Identifying Challenges in the Development of Subsea Petroleum Production Systems

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Abstract. There are many challenges associated with development of offshore petroleum fields. Subsea production facilities are increasingly used in the petroleum industry as the technology has matured and quality increased. The use of subsea technology has advantages as well as challenges. Based on a literature review this paper identifies some if the development challenges related to the design and operation of subsea petroleum production facilities.

Keywords: Subsea petroleum production facilities, Development challenges

1 Introduction

Oil companies are tending to use subsea technology in new field developments because it has several advantages over traditional exploitation. The type of technology used for reservoir exploitation and challenges should be determined before operations are started. Identifying activities associated with the development of subsea systems entails knowing and designing for the oil and gas (O&G) production process, reservoir flow and seabed conditions, environmental risks, costs and performance requirements. Each subsea installation design case may be different since the equipment needs to be designed for the reservoir fluid composition, oil and/or gas quality, pressure and flow, as well as sea depth, seabed conditions and topography, distance to shore, etc. Furthermore, from a management perspective, in each petroleum production development phase there are many companies involved which need to be coordinated and managed with respect to work activities, contractual issues, scheduling, supply logistics and quality assurance, etc.

For example, in Norway the Ormen Lange gas field located in the Norwegian Sea, at 800-1100 m depth approximately 140 km from the coast, was developed as subsea production for a new onshore gas processing plant [1]; [2]. The field was discovered in 1997, and production started in 2007. The field is located far from shore and even farther from the market and presented many unprecedented challenges including the fact that Norwegian industry lacked experience with such deep-water gas production. The operator performed high-resolution seismic surveys, seabed mapping, shallow coring and deep geotechnical drilling. The gas, condensate and water are transported from subsea installations using pipelines to an onshore process terminal where they are processed before a further 1200 km transportation through a pipeline to the UK via the Sleipner production platform in the North Sea. This is the largest pipeline in the world, and it required one million tonnes of steel and 25,000 tonnes of reinforced iron to build it. The subsea installations were designed to take into account the currents and sub-zero temperatures on the seabed, as well as extreme wind and wave conditions creating problems during installation and maintenance work. The field is expected to continue to produce gas for 30-40 years and delivers up to 20% of the UK´s gas requirements. The total costs are reported to be 66 billion Norwegian Crowns (NOK) (approximately 12 billion USD, June 2010 exchange rate) [3].

Preview studies of the reservoirs will decide the necessary subsea infrastructure, the number of production years expected and the total O&G assets' value. Often long and expensive engineering studies are needed to decide the production installation type, size and location. However, sea floor production installations are increasingly used as an alternative to topside facilities. Thus, the use of new and more reliable technology in deep-water environments has helped to bring about faster production, reducing risks and equipment failures.

Operators often choose to work with proven technology that is used in projects with the same or similar environmental characteristics and technical requirements. Waiting time costs money, and managers usually have economic pressures to complete the production facilities. Competition forces companies to work in the same technological conditions, getting new processes and technology as soon as they are in the market [4]. The experience gained in earlier projects, and the acquisition of assets needed in those projects, allows companies to develop new projects faster, getting data for statistical analysis and, moreover, valuable experience in subsea environments. However, in each exploration area there are uncertainties and new challenges that will need new or improved technological solutions. With new technology and prototype equipment, the uncertainty increases and unforeseen events may occur due to the fact that the equipment has not been totally proven [5].

Based on a literature review and interviews of industrial experts this paper identifies and discusses some of the challenges related to development of subsea petroleum production facilities.

2 Field Development

The oil and gas production can broadly be defined in two phases, namely the oil and gas exploration and the oil and gas exploitation phase. There are direct and indirect costs as well as taxes and insurances which all have to be taken into account in both phases.

2.1 Exploration Phase

There are high investment costs related to the exploration phase, and the use of advanced technology does not always result in finding a viable O&G field. Exploration and development activities are long-term investments and quite important to companies which can learn from the information that they acquire [6]. Operators lease a geographical area based on geological analysis, geophysical data, etc., and invest in equipment and knowledge to obtain additional data about the potential for finding hydrocarbons in the ground [7]. Often drilling and exploration efforts result in no O&G found in the reservoir. The reasons are many, but are often due to imprecision in the pre-exploratory studies of geophysical data. This results in a loss for the operator. Furthermore, if O&G is found, the question remains of what technical solution should be used to produce the O&G.

Exploration is the first activity that oil companies have to carry out, mapping the area for further analysis. When a rock formation containing potential oil and gas is found, it is necessary to drill wells to obtain data and information about the geology, and then the type of equipment needed in the production systems will be decided. The drilling of wells generates information about hydrocarbon reserves, quantity and type, as well as information about reservoir characteristics and other factors which will later determine the possible oil exploitation. Results and data obtained from this phase provide valuable information for use in the production system's design and the strategy for developing the oil field.

However, the probabilities of a commercial discovery are low, often less than 10% [6]. Furthermore, reservoirs have to be capable of producing oil and/or gas at a minimum flow rate to be economically profitable. Large companies develop their studies and decisions for drilling in a new field based on the production expected and the size of the organization. Hence, a lot of smaller reservoirs are not economically attractive to the large companies.

2.2 Exploitation Phase

The raw oil and gas comes from reservoirs containing "pollutants" or organic compounds which need to be separated before it is sent to the customers. Depending on the oil, gas and water composition of the well-stream, one makes decisions about the design of the process plant. One has to decide whether to use a topside process facility or a subsea facility. One also has to consider risks related to costs, HSE (Health, Safety and Environment), flow assurance, asset integrity, and operational and maintenance strategies. The conditions in each well will influence the chosen concept; low flow rates and the composition fluids are going to make the well behave differently at the beginning of the operations [8].

Some decisions are influenced by the reservoir depth. For instance, the separation process may have to be carried out on the seabed if the crude has high viscosity. In some cases it may be cheaper to install separation equipment on the seabed instead of pumping it to the surface. Processing decisions depend on the seabed soil type, reservoir characteristics, environmental conditions, company policies and technical feasibility. However, the final decision will be based on economics and technical solutions [9].

Many activities, equipment and people with different expertise areas are needed to move the oil and gas from the reservoir to the surface. There are many companies involved in getting the oil to the surface, and the costs may be tremendous. People and companies working on the project and service activities have to align their activities with the operator's strategy [10]; [11], according to their role in the subsea installation life cycle. Companies with different expertise and culture join in the project and should be coordinated and managed. This is not an easy task, as one has to be able to maximize the resources of the company during the total life cycle cost [12]. The purpose is to plan and ensure the resources are available before they are needed to keep expenses as low as possible.

Subsea systems involve separators, valves, compressors, pumps and associated piping [13]. Nowadays 3D design and modeling software tools are used to design the hardware and to implement complex technical requirements and operating strategies. This reduces costs as it enables operational subsea activities to be simulated before the expensive resources are used in the project implementation and execution phase [14]. When a subsea production system is shown in a computer simulator, it is easier to recognize the critical points and the challenges that will face the project. One can figure out the equipment needed such as the type of Christmas tree, manifolds, control systems, vessels, as well as decisions related to the pipelines routes [12]. Also, the costs in drilling operations have been reduced with the 3D technology.

Installation of subsea production systems entails the use of vessels capable of moving equipment and tools with cranes to the seabed. Oil and gas produced are transported through flow lines and risers to platforms, using production systems. In some cases, companies send the oil to land facilities for further processing [15]. Occasionally, new equipment failures occur in the design, fabrication or installation phases [16].

The installation of subsea systems involves many vessel movements; the equipment also has to be set in accordance to the specifications provided by the fabricator. Different types of vessels are used such as drilling, derrick barge, and tugs. Before starting operations the equipment is usually tested by the fabricator, checking that all is working before sending it offshore to be installed on the seabed. In this phase it is important that the management coordinates the activities and services provided by external companies, verifying that the system quality is working. Changes that have to be made offshore represent high costs. Hence, coordination, scheduling and prediction of activity duration are factors that should be considered [17].

3 Factors Influencing the Subsea Design

By surveying and analyzing the subsea petroleum resource, the operator may decide what types of production systems are needed. Furthermore, they have to make sure they are selecting the suppliers and service providers that are able and best suited for the tasks considering their products, quality, experience and after-sales support. Challenges in subsea operations include environmental factors such as temperature, salinity, depth and sea currents. In the design of equipment for reservoir exploitation, one has to consider factors such as structure types, vessels and the people needed for operating and controlling them [18].

Harsh climate and environmental conditions may affect the subsea installations or the interventions performed with vessels as they can contribute to damages and failures, add loads to marine structures or recalibration of subsea instruments and components [19]. Historical environmental data of the area is used in the design of the equipment and to establish the strategy to transport and install it, as well as to plan maintenance requirements.

The pressure and temperature of the O&G arriving from the well may vary from field to field. The pressure required to lift production to the host facility in shallow water is typically between 6.89 to 13.78 bars, and from reservoirs located in deep water between 68.9 to 138 bars [20]. The characteristics of hydrocarbons and the mixture between temperature and flow rate can cause solid deposits forming hydrates, waxes or asphaltenes inside the flowlines or pipelines.

3.1 Environment and Location Factors

The strategy will be different for each field due to the geographical locations. For example, subsea designs in the Gulf of Mexico are focused on the metocean conditions caused by hurricanes [15]. However, in all cases, drilling and producing oil and gas in deep water mean high pressure as well as rock formations and disruptions on the seafloor. The main environmental factors that have to be taken into account are temperature, salt, and geographical location.

Temperature

Cold and warm environments change the properties in metal and steel. Therefore, the structures and pipelines have to be fabricated and coated in accordance with the temperature on the seabed. When the oil comes to the seabed it is warm due to the temperature in the reservoir, and the oil produced tends to behave differently when temperature and pressure change. Hence, the oil will be cold in the flow lines, and need to be insulated to stabilize the temperature for maintaining the oil properties and transporting production to onshore [21]. Designers have to take into account the materials and equipment for resisting local temperatures, and measure and test the performance in each case. Using equipment and materials that can resist different temperatures without losing their properties will allow for better performance and durability, and there will be less need for corrective maintenance.

Salinity

The exposure to salt in the sea environment causes the equipment to deteriorate. Oxygen in the water reacts with salt and causes pipelines, risers and any equipment underwater to corrode. Corrosion is the transfer of electrons from one substance to another and is an electrochemical reaction that oxidizes metals very quickly [22]. Hence, the preventive maintenance should be focused on preparing the equipment and tools for working under these conditions. More research is needed to design materials for resisting the salt effects for longer periods, thus resulting in lower maintenance costs.

Geographical Location

Maintenance strategies also need to be designed according to the field location. There are zones with soil disruptions or pockmarks where it is sometimes necessary to level the land to install and stabilize the equipment. It also may be necessary to install additional equipment or concrete mattresses, special support structures or ramps for withstanding the weight or to balance structures or pipelines.

If the seabed is uneven, debris could accumulate over time. As a result, it may become necessary to remove debris brought by currents from the area where the pipelines and umbilicals are placed. The production system and the pipeline route selection is one of the more critical activities. If it is done poorly without taking care of the geotechnical and marine conditions, it may be costly and result in operational delays [23].

4 Intervention Vessels and Equipment

Since deep-water interventions represent high costs, companies need to optimize the use of vessels, equipment, subsea services and intervention activities in general. It is common for operators to sign agreements and contracts with service companies to have equipment ready for installation, testing, preventive maintenance activities, as well as corrective maintenance.

Specialized vessels are also contracted to carry out the offshore subsea intervention activities and to transport the equipment and tools. The vessels stop approximately four hours every two weeks for maintenance and supply, and stay in motion around 20 to 30 percent of the time [24].

The oil prices worldwide have increased, and oil-producing countries have changed companies' policies to explore and exploit new reservoirs. The demand for vessels is higher, and the competition for getting new vessels is harder as equipment is busy and the market prices are higher. In 2007, the time needed for the construction and delivery of a new vessel was close to two and a half to three years [24]. It has also become more difficult to find and employ qualified and experienced personnel to work on vessels.

New smaller vessel companies have identified the trend and, in pursuit of profits, they are now getting involved in subsea operations. However, they focus on providing integrated and complete services, taking into account all the subsea areas. They design new vessels that can carry out packages of activities to install, inspect, maintain, store and transport materials as well as repair eventual failures.

The use of support vessels is planned one or two years ahead by the operator. To select the type of vessel needed, the type of activities to be performed is analyzed. One of the primary activities before installing any subsea equipment is to inspect the seafloor area. The vessel provider should ensure that the area is free of debris by the use of ROVs. However, the sea conditions in the area may influence the launching of the ROVs from the vessel. To launch the ROVs the wave height should be maximum 3m Hs. However, modern vessels with a wave heave compensating system can handle from 4.5 to 5m Hs. Specialized vessels with moonpool systems can deploy ROVs and equipment with a wave height up to 6m Hs [25]. Table 1 shows some of examples of average wave heights for various offshore regions.

Table 1. Wave heights conditions for offshore locations

Location	**Hs (m)**
Gulf of Mexico (offshore Mexico)	2.45
Kikeh (offshore Malaysia)	3.5
Girassol (west coast of Africa)	3.4
Campos Basin (offshore Brazil)	5.7
Shtockman (eastern Barents Sea)	9.4
Snøhvit (southern Barents Sea)	10.0
White Rose (Grand Banks)	10.5
Oseberg (northern North Sea)	10.8
Ormen Lange (Norwegian Sea)	11.7

The analysis of contracting multi-tasks vessels to develop subsea operations should be considered. It is cheaper to use the same vessel for surveying, installing and tie-in of subsea components instead of contracting individually [26]. This analysis should be performed in the initial stage to plan the subsea development in the life cycle. To be able to execute actions fast in case of unexpected happenings, it is important to establish frame agreements for contracting vessels early. The mobilization of equipment and vessels to carry out subsea operations takes around two or three days, and demobilization between 12 to 24 hours. In addition, the traveling to the field might take from 12 hours to several days, considering the distance to the field site [27].

5 Concluding Remarks

Based on a literature review this paper has identified some of the development challenges related to subsea petroleum production facilities. The subsea life cycle through the exploration and exploitation was briefly reviewed and also some of the factors influencing the design were discussed. Even though there has been a tremendous development in subsea technology there still are many challenges to overcome. Each subsea field is different with its unique characteristics. Therefore, each field requires a customized design and this makes it difficult to standardize the technological solutions.

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