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Bao-quan Yang, Li Yang, Fan-jie Shang, Xin Zhang, Chen-xi Li

Risk Identification and Mitigation Strategies for Deepwater Oilfields Development

Abstract Deepwater oilfields will become main sources of the world's oil and gas production. It is characterized with high technology, huge investment, long duration, high risk and high profit. It is a huge system project, including exploration and appraising, field development plan (FDP) design, implementation, reservoir management and optimization. Actually, limited data, international environment and oil price will cause much uncertainty for FDP design and production management. Any unreasonable decision will cause huge loss. Thus, risk foreseeing and mitigation strategies become more important. This paper takes AKPO and EGINA as examples to analyze the main uncertainties, proposes mitigation strategies, and provides valuable experiences for the other deepwater oilfields development.

Keywords: deepwater oilfield, field development plan, implementation, reservoir management, risk identification, mitigation strategies

1 Development status and risks in deepwater oilfield

Deepwater oil and gas exploration and development has been booming since the first deep-water well in 1975. Until now, more than 70% of deepwater oilfields are located in the 10 sedimentary basins distributed in three main deepwater areas of northern Gulf of Mexico, West Africa, and southeastern Brazil. As technology progress, the drilling depth record has been broken continuously and now the record is more than 3000 m. Currently, deepwater oil and gas exploration and development activities are undergoing in more than 60 countries. Top five countries are Brazil, the United States, Angola, Australia, and Nigeria. As prediction, about 35% production will come from deepwater oilfield by the year of 2035 (Lian, Sun, & Chen, 2006; Wang, Chen, & Zhao, 2010; Xiao, 2011).

Chinese deepwater oil and gas resources are mainly in the South China Sea. Total reserve in the South China Sea is between 23 billion and 30 billion tons (Lian, Sun, & Chen, 2006; Xiao, 2011). China's first deepwater gas field Liwan 3-1 was successfully put into production in 2014. During 2014 to 2015, CNOOC had important deepwater oil and gas discoveries, including Lingshui 17-2, Lingshui 25-1 and Liuhua 20-2. Besides, CNOOC has cooperated with Total and Petrobras to develop large deepwater oilfields including AKPO and EGINA in Nigeria and Libra in Brazil, which provides an important platform to accumulate experience.

Deepwater oil and gas field development is characterized with high technology, huge investment, long duration, high risk and high profit. It is a huge system project, including exploration and appraising, FDP design, implementation, reservoir management and optimization. Actually, limited data, international environment and oil price will cause much uncertainty for FDP design and production management. Any unreasonable decision will lead to huge cost loss. Thus, foreseeing risk and mitigation strategies become more important. This paper takes AKPO and EGINA as examples to analyze the main uncertainties, proposes measures to avoid risks, and provides valuable experience for the other deepwater oilfields development.

2 Overview of OML130 deepwater projects in Nigeria

OML130 includes AKPO, EGINA, Preowei and EGINA south field, and CNOOC's work interest is 45%. AKPO field started production in 2009. The number of the well is 44, including 22 oil producers, 20 water injectors and 2 gas injectors. The maximum annual oil production is 60 MM bbls. Engineering pattern is FPSO + subsea production system (*Figure 1*). Until 2015, it maintains about 6 years of production plateau. EGINA is similar to AKPO in scale and will begin to produce oil in 2018. 44 wells are planned in FDP with 21 oil producers and 23 water injectors. The engineering model is also FPSO + subsea production system, and peak annual production is almost 70 MM bbls.

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Bao-quan Yang (✉), Li Yang, Fan-jie Shang, Xin Zhang, Chen-xi Li
CNOOC Research Institute, Beijing 100028, China
Email: yangbq@cnooc.com.cn

OML130 block plays an important role in CNOOC's overseas production growth, which is also an important chance for CNOOC to accumulate deepwater oilfield development experience.

3 Risks and mitigation strategies for FDP design

3.1 Risk analysis for FDP design

After the discovery of deepwater oilfields and productivity tests, if their commercial values can be identified, several appraisal wells will be necessary to acquire enough data. Generally speaking, the drilling cost of a single well is up to \$70–\$200 million. Therefore, the less appraisal wells to obtain more data or information, the better. However, fewer wells will cause uncertainties or risks.

a) Risks of formation distribution: formation distribution forecast mainly depends on the reliability of seismic data. Limited resolution and poor quality of seismic data will lead to certain deviation with oil-bearing area, boundary and reservoir distribution prediction, which may bring high uncertainties for further studies. OOIP evaluation can be influenced by many factors, such as reservoir boundary, reservoir thickness and OWC. OOIP will influence well numbers and engineering facility. With development wells drilled, if reservoir connectivity becomes poor and OOIP decreases, more wells are needed.

b) Risks of engineering pattern. The deepwater oilfield engineering pattern is influenced by many factors, such as water depth, wind flow conditions, offshore distance, geological condition, field scale, development life span, reservoir characteristics and reservoir pressure. Capex and Opex are quite different for each pattern. It is necessary to choose the optimized pattern.

c) Risks of drilling and completion design. Conventional drilling technology may be normal in onshore or shallow area, such as IWC wells and horizontal wells across the fault. However, it will become unreliable in deepwater field.

d) Risks of low oil price. Oil price is the core factor influencing the whole project economy. Development plan designed under high oil price may not be profitable once oil price goes down. Huge initial investment puts oil companies in a dilemma. Those deepwater projects which are still in the designing phase may need to be redesigned so as to reduce cost or delay development.

3.2 Mitigation strategies for FDP design

3.2.1 Data acquisition and test design

Using less wells to obtain essential information means decreasing exploration cost. Appraisal well location should cover main reservoir distribution. Firstly, reservoir deposi-

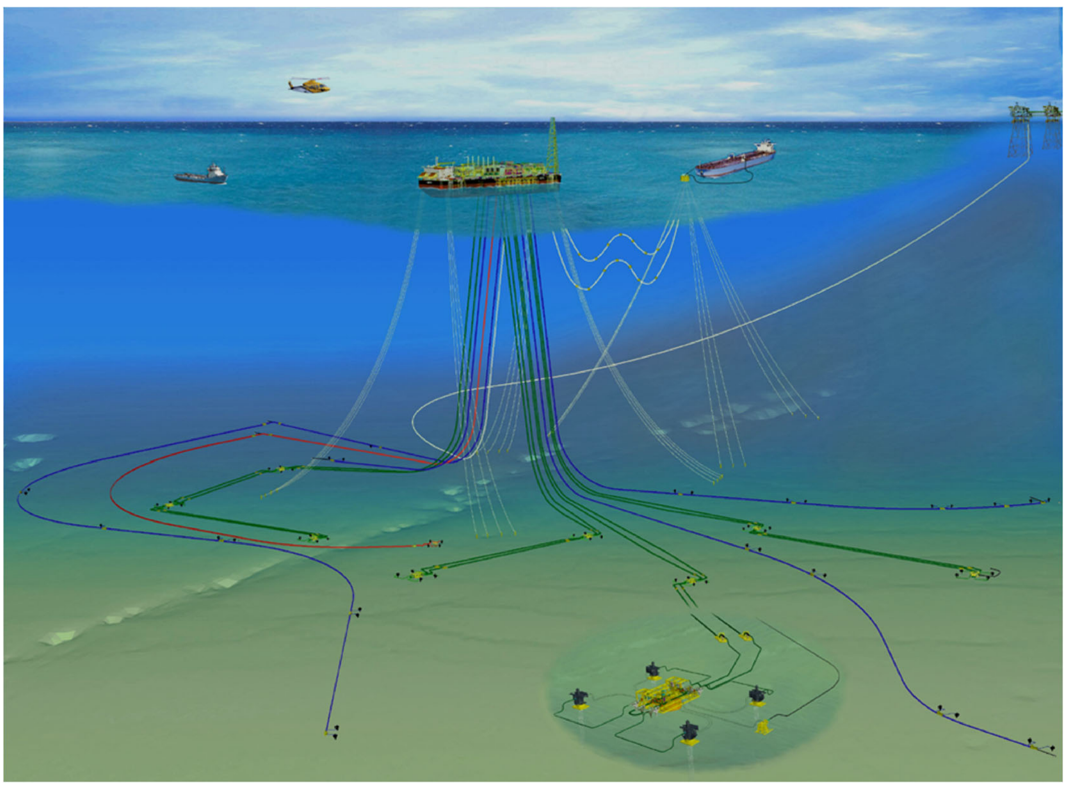

Figure 1. FPSO and subsea system of AKPO oilfield.

Table 1

Data Acquisition of AKPO and EGINA at Appraisal Stage

Project	AKPO	EGINA	Purpose
Mud logging	5 wells	5 wells	Geological analysis
Well logging	Conventional wireline logging on 5 wells, sonic logging on 5 wells, resistivity imaging logging on 3 wells	Conventional wireline logging on 5 wells, sonic logging on 5 wells, resistivity imaging logging on 5 wells, NMR logging on 5 wells	Geological analysis
Coring	4 wells	4 wells	Reservoir characteristics, lab test
Sidewall coring	2 wells	1 well	Reservoir characteristics
Pressure	5 wells, 435 pressure points	5 wells, 354 pressure points	OWC and reservoir connectivity
DST	3 wells, 5 in total	3 wells, 3 in total	Productivity and reservoir analysis
Fluid sampling	5 wells, 22 MDT samples, 5 DST samples	5 wells, 64 MDT samples	Fluid properties

tional model research should be done based on seismic data and similar reservoir experience. Secondly, appraisal wells should identify main reservoir boundary, fluid, and permeability. Thirdly, appraisal wells can identify main uncertainty for OOIP and reservoir connectivity.

Data acquisition plan should be representative and economical. Main data acquisition includes geological logging, VSP, coring, pressure, fluid, DST, and MDT. Generally speaking, the more initial data the researchers could collect, the better for research. However, less deepwater operation time means less cost. So reducing un-necessary data acquisition can decrease operational time. For example, if fluid characteristics show no compositional gradient, it is no necessary to obtain new fluid sample acquisition in some reservoir. For AKPO and EGINA field, all of data acquisition has been optimized, which is more economical (Table 1).

3.2.2 FDP design based on P50 OOIP

According to the common practice, probabilistic method is applied for OOIP evaluation. High, medium and low values are assigned for each parameter and P10, P50, and P90 distribution of OOIP are obtained. The development scale of an oilfield can be controlled under a reasonable scope if the FDP is designed with P50 OOIP. Take the determination of OWC as example, if the actual OWC is not discovered, then P50 of OWC can be acquired with the regression of static pressure, DHI (direct hydrocarbon indicator) or analogy. Generally, actual OWC will be in predicted scope. So it can reduce the risk of OOIP evaluation.

3.2.3 Evaluation on connectivity risks of the fault and reservoir

Faults sealing affects distribution and connectivity of the reservoir. It is identified by shale content, fault distance, and hydrocarbon heights. Results of fault sealing can provide significant information for OOIP and well design. Interference test can be an important method to identify reservoir and faults connectivity. It observes pressure on other wells when one well is under water injection. As the example of AKPO, pressure on other wells can be monitored after three days for about 1500 m well distance. Another method is EWT (Extend Well Test), one injector and one producer connect to a small FPSO and produce for 6–12 months. Valuable dynamic data can be acquired at different production regimes, which can be used to modify reservoir model and provide information for FDP design.

3.2.4 FDP covers whole oilfield development

After oilfield production, it is impossible to change the engineering facilities as need of well locations and well count. All infill wells have to be carried out based on current facilities. Therefore, the development strategy of deepwater oilfields must be based on their whole production life span. OOIP of high quality or main reservoirs shall be developed firstly, after less producers reach to peak production, add new wells for production succession. Designing reasonable facilities capacity is preserving space for future infill wells.

3.2.5 Uncertainty analysis of field development plan

Well count, well pattern, well type, development method and well productivity are key parameters for FDP design. Successful deepwater field development is based on optimized FDP. In order to decrease uncertainty, probability method is necessary for FDP. Orthogonal design can generate a probabilistic distribution for some key factors, and a reasonable P50 case will be acquired. P50 development case can represent most of uncertainty and should be recommended.

3.2.6 Optimized deepwater engineering pattern

Engineering investment usually accounts for 50%–60% of the total CAPEX for deepwater oilfields. Engineering pattern designs are based on geological conditions and reservoir development plan. For deepwater fields in West Africa (Wang, Duan, Feng, Liu, Wang, & Li, 2010), main engineering pattern is FPSO + subsea systems + shuttle tankers. In addition, FDPSO is a new pattern, and it includes drilling, work over, production, storage and oil lifting. Optimized engineering pattern can decrease CAPEX and improve production efficiency.

Besides, local content requirement is a common international practice for protecting the interest of the home country. However, local content requirement for deepwater oilfields will greatly increase construction cost and time, especially for undeveloped countries. Therefore, negotiations shall be started in advance, and local content requirement should be written in details. In addition, the conditions at which contractor can change the local content requirement should be agreed on in case of unexpected modifications during project execution phase.

3.2.7 Optimization on drilling design

Using deviated wells and horizontal wells crossing faults can decrease well number and increase productivity. Besides, intelligent completion technology can be adopted to develop two or more layers. Also, ICV can control rate of flow for special layer. However, these technologies can cause more complex drilling design, drilling risks and cost. So choosing horizontal wells and ICVs should be considered carefully, because it requires repeatedly calculation and evaluation. At last, low risk drilling and completion plan should be a priority if there are no enough advantages using new technologies.

3.2.8 Development strategy for deepwater oilfields at low oil price

Oilfield development economy is very sensitive to oil price. The Brent oil price has been decreased from \$120 in 2014 to \$40 in 2016, while deep-water oilfield break-price is about \$40–50. If the oil price keeps at this level, some developing deep-water oilfields projects will not be profitable. They are at high risks of financial loss. Therefore, with such low oil price background, it is necessary to optimize FDP to reduce well count and facility scale, decrease cost of drilling and facilities, and apply for more preferential terms by negotiating with the government.

4 Risks and mitigation strategies for project implementation

4.1 Risk analysis for project implementation

Project implementation includes the construction and installation of engineering facilities, drilling and completion, drilling and development program optimization. It should be on time or ahead of schedule. Firstly, facilities, mainly including FPSO, umbilical, subsea facilities, and UFR installation, are not completed in accordance with the plan. The delay of the plan will affect the first oil production. Secondly, reservoir conditions change a lot after being drilled. In this case, if drilling follows initial FDP, it will face low productivity wells. So FDP optimization is necessary and urgent. Thirdly, accidents of deepwater drilling take place frequently and lead to over budget. Drilling and completion costs account for about 30% of the total project CAPEX. Deepwater drilling may come across the challenges of shallow gas flow, hydrate, low temperature, and pressure control. Once the drilling lose control, accidents may take place. As a result, this will cause more cost and security accidents.

4.2 Mitigation strategies for project implementation

4.2.1 Contract change order and progress control

Construction and installation of the deepwater facilities are challenging. Scientifically planning facilities procurement and avoiding delay risks are necessary. Many core deepwater technologies and equipment are monopolized by a few companies. The contractor may offer a monopoly price and a long construction period. So the delivery time of main facilities should be planned at the beginning of the deepwater oilfield construction, reserve enough time and carry out the "long-term equipment bidding" as soon as possible. In addition, prepare alternative plan and make punishment measure in the contract clear and executable in case of the contractor's delay in delivery.

Besides, main contract change order should be examined and approved by operators and partners. If cost and schedule changes, operator should hold a workshop to control total cost and project schedule. To ensure the installation schedule on time, operation ships should be determined by one year ahead, and the alternative plan should be prepared. All the procedures of offshore installation operations should be approved by the operator. All major changes should be approved by the operator.

4.2.2 Updated reservoir research after drilling and FDP optimization

FDP should be optimized with updated reservoir information. Reservoir information may change after several wells being drilled, such as reservoir boundary, oil-water contact, reservoir connectivity and permeability. Drilling sequence should be optimized based on updated reservoir research. Uncertainty analysis and identification are main principles for drilling sequence. They can reserve chance and time for the subsequent wells. Secondly, FDP optimization must be done in time to avoid more risks. After the main reservoir uncertainties are identified, subsequent wells can be arranged according to the needs of field production.

4.2.3 The risk control of deepwater drilling

Compared with the mitigation strategies of conventional shallow water and onshore drilling, those of deepwater drilling are as follows (Hou, Wang, Ren, & Hu, 2009):

The geological hazards should be investigated to avoid shallow geological disaster. Shallow geological hazards mainly are the shallow gas and shallow water flow. These are the most common, most complex and most harmful risks to the deepwater drilling. For example, shallow gas will decrease bearing capacity and the shear strength of overlaying reservoir, and sudden eruption of shallow gas will easily cause blowout accidents. Therefore, shallow geological disaster investigation and evaluation should be made before drilling. Corresponding preventive measures should be made, such as increasing the casing classification, and adding blow-out preventer.

Temperature should be controlled to prevent natural gas hydrate. Hydrate can lead to the blockage and broken of blow-out preventer. Failure of the well control system will lead to the barite sediment and sticking accident. Controlling temperature and pressure, and adding hydrate inhibitor can avoid hydrate in pipeline. Drilling technology should also be optimized to prevent accidents. The pressure window between reservoir pressure and fracture pressure is quite small. It is easy to cause drilling fluid leakage, well kick, sticking, wellbore collapse and multilayer problems. These problems can be solved by optimizing drilling fluid, controlling pump speed and circulation speed.

5 Risks and mitigation strategies for reservoir production management

5.1 Risk analysis for reservoir production management

Reservoir production management will last for the whole field life and is based on reservoir technical research. Unreasonable production control can lead to earlier water breakthrough, faster production decline, lower recovery factor or recoverable reserve. If these happens, they will lead to production loss. For example, if volatile oil reservoir pressure is below saturation pressure as a result of less water injection, recovery factor will decrease a lot because of high fluid contractility. In addition, if infill well is drilled in developed area and productivity is less predicted without rigorous remaining oil research, it means losing money. In other words, comprehensive reservoir performance research can provide scientific decision-making to maximize potential production.

5.2 Mitigation strategies for reservoir production management

5.2.1 Dynamic data monitoring

Whole production data recording is very important for reservoir research and management. Key data recordings are as follows.

a) Measurement of single well production data. It mainly includes down hole pressure gauge measurement of bottom hole pressure, and three-phase flow meter on the well top is used to metering oil, gas, water, and top hole pressure.

b) Production dynamic information monitoring, including formation static pressure test during well temporary shut-in, MER test to ascertain the production capacity, PLT test to identify injection capacity and production capacity of different layers, and tracer test to verify reservoir connectivity.

c) 4D seismic monitor. Carry out a seismic data acquisition every 3–4 years after production. Seismic data difference can show water-flooding area, oil saturation, and pressure change. It also provides important evidence for history matching and infill wells design.

5.2.2 Fine reservoir management to ensure maximum production

The daily production of a single well in deepwater oilfield could reach 6000–25,000 bopd. Fine reservoir management could maintain the most potential productivity and maximum EUR per producer. Reservoir performance focuses on a single well or well groups because of large well distance. Well performance analysis includes pressure, water cut, GOR, VRR, and decline rate. Based on well performance, measures could be used to extend production plateau, delay water breakthrough, and decrease oil production decline. For example, after water breakthrough, water injection could be shut down, and oil production or on-off water injection could be decreased to control water cut rise. For gas injection breakthrough, changing production layer, gas injection capacity, or decreasing oil production can prevent GOR from rising fast.

5.2.3 Optimize uncompleted FDP well and infill wells

Generally, it takes 3–5 years to complete all the FDP wells in deepwater oilfield. Besides, infill wells will be necessary to develop undeveloped area. Well location design becomes more difficult because of several years of production. Generally, developers can use effective method to identify remaining oil distribution. 4D monitor can be an ideal way for deepwater field. Seismic data difference can show water-flooding area, oil saturation, and pressure change. So geological and reservoir model can be modified, and reservoir connectivity can be identified. As a result, infill well location will gave less risk. For AKPO field, 3 infill wells were drilled successfully in 2014 to 2015 based on 4D and reservoir comprehensive research.

5.2.4 Increasing production efficiency to reduce production loss

Full field shut down (FFSD) should be planned every 3–4 years. Although field has been shut down for several weeks, it is important to eliminate potential safety hazards and improve the production efficiency. In the meanwhile, optimizing operational schedule and reducing shutdown time are significant for minimizing production loss.

Besides, operation efficiency can evaluate each event production loss. The advantage of this method is that it can show real productivity and production loss for each event, including planned event, un-planned event, and non-operational event. For future operation plan, it can optimize operation schedule for minimizing production loss.

6 Conclusions

Risk identification and mitigation strategies are significant for deepwater oilfields development, because these could help avoiding investment risks and maximizing project economy.

a) Appraisal well can cover main reservoir and design economic data acquisition plan. Probability design method of development plan can control unpredicted risk within acceptable scope.

b) Optimized engineering pattern can decrease CAPEX and improve production efficiency.

c) Low risk drilling and completion plan should be a priority if there are no obvious advantages with new technologies. Investigating the geological hazards can avoid shallow geological disasters.

d) FDP should be optimized based on updated reservoir information, including drilling sequence and well location. It can decrease development cost and secure project economy under low oil price.

e) Whole production data recording is very important for reservoir research and management. Fine reservoir management can maintain most potential productivity and maximum EUR per well.

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