Abstract

Subsea technology has come a long way from the first of its kind deployed in the Ekofisk field, Norway in the 1970s. The continuous advancement of these technologies has been hinged on the associated technical and economic benefits. Subsea technology encompasses a host of technologies, all of which attempt to relocate specific production operations from the platform to the seabed. In an environment that is both harsh and fragile, key challenges for these technologies are long-term reliability and safety — with the flexibility to meet each field’s unique characteristics and enable expansion over time. This paper presents a review of the various technologies employed and the inherent challenges.

Keywords: Subsea Completion, Subsea processing, Subsea Production, Subsea Technology

1. INTRODUCTION

The traditional way to extract offshore reserves is via a fixed or floating production facility, with all the equipment needed (pumps, separators, water handling, compressors, processing and storage) located topside. However, in deep or remote waters, surface facilities are expensive and space optimization is critical, making production from such locations challenging [1]. Subsea technology provides a means to technically and economically produce remote and/or deepwater reserves by placing wellheads and associated mechanical and electrical infrastructure on the sea bed [1]. Production from such wells can be tied back to surface facilities like Floating production systems or to the shore. The advantages of this technology include, but are not limited to, reduced development and production costs and in the case of technologies like multiphase pumping or subsea separation, increased recovery factors due to the reduction of backpressures on wells [1].

The first subsea technologies were developed in the 1970s by placing wellhead and production equipment on the seabed with some or all components encapsulated in a sealed chamber for shallow production [1,2,3]. The hydrocarbon produced would then flow from the well to a nearby processing facility, either on land or on an existing offshore platform [2,4]. Technology has advanced since then to enable production at water depths greater than 2000 m and the industry is constantly extending this reach [1]. The oil industry is reluctantly, but inexorably, accepting these technologies as the new “mainstream”, primarily out of economic necessity due to the reduced development and production costs [3].

Initially, subsea tapped the fringes of reservoirs not reachable from the platform. When these wells declined, the economics had been met, and a simple well abandonment was required [3]. Now, however, the availability of subsea technology is a key requirement for deepwater and remote developments, and the rise in this need for subsea technology is expected to persist. Technology reliability, rather than cost, is likely to remain the most important aspect for all applications in the medium-term [1]. A study conducted by ADL show that respondents expect that subsea processing, long-distance tie-back and electric control systems will be the most prominent growth areas in the next five years, particularly for developments in the Gulf of Mexico, offshore Brazil and West Africa [1].

However, quite a host of technical, operational and safety challenges face this evolving technology. Some of the challenges identified thus far include Subsea Power, Flow Assurance, Subsea Separation, Temperature Management, Pipeline Integrity Management/Cost Reduction, Low Cost Intervention, Specific Regional Challenges, amongst others [5].
2. SUBSEA STRUCTURES AND EQUIPMENT

The subsea technology used for offshore oil and gas production is a highly specialized field of application that places particular demands on engineering. The development of these subsea production systems requires specialized subsea equipment [3]. Some of them are briefly discussed and illustrated as follows.

2.1 Subsea Manifolds and Connection Systems

The manifold is an arrangement of piping and/or valves designed to combine, distribute, control, and often monitor fluid flow. They are used to merge the flow from multiple subsea wells for transfer into production flowlines and to manage distribution of injected water, gas and chemicals [6]. Subsea manifolds are installed on the seabed within an array of wells to gather production or to inject water or gas into wells. The available types of manifolds range from a simple pipeline-end manifold to large structures such as a subsea processing system.

Subsea connection systems are used to provide diverless links between subsea wells, manifolds, pipelines, risers and control umbilicals [6].

Manifolds and connection systems are the key building blocks for subsea infrastructure. This is mainly because they connect wells to export pipelines and risers, and forwards them to receiving floater, platforms and onshore facilities [5,6].

2.2 Jumpers

In subsea oil/gas production systems, a subsea jumper is a short pipe connector that is used to transport production fluid between two subsea components, for example, a tree and a manifold, a manifold and another manifold, or a manifold and export sled [6].

2.3 Subsea Wellheads

Wellhead is a general term used to describe the pressure-containing component at the surface of an oil well that provides the interface for drilling, completion, and testing of all subsea operation phases. It can be located on the offshore platform or onshore [surface wellhead] or settled down on the mudline [subsea wellhead or mudline wellhead] [5].

2.4 Subsea Trees

The subsea production tree is a system of valves, pipes, fittings, and connections placed on top of a wellbore. Orientation of the valves can be in the vertical bore or the horizontal outlet of the tree (see Fig. 5). The valves can be operated electrically or hydraulically or manually by a diver or Remote operated Vehicle (ROV).
2.5 Umbilical Systems

“An umbilical is a bundled arrangement of tubing, piping, and/or electrical conductors in an armored sheath that is installed from the host facility to the subsea production system equipment” [4]. It is used to transmit the control fluid and/or electrical current necessary to control the functions of the subsea production and safety equipment (tree, valves, manifold, etc.) [6]. Each tube in an umbilical is used to specifically monitor pressures and inject fluids (chemicals such as methanol) from the host facility to critical areas within the subsea production equipment. Electrical conductors transmit power to operate subsea electronic devices.

2.6 Risers

The riser is the portion of the flowline that resides between the host facility and the seabed adjacent to a host facility. Riser length is defined by the water depth and riser configuration which can be vertical or a variety of wave forms. During the drilling phase of a project, the drilling riser forms a conduit for transporting of the drillstring and fluid to the hole bottom, protecting them from the harsh subsea conditions. A slightly different design is also employed during the production phase.

3. SUBSEA DRILLING

Drilling offshore began near the turn of the 20th century when shallow water fixed platforms were used to access offshore reservoirs. But offshore drilling and production did not really develop to be widely viable until after 1947 when the first offshore well was drilled at a location completely out of sight of land [11]. Since then, offshore production, particularly in the US Gulf of Mexico, has resulted in the discovery and delivery of a significant contribution to the total US energy production, with about 35% of crude oil production in the US coming from offshore developments [11]. More recently, international oil companies in West Africa have embarked on a “near-total” deep offshore production. The first subsea well was installed at West Cameron 192 in 55 ft. water in the Gulf of Mexico (GOM) in 1961 [11]. Others soon followed but a significant departure was introduced in 1993 with the advent of the first horizontal tree [12]. Developments of subsea and other equipment for higher pressures and temperatures continued as operators progressed to drill deeper wells with more stressful physical conditions. The next major advance in subsea trees came in 2007 with the introduction of an all-electric tree [13].

Subsea wells can be classified as either satellite wells or clustered wells [4]. Satellite wells are individual and share a minimum number of facilities with other wells. They are usually drilled vertically and can be produced directly to a surface facility (the platform of a floating vessel) or through a subsea manifold that commingles the production of several satellite wells. The primary advantage of satellite wells is the flexibility of individual well location, installation, control, and service. Each well is handled separately, so that its production and treatment can be optimized. Alternatively, a
clustered system can be employed. In this system, several subsea wellheads are located on a central subsea structure. This arrangement provides the possibility of sharing common functions among several wells, such as manifolded service or injection lines and common control equipment, which then require fewer flowlines and umbilicals, thus reducing costs [4].

4. SUBSEA COMPLETION

“A subsea completion is one in which the producing well does not include a vertical conduit from the wellhead back to a fixed access structure” [11]. A subsea well typically has a production tree to which a flowline is connected allowing production to another structure, a floating production vessel, or occasionally back to a shore-based facility. Subsea completions may be used in deep water as well as shallow water and may be of any pressure and temperature rating including high-pressure, high-temperature (HPHT) ratings. Subsea completions consist of a production tree sitting on the ocean floor, an upper completion connecting the production tree to the lower completion and the lower completion which is installed across the producing interval [4,11]. Advances in upper and lower completions followed normal developments in materials, pressure, and temperature ratings [14]. However, significant advancements in the area of gravel packing the lower completion occurred with the introduction of one-trip installation of multiple-zone systems. This advancement reduced operational costs and led to the capability to develop more stratified reservoirs with one-trip and single system [15]. Most recently, however, FMC reports that operators have been successful deploying solutions this technology in mature or brownfield projects such as Statoil’s Tordis, Petrobras’ Marlim and Espadarte; and new or Greenfield projects like Total's Pazflor, Shell’s Perdido and Parque Das Conchas (BC-10) [16].

5. SUBSEA PRODUCTION

It can range in complexity from a single satellite well with a flowline linked to a fixed platform, FPSO (Floating Production, Storage and Offloading), or onshore facilities, to several wells on a template or clustered around a manifold that transfer to a fixed or floating facility or directly to onshore facilities. The subsea production system consists of the following components [4,5,11]:

- Subsea drilling systems;
- Subsea Christmas trees and wellhead systems;
- Umbilical and riser systems;
- Subsea manifolds and jumper systems;
- Tie-in and flowline systems;
- Control systems;
- Subsea installation.

6. SUBSEA PROCESSING AND TRANSPORT

Subsea processing and transport are two of the key enabling technologies in the development of resources in the Arctic. This includes both long range multiphase transport to shore, future ultra-long multiphase transport and sub-ice developments [17,18,19].

“Subsea processing (SSP) can be defined as any handling and treatment of the produced fluids for mitigating flow assurance issues prior to reaching the platform or onshore” [20]. This includes [4,20]:

- Boosting;
- Separation;
- Solids management; Gas treatment;
- Chemical injection.

The benefits of introducing SSP in a field development could be [19,21]:

- Reduced total CAPEX, by reducing the topside processing and/or pipeline CAPEX;
- Accelerated and/or increased production and/or recovery;
- Enabling marginal field developments, especially fields at deepwater/ultra-deepwater depths and with long tie-backs;
- Extended production from existing fields;
- Enabling tie-in of satellite developments into existing infrastructure by removing fluid;
- Handling constraints;
- Improved flow management;
- Reduced impact on the environment.

Subsea processing holds the potential to off-load fluid equipment to the seafloor. This provides for reduction in platform/FPSO deck load requirements while also eliminating the backpressure imposed by the production riser [17]. As opposed to the traditional methods of processing reservoir fluids at a process station, subsea processing holds great
promise in that all of the processing to the point where the product is final salable crude is done at the seabed itself [4]. This offers cost benefits and also improves recovery factors from the reservoir. Other advantages include a lesser susceptibility to hydrate formation and lower operating expenditures. It, however, ranks as the most targeted technology for rapid development and application due to its huge potential for cost savings according to a recent survey of subsea technologies conducted by officials with FMC Technologies Inc. [22]. This technology also improves flow assurance such as hydrates, wax and slugging with less chemical injection.

Subsea flowlines are used for the transportation of crude oil and gas from subsea wells, manifolds, off-shore process facilities, loading buoys, S2B (subsea to beach), as well as re-injection of water and gas into the reservoir. Achieving successful tie-in and connection of subsea flowlines is a vital part of a subsea field development [24]. Subsea flowlines are the subsea pipelines used to connect a subsea wellhead with a manifold or the surface facility [4]. The flowlines may be made of flexible pipe or rigid pipe and they may transport petrochemicals, lift gas, injection water, and chemicals. Subsea flowlines are increasingly being required to operate at high pressures and temperatures. The higher pressure condition results in the technical challenge of providing a higher material grade of pipe for high pressure, high-temperature (HP/HT) flowline projects, which will cause sour service if the product includes H₂S and saltwater. In addition, the higher temperature operating condition will cause the challenges of corrosion, down-rated yield strength, and insulation coating. Flowlines subjected to HP/HT will create a high effective axial compressive force due to the high fluid temperature and internal pressure that rises when the flowline is restrained [4,9].

7. FLOW ASSURANCE AND WELL INTERVENTION

The buildup of wax, scale and hydrate in subsea flowlines, wellheads and risers is a special problem for subsea production where temperatures are quite low and the fluid is an un-processed well stream. “Flow assurance is the term given to a study of the complex phenomena involved with transportation of produced fluids” [17]. These fluids are comprised of a combination of gas, crude/condensate and water together with solids such as Hydrate, Scale, Wax / Paraffin, Sand and Asphaltenes.

For effective subsea production, it is necessary to identify the potential for and quantify the magnitude of any of these solids in the system. Changing pressures, temperatures and production profiles over the field life also complicates the
difficulties posed. Apart from this, it is also necessary to control and predict potential problems during transient periods, which means that the system should be able to shutdown and restart in a controlled manner.

The cost of intervention in subsea wells in extremely high and has limited efforts to monitor wells. Conventional (non-intelligent) well designs require intervention via wireline, coiled tubing, or rig to make measurements or alter zone flow. By installing downhole well measurement and control devices connected to the surface (i.e.,” intelligent technology”), measurement and control become possible without intervention [17]. One of such technologies is the Installed FlowManager™. It provides accurate production and injection flow rates in addition to advice for optimal choke setting and well routing. Installed Flow Manager™ can easily be expanded to become a Flow Assurance System (FAS) to include online monitoring of potential flow assurance issues. The technology has been in operation since 1995 and is currently operating on 450 wells distributed on 20 fields globally [26].

Alternatively, thermal insulation and protective coating can be applied to components subjected to deepwater immersion. Subsea Thermal Insulation with materials of superior thermal properties helps delay the onset of hydrate formation and wax deposition [27]. Direct electric heating, the current applications for which are focused on hydrates, is also an alternative mature and growing technology [22]. DEH can keep fluid temperatures above the hydrate formation temperature and above the wax appearance temperature. It has mostly been used in North Sea fields, such as Statoil's Asgard, Huldra, Kristin, Urd, Tyrihans, Alve, Ormen Lange, Morvin, BP's Idun and Skarv fields, Shell's Serrano, Oregano, Nakika and Habanero [22], [28].

One of the chemical flow assurance technologies, scale inhibitor chemistry is a matured technology but its treatment applications are still evolving. It has found onshore applications in recent years as hydraulic fracturing activity has picked up in the United States [26], [27]. Some key flow assurance technologies benefiting from further development include [27];

- Rheology modification, or flowing hydrates
- Long distance direct electrical heating
- Monoethylene glycol (MEG) loop optimization
- Low dose inhibition

8. CONCLUSION
A basic introduction to subsea engineering and technology has been presented. Economic and technical advantages have been identified as the main propellants for the continued growth of this industry. However, key challenges for these technologies remain which need to be addressed for further deployment in more difficult terrains. Some of these challenges are long-term reliability and safety, with the flexibility to meet each field’s unique characteristics and enable expansion over time. Nevertheless, the subsea technology industry offers a whole new level of technological advances whose numerous advantages may have already cemented its place in the sands of time.

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References


