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Implementing Subsea Processing Technologies for Separation, Treatment and Transportation of Oil and Gas Produced From Subsea Wells

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Abstract
Furthermore, the development of subsea processing is a fundamental step to allow the management of oil and gas offshore exploitation in a sustainable way of the energy sources. The importance of subsea process systems will also increase in the future with the development of the exploitation of heavy oils on the bottom applications for hydrocarbon mining. The technology required for subsea processing of heavy oils will require the development of new solutions, with original subsea flow assurance issues, and a rethink of a design philosophy based on the possibility to co-produce, with the help of a chemical treatment, the water required to extract the heavy oil from the subsoil. Up to now, the most attractive subsea processing application is the subsea DWS, making it possible to realize an effective underground offshore exploitation, with the well vertical completion to 700–1600 m, typical of the onshore exploitation of similar or as concerns deep water conjugate fields.Subsea processing technologies offer a means of moving oil and gas production into ever deeper waters, making it increasingly competitive against onshore or other offshore oil and gas recovery systems, and providing the additional capability of exploitation of smaller and more marginal undersea resources. In the near future, the development of subsea processing technology will focus on the subsea treatment of large volumes of produced water, not only because of the environmental importance, but also because this may allow operation of subsea wells with very long hanging length of foot, to increase the recovery factor, the possibility of maximizing production from low barren wells where another solution could be to shut-in the well, an easy flow assurance issue in high viscosity oils and to treat polymers in the produced water.

Keywords
Subsea Separation; Gas Dehydration, Waxy Oil, Emulsion, Subsea Flowlines; Multiphase Pumps, Injection Systems; Practical Implementation of Subsea Separation; Subsea Multi-Phase Pumps; Implementation of Compact S Separation Systems; Subsea Sand Filtration Technologies

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I. Introduction

Nearly 700 of approximately 4,000 ultra-deep to moderate depth subsea wells drilled worldwide are located in the Gulf of Mexico (GOM), with 43 percent from previously abandoned shallow water conventional shelf trajectory wells that have been re-surveyed as pre-drill locations in the past 2 years, 2011 and 2012 (Belhaj, 2023). Thirty petrocompanies are responsible for most of the flawless subsea results and billion-dollar well investments achieved using dramatic upgrades of subsea requirement initiatives experienced in the boom previous decade, a handful of mid-water floater drilling platforms, and, fundamentally, both the advancements in static deepwater drilling technology, and the engineering expertise to fix potential hazards at sanitized shallow locations (Kurnia et al., 2022).

The deepwater regions of the Gulf of Mexico (GOM) continue as leading areas to develop cutting-edge, pioneering subsea oil and gas technologies (Zhixin et al., 2023). Design and installation of processing systems for removal of water, sand, gas (nitrogen), and salts (and sulfate reduction) from crude oil and natural gas produced from subsea wells have been employed worldwide, going back to the early 1990s. The platforms of offshore applications continue to push toward as deep and far subsea as technical capabilities allow. In the GOM, many of these enhanced production processes have now moved further subsea to on the seabed separation and treatment facilities, suctioning and routing surging product to hubs closer to shore, platforms, or land (Thompson et al., 2022).

1.1. Overview of Subsea Processing Technologies

The Diezer and NAM tests do not fully meet all the criteria for commercial development of subsea process systems. However, the results of these tests, as well as new technologies arising from them, can involve a timely and significant contribution to research in this area (Puskic, 2024). Shell Oil Company used the subsea technology developed within the framework of a Northern Oil Engineering Project to provide economic benefits in 1995 on the Flying Shearwater project in the Gulf of Mexico (Lee-Zuck, 2023). Subsea separation and allocation system is designed for the separation of oil, water and gas in a single subsea system that allows the discharge of several oil production trunk lines connected to various subsea wells (Whitehead, 2023). The main aspects considered in the development of this system include the possible problems arising from the dispersion of gases in the fluid flow produced with complex distribution of fluids at various subsea wells through various commingled well drains located on the platform of floating drilling facilities.

The research into the potential use of subsea processing for the removal of water from oil and treatment of gas was focused mainly on the North Sea (Kaiser, 2022). Dutch companies Speed Curing and Atlantic Richfield Company (ARC) carried out engineering studies and designed a number of subsea processing systems. Shell has also worked on the topic for many years. Houston Offshore Engineering, Cal-Dive Inc., SPT Group, and many other companies also attempted to develop subsea technologies. The practical part of the work on subsea separation and the allocation of reservoirs between export pipelines was carried out under a northern oil engineering project (Li et al., 2022). Conoco submitted a statement of the potential use of subsea process systems on the KD field. The real production tests of subsea separation and measurement systems are the first step towards creating subsea systems that are ready for application on a commercial scale, provided that such systems meet standard requirements (Mohammed et al., 2022).

II. Subsea Separation Systems

Oil and gas operators with mature assets located in shallow water locations are looking for new technologies to revitalize recovery and extend asset life, particularly when considering developing new deepwater resources in close proximity to existing infrastructure (Sales et al., 2023). The goal of developing technology suitable to operate at the bottom of the sea by means of subsea oil and gas processing is to improve nearer field oil recovery, increase ultimate oil and gas recovery, and reduce operating costs and risks, thus extending the life of field development solutions for these marginal and deepwater fields (Hammond et al., 2022). Based on recent pilot projects, it has been proved that the implementation of subsea processing technologies has the potential to make marginal and deepwater developments more attractive. With the increase in exploration in deep and ultra-deep waters, it is becoming apparent that a considerable amount of these reserves are in locations with a large inventory of wells surrounding multiple fields and that in these types of cluster developments, subsea separation of the hydrocarbon phases will lead to a significant increase in recovery. Such separation will also mitigate hyper-dynamic multiphase flow line flow conditions and minimize water recycling in wet gas applications (Ochulor et al., 2024).

Implementing subsea processing technologies for the separation, treatment, and transportation of oil and gas produced from subsea wells is a crucial aspect of the offshore oil and gas industry (Igbinenikaro et al., 2024). This innovative approach allows for the extraction of hydrocarbons in harsh and deep waters, where traditional methods are not feasible or cost-effective.

Subsea processing involves the installation of various equipment and systems on the seabed, close to the wellhead, to perform essential functions that were historically carried out on surface platforms (Edwards et al., 2023). These functions include the efficient separation of oil, gas, and water, as well as the treatment of fluids to meet quality specifications before transportation to onshore facilities.

One of the primary advantages of subsea processing is the reduction in topside infrastructure. By moving the processing activities closer to the source, the need for large and expensive offshore platforms is minimized (Kaiser, 2022). This not only lowers capital and operating costs but also reduces the environmental footprint associated with traditional offshore installations.

Subsea separation systems are designed to handle varying flow rates, pressures, and oil and gas compositions, making them adaptable to a wide range of reservoir conditions (Liu et al., 2022). These systems utilize advanced technologies such as cyclonic separators, hydrocyclones, and centrifuges to achieve efficient and effective separation of oil, gas, and water phases. The recovered oil and gas are then further processed, while the separated water is treated and discharged in compliance with environmental regulations.

In addition to separation, subsea processing also encompasses various other functions such as boosting, compression, and injection (Zheng et al., 2022). Subsea boosting systems are utilized to enhance the flow of hydrocarbons from the wellhead to the processing facility, overcoming the challenges posed by long tieback distances and low reservoir pressures. Compressor stations installed on the seabed ensure the maintenance of optimal gas pressures for efficient transportation through subsea pipelines. Furthermore, injection systems are employed to re-inject produced water or gas back into the reservoir for pressure maintenance or enhanced oil recovery, minimizing waste and maximizing resource utilization.

The implementation of subsea processing technologies requires careful planning, engineering, and integration with existing field infrastructure (Edwards et al., 2023). It involves considerations such as subsea architecture, equipment selection, power supply, control systems, and flow assurance. Remote monitoring and control systems enable efficient and safe operation of subsea facilities, ensuring optimal performance and minimizing the need for human intervention.

Overall, subsea processing technologies play a vital role in unlocking the potential of offshore oil and gas reserves (Ochulor et al., 2024). They provide significant cost savings, improve project economics, and enable the development of fields that were previously considered uneconomical. As the industry continues to advance in subsea engineering, the future holds promising possibilities for the widespread adoption of these innovative technologies, revolutionizing the way oil and gas are produced from subsea wells.

2.1. Different Types of Separation Systems and their Functions

Subsea separation applications are classified and distinguished based on their capacity to effectively handle various substances such as oil, gas, water, and gas hydrates (Fu et al., 2024). Additionally, they are capable of managing non-ideal and unconventional fluid behaviors. The diverse range of these applications is further explained by providing a comprehensive list of process technologies. This list encompasses their current state, potential future requirements, as well as the commercial vendors involved. Within the realm of subsea separation, four distinct unit operations are currently in progress. These operations are integral components of the overall development in this particular field. The first operation involves initial preseparation, which precedes the subsequent phase separation and eventual complete separation in conventional upstream processes. Furthermore, these separation techniques can be synergistically combined with the capability to recycle water back into the well. Additionally, they also possess the ability to effectively process non-ideal and unconventional hydrocarbons, further enhancing their versatility and effectiveness (Englezos, 2022).

The available range of subsea separation technologies spans a number of functions and configurations (Malozyomov et al., 2023). This technology can be targeted for meeting the requirements of a number of reservoir and well types as well as producing various types of hydrocarbons such as oil, gas, water, and foamy oil-natural gas mixtures. As a result, numerous separation configurations are being considered in the available technologies. These areas of technological challenge and potential separation technology crossovers also point the way to considering current subsea separation developments not as prepackaged unit operations but as processes. And these processes may take place through collaboration and operation of multiple separation devices over a field's life or through larger, longer, and more complex operation of single vessels and associated equipment (Luo et al., 2023).

III. Subsea Treatment Technologies

Subsea treatment includes producing subsea water when gas hydrates are present, processing and separating the reservoir fluids downhole before the fluids and gases are sent to the surface production facility where further separation, gas compression, and market-ready products are performed (Manzano-Ruiz & Carballo, 2024). Subsea separation handles the multiphase flow to provide gas, crude, and water streams to the surface with or without pre-treatment. It is at the more extreme end of subsea processing as the process is likely to deal with a variety of flow rates with the associated high hydraulic load and process upsets.

Subsea treatment technologies encompass a number of activities which can be carried out close to the hydrocarbon source rather than utilizing vessel topsides to perform the necessary surface processing (Ochulor et al., 2024). The amount of processing that can be handled subsea is primarily driven by the field life and production levels, along with economic drivers including reduced production downtime.

As a direct consequence of the physical and technical constraints associated with routing fluids produced from the subsea wells to the host production facility, subsea treatment and processing is required to remove impurities, transport and treat the crude without re-injection of production fluid or water handling (Roland et al., 2023). Subsea treatment and processing can minimize the need for costly and inefficient methods of boosting production that are used when the pipelines and FPS installed have high back pressures, need for hydrate and wax treatment, and when the development concept calls for deepwater reservoir drainage.

Subsea processing technologies are primarily used to address and manage flow assurance issues and maximize hydrocarbon recovery (George et al., 2024). The selection of specific subsea processing technologies/processes can greatly influence the topsides facilities, transportation requirements, and profitability of a deepwater oil and gas development project. In almost all cases, producing from subsea wells is a necessity due to many environmental and operational deepwater challenges.

3.1. Chemical Injection Systems

Initially implemented in water depths up to 350 m, these trees provided valuable increased certainty to the production system hygiene (Haalboom et al., 2023). Remedial chemical dosing was effectively achieved over the field's ten-year delivery schedule, with the platform having completed processing of the produced well flows. By value-adding with chemical injection on existing or new pipelines, deepwater systems also become commercially attractive, with pigging support over extended lengths of line. Community acceptance of planned higher still barrier systems can be made more achievable with the additional security and management built in by the availability and support of system-injected and carried chemistry (Kaiser, 2022).

Chemical injection systems are an essential part of any subsea field handling system used for the production or processing of hydrocarbons (Hegdal & Passarelli, 2023). The function of the chemical injection system is to inject and distribute various types of chemicals in different phases, at different times and locations, as required to maintain process control of parameters affecting production, such as corrosion, scale, wax, and hydrates. These systems can be driven by gas supply using topsides cooling or as part of the chemical re-dosing system, further increasing the operating envelope. The chemical supply system is a modular process system addition, so it can be readily added in a subsea factory framework to existing facilities. Subsea chemical injection trees have been installed and are operating in the Troll field.

IV. Subsea Transportation Systems

The ability to transfer produced fluids for very long distances from the reservoirs to the host facility without the transportation conditioning typically associated with sending fluids from the seabed to the surface and from the surface to the facility can provide significant benefits, such as the ability to operate at deeper water depths, fewer field processing steps and their associated CAPEX and OPEX cost (Zhao et al., 2024). Subsea transportation can minimize the number of exposed dry trees to minimize vessel operational risks, has a smaller subsea hardware footprint that may simplify flowline installation and host facility tie-in. With separation and treatment equipment on the output side of the transportation line, subsea processing results in a transportation-ready fluid being delivered to the receiving host facility with minimal rental items. In the event of a subsea processing system upset or integrity issue that cannot be resolved in a timely manner, insertion of temporary spool pieces with topside disposal system access can provide a short-term fix followed by a more economical long-term solution (Zhang, 2023).

Advancements in subsea processing technologies, as well as in both subsea hardware and infrastructure, allow oil and gas producers to transfer produced fluids to the host facility with no modification, as well as to boost produced fluids to the host facility with significant increases in tieback distances as compared with traditional subsea production practices (Kumar, 2023). Transportation options, benefits, and considerations for both the produced fluid transportation methods and boost transportation methods are provided. Key subsea processing technologies discussed that allow the transportation of the produced fluids directly from the reservoirs to the host facility with very minimal transportation conditioning are multiphase boosting, multiphase pumping, and compact inline separation technologies. Offshore crude oil relief systems provide another subsea processing option to enhance transportation of high gas to oil ratio produced fluids.

4.1. Pipeline Networks

Transport and export of separated oil and water, and gas, to their various delivery destinations within acceptable specifications require some form of subsea processing systems (Ochulor et al., 2024). The form and complexity of the processing equipment will, to a large extent, depend on the distance from the subsea well location to the facilities where the treated and separated products are finally discharged. If the distance between a subsea processing equipment and point of final product(s) delivery is long, the product has to be delivered through long pipeline networks, which could be expensive and require provision of pigging facilities to ensure that pipeline internal conditions are maintained throughout the delivery period (Czachorowski, 2021). Due to difficulty associated with subsea pigging, which increases in operational difficulty as pipeline diameter increases, especially considering longer pipeline systems, and the costs associated with equipment installation and operations, their use has a generally established minimum requirement of a fully qualified return for subsea pipeline capital and operating investment.

V. Integration of Subsea Processing Technologies

To turn an offshore oil and gas reservoir into an economically attractive project, our interest is to recover the maximum amount of valuable contents thoroughly, or in other words, it requires the application of efficient reservoir management practices focused on subsea completion technology (Daramola et al., 2024). It has been made possible by the innovations of the recent years in subsea technologies, including the advances in subsea control and chemical injection, facing the myriad of obstacles that were formerly in the way of the rapid growth of the ultimate subsea reservoir management. The early subsea production systems consisted mainly of just a production tree and flowlines exposed to the full process, both of the ejection and the flow assurance. The pace in the necessity for more costly subsea manifolds was conducted by the rapid profitability brought about by riser caissons (Onwuka & Adu, 2024).

Frequently, a subsea system is composed of different modules installed at the sea bottom, which are linked to the sea surface by flowlines that incorporate control umbilicals allowing the communication between the onshore facilities and the seabed equipment (Liu et al., 2024). A subsea module can be briefly described as a pressure-resistant structure and environment that contains process equipment for conditioning products and well fluids. The flowlines are capable of providing the flow from and to the subsea facilities and the control cables, the flow of electrical power and communication signal. The main functions of the subsea module are to connect the deepwater wellhead, provide the primary casing point for shallow gas, initiate primary well startup, receive the hydrocarbon production flow, process oil and gas into the risers, produce the water stream out of the risers, and provide the necessary subsea control for the well (Wang et al., 2024).

5.1. Benefits and Challenges

Reductions in the sizes and operational costs of processing systems on fixed or floating offshore platforms can be achieved. Reduced CAPEX can be achieved due to savings in topside weight, space and engineering with smaller separators (or fewer of them), lighter power requirements, and reduced requirements for produced water treatment equipment (PWT) (Pope et al., 2023). Reduced operating costs can be achieved through reduced and simpler well manifolding, reduced chemical usage and less chemical injection equipment, lower utilities requirements for cooling water and steam production, and potentially, also lower parasitic losses and greenhouse gas emissions. Subsea separators also allow more exported and therefore patented fluid allocations and stabilized/proven product demarcations.

In addition to handling increased volumes of undiluted heavy oil and water with potential for hydrates, separators will often also be located further away from the production sites with less reliable surface facilities and less regular vessel visits for operation and maintenance (Paulsen, 2023). However, recognizing these challenges, the following sections outline a number of significant benefits and differences between subsea separators and topside separators. Depending on the profile of the particular oil or field, subsea separation can offer benefits in terms of CAPEX, OPEX, and HSE. These benefits can derive from enabling more (total) production from a field for which topside space and weight is a limiting factor or enabling subsea developments of smaller oil fields that would not be economic to bring to the surface (Khan et al., 2023).

VI. Case Studies of Successful Implementations

The technology and resources for successfully implementing subsea processing are available, and the engineering bottlenecks are fully understood (Luo et al., 2023). Economic justification for field development and robust expected production profiles exist, though the added complexity, cost, energy requirements, and logistics concerns must be managed carefully prior to implementing subsea system technologies. The best time for implementation of subsea system elements is during the concept and Front End Engineering Design phase of development, as demonstrated throughout the article (Yazdi et al., 2022). The level of cooperation required with key members of the supply chain, as well as through early installation as part of the planned production timeline and strategy, will be crucial in enabling the execution of these challenging projects. The development and implementation of subsea system technologies for boosting recovery have been continuously improving, demonstrated by several success stories (Aryai et al., 2021).

To highlight successful subsea processing design applications as proof of concept, three case studies demonstrate that these technologies are ready to handle oil, gas, and produced water from subsea fields while overcoming ultra-deep water challenges economically (Salem & Thiemann, 2022). The first case study involved a dry tree design with a production Syphon EL system, while the second featured a subsea production system with multiphase pumps suitable for the ultra-deep Golfinho water field. The third case study demonstrated a complete subsea separation system design for the Petrobras BSR (RJS-542 & BM-PAR-02) oilfield (Ochulor et al., 2024).

6.1. North Sea Projects

Two companiesFramo Engineering (which, after merging with affiliate companies, is named FMC) and ABB Offshore Systemshave promoted both full-scale demonstrations and implementation projects in the North Sea. FMC built the first commercial subsea oil desander for Statoila land-based version of the subsea separator Pilot III demonstrator tested in 1996(the Statoil solution was designated as TAGD, Tordis Amine Green Dew pointing). The work took place from April 2001, and the first gas-free oil production was achieved at the North Sea's Tordis field when the system was hardwired in June 2003 (Bhardwaj et al., 2022).

In 1994, Saga Petroleum built an experimental subsea separator with gas flooding and electrical heating as the primary separating energy at approximately 200-m depth in the Fjord field in the North Sea (Edo et al., 2024). A smaller version (Pilot III demonstrator) of an external electrostatic separator was also tested in 1996 at the surface at NorSea Test Center in near full-scale. In 1999, Norsk Hydro (Hydro) partially implemented an open-loop separation system for Tordis on the Norwegian Continental Shelf, where the system used conventional pumps adapted for subsea operation and the separator solution acted as riser base ramp up of the heavy oil-gas mixture (Briguglio & Crupi, 2024).

VII. Future Trends in Subsea Processing Technologies

There is the need to achieve VPH (i.e., Viable Platform Host) tiebacks in deep water of more than 100 miles distance. Such tiebacks could be from 20 to 200-m water depth using low-pressure wet-gas flow in a gas transmission line to a host platform or storage vessel. To address the issues associated with metallurgy (i.e., high capital/operating cost), separation and oil treatment as well as gas dehydration and/or compression and the overall subsea system performance, the industry is focusing on a move to the development of VPH and novel configurations. While VPHs down to 20-m water depth with tiebacks of more than 20 miles length are possible and would be of great interest, beyond this, operations are then considered to be more suited to the conventional platform concept. However, with the high level of activity on the VJ8 project implementation, it is likely that such a development initiative utilizing VPH technology would become an exciting reality in the near future. The future development will likely encompass early gas monetization that would lead to improved stranded gas performance. In addition, subsea gas-liquid-separation with subsea re-compression is likely to become a reality in the future due to high demand for subsea fields not requiring a manifold. The field developments will be considered more cost-effective if such facilities were installed to sustain future development drilling and allow for the structural importation of the gas to meet high market demands (Xiao, 2023).

The need for subsea processing technologies has become widely acceptable in the petroleum industry, especially following high investment in R&D over the years (Igbinenikaro et al., 2024). There has been commendable leapfrog advancements in the suite of subsea technologies, including new and improved processing systems. Many oil and gas fields are increasingly moving toward the subsea environment as restoration efforts appear to be maximized optimally with all subsea facilities. As these facilities are seeing greater utilization, the need to improve the subsea oil/gas treatment process has become paramount to most operators for both economic and environmental reasons. The future trends are focused on more reliable, cost-effective, and high processing system availability. The need for innovation to improve the enabling process, especially to enhance the performance of all systems, plays out as a major future trend (Guo et al., 2022).

7.1. Advancements in Automation

Presentday subsea process control systems are still based on conventional components. As a rule, these purposes still operate under the condition that the wireless communications system and its communication patterns are still equal, real-time action can no longer be guaranteed. Upward communication is not a critical task because it is only needed for configuration and supervision, and it is acceptable that this does not occur or is delayed in real-time. Downward communication is also not real-time critical because it is only necessary to reprogram if the system configuration or working points need to change without the possibility of human inspection on site. These are also open control issues that need contributions. Within these patterns, bandwidth concern is less critical than in the control loop. Presently available mobile subsea communication systems and other systems specialized for the wireless subsea substation could already provide an answer to the communication challenge within these patterns. The first qualification of the essential communication technologies and architectures intended for this application has already been made (Jurdik et al., 2022).

To be able to exploit and optimize subsea oil and gas processing plants, the controlling system must be extraordinary. Due to the absence of human operators at deep waters, the unmanned subsea plant depends heavily on the proper behavior of the controlling system (Solovyeva et al., 2023). Any maintenance and interaction with the controlling system is only possible when the ROV is available. Even so, a real present-day optimal process model has too much potential. What will be hard on the process side is to cope with the effects of pipeline design, topside and subsea connections, and the other supplies and operation constraints that can change during the operation of different fields unfailingly. In many cases, the control system should be robust rather than optimal because it is too hard to bring all the disturbances level to an acceptable range during the design phase. For subsea chemical systems that are controlled by manipulations on the separator's chemical composition (addition of chemicals), optical (semi-) direct (measurement), on-line measurement of the quality is nowadays being realized. Subsea use of on-line measurement for separator quality assessment is not yet commercially a reality. For the envelope of fully utilizing separator properties, evolutionary steps are necessary (Zheng et al., 2022).

VIII. Conclusion

The adoption of subsea processing/production technologies and the development of best practices will depend on a host of factors that include the local ecosystem, geography, water depth, reservoir characteristics, opportunities for secondary well control, reliability uptime, weight and outer dimensions of the processing unit, the performance of the process, and many more. The active participation of industry players is crucial to determine how subsea processing can help meet these critical industry objectives and technical goals. More work is needed to develop transformative technologies that can aid in full-field development cost and footprint reduction for these unique reservoirs in remote regions. With massive oil reserves in deep offshore locations, which are often found in harsh climates, subsea operations have a crucial role to play in extending the life of existing facilities and making production viable. Deployment of Sandy well operations and innovation in this market segment will be primary to be effective in sustaining difficult summit/peak demand over the next 20-30 years. Our recommended technical development will definitely contribute to stimulate technical cooperation and the creation of a new blue ocean market.

Technological developments, such as subsea processing, that reduce costs, improve recovery rates, and help exploit the most challenging reservoirs, are critical. These technologies will push the subsea sector forward over the next 20-30 years. This paper aims to provide insight into various subsea processing technologies available for the separation, treatment, and transportation of oil and gas produced from subsea wells. These technologies also hold the potential to advance the win-win agreement between the goals of economic and environmental interests of the oil and gas sector. Although the adoption of these technologies is increasing, and constant R&D efforts continue to develop novel technologies, more work is needed to realize the transformational technology shift in deep water and ultra-deep-water settings. This work presents a systematic review based on existing subsea processing technology and further areas of development, covering the areas enabling understanding, research, and ultimately targeting the needs of the market and both current and proposed system installation.

References

[1]. Aryai, V., Abbassi, R., Abdussamie, N., Salehi, F., Garaniya, V., Asadnia, M., ... & Wang, C. M. (2021). Reliability of multi-purpose offshore-facilities: Present status and future direction in Australia. Process Safety and Environmental Protection, 148, 437-461. nih.gov

[2]. Belhaj, H. (2023). Tight Oil Reservoirs: Characterization, Modeling, and Field Development. [HTML]

[3]. Bhardwaj, U., Teixeira, A. P., & Soares, C. G. (2022). Bayesian framework for reliability prediction of subsea processing systems accounting for influencing factors uncertainty. Reliability Engineering & System Safety, 218, 108143. [HTML]

[4]. Briguglio, G. & Crupi, V. (2024). Review on Sensors for Sustainable and Safe Maritime Mobility. Journal of Marine Science and Engineering. mdpi.com

[5]. Czachorowski, K. V. (2021). Cleaning up our act: systems engineering to promote business model innovation for the offshore exploration and production supply chain operations. Sustainability. mdpi.com

[6]. Daramola, G. O., Jacks, B. S., Ajala, O. A., & Akinoso, A. E. (2024). AI applications in reservoir management: optimizing production and recovery in oil and gas fields. Computer Science & IT Research Journal, 5(4), 972-984. fepbl.com

[7]. Edo, G. I., Samuel, P. O., Jikah, A. N., Ekokotu, H. A., Ugbune, U., Oghroro, E. E. A., ... & Owheruo, J. O. (2024). Petroleum Discovery, Utilization and Processing in the World and Nigeria: A Comprehensive Literature Review. Sustainable Chemical Engineering, 192-216. wiserpub.com

[8]. Edwards, E. C., Holcombe, A., Brown, S., Ransley, E., Hann, M., & Greaves, D. (2023). Evolution of floating offshore wind platforms: A review of at-sea devices. Renewable and Sustainable Energy Reviews, 183, 113416. sciencedirect.com

[9]. Englezos, P. (2022). Applications of clathrate (gas) hydrates. Clathrate Hydrates: Molecular Science and Characterization, 2, 749-781. [HTML]

[10]. Fu, C., Yang, J., Liu, S., Lu, M., Luo, M., Ma, C., ... & Li, X. (2024). Analysis of the Application of Horizontal Well Technology in the Development of Offshore Natural Gas Hydrate. Chemistry and Technology of Fuels and Oils, 60(1), 207-216. [HTML]

[11]. George, I. S., Orji, C. U., & Douglas, I. E. (2024). Flow assurance analysis in Front End Engineering Design (FEED) of Subsea Flowline and Riser. World Journal of Advanced Research and Reviews, 22(2), 1326-1338. wjarr.com

[12]. Guo, Y., Wang, H., & Lian, J. (2022). Review of integrated installation technologies for offshore wind turbines: Current progress and future development trends. Energy Conversion and Management. [HTML]

[13]. Haalboom, S., de Stigter, H. C., Mohn, C., Vandorpe, T., Smit, M., de Jonge, L., & Reichart, G. J. (2023). Monitoring of a sediment plume produced by a deep-sea mining test in shallow water, Málaga Bight, Alboran Sea (southwestern Mediterranean Sea). Marine Geology, 456, 106971. sciencedirect.com

[14]. Hammond, S., Zahari, I., & Berwanto, A. (2022, March). Direct Hydraulic Control Systems as a Key Enabler for Developing Shallow Water Marginal Fields. In Offshore Technology Conference Asia (p. D041S037R003). OTC. [HTML]

[15]. Hegdal, T. & Passarelli, F. M. (2023). Decentralized Subsea Water Treatment And Injection System For Unlocking FPSO Hydrocarbon Processing Capacity And Reduce Costs. Offshore Technology Conference Brasil. [HTML]

[16]. Igbinenikaro, O. P., Adekoya, O. O., & Etukudoh, E. A. (2024). A comparative review of subsea navigation technologies in offshore engineering projects. International Journal of Frontiers in Engineering and Technology Research, 6(02), 019-034. researchgate.net

[17]. Igbinenikaro, O. P., Adekoya, O. O., & Etukudoh, E. A. (2024). Emerging underwater survey technologies: a review and future outlook. Open Access Research Journal of Science and Technology, 10(02), 071-084. researchgate.net

[18]. Jurdik, E., Aksyutin, O., Hugaas, B. A., & Liu, P. (2022). TurkStream Technological Advancements. International Journal of Offshore and Polar Engineering, 32(03), 257-266. [HTML]

[19]. Kaiser, M. J. (2022). Offshore oil and gas records circa 2020. Ships and Offshore Structures. [HTML]

[20]. Khan, R., Rahman, A. B., Shafie, W. H. F. B., & Nezamian, A. (2023, June). Performance Based Approach for the Structural Design for Fixed Offshore Structures. In ISOPE International Ocean and Polar Engineering Conference (pp. ISOPE-I). ISOPE. [HTML]

[21]. Kurnia, J. C., Shatri, M. S., Putra, Z. A., Zaini, J., Caesarendra, W., & Sasmito, A. P. (2022). Geothermal energy extraction using abandoned oil and gas wells: Techno-economic and policy review. International Journal of Energy Research, 46(1), 28-60. [HTML]

[22]. Lee-Zuck, C. (2023). Foraging behaviour and flight dynamics of rhinoceros auklets (Cerorhinca monocerata) experimentally dosed with diluted bitumen. sfu.ca

[23]. Liu, B., Chen, B., Ling, J., Matchinski, E. J., Dong, G., Ye, X., ... & Zhang, B. (2022). Development of advanced oil/water separation technologies to enhance the effectiveness of mechanical oil recovery operations at sea: Potential and challenges. Journal of Hazardous Materials, 437, 129340. [HTML]

[24]. Li, Z., Xie, R., Wu, Y., & Yuan, J. (2022). Progress and prospect of CNOOC's oil and gas well drilling and completion technologies. Natural Gas Industry B. sciencedirect.com

[25]. Luo, J., Xie, Y., Hou, M. Z., Xiong, Y., Wu, X., Lüddeke, C. T., & Huang, L. (2023). Advances in subsea carbon dioxide utilization and storage. Energy Reviews, 2(1), 100016. sciencedirect.com

[26]. Malozyomov, B. V., Martyushev, N. V., Kukartsev, V. V., Tynchenko, V. S., Bukhtoyarov, V. V., Wu, X., ... & Kukartsev, V. A. (2023). Overview of methods for enhanced oil recovery from conventional and unconventional reservoirs. Energies, 16(13), 4907. mdpi.coml

[27]. Manzano-Ruiz, J. J. & Carballo, J. G. (2024). Multiphase Transport of Hydrocarbons in Pipes. [HTML]

[28]. Mohammed, A. S., Reinecke, P., Burnap, P., Rana, O., & Anthi, E. (2022). Cybersecurity challenges in the offshore oil and gas industry: an Industrial Cyber-Physical Systems (ICPS) perspective. ACM Transactions on Cyber-Physical Systems (TCPS), 6(3), 1-27. [PDF]

[29]. Ochulor, O. J., Sofoluwe, O. O., Ukato, A., & Jambol, D. D. (2024). Technological innovations and optimized work methods in subsea maintenance and production. Engineering Science & Technology Journal, 5(5), 1627-1642. fepbl.com

[30]. Ochulor, O. J., Sofoluwe, O. O., & Ukato…, A. (2024). Challenges and strategic solutions in commissioning and start-up of subsea production systems. Magna Scientia …. magnascientiapub.com

[31]. Onwuka, O. U. & Adu, A. (2024). Subsurface carbon sequestration potential in offshore environments: A geoscientific perspective. Engineering Science & Technology Journal. fepbl.com

[32]. Paulsen, E. H. (2023). … and Assess Business Performance Differences and Opportunities Regarding Traditional Topsides versus Subsea Chemical Storage and Injection for Subsea Wells. unit.no

[33]. Pope, R., Douglas, S., Chowdhery, A., Devlin, J., Bradbury, J., Heek, J., ... & Dean, J. (2023). Efficiently scaling transformer inference. Proceedings of Machine Learning and Systems, 5, 606-624. mlsys.org

[34]. Puskic, P. (2024). Impacts of plastic ingestion on seabirds. utas.edu.au

[35]. Roland, P., Vasquez-Quintero, F., Pouplin, A., Shaiek, S., & Giolo, R. (2023, April). A New Subsea Station for Deep Gas Treatment Allowing to Maximize Subsea Gas Fields Production. In Offshore Technology Conference (p. D041S048R002). OTC. [HTML]

[36]. Salem, F. & Thiemann, T. (2022). Produced water from oil and gas exploration—problems, solutions and opportunities. Journal of Water Resource and Protection. scirp.org

[37]. Sales, L., Stolpnes, T., Stanko, M., & Faanes, A. (2023, June). Subsea Processing Optimization Considering Reliability and Maintenance. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 86830, p. V001T01A007). American Society of Mechanical Engineers. [HTML]

[38]. Solovyeva, V. A., Almuhammadi, K. H., & Badeghaish, W. O. (2023). Current downhole corrosion control solutions and trends in the oil and gas industry: a review. Materials. mdpi.com

[39]. Thompson, C., Jegannathan, M., & Jeansonne, N. (2022, April). Maximizing value from mature assets in deepwater Gulf of Mexico. In Offshore Technology Conference (p. D021S018R006). OTC. [HTML]

[40]. Wang, J., Tang, Y., Li, S., Lu, Y., Li, J., Liu, T., ... & Yan, S. (2024). The Haidou-1 hybrid underwater vehicle for the Mariana Trench science exploration to 10,908 m depth. Journal of Field Robotics, 41(4), 1054-1079. [HTML]

[41]. Whitehead, E. A. (2023). Oceanic Storytellers Integrative methods for seabird conservation monitoring. auckland.ac.nz

[42]. Xiao, A. (2023). Surveillance of SARS-CoV-2: From Sewage to the Clinic. mit.edu

[43]. Yazdi, M., Khan, F., Abbassi, R., & Quddus, N. (2022). Resilience assessment of a subsea pipeline using dynamic Bayesian network. Journal of Pipeline Science and Engineering, 2(2), 100053. sciencedirect.com

[44]. Zhang, D. (2023). Key Technologies for Safety Construction of Mined Subsea Tunnels. [HTML]

[45]. Zhao, Y., Ma, Y., Peng, Z., & Zhou, J. (2024). A risk-based decision-making scheme for short-sea liner fleet renewal to achieve carbon reduction targets. Research in Transportation Business & Management, 54, 101112. [HTML]

[46]. Zheng, X., Junfeng, S. H. I., Gang, C. A. O., Nengyu, Y. A. N. G., Mingyue, C. U. I., Deli, J. I. A., & He, L. I. U. (2022). Progress and prospects of oil and gas production engineering technology in China. Petroleum Exploration and Development, 49(3), 644-659. sciencedirect.com

[47]. Zhixin, W. E. N., Jianjun, W. A. N. G., Zhaoming, W. A. N. G., Zhengjun, H. E., Chengpeng, S. O. N. G., Xiaobing, L. I. U., ... & Tianyu, J. I. (2023). Analysis of the world deepwater oil and gas exploration situation. Petroleum Exploration and Development, 50(5), 1060-1076. sciencedirect.com