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Production availability for new subsea production systems with seabed storage tanks

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ABSTRACT

This paper proposes a new concept for subsea production systems based on the use of seabed storage tank in oil fields and studies the production availability for new subsea production systems with a seabed storage tank. The proposed concept is expected to optimize production from oil fields in the deep sea, helping to improve the production and transportation of hydrocarbon resources from deep sea fields. The proposed concept may dramatically reduce the floater size by removing the floater from the crude storage function and may widen the operational envelope of the production and transfer of the well fluid to shuttle tankers. The analysis of production availability is an important indicator of the production performance of the oil and gas industries. The production availability is analyzed using the commercial code MAROS, which is based on Monte-Carlo simulation methods. The failure rates and active repair times of the equipment for the proposed new subsea systems are collected from generic reliability data sources.

1. INTRODUCTION

Oil and gas production have gradually moved from shallow waters to deep-water locations. Deep-water oil and gas production are expected to be major contributors to global supply needs in coming decades. In deep-water production, oil and gas are extracted from the wells and brought to the surface to a floating facility above the ocean surface. The type of floating facility depends on the location, water depth, climate and the facility's size and capabilities.

Conventional floating facilities are temporarily stored in floating structures and are transported by shuttle tankers to be processed further onshore. Four conventional floating structures are used to produce oil and gas: Tension Leg Platforms (TLPs),

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semi-submersible, Spars and Floating Production Storage and Offloading (FPSO).

FPSO is particularly effective in remote or deep-water locations where seabed pipelines are not cost effective. Therefore, FPSO is a more convenient and practical solution than other conventional floating structures. However, FPSO requires a huge hull to store the oil as well as heavy and complicated topside facilities, and it must be stationary for its operating periods.

Therefore, a new subsea production systems based on a seabed storage tank is proposed to overcome FPSO's disadvantages. The new subsea production systems with a seabed storage tank have four advantages: minimization of the floating structure (Floater), freedom from transportation distances (Ship transportation), insensitivity to sea depth and eco-friendly (No gas flaring).

The main objective of this paper is to propose a new concept for subsea production systems based on a seabed storage tank and to study the production availability for new subsea production systems with a seabed storage tank in oil fields.

The analysis of production availability is an important indicator of the production performance of the oil and gas industries. Previous studies have discussed the production availability of systems. The main focus of the literature on the production availability is on the model and a method for analyzing system performance (Aven 1987, Hokstad 1988, Aven 1989, Rausand 1998, Signoret 1998, Kawauchi and Rausand 2002, Zio 2006). However, how to implement and execute the production availability on a detailed level has not been clearly discussed.

In this paper, the production availability is analyzed using a commercial program, MAROS, which is based on Monte-Carlo simulation methods. The failure rates and active repair times of the equipment for the proposed new subsea systems are collected from generic reliability data sources.

2. SYSTEM DESCRIPTION

Fig. 1 shows the schematic of new subsea production systems based on a seabed storage tank in oil-dominant fields. These systems consist of wellhead/X-mas tree, subsea manifold, subsea separator, seabed storage tank, subsea booster pump, subsea riser, umbilical, floater, and High Pressure Fluid Carrier (HPFC).

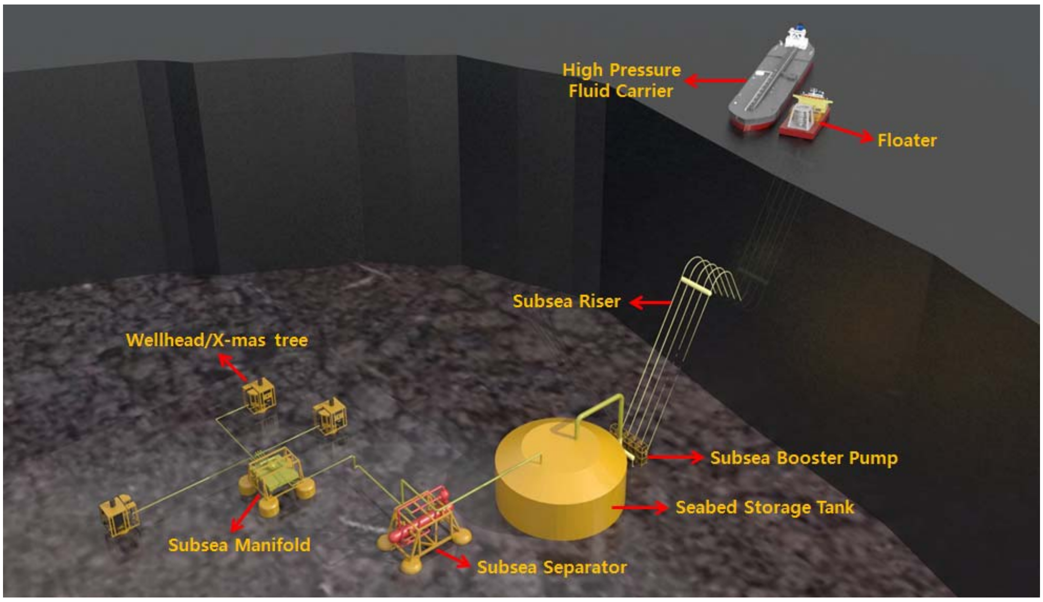


Fig. 1 Schematic for subsea production system based on LSST

2.1 Wellhead/X-mas tree

The wellhead consists of spools, valves and assorted adapters that provide pressure control to the production well. The wellhead also incorporates a means of hanging the production tubing and installing the X-mas tree and surface flow-control facilities in preparation for the production phase of the wells.

The X-mas tree is the set of valves, spools and fit-tings connected to the top of a well to direct and control the flow of formation fluids from the wells. An assembly of valves, spools, pressure gauges and chokes fitted to the wellhead of a completed well is used to control production. Christmas trees are available in a wide range of sizes and configurations, such as low or high-pressure capacity and single- or multiple-completion capacity.

2.2 Subsea Manifold

The subsea manifold incorporates chokes, valves and pressure sensors used to control flow back or treatment fluids. A set of high-pressure valves and associated piping, which usually includes at least two adjustable chokes, are arranged such that one adjustable choke may be isolated and taken out of service for repair and refurbishment while well flow is directed through the other.

2.3 Subsea Separator

The subsea separator separates the well fluids into gas and two types of liquids: oil and water. The liquid (oil, emulsion) leaves the separator at the bottom through a level-control or dump valve. The gas leaves the separator at the top, passing through a mist extractor, which removes the small liquid drop-lets in the gas. The subsea separator is also used to remove any free water that can cause problems, such as corrosion and the formation of hydrates or tight emulsions, which are difficult to break.

2.4 Subsea Booster Pump

The purpose of the subsea booster pump is to drain the condensate water from the separator and to further boost the liquid. The condensate pump module includes a pump and motor.

2.5 Seabed Storage Tank

The seabed storage tank is the assembly of the storage tanks where the well fluid is stored until it is transported to the subsea booster pump. The unit has three storage spaces: a gas storage space, an oil storage space and a seawater storage space. The body may be in the form of a cylinder or a poly-prism. The body may be built out of lightweight concrete. In this case, the inner and outer sides of the lightweight concrete must be watertight-coated or surface-plated.

2.6 Riser/Umbilical

The subsea riser includes multiple risers that transfer the well fluid to the floating facility. The umbilical comprises the lines for chemicals, electric power, and other utilities.

2.7 Floater

The floater is supplied by the subsea control station through a combined power and control umbilical. In addition, a topside manifold is installed on the floater. This facility is similar to floating structures in normal offshore installations. The cargo pumping and compression units may be removed if the pressure of the well fluid from the subsea transportation facility is high enough.

2.8 Control Module

The typical subsea control module receives communication signals and electrical power from the topside control equipment. These modules then use the signals to control the subsea system.

3. FAILURE AND REPAIR DATA

3*.1 Data Source*

A reliability analysis requires several types of input data, such as failure data, which give information related to how often components and subsystems fail. Due to the lack of reliability data for new subsea systems, it is common to use estimated failure rates from data handbooks and computerized databases. This section presents the results from three different data sources: OREDA, Well-master and Subsea-Master from Exprosoft.

3*.2 OREDA*

Offshore Reliability Data (OREDA) is one of the most relevant reliability data sources for offshore use, which covers a wide range of equipment used in oil and gas exploration and production. The OREDA project is sponsored by oil and gas companies worldwide, and has been developed since 1981. Data analysis software is developed and only provided to companies participating in the OREDA project. In addition, selected data are published as handbook from time to time. The 2009 edition is the most recent version of the OREDA handbook and includes two volumes, on for topside and one for subsea equipment.

3.3 Well-Master

Well-Master is a Windows-based program developed for the purpose of storing and analyzing historical data on well completion equipment. In the Well-Master program, a completion schematic is first built to represent the completion configuration and give details on the equipment in the well. Failure data are input directly via this schematic by pointing at the failed item and entering detailed data. Failure modes unique for each item are predefined and can be selected when entering information on new failures. This way a comprehensive and consistent database can be generated. An integrated processing package is then used to prepare a range of different reliability data from the database. Operators using Well-Master may confidently monitor and make decisions on issues involving safety, reliability and profit of their wells supported by use of a comprehensive and industry recognized experience data source and analysis tool.

3.4 Subsea-Master

Subsea-Master is the world's first database to integrate a full description of well completions and subsea production systems with full reliability data input, retrieval and analysis capability. As such, the database is an indispensable tool during quantitative risk assessment of subsea production systems. The following equipment is included in the database: Wellhead, X-mas tree, Connectors, Tree valves, Isolation valves, Injection valves, Control system, Flowline/Umbilical, Manifolds, Chokes, Multiphase flow meters, Wireline BOP (disconnect package), Completion risers, Intervention tools/systems (ROT/ROV) and Pipelines.

4. SIMULATION

4.1 Limitations and Constraints

The main assumptions and limitations that may have an effect on this report are listed below:

- All the components comply with the exponential failure model.
- Only the critical failures are considered over the operational time.
- Repair time is only for active repair and repair adjustment is complete.
- Down-hole equipment is not considered.
- Gas lift is not considered.
- The pumps have a back-up system.

4.2 Operating condition

Table 1 shows the operating conditions for new subsea production systems. Wellhead pressure and temperature are assumed to be 166.7 bar and 70 °C. Production rates from the wellhead are also assumed to be 200,000 bbls/day. The arrival pressure at the floater is set to the storage pressure at the seabed storage tank to avoid the two-phase flow in the riser. The storage pressure of the cargo tanks of the HPFC is set to match the state-of-the-art of pressure-vessel technology.

As the pressure of the well fluid falls below 100 bar, the dissolved gases from the liquid-state well fluid are released, and the vapor fraction increases. As a consequence, the volumetric loading rate at the seabed tank is different from that at the HPFC. The HPFC is filled with well fluid within 10 hours. The loading flow rate, the diameter of the riser and the number of risers are estimated using the above operating conditions.

Table 1 Operating conditions for new subsea production system with a seabed storage tank

Parameters	Value
Wellhead pressure (bar)	166.7
Wellhead temperature (°C)	70
Production rates at wellhead (bbls/day)	200,000
Storage pressure in the seabed storage tank (bar)	100
Arrival pressure for riser outlet (bar)	100
Storage pressure of cargo tanks of HPFC (bar)	50
Capacity of High Pressure Fluid Carrier (m^3)	150,000
Loading time (hour)	10
Seabed tank capacity (m^3)	300,000

4.2 Estimation Procedure of Production Availability

The procedure of production availability comprises four steps:

- Step 1 (P&ID study): The first step in the modeling process is to study P&ID which will identify the important equipment in the system. Logic networks are similar to reliability block diagrams and show the logical process of the system being considered. Questions which should be answered as part of this exercise are:
  - What equipment will be considered?
  - What failure modes of the equipment are important?
  - How does the equipment function (series or parallel)?
  - How much system capacity is governed by the specific equipment?

- Step 2 (Reliability Block Diagram): The most important and thought provoking step is to formulate a logic network which will reflect the functionality of the system and interdependence of the elements. Logic network representations of systems need not be unique, new users tend to form logic networks which look very similar to the original flow diagram, hence they tend to contain too many branches. In many cases a much simplified arrangement can be presented. It is necessary to decide from the outset which primary function of the system is to be monitored.

- Step 3 (Collection of Reliability Data): The reliability data that form the basis for subsea systems is obtained in reliability data sources for OREDA and Well-Master and Subsea-Master from Exprosoft. Table 2 indicates the failure and repair time data from OREDA, Well-Master and Subsea-Master.

Table 2 Failure and repair data for new subsea production system based on a seabed storage tank

System	Subsystem	Failure rate	Active repair time

		(per 10^6 hours)	(hours)
Wellhead	Casing hangers	0.05	288
	Conductor housing	0.1	200
	Permanent guide base (PGB)	0.11	100
	Temporary guide base (TGB)	0.5	30
	Wellhead housing	0.06	300
	Tubing hanger	0.31	168
	Flow base	1.96	6.7
X-mas tree	Chemical injection coupling	0.06	10
	Connector	0.37	8.8
	Debris cap	0.1	10
	Flow spool	0.21	72
	Hose (flexible piping)	0.52	15
	Hydraulic coupling	0.06	9.3
	Piping	22.47	3
	Tree cap	1.08	16.3
	Tree guide frame	0.69	8
	Check valve	0.07	4
	Choke valve	5.89	28.7
	Control valve	0.55	3.3
	Other valve	0.5	4
	Utility isolation valve	0.37	9
	Chemical injection unit	9.51	12
	Electrical power unit	19.02	12
	Hydraulic power unit	722.65	10.7
	Master control station	171.15	6.1
	Sensors	21.17	3.9
	Static umbilical	2.05	5~10
	Subsea control module	23.83	10.7
	Subsea distribution module	20.9	25.4
Subsea Manifolds	Chemical injection coupling	0.28	10
	Connector	0.11	24
	Control valve	2.35	3.3
	Hydraulic coupling	0.04	9.3
	Piping	1.02	50.5
	Structure protective	0.2	24
	Structure support	0.16	8
	Check valve	0.07	4
	Choke valve	9.72	240
	Control valve	92.14	2
	Process isolation valve	1.01	18.2
	Utility isolation valve	0.02	9
	Dynamic umbilical	3.36	12
	Sensors	2.18	3.9
	Static umbilical	2.18	5~10
	Subsea control module	13.07	2.5
	Subsea distribution module	13.07	4
Subsea separator	-	39.62	10
Seabed storage tank	-	80.12	20
Flowline	Piping	0.49	22.2
	Subsea isolation system	2.92	5

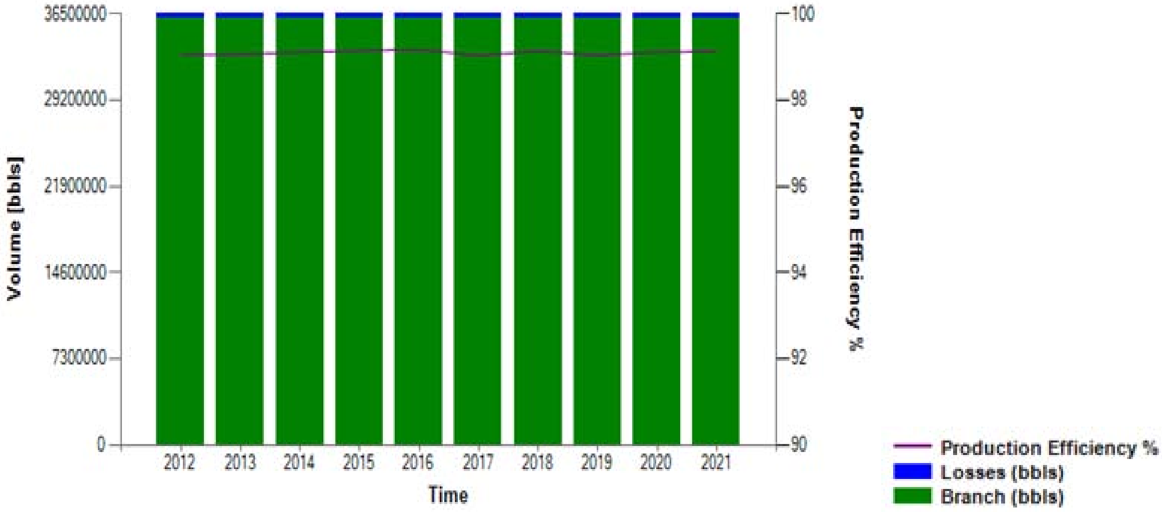
Export flowline	Piping	6.41	30
	Subsea isolation system	7.05	5
Injection line	Piping	0.61	2
	Subsea isolation system	8.13	5
Production line	Piping	0.59	35.7
	Subsea isolation system	3.82	5
Service line	Piping	0.41	5
Pipeline	Piping	4.01	20
	Subsea isolation system	3.74	27.4
Riser	Accessories	4.45	240
	Protection	0.21	15
	Riser base	2.21	5.1
	Riser elements	3.13	57
Floater	Pig launcher (PL)	4	11.4
	Topside compression unit (TCU)	3	5
	Topside manifold (TM)	3	5

- Step 4 (Simulation of Production availability): Production availability is estimated in the commercial simulation programs MAROS (Maintainability, Availability, Reliability and Operability Simulation program).

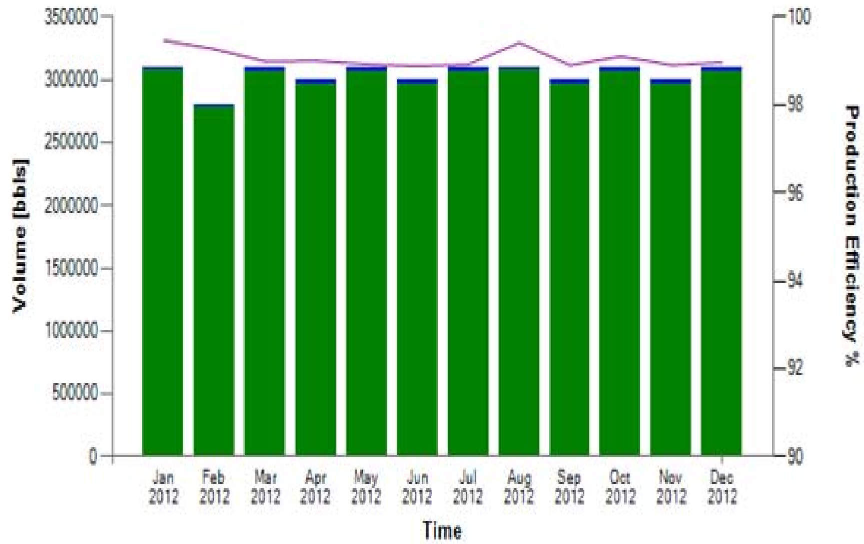
5. RESULTS & DISCUSSION

The production availability, based on 250 simula-tions over 10 years (From 2012 to 2021), is 99.107% within a standard deviation of +/- 0.328%. Fig. 2(a) indicates the production volume and efficiency on an annual basis. These data can be examined to view production on a monthly or daily basis (Fig. 2(b)).

As shown in Fig. 2(a), the average volume pro-duced over the well lifetime is 351,365,000bbls starting from 35,095,688 bbls in 2012 and rising to 35,127,564 bbls in 2021. The average loss over the well lifetime is 13,635,400 bbls, averaging 1,363,540 bbls per year.



(a)



(b)

Fig. 2 Production availability and volume for new subsea production systems based on LSST: (a) Annual data, (b) Monthly data

The system criticality report contains a graphical representation of the data and a tabular representation, as shown in Fig. 3. The subsea manifold is the most critical component in the system (30.854%).

The second most critical component is the control systems (19.853%), while the criticality decreases for the seabed storage tank, riser, floater, subsea separator, flowline, pipeline and wellhead & x-mas tree, in that order.

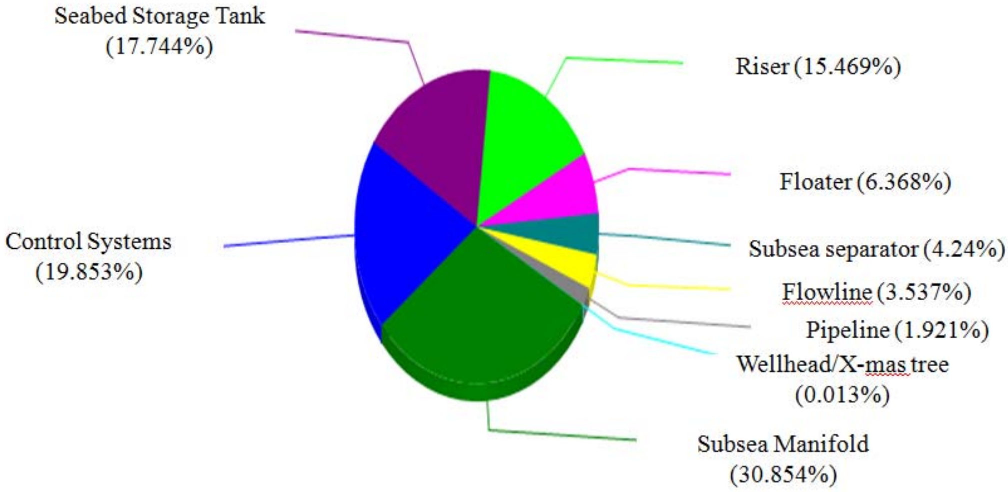


Fig. 3 System criticality for new subsea production systems based on LSST

Fig. 4 shows a chart of subsystem criticality in the subsea manifold. The choke valve is the most critical component of the subsea manifold. These data indicate that the global relative loss of the choke valve is 26.279%.

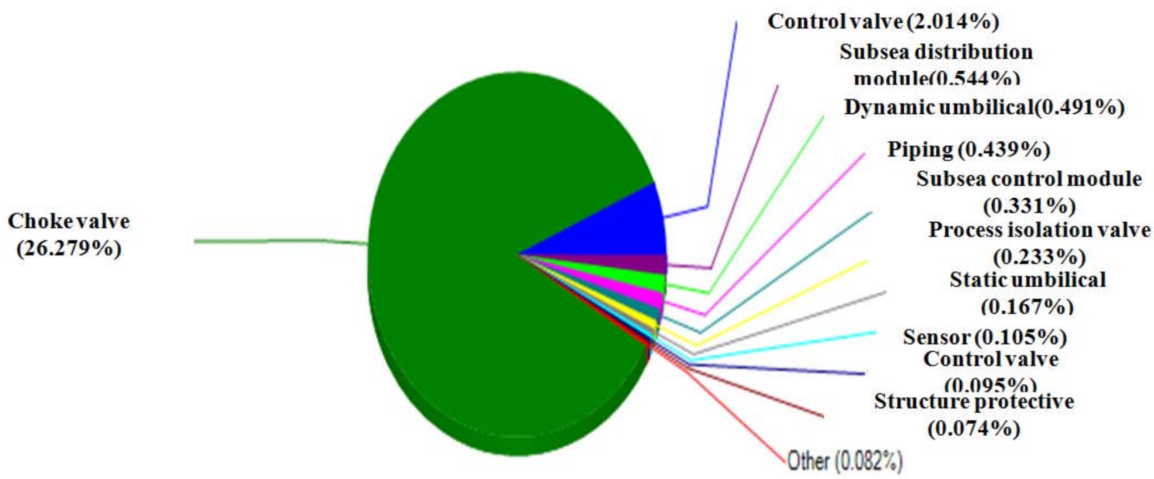


Fig. 4 Subsystem criticality for subsea manifold

6. CONCLUSION

This paper proposes new subsea production systems concepts for large-scale seabed storage and well flu-id transport. These proposals can intrinsically solve the problems inherent to the conventional floater- and pipeline-based approaches. The proposals in this paper may dramatically reduce the floater size by removing the crude storage function of the floater and widen the operational envelop of the production and transfer of the well fluid to shuttle carriers.

The analysis of production availability is an important indicator of the production performance in the oil and gas industries. This study performed a production availability analysis using the commercial program MAROS, which is based on the Monte-Carlo simulation methods, and discussed the out-comes of the production availability. The production availability, based on 250 simulations over 10 years, was found to be 99.107%.

ACKNOWLEDGE

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