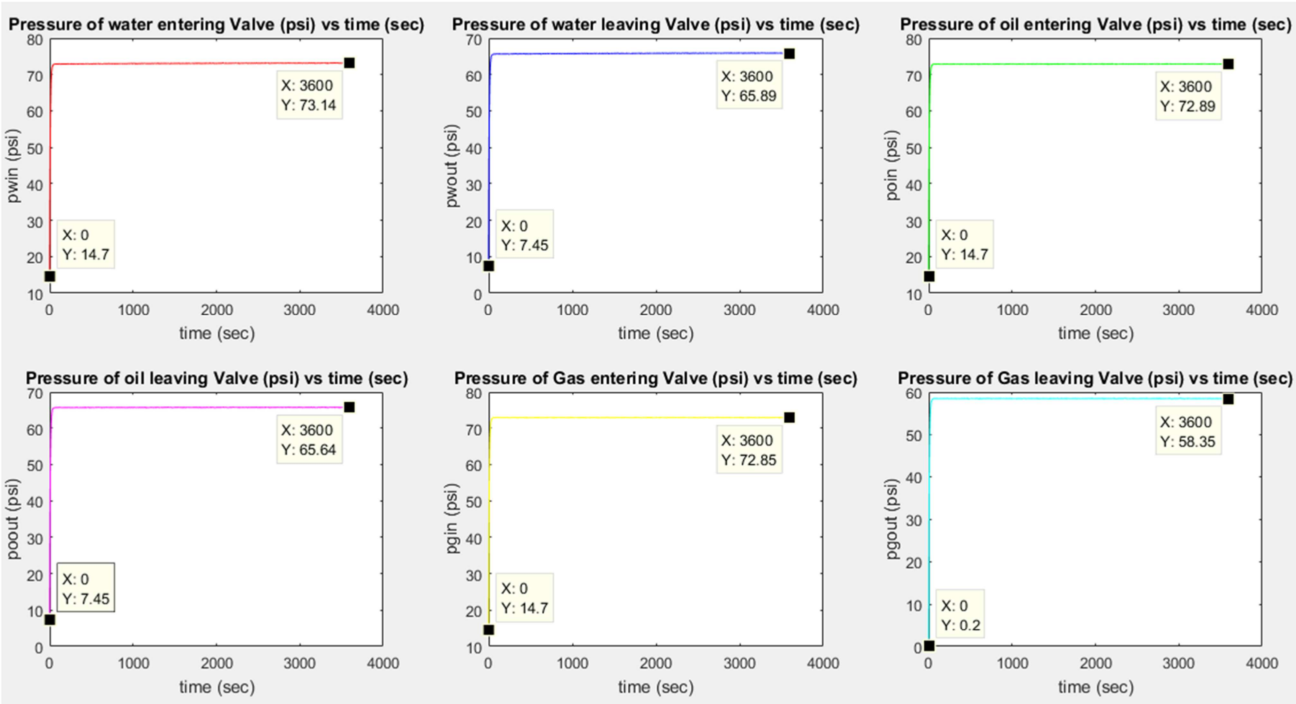

Figure 13. *Control valve's stem position of Water was increased.*

Increasing α_w will decrease the flowrate of water inside which means decreasing the pressures of water, hence P_{win} and P_{wout} are decreased but Oil and Gas Pressures will have a small increase, hence P_{oin}, P_{oout}, P_{gin}, and P_{gout} will have a small increase.

$$\alpha_o = 80, \alpha_w = \alpha_g = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

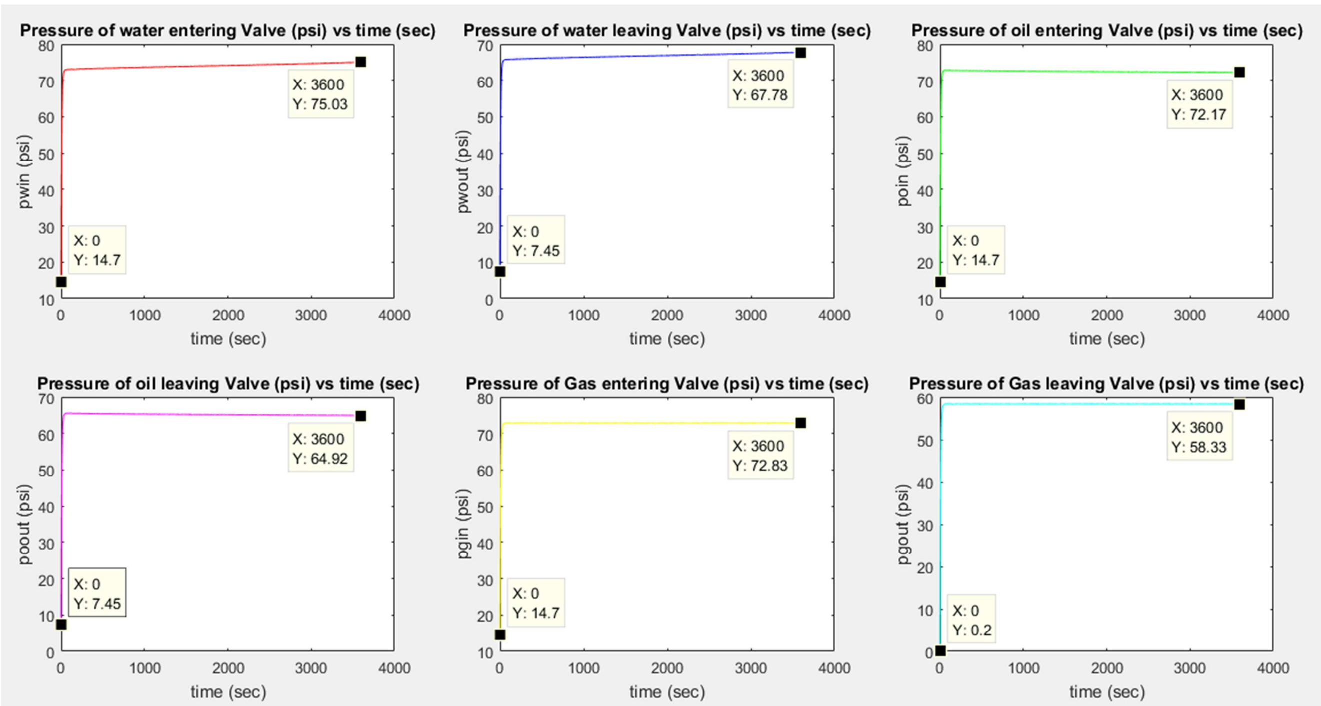

Figure 14. *Control valve's stem position of Oil was increased.*

Increasing α_o will not affect the Pressures of water and Gas (in and out of the valves) but will decrease the flowrate of Oil in the right chamber, hence decreasing the pressures of oil that is why P_{oin} and P_{oout} are decreased.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 1.655\frac{m^3}{sec}, Q_{win} = 0.0131\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

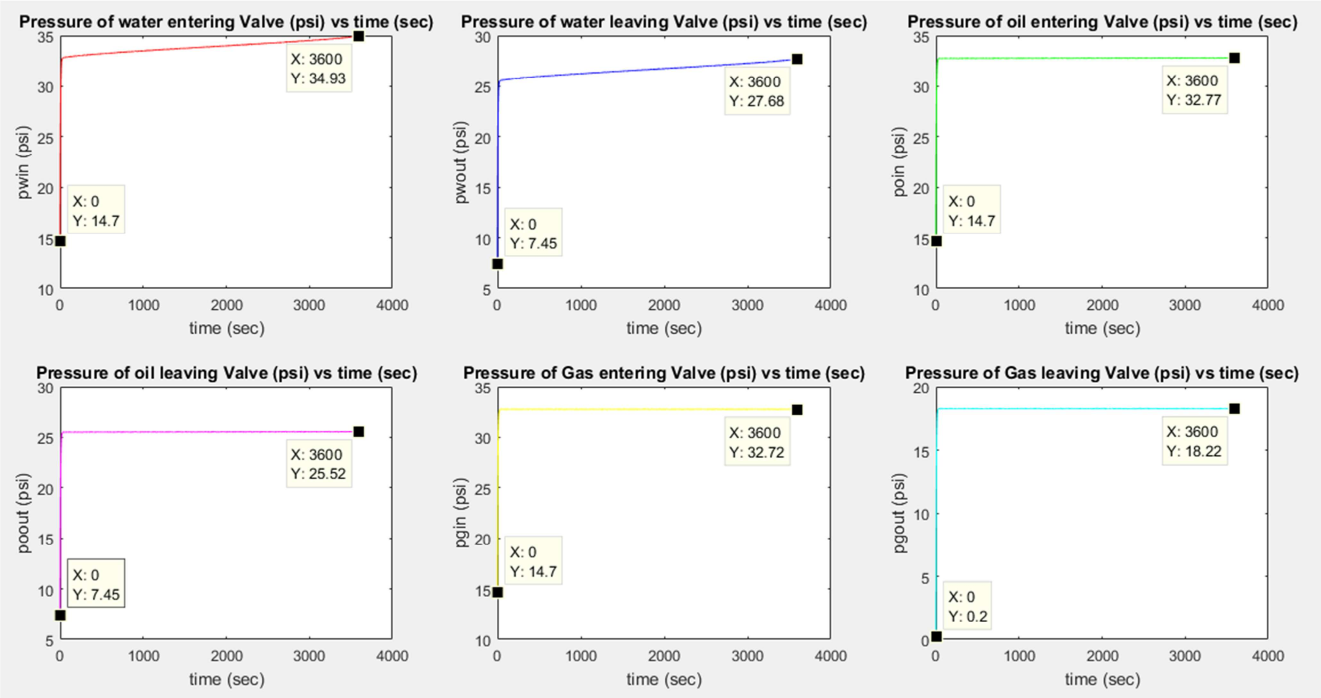

Figure 15. *Inlet volumetric rate of Gas was decreased.*

Decreasing Q_{gin} means decreasing the natural gas inlet volumetric rate entering to the separator which means decreasing the natural gas volumetric rate inside the separator which will be going out of the separator to the valve and this will affect all pressures to decrease (in and out of the valves), hence maintaining all system at low pressures which are not dangerous.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\frac{m^3}{sec}, Q_{win} = 0.0120\frac{m^3}{sec}, Q_{oin} = 0.0044304\frac{m^3}{sec}$$

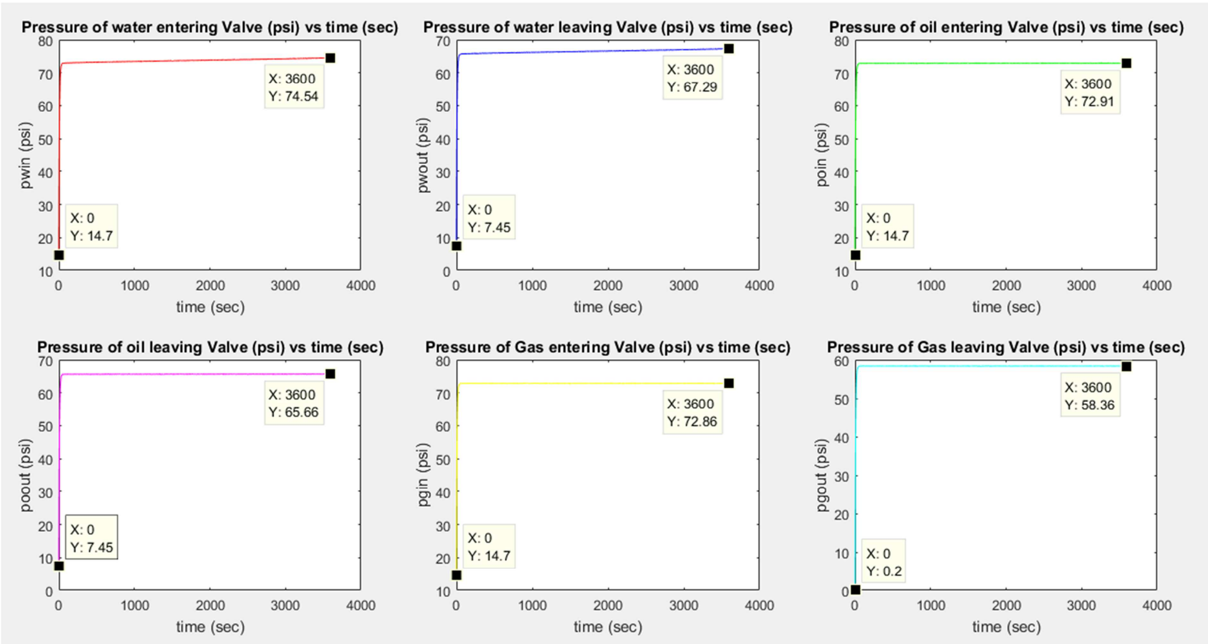

Figure 16. *Inlet volumetric rate of Water was decreased.*

Decreasing Q_{win} means decreasing the water inlet volumetric rate entering to the separator which means decreasing the water volumetric rate inside the separator which will be going out of the separator to the valve and this will not affect the Pressures of Oil and Gas, hence P_{oin}, P_{oout}, P_{gin}, and P_{gout} will not be effected but decreasing the water volumetric flowrate means decreasing the Pressures of water (in and out of the valve), hence P_{win} and P_{wout} are decreased.

$$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\,\frac{m^3}{sec}, Q_{win} = 0.0131\,\frac{m^3}{sec}, Q_{oin} = 0.0034304\,\frac{m^3}{sec}$$

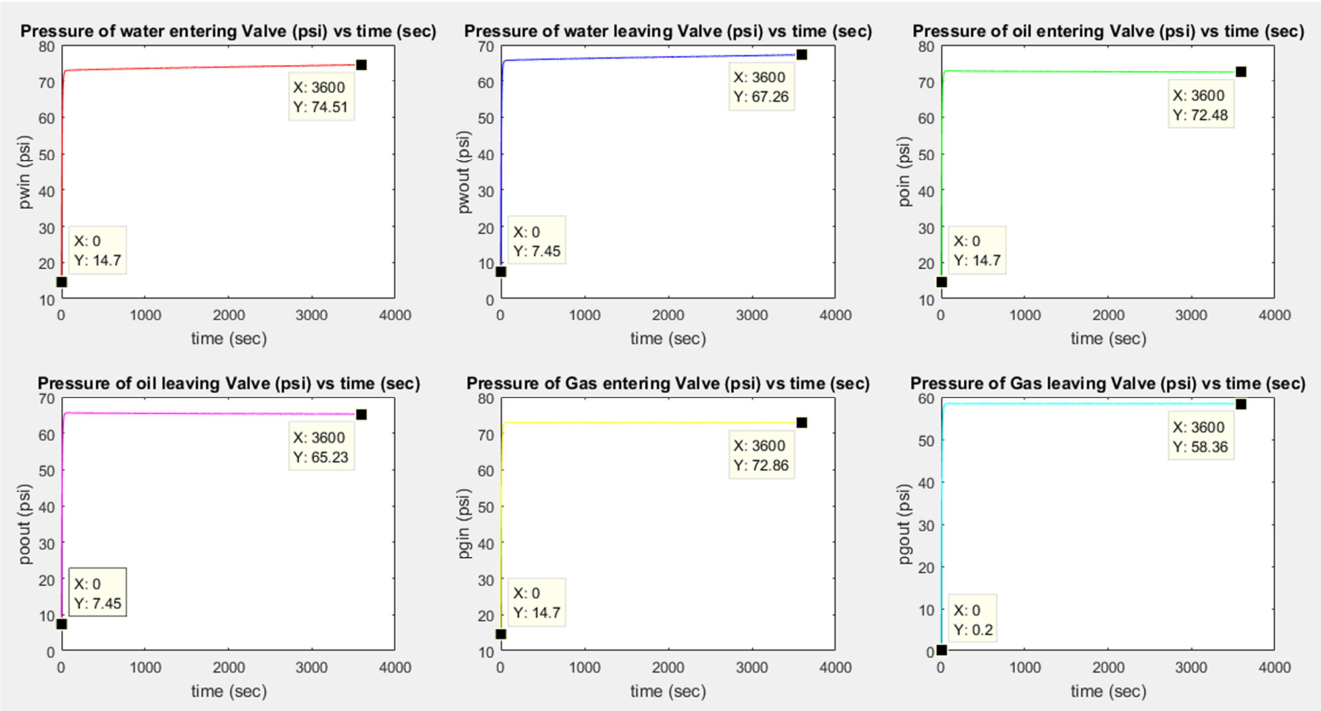

Figure 17. *Inlet volumetric rate of Oil was decreased.*

Decreasing Q_{oin} means decreasing the oil inlet volumetric rate entering to the separator which means decreasing the oil volumetric rate inside the separator which will be going out of the separator to the valve and this will affect the Pressures of Oil in the right chamber (in and out of the valve) to be decreased and the Pressures of water (in and out of the valve) to be also decreased but the Pressures of Gas (in and out of the valve) will have a small increase, hence P_{oin}, P_{oout}, P_{win}, and P_{wout} will be decreased while P_{gin} and P_{gout} will have a small increase.

It was noticed that $\Delta P = 7.25$ psi $= P_{win} - P_{wout} = P_{oin} - P_{oout}$ and $P_{gin} - P_{gout} = 14.5$ psi in which the system always keeps them constant.

Table 2. *Discussion summary on the Results of the Modeling and Simulation using Matlab.*

Compared to $\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\,\frac{m^3}{sec}, Q_{win} = 0.0131\,\frac{m^3}{sec}, Q_{oin} = 0.0044304\,\frac{m^3}{sec}$ (Normal)							
In t = 3600 sec		**P_{win}(psia)**	**P_{wout}(psia)**	**P_{oin}(psia)**	**P_{oout}(psia)**	**P_{gin}(psia)**	**P_{gout}(psia)**
Increasing α	$\alpha_g = 50$	Normal	Normal	Normal	Normal	Normal	Normal
	$\alpha_g = 80$	Decreases	Decreases	Decreases	Decreases	Decreases	Decreases
	$\alpha_g = 100$	Decreases	Decreases	Decreases	Decreases	Decreases	Decreases
	$\alpha_w = 50$	Normal	Normal	Normal	Normal	Normal	Normal
	$\alpha_w = 80$	Decreases	Decreases	Small Increase	Small Increase	Small Increase	Small Increase
	$\alpha_w = 100$	Decreases	Decreases	Small Increase	Small Increase	Small Increase	Small Increase
	$\alpha_o = 50$	Normal	Normal	Normal	Normal	Normal	Normal
	$\alpha_o = 80$	No effect	No effect	Decreases	Decreases	No effect	No effect
	$\alpha_o = 100$	No effect	No effect	Decreases	Decreases	No effect	No effect
Decreasing $Q_{in}\left(\frac{m^3}{sec}\right)$	$Q_{gin} = 2.655$	Normal	Normal	Normal	Normal	Normal	Normal
	$Q_{gin} = 1.655$	Decreases	Decreases	Decreases	Decreases	Decreases	Decreases
	$Q_{gin} = 1.3$	Decreases	Decreases	Decreases	Decreases	Decreases	Decreases
	$Q_{win} = 0.0131$	Normal	Normal	Normal	Normal	Normal	Normal
	$Q_{win} = 0.0120$	Decreases	Decreases	No effect	No effect	No effect	No effect
	$Q_{win} = 0.0105$	Decreases	Decreases	No effect	No effect	No effect	No effect
	$Q_{oin} = 0.0044304$	Normal	Normal	Normal	Normal	Normal	Normal
	$Q_{oin} = 0.0034304$	Decreases	Decreases	Decreases	Decreases	Small Increase	Small Increase
	$Q_{oin} = 0.0024304$	Decreases	Decreases	Decreases	Decreases	Small Increase	Small Increase

As a result, this Scientific Research Paper solved those complicated equations in the Crude Oil Separation Process and then monitored the whole separation process. By seeing the effect of changing the variables, new monitoring will be there from the system; thus, putting a point of interest in the separation, assuming the point of interest is to extract Natural Gas more than Crude Oil, the Optimal conditions can be determined using this study. This paper can be compared to the work done by Ref. No: [9] in that those authors did not solve the obtained differential equations and did not go further in Aspen Hysys Modeling and Simulation, whereas this paper provides everything related to a three-phase gravity separator, including changing of variables and observing the effect on the system when those variables were modified.

3.2. Modeling and Simulation Using Aspen Hysys

Inputs:

Use Peng-Robinson, $m^{\circ} = 13.1 + 3.5 + 7.3 = 23.9\ \frac{Kg}{sec}$, $P_{oin} = 72.92$ psia, $T_{Gas} = 288.15$ K, D = 2 m, L = 6.1 m.

Heater: 0.5 vapor fraction, neglect pressure drop i.e., it is 72.92 psia.

Valve: $\Delta P = 7.25$ psi

Table 3. *Inputs of Composition of sweet crude oil.*

(In mole fraction)	
Nitrogen	0.0003
H_2S	0
CO_2	0.0068
H_2O	0.3018
Methane	0.0875
Ethane	0.0376
Propane	0.0398
i-Butane	0.0126
n-Butane	0.0265
i-Pentane	0.0163
n-Pentane	0.0218
KC6	0.0429
KC7	0.0579
KC8	0.0399
KC9	0.0367
KC10	0.0342
KC11	0.0245
C12+	0.213

Table 4. *Inputs of Hypo-Components.*

Component name	T_c (0C)	P_c (barg)	V_c (m^3/Kg mole)	W	Liquid Density (Kg/m^3)	Molecular Weight	Boiling Point (0C)
KC6	234.65	32.82	0.35	0.271	689.9997	84	63.9
KC7	269.05	31.51	0.387	0.31	727	96	91.9
KC8	297.45	29.51	0.431	0.349	749	107	116.7
KC9	325.15	27.37	0.481	0.392	768	121	142.2
KC10	349.05	25.3	0.537	0.437	782	134	165.8
KC11	370.15	23.51	0.587	0.479	793	147	187.2
C12+	627.31	9.95	1.6455	0.9071	921	408	463.15

W stands for acentric factor and KC_6 means K-value of C_6 because it is a Hypothetical component.

The inputs show an example of a sweet crude oil with large amount of water and heavy hydrocarbons with some hydrocarbons which are hypothetical having special properties.

Outputs:

The outputs show the whole separation process Flowsheet with the material streams, energy streams, and Compositions.

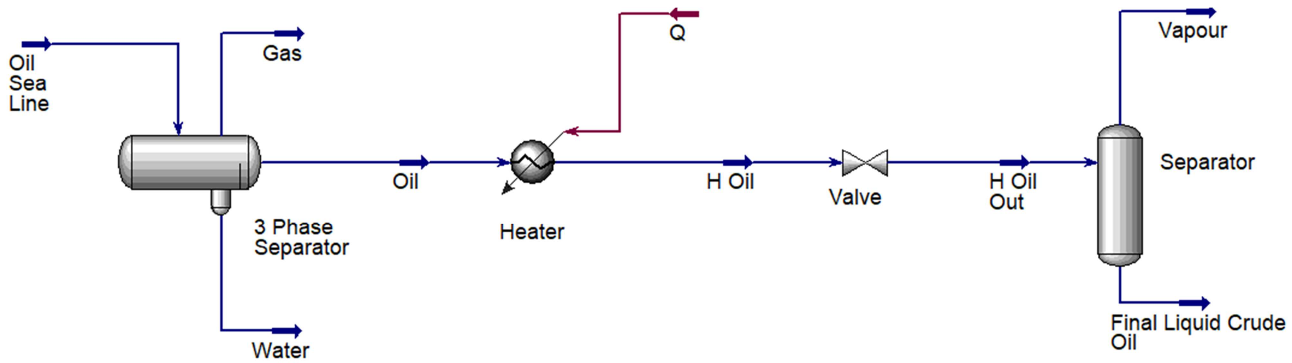

Figure 18. *The whole separation process Flowsheet.*

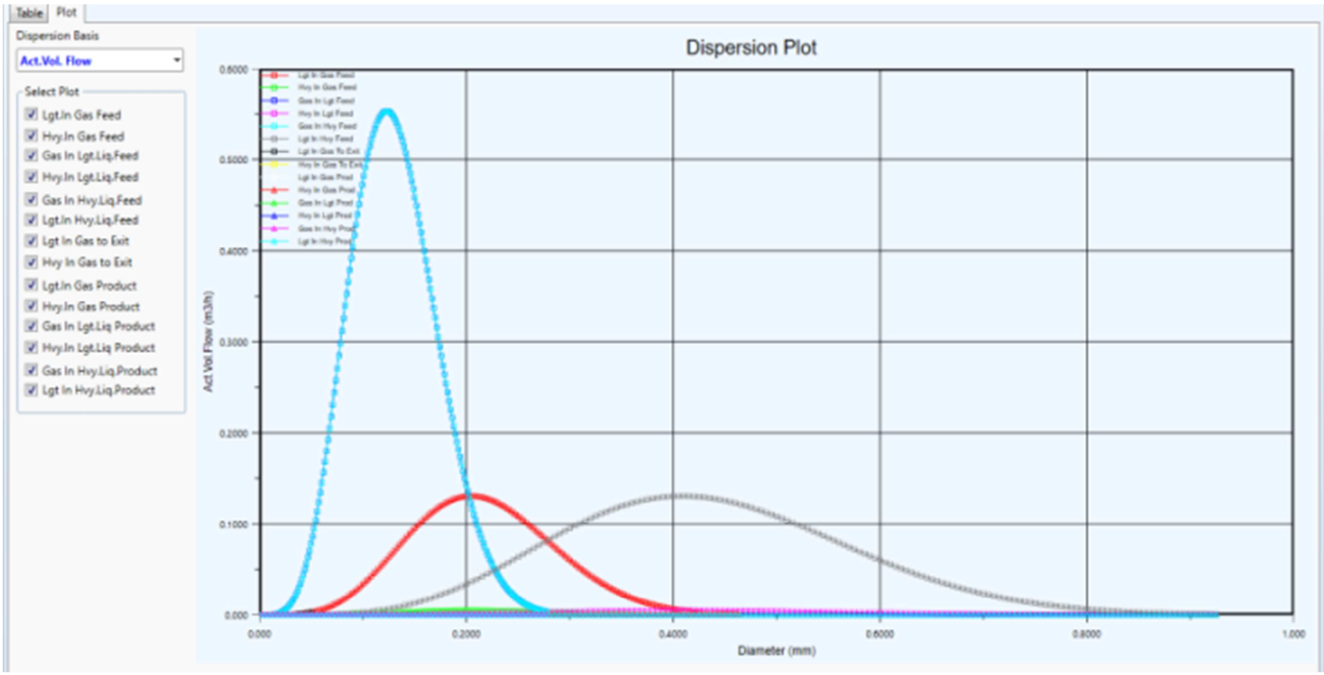

Figure 19. *Dispersion Plot.*

Carry over dispersion results plot was made which shows the dispersion of all components within the crude oil (like Gas in heavy liquid product and many more), so it is an important plot happening in real time process of the crude oil.

Table 5. *Material Streams.*

Material Streams Fluid Pkg: All						
Name		**Oil Sea Line**	**Gas**	**Oil**	**Water**	**H Oil**
Vapour Fraction		0.1260	1.0000	0.0000	0.0000	0.5000 *
Temperature	(C)	15.00	15.00 *	15.00	15.00	252.0
Pressure	(kPa)	502.8	502.8	502.8 *	502.8	502.8 *
Molar Flow	(kgmole/h)	672.2	84.72	385.0	202.5	385.0
Mass Flow	(kg/h)	8.604e+004 *	2113	8.028e+004	3648	8.028e+004
Liquid Volume Flow	(m^3/h)	103.9	5.512	94.73	3.656	94.73
Heat Flow	(kJ/h)	-2.411e+008	-8.145e+006	-1.749e+008	-5.811e+007	-1.269e+008

Name		**H Oil Out**	**Vapour**	**Final Liquid Crude Oil**
Vapour Fraction		0.5121	1.0000	0.0000
Temperature	(C)	251.5	251.5	251.5
Pressure	(kPa)	452.8	452.8	452.8
Molar Flow	(kgmole/h)	385.0	197.1	187.8
Mass Flow	(kg/h)	8.028e+004	1.685e+004	6.343e+004
Liquid Volume Flow	(m^3/h)	94.73	24.62	70.12

In material streams table, the properties of every stream were shown. The Oil stream temperature was raised with a heater to give H Oil stream. The H Oil stream contains vapour and liquid. The H Oil stream pressure was decreased with a valve to give H Oil Out stream. The H Oil Out stream contains vapour and liquid.

Table 6. *Energy Streams.*

Energy Streams Fluid Pkg: All	
Name	**Q**
Heat Flow (kJ/h)	4.795e+007

In energy streams table, the input to the heater Q was known.

Table 7. *Compositions.*

Compositions Fluid Pkg: All								
Name	**Oil Sea Line**	**Gas**	**Oil**	**Water**	**H Oil**	**H Oil Out**	**Vapour**	**Final Liquid Crude Oil**
Comp Mole Frac (Nitrogen)	0.0003 *	0.0023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (H2S)	0.0000 *	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0068 *	0.0387	0.0033	0.0001	0.0033	0.0033	0.0063	0.0001
Comp Mole Frac (H2O)	0.3018 *	0.0034	0.0003	0.9999	0.0003	0.0003	0.0005	0.0000
Comp Mole Frac (Methane)	0.0875 *	0.6248	0.0153	0.0000	0.0153	0.0153	0.0294	0.0004
Comp Mole Frac (Ethane)	0.0376 *	0.1839	0.0252	0.0000	0.0252	0.0252	0.0480	0.0012
Comp Mole Frac (Propane)	0.0398 *	0.0950	0.0486	0.0000	0.0486	0.0486	0.0914	0.0037
Comp Mole Frac (i-Butane)	0.0126 *	0.0137	0.0190	0.0000	0.0190	0.0190	0.0351	0.0020
Comp Mole Frac (n-Butane)	0.0265 *	0.0214	0.0415	0.0000	0.0415	0.0415	0.0764	0.0049
Comp Mole Frac (i-Pentane)	0.0163 *	0.0052	0.0273	0.0000	0.0273	0.0273	0.0489	0.0046
Comp Mole Frac (n-Pentane)	0.0218 *	0.0052	0.0369	0.0000	0.0369	0.0369	0.0658	0.0066
Comp Mole Frac (KC6*)	0.0429 *	0.0039	0.0740	0.0000	0.0740	0.0740	0.1269	0.0185
Comp Mole Frac (KC7*)	0.0579 *	0.0018	0.1007	0.0000	0.1007	0.1007	0.1635	0.0347
Comp Mole Frac (KC8*)	0.0399 *	0.0004	0.0696	0.0000	0.0696	0.0696	0.1052	0.0322
Comp Mole Frac (KC9*)	0.0367 *	0.0001	0.0640	0.0000	0.0640	0.0640	0.0872	0.0398
Comp Mole Frac (KC10*)	0.0342 *	0.0000	0.0597	0.0000	0.0597	0.0597	0.0710	0.0479
Comp Mole Frac (KC11*)	0.0245 *	0.0000	0.0428	0.0000	0.0428	0.0428	0.0432	0.0424
Comp Mole Frac (C12+*)	0.2130 *	0.0000	0.3719	0.0000	0.3719	0.3719	0.0012	0.7609

In Compositions table, the Gas outlet stream from the 3 phase separator contains high mole fractions of light hydrocarbons with methane the largest mole fraction. The Water outlet stream from the 3 phase separator contains only water. The Vapour stream from the Separator contains light and heavy hydrocarbons Vapour. The Final Liquid Crude Oil stream from the Separator which is liquid contains C12+ as the largest mole fraction.

4. Conclusions

Using Matlab, this article discovered that increasing the control valve stem position and decreasing the inflow volumetric flowrate of both oil and water was extremely dangerous and caused significant variations in system heights and pressures. The Aspen Hysys analysis optimally separates oil, gas, and water to determine material, energy streams properties, and compositions. As a result, this complex dynamic behaviour was observed, and no additional articles addressing this topic were found. This process monitoring will determine the best conditions for flawless separation, with the primary goal of selecting the desired product or products.

This Study can be applied to verify the theoretical investigations.

This Scientific Paper shows many interactions which are too difficult, hence further studies and the next phase for this work must include Control for such a process [10, 13, 15, 16].

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