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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, and simulation. Understanding its dynamic behavior 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. As a result, this Research Paper is unique and novel, and it can be compared to the work done by some authors who 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 separator, including changing of variables and observing the effect on the system when those variables were modified. Furthermore, separators are designed with internal baffles to promote laminar flow and increase separator efficiency. However, it has been assumed that there are no baffles here, which is a significant problem, but with the help of these equations, the horizontal three-phase gravity separator can be operated at its maximum efficiency. 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 (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 behavior 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.

Key words: Modeling and Simulation, Matlab, Aspen Hysys, three-phase gravity separator

I. INTRODUCTION

Three-phase gravity separators are an essential component of the petroleum industry’s manufacturing process [1]. 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 [2]. 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. There are, however, very few papers about their dynamics, modelling, and simulation. Here are a few examples of such publications: Grodal et al., Optimal design of two- and three-phase separators: A mathematical programming formulation Monnery et al. successfully specify three-phase separators. Chemical Engineering Progress Al-Hatmi et al. 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 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 separator, including adjusting variables and observing the effect on the system when those variables were modified [3]. 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 behavior 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.
A. How does a Horizontal Three-Phase Separator Work?

Fluid enters the vessel through an entrance and is diverted instantly by an intake diverter in a horizontal three-phase separator [4], [5]. This abrupt impact separates the liquid and vapor and starts the gas-oil separation process [6]. 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.

II. Methodology

The assumptions [1] [7] [8] [9] [10] 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, modeling and simulation using Aspen Hysys V10 was performed, and the results were obtained, along with discussions that described the entire process. The Top 50 Oil & Gas Companies in the World (2021 Ranking) was displayed. Following that, the Conclusions and Acknowledgment were written down. In addition, the references utilized were displayed.

A. Assumptions

• The separator has a constant operating temperature. As a result, temperature effects are unnecessary, and constant liquid densities can be assumed further.
• 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.
• Only the suitable flow streams allow liquids to enter and exit the tank (i.e. no evaporation).
• 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.

B. 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 [11] [12] [13] [14]. According to 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:

\[ Q_\text{in} = \frac{d}{dt} \left( \frac{\pi H^2}{2} + \frac{\pi H D}{2} + \left[ l_s \left( \pi r^2 A_{\text{in}} \right) + (H_s - r) \sqrt{H_s (2H_s - r)} \right] \right) \]

\[ \times \frac{\alpha_m}{100} \times C_{\text{sw}} \times 6.309 \times 10^5 \sqrt{\frac{\rho \phi H_r + \rho \phi H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) - P_{\text{out}} \]

\[ \frac{d}{dt} \left( \frac{H^2}{2} \right) = \frac{\pi}{2} \frac{H^2}{D} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( \frac{H D}{2} \right) = \frac{\pi}{2} \frac{H D}{D} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( l_s \left( \pi r^2 A_{\text{in}} \right) \right) = \frac{\pi}{2} \frac{l_s \left( \pi r^2 A_{\text{in}} \right)}{H_s} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( (H_s - r) \sqrt{H_s (2H_s - r)} \right) = \frac{\pi}{2} \frac{(H_s - r) \sqrt{H_s (2H_s - r)}}{H_s} \frac{dH_s}{dt} \]

Left oil sub-system:

\[ Q_{\text{in}} = \frac{d}{dt} \left( \frac{\pi H^2}{2} + \frac{\pi H D}{2} + l_s \left( \pi r^2 A_{\text{in}} \right) + (H_s - r) \sqrt{H_s (2H_s - r)} \right) \times \frac{\alpha_m}{100} \times C_{\text{sw}} \times 6.309 \times 10^5 \sqrt{\frac{\rho \phi H_r + \rho \phi H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) - P_{\text{out}} \]

Right oil sub-system:

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

\[ Q_{\text{in}} = \frac{d}{dt} \left( \frac{\pi H^2}{2} + \frac{\pi H D}{2} + l_s \left( \pi r^2 A_{\text{in}} \right) + (H_s - r) \sqrt{H_s (2H_s - r)} \right) \times \frac{\alpha_m}{100} \times C_{\text{sw}} \times 6.309 \times 10^5 \sqrt{\frac{\rho \phi H_r + \rho \phi H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) - P_{\text{out}} \]

Gas sub-system:

\[ \rho g \left( \frac{Q_{\text{in}}}{Q_{\text{in}}} \right) = 6894.757 \times M_{\text{atf}} \times \frac{dP_t}{dt} \div \frac{\rho}{\rho_{\text{atf}}} \times 1000 \times R \times T_k \times \frac{m}{V_G} \times \frac{p^2}{q^2} \times \frac{\sqrt{\frac{\rho g H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right)}{p_r \times T_r} \times \frac{p_r \times T_r}{\rho g H_s} \]

\[ \frac{\rho g \left( \frac{Q_{\text{in}}}{Q_{\text{in}}} \right)}{\frac{\rho g H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) = 962 \times \frac{\rho g \left( \frac{Q_{\text{in}}}{Q_{\text{in}}} \right)}{\frac{\rho g H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) \]

Substitute \( \frac{dH_s}{dt} \):

\[ Q_{\text{in}} = \frac{d}{dt} \left( \frac{\pi H^2}{2} + \frac{\pi H D}{2} + l_s \left( \pi r^2 A_{\text{in}} \right) + (H_s - r) \sqrt{H_s (2H_s - r)} \right) \times \frac{\alpha_m}{100} \times C_{\text{sw}} \times 6.309 \times 10^5 \sqrt{\frac{\rho \phi H_r + \rho \phi H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) - P_{\text{out}} \]

\[ \frac{\rho g \left( \frac{Q_{\text{in}}}{Q_{\text{in}}} \right)}{\frac{\rho g H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) = 962 \times \frac{\rho g \left( \frac{Q_{\text{in}}}{Q_{\text{in}}} \right)}{\frac{\rho g H_s}{S G_{\text{sw}}}} \times \left( 1.45 \times 10^{-4} + P_r \right) \]

Left oil sub-system:

\[ \frac{d}{dt} \left( \frac{\pi H^2}{2} \right) = \frac{\pi}{2} \frac{H^2}{D} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( \frac{H D}{2} \right) = \frac{\pi}{2} \frac{H D}{D} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( l_s \left( \pi r^2 A_{\text{in}} \right) \right) = \frac{\pi}{2} \frac{l_s \left( \pi r^2 A_{\text{in}} \right)}{H_s} \frac{dH_s}{dt} \]

\[ \frac{d}{dt} \left( (H_s - r) \sqrt{H_s (2H_s - r)} \right) = \frac{\pi}{2} \frac{(H_s - r) \sqrt{H_s (2H_s - r)}}{H_s} \frac{dH_s}{dt} \]

is no \( \frac{d}{dt} \) term since \( f \) itself does not depend on dependent variable \( t \) directly.
Gas sub-system: Case 1:

\[
\rho_{gin} Q_{gin} = \frac{M_{ut} \rho_{gin}}{1000 \times R \times T_{K}} \frac{d(P_{gin} V_{g})}{dt} + (8)
\]

\[
\frac{m}{V_{g}} \left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right]
\]

\[
P_{g}(p_{gin} V_{g}) = nRT_{K}
\]

\[
\rho_{gin} Q_{gin} = \frac{M_{ut} \rho_{gin}}{1000 \times R \times T_{K}} \frac{d(nRT_{K})}{dt} +
\]

\[
\frac{m}{V_{g}} \left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right]
\]

\[
r_{gin} Q_{gin} = \frac{M_{ut} \rho_{gin}}{1000 \times R \times T_{K}} \frac{d(nRT_{K})}{dt} +
\]

\[
\frac{m}{V_{g}} \left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right]
\]

\[
r_{gin} Q_{gin} = 0+
\]

\[
r_{gin} Q_{gin} = \frac{M_{ut} \rho_{gin}}{1000 \times R \times T_{K}} \frac{d(nRT_{K})}{dt} +
\]

\[
\frac{m}{V_{g}} \left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right]
\]

\[
\frac{m}{V_{g}} = \frac{P_{g}(p_{gin} V_{g}) M_{ut}}{1000 \times R \times T_{K}} = \frac{P_{g} V_{g} M_{ut} \times 6894.757}{1000 \times R \times T_{K}}
\]

\[
r_{gin} Q_{gin} = \frac{P_{g} V_{g} M_{ut} \times 6894.757}{1000 \times R \times T_{K}}
\]

\[
\left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right]
\]

\[
(\rho_{gin} Q_{gin}) - (\frac{P_{g} M_{ut} \times 6894.757}{1000 \times R \times T_{K}})
\]

\[
\left[ 962 \times \frac{\alpha_{g}}{1000} \times 7.866 \times 10^{-6} \times C_{vg} \times \frac{P_{gin} - P_{g} \rho_{gin}}{\sqrt{2} \rho_{gin} V_{g} \times P_{g} T_{g} / R_{g}} \right] = 0
\]

C. Solving the unsolved equations yielding Bishoy’s equations [15]

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 the Matlab scripts developed.

III. RESULTS AND DISCUSSION

A. Modeling and Simulation using Matlab

By changing the inputs \(\alpha_{w}, \alpha_{g}, \alpha_{o}, Q_{win}, Q_{oin}\) the outputs \(H_{w}, H_{our}, P_{g}, H_{g}\) were also changed.

\[
\alpha_{g} = \alpha_{w} = \alpha_{o} = 50, Q_{gin} = 2.655 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0131 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0044304 \text{ m}^{3} / \text{sec}
\]

Fig. 4. The system is operating normally

50, \(Q_{gin} = 2.655 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0131 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0044304 \text{ m}^{3} / \text{sec}\) Increasing \(\alpha_{g}\) will not affect the heights but will decrease the pressure inside.

\(\alpha_{w} = 80, \alpha_{g} = \alpha_{o} = 50, Q_{gin} = 2.655 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0131 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0044304 \text{ m}^{3} / \text{sec}\) Increasing \(\alpha_{w}\) will not affect right chamber \((H_{our})\) and will not affect but \(H_{w}\) will begin decreasing, hence \(H_{w}\) will decrease by a small amount,hence making \(H_{g}\) to increase but keeping \(P_{g}\) constant with no effect on it.

\(\alpha_{o} = 80, \alpha_{w} = \alpha_{g} = 50, Q_{gin} = 2.655 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0131 \text{ m}^{3} / \text{sec}, Q_{gin} = 0.0044304 \text{ m}^{3} / \text{sec}\) Increasing \(\alpha_{o}\) will not affect left chamber \((H_{w})\) and \((H_{o})\),hence no effect on and \((H_{o})\)

Fig. 5. Control valve’s stem position of Gas was increased.

The preceding equations Eq. (II-B, II-B, II-B, II-B, II-B) were called Bishoy’s equations, which were implicit and difficult to solve. They were solved using the Matlab scripts developed.
right chamber \((H_{out})\) 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.

\[ \alpha_g = \alpha_w = \alpha_g = 50, Q_{gin} = 2.655 \text{m}^3/\text{sec}, Q_{gin} = 0.0131 \text{m}^3/\text{sec}, Q_{gin} = 0.0044304 \text{m}^3/\text{sec} \]

Decreasing \(Q_{win}\) 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 \(onH_g\) which will increase but keeping the pressure constant (no effect on \(P_g\)) but of course right chamber is effected and \((H_{our})\) begin decreasing since was decreased. By changing the inputs \(\alpha_g, \alpha_w, Q_{gin}, Q_{win}, Q_{oin}\), the Pressures \(P_{win}, P_{wout}, P_{oin}, P_{gin}, P_{gout}\) were also changed.

\(P_{win}\) is the Pressure of water going out from the valve.

\(P_{wout}\) is the Pressure of Oil inside the separator going to the valve.

\(P_{oin}\) is the Pressure of Oil going out from the valve.

\(P_{gout}\) is the Pressure of Gas inside the separator going to the valve.

\(P_{gin}\) is the Pressure of Gas going out from the valve.

\[ \alpha_g = \alpha_w = \alpha_g = 50, Q_{gin} = 2.655 \text{m}^3/\text{sec}, Q_{gin} = 0.0131 \text{m}^3/\text{sec}, Q_{gin} = 0.0044304 \text{m}^3/\text{sec} \]

Increasing \((\alpha_g)\) will affect all pressures to decrease (in and out of the valves) hence maintaining all system at low pressures which are not dangerous.
TABLE I
DISCUSSION SUMMARY ON THE RESULTS OF THE MODELING AND SIMULATION USING MATLAB.

<table>
<thead>
<tr>
<th>Compared to $\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655, \text{m}^3\text{/sec}, Q_{win} = 0.0131, \text{m}^3\text{/sec}, Q_{win} = 0.0044304, \text{m}^3\text{/sec} (Normal)</th>
<th>$H_w(m)$</th>
<th>$H_o(m)$</th>
<th>$H_{out}(m)$</th>
<th>$p_g$(psia)</th>
<th>$H_g(m)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>In $t=3600, \text{ses}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_g = 50$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$\alpha_g = 80$</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>Decreases</td>
<td>No effect</td>
</tr>
<tr>
<td>$\alpha_g = 100$</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>Decreases</td>
<td>No effect</td>
</tr>
<tr>
<td>$\alpha_g = 50$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$\alpha_g = 80$</td>
<td>Decreases</td>
<td>Small Decrease</td>
<td>No effect</td>
<td>No effect</td>
<td>Increases</td>
</tr>
<tr>
<td>$\alpha_g = 100$</td>
<td>Decreases</td>
<td>Small Decrease</td>
<td>No effect</td>
<td>No effect</td>
<td>Increases</td>
</tr>
<tr>
<td>$\alpha_o = 50$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$\alpha_o = 80$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$\alpha_o = 100$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Decreases $Q_{in}(\text{m}^3\text{/sec})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{gin} = 2.655$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{gin} = 1.655$</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>Decreases</td>
<td>No effect</td>
</tr>
<tr>
<td>$Q_{gin} = 10.3$</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>Decreases</td>
<td>No effect</td>
</tr>
<tr>
<td>$Q_{win} = 0.0131$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{win} = 0.0131$</td>
<td>Decreases</td>
<td>Small Decrease</td>
<td>No effect</td>
<td>No effect</td>
<td>Increases</td>
</tr>
<tr>
<td>$Q_{win} = 0.0120$</td>
<td>Decreases</td>
<td>Small Decrease</td>
<td>No effect</td>
<td>No effect</td>
<td>Increases</td>
</tr>
<tr>
<td>$Q_{oin} = 0.0044304$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{oin} = 0.0044304$</td>
<td>No effect</td>
<td>Decreases</td>
<td>Decreases</td>
<td>No effect</td>
<td>Increases</td>
</tr>
<tr>
<td>$Q_{oin} = 0.0024304$</td>
<td>No effect</td>
<td>Decreases</td>
<td>Decreases</td>
<td>No effect</td>
<td>Increases</td>
</tr>
</tbody>
</table>

Fig. 11. The system is operating normally.

Fig. 12. Control valves stem position of Gas was increased.

Fig. 13. Control valves stem position of Water was increased.

Fig. 14. Control valves stem position of Oil was increased.

$\alpha_w = 80, \alpha_g = \alpha_o = 50, Q_{gin} = 2.655\, \text{m}^3\text{/sec}, Q_{gin} = 0.0131\, \text{m}^3\text{/sec}, Q_{win} = 0.0044304\, \text{m}^3\text{/sec}$. Increasing $\alpha_w$ 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 $P_{oin}, P_{out}$ and $P_{gin}$ and $P_{out}$ will have a small increase.

$\alpha_o = 80, \alpha_w = \alpha_g = 50, Q_{gin} = 2.655\, \text{m}^3\text{/sec}, Q_{gin} = 0.0131\, \text{m}^3\text{/sec}, Q_{win} = 0.0044304\, \text{m}^3\text{/sec}$. Increasing $\alpha_o$ 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 $P_{out}$ are decreased.

$\alpha_g = \alpha_w = \alpha_o = 50, Q_{gin} = 2.655\, \text{m}^3\text{/sec}, Q_{gin} = 0.0131\, \text{m}^3\text{/sec}, Q_{gin} = 0.0044304\, \text{m}^3\text{/sec}$.

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...
Fig. 15. Inlet volumetric rate of Gas was decreased.

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. 

\[ \alpha_w = \alpha_g \Rightarrow \alpha_g = 50, Q_{gin} = 2.655 \text{ m}^3/\text{sec}, Q_{gin} = 0.0131 \text{ m}^3/\text{sec} \]

Decreasing \( Q_{vin} \) 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 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 \( P_{gin}, P_{win} \), and \( P_{wout} \) will be decreased while \( P_{gin} \) and \( P_{gout} \) will have a small increase.

It was noticed that

\[ \Delta P = 7.25 \text{ psi} = P_{win} - P_{wout} = P_{gin} - P_{gout} \text{ that and } P_{gin} - P_{gout} = 1405 \text{ psi} \]

in which the system always keeps them constant. 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.

B. Modeling and Simulation using Aspen Hysys Inputs:

Inputs:

Use Peng-Robinson,

\[ m^\circ = 13.1 + 3.5 + 7.3 = 23.9 \text{ kg/m}^3 \]

\[ P_{vin} = 72.92 \text{ psia}, T_{Gas} = 288.15 \text{KD} = 2m, \ L = 6.1m \]

Heater: 0.5 vapor fraction, neglect pressure drop i.e., it is 72.92 \text{ psia} \n
Valve: \( \Delta P = 7.25 \text{ psi} \)

\( W \) stands for acentric factor and \( k_{c6} \) 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 out puts show the whole separation process Flowsheet with the material streams, energy streams, and Compositions.

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.

In material streams table, the properties of every stream were shown. The Oil stream temperature was raised with a
TABLE II
DISCUSSION SUMMARY ON THE RESULTS OF THE MODELING AND SIMULATION USING MATLAB

<table>
<thead>
<tr>
<th>Compared to</th>
<th>$P_{\text{win}}$ (psia)</th>
<th>$P_{\text{wout}}$ (psia)</th>
<th>$P_{\text{oin}}$ (psia)</th>
<th>$P_{\text{out}}$ (psia)</th>
<th>$P_{\text{gin}}$ (psia)</th>
<th>$P_{\text{gout}}$ (psia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_g = \alpha_w = \alpha_o = 50$, $Q_{\text{gin}} = 2.655 \frac{m^3}{sec}$, $Q_{\text{win}} = 0.0131 \frac{m^3}{sec}$, $Q_{\text{win}} = 0.0044304 \frac{m^3}{sec}$ (Normal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing $\alpha$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{\text{gin}} = 2.655$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
<tr>
<td>$Q_{\text{gin}} = 1.655$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
<tr>
<td>$Q_{\text{gin}} = 1.3$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
<tr>
<td>$Q_{\text{win}} = 0.0131$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{\text{win}} = 0.0120$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>$Q_{\text{win}} = 0.0105$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>$Q_{\text{oin}} = 0.0024304$</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>$Q_{\text{oin}} = 0.0044304$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
<tr>
<td>$Q_{\text{oin}} = 0.0024304$</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
</tbody>
</table>

TABLE III
INPUTS OF COMPOSITION OF SWEET CRUDE OIL.

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.0003</td>
</tr>
<tr>
<td>$H_2S$</td>
<td>0</td>
</tr>
<tr>
<td>$CO_2$</td>
<td>0.0068</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>0.3018</td>
</tr>
<tr>
<td>Methane</td>
<td>0.0875</td>
</tr>
<tr>
<td>Ethane</td>
<td>0.0376</td>
</tr>
<tr>
<td>Propane</td>
<td>0.0398</td>
</tr>
<tr>
<td>i-Butane</td>
<td>0.0126</td>
</tr>
<tr>
<td>n-Butane</td>
<td>0.0265</td>
</tr>
<tr>
<td>i-Pentane</td>
<td>0.0163</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>0.0218</td>
</tr>
<tr>
<td>KC6</td>
<td>0.0429</td>
</tr>
<tr>
<td>KC7</td>
<td>0.0579</td>
</tr>
<tr>
<td>KC8</td>
<td>0.0399</td>
</tr>
<tr>
<td>KC9</td>
<td>0.0367</td>
</tr>
<tr>
<td>KC10</td>
<td>0.0342</td>
</tr>
<tr>
<td>KC11</td>
<td>0.0245</td>
</tr>
<tr>
<td>C12+</td>
<td>0.213</td>
</tr>
</tbody>
</table>

Fig. 19. Dispersion Plot.

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.

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.

C. Oil & Gas Top 50 Companies in the world (2021 Ranking) [16]

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
TABLE IV

<table>
<thead>
<tr>
<th>Component name</th>
<th>Tc (°C)</th>
<th>Pc (barg)</th>
<th>Vc (m³/Kg mole)</th>
<th>W</th>
<th>Liquid Density (Kg/m³)</th>
<th>Molecular Weight</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC6</td>
<td>234.65</td>
<td>32.82</td>
<td>0.35</td>
<td>0.271</td>
<td>689.9997</td>
<td>84</td>
<td>63.9</td>
</tr>
<tr>
<td>KC7</td>
<td>269.05</td>
<td>31.51</td>
<td>0.387</td>
<td>0.31</td>
<td>727</td>
<td>96</td>
<td>91.9</td>
</tr>
<tr>
<td>KC8</td>
<td>297.45</td>
<td>29.51</td>
<td>0.431</td>
<td>0.349</td>
<td>749</td>
<td>107</td>
<td>116.7</td>
</tr>
<tr>
<td>KC9</td>
<td>325.15</td>
<td>27.37</td>
<td>0.481</td>
<td>0.392</td>
<td>768</td>
<td>121</td>
<td>142.2</td>
</tr>
<tr>
<td>KC10</td>
<td>349.05</td>
<td>25.3</td>
<td>0.537</td>
<td>0.437</td>
<td>782</td>
<td>134</td>
<td>165.8</td>
</tr>
<tr>
<td>KC11</td>
<td>370.15</td>
<td>23.51</td>
<td>0.587</td>
<td>0.479</td>
<td>793</td>
<td>147</td>
<td>187.2</td>
</tr>
<tr>
<td>C12+</td>
<td>627.31</td>
<td>9.95</td>
<td>1.6455</td>
<td>0.9071</td>
<td>921</td>
<td>408</td>
<td>463.15</td>
</tr>
</tbody>
</table>

TABLE V

Material Streams Fluid Pkg: All

<table>
<thead>
<tr>
<th>Name</th>
<th>Oil Sea Line</th>
<th>Gas</th>
<th>Oil</th>
<th>Water</th>
<th>H Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapour Fraction</td>
<td>0.1260</td>
<td>1.000</td>
<td>0.000</td>
<td>0.0000</td>
<td>0.5000</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>15.00</td>
<td>15.00 *</td>
<td>15.00</td>
<td>15.00</td>
<td>252.0</td>
</tr>
<tr>
<td>Pressure (kPa)</td>
<td>502.8</td>
<td>502.8</td>
<td>502.8 *</td>
<td>502.8</td>
<td>502.8</td>
</tr>
<tr>
<td>Molar Flow (kg/mole/h)</td>
<td>672.2</td>
<td>84.72</td>
<td>8.028e+004</td>
<td>8.028e+004</td>
<td>3648</td>
</tr>
<tr>
<td>Mass Flow (kg/h)</td>
<td>8.028e+004</td>
<td>8.028e+004</td>
<td>8.028e+004</td>
<td>8.028e+004</td>
<td>8.028e+004</td>
</tr>
<tr>
<td>Liquid Volume Flow (m³/h)</td>
<td>103.9</td>
<td>94.73</td>
<td>70.12</td>
<td>70.12</td>
<td>70.12</td>
</tr>
</tbody>
</table>

TABLE VI

Energy Streams

<table>
<thead>
<tr>
<th>Heat Flow (kJ/h)</th>
<th>Q</th>
<th>4.795e+007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Flow KJ/h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this table, the input to the heater \( Q \) was known.

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

TABLE VII

Compositions Fluid Pkg: All

<table>
<thead>
<tr>
<th>Name</th>
<th>Oil Sea Line</th>
<th>Gas</th>
<th>Oil</th>
<th>Water</th>
<th>H Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp Mole Frac (Nitrogen)</td>
<td>0.1260</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (H₂)</td>
<td>0.6248</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (CO₂)</td>
<td>0.0387</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (H₂O)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (Methane)</td>
<td>0.6248</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (Ethane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (Propane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (n-Butane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (n-Pentane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (i-Butane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (i-Pentane)</td>
<td>0.1839</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC6)</td>
<td>0.0039</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC7)</td>
<td>0.0018</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC8)</td>
<td>0.0008</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC9)</td>
<td>0.0004</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC10)</td>
<td>0.0002</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (KC11)</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Comp Mole Frac (C12+)</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
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

IV. 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.

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References


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