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Multiphase Flow in Long-Length Semi-Buried Flexible Tiebacks

Wayne Gabriel N. Firme[1*], Mariana Laiane S. Dutra[2], Tony Herbert F. de Andrade[2], Welson B. de Azevedo[1]
[1]Post-Graduate Program in Mechanical Engineering, Federal University of Campina Grande, Campina Grande - PB, Brazil
[2]Petroleum Engineering Academic Unit, Federal University of Campina Grande, Campina Grande – PB, Brazil *engwaynenobrega@gmail.com

Abstract

The oil industry has been exploring new approaches to enhance offshore production in distant fields with smaller reserves over time. One solution to this challenge is the construction of long-range production lines, known as tiebacks, which eliminate the need for specific production units. With advancements in flow assurance studies and computational simulation, it has become feasible to develop more efficient production systems. This study aims to evaluate multiphase flow in long-distance semi-buried submarine pipelines using the computational tool ALFAsim. A base case of the production system was adopted with all essential information to assess flow parameters such as temperature, volumetric fraction, flow pattern, and pressure along the pipeline, with variations in the insulation layers of the tieback. The research focused particularly on the effect of temperature on multiphase flow under burial conditions, both in the presence and absence of thermal insulation. Validation of the simulator was performed using data from Guedes et al. [1], followed by a comparison of the results obtained by the author using the one-dimensional OLGA simulator.

Keywords

Tieback; ALFAsim; Multiphase Flow

Introduction

The subsea production system is considered the link between subsea wells and a production facility. The layout of its design directly impacts production efficiency, safety, and costs associated with deepwater oil and gas fields. A well-designed subsea production system contributes to optimizing production performance due to favorable hydraulic properties and the resolution of problems related to flow assurance. Therefore, the layout of the production system plays a key role in the development of marine production fields.

According to Wiles, Widjaja, and Davalath [2], the simultaneous deployment of all equipment in a complete offshore production system requires a large investment and results in low utilization as production rates decrease. An alternative that may become more viable is the incremental development of a field with so-called long-distance tiebacks. This has been made possible both by advances in flow guarantee management and by advanced studies into technologies with lower operating costs.

Generally, subsea tiebacks, depicted in Figure 1, require significantly lower initial investments compared to developments utilizing FPSOs or other fixed facilities. However, the economics of having a long tieback are governed by a number of field-specific factors, such as distance from the existing facility, water depth, and recoverable volumes, among others.

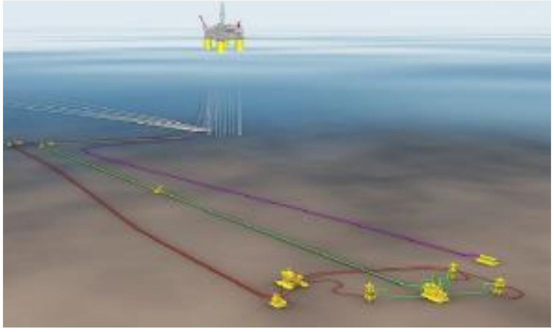

Figura 1. Tiebacks.
Fonte: Guo [3].

According to Bai and Bai [4], installing tiebacks is an ideal way to take advantage of existing infrastructure, especially for marginal fields.

Multiphase modeling of fluids produced in subsea environments is crucial to guarantee the safe production of hydrocarbons, however, multiphase flow over long distances of tiebacks imposes limitations and technical considerations such as the difficulty of conserving heat in production fluids, due to the long traveled distance. In this way, the temperature of the fluids can approach the temperatures of the seabed, which may cause problems related to flow assurance.

In this sense, the use of one-dimensional multiphase fluid flow simulators to enable the efficient production of a tieback is of paramount importance for the petroleum industry.

Therefore, the main objective of this research is to evaluate, through one-dimensional numerical simulation, the multiphase fluid flow in an offshore production system composed of a long-length semi-buried tieback and a riser, using the Artificial Lift Flow Assurance Simulation software (ALFAsim). Specifically, the influence of Mixture temperature on the presence or absence of insulation layers throughout the duct network is evaluated, as well as the effect of temperature on multiphase flow under buried tieback conditions. Furthermore, this research validates the simulator using data from Guedes et al. [1], followed by comparison of the results obtained by the author using the one-dimensional simulator OLGA.

Methodology

To conduct the research, fluids from the Caratinga producing field, located in the Campos Basin, approximately 100 km from the coast, were used as a base. In this field, production is predominantly gas in solution, and the reservoir covers water depths ranging from 850m to 1350m [5]. Next, PVT simulations were carried out using the RF-DAP FASE software, version 2023.09.1, with the aim of preparing a phase equilibrium report, using the Peng-Robinson equation of state. Subsequently, this data was entered into the 1D multiphase flow simulator known as Artificial Lift Flow Assurance Simulator – ALFasim. In this, it was possible to define the profile of a tieback buried under a layer of sand 5m deep by 6km, extending to the platform, totaling approximately 16km in length. Furthermore, two transient regime scenarios were evaluated, in which a mass-type boundary condition was established at the tieback inlet. The first scenario was defined with mass flow values of 0.02 kg/s for gas and 0.3 kg/s for oil, while the second scenario was specified with mass flow values of 0 kg/s for gas and 10 kg/s for oil.

In the absence of field or experimental data, the validation of the ALFAsim software was carried out by comparing the results obtained in simulations carried out by Guedes et al. [1], who in turn, obtained the results using the one-dimensional multiphase flow simulator, OLGA. In order to compare the results of the simulators, efforts were made to feed both simulator models with the same input parameters.

Multiphase Modeling

The multiphase flow was governed by the conservation equations of mass, linear momentum, and energy, thus allowing the transient evaluation and analysis of flow properties.

Results and Discussion

It is possible to observe a gradual decrease in temperature along the flowline-riser production system in both ALFAsim and OLGA simulators, as shown in Figure 2.

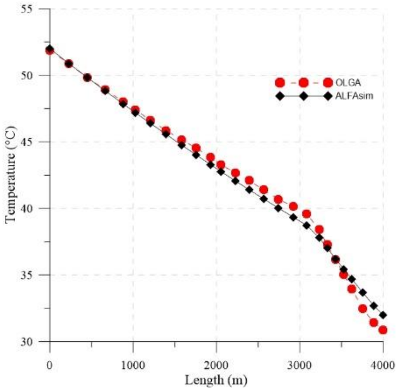

Figure 2. Comparison of temperature profiles obtained with ALFAsim and OLGA in entire production system.

The temperature profile observed in Fig. (2) can be explained by the heat loss from the hydrocarbon mixture to the external environment of the pipelines. This is because the temperature of the entire flowline-riser external environment was set to 276.15 K. Onyegiri, Briggs, and Ekwe [6] noted that the temperature profile behavior obtained through numerical simulation with the PIPESIM software decreased along a pipeline of approximately 10.2 km. The temperature curve observed by the authors exhibited a steep decrease, as no insulating materials were used throughout the pipeline. This temperature profile behavior can also be seen in Fig. (2), where approximately 3000 meters into the length, the temperature curve decreases slightly more steeply than in the first 3000 meters of the pipeline. This is because beyond 3000 meters, no insulating material was established, and this facilitates the heat transfer from the hydrocarbon mixture to the external environment.

Through Figure 2, it is still possible to observe that the results obtained for the temperature profile using the one-dimensional multiphase simulator ALFAsim are consistent when compared to the results obtained by Guedes et al. [1], since the temperature profile curves are close to each other. Observing the behavior of the temperature curves of the mixture relative to the length from the well to the FPSO in Fig. (3), it can be observed that there were no changes in the temperature values along the initial 10900 meters of the tieback. However, after 10900m, at the starting point of the riser, the temperature curve without insulation showed a steeper slope when compared to the curve with insulation. This indicates that there was a faster heating during the trajectory to the surface.

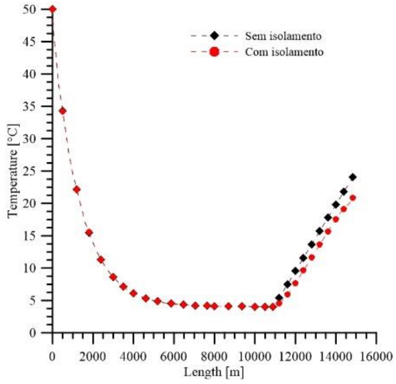

Figure 3. Temperature of the mixture with and without insulation for mass flow rates of 0.02 kg/s for gas and 0.3 kg/s for oil.

These results indicate that at low mass flow rates, the buried pipeline method, with or without insulation, does not provide effectiveness in the thermal control of the fluid, as the fluid temperature reached approximately 5°C, which corresponds to the temperature of the seabed.

On the other hand, when the flow rate is high, the fluid moves quickly through the pipeline, which means there is less time in contact with the pipeline. This reduces the amount of time available for heat exchange to occur between the fluid and the pipeline. Consequently, the temperature of the mixture does not decrease as quickly compared to when the flow rate is low. This can be seen in Figs. (4) and (5).

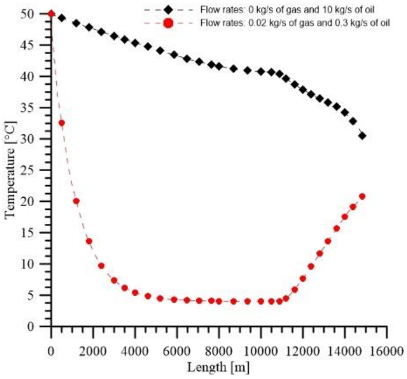

Figura 4. Insulated tieback temperature.

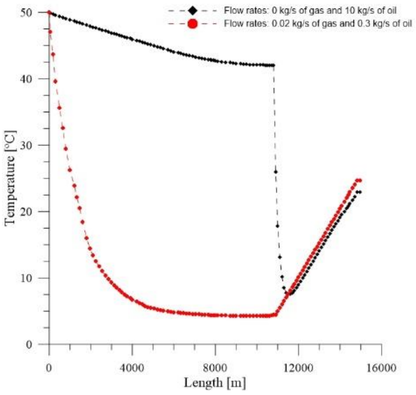

Figure 5. Temperature the tieback without insulation.

Tarantino [7] highlights that the residence time of the oil in the pipe directly affects its temperature, as it remains longer losing heat to the medium where the pipe is inserted. Therefore, the lower the fluid flow rate in the system, the longer the residence time in the pipeline, which implies a lower average fluid temperature.

According to Figures 4 and 5, at high mass flow rates, the temperature behavior of the Mixture for the insulated and non-insulated tieback is similar. These results indicate that the buried pipeline method provides control of the thermal stability of the Mixture, as long as the fluid mass flow rate is high enough.

According to Queiroz [8], the soil in the seabed has low thermal conductivity, which improves the thermal performance of the line by reducing the overall heat transfer coefficient and adding thermal mass to the system, thus increasing heat retention. This configuration, combined with proper insulation, could provide sufficient thermal insulation and eliminate the need for a Pipe-in-Pipe system, for example. The study by Bau and Sadhal [9] demonstrates that the maximum temperature of the system always occurs below the central axis of the tube. However, as the burial depth increases, the location of the maximum temperature migrates to the center of the tube due to the influence of the thermal conductivity ratio of the system on the temperature distribution along the diameter. At high ratios, the relatively high thermal conductivity of the medium tends to equalize the temperature distribution on the tube surface and forces the temperature profile inside the tube to be nearly symmetrical. Consequently, the location of the temperature peak migrates towards the center of the tube, where the fluid is located, which explains the good temperature conservation during flow.

Furthermore, according to Figure 4, the mixture temperature drops when it reaches 11000 meters, the point where the riser begins, practically matching the behavior of the low-flow curve. Due to the tieback being buried, its temperature behavior remains stable due to the thermal protection provided by the soil, while the riser is subject to rapid fluctuations in external ambient temperature.

For the interpretation of the multiphase flow pattern, the software classifies flow patterns as follows: 0 - Closed duct; 1 - Stratified; 2 - Bubbly; 3 - Slug; 4 - Annular; 5 - Single phase. On analyzing Figure 6, it can be seen that the flow pattern is stratified up to 13000 meters. In the stratified pattern, the liquid phase flows at the bottom of the tieback while the gas flows at the top, with no interaction between the two phases. At low velocities for both the gas and liquid phases, the interface is smooth, characterizing the smooth stratified flow regime. As the gas flow rate increases, the interface becomes wavy, giving rise to the wavy stratified flow regime.

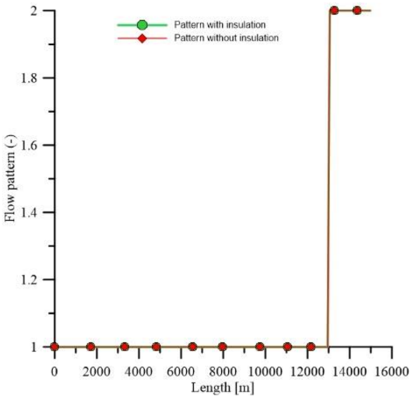

Figure 6. Flow pattern throughout the pipeline network.

Conclusions

A detailed analysis of thermal and hydrodynamic behavior is crucial for understanding the dynamics and efficiency of an offshore production system. In summary, the results obtained in this work revealed the following conclusions:

1. The results obtained in this research proved to be entirely reliable, as the comparison of the Mixed Temperature curve results were similar to those obtained through OLGA.
2. The thermal stability along the tieback demonstrates the effectiveness of buried pipelines in controlling fluid temperature at a sufficiently high flow rate.
3. Changes in flow patterns, from stratified to bubbly, are influenced by gravity and pressure decrease, facilitating bubble formation in the multiphase fluid.

Acknowledgments

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Responsibility Notice

The authors are the only responsible for the paper content.

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