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TÍTULO DO TRABALHO:

Evaluation of Subsea Production System in Deepwater Oil Fields Using ALFAsim: Definition of Base Layout and Flow Analysis

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EVALUATION OF SUBSEA PRODUCTION SYSTEM IN DEEPWATER OIL FIELDS USING ALFASIM

Abstract

The subsea production system links subsea wells and FPSOs (Floating Production Storage and Offloading). Its layout design impacts deep-water oil and gas fields' efficiency, safety, and costs. A well-designed subsea production system can reduce costs, optimize production, and prevent flow assurance issues. This study aims to use computational simulation to evaluate the design and modeling of a subsea production system, investigating oil and gas flow phenomena. Multiflash was used to characterize crude oil from the Caratinga field, with a Gas-Oil Ratio (GOR) of 46.39 sm³/sm³, using the Peng-Robinson equation of state and classical mixing rules. The PVT table generated provides essential thermo-physical data for ALFAsim, covering temperatures from 0°C to 77°C and pressures from 1 to 500 bar, with 50 equidistant points each. The base case features a satellite well system, with the well CRT-28 at a depth of 2006.24 meters, a temperature of 74°C, and an absolute pressure of 300 bar, having a productivity index of 70 m³/day/bar. The layout requires a 10.9 km flowline and a 4.2 km riser with a 6-inch internal diameter. Initial simulations considered segment sizes of 25, 50, and 100 meters. The mixture temperature at the topside, 17031.42 m, was 31.2°C for 25m segments, 31.8°C for 50m, and 32.6°C for 100m, showing temperature variation with segment size. Consequently, a 25-meter segment mesh was chosen for accuracy in further analyses. The production rate of the satellite well was 2236.87 sm³/day. Liquid retention, influenced by flow regime, fluid properties, and pipeline characteristics, decreased the volumetric fraction from 1 to 0.58, indicating gas release along the riser. Using ALFAsim to size a subsea production system with a satellite well proved satisfactory, highlighting the importance of flow analyses in oil and gas field design.

Keywords: Caratinga field, multiphase flow, simulation, Multiflash, ALFAsim.

Introduction

According to the International Trade Administration (2022), Brazil is the largest oil producer in South America and the eighth largest globally, with predominantly offshore production (96.7%). This offshore oil exploration and production leadership is driven by the prolific pre-salt province, known for its high-quality oil and high field productivity. The International Energy Agency (IEA) predicts that by 2040, Brazil will be responsible for about 50% of the world's offshore oil production, estimated at approximately 5.2 million barrels per day (International Trade Administration, 2022).

In offshore hydrocarbon developments, subsea production systems are becoming increasingly popular due to their ability to explore remote and marginal resources and their greater flexibility in placing subsea wells compared to traditional systems. Economically, the trend is to place sub-systems increasingly on the seabed along the production chain (MUDRAK, 2016).

Typical offshore production systems consist of three main parts: the well system, the subsea production system, and the terminal system. The well system penetrates the reservoir, allowing hydrocarbons to flow to the surface. The subsea production system, installed on the seabed, includes components such as flowlines, jumpers, umbilicals, wellheads, manifolds, compressors, and pumps, which transport the produced fluids to the terminal system. The terminal system, generally represented by floating platforms like the Floating Production Storage and Offloading unit (FPSO), receives and processes the produced fluid. Risers are used as the flow path for the fluids to reach the floating platform and are classified as part of the terminal system (HONG, 2019). These components are configured and combined to optimize production, with the system architecture designed according to strict regulations and specifications, considering future expansions (GRIMSTAD, 2015). Developing a subsea field involves a complex design process and high costs. Factors such as low oil prices, adverse environmental conditions, great depths, high drilling costs, and other complex issues make it essential to reduce both CAPEX and OPEX while maintaining effective development performance (HONG, 2019). To model the best subsea production system architecture, transient multiphase flow simulators are crucial tools, allowing the prediction of operational problems and the development of mitigation procedures. These simulators are available as commercial tools or internal codes developed for specific applications (GASPARI et al., 2006).

Most existing subsea simulations focus on dynamic behaviors during the installation of subsea facilities or on multiphase flow behavior within pipes (Woo et al., 2014). The layout design of the subsea production system, perceived as the link between subsea wells and the FPSO, directly affects exploration efficiency, safety, and the costs of deepwater oil and gas fields. Therefore, a well-designed subsea production system is vital for optimizing production performance and reducing costs (HONG et al., 2018). Nowadays, it is essential to use commercial software to perform virtual production simulations, from the concept and design of equipment to the validation of the subsea system.

The objective of this study is to use the 1D dynamic multiphase flow simulator, ALFAsim, to evaluate the design and modeling of a subsea production system, considering base layouts and investigating the physical phenomena in oil and gas flow.

Methodology

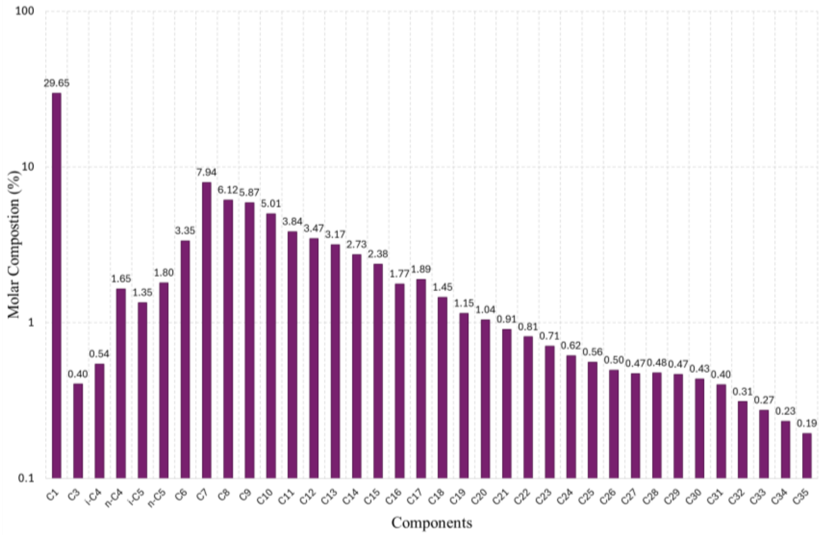
The following sections describe the methodology used in this work and outline the required input data for each software.

Fluid Characterization

The PVT mixture under analysis in this study originates from the Caratinga Field, located in the Campos Basin, Brazil. At first, the Multiflash software was used to characterize the crude oil, which had a GOR of 46.39 sm^3/sm^3, using the Peng-Robinson equation of state with Peneloux volume shift and the classical mixing rules. Figure 1 shows the fluid composition.

The results of the SARA analysis, necessary to determine the composition of crude oil in terms of specific fractions for Caratinga crude oil, reveal the following contents: 39.8% saturates, 6.2% asphaltenes, 14.3% resins, and 39.8% aromatic components. These data were adapted from the study by Sjöblom et al. (2010).

Figure 1 – Caratinga crude fluid composition



Source: Elaborated by the authors (2024).

In Multiflash, the PVT table is generated, containing all the physical property data required for ALFAsim. These data result from a series of flash calculations performed at different pressure and temperature values. The temperature range used varies from 0°C to 77°C, while the pressure ranges from 1 bar to 500 bar, with 50 equidistant points for both properties.

Subsea System

In 1984, Petrobras discovered Brazil's first giant field in deep waters, Albacora. Subsequently, other giant fields emerged, such as Marlim, Roncador, Barracuda, and Caratinga (Petrobras, [s.d.]). The offshore Caratinga field, discovered in 1994 and in production since 1997, extends through a water depth of 850 to 1350 meters and is located in the south-central part of the Campos Basin, approximately 100 km offshore. The production fluid comes from a gas-in-solution reservoir (GASPARI et al., 2006), with an average density of 24° API (DA COSTA FILHO, 2005). Since 2005, it has been exploited by an FPSO named P-48, designed to produce 300,000 barrels a day (FERRAZ; G. OLIVEIRA; M. VASCONCELLOS, 2008).

Satellite well system

A satellite well is an individual subsea well connected directly to the host through a dedicated flowline/riser. The geometrical profile of Caratinga's natural flowing well CRT-28, as well as the flowline and riser profiles presented in GASPARI et al. (2006), was selected to perform the case study in ALFAsim.

Well configuration

The well was defined with a length of 2006.25 meters for the geometric profile. Three different maximum segment sizes (25, 50, and 100 meters) were established in the automatic discretization parameters to perform a mesh sensitivity analysis.

This well has four types of casing strings: conductor, surface, intermediate, and production, and its properties are shown in Table 1.

Table 1 – Casing configuration

Casing Name	Setting Depth (m)	Hole Diameter (in)	Outer Diameter (in)	Inner Diameter (in)	Top of Filler (m)	Above Filler Fluid
Conductor	99.1617	36	30	27	0	None
Surface	950.211	26	20	16	851.05	Brine
Intermediate	1668.35	16	14	12.5	718.14	Brine
Production	1758.5	12.5	9.5	8.5	90.15	Brine

Source: Elaborated by the authors (2024).

The production tubing was installed with a length of 1758.5 meters and an outer diameter of 5.5 inches. The four types of casing are made of carbon steel and fill with cement. A packer is a device installed at the bottom of the well, used to isolate the annulus from the production conduit. The completion fluid above the packer is Potassium chloride (KCl – completion fluid). Also, as to the formation, the well is situated in a formation of shale, sandstone, and marl.

For the bottom boundary condition, a closed mass node was created, with a null mass flow rate, once equipment known as reservoir inflow was modeled and set at 2006,24 meters, with 300 bar and 74°C. Furthermore, an Inflow Performance Relationship (IPR) was defined for the oil phase using a linear model. According to Alves et al. (2005), the productivity index, a measure of a well's capacity to produce hydrocarbon liquids, is 70 m³/day/bar for this reservoir.

Flowline and Production Riser

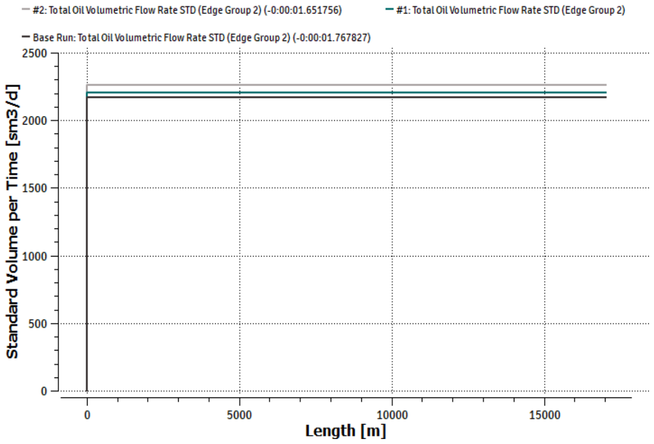
The flowline and production riser in ALFAsim were configured with a length of 10.9 km, an internal diameter of 6 inches, and an ambient temperature of 4°C. On the other hand, the production riser was defined with a length of 4.2 km, an internal diameter of 6 inches, and an ambient temperature of 5.1°C. Both components used the transient heat transfer model for the wall and the standard material of ALFAsim.

Results and Discussion

Simulations were conducted on a single well subsea production system, evaluating three distinct maximum segment sizes of 25, 50, and 100 meters. The results revealed that the total oil volumetric flow rate for the segments of 25, 50, and 100 meters corresponded to 2173.78 m³/day, 2205.36 m³/day, and 2264.09 m³/day, as depicted in Figure 2.

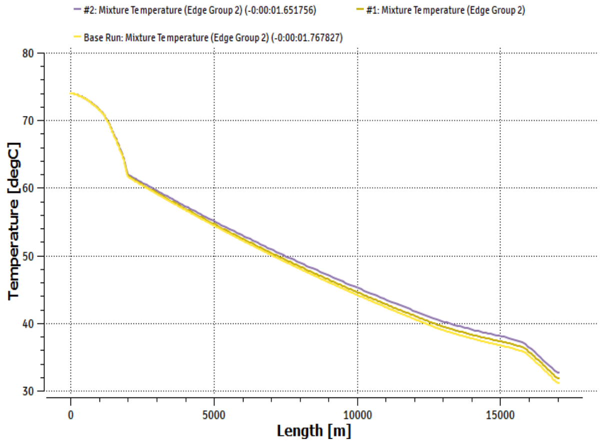
The total oil volumetric flow rate was observed to increase as the segment sizes increased, resulting in a higher value for the largest segment size. This behavior is influenced by the reduction in the interpolation range, which, in turn, affects pressure and temperature, thereby impacting the flow rate. This phenomenon is attributed to the size of the control volume, where reducing the control volume size leads to more accurate calculations of PVT properties. Figure 3 illustrates the behavior of the mixture temperature across three distinct maximum segment sizes.

Figure 2 – Total oil volumetric flow rate behavior for different segment sizes of the mesh
(base case: 25 m, #1: 50 m, and #2: 100 m)



Source: Elaborated by the authors (2024).

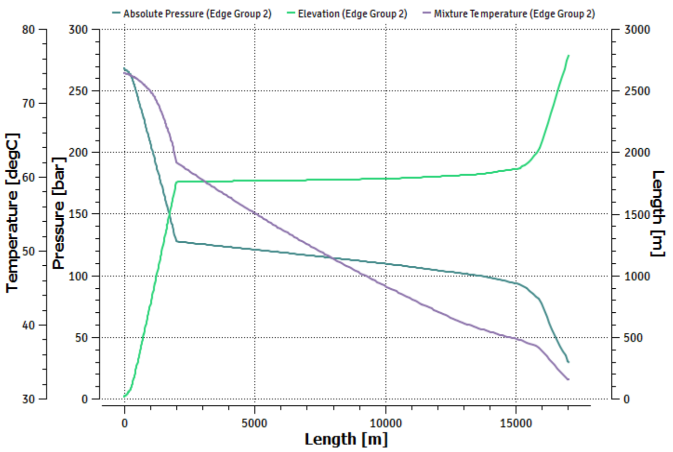
Figure 3 – Mixture temperature behavior in three different maximum segment sizes
(base case: 25 m, #1: 50 m, and #2: 100 m)



Source: Elaborated by the authors (2024).

The mixture temperature at 17031.42 meters, at the top position, varies according to the segment size: for a 25 m segment, it is 31.23°C; for 50 m, it records 31.81°C; and for 100 m, it reaches 32.62°C. This result highlights that the mixture temperature is directly proportional to the segment size. Hence, the decision was made to define the maximum segment size as 25 m, which was adopted in the mesh for subsequent designs, as smaller segments (smaller control volumes) provide more accurate results. Figure 4 illustrates the curves of absolute pressure and temperature as a function of elevation for the chosen control volume size.

Figure 4 – Base case absolute pressure, elevation, and mixture temperature



Source: Elaborated by the authors (2024).

Table 2 presents the values of absolute pressure and mixture temperature at different positions of the subsea system corresponding to the base case.

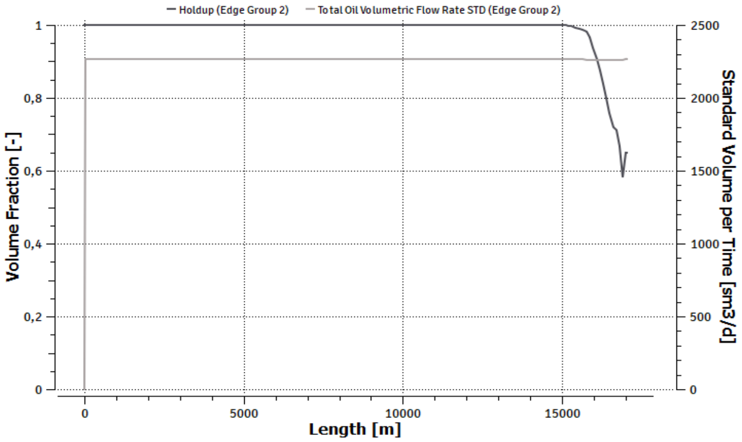
Table 2 – Base case absolute pressure and mixture temperature at different positions

Position (m)	**P (bar)**	**T (°C)**
0	268.975	73.99
2006.24	129.374	61.59
12890.55	105.269	39.14

Source: Elaborated by the authors (2024).

The pressure and temperature decrease along the pipeline length due to pressure drop due to various factors, including gravitational forces, friction, and acceleration. The flow rate, fluid viscosity, and pipe roughness influence frictional pressure loss. Furthermore, it is important to consider the pressure drop due to acceleration, especially in areas where there is a two-phase flow, such as in the riser section. It is also relevant to mention the contribution of gravitational pressure, especially in ascending sections of the flow line. Figure 5 illustrates the variation of holdup and the total oil volumetric flow rate along the pipeline.

Figure 5 – Base case a liquid holdup and total oil volumetric flow rate



Source: Elaborated by the authors (2024).

The production rate of this satellite well is 2236.87 m³/day, designated for a 25 m size. A Liquid holdup depends on flow conditions, fluid characteristics, and pipe size and configuration. The volume fraction 1 indicates single-phase liquid flow and 0 represents single-phase gas flow. The decrease in the volume fraction from 1 to 0.58 indicates the release of a certain amount of gas along the riser.

Conclusion

Through the computational simulation performed in the ALFAsim software, this study evaluated the design and investigated the physical phenomena of oil and gas flow in a subsea production system. The input data were based on real information from the Caratinga Field obtained from the literature.

The base case results revealed a proportional relationship between the flow rate and the mixture temperature with the segment size, ranging from 25, 50, to 100 meters. The precision of calculating the PVT properties increased with mesh refinement, resulting in a maximum segment size of 25 meters for the other layouts. The total oil volumetric flow rate in the base case was 2173.78 m³/day, at a pressure of 30 bar and temperature of 31.23°C.

Furthermore, the mixture temperature behavior analysis, conducted in different segments, highlighted significant variations. Following this sensitivity analysis, it was decided to use 25-meter segments to ensure more accurate results in subsequent analyses. The satellite well's production rate was 2236.87 sm³/day.

It is important to note that liquid retention, influenced by various factors including flow regime, fluid properties, and pipeline characteristics, reduced the volumetric fraction from 1 to 0.58, indicating gas release along the riser. The use of ALFAsim to evaluate the sizing of a subsea production system with a satellite well has proven satisfactory, as flow analyses are crucial in the design and development of oil and gas fields.

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