Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 6, Issue 1, 2021, Page 44-49
ISSN: 2616-1192

(www.ujesr.org)

Development of Pressure Drop Correlation for Offshore Pipeline-Riser Systems Using OLGA

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Abstract
This study focused on developing a correlation for pressure drop in offshore pipeline riser system using Oil and Gas software (OLGA software). Flowlines of 8 inches, 10 inches, 12 inches and 14 inches were deployed at 2300 m water depth and parametric analysis was carried out using OLGA software to determine the effect of the flowline size on pressure requirements, liquid hold-up and erosional velocity. The outcome of the parametric analysis revealed that the higher the line size (pipeline diameter), the more the required outlet pressure for the system. Also, higher pipeline diameter leads to lower values in both liquid hold-up and erosional velocity. A model of pressure drop as a function of length of pipeline, total volume flow, total mass flow, liquid hold-up and fluid temperature was developed from the results of the parametric analysis using regression capabilities in Excel. The pressure drop model was validated using an already established homogenous flow model. The homogenous flow model estimated pressure drop in the system to be 14.3 bar while the correlation developed with Excel estimated the pressure drop to be 50.04 bar, the developed model is thus more conservative. With this model which is more conservative, production and flow assurance engineers can with ease, determine the outlet pressure of the system.
Keywords: *Pressure drop, Pipeline riser, Correlation, OLGA*

Received: 23rd August, 2021 *Accepted: 8th November, 2021*

1. Introduction

Approximately 35% of the energy supplied to the world is from oil and gas (Ogazi, 2011). In order to meet the global energy demand, there is the need to optimize production of oil and gas from deepwater reserves as production rates drop. Pressure fluctuation is a major threat to optimizing oil production from deepwater reserves in order to meet the daunting global energy demand (Westwood, 2010). Typical production loss from excessive drop in pressure can be as high as 50% as highlighted in Yocum (1973). When this pressure fluctuation grows over the pipeline-riser section, it causes trips on the valves and chokes on the separator, leading to a shut-down of production. Also, the structural damage on pipeline-riser sections as a result of accompanied pressure drop issues like slugging and liquid hold-up can cause huge economic loss to operators. Multiphase flow transportation in deepwater pipeline-riser systems becomes more challenging with complex piping networks and undulations that are common in deepwater scenario, leading to increased liquid accumulation (liquid holdup) at the low points (Hoogendoorn, 2009). In-view of these inherent challenges, more efforts need to be made to optimize oil recovery from deepwater reserves.

According to Hassanein and Fairhurst (2008), typical cost figures for the reliability failure is in the range of $30 to $50 million for typical systems of 350.52 meters to 502.93 meters water depths. Flowlines are commonly used for transporting gas-1iquid mixtures. In some cases, a two-phase line can save capital cost by 20 to 25% over two single-phase lines. Conventionally, hydrocarbon products produced from subsea wells are transferred to processing facilities through long and slender flowlines (pipelines and risers) which can span over many kilometres. Due to pressure change, solid (hydrate) may form in the line which in turn affects the pressure profile (Gould, 2009). In order to achieve a suitable design of pipeline-riser systems, the industry has relied on flow regime transition maps based on air-water experiments as highlighted in Mandhane *et al*. (1974) for horizontal map and Barnea (2007) for vertical map.

Quite a number of empirical correlations have been developed for predicting pressure drops in two-phase-flow (Dukler *et al.*, 1964; Beggs and Brill, 1973; Zhang *et al.*, 2013). Ferguson and Spedding (2015) made use of experimental data to test for pressure drop against different correlations from literature. A comparative review of other predictions also presented in their paper showed a number of inconsistencies. Mandhane *et al*. (1977) tested 14 models for pressure-drop predictions and observed that the scatter in the predictions is wide, even when the average of error is relatively small.

The complex mixture of hydrocarbon compounds or components can exist as a single-phase liquid, a single-phase gas, or as a multi-phase mixture, depending on its pressure, temperature, and the composition of the mixture (Badie, 2010; Matsui, 2014). This work focuses on modelling, simulation and analysis of multiphase systems using OLGA Software. It involves estimation of pressure profile of a pipeline-riser system as a function of flowline sizes, distance, elevation, flow rate and friction using OLGA.

2. Materials and methods

2.1 System description

In this study, a pipeline-riser system transporting multiphase hydrocarbon fluid in ultra-deepwater subsea production field was modelled using OLGA Software. The flow path profile consists of a horizontal pipeline of 60 km long and a riser of 2200 m high connecting the subsea facilities to the topside facility as in Fig. 1.

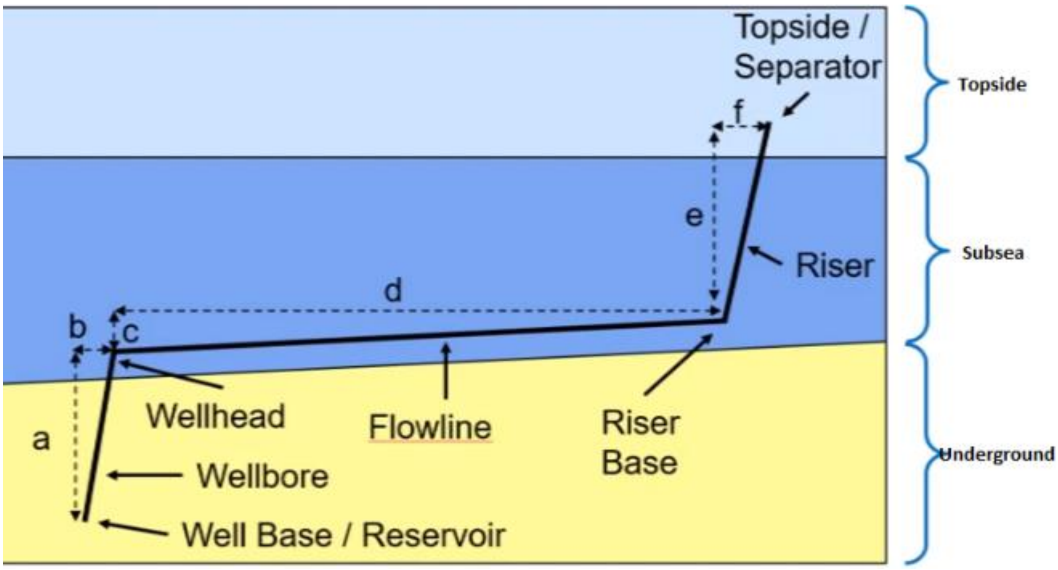

Fig. 1: Schematic of typical subsea production system to be modelled

2.2 Pipeline and pipe flow equations

For steady-state fluid flow in a constant diameter horizontal pipe, using the Darcy-Weisbach friction loss equation, OLGA calculates the pressure drop from one location to another along the pipeline using the energy equation expressed in terms of the pressure drop as (Kanin *et al.*, 2019):

$$P_1 - P_2 = \frac{f\rho L V^2}{2D} \quad (1)$$

where P is pressure, *f* is friction factor, ρ is density, L is length, V is velocity, and D is pipeline diameter. The momentum equation for the separated flow model is quite complex and is given by:

$$\Delta P_{momentum} = \dot{m}_{total}\left\{\left[\frac{(1-x)^2}{\rho_L(1-\varepsilon)} + \frac{x^2}{\rho_G\varepsilon}\right]_{out} - \left[\frac{(1-x)^2}{\rho_L(1-\varepsilon)} + \frac{x^2}{\rho_G\varepsilon}\right]_{in}\right\} \quad (2)$$

where $\dot{m}_{total}$ is the total mass velocity of liquid plus vapour, x is the vapour quality, and ε is the void fraction of the two-phase flow and can be obtained from:

$$\varepsilon = \frac{x}{\rho_G}\left[\left(1 + 0.12\,(1-x)\right)\left(\frac{x}{\rho_G} + \frac{1-x}{\rho_L}\right) + \frac{1.18(1-x)[g\sigma(\rho_L-\rho_L)]^{0.25}}{\dot{m}^2{}_{total}\rho_L{}^{0.5}}\right]^{-1} \quad (3)$$

The two-phase density is obtained from:

$$\rho_{tp} = \rho_L(1-\varepsilon) + \rho_G\varepsilon \quad (4)$$

2.3 Mathematical equations programmed in OLGA

The OLGA code is based on seven (7) key equations which consist of three continuity equations, three momentum equations and a combination of the liquid within gas and gas-phase equation. The equations are presented below.

2.3.1 Continuity equations

Gas-phase equation:

$$\delta\frac{(V_g\rho_g)}{\delta t} = -\frac{1}{A}\frac{\delta}{\delta t}(AV_g\rho_gV_g)+\varphi_g + G_g \quad (5)$$

Bulk liquid phase equation at the wall:

$$\delta\frac{(V_L\rho_L)}{\delta t} = -\frac{1}{A}\frac{\delta}{\delta t}(AV_L\rho_LV_L) - \varphi_g\frac{V_L}{V_{L+V_D}} - \varphi_e + \varphi_d + G_L \quad (6)$$

Liquid droplet within the gas phase:

$$\delta\frac{(V_D\rho_L)}{\delta t} = \frac{1}{A}\frac{\delta}{\delta t}(AV_D\rho_LV_D) - \varphi_g\frac{V_D}{V_{L+V_D}} + \varphi_e - \varphi_d + G_D \quad (7)$$

2.3.2 Momentum equations

Gas-phase equation:

$$\frac{\delta(V_g\rho_gV_g)}{\delta t} = -V_g\left(\frac{\delta P}{\delta Z}\right) - \frac{1}{A}\frac{\delta}{\delta Z}\quad\frac{\delta}{\delta Z}\left(AV_g\rho_gV_{g^2}\right) - \lambda_g\frac{1}{2}\rho_{g|V_g|}V_g\cdot\frac{S_g}{4A} - \lambda_I\frac{1}{2}\rho_g|V_r|V_r\cdot\frac{S_i}{4A}$$

$$+V_g\rho_g g cos\theta + \varphi_gV_a - F_D \quad (8)$$

Liquid droplets equation:

$$\frac{\delta(V_D\rho_LV_D)}{\delta t} = -V_D\left(\frac{\delta P}{\delta Z}\right) - \frac{1}{A}\frac{\delta}{\delta Z}(AV_D\rho_LV_{D^2}) + V_D\rho_L g cos\theta - \varphi_g\frac{V_D}{V_{L+}V_D}V_a + \varphi_eV_i - \varphi_eV_D + F_D \quad (9)$$

Liquid at wall equation:

$$\delta\frac{(V_L\rho_LV_L)}{\delta t} = -V_L\left(\frac{\delta P}{\delta Z}\right) - \frac{1}{A}\frac{\delta}{\delta Z}(AV_L\rho_LV_{L^2}) - \lambda_L\frac{1}{2}P_L|V_L|V_L\cdot\frac{S_L}{4A} + \lambda_i\frac{1}{2}\rho_g|V_r|V_r\cdot\frac{S_i}{4A} + V_L\rho_L g cos\theta - \varphi_g\frac{V_L}{V_{L+}V_D}V_a - \varphi_eV_i + \varphi_dV_d - V_Ld(\rho_L-\rho_g)g\frac{\delta V_L}{\delta z}Sin\theta \quad (10)$$

Combination of liquid droplet and the gas phase equations:

$$\delta\frac{(V_g\rho_gV_g)}{\delta t} = -(V_g+V_D)\left(\frac{\delta P}{\delta Z}\right) - \frac{1}{A}\frac{\delta}{\delta Z}\left(AV_g\rho_gV_{g^2} + AV_D\rho_LV_{D^2}\right) - \lambda_g\frac{1}{2}\rho_g|V_g|V_g\cdot\frac{S_g}{4A} - \lambda_i\frac{1}{2}\rho_g|V_r|V_r\cdot\frac{S_i}{4A} + (V_g\rho_g+V_D\rho_L)g cos\theta + \varphi_g\frac{V_L}{V_L+V_D}V_a + \varphi_eV_i - \varphi_dV_D \quad (11)$$

Key parameters in the equations are V_g, V_L and V_D, volume fractions of gas, liquid and liquid droplet, A represents the pipe cross-sectional area, φ_g represents the mass transfer between phases, $\varphi_e and \varphi_D$ are entrainment deposition rates, G is the mass source, θ is the angle of inclination, P is Pressure, d is droplet deposition, S is wetted perimeter and V_r is relative velocity.

2.4 Data collection and method of data analysis

Design and operating data were collected and used as inputs in the simulations. Multiphase simulations were carried out in this study using OLGA software. Parametric studies were carried out to ascertain the effect of flowline sizes and flow rates on pressure requirements. From the output of the OLGA simulations, 40 data points were generated, which were exported to Excel. Statistical analysis using data analysis toolpak in Excel was used to develop new pressure drop model. The data analysis toolpak can be used to create a (linear) model of a dependent parameter (pressure drop in this case) as a function of a number of variables.

3. Results and discussion

3.1 Effect of pipeline sizes on the minimum outlet pressure requirement

Fig. 2 shows the effect of the different flowline diameters on the system outlet pressure requirement. It can be seen that the larger the line size, the more the required outlet pressure for the system. For a flowline diameter of 0.3048 m (12 in), a system outlet pressure of 63.58 bar (922.15 psi) is needed to achieve the mass flowrate of 10 kg/s over a distance of 60 km and elevation of 2200m. Therefore, considering the impact of pressure drop on flow assurance and economics, the recommended flowline size for this field will be 0.2032 m (8 in). With this flowline size, the required system outlet pressure will be very minimal, which implies that without the aid of external energy, more of the fluid being conveyed in the system will be delivered to the first stage separator at the topside.

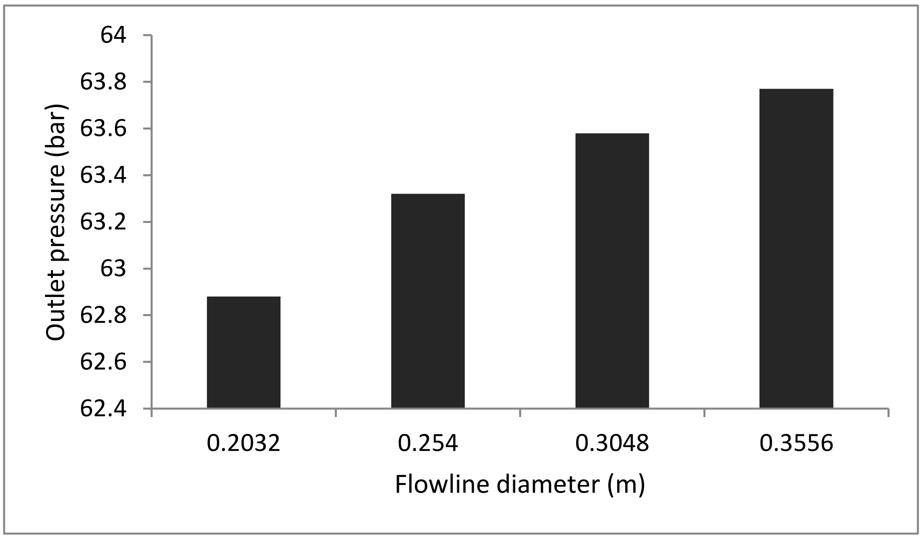

Fig. 2: Parametric trend plot of the different line sizes vs the minimum required outlet pressure

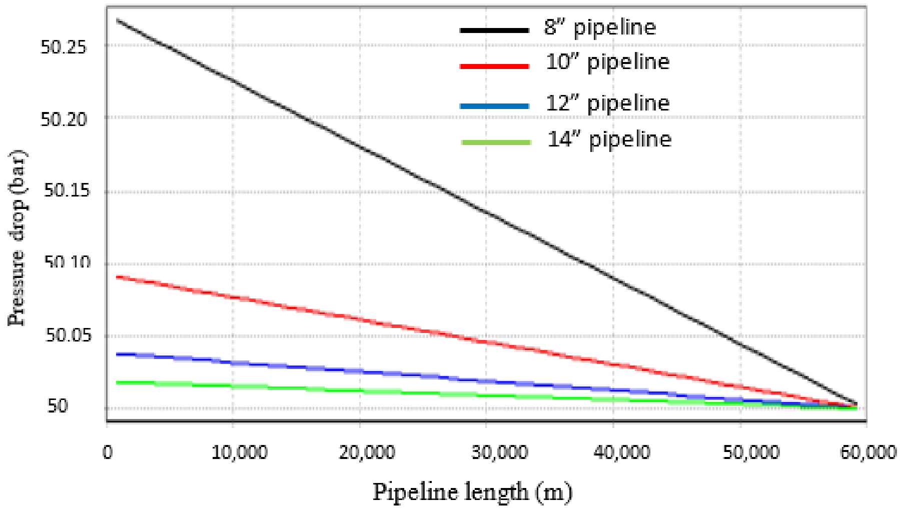

Fig. 3: Pressure profile for different pipeline diameters

3.2 Pressure profile for different pipeline diameters

Fig. 3 shows that the larger the pipeline diameter, the lower the pressure drop and the pressure requirement for the system. The largest diameter of 14 inches had the lowest pressure drop and pressure requirement for the system. However, it is good to note that the larger the diameter of the pipeline, the more the cost that would be incurred for the design, construction, and pipe laying.

3.3 Development of pressure differential model

From the output of the OLGA simulation, 20 data points were generated, having one dependent variable (pressure differential term in bar), and five independent variables which include: pipeline length, L (m), the total volumetric rate, Q_T (m^3/day), liquid hold-up, H_{OL}, total mass flow, G_T (kg/s), and fluid temperature, T_M (°C) (the data points are shown in Table 1). The data points from OLGA were exported to Excel and a correlation relating the dependent variable with the independent variables was developed. A linear function between the pressure drop and the independent variables (length of pipeline L, total volume flow Q_T, total mass flow G_T, liquid hold-up H_{OL} and fluid temperature T_M was proposed and expressed as:

$$\Delta P_T(bar) = A + BL + CQ_T + DH_{OL} + EG_T + FT_M \quad (12)$$

where ΔP_T is the differential pressure (P_1-P_2); A, B, C, D, E and F are constants to be determined. Using the results of the parametric analysis, the coefficients were determined using the data analysis toolpak Equation (13) shows the results pressure drop model.

$$\Delta P_T(bar) = 50.0381 - 6.4x10^{-7}L + 3.521\,x\,10^{-7}Q_T + 1.1\,x\,10^{-3}H_{OL} - 2.6\,x\,10^{-4}G_T - 3.38\,x\,10^{-6}T_M \quad (13)$$

This model will help examine if the estimated pressure output meets the required or set system outlet pressure which is usually given during conceptual design, and from this, the need for pressure boost will be ascertained.

3.5 Validation of the developed model

To validate the pressure drop correlation developed in this study, the correlation was compared with a homogenous flow model given in Equation (14).

$$\Delta P = \frac{4f\rho_m u_m^2 L}{2D} \quad (14)$$

To do the comparison, the following parameters were assumed (Baxter, 2012):

Q_T = 3.975 x 10^{-3} m^3/s (343.44 m^3/d), ρ_m = 50.21kg/m^3, GT = 0.20 kg/s, D = 0.001m,

u_m = 50.6m/s, L = 20m, friction factor, f = 0.00278, H_{OL} = 0.87 and T_M = 50 ºC.

Using Homogenous flow model, the pressure drop is obtained as,

$\Delta P = 14.3\ bar$

Therefore, using a homogenous flow model, the pressure drop within the considered system is 14.3bar. And using the correlation developed with Excel data regression analysis (Equation 13) and substituting the values gives:

$\Delta P_T = 50.04$ bar

From the outcomes of these two correlations, it is clear that the correlation developed in this study is more conservative. This difference is largely due to the fact that the model developed in this study is for a flow with two phases-gaseous and liquid while the existing model is for homogeneous flow.

Table 1: Generated data points from OLGA

Pressure drop P_T [bara]	**Length [m]**	**Total vol. flow Q_T [m3/day]**	**Hold-up H_{OL}**	**Total mass flow GT [kg/s]**	**Fluid temp. T_M [ºC]**
50.03847	0	0	0.558715	0	60.1176
50.03746	1500	739.153	0.580315	1.793455	22.9463
50.03556	4500	597.608	0.592183	1.793455	7.4259
50.03364	7500	583.043	0.593341	1.793455	6.1155
50.03172	10500	581.893	0.59343	1.793455	6.0093
50.02980	13500	581.820	0.593431	1.793455	6.0007
50.02788	16500	581.835	0.593425	1.793455	5.9999
50.02596	19500	581.856	0.593418	1.793455	5.9999
50.02404	22500	581.878	0.593411	1.793455	5.9999
50.02212	25500	581.900	0.593404	1.793455	5.9999
50.02020	28500	581.923	0.593397	1.793455	5.9999
50.01828	31500	581.945	0.59339	1.793455	5.9999
50.01636	34500	581.967	0.593383	1.793455	5.9999
50.01444	37500	581.989	0.593376	1.793455	5.9999
50.01252	40500	582.011	0.593369	1.793455	5.9999
50.01060	43500	582.033	0.593363	1.793455	5.9999
50.00868	46500	582.055	0.593356	1.793455	5.9999
50.00676	49500	582.078	0.593349	1.793455	5.9999
50.00484	52500	582.100	0.573593	1.793455	5.9999
50.00288	55500	582.122	0.526178	1.793455	5.9999

4. Conclusions

Multiphase simulations were carried out in this study using OLGA software in order to investigate the effects of flowline sizes on pressure requirements. Considering the implications of the outcomes of these simulations in this study to flow assurance, the data and results obtained suggest that a flowline size of 0.2032 m (8 inches) is favourable to flow assurance of the fluid and other operating conditions considered in this study with respect to delivering the fluids to the platform at an optimum pressure. From the outcomes of the parametric analysis, it was observed that larger pipeline diameter leads to higher value of the required outlet pressure for the system. Finally, pressure drop correlation was developed and validated by comparing it with an existing homogenous flow model. The developed model was found to be more conservative compared to the existing homogeneous flow model.

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