Abstract

This paper presents a first principles dynamic model of a horizontal three-phase gravity separator equipped with an interface control and weir. A number of assumptions were made: phase separation is complete; the vapour phase behaves like an ideal gas and liquid densities are constant. In practice, separators are designed with internal baffles to promote laminar flow, but it was assumed that no baffles are present. Nevertheless, the resulting set of equations is quite comprehensive and easily tailored to similar separators of different dimensions. The simulation results revealed that the separator has an interesting mix of self-regulating and non-self regulating dynamics, giving insight into the behaviour of the separator especially when it is subject to slugs of gas in the feed. Linear transfer functions between input and output variables were extracted by subjecting the first principles model to a series of step tests. These will allow the interactions between the variables to be quantified as well as controllability analyses to be performed, thus facilitating the design of linear control strategies.

1. Introduction

Three-phase gravity separators are one of the main surface production units in the petroleum industry. They are used to separate hydrocarbon streams produced at the wellhead into their constituent phases: gas, oil, and water, by virtue of immiscibility and differences in the densities of the three phases. They are designed as either horizontal or vertical separators. Depending on the philosophies used to control the liquid phases, horizontal separators come in three common configurations: interface control with boot, interface control with weir, and bucket and weir. However, the most common is the configuration with interface control and weir.

There are many studies addressing in detail, the separation mechanisms, sizing and design of such horizontal separators,[1, 6, 10]. Surprisingly, however, there are very few publications about their dynamics and control. Nevertheless, the control of the separator is essential and critical for efficient operation, safety and profitability. An understanding of its dynamic behaviour will facilitate the design and tuning of the control algorithms that can be used to regulate the water level, oil level, and gas pressure against feed variations. The aim of this paper, therefore, is to develop a dynamic model of a horizontal separator equipped with interface control and weir.

2. System definition and modelling assumptions

A diagram of the horizontal three-phase separator with hemispherical heads and equipped with an interface controller and weir is shown in Fig.1. The unit separates a three-phase feed into its constituent parts: gas, oil and water. The oil/water interface in the left hand chamber is maintained at the desired level by an interface level controller which manipulates the water outlet valve. The separated oil is skimmed over the weir to the right hand chamber and its level is kept at the desired point by another controller which manipulates the oil outlet flow. The gas disengages from the liquid phases and flows horizontally through the vessel. Separator pressure is regulated by manipulating the gas outlet flow. The dimensions of the separator and typical feed compositions were provided by a Middle Eastern oil company and presented in Table 1.
Figure 1: Schematic diagram of a gravity three-phase horizontal separator

Table 1. Separator dimensions and inlet flow data

<table>
<thead>
<tr>
<th>$Q_{\text{win}}$ (kg/s)</th>
<th>$Q_{\text{oil}}$ (kg/s)</th>
<th>$Q_{\text{gas}}$ (kg/s)</th>
<th>$L_1$ (m)</th>
<th>$L_2$ (m)</th>
<th>$H_{\text{wir}}$ (m)</th>
<th>$H_{\text{g}}$ (m)</th>
<th>$D$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1</td>
<td>3.5</td>
<td>7.3</td>
<td>4.5</td>
<td>1.6</td>
<td>0.8</td>
<td>1.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

It is clear from Fig.1 that the separator is described by four sub-systems, namely; water sub-system, left oil sub-system, right oil sub-system and gas sub-system. Thus, the model of the separator was developed by formulating dynamic material balances for each sub-system, using the following simplifying assumptions:

- The operating temperature in the separator is constant. Thus, temperature effects need not be considered and constant liquid densities can be further assumed.
- Separation is 100% efficient. Therefore, except for the weir dividing the 2 chambers in the separator, other internals such as diverter, wave breakers, defoaming plates, vortex break, mist extractor, baffle plate, etc. need not be considered as they can only improve the efficiency of separation [1].
- Liquids enter and leave the tank only through the appropriate flow streams, (i.e. no evaporation).
- The vapour phase behaves like an ideal gas, which is reasonable since most real gases obey the general gas laws reasonably well at moderate pressures and at temperatures which are significantly higher than their liquefaction point [4].

These assumptions will affect model accuracy but, since the model is to be used for studying the separator’s operation and control, only the trends in its behaviour at different operating conditions are of interest.

3. Model formulation

Following the assumptions made in Section 2, the separator model was formulated by developing the respective unsteady state mass balance equation for each sub-system.

Water sub-system

The balance equation that describes the water level dynamic under variation in inlet and outlet flow conditions is:

$$
\rho_w Q_{\text{win}} = \rho_w \frac{dV_w}{dt} + \rho_w Q_{\text{wout}}
$$

(1)
\( \rho_w \left( \frac{kg}{m^3} \right) \) is the density of water; \( Q_{\text{win}} \left( \frac{m^3}{s} \right) \) is the water inlet flow rate, \( Q_{\text{wout}} \left( \frac{m^3}{s} \right) \) is the water outlet flow rate and \( V_w \left( m^3 \right) \) is the volume of the water in the separator. Since the density of water is assumed constant,

\[
Q_{\text{win}} = \frac{dV_w}{dt} + Q_{\text{wout}} \tag{2}
\]

\( V_w \) is the sum of the volume of the water in the half spherical cap, \( V_{sc} \left( m^3 \right) \), plus the volume of the water in the partially filled cylindrical section, \( V_{cyl} \left( m^3 \right) \), that is:

\[
V_w = V_{sc} + V_{cyl} \tag{3}
\]

The volume of a half spherical cap is given by [7]:

\[
V_{sc} = \frac{1}{2} \left( \frac{\pi}{6} \right) \left( 3r_1^2 + H_w^2 \right) H_w \tag{4}
\]

\( r_1 \) is the base radius of the hemi-spherical cap \( (m) \), as shown in Fig. 2. From the geometry,

\[
r_1 = \left[ H_w (D - H_w) \right] \tag{5}
\]

\( H_w \left( m \right) \) is the water level and \( D \left( m \right) \) is the diameter of the cylindrical section of the separator. Substituting Equation (5) into Equation (4) and rearranging gives:

\[
V_{sc} = -\frac{\pi}{6} H_w^3 + \frac{\pi}{4} H_w^2 D \tag{6}
\]

The volume of a partially full cylinder is:

\[
V_{cyl} = A_{cyl} L_1 \tag{7}
\]

where \( A_{cyl} \left( m^2 \right) \) is the cross-sectional area of the cylindrical part of the separator and \( L_1 \left( m \right) \) is the length of the left chamber, excluding the hemispherical end. For a partially full cylinder [6],

\[
A_{cyl} = \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_w - R}{R} + (H_w - R) \sqrt{H_w (2R - H_w)} \tag{8}
\]

Where \( R \left( m \right) \) is the radius of the separator. Substituting Equation (8) into Equation (7) gives:

\[
V_{cyl} = L_1 \left\{ \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_w - R}{R} + (H_w - R) \sqrt{H_w (2R - H_w)} \right\} \tag{9}
\]

Using Equations (9) and (6) in Equation (3) gives the overall water volume as:
The water outlet flow rate can be described by: [5].

\[ Q_{\text{wout}} = \frac{\alpha_w}{100} \times C_{\text{tw}} \times 6.309 \times 10^{-5} \sqrt{\frac{P_{\text{win}} - P_{\text{wout}}}{SG_w}} \]  

(11)

\( \alpha_w \) (%) is the water control valve’s stem position; \( C_{\text{tw}} \left( \frac{\text{GPMUS}}{\text{psiu/2}} \right) \) is a flow coefficient; \( SG_w \) is the specific gravity of the water. The constant, \( 6.309 \times 10^{-5} \), converts \( Q_{\text{wout}} \) from \( \text{GPMUS} \) to \( \frac{m^3}{s} \). \( P_{\text{win}} \) (psig) is the outlet pressure downstream of the valve and \( P_{\text{wout}} \) (psig) is the pressure upstream of the valve given by Equation (12).

\[ P_{\text{win}} = (\rho_w g H_w + \rho_o g H_{\text{ol}})1.45 \times 10^{-4} + P_g \]  

(12)

\( \rho_o \) (kg/m\(^3\)) is the oil density; \( g \) (m/s\(^2\)) is the gravitational constant; \( H_{\text{ol}} \) (m) is the thickness of the oil layer;

\( P_g \) (psig) is gas pressure and \( 1.45 \times 10^{-4} \) is used to convert pressure from Pa to psi. Substituting Equation (12) into Equation (11) gives the water outlet flow rate:

\[ Q_{\text{wout}} = \frac{\alpha_w}{100} \times C_{\text{tw}} \times 6.309 \times 10^{-5} \sqrt{\frac{((\rho_w g H_w + \rho_o g H_{\text{ol}})1.45 \times 10^{-4} + P_g) - P_{\text{wout}}}{SG_w}} \]  

(13)

The dynamic model of the water sub-system is given by Equation (14), the result of substituting Equations (13) and (10) into Equation (2).

\[ \frac{dV_{\text{ol}}}{dt} = \left( -\frac{\pi}{6} H_w^3 + \frac{\pi}{4} H_w^2 \cdot D + \left[ L_1 \left( \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_w - R}{R} + (-R)\sqrt{H_w(2R - H_w)} \right) \right] \right) + \frac{\alpha_w}{100} \times C_{\text{tw}} \times 6.309 \times 10^{-5} \sqrt{\frac{((\rho_w g H_w + \rho_o g H_{\text{ol}})1.45 \times 10^{-4} + P_g) - P_{\text{wout}}}{SG_w}} \]  

(14)

**Left oil sub-system**

As the oil density is constant, the unsteady state mass balance that describes the oil layer thickness dynamics in the left section of the separator is given by Equation (15).

\[ Q_{\text{oil}} = \frac{dV_{\text{ol}}}{dt} \]  

(15)

\( V_{\text{ol}} \) (m\(^3\)) is the volume of the oil in the left chamber and is the sum of the oil volumes in the half spherical segment \( V_{ss} \) and the partially full cylinder \( V_{acyl} \) as given by Equation (16).

\[ V_{\text{ol}} = V_{ss} + V_{acyl} \]  

(16)

The volume of a half spherical segment of two levels is given as follows, [7]:

\[ V_{ss} = \frac{1}{2} \pi \left( 3r_1^2 + 3r_2^2 + H_{\text{ol}}^2 \right) \]  

(17)

\( r_1 \) and \( r_2 \) are the bases of the segment as shown in Fig. (3) and can be calculated as follows:

\[ r_1 = \sqrt{\frac{D^2}{4} - \left( \frac{D}{2} - (H_{\text{ol}} + H_w) \right)^2} = \sqrt{H_{\text{ol}}^2 + H_{\text{ol}}(D - 2H_w) + H_w(D - H_w)} \]  

(18)
\[ r_2 = \sqrt{\frac{D^2}{4} - \left(\frac{D}{2} - H_w\right)^2} = H_w(D - H_w) \]  

(19)

Figure 3: A sphere with two liquids.

Substituting Equations (18) and (19) into Equation (17) gives

\[ V_s = \frac{\pi}{12} \left( -2H_{ol}^3 + 3H_{ol}^2(D - 2H_w) + 6H_{ol}H_w(D - H_w) \right) \]  

(20)

As with the water sub-system, the volume of the oil in the cylindrical section is expressed as.

\[ V_{o cyl} = L_1 \left( \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_{ol} - R}{R} + (H_{ol} - R)\sqrt{H_{ol}(2R - H_{ol})} \right) \]  

(21)

Substituting Equations. (20) and (21) into Equation. (16) results in the overall volume of the oil in the left chamber:

\[ V_{ol} = \frac{\pi}{12} \left( -2H_{ol}^3 + 3H_{ol}^2(D - 2H_w) + 6H_{ol}H_w(D - H_w) \right) + \]  

\[ L_1 \left( \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_{ol} - R}{R} + (H_{ol} - R)\sqrt{H_{ol}(2R - H_{ol})} \right) \]  

(22)

The expression that describes the dynamic behaviour of the oil layer thickness in the left chamber is therefore obtained by substituting Equation (22) into Equation (15):

\[ Q_{oin} = \frac{d}{dt} \left[ \frac{\pi}{12} \left( -2H_{ol}^3 + 3H_{ol}^2(D - 2H_w) + 6H_{ol}H_w(D - H_w) \right) + \right]  

\[ L_1 \left( \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_{ol} - R}{R} + (H_{ol} - R)\sqrt{H_{ol}(2R - H_{ol})} \right) \]  

(23)

Right oil sub-system

The expression describing the changes in the oil level in the right chamber is derived in the same manner as for the water sub-system and is given by Equation (24)

\[ Q_{oir} = \frac{d}{dt} \left[ \left( -\frac{\pi}{6} H_{or}^3 + \frac{\pi}{4} H_{or}^2D \right) + \right]  

\[ L_2 \left( \frac{\pi}{2} R^2 + R^2 \arcsin \frac{H_{or} - R}{R} + (H_{or} - R)\sqrt{H_{or}(2R - H_{or})} \right) \]  

(24)

\[ + \left( \frac{\alpha_o}{100} \right) \times C_v \times 6.309 \times 10^{-5} \times \sqrt{ \frac{\rho_{o,g} \cdot H_{or} \times 1.45 \times 10^{-4} + P_c - P_{out}}{SG_o} } \]
$L_2 \ (m)$ is the length of the cylindrical part of the right chamber; $H_{or} \ (m)$ is the oil level in the right chamber; 
$\alpha_v \ (%)$ is the oil control valve’s stem position; $C_{vo} \ \left( \frac{GPMUS}{psig^{1/2}} \right)$ is the flow coefficient of the oil valve; $SG_o$ is the specific gravity of the oil; $P_{out} \ (psig)$ is the outlet pressure (downstream of the valve).

**Gas sub-system**

The unsteady state mass balance for the gas is given by Equation (25).

$$\rho_{gin} Q_{gin} = \frac{dm}{dt} + \rho_{gout} Q_{gout} \quad (25)$$

$\rho_{gin} \ \left( \frac{kg}{m^3} \right)$ is inlet gas density; $Q_{gin} \ \left( \frac{m^3}{s} \right)$ is the volumetric inlet gas flow rate; $m \ (g)$ is mass of the gas; 
$\rho_{gout} \ \left( \frac{kg}{m^3} \right)$ is outlet gas density and $Q_{gout} \ \left( \frac{m^3}{s} \right)$ is volumetric outlet gas flow rate. Assuming that the gas behaves like an ideal gas, the relationship between pressure, volume and temperature is given as [2]:

$$P_{gp} V_g = nRT_k \quad (26)$$

$P_{gp}$ is the gas pressure (Pa), $V_g$ is the gas volume (m$^3$), $n$ is the amount of gas in moles, $T_k$ is temperature (K) and $R$ is the universal gas constant ($8.314JK^{-1}mol^{-1}$). Since by definition,

$$n = \frac{m}{MB} \quad (27)$$

where $MB$ is Molecular weight (g mole$^{-1}$), $m$ can be expressed as follows:

$$m = \frac{P_{gp} V_g MB}{R T_k} (g) \quad \text{or} \quad m = \frac{P_{gp} V_g MB}{1000 \times R T_k} (kg) \quad (28)$$

The gas outlet density ($\rho_{gout}$), based on the mass and volume of the gas inside the separator is therefore:

$$\rho_{gout} = \frac{m}{V_g} \quad (29)$$

In addition to the pressure drop across the gas control valve, gas flow coefficient ($C_{vg}$) and gas specific gravity ($SG_g$), the outlet gas flow depends on the separator temperature as well. In this paper, Equation (30) will be used to determine an expression for $Q_{gout}$ [8].

$$C_{vg} = \frac{Q_{scf/h}}{962} \sqrt{\frac{SG_g T_r}{P_{g}^{2} - P_{gout}^{2}}} \quad (30)$$

$Q_{scf/h}$ is the gas outlet flow rate in Standard Cubic Feet per Hour ($\frac{scf}{h}$), $T_r$ is the gas temperature (R), and $P_{g}$ and $P_{gout}$ are the inlet and outlet gas pressure (psia), respectively.

$$Q_{scf/h} = \frac{P_t T_r}{P_{g} T_s} \quad (31)$$
Converting the outlet flow rate from \( \text{ft}^3 / \text{h} \) in Equation (31) to \( \text{m}^3 / \text{s} \) using a conversion factor of \( 7.866 \times 10^{-6} \), substituting in Equation (30) and after some manipulation, results in an expression for \( Q_{\text{gout}} \):

\[
Q_{\text{gout}} = 962 \times \left( \frac{\alpha_g}{100} \right) \times 7.866 \times 10^{-6} \times C_{vg} \times \left( \frac{P_g^2 - P_{\text{gout}}^2}{SG_g \cdot T_r} \right) \frac{P_s \cdot T_r}{P_g \cdot T_s}
\]

Substituting Equations (32), (29) and (28) into Equation (25) gives the dynamics of the gas pressure as:

\[
\rho_{\text{gin}}Q_{\text{gin}} = 6894.757 \times \frac{MB}{1000 \times RT_g} \frac{d(P_g \cdot V_g)}{dt} + \frac{m}{V_g} \times 962 \times \left( \frac{\alpha_g}{100} \right) \times 7.866 \times 10^{-6} \times C_{vg} \times \left( \frac{P_g^2 - P_{\text{gout}}^2}{SG_g \cdot T_r} \right) \frac{P_s \cdot T_r}{P_g \cdot T_s}
\]

The term 6894.757 is used to convert \( P_g \) from Pa to psi (\( P_g \)).

### 4. Open loop simulation

The purpose of this Section is to study the dynamic behaviour of the output variables (\( P_g \), \( H_w \) and \( H_{or} \)) when there are variations in the input variables (\( \alpha_w \), \( \alpha_o \), \( \alpha_g \), \( Q_{\text{win}} \), \( Q_{\text{oin}} \), \( Q_{\text{gin}} \)). The model equations, Equations (14), (23), (24) and (33), were solved using SIMULINK-MATLAB. The unknowns are \( P_g \), \( H_w \), \( H_{ol} \), \( H_{or} \), \( \alpha_w \), \( \alpha_o \), \( \alpha_g \), i.e. there are 4 equations and 7 unknowns. When controllers are included in the simulation, they will provide the 3 remaining equations to define \( \alpha_w \), \( \alpha_o \) and \( \alpha_g \). Since this paper considers the uncontrolled (open loop) situation, the values for \( \alpha_w \), \( \alpha_o \) and \( \alpha_g \) were set to nominal values during the simulation using the data listed in Tables 2 and 3.

<table>
<thead>
<tr>
<th>( H_w ) (m)</th>
<th>( H_{or} ) (m)</th>
<th>( P_g ) (psi)</th>
<th>( \alpha_w ) (%)</th>
<th>( \alpha_o ) (%)</th>
<th>( \alpha_g ) (%)</th>
<th>( Q_{\text{win}} ) (kg/s)</th>
<th>( Q_{\text{oin}} ) (kg/s)</th>
<th>( Q_{\text{gin}} ) (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>0.48</td>
<td>57.82</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
<td>13.065</td>
<td>3.50</td>
<td>7.30</td>
</tr>
</tbody>
</table>

Table 2. Steady state values for the input and output variables.

<table>
<thead>
<tr>
<th>( C_{rw} )</th>
<th>( C_{io} )</th>
<th>( C_{vg} )</th>
<th>( \rho_w )</th>
<th>( \rho_o )</th>
<th>( \rho_{\text{gin}} )</th>
<th>( \Delta P_w )</th>
<th>( \Delta P_o )</th>
<th>( \Delta P_g )</th>
<th>( SG_w )</th>
<th>( SG_o )</th>
<th>( SG_g )</th>
<th>( T_r )</th>
<th>( MB )</th>
</tr>
</thead>
<tbody>
<tr>
<td>153.9</td>
<td>46.3</td>
<td>902.6</td>
<td>999</td>
<td>790</td>
<td>2.75</td>
<td>7.25</td>
<td>7.25</td>
<td>14.5</td>
<td>0.79</td>
<td>0.865</td>
<td>518.67</td>
<td>24.6</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Values for constants defined in the model equations.

Plots of some of the simulation results are compiled in Fig. 4, where the first column shows the step changes in the input variables \( \alpha_w \), \( \alpha_o \), \( \alpha_g \), \( Q_{\text{win}} \), \( Q_{\text{oin}} \) and \( Q_{\text{gin}} \) (in that order). The corresponding responses of \( H_w \), \( H_{or} \) and \( P_g \) are shown in columns 2, 3 and 4 respectively. Note that the units of \( H_w \) and \( H_{or} \) are given in percent with respect to the weir height (\( H_{w\text{or}} \)).
It can be seen that the output variables are affected differently by each of the inputs. A particularly important observation is that water and oil levels increase or decrease continuously in a ramp-like fashion without settling to new steady-state values. This means that separator will eventually be flooded or emptied if no further action is taken, i.e., the levels are “non self-regulating” or “integrating” processes [11]. In contrast, the gas pressure always settles to new equilibriums, i.e., “self-regulating” [9], regardless of the inputs and its responses are similar to those of a first order system.

Interactions also exist among the output variables. It is obvious that the effects of variations in the water level are significant on the oil level but not on gas pressure. For example, from the plots in the first row of Fig. 4, a step change of -20% in $\alpha_w$ caused the water level to increase by about 8% over a period of 100s. Oil level also increased, but by about 15%. However, the change in gas pressure is barely perceptible. When the water level increases, it pushes more oil to the right chamber and hence the right oil level increases. Water level can only affect the gas pressure through changes in the volume of the separator’s vapour space. This is a slow process because the water level changes slowly. The gas can therefore compensate for the volume, and hence pressure variations, by allowing more or less gas to flow out of the separator. Thus, separator pressure is almost unchanged. As expected, oil level changes have no effect on water level while gas pressure is not affected for the same reason as for changes in the water level. Variations in the gas pressure affect both water and oil levels significantly. This is clear from the plots in rows 3 and 6 of Fig. 4. For example, when the gas pressure increased by 19.5 psi due to a step of -20% in $\alpha_g$, the water and oil levels dropped by about 19% and 30%, respectively.
This is because a high separator pressure “forces” more liquid to flow out of the system, hence reducing the respective liquid levels.

The behaviour of the separator is non-linear, as is obvious from the balance equations and illustrated by the responses of the output variables. For example, the plots in row 3 of Fig. (4) show that the output variables respond differently to positive and negative changes in $g_\alpha$ even though the magnitude of each step was identical.

Since one of the aims of developing this model is to study the operability and controllability of gravity three-phase horizontal separators using established (linear) techniques, a linearised form has to be extracted. This was accomplished by fitting the step responses to common Laplace transfer function structures.

Non self-regulating process (water and oil levels) can be described by the following simple model [3].

$$\frac{Y(s)}{U(s)} = \frac{K_p e^{-\theta s}}{s}$$  \hspace{1cm} (34)

$Y(s)$ is the output variable while $U(s)$ is the input (in the Laplace or $s$-domain), $\theta$ is the time delay and $K_p$ is integral process gain as given by Equation (35)

$$K_p = \frac{\Delta y / \Delta t}{\Delta u}$$  \hspace{1cm} (35)

$\Delta y$ is the change in the output variable due to a change in input variable, $\Delta u$, over a period time of $\Delta t$. The dynamics of the gas pressure, on the other hand, can be approximated by a first order model with no time delay as given in Equation (36).

$$\frac{Y(s)}{U(s)} = \frac{K}{\tau_p s + 1}$$  \hspace{1cm} (36)

Here, $K$ is the process gain which describes how much the controlled variable changes in response to changes in the input variable and $\tau_p$ is the process time constant. Using Equations (34) to (36) with the responses shown in Fig. 4, the linear transfer functions between the input and output variables were determined and are expressed in vector-matrix form in Equation (37). Note that Equation (37), which is now in an appropriate form for investigating the controllability, operability and resiliency of the separator, was scaled using the approach suggested by Skogestad and Postlethwaite [12].

$$\begin{bmatrix} H_w \\ H_{or} \\ P_g \end{bmatrix} = \begin{bmatrix} -4.0600 \times 10^{-2} & 2.6000 \times 10^{-4} & 6.5020 \times 10^{-2} \\ -7.7483 \times 10^{-2} e^{-3} & -2.2417 \times 10^{-2} & 1.4800 \times 10^{-1} \\ -4.6600 \times 10^{-2} & -1.5900 \times 10^{-2} & -4.5140 \end{bmatrix} \begin{bmatrix} \alpha_w \\ \alpha_o \\ \alpha_g \end{bmatrix} + \begin{bmatrix} 3.7849 \times 10^{-2} \\ 6.0709 \times 10^{-2} \\ 4.6851 \times 10^{-2} \end{bmatrix} \begin{bmatrix} \frac{Q_{win}}{s} \\ \frac{Q_{oin}}{s} \\ \frac{Q_{gin}}{s} \end{bmatrix}$$  \hspace{1cm} (37)

5. Conclusions

This paper has presented a mechanistic dynamic model for a horizontal three-phase gravity separator equipped with an interface and weir. This type of processing unit is commonly used to separate hydrocarbon streams produced at the wellhead into gas, oil, and water phases. The resulting equations were solved using MATLAB-
SIMULINK and the simulation results revealed that the separator has an interesting mix of self-regulating and non-self regulating dynamics, giving insight into the behaviour of the separator especially when it is subject to slugs of gas in the feed. Similar results were observed using different separator dimensions and operating conditions. Linear transfer functions between input and output variables were extracted by subjecting the first principles model to a series of step tests. These will allow the degree of interaction between the variables to be quantified as well as controllability analyses to be performed, thus facilitating the design of linear control strategies – which is the next phase of work.

6. Acknowledgement

Mr Al-Hatmi would like to express his appreciation to Petroleum Development Oman (PDO) for providing the separator data and for supporting this work financially.

7. References