



Offshore Production Technology Innovation: Subsea Processing and Digital Twin Integration for Deepwater Oil and Gas Extraction Optimization

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Abstract: Offshore oil and gas exploration and production are currently increasingly shifting to deepwater and ultradeepwater environments, which present technical challenges in the form of extreme hydrostatic pressure, low temperatures, and very long distance of surface facilities. Offshore production technology has undergone a fundamental transformation through the application of subsea processing technology and the integration of digital twin systems. This review aims to analyze the technical reliability and operational efficiency of the application of subsea separation, subsea boosting, and digital twin-based monitoring in increasing hydrocarbon acquisition and extending the service life of offshore fields. The study method was carried out through the synthesis of operational data and literature studies referring to the industry standards API, ISO 13628, and DNV-RP-F302. The results of the analysis show that the application of subsea boosting and multiphase separation on the seabed significantly reduces backpressure on wells, increases flow rate (flow assurance), and reduces the energy consumption of floating facilities (FPSOs). In addition, the integration of digital twin frameworks in real-time has been proven to be able to predict the accumulation of hydrate and internal corrosion, thereby minimizing unplanned downtime. This study concludes that the convergence between advanced subsea system engineering and digitalization is a crucial solution to improve reliability, operational cost efficiency (OPEX), and sustainability of offshore oil and gas production in the era of energy transition.

Keywords: Offshore Production Technology; Subsea Processing; Flow Assurance; Digital Twin; FPSO

1. Introduction

The development of oil and gas fields in offshore areas is now facing complex dynamics along with declining shallow reserves and high demands on operational efficiency. Offshore production operations in deepwater areas require advanced engineering infrastructure that can withstand high hydrostatic pressures, strong underwater currents, and complex flow phenomena such as the formation of gaseous hydrates and wax deposition in underwater pipelines. In this context, the development of offshore production technology is the main key to maintaining the economy and operational safety of facilities [1]. Traditionally, hydrocarbon fluids are flowed raw from subsea trees directly to surface processing facilities such as Floating Production Storage and Offloading (FPSO) or bonded platforms. However, at long tie-backs and extreme water depths, drastic pressure drops and temperature drops trigger severe flow assurance problems. Failure to handle hydrocarbon flows can trigger a complete blockage in the pipeline network and stop the production process. Therefore, the paradigm shift from surface-based to subsea processing and the use of modern digital analytics technology are now the main focus of offshore engineering research development [2].

2. Materials and Methods

This study synthesizes engineering and operational data from various applications of subsea production technology, including subsea multiphase boosting pump systems, subsea water separation & reinjection, and

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digital twin-based monitoring architecture. Operational reliability evaluation was carried out by referring to international regulations and standards such as API 17 series, ISO 13628 (Design and operation of subsea production systems), and DNV-RP-F302 for the integrity management of offshore facilities [1], [7]. In addition, historical data on deepwater field operational performance was evaluated to compare the accumulation factor acquisition (recovery factor) between conventional configurations and integrated subsea boosting-based configurations [7].

3. Discussion

The integration between underwater physical treatment technology and digitalization systems emphasizes that the sustainability of offshore operations no longer relies solely on material thickness or surface processing capacity. The combination of subsea boosting, advanced thermal insulation protection, and predictive-based condition monitoring forms a highly reliable hybrid production architecture [8]. The application of machine learning algorithms in digital twin models allows operators to dynamically optimize the rate of injection of hydrate inhibitor chemicals, thereby reducing the operational costs of chemicals without compromising the safety aspect of flow [8]. However, a comprehensive review of the implementation of subsea infrastructure confirms that the high initial capital cost (CAPEX) and the difficulty of maintenance interventions on the seabed require a very high level of reliability of components. The welding quality of the subsea pipeline, the robustness of the umbilical electrical system, as well as the compatibility of the anti-corrosion coating remain the main foundations before the automation system can be fully operational. A continuous risk-based risk management (Risk-Based Inspection (RBI) approach is recommended to ensure smooth operation over the life of the structure [9].

4. Conclusion

Based on the results of operational analysis and literature studies, the integration of subsea processing technology and digital twin systems provides the most reliable solution in improving the efficiency and reliability of deep-sea offshore oil and gas production. This integrated approach effectively reduces reservoir backpressure, prevents flow blockages due to hydrating or slugging, and optimizes the surface load capacity of FPSO facilities. In the future, the direction of offshore production technology development needs to be focused on strengthening energy efficiency through the electrification of all-electric subsea systems, automation of independent AUV/ROV-based underwater maintenance, and integration of offshore production facilities with carbon storage infrastructure (CCS) to support clean and sustainable operational targets.

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