講演
Lecture

Oil Field Development and Production Operation Deepwater, Gulf of Mexico*

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Abstract : An oil field located 180 miles South of New Orleans (typical deepwater field, Gulf of Mexico) has been producing since 2005 and JX Nippon Oil & Gas Exploration Corporation joined the project in early 2007. During the past 4 years, certain topics and lessons learned have been identified through development studies, drilling and workover operations, subsea production and other activities.

Despite deepwater development progress since ca. 1990, operational difficulties resulting in high CAPEX and high OPEX costs have been experienced. This is partly due to limited access to subsea production systems. Nevertheless, because of economic feasibility, further deep water development will continue.

In this paper, typical issues, lessons learned, etc. associated with the deepwater setting are reported. The intent is to share findings for interested parties and engineers about deepwater field development.

Keywords : deep water, Gulf of Mexico, field development, production operation

1. Introduction

Year 2007, JX Nippon Oil Exploration Corporation (JX) joined a deepwater oil field development project in the Gulf of Mexico (GoM), located 180 miles South of New Orleans (approximately 4000 ft water depth, refer Fig. 1). The field reservoirs are Miocene age sub-salt turbidite sandstones. The field exists in a North America GoM geological trend where many oil/gas fields have been discovered and developed (Fig. 2). Oil and Gas production in the deep GoM USA (> 1000 ft beyond diver's direct access) is reported to be 1 MMb/d and

4 Bcf/d (80% and 45% of the total 2009 GoM production respectively). The GoM maximum water depth for drilling is 9,000 ft and platform installation depth reaches 8,000 ft (Fig. 3, 4, 5).

2. Field Information

The deepwater field was discovered in 1999, and began production in 2005. Anadarko Petroleum Company, a major player in the Gulf of Mexico deep water, is the field operator.

Approximate reservoir conditions include producing reservoir depth ranges of 25,000-30,000ft subsea, initial reservoir pressure ca 14,000 psia, reservoir temperature 200 degF, API gravity 25 deg, saturation pressure 3000 psia, porosity 23%, and permeability 500 md. Eight (8) production wells are in service producing from 3 reservoirs that exhibit natural depletion with local aquifer support. A partial gas lift at the riser is being applied for some of the wells.

During the delineation phase of field development and after production started, new oil and gas condensate reservoirs were discovered. However, due to the variety of reservoir fluid and rock character, different hydrocarbon distribution areas, and relatively high investment cost, some new reservoirs remain undeveloped.

3. Production System

Production wells are completed with a fracpac to control sand production. Chemical injection ports for inhibition of scale and asphaltene precipitation are installed in the tubing near and above the perforations. Each completion also includes

Fig. 1 Field Location

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Fig. 2 Geological Concept

Fig. 3 Deepwater Production / GoM

Fig. 5 Permanent Platform Depth / GoM

Fig. 4 Numbers of Borehole / Deepwater, GoM

permanent gauges, and a subsurface safety valve (SCSSV).

Hydrocarbons produced from subsea wellheads (15,000 psi WP) are routed to common field flow lines (7" + 12" pipe-in-pipe for 3degC low temperature), and the flow lines are gathered at the Marco Polo hub Tention Leg Platform (TLP). The flow line

system is designed as a loop to enable clean-up, pigging, by-pass in case of hydrate clogging, etc. Each well is controlled by the umbilical system. Umbilicals include electric power cables, instrumental lines, a hydraulic control line, and injection chemical flow lines. The umbilical system is used to open or shut-in a well, control the choke, gather data, and inject various chemicals (Fig. 6).

4. Development Planning

Since 1999, delineation wells have been drilled, seismic has been reinterpreted, and G & G and reservoir simulation studies have been performed. New reservoirs, faults, sand channels, and new reservoir limits have been identified. However uncertainties remain regarding reservoir distribution and heterogeneity, fluid contacts, original hydrocarbons-in-place, fault distribution, fault sealing character, and amount of aquifer support. No enhanced oil recovery (EOR) systems have been installed and the current production scheme remains natural depletion with limited gas

Fig. 6 Subsea Production System

Fig. 7 Deepwater Floating Facilities

lift.

Operator is continuing the following efforts :

- Reservoir monitoring and production operation optimization
- EOR Laboratory Studies
- 3D Seismic re-interpretation, G&G and Simulation Studies
- EOR Injectant Selection and Facilities Screening/Design
- Artificial lift (Gas lift, ESP, Subsea Separation, Multi-phase Pump)

Early in the EOR study, water injection was a primary candidate because of the availability of the injectant. However due to an average 20 degree dip angle and very high reservoir

pressure of 14,000 psia, crestal nitrogen gas injection also seemed attractive as miscibility will be achievable. The current host (Marco Polo) platform is occupied with production facilities and therefore a new floater may be necessary depending on the size of the needed injection facilities for EOR. Hence numerous possible EOR options have been comprehensively evaluated thru reservoir and facilities studies.

To help determine the optimal EOR injectant, JX studied various fluids with a cross-sectional compositional simulation model applied to the main reservoirs. Black-oil full field models were also constructed and then validated with history-matching

Fig. 8 Gas Flooding / X-Section Simulation

Fig. 9 GI vs WI Recovery / X-Section Simulation

(Fig. 8, 9 and 10).

Results of the studies are: (1) Although a miscible condition will be achieved with dry gas (nitrogen) injection throughout the expected field life, the light components of oil are vaporized into gas. The loss of the light component results in a heavier oil remaining in swept pores and this fluid is extremely viscous and difficult to migrate. Therefore, injection gas is forced into shallower permeable sublayers toward the downdip producer causing a limited recovery factor. (2). As for the CO₂ injection case, CO₂ gas is heavier than oil under reservoir conditions, and down-dip gas injection is required. Recovery is remarkably higher than N₂ injection but more injectors are needed. The conclusion is that EOR by miscible gas injection may not cause the highest recovery factor, depending on oil and gas properties, reservoir conditions, heterogeneity, etc.

The operator conducted feasibility studies using many technical and economical points of view, and due to high CAPEX and OPEX requirements, also concluded that gas injection EOR is not superior to water injection with artificial lift.

Since then, development studies have mainly focused on the optimization of water injection combined with artificial lift such as gas lift and ESP. Also, field operation optimization efforts are continuing. These include reservoir monitoring, well performance interpretation, optimization of infill well location, completion design, flow assurance (asphaltene, hydrate, wellbore skin, SCSSV reliability), etc.

Fig. 10 FF Model Study

5. Deepwater Operations

In the deepwater project, the wellbore related investment is remarkably large compared to other conventional projects as shown hereunder :

Operations	Cost (US \$ MM)
Drilling:	80–110/well
Sidetrack:	30–70/hole
Completion:	40–70/well
Subsea Tie-in:	10–40/well
W/O (Replace Comp) :	20–60/well

Fig. 11 Drillship (Max water depth 10,000ft, drilling depth 35,000')

These high costs are due mainly to the following reasons :

- Drilling, completion, sidetrack and workover operations require a drillship (Fig. 11, or capable semi sub) and the current market rig daily rate is in the order of US\$0.4 - 0.5MM/day.
- The rig operational period in deepwater is longer with conditions such as the preparation of access to subsea well equipment and setting the riser.
- Deepwater operations require higher cost of drilling and completion equipment and numerous sub-contractors.
- The Maconda explosion and blow-out has also resulted in operational period and cost increments as per recently modified regulations.

Production operations in this deepwater field experienced some flow assurance issues caused by asphaltene precipitation and hydrate formation. Increased wellbore skin, oil rate reduction and SCSSV malfunctions are mostly caused by the very sticky asphaltene precipitation.

The flow assurance problem is being studied by the operator. Efforts include laboratory analysis to characterize the nature of the asphaltene problem (Fig. 12 and 13). Countermeasures include injection of chemical inhibitors, soaking with xylene then flush, and sometimes a workover operation. Asphaltene precipitation occurs in the wellbore under current fluid composition, pressure and temperature conditions. Reservoir fluid properties are history and/or location dependent, and hence there is an ongoing injection fluid characterization effort.

Asphaltene inhibitor injection from chemical injection ports in the tubing is continuously ongoing. Hydrate is primarily controlled by inhibitor injection and production flow through by-pass lines.

Fig. 12 Asphaltene Onset Pressure Analysis

Fig. 13 Asphaltene Onset Pressure

At present, the operator is applying the following efforts for further development planning :

- 1) G & G and Reservoir Engineering
 - Sand Distribution Mapping
 - Geocellular Modeling and Exporting for Simulation Model
 - Reservoir Simulation (H-M Update) for 3 Producing Reservoirs
(When and if Artificial Lift / Water Flood is to be applied)
- 2) Petroleum Engineering
 - Infill Drilling and Completion Design
 - Workover Planning
 - Productivity Improvement Planning (Stimulation)
- 3) Laboratory and Others
 - Asphaltene Inhibition Optimization
 - PVT Update
 - Geochemical Analysis
 - SCAL (Kr, Pc, Wettability) for composite / plug cores
 - Compiling Elec. Properties & Petrology Tests
- 4) Facilities
 - Flow Assurance
 - Umbilical Upgrade Planning

JX is also independently continuing G & G and Reservoir Simulation studies in parallel to the operator. The intention is to contribute to the field optimization through discussions with the operator.

6. Future of Deepwater Operation

Due to constrained access to the subsea production / injection / operation systems in deepwater, all parts and equipment must be highly reliable and durable, high pressure proof, high corrosion resistant, and must have the lowest frequency of maintenance.

6.1 Deepwater Subsea Processing

As a replacement for a floating platform, main production and injection process equipment are subsea installed and electric power and control signals are provided from a host platform or onshore (Fig. 14). Technology is innovative and examples of field applications are as follows :

Tordis Field : 2007

Operator : Statoil, Field : Norway, / North Sea, Water

Fig. 14 Subsea Processing

depth : 650ft

The first oil/water subsea separation, boosting and injection system.

BC-10 Field : 2009

Operator : Shell, Field : Brazil / Campos Basin, Water depth : 5,800 ft

The first gas/liquid separation and boosting system.

Pazflor Field : 2011 (scheduled)

Operator : Total, Field : Angola / West Africa, Water depth : 2,600 ft

Region's first subsea gas/liquid separation system.

Great White Field : 2010

Operator : Shell, Field : GoM / US, Water depth : 7,800 ft

The deepest field with a subsea separation and boosting system.

These applications separate the producing fluid at the seabed, inject produced water into the formation, and boost production to the surface. The results are extended well producing life and improved recovery. In ultra deep water the impact to recovery is significant because subsea pumping effectively overcomes fluid static head between the surface and the seabed.

6.2 SWIT (Subsea water injection and treatment)

In cases of long distances or for reasons of limited platform space, water is treated and injected on the seabed far from a satellite or host platform. In the Norway offshore, a pilot test for water treatment started July 2009 and was completed August 2010. Operational working efficiency was recorded to be over 99% (Fig. 15). Further study in the deep water environment will reveal reliability and operational sustainability for required water quality and for continual injection.

6.3 Re-deployable P/F

This is the same as semi-sub rig in principle but utilizes an oil producing floater with typical capacity up to 75,000 bopd. Nothing is new, but it would be suitable for a small to medium size oil field if it is competitive to the cost for a permanent

Fig. 15 Subsea WI / Pilot

floater.

7. Summary

Development and production operations of a deepwater oilfield requires significant investment and operational cost in all the stages. High costs include well drilling and completion, installation and tie-in of subsea facilities and control systems, maintenance and trouble shooting for subsea systems with ROV's, and any kind of well intervention, etc.

For example, well drilling, completion and tie-in costs total US\$200MM/well for the typical case. Therefore, numbers of new wells must be minimized for reservoir delineation and development. This requires : (1) careful selection of the well location, (2) optimization of the completion design, (3) setting priority of reservoir to develop, (4) optimization of production profile to maximize recovery per well, and (5) maximizing well working efficiency.

Maximizing production with a minimum of wells is a key for development. Well trouble, being minor in shallow water or onshore fields, will affect deep water field costs significantly. Minimizing operational downtime is very crucial for the success of a deepwater project. In addition to the wells, the entire production system must be maintained in a healthy condition, including well control lines, hydraulic lines, flow lines and pipelines. Also, the exporting location is generally far from the field through several pipelines and platforms. These pipelines and platforms are operated by different parties that affect each other.

Taking these factors into consideration, requirements for deepwater operations are :

- Preventive and tailor-made well/facilities design initially assessing all expected risks (e.g. enough umbilical and flow line capacity, chemical injection port for well treatment, loop flow line system....).
- Well managed stock control and logistics for subsea

Re-deployable Semisub, OPTI Series / EXMAR

Fig. 16 Re-deployable Semisub

operations with spare parts/materials relating to all production and control systems.

- Immediate identification of the nature of all operational problems and immediate countermeasures to be taken including relationships with government officials.

Therefore, massive experience and lessons learned are necessary in deepwater and there are limited major player companies at present .

Deepwater development projects have been active for the past 20 years. In spite of maturity of technology and accumulation of lessons learned, the situation of high risk and high cost remains unchanged. Nevertheless, deepwater development and challenging ultra deep development will continue as long as they are economically feasible.

The reported deepwater project here has only produced less than 3% of the original oil-in-place i.e. potential is extremely large. JX is managing this project by noting identified risks and lessons learned, and it is our pleasure to further the development optimization, particularly in regard to G & G and reservoir studies.

At the end, great thanks to operator, all partners, and JX allowing me to submit this paper. Also thanks to my colleagues who strongly supported me in all aspects.

要 旨

メキシコ湾深海油田における開発操業例

高 木 睦 人

当社が米国メキシコ湾の深海油田開発プロジェクトに参加して三年あまりが経過している。この間に実施された開発計画の策定作業・評価井や開発井の掘削仕上げ・生産操業などに関して、メキシコ湾における深海開発操業の特徴的なトピックス・知見・対策などについて報告する。