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DEVELOPMENT OF MARINE HYDROCARBON RESOURCES USING UNDERWATER PRODUCTION SYSTEMS

Kirill Dedov[1,*], Andrey Sergeev[1], Alexander Barmin[1], Daniil Belyaev[1]

[1] *Astrakhan State University, Astrakhan, Russia*

**Corresponding author. Email: kirill97q@mail.ru*

ABSTRACT

This paper discusses the subsea production of hydrocarbons. It shows the relevance, prospects and equipment used within that special type of hydrocarbon production. It also analyses the characteristics of subsea equipment and the factors influencing the performance and selection of technical designs.

Keywords: *oil, gas, shelf, subsea technology, manifold, well, production.*

1. INTRODUCTION

The development of marine hydrocarbon resources is becoming more and more important now. It becomes necessary because of the depletion of land-based sources of oil and gas, and, consequently, people need to search for new production targets that have been discovered in the sea [1]. The development of offshore hydrocarbon production facilities is also caused by the need to include expensive methods and projects to increase oil recovery ratio and ensure production growth (or at least keeping it at the project level) of land-based sources of oil and gas [4].

At present we can see more often there are a lot of projects related to the production of hydrocarbons on the sea shelf in the world. However, the use of offshore platforms for this purpose may turn out to be insufficient, or have certain obstacles, due to which production may be not profitable [2].

Insufficient autonomy, difficult climatic conditions (ice cover, strong wind loads), big sea depth, complexity of equipment for monitoring and repair, corrosive effects of sea water and other aggressive environments, high cost of platforms and sea drilling - these and many other factors make a challenge for engineers from all over the world to come up with a unique, innovative solution for the development of offshore fields [3].

Subsea complexes containing the elements necessary for the extraction of hydrocarbons directly from the seabed at the short distance from the wells are particularly widespread in the fields of the North Sea in Norway [5, 7]. Therefore, to develop offshore hydrocarbon reserves it is not at all necessary to build offshore platforms.

Underwater elements of the subsea Christmas tree, manifolds, and other elements of the subsea oil and gas production system operate in an automatic mode, however, if necessary, control over the elements of the system can be carried out remotely (for example, to supply an inhibitor into the well or a section of a flowline, to open and close high-pressure valves) using hydro / electric drives, or a combined system for the highest reliability [6].

Control at great depths is carried out by special robotic equipment of the RCUUV-type (Remotely controlled unmanned underwater vehicle) (Fig. 1) [10], which collect and transmit information to the surface. It also capable to perform a technological process for replacing equipment elements, or for moving them. Such devices can be controlled by specially trained personnel from the surface.

Figure 1. General view of a remotely controlled unmanned subsea vehicle.

2. TYPES OF EQUIPMENT FOR SUBSEA PRODUCTION

Equipment for subsea production (subsea production complex) includes the following elements [9, 12]:

FPSO (floating production storage and offloading) unit, subsea Christmas tree, foundation bottom structure and protective tools, riser system and manifold as a product collection system, robotic systems for tracking, evaluating and transmitting information (as well as performing technological operations at great depths), related jumpers, umbilicals and many other types of auxiliary tools used for operations of the subsea complex.

There are many suppliers of equipment for subsea production. Among them such companies as: Akersolutions™, Roxar™ (Emerson) and many others. [11].

The elements of subsea production complex can be combined and secured with one template (bottom foundation structure) and it can include integrated protection [13].

In terms of complexity, subsea production systems can contain from one to several wells in a template [14]. Production from wells is sent either to an offshore technological vessel, with further additional technological processes, or directly to the shore, depending on the distance from the shore to the production site. An example of the bottom foundation structure is shown in figure 2 [10].

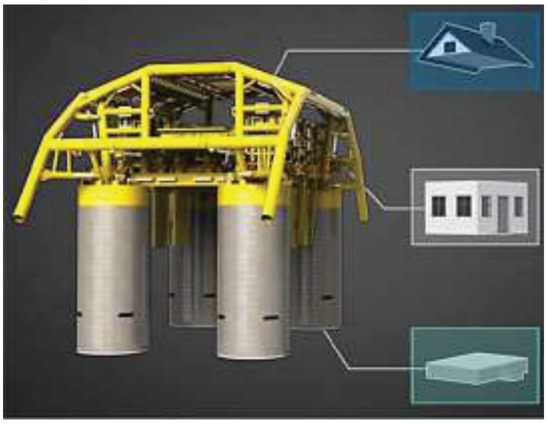

Figure 2. An example of a bottom base of a subsea production complex.

The factors that determine the design of bottom bases include the following [15]:

- Soil characteristics
- Accessibility of vessels (installation method)
- Number of wells and their location
- Type of connection system (horizontal / vertical) and loads
- Requirements for providing protection (falling objects, fishing activity)

In total, there are several types of bottom foundation structures, depending on the distance between the wells. Their classification, respectively, is shown in figures 3, 4 [10].

Figure 3. Types of subsea production bottoms where wells are well spaced apart.

Figure 4. Types of bottom structures where wells are located at the short distance from each other and advantages of these types.

The core of the whole subsea production complex is the manifold system. It can be used for applying many objectives. Among them:

- gathering production, distributing gas and water to multiple gas or water injection wells.
- contain manifold headers
- direct flow of hydrocarbon fluids through headers
- provide isolation of every single well slot from manifold header
- combine flowline connections between manifolds and appropriate flowlines and/or test lines
- provide propriety of pigging operations of flowline system

Construction flexibility of the manifold system needs to be considered as well. It can be explained as a measure for retrofitting or replacing of modules included in the manifold system (pumps, separators, etc.). For any project, a number of potentially possible future requirements are studied, which clearly indicate how the manifold system will be represented for fulfilling the required functions.

Depending on the number of well clusters connected, manifold can be clustered, prefabricated or integrated.

These manifold types are shown in more details in the figure below.

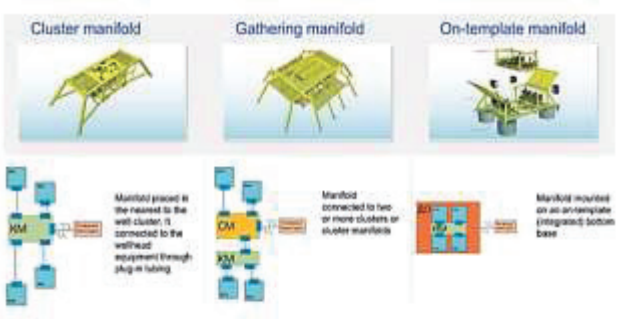

Figure 5. Types of subsea production complex manifolds.

Usually, manifold consists of six main blocks: a steel frame, pipelines of large and small diameters, a subsea control module, electrical distribution, and rigging equipment [16]. In more details, the composition and arrangement of the manifold elements are shown in the scheme below (Fig. 6) [10].

A cluster manifold combines flows from several subsea wells into one or more manifold headers. The cluster manifold is the foundation for sufficiently transfer design loads to the bottom of the sea.

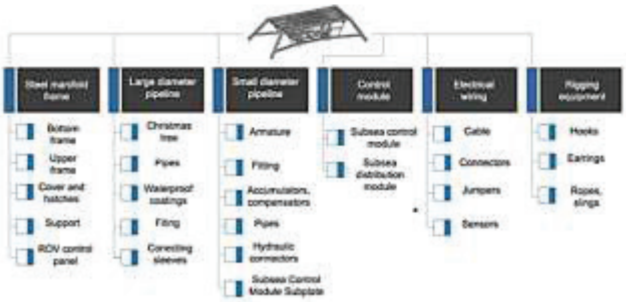

Figure 6. Composition of subsea production manifold.

The cluster manifold represents a guidance system. It also provides support for operations throughout the life cycle. In case, when guidelines system is applied, the cluster manifold provides proper spacing and installation of guideposts. Otherwise, when guideline-less method is used, the cluster manifold needs to provide enough space and passive guidance capability for successful installing the main equipment components.

The next necessary element of the subsea production system is subsea wellhead equipment, which consists of the manifold (hanging off and sealing in annulus), casing strings (CS) and the subsea Christmas tree (SCT). The latter has special devices for connecting it to the wellhead, as well as the riser. SCT equipment includes: pressure caps, wellhead connector, block valves, multichannel connector, piping structure and hub, multichannel connector for downhole equipment, frame and production control system [17]. The general scheme of the subsea Christmas tree is shown in figure 7.

Figure 7. Scheme of subsea Christmas tree.

Casing heads have compartments and bridges, which are used to connect the device to subsea blowout equipment (BOE) or Christmas tree. The system of hanging heads along with the sealing units is making the possibility of reliable strapping of intermediate and production casing pipes and the casing head.

The composition of the subsea Christmas tree (SCT) elements also contains vertical hydraulic connectors, which are necessary for lifting the SCT to the surface without disconnecting the flow lines. Wells equipped with subsea wellhead equipment are grouped near the operating vessel / offshore platform. Subsea Christmas tree control is carried out from the platform remotely.

3. INTERFACES FOR SUBSEA EQUIPMENT

Most of the applied equipment should accord to the interface requirements. The subsea system interfaces must ensure operational integrity and functionality. The interface specifications are considered when defining the critical external areas while installation and operating of the subsea equipment. On that stage, the design constraints, dimensions and weight of the facility elements are determined, and all the data is entered into the database [5]. There are areas should be covered and determined (divided into major three groups):

- interfaces of equipment connected to the wellhead while drilling, include: the values of the maximum conductor angle, hang off weights, conductor length, envelopes of blowout preventer (BOP), other requirements (the number of wells to be drilled before reaching the design permissible capacity point, the sequence of well to be drilled), drilling fluid injection and circulation rates, restrictions on pressure and flowrate when drilling conductor, the rate of solidification and strength of cement, wellhead design, change in the depth of the well over time while drilling, and so on;
- interfaces relating to contractors (interface parameters include weight, size, lifting height of the ship equipment, volume of space on deck, carrying capacity of cargo points and tie-in structures, support structures, installation limitations, sea weather conditions, and many others);

- interfaces including control of flying leads and flowline and well jumpers – small diameter pipes connecting the system of subsea equipment into a single network.

4. EXPERIMENTAL TESTS OF MATERIALS AND CORROSION PROTECTION MEASURES

Low-alloy steels, corrosion-resistant steels and alloys are used to craft many types of equipment of the subsea production system. In the course of preparing these elements for operation, various tests are carried out to identify deficiencies, defects, unwanted impurities and a tendency to corrosion [18].

During mechanical tests, the yield strength, ultimate strength, hardness, and plasticity characteristics are determined. When studying materials, the next parameters are being determined: microstructure, the sizes of metal grains, phase composition, the presence of non-metallic inclusions and so on.

When carrying out non-destructive testing, visual, ultrasonic, magnetic particle and capillary methods of inspection are used.

Examination of the microstructure of the equipment material is carried out on all duplex stainless-steel products of types 22Cr and 25Cr. Micrographic examination makes it possible to determine the presence of microcracks and other violations in the composition of the crystal lattice of the materials used. The study is usually carried out over the area from the surface of the material to the middle of its thickness, or at the same point as in the impact test. The surface area to be examined should be 10 mm x 10 mm or more (0.40 in x 0.40 in).

The required ferrite content is established in accordance with ASTM (American Society for Testing and Materials) E562 or by an equivalent standard and, according to various estimates, the content should vary from 40% to 60% mass fraction. A sample is considered to have passed the test if its microstructure, examined at a minimum 400-fold resolution, does not contain any intermetallic phases and precipitates. If inclusions are present, they are reported, and the choice of this material will already depend on its corrosion/impact tests [3].

The rate and tendency to corrosion are the most important characteristics determining due to the conducting of chemical research. The composition and the presence of harmful impurities in sample are also analyzed.

There are three major types of metal corrosion in subsea production: 1) general corrosion (affects low alloy steels); 2) localized corrosion (usually affects stainless steels and corrosion-resistant alloys); 3) Contact corrosion (occurs when contact of dissimilar metallic materials).

As corrosion protection measures the following methods are used: the protective materials (epoxy coatings, anti-corrosive paints, enamels, inhibitors), electrochemical protection (tread protection), applying of corrosion-resistant materials (special resistant-to-corrosion steels and alloys), corrosion monitoring (protective potential and current density control, visual monitoring of protectors, visual monitoring of the corrosion influence to structures and equipment, cleaning) [2].

The monitoring includes:

- Determination of the content of alloying elements (C, Cr, Ni, Si, Mn, etc.);
- Determination of the content of harmful impurities (S, P, O_2, etc.);
- Analyzing the chemical composition of a ladle sample or finished product
- Atomic emission spectrometry

Corrosion testing is carried out on all materials of 25Cr duplex steel, type 6Mo and other high alloyed austenitic stainless steels.

Study should be done in accordance with ASTM G48 (method A). The temperature in that test should be 50 °C (or 122 °F) in pickled condition and 40 °C (or 104 °F) if using polished materials [2]. The time of the exposure time is around 24 h.

Corrosion testing and impact testing use samples taken from the same location. Samples should be trimmed as it stated in ASTM G48 standard. Once the sample has been pickled, it must be weighed and then can be tested.

Pickling lasts for 5 min at 60 °C (or 140 °F), solution must contain 20 % volume fraction of HNO_3 and 5% volume fraction HF.

The acceptance criteria for studied materials are:

- no pitting visible at 20x magnification;
- mass loss ≤ 4.0 g/m^2 (0,0074 lb/yard^2)

Surfacing metal technology can also be applied as a protective material. Surfacing technology is the deposition of a relatively thin layer of metal onto a substrate.

In many cases, the material for surfacing is chosen for its useful properties like resistance to corrosion, erosion, deformation. A wide variety of alloys are used as a surfacing material. It includes stainless steels and nickel-based alloys with rare metals such as zirconium and tantalum.

The substrate is usually selected to meet the required mechanical requirements of the design (strength and toughness). The base material is mainly carbon steel or low alloy steel.

A key feature of surfacing metals is their ability to cut expenses by buying a way cheaper metal becoming the main protector. So surfacing products can offer significant cost savings over using all-corrosion-resistant metal / alloy products [10].

Following the testing stage is creation of 3D models in a CAD system for performing calculations by the finite element method and issuing design documentation.

Through the modeling it become available to conduct calculations on the studied object - Importing a SAT file into a finite element package, meshing, application of loads (corresponding to the installation and operation modes), execution of calculation, verification of the resulting stresses in accordance with design criteria.

It needs to be mentioned that before creating the necessary structure, calculations are used for determining strength, fatigue resistance, rigidity, stability, heat resistance, vibration resistance and tightness. Those properties will depend on the parameters of the fluid and environmental conditions.

5. CONCLUSION

Russia has a great potential in the sphere of development of oil and gas fields of the Arctic Ocean and promising technological capabilities to achieve that target. In the current political and economic conditions, the Russian Federation has a special motivation to rapidly develop its own innovative and promising oil and gas technologies for subsea production and improve domestic oil and gas industry generally. This trend is strengthened by restrictions on the import of foreign technologies for the development of offshore hydrocarbon deposits. It needs to be noticed that the optimal and timely stimulating of financial and organizational conditions will improve the state of affairs of national oil and gas companies upon the deployment of their projects on the Russian shelf. At the same time, that would also help to engage and launch the mechanisms of high efficiency and safety level while applying modern methods and innovative equipment.

However, there are also a number of technical problems associated with the adaptation of these technologies to the difficult conditions of the waters of the Arctic Ocean. The development of deposits in the Arctic shelf of Russia requires the applying of advanced subsea production technologies, as well as the use of world experience in the question of development of offshore fields.

Therefore, it can be concluded that subsea oil and gas production remains promising and reliable technology for obtaining hydrocarbon reserves lying deep beneath the water.

AUTHORS' CONTRIBUTIONS

The article has been written by a team of authors. All authors have taken equal part in the theoretical studying and analysis of the problem and carrying out the research as well. And, particularly, every member of our team made his own part of work, of course. K.V. Dedov was responsible for the structure and semantic coherence of the elements of the article, making pictures and enhancing the quality of the translation. Sergeev A.O. analysed and generalized ideas of the Russian and foreign authors on the problem of the research. He also helped in translation of the content of the article. A.N. Barmin provided the team with necessary information about complex of experimental tests of materials and corrosion protection (the chapter № 4). Belyaev. D.U. worked on editioning of the article and its design to be accorded to the article requirements. He also helped to make abstract and conclusion as well.

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