SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 15 – 18 2022

Evaluation and simulation of gas-liquid separation and performance degradation of an ESP pump under two-phase flow applied to a production system equipped with Skid-ESP

Rodrigo C. Sales[1], Valdir Estevam[2], Marcelo Souza de Castro[2,3]
[1]Production operation, Petrobras, Brazil
[2]Center for Energy and Petroleum Studies - CEPETRO, UNICAMP, Brazil
[3]School of Mechanical Engineering, UNICAMP, Brazil

Abstract
Conventional ESP presents high operating cost interventions, and this fact motivated the development of skid-ESP outside the well, installed at the seabed. This position favors higher gas void fractions due the pump position at the system that presents a lower inlet pressure than a conventional installation. This multiphase flow condition can cause repercussions on the flow of the pump inlet and impellers presenting signals of surging. The position and pump assembly also permit a separation of the gas at the pump inlet. Therefore, this work intends to evaluate the operational impacts on the whole system using the nodal analysis considering the effects of gas separation in the suction and the pump performance degradation under multiphase flow.

Keywords
Skid-ESP; Multiphase flow; Nodal Analysis

Introduction
The need to expand production capacity, when the natural pressure difference between the reservoir and the production facility is not enough to generate economically viable flows, requires the development of artificial production methods.
The ESP (Electric Submersible Pump) is composed of a multi-stage centrifugal pump, driven by an electrical motor, also submerged.
The main economic factor of these pumping systems is the operating cost interventions for equipment replacement due to their relatively low life expectancy. This motivated the development of ESP outside the well, installed at the seabed to facilitate the retrieve and reinstallation of equipment without the need for removal of the production column as the ESP Skid presented in Fig. 1 [1].

Figure 1. Representation of the ESP in the skid [1]

However, it was observed that under certain conditions, this ESP configuration showed signs of surging, that is, oscillations in the pump pressure gain [2].
The position of the pump on the seabed, a zone in which the pressure is lower than at the bottom of the well, favors higher gas void fractions, causing possible repercussions on the flow of the pump inlet and impellers. Therefore, it is necessary to understand the operational limits and impacts on the system, mainly the effect of gas separation in the suction due to the peculiar geometry of the pump and the direct degradation of the performance of the pumps due to the presence of higher gas void fractions.

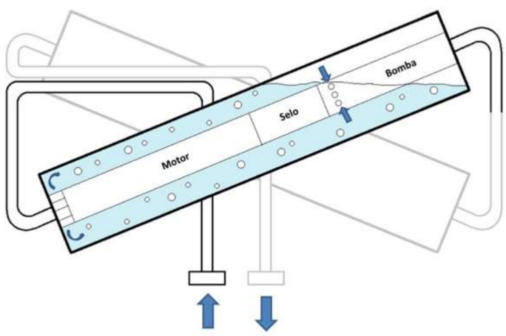

Figure 2. Schematic drawing of the possibility of ESP operation on the skid [2]

Therefore, this work uses the nodal analysis technique to simulate the behavior of a real production system, considering models of free gas separation in the pump suction and performance degradation due to the gas void fraction, to evaluate the dimension of the effects of these phenomena, the applicability of the models together in the oil production systems, as well as defining paths for simulation and evaluation to be used in any production system.

Methodology

The flow simulations are being carried out using the MARLIM® (Multiphase Flow and Artificial Lift Modeling) software, developed by Petrobras, considering steady-state flow.
The flow was simulated by the multiphase flow correlation of Beggs & Brill [3] and properties for the pressure x temperature pairs, according to black-oil model correlations.
The system (lines – risers and flowlines, equipment and well) was assembled in the flow simulator according to characteristic production configurations of the oil and gas industry, considering a catenary riser up to the TDP (touchdown point), flowline up to the discharge of the ESP skid, the pump installed on a skid on the seabed at an angle of 5° to the horizontal, connected by a jumper to the Xtree that controls a directional well fed by a reservoir (Fig. 3).

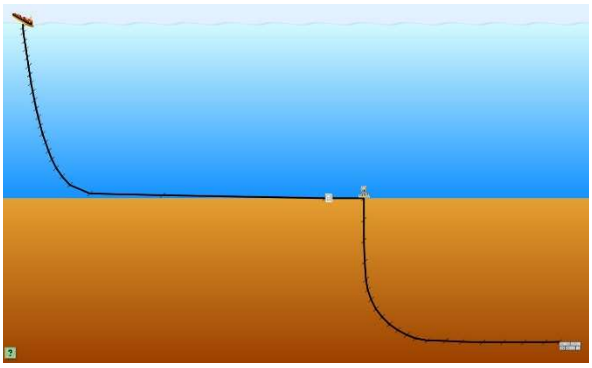

Figure 3. System in MARLIM software

Boundary conditions were also defined from real production system data.
The simulation method considers the pump inlet, on the seabed, as a "node of interest" in the system.
Combinations of flow rate and GOR (Gas-oil ratio) pairs are then simulated to evaluate the behavior of the system in different gas void fractions.

Table 1. Points of Simulation Matrix

	GOR					
Flow rate (m³/d)	25	50	63,6	100	150	250
500	1	9	17	25	33	41
1500	2	10	18	26	34	42
2517	3	11	19	27	35	43
3000	4	12	20	28	36	44
3429,1	5	13	21	29	37	45
4000	6	14	22	30	38	46
4300	7	15	23	31	39	47
5000	8	16	24	32	40	48

For each flow rate x GOR pair, the simulation process follows, in a simplified way, this methodology:

1- Simulation of the flow from the well to the ESP to calculate the fluid inlet conditions in the pump and available pressure at the pump inlet;
2- Calculation of the gas void fraction at the pump inlet, through the drift-flux model of Zuber and Findlay [4], considering, for the annular duct (between pump and casing) the coefficients predicted by Custodio [5] for slug flow pattern;
3- Calculation of the free gas separation efficiency in the pump suction from the Vieira's model [6] with parameter adjustments by Custodio [5];
4- Calculation of pump curve correction factors according to the Monte Verde model [7] for viscous fluids and homogeneous model for degradation by gas void fraction;
5- Simulation of the flow from the ESP to the production platform to calculate the pressure required at the pump discharge;
6- Nodal analysis at the pump.

Equations

Each step of the simulations and calculations involves numerous equations, most of which can be found in the references.
For step 1, the most important equation is Eq. 1 for the simulation of the pressure gradient used in the multiphase flow model of the Beggs & Brill correlation.

$$-\frac{\mathrm{dP}}{\mathrm{dZ}} = \frac{\frac{g}{g_c}\sin\theta\left[\rho_L H_L + \rho_g(1-H_L)\right] + \frac{f_{tp} G_m v_m}{2 g_c d}}{1 - \frac{\left[\rho_L H_L + \rho_g(1-H_L)\right] v_m v_{sg}}{g_c P}} \quad (1)$$

where P is the pressure, z is the length of the section, g is the acceleration due to gravity, θ is the angle of the section with the horizontal plane, ρ_L e ρ_g is the liquid and gas phases density respectively, H_L is the liquid Holdup, f_{TP} is the two phase friction factor, G_m is the mixture mass flux rate, v_m is the mixture velocity, d is the pipe diameter and v_{SG} is the superficial gas velocity.
The Beggs & Brill correlation involves other equations, mainly for the determination of the liquid holdup (*HL*) that can be verified in the reference.
For the step 2, the Eq. 2 calculates the gas void fraction prediction in the annular duct.

$$\alpha = \frac{\frac{j_g}{j}}{C_0 + \frac{\tilde{V}_{jg}}{j}} \quad (2)$$

where α is the gas void fraction, j_g is the gas superficial velocity, j is the mixture velocity and C_0 and $\tilde{V}_{jg}$, the distribution coefficient and drift velocity, obtained experimentally by Custódio [5].

For step 3, Eq. 3 is used, according to the model developed by Vieira [5] that considers the influence of the gas void fraction and slip between the phases in the free gas separation at the pump suction. The experimental parameters are used from the work developed by Custódio [5]. This work considers an average separation, considered in the average radius of the pipe.

$$\bar{E} = 1 - \left[\frac{\alpha}{1-\alpha}\right]\left[\frac{1-\lambda}{\lambda}\right] - \left(\frac{\alpha}{j_g}\right)\left[\frac{\widetilde{v_{SR}}}{\left(\frac{r_e}{2h}\right)\left(\frac{r}{r_e}-\frac{r_e}{r}\right)}\right] \quad (3)$$

where *E* is the separation efficiency, *λ* is the no-slip gas void fraction, *r* is the pipe radius (with the index *"e"* representing the outer radius), *h* is the control volume length in the intake region and $\widetilde{v_{SR}}$ is the average relative velocity between the phases in the radial direction.
The Eq. 4, Eq. 5 e Eq. 6 are used to calculate the head, flow rate and efficiency correction factors according to the Monte Verde [7] model. The utilization is extrapolated to the entire curve, not just the best efficiency point (BEP).

$$C_H = \frac{H_{vis}}{H} = Re_{mod}^{-\left(\frac{145{,}965}{Re_{mod}^{1{,}139}}\right)} \quad (4)$$

$$C_q = \frac{q_{vis}}{q} = Re_{mod}^{-\left(\frac{9{,}257}{Re_{mod}^{0{,}610}}\right)} \quad (5)$$

$$C_\eta = \frac{\eta_{vis}}{\eta} = Re_{mod}^{-\left(\frac{41{,}651}{Re_{mod}^{0{,}688}}\right)} \quad (6)$$

where Re_{mod} is the modified dimensionless Reynolds number which is calculated from the Reynolds number and specific velocity (w_S) [7].

Results and Discussion

The results presented here are preliminary, simulation products of some points of the proposed matrix.
It is possible to evaluate the behavior of the pump pressure curve for 3 cases (Fig.4): two-phase flow "BF", using the simulated gas void fraction for the non-annular duct (just before the annular duct), two-phase flow "DF", using the gas void fraction of the annular and two-phase duct modeling named as "Sep", which considers the gas separation.

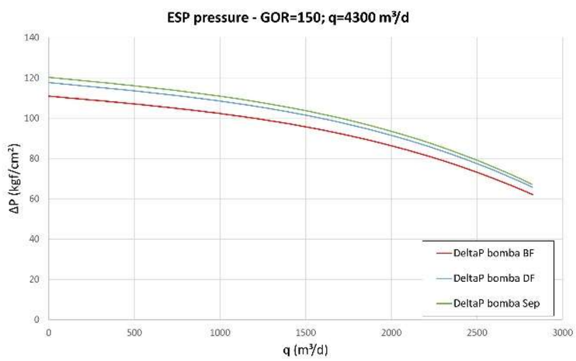

Figure 4. Comparison of impact on pump performance by different models

In the result of the simulation point 39, it is possible to notice that, due to the smaller local gas void fraction, the modeling that considers the slip between the phases in the annular duct presents a better pump performance. The phenomenon of gas separation favors this performance due, precisely, to the separation of free gas, carrying less gas to the pump suction.
Fig. 5 and Fig. 6 presents the nodal analysis for GOR=150 (simulated points 35, 37 and 39) and GOR=63.6 (simulated points 19, 21 and 23).

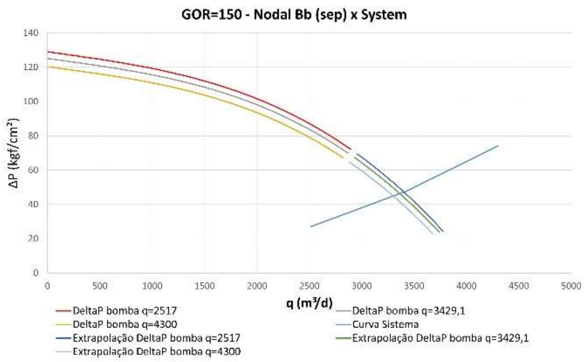

Figure 5. GOR=150, Nodal Analysis

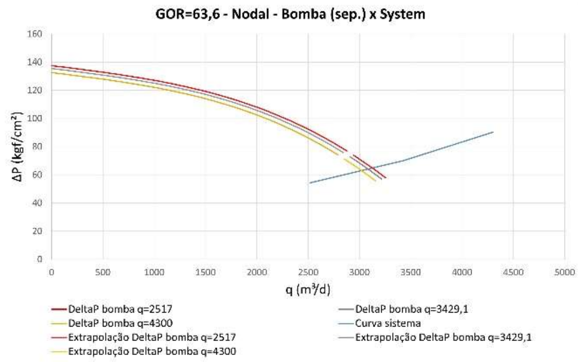

Figure 6. GOR=63,6, Nodal Analysis

In these results it is possible to notice that, despite a greater degradation of the pump performance in the situation of higher GOR, the pressure drop of the system for a smaller GOR results in a higher equilibrium flow rate of the system in a higher GOR. Other results will still be analyzed as the simulation becomes more mature. The goal is to analyze and compare the behavior of the curves in different GOR and show a graphic relationship between suction pressure and separation efficiency.

Conclusions

Based on the present results, it is possible to conclude that this study has an importance in the analysis of the general context of the system by applying and joining models that interfere in the multiphase flow in systems equipped with skid ESP.
The proposed models show results compatible with real systems, revealing their potential applicability for real operations analysis.

It is possible to realize the impact of the gas void fraction in different models in the multiphase performance of the pump.
The balance of the system is directly impacted by the increase in the amount of gas void fraction. Although this increase results in a decrease of the pressure drop, which would have a positive effect on productivity, it is also responsible for the high degradation of pump performance, resulting, therefore, in a worsening of the overall performance of the system.

Acknowledgments

The authors are grateful to University of Campinas, School of Mechanical Engineering and Center for Energy and Petroleum Studies for the support. Acknowledgments are extended to ALFA (Artificial Lift and Flow Assurance Research Group). Finally, acknowledgments are extended to Petrobras for providing MARLIM license.

Responsibility Notice

The authors are the only responsible for the paper content.

References

[1] Tarcha, B. A.; Borges, O.C.; Furtado, R. G. *ESP Installed in a Subsea Skid at Jubarte Field*. SPE. SPE Artificial Lift Conference, Salvador-BA, Brazil, May, 2015

[2] Daun, L. G. *Estudo Experimental da Garantia de Escoamento em Curvas Horizontais Descendentes e Aplicação à Operação de um S-BCSS*. 2013. 117p. Dissertation (Master degree) – Universidade Estadual de Campinas, Campinas-SP, 2013

[3] Beggs, H. D.; Brill, J. P. *A Study of Two-Phase Flow in Inclined Pipes*. SPE. SPE-AIME 47th Annual Fall Meeting, San Antonio, Texas, 1972

[4] Zuber, N.; Findlay, J. A. *Average Volumetric Concentration in Two-Phase Flow Systems*. Journal of Heat Transfer, v. 87, n. 4, p. 453, 1965

[5] Custódio, D. A. S. *Estudo Experimental da Influência da Inclinação da Tubulação e da Viscosidade do Líquido no Escoamento Bifásico Gás-Líquido em Duto Anular*. Dissertation (Master degree) – Universidade Estadual de Campinas, Campinas-SP, 2020

[6] Vieira, S. C. *Separação Gás-Líquido no Escoamento Bifásico Intermitente em um Duto Anular.* Dissertation (Master degree) – Universidade Estadual de Campinas, Campinas-SP, 2018

[7] Monte Verde, W. *Modelagem do Desempenho de Bombas de BCS Operando com Misturas Gás-Óleo Viscoso.* Dissertation (Doctorate degree) – Universidade Estadual de Campinas, Campinas-SP, 2016