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Abstract

The thesis start form the introduction of the background and basic information of the deepwater operations both in the world and in South China Sea, make all the readers have a comprehensive and clear understand on the deepwater oil and gas area, especially in South China Sea; and then fully identify the challenges and problems which the deepwater operation in South China Sea faced, from Three aspects which are environment conditions, facilities, and technologies.

Chapter 2 will introduce the detailed environment factors, which include typhoon, current, temperature, water depth, shallow water flow, shallow gas, and hydrate formation. In the end of chapter 2 the author will emphasize the special marine nature and geological environment conditions.

Chapter 3 will introduce the challenges from the facilities, and primarily introduce the facility selection criteria. Chapter 4 will introduce the technology challenges of offshore deepwater oil and gas development, the author also divide the introduction into two parts, first part is the common technology challenges worldwide, the second part is the special technology challenges in the South China Sea.

The solutions and advices of some of the challenges and problems will list out, and the further study areas also will point out. At last, a case study of the successful development of the first deepwater oilfield in South China Sea, the development of the Lufeng 22-1 oilfield, will be discussed particularly, and some inspirations and experiences will be summarized in the discussions and conclusions as the suggestion for the deepwater operation in South China Sea.

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List of Abbreviations

BOP	Blow out Preventer
CNOOC	China National Offshore Oil Corporation
COSL	China Oilfield Service Limited
FPS	Floating Production System
FPSO	Floating Production， Storage and Offloading Unit
GOM	Gulf of Mexico
LSRV	Low Share Rate Viscosity
LMRP	Lower Marine Riser Package
MST	Multipurpose Shuttle Tanker
ODP	Overall Development Plan
SPM	Single Point Mooring System
STP	Submerge Turret Production

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Chapter 1. Introduction

As the standard of living and production continuously rising, human is relying more on resources. The oil and gas is the hottest energy in the world, after decades of exploration and development, the number and scale of major hydrocarbon discovery in land and shallow sea is becoming smaller and smaller. So the Deep sea area with a very low degree of exploration is the new target.

We have achieved great breakthrough in exploration and development of deepwater oil and gas resources in recent years. The construction of "HYSY 981", the first ultra deepwater semi-submersible drilling platform in china, which upgrade China deepwater drilling equipment to the world's advanced level ranks, however, compared with foreign advanced level, there are several weak points in China deepwater drilling and completion, for example, lack of operation experience, technology and technique stays low level, basic Theoretical research is weak and other issues. In order to achieve safe and efficient development of the South China Sea deepwater oil and gas resources finally, we need a comprehensive understanding of the special challenges on drilling and completion which bring from the special marine environment of the South China Sea, special offshore geological conditions, and problems from the long distance to shore. A series of key technologies and further research should be broken through to find the most suitable way to develop the deepwater oilfield in South China Sea.

This thesis will focus on the challenges of the deepwater development in South China Sea, and study a successful deepwater development case in South China Sea. The solutions and advices of some of the challenges and problems will list out, and the further study areas also will point out.

1.1 Background

What is Deepwater? Deepwater is typically a water depth greater than 1000 ft (300m) while water depth exceed 5000ft is considered ultra deepwater. Well drilled in water depth exceed 5000ft will typically be drilled with dynamically positioned rigs, and not the conventionally moored drilling vessels used to drill wells in shallow water.

With deepwater continue to make major discoveries, global deepwater oil and gas exploration and development continues to heat up, deepwater oil and gas exploration and development investment is increasing. According to Douglas Westwood's Report, from 2008 to 2012 the global deepwater oil and gas exploration and development investment is 112 billion dollars in total. And in 2013 to 2017 it is expected to reach 223 billion dollars in total (Figure 1.1), which is doubled comparing to the last five years. Among them, the "Golden Triangle" (the Gulf of Mexico, Brazil and West Africa) was 178.4 billion dollars (80%), Asia will have a more substantial increase (expected to grow by 20%), subsea well drilling and completion of the investment is estimated at 78 billion dollars. According to Infield Systems predicts that global deepwater oil and gas exploration and development investments accounted for the proportion of offshore oil and gas exploration and development of the total investment, increasing from 38% in 2012 to 53% in 2017.

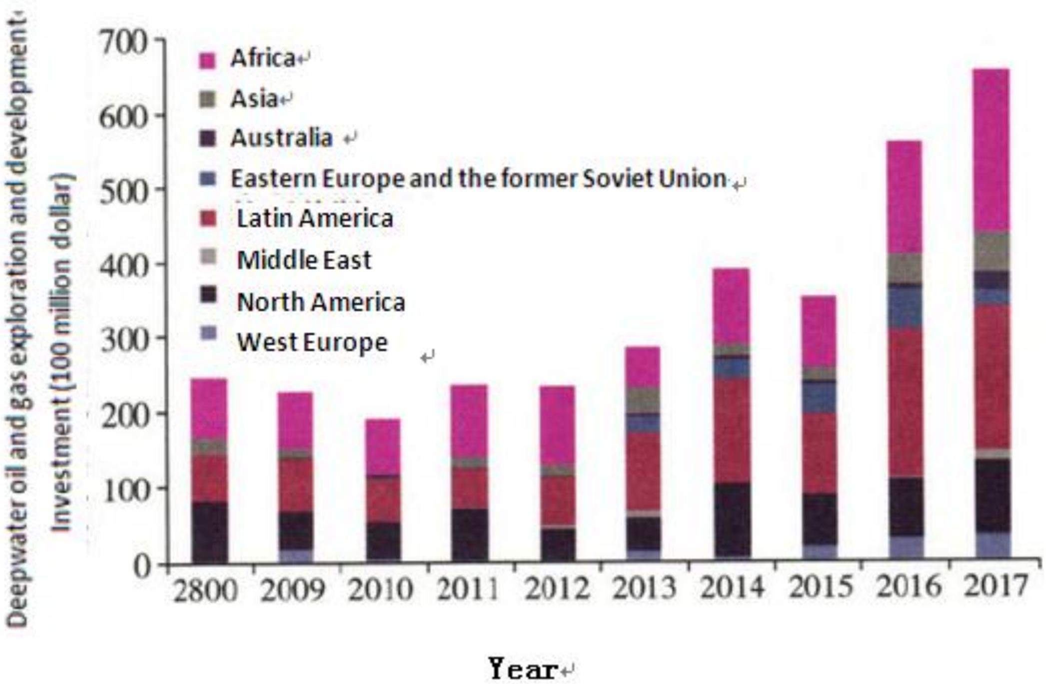

Figure 1.1 Global deepwater oil and gas exploration and development investment (Douglas Westwood, 2013, Feb)

As the global drilling in deep water increasingly grows, the market of drilling contract in deep water expands increasingly and the record of drilling depth has been broken constantly. Due to the high demand in the market, the construction of global deep-water floating drilling facilities become thriving. The number of the facilities raises and the supply is urgent in general. The ultra deep-water drilling ship gradually becomes the main trend of the construction. Deep-water floating drilling facilities can be seen mainly in golden triangle areas, including the Gulf of Mexico, Brazil and West Africa. With great difficulties and high risks, the deep-water drilling still takes a giant leap in development in a few years. For example, Seadrill become the second largest contractor of world offshore drilling and the top deep-water drilling contractor from a small company over the past five years through acquiring corporation, investment in construction, purchasing offshore drilling facilities, optimizing and adjusting structure and capital running. It's worth learning from their experience.

1.2 World offshore oil developments

The newly discovered onshore and shallow water oil reserves in States each year have been decreasing. According to data analysis, since 1990's, there are only 11 large oil fields in total in the world which have remaining recoverable reserves of more than 1O million barrels of oil; there are 2 large oil fields in each of West Africa, Central Asia, the Gulf of Mexico and Latin America, and only one in each of the Middle East, the Russian Far East and North Africa. The oil and gas reserve in the Middle East ranks first in the world.

Although the oil and gas production in North Sea which located in west Europe has been in a high level, but the exploration has shown a downward trend. Pakistan, India and Bangladesh, Located in South Asia, have abundant natural gas resources, but exploration is difficult. In Malaysia, Indonesia, Thailand and Vietnam, have a high degree of exploration but have a greater risk in oil and gas projects development.

Australian onshore exploration risk is higher, its maritime traditions shallow oil zone output declined, but the deep-water area of the North West Shelf of Australia is likely to be the emerging oil-producing region.

In North America, the United States and Canada, exploration and development is already high. To continue the new proven reserves and to achieve a significant increase in oil and gas production, it only can achieve in the Gulf of Mexico and California waters, Alaska, and Newfoundland waters.

From a global perspective, due to the higher level exploration on land and in shallow water, oil and gas production has been close to the peak. The world's new oil and gas reserves discovered by land and shallow waters have turn to vast deep sea waters. In recent years, the world's major exploration discovery obtained, nearly 50% from deep waters, its proven reserves of about 1 000 × 108 t of oil equivalent. The Gulf of Mexico, the Brazilian sea, West African waters and the South China Sea is known as the second Persian Gulf is the most promising deepwater areas.

Since 1999, more than half of the world's major discovery was made in deep water. Since 1999 to 2003, there are 14 newly discovered large oil fields with reserves in 6850 ×104t or more worldwide, 9 in deepwater, 2 in shallow water, 3 on land. During this period, 23 large gas fields were discovered, more than half from deep water. From the point of view on newly discovered Reserves, in 2000 - 2005 the world's new oil and gas equivalent is 164 ×108 t, deepwater accounting for 41%, shallow water and land only 31% and 28% respectively. See Table 1.1

Table 1.1 Statistics of large oil and gas fields discovered worldwide since 21-century (Sources: COSL)

	Total	Onshore	Offshore shallow	Offshore deepwater
Large Oilfield discovered since 1999	14	3	2	9
Large gas field discovered since 1999	23	5	4	14
newly discovered Reserves/ equivalent 10^8 t	164 (100%)	45.9 (28%)	51.8 (31%)	67.2 (41%)

In recent years, the world's major exploration discovery obtained, half from the sea, especially in deep water. The deepwater areas with oil and gas discovery mainly are West Africa, offshore Brazil, and the Gulf of Mexico, followed by the South China Sea. According to Douglas-Wood company and the world's oil system industrial data statistics, when the water depth in 500 to 1 500 meters, the average reserves in the world deepwater fields increased significantly with depth, deepwater oil and gas production was significantly higher than the shallow water oil and gas fields, although this cannot be explained by the theory of petroleum geology, but it really is not ignore the fact.

1.3 Status of Chinese offshore oil developments

Chinese offshore oil and gas resources are very rich. Chinese offshore development of a series of sedimentary basins, with a total area of nearly one million square kilometers, is rich in oil and gas prospects. These sedimentary basin from north to south are: the Bohai Basin, North Yellow Sea Basin, South Yellow Sea Basin, the East China Sea basin, basin Okinawa Trough, Taihsi Basin, Southwest Taiwan Basin, Southwest Taiwan Basin, Taitung basin, Pearl River Mouth Basin, Beibu Gulf Basin , Yingge sea - Qiongdongnan Basin, southern south China sea various basins. Chinese offshore oil and gas exploration focused on the continental shelf north of the Bohai Sea, Yellow Sea, East China Sea and South China Sea.

The South China Sea is even more oil treasure. The exploration area in the South China Sea is only 16 square kilometers, oil reserves discovered is 5.22 billion tons, The development value of oil and gas resources in the South China Sea is over 2 billion RMB, over the next 20 years as long as 30% reserves was explored, the contribution for the Chinese GDP to growth is 1 to 2 percentage points per year. The data was shown that the total oil reserves only in Zengmu Basin, Sabah Basin and Wanan basin in the South China Sea is nearly 20 billion tons, which was the world's large untapped reservoir, of which more than half should be classified in Reserves owned waters under the jurisdiction of China.

Preliminary estimates the total oil reserves in the South China Sea, is roughly between 23 billion to 30 billion tons, accounting for one third of China's total amount of resources, is one of the world's four major offshore oil and gas gathering center, was called the "second Persian Bay". According to CNOOC's 2003 annual report, the company in the western areas of the South China Sea and East China Sea, and at the end of 2003, net proved oil reserves of 6.01 billion barrels, accounting for CNOOC's proven reserves of 42.53%. So far, 7 large oil fields with hundred million tons of oil has been found in the Bohai Bay area, of which the Penglai 19-3 oil field, located in central Bohai bay, is by far China's largest offshore oil field, and is the second largest oil field in China currently. The proven reserve is 6 million tons, only smaller than the Daqing oilfield till 2010. The Bohai offshore oilfield production will reach 55.5 million tons of oil equivalents, becoming China's main oil and gas growth.

With the great development of China’s economy, especially in the petrochemical and automotive industries, shortages of oil and gas have become increasingly frequent. Since 1993, China's crude oil supply has not met domestic market demand, and the country has turned from a net oil-exporting country to a net oil importer. In 2005, China's crude oil imports reached 90 million tons, and the shortage of the oil resource became a major factor constraining China’s economic development. Thus in 2006, in order to meet the demands of its economic and social expansion, China proposed the 11th Five-Year Program; this intends to strengthen the exploration for and development of oil and gas resources, increase backup reserves, and reverse the stagnant oil and gas production.

China’s offshore oil resources are far from being fully exploited; its coastal waters are still a blue territory full of rich resources. In waters under China's jurisdiction, oil and gas resources have produced more than 40 million tons oil equivalent and offshore oil and gas production has become a major part of China’s oil and gas incremental production. Given the country’s rapid economic growth, however, the development of offshore oil and gas resources alone has been unable to satisfy domestic demands. It has become more and more urgent for China’s oil and gas industry to march toward deeper water.

The South China Sea is one of the 4 largest oil and gas accumulations in the world and the largest sea area in China, with the deepest average depth. However, because of the country’s late involvement in the offshore oil and gas industry, its exploration and development (E&D) technologies and independent intellectual property rights are still underdeveloped, and the key technologies used in deepwater equipment are behind those of the countries advanced in offshore E&D by 15 to 20 years. Domestic production of the high-technology equipment required for deepwater development is at a low level. As a result, the most urgent and continuing task of the CNOOC has been to use China's deepwater oil and gas resources in an efficient way, to bring about a continuing energy supply, and to solve the growing energy crisis.

Table 1.2 China's representative wells in the deepwater region of South China Sea (Sources: COSL)

Well name	Spud date	Water depth/m	Well depth/m	Well types	Basin
LW3-1-1	*2006-08*	1480	3843	Wildcat well	Pearl River Mouth Basin
LW3-1-2	2009-02	1376	3918	Appraisal well	Pearl River Mouth Basin
LH34-2-1	2009-12	1145	3449	Exploration well	Pearl River Mouth Basin
LW6-1-1	2012-05	1496	2335	Wildcat well	Pearl River Mouth Basin
LW21-1-1	2012-08	2456		Exploration well	Pearl River Mouth Basin
LS17-1-1	*2014-08*	1455	3510	Exploration well	Southeast Hainan basin
LS17-2-2	2014-08	1547	3450	Exploration well	Southeast Hainan basin

Chapter 2. Challenges from the environment

In this paper, the environment includes the nature environment and geological environment which both affect and limit the offshore deepwater development. The nature environment factors include typhoon, current, temperature and water depth. The geological environment factors include shallow water flow, shallow gas, hydrate formation.

2.1 The Effects of Typhoons

The term "typhoon" refers to a tropical, cyclonic storm that originates in the western Pacific Ocean (in the Atlantic, this type of storm is referred to as a hurricane). Typhoons can generate winds of more than 75 miles/hour and have been known to cause flash floods with their intensive rainfall. The two most destructive forces associated with typhoons are wind and rain. Individuals on watercraft or those performing water operations (such as on oil rigs) not only have to contend with heavy winds and rain, but also they have to deal with massive waves and, in general, turbulent water conditions.

2.1.1 The case of offshore platforms destroyed by typhoon.

The follow Pictures show Mars and Typhoon platforms in GOM that were damaged in 2005.

Figure 2.1 Mars platform was damaged in 2005 (Ove T. Gudmestad, 2006)

Figure 2.2 Chevron Typhoon Platform was damaged in 2005 (Ove T. Gudmestad, 2006)

The Possible causes for the platforms were damaged in the storms include:

- –Large wind forces
- –Wave in deck loads
    - •Very high waves
    - •Storm surge
- –Seabed slides

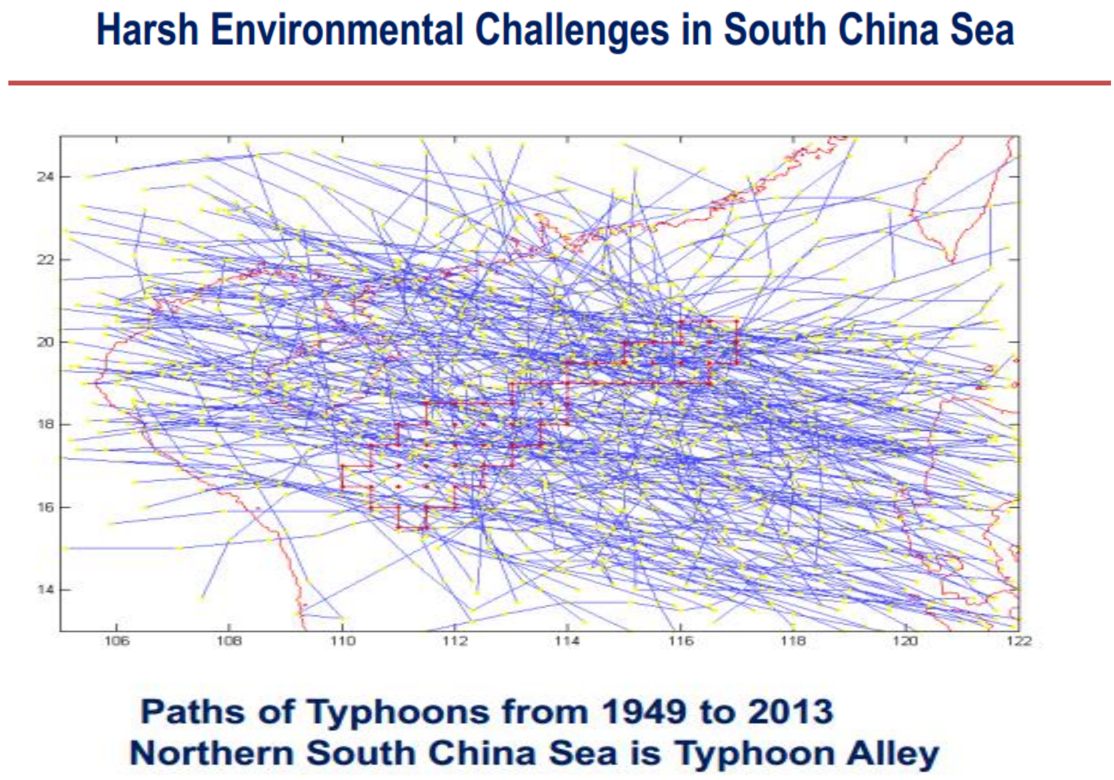

Figure 2.3 statistics of typhoon paths from 1949 to 2013 in South China Sea (Sources: COSL)

2.1.2 Environmental Window

The deployment of casing and subsea equipment during all open water work can be inhibited by the maximum sea-states and surrounding conditions. This varies considerably from region to region e.g. Benign conditions West Africa, to Gulf of Mexico (loop currents, hurricanes, temperate environment), or West of Britain (high sea states, high winds, difficult subsea currents) etc. Working limits and operating windows therefore have to be defined for drilling, especially open water operations. E.g. Deepwater Semi-Submersible, rig, “Polar Pioneer” evaluated operating working criteria for the Norwegian Sea.

Table 2.1: "Polar Pioneer" Operating criteria (Sources: Transocean)

Operation	*Maximum heave response*
BOP & marine riser	2.0m
Testing	3.0m
Drilling	6.0m

To meet such operating criteria, specific equipment must be fully evaluated as “fit for purpose” and technical analysis must be performed to ensure preferred technical and regional environmental requirements can be met. Note: Safety is the utmost importance and supersedes equipment considerations. Also environmental criteria considers equipment reliability without due regard to personal safety. Operations should not be conducted if weather is such that rig motions do not allow safe operations.

2.2 Currents

Contrasts in water density may arise due to temperature, salinity and turbidity. The result is a steep boundary interface, separating two distinct water masses. As a result, the light surface water spreads over the dense deepwater inducing complex flow patterns (currents). Deepwater is characterized by low speed as compared to surface water due to low temperature, high density and less exposure to ocean wind at ocean depths. Its masses move continually and slowly, in response to density gradients that result from differences in salinity and temperature of the water. Dense water sinks and displaces less dense water as illustrated in figure 2.4 below.

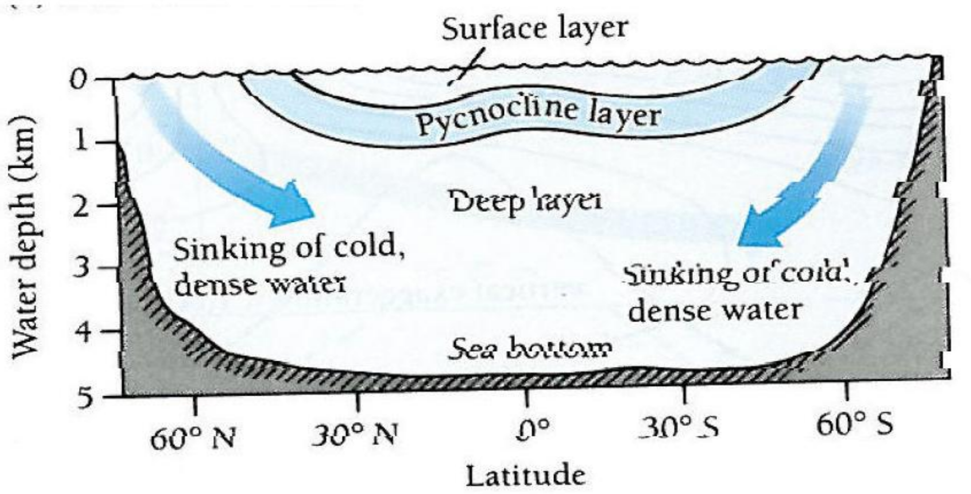

Figure 2.4 Density Distributions in Oceans

2.3 Temperature

Both vertical profiles and longitudinal cross sections of water temperature reveal that the oceans have a layered thermal structure. Warm, tropical and subtropical surface water, several hundred meters in depth, float over colder, denser water. These two water masses are separated by a band of water, the thermocline, which has a steep temperature gradient. Unlike the surface water, where temperature changes with seasons, water below the permanent thermocline remains remarkably uniform to a particular depth and stable in temperature over time, averaging < 4 o C. The temperature of the ocean water decreases as water depth increases. There are two major considerations regarding the behavior of the ocean water in relation to temperature interactions:

(a) Salt Content and temperature effect: Exposure of the big ocean seawater (saltwater) to fresh water could alter its salt content.
(b) Pressure and temperature

2.4 The effects of water depth

Offshore deepwater shallow formations are buried under and impregnated with much greater water hydrostatic, giving them a lower fracture resistance than the same formation at the same sedimentary depth onshore. The presence of the water column above the shallow formations reduces the equivalent fracture density. Lacking regional data, the fracture gradient for shallow formations can only be approximated. Modern seismic techniques sometimes enable the accuracy of the estimate to be improved.

2.4.1 Pilot holes in deepwater.

In deep water drilling operations, it is often practiced to drill a pilot hole to assess potential geo-hazards near the planned well location without the use of a marine riser. A small pilot hole, typically 9 7/8 – 12 ¼", is drilled to a depth which is below the planned setting depth of the surface casing. Pump rate is held constant while drilling the pilot hole and pump and annular pressure measurements are utilized as the primary indicator of well flow. If changes in pump pressures are observed while drilling the pilot hole, drilling is ceased and the ROV camera or drilling measurement tools will be used to determine if well flow is detected. If flow is observed, dynamic well killing operations are then immediately initiated by pumping kill mud at a pre-determined modeled kill rate with the rig pumps until the well is killed.

If no well flow occurs after reaching total depth of the pilot hole, the hole is displaced with mud before pulling out with the drilling assembly. Once it has been determined that the well can be safely drilled without the riser, the well is drilled riser less to the setting depth of the surface casing string(s).

The two basic reasons for sacrificial riserless pilot holes in deepwater operations are :

a. It is difficult to bring mud returns to the surface as water depth increases, due to the fact that the formation fracture gradient decreases with increasing water depth. The formation below the "normal" setting depth is thus unable to support the hydrostatic pressure of the mud column in the riser.

b. Drilling a small pilot hole and having seawater hydrostatic pressure available for back pressure may enhance well killing ability (although there are differing opinions on this). If a gas or shallow water flow does occur while drilling in deepwater, flow is deflected down current and will safely surface away from the rig which can reduce risk of fire or explosion occurring on the rig.

2.5 Shallow Water Flow

"Shallow water flows" have been encountered from over-pressured water reservoirs in deepwater areas, and the relatively shallow depths as deep as +/- 2500 ft below the seabed. When penetrated during drilling, weighted mud is required to be pumped to balance the shallow water flow pressures drilled into. Often the maximum mud weight used is limited by the strength of the formations above and below the water reservoir. Furthermore, when these reservoirs are penetrated the soil strength around the casing can be compromised which can cause additional problems as:

- Buckling of casing
- BOP sinking below mud line and ultimately
- Loss of well

2.6 Shallow gas

Shallow gas accumulators have also historically caused severe accidents to happen in certain areas where drilling for oil and gas has taken place, e.g. shallow gas has been reported in approximately 27% of all wildcat and appraisal wells drilled on the Norwegian continental shelf. Evidence of gas from gas chimneys and "bumps" can be seen however above a number of fault blocks however in deepwater regions, where shallow high amplitude reflections and pull down effects can be seen over the crest of the fault blocks. Hence shallow gas in deepwater cannot be discounted. Because shallow gas hazards may exist, so casing is required to be set shallow to establish well containment. It is important to ensure that specific shallow well control procedures are initiated during drilling and tripping operations through any such shallow gas bearing anomalous zones.

2.7 Effects of Hydrate Formation

Hydrates exhibit a potential serious risk in deep water especially so with regards to well control scenarios where the formation of hydrates can have several effects:

- Plugging of choke and kill lines preventing their use in well circulation;
- Formation of a plug at or below the BOPs, that prevents monitoring well pressures below the BOPs.
- Formation of a plug around the drill string in the riser, BOP's or casing that will restrict drill string movement.
- Formation of a plug between the drill string and the BOPs to prevents closure.
- Formation of a plug in the ram cavity of a closed BOP preventing full opening.

Due to the water depths in certain deepwater area one must therefore be aware of and be prepared for the formations of gas hydrates during well control operations.

2.7.1 Prevent the Formation of Hydrates at the Wellhead/BOP.

The primary means of suppression is to have a high concentration of salt in the mud if possible. A concentration above 20% should be maintained. A secondary means is achieved by having the kill line full of a glycol/mud mix, which would be circulated into the BOP's and wellhead to prevent hydrates forming. Whenever pumping is stopped a small amount (5-10 bbls) should be spotted at the BOP's.

2.7.2 Remove any Hydrates that have formed at the Wellhead/BOP.

This is done by circulating methanol down the kill line and up the choke line, first through the lower choke valve on the BOP. The methanol should be given time to "soak" and dissolve the hydrates. Some patience expended can save the need to round-trip the BOP/LMRP. Once the hydrates have been dissolved, the gas may be either bullheaded back to the formation via the drill string and annulus or circulated out.

Note: Pumping seawater or mud will not be effective due to the cooling effect of the deepwater. The most effective way of removing hydrates is depressurizing. Applying pressure will only make the situation worse.

2.8The special challenges faced during drilling and completion in the South China Sea.

In addition to the common challenges which are deep water depth, wind, wave, current, temperature change, narrow safe density window, shallow drilling and shallow geological disasters, the South China Sea deepwater drilling also face some special problems, including special marine environment, special geological conditions and long offshore distance and so on.

2.8.1 Special marine environment

The special marine environment in the South China Sea include: local typhoon, unclear seawater temperature distribution, and internal solitary wave.

Local Typhoon: The frequency of occurrence of Local Typhoon in the South China Sea is greater and the intensity of typhoon in deepwater area is greater too. It is very difficult to monitor and forecast the abrupt local typhoon with a complex and changeable path. The technology for the drilling platforms and riser systems against typhoon is one of the difficulties of the South China Sea deepwater drilling emergency technology.

Seawater temperature distribution is not clear: So far, the temperature distribution of the South China Sea water is not very clear, authoritative data are not directly available. Low temperature can significantly affect the rheological properties of drilling fluid, and increase the flow resistance of drilling fluid in the wellbore, also affect the properties of cement paste and the deepwater cementing technology. The low temperature will make the pressure loss of fluid circulation in the kill line increased, and the difficulty of deepwater well control increased too; the annulus pressure profile prediction of deepwater dual gradient managed pressure drilling, deepwater well control parameter design, gas hydrate formation region prediction during testing are all closely related with the temperature field. Thus, the seawater temperature field is not clear increases the difficulty of the drilling design and operating risks.

Internal solitary wave:The South China Sea has a complex and varied terrain and severe seawater density stratification. The internal waves are frequent and wave forms different from regions to regions, significant changes with the seasons. Internal waves formed in indefinite periods of time with impermanence flow rate, regular direction, short single point duration and large differences in regional distribution. The internal solitary wave has a great influence on the stability of large offshore structures. In a light accident the drilling platform was easily drifted by the internal solitary wave, or even worse a serious accident will occur. As far as we know that the amplitude of internal solitary wave in the South China Sea is up to 150 m, the highest in the world. Therefore, in order to effectively deal with internal waves issues, the characteristics of the platform motion response were studied.

2.8.2 Special geological condition

Compared with the world's major deep-water oil and gas basins, the South China Sea deep-water basin main source rocks in different regions varied in its formation year, tectonic setting, sedimentary environments and types, which has brought great Negative Effects on the oil and gas exploration and development in the South China Sea.

The geological environment of South China Sea is complex, such as the sand and Shagou is obvious; the Shapo and sand ridges are mobile, the moving speed is up to about 300 meters per year. Meanwhile, the geological environment in South China Sea is diverse, the types is different from block to block, which was resulting in the different geotechnical properties. Due to our current investigation and research on the geological environment of the South China Sea in its infancy, there is less data available to determine the three pressure profile of drilling, and the uncertainty of narrow safe density window increases, so that it is more difficult to control the design and operation of drilling wellbore pressure.

The deepwater geothermal features data in Northern South China Sea is more comprehensive, but the data is limited; southern deepwater lack of geothermal features data and the measured temperature gradient data are scarce. Geothermal field distribution is unclear, which increased the difficulty for forecasting temperature and pressure fields of the drilling and completion fluid flow.

The South China Sea is an important part of the Western Pacific metallogenic belt of gas hydrates, gas hydrates have good mineralization conditions often coexist with oil and natural gas. On the one hand, the drilling would bring external perturbations induced diapir and landslides; on the other hand, natural gas hydrate dissociation cause seawater density decreases, causing the drilling platform capsized, fires and other accidents.

There is a typical shallow gas distribution in South China Sea, and there are 12 shallow gas areas in Pearl River Mouth Basin by preliminary statistics. The Shallow gas stratum has low shear strength and carrying capacity, and the gas resulting in pore pressure increased. When drilling in shallow gas area, it may cause a sudden release of gas, even burning.

The shallow water danger zone exist in northern South China Sea Deep Water Basin area, but is limited by the extent of existing surveys, the distribution of shallow water is not clear which may increase the South China Sea operational risk. Shallow water formation has shallow burial depth, overpressure, unconsolidated sand and other characteristics, it cannot easily be found. It is very easy to cause blowout accident when drilling in shallow water zone and the blowout speed is very fast. If the wellhead was not properly installed the well cannot be killed, and may cause sand flow, which damage the wellhead and wellbore and pose a risk to adjacent wells. Shallow water disasters are difficult to control and deal with, though there are methods already available to identify, prevent and control, but it is not mature.

2.8.3 Long offshore distance

The deepwater oil and gas resources in South China Sea are far from the land, it is almost more than 300 km away from the land, so the logistics demand is high. When facing the typhoons and other inclement weather, the high capacity requirements of the job is needed, and the required time of the evacuation and drilling equipment maintenance will increase, and the design construction and cost control become more difficult.

Chapter 3. Challenges from the facility

In offshore oil and gas development, hundreds of tons of heavy drilling rigs must have enough space for support and place, and the drilling crew also needs enough room to live in, offshore platform assume this task. Due to the ever-changing sea weather, destruction by storms at sea and seabed undercurrent, stability and safety of offshore drilling unit become more important. Therefore, the offshore facility is an extremely high cost structure, and there are a series of challenged factors during the whole development processes, from the exploration, drilling, completion to the production, such as safety, cost, technology, experience, and so on.

The facility design is the first important step for deepwater oil and gas development. To achieve the success of the facility selection, a set of drivers was determined.
Main HSE drivers:
• Number of people onboard the platform
• Hydrocarbon inventory
• Power requirement
• Layout

Main cost drivers:
• Weight and area requirement
• HSE requirement
• Number of people onboard
• Complexity of facility

Prior to planning to drill and test a deepwater prospect, it is essential to review and select the type of drilling vessel that will be used. The types of drilling vessels available to drill a deepwater well are:
• An anchored semi-submersible.
• An anchored drillship.
• A dynamically positioned semi-submersible.
• A dynamically positioned drillship.

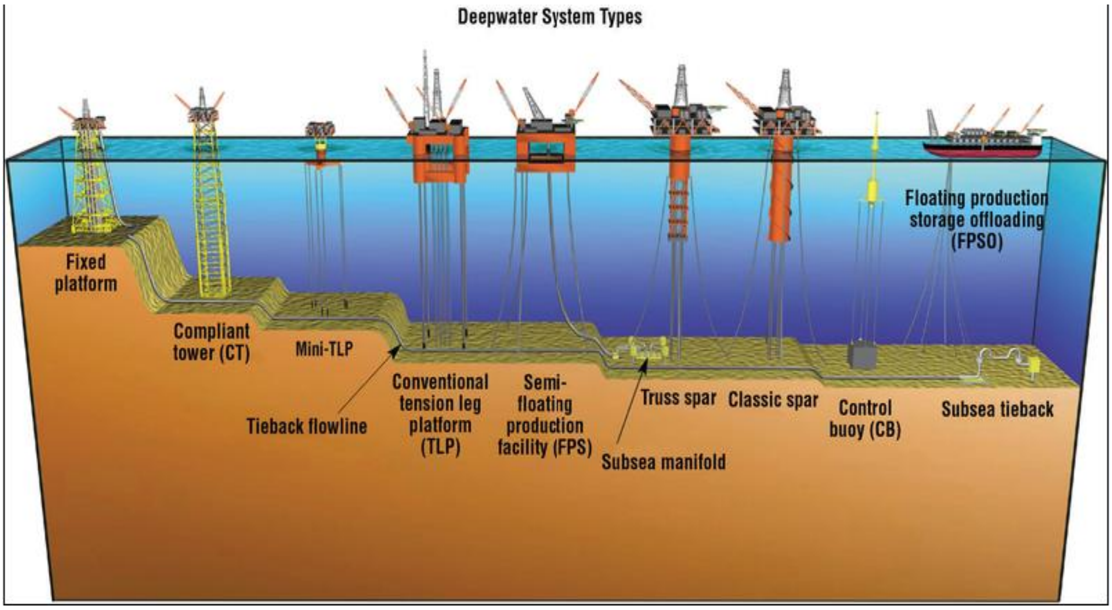

Figure 3.1 Alternative proven technology field development options (courtesy of BP).

3.1 Deepwater Drilling Vessel Selection

In water depths up to 2,000 ft it will be possible in most cases to utilize a standard anchored semi-submersible drilling vessel. As the water depth increases beyond 2,000 ft, the need to utilize a dynamically positioned semi-submersible and ultimately a drillship increases. Note: New 5th generations, or upgraded drilling vessels, are now able to operate whilst anchored - even in water depths of (4,000 ft – 6,000 ft) that were previously considered suitable only for a dynamically positioned drilling vessel.
It is recommended that the operator inspects the drilling vessel at the earliest stage. If possible this should be performed before contracts have been finalized and well planning has commenced. This will allow the operator to recommend improvements to the drilling vessel, which may allow an improved standard of service during drilling operations.

Note:It may be possible to negotiate improvements to the drilling vessel, prior to the final acceptance and the signing of contracts. Improvements after this will typically result in the full cost being passed on to the operator.

A dynamically positioned drilling vessel does not use the traditional anchoring system, but utilizes a set of computer controlled thrusters that are linked to sensors on the wellhead and a global positioning system that maintains the drilling vessel's position above the wellhead.

It is important that key drilling persons are involved during the selection of the drilling vessel. His primary responsibility is to ensure that the drilling vessel's operating criteria is understood and compatible with all contractors' subsea equipment. The planning for drilling operations would require with checks for the following:

- The ability of the drilling vessel to remain on location, above the wellhead with minimal lateral movement.
- The ability of the subsea equipment operations in terms of deck space areas, moon pool facilities, BOP stack configuration's etc.
- The motion of the drilling vessel (heave, roll etc.) and the resulting operating parameters during all drilling operations. The ability of the drilling vessel to remain above the wellhead during the drilling test is particularly important. Too much lateral movement will eventually result in a need to unlatch the marine riser hence the drilling vessel that can remain above the wellhead under severe weather conditions and /or current velocities will be the preferred choice.

Chapter 4. Challenges from the technologies

In this chapter, the technology challenges will be introduced in two parts, first part is the common technology challenges of deepwater drilling worldwide, and the second part is the special technology challenges of deepwater in the South China Sea. And the solutions of some challenges will also be introduced.

4.1 technical issues of deepwater drilling worldwide

The main technical issues of deepwater drilling are: the stability of seabed shale, large consumption of drilling fluid, shallow water flow, wellbore cleaning, shallow gas and gas hydrate and low temperature.

4.1.1 The stability of seabed shale

Depending on the deposition rate, compaction mode and moisture content, the activity of seabed shale is very large. River water and sea water carrying fine sediment and farther away from the coast, the upper portion of these deposits due to lack of compaction, cementation is poor. In some areas, the seabed shale expand easily and has a high dispersion, this will lead to an excess of solid or fine particles are dispersed in the drilling fluid.

In Norwegian offshore drilling mud system, a small amount of calcium chloride and the cloud point glycerin is used to enhance the stability of shale.

4.1.2 Large consumption of drilling fluid

A significant amount of drilling fluid is required in deep water drilling operations, generally the riser volume is as high as 1,000 barrels, together with the platform drilling fluid system, as well as due to the large diameter borehole, in order to complete drilling design depth, the casing also generally was set lower and more, so the total volume of circulation drilling fluid would need more than others with the same depth but different drilling conditions. By using effective solid control equipment, to control the drill cuttings content in drilling fluid in the appropriate range, you can save a lot of drilling costs. During deepwater drilling, solids control equipment such as three high-frequency deepwater drilling shaker, large flow desander, desilter, mud cleaner and centrifuges should be equipped at least.

4.1.3 Shallow water flow

Deepwater drilling in the seabed within the following depth 90 to 2100 meters, there is likely to occur shallow water flow (SWF). It is reported that the shallow water flows are the reasons that drilling become complex, which bring more difficulties in drilling, running casing and cementing. It is reported that 80 deepwater wells In the Gulf of Mexico (depth of over 600 meters), more than 60 percent of the wells have had varying degrees of shallow water flow. Under the worst case the oil well had scrapped. In the drilling process, if the problem is found, the solution is running the casing to the top layer of sand, then isolate with clean liquid before cementing. Shallow water flow problem is one of the main problems in deepwater cementing operations encountered.

4.1.4 Wellbore cleaning

As long as the drilling fluid flow rate is high enough, you can clean the wellbore in any size. However, in deepwater drilling, due to the diameter of wellbore, casing and riser is relatively large, the flow rate of the drilling mud provide by drilling equipment cannot achieve the purpose of cleaning the wellbore. Therefore, the ability of mud to clean the wellbore must be measured.

4.1.4.1 Common methods to clean the wellbore

There are four common methods to clean wellbore which are: thick paste cleaning, thin paste cleaning, combined cleaning, increase the low share rate viscosity.

The thick paste and thin paste were used in deviated wells, collapse wellbore sections or large annular segment. First use the thin paste to remove debris from the deviated wellbore, collapse wellbore sections or large annular segment, and then followed by thick paste to carry cuttings out of the wellhead. To complete this operation the mud pumps must have enough displacement, and at least three mud pumps are required. Two of the pumps were used in wellbore, and one used in the riser.

To clean up the cuttings from the riser, the riser pump must start to add mud in the riser to increase the mud flow rate. But only use the riser pump cannot prevent the cuttings deposit in the riser, especially when use the thick and thin paste to washing the wellbore and push the cuttings to the riser. If apply the combined cleaning methods, the cuttings are difficult to deposit in the riser.

The so-called combined cleaning method is first pump half of cleaning mud into the annulus through the drill pipe, and when this part of the cleaning mud returns to the riser section, and then pump the other half cleaning mud to the bottom of riser, combined with the first part of the cleaning mud work together. Using this cleaning method can increase the efficiency of the cleaning mud which contains a high content of cuttings. The flow rate increases, and then it contribute to clean the riser.

Increase effective mud viscosity at low shear rate helps to increase the transmission capacity of cuttings. If you cannot adjust the mud effective viscosity at low shear rates, it is necessary to improve and adjust the yield value, gel strength, and n values of the mud in order to fully meet the needs of wellbore cleaning. This method produces advection flow patterns in order to improve the annulus for cuttings transport extremely effective. However, doing so will make the drilling fluid equivalent circulating density increases, and for deepwater drilling which has a very large amount of circulating mud, the cost of mud will be greatly increase.

4.1.5 Shallow gas and gas hydrate

One of the major problems encountered in deepwater drilling is gas sand. Usually biogas (methane) was found in the mud pipeline is not a big problem. However, if you find gas sand in relatively deep place it can cause big problems. Gas hydrate has the similar structure with ice, consist of gas molecules and water molecules, the appearance is like dirty ice, but it's not like ice in nature, if the pressure is sufficient, it may be formed above zero degrees Celsius. In deepwater drilling operations, the higher seabed hydrostatic pressure and lower ambient temperature increases the possibility of generating a gas hydrate, and once gas hydrate formation, it will block the air pipe, conductor, riser and subsea BOP and so on.

4.1.5.1 The formation reason of gas hydrate

Main reason: The free water which temperature at or below the dew point of water mixed in the gas; low temperature; high pressure. Secondary cause: High flow rate; pressure fluctuations; various stirring; mixing small hydrate crystals.

4.1.5.2 The methods of inhibiting gas hydrate

In order to prevent the formation of the gas hydrate in deep water drilling some stringent measures has carried out. When using drilling mud which contain 20% salt can make the gas hydrate formation temperature is lower than with fresh water drilling fluid 25 ~ 28 ℉. In order to make the gas hydrate formation temperature further reduced during rig demolition, you can put some special small balls in the subsea BOP. The small balls contain an amount of hydrate inhibitor. Through these measures, the formation temperature of the gas hydrate decreased 35 ~ 43 ℉ in total. Characteristics of gas hydrate inhibitors are: hydrate inhibition at maximum level, as far as possible with the minimum density and compatible with most commonly used drilling fluid.

4.1.6 Low temperature

With the increasing depth of water, the temperature of the drilling environment will also be getting lower and lower, which will bring to the drilling and oil production operations a lot of problems. Currently mainly through manifold additional insulating layer, so you can keep in the heat of production equipment during production stops, thus preventing the formation of hydrates when temperature decreases.

4.2 The main technical challenges in South China Sea deepwater drilling and completion

Integrate worldwide deepwater oil and gas exploration and development history and combine with the special marine environment and special geological conditions in the South China Sea, the engineering challenges of technological development in South China Sea deepwater drilling and completion mainly in the following three aspects:

"Three shallow" prone to geological disasters, shallow weak cement, low bearing capacity, difficulty in drilling operation, high risk. There is more shallow water, shallow gas and shallow gas hydrate in South China Sea deepwater shallow strata, and it is often difficult to predict accurately and precisely identify, with some uncertainty, easy to bring drilling geological disasters caused by drilling accident. High uncompaction degree in deepwater shallow strata, having mechanical properties such as weak cement and low bearing capacity, combined with the presence of tension and compression, and other complex load currents in deep water environment, prone to well accidents such as sudden instability wellhead, drain well, well collapse and failure of cement packer.

The harsh marine environment resulting in complex acting load on string structure in deepwater drilling and completion process, which is difficult to control. Deepwater drilling riser string system is the key equipment of deepwater drilling and completion operations different from onshore and shallow water, and it was affected by the complex load from the marine environment such as the wind, waves and currents and internal solitary waves. It also has a harsh operating environment and complex engineering conditions. The subsea wellhead riser platform coupled system facing a series of safety problems during deepwater drilling and completion operations, such as random vibration, fatigue fracture, equipment wear, and so on. It brings to structural design and safety control a huge challenge. Deepwater drilling and completion riser string system in case of failure, it might lead to a major accident such as riser broken, platform spacing failure, fire or explosion.

Wellbore temperature and pressure field is complex; safe density window is narrow; wellbore security issues are outstanding; high risks in flow assurance. Deepwater shallow strata undercompaction, safe density window is narrow, prone to lost circulation, kicks, blowout, well collapse and other downhole failures, wellbore pressure is difficult to control; The low temperature and high pressure environment in the deepwater wellbore near the mud line is easy to form gas hydrates, causing flow obstacle, drilling or completion test interruption, even abandoned oil and gas wells; due to lack of annulus multiphase flow theory of gas hydrate phase transition, so it is difficult to accurately calculate the deep water wellbore pressure; the higher the formation temperature of deep wellbore, alternating temperature drilling fluid rheology vary widely, unsteady multiphase flow-through mechanism under constant flow conditions is not clear, bring to the deep water wellbore pressure control challenges.

4.3 The technology countermeasures of deepwater drilling and completion in South China Sea.

Due to the special challenges in drilling and completion which bring from the special marine environment, complicated geological conditions and long offshore distance in the South China Sea, a series of research studies of key technologies should be carried out to achieve safe and efficient development of deepwater fields in the South China Sea.

4.3.1 Deepwater drilling geological disaster forecast and shallow drilling risk prevention.

According to the South China Sea deepwater environmental conditions and geological characteristics, to study the seismic sound waves physical characteristics response mechanism of component, pressure and other parameter changes in shallow water, shallow gas, shallow gas hydrate, to solve the problem which is the accurate prediction of "three shallow" geological disasters; to study the geotechnical engineering mechanics parameters and distribution of the deep Water shallow, to solve the technical problems of running deep-water conductor, the subsea wellhead stability and wellbore stability; to study drilling "three shallow" mechanism of evolution of geological disasters, to solve the problem of effective prevention and treatment; to study the mechanism and control of deepwater shallow wellbore instability, loss and cementing ring packer integrity failure and other shallow issues, to create the deep water drilling shallow operational risk control methods to solve the problem of the deep-water drilling operations in shallow risk control.

4.3.2 Dynamics coupling mechanism and safety control of the deepwater subsea wellhead riser platform.

According to the deepwater marine environment typhoon, strong internal waves and currents, complex deep water drilling structural loads, safety design and control difficulties, to construct nonlinear full-time domain coupling model of deepwater subsea wellhead riser platform, explore the coupled characterization methods of long-term dynamic response of riser system under the typical operation conditions such as suspension and connections; carry out the semi-submersible platform motion response analysis under different limit modes and drift analysis under the limit failure mode, achieve a response mechanism of deepwater semi-submersible platform and the law of motion response of drilling risers; Finally, to construct integrity management strategy of deepwater drilling and completion string system in the whole life cycle, to solve the design and risk control issues of the drilling riser and the drilling and completion string structure system.

4.3.3 Deepwater drilling unsteady multiphase flow rule and wellbore pressure fine control

According to the large changes in drilling fluid rheology under low temperature, high temperature and alternating temperature, and multiphase flow-through mechanism is unclear, to study deepwater drilling fluid rheology law and deepwater drilling Multiphase Flow-through mechanism under unsteady flow conditions；For the presence of phase transition of gas hydrates under high pressure low temperature, and wellbore pressure is difficult to accurately predict, to establish unsteady multiphase flow model of petroleum and gas hydrate-containing phase change and its Algorithm; For the wellbore pressure is difficult to control under the condition that formation pressure is unknown, to research kicks diagnosis and assessment methods; For the narrow drilling fluid safe density window caused by deep water shallow formation fracture pressure is similar with the formation pressure, which lead to drilling wells prone to collapse, lost circulation, well kick and blowout, to solve the problems of narrow safe density window and wellbore pressure fine control; According to the problems during the deepwater testing process, for example, testing pipe structure is complex, changing test conditions, and the distribution of temperature and pressure within the wellbore field is complex, to study the temperature and pressure distribution, heat and mass transfer mechanism of the completion testing process, to find the safe and efficient way to deep-water test and test parameters design.

4.3.4 Deepwater drilling and completion engineering design theory and risk control

According to the deepwater drilling and completion problems "three shallow” geological hazard, narrow safe density window, column system reliability and other aspects of design theory, to establish theory and guidelines for deepwater well construction, and determine the design method of well construction in deep-water drilling; Carry out deepwater drilling string system vulnerability analysis, and establish deepwater string system varying reliability analysis model under condition of information uncertainty, determine a key component strength analysis and system configuration optimum design method of the drilling string; Study on drilling fluid flow regulation mechanism under low temperature, establish low-temperature rheology-control methods, research and develop the environmentally friendly deepwater drilling fluid system, determine the deep water drilling fluid design method. Based on the above studies, to research risk status recognition criterion and risk transformation model based on the factors of uncertainty, to build deepwater drilling safety barrier model system, and build the engineering risk warning methods and control system on South China Sea deepwater drilling and completion.

Chapter 5. A case study for overcome the challenges

The reasons I chosen the lufeng oil field as the case study of oil development in the South China Sea are: First, it was the first successful deepwater oilfield, and the water depth was the Asia record at that time. Second, the project was developed by innovation thinking from the beginning to the end which was combining the original and advancing technologies into the practical and conventional technologies to achieve the economically feasible and practical objectives. Third, the experiences of the Lufeng oil field development can help and inspire CNOOC to do a good job in the present and future deepwater oil field development in the South China Sea from many aspects such as project management, development design, concept selection, technologies application, development mode and so on. So it is really the ideal study case for developing the deepwater oil field in the South China Sea especially from the asset management perspective.

5.1 The introduction of Lufeng 22-1 oil field

The Lufeng 22-1 oil field lies in the South China Sea, about 250 kilometers south-east of Hongkong. It was discovered in 1983 by Occidental, which gave up after test production in the late 1980s. Ampolex took over in 1991 and sold its interests on to Statoil in 1996.

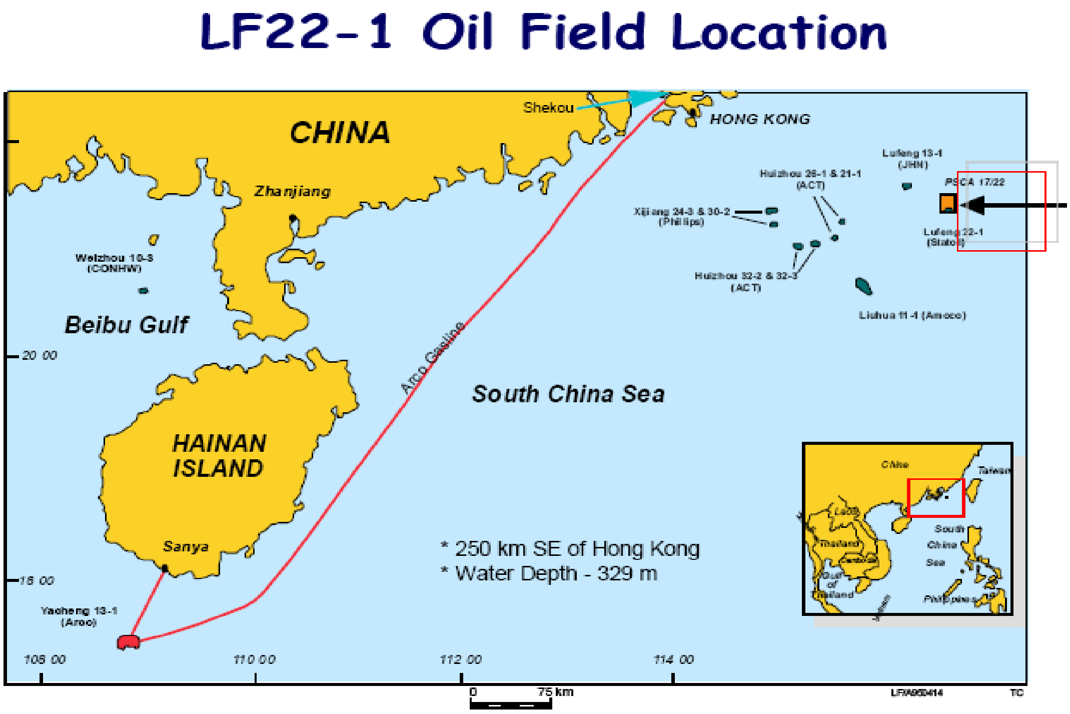

Figure 5.1- Lufeng 22-1 oilfield location(Sources: COSL)

The challenge was to demonstrate that this small field could be developed with modern and cost-effective technical solutions. New well technology has made it profitable to extend production from Lufeng until at least 2008, rather than shutting it down in 2004 as originally planned.

Lufeng 22-1 was brought on stream by Statoil on 27th December 1997. Statoil has a 75 percent interest in Lufeng, while the China National Offshore Oil Corporation (CNOOC) holds the remaining 25 per cent. The field is developed with five subsea horizontal production wells drilled through a five-slot template on the seabed. One of these has the longest horizontal section ever drilled off China - it is 2,060m long. The wells produce into an integral manifold, installed on the template.

The field has been developed with MST (multipurpose shuttle tanker) Navion Munin in production ship mode, and five horizontal wells drilled through a seabed template in 333 meters of water. Processing equipment installed on deck stabilizes oil from the subsea wells for storage in the ship's cargo tanks before transfer to conventional shuttle tankers for shipment to land.

The Lufeng production concept:

–Subsea wells
–Production risers
–Disconnectable production vessel
–Shuttle tanker offloading

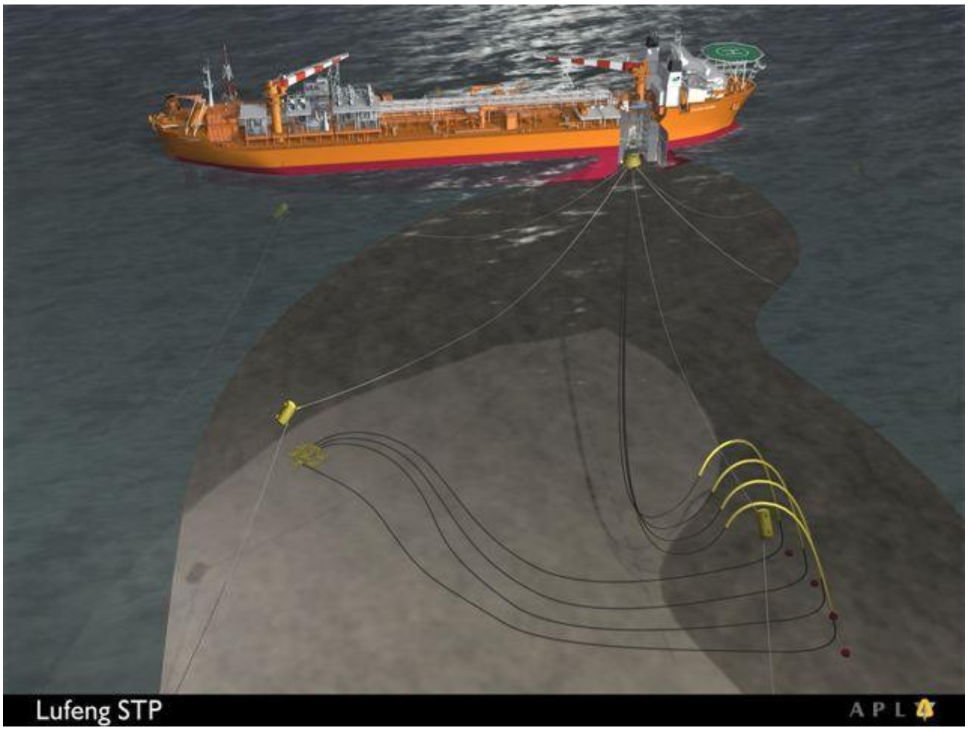

Figure 5.2- Lufeng submerged Turret Production System(Sources: COSL)

5.2 The development background and difficulty of the Lufeng 22-1 oilfield

The Lufeng 22-1 oilfield has its special geologic feature and reservoir condition, which has result in the major difficulties on drilling technology. And the detail inormation will be introduced as folow:

5.2.1 Geologic feature

Lufeng 22-1 region, because lack of Paleocene-Eocene formation, so Middle Oligocene-early Miocene Zhujiang formation unconformity cover on the basement of igneous rocks and metamorphic rocks. This set porosity sandstone was the exploration target zone of the Lufeng 22-1 oilfield and the total thickness of the oilfield was only 80 meters, whereas the reservoir features as porosity and permeability are high.

5.2.2 Reservoir conditions

In the reservoir simulation, take the reservoir oil-water interface (1626 meters under the sea level) as the reference depth, the original formation pressure in the reference depth is 2371 psi. The oil-water two phase simulation and research method was adopted. The research of the porosity limestone of the lower Zhujiang formation shown that the continuity on the flat of the limestone reservoir is bad, and there is no large amounts movable oil in the permeable layer with the permeability higher than 100 mD. To develop this kind of formation the horizontal well is better than straight well and directional well. The well stream can blow out to the mud line by stream pressure, and the well head pressure is higher than 100 psi (the lowest pressure of the booster pump inlet).

5.2.3 Risk factor

The uncertain parameter adopted in the research and simulation may affect the result of the recoverable reserves. The risk factors of the reservoir parameter include: sedimentation models, reservoir heterogeneity (horizontal permeability, support of water bodies), operation efficiency and the deviation of the model input parameters. The analysis of sensitivity about the variation range of all the uncertain parameters is carried out base on the basic scheme. For the recommendation, the field daily average oil production is 40000 barrel / day and the maximum daily average fluid production is 125000 barrel/day when the Non-production time is 15%. According to the research and simulation the 5 horizontal wells can run 3years, product 23.8 million barrel oil in total, and the recovery ratio is 25%.

5.2.4 Major difficulties on drilling technology

a. The rig location and the well path optimization are difficult to determine due to serval uncertain factors.

b. Challenges on well clean and hole stability due to the potential risks of leak and collapse bring from the multi faults.

c. The L type well path may cause the risk of keyway formation and casing wear.

d. It is very difficult to drill ahead due to the super-long horizontal segment (Table 5. 1).

e. It is difficult to hit the target, so the high measuring accuracy tools are needed.

f. It is very difficult to run liner.

Table 5. 1 The design length of horizontal well (Sources: COSL)

Well NO.	The design length of horizontal segment(m)	The actual length of the horizontal section drilled(m)
NO. 1(L9)	719	470
NO.2(L7)	2005	1744
NO.3(L5)	821	842
NO.4(L3)	1673	1738
NO.5(L1)	1543	1490

5.2.5 Sea conditions

There is a special sea condition, internal solitary wave, which greatly affect the operation in the South China Sea except the another two sea conditions which are the strong winter monsoon and severe tropical storm (typhoon). The internal solitary wave also is the key factor which affects the operation and system selection. Whether for marine installation or FPSO mooring system design, so the internal solitary wave is an essential design parameter. In 1990, during the Single well extended test in Lufeng 22-1 oilfield, several accidents happened which were caused by the internal solitary wave, such as mooring rope broken several times, ship collision and floating soft pipe broken.

The internal solitary wave has no direct connection with the wave. Amploex hired the consulting company Eavns-Hamilton to research this issue. Long-term data acquisition and a great number of research analysis and model test also has been carried out by CNOOC. The internal solitary wave in Lufeng 22-1 area is formed from the strong accidental and emergent wave originate from the Bashi Channel. The surface current has an opposite direction with the intermediate current (The change of the flow velocity and flow direction as shown in Table 5.2). The maximum relative flow velocity in every 100 years reach to 3.5 m/s, the strongest flow direction is 265° to 305° , and the Centering direction is 303° . So we take the internal solitary wave effect into consideration when design the whole project system especially the model selection of subsea production system.

Table 5. 2 The regression value of the internal solitary wave flow rate in the corresponding year under different water depth. (Sources: COSL)

Recurrence interval (a)	Flow rate (m/s)				
	Water depth 0m	Water depth 5m	Water depth 10m	Water depth 35m	Water depth 270m
1	1.01	1.31	1.56	1.98	-1.16
5	1.19	1.52	1.79	1.38	-1.45
10	1.31	1.65	2.01	2.58	-1.61
25	1.38	1.78	2.18	2.78	-1.76

5.2.6 Basic design parameters

Specific gravity: 31.1° API(0.87)
Pour Point: 46℃
Viscosity: 4.35 – 5.1 cps (194 ℉,2356psia)
Cloud point: 62℃
Freezing point: 43℃
Bubble point: 88psi (90℃)

Liquid level: maximum single well daily average fluid production 25000 barrel. FPSO daily fluid processing volume is 125000 barrel.

Temperature: design stream temperature in well head is 85℃, design temperature of manifold and oil tank is higher than 65℃.

Pressure: the maximum operating pressure of subsea wellhead and corollary equipment (include pressure instrument) is 3000psi. The operating pressure of the tree and 18-3/4" well head is 5000psi.

Materials and anticorrosion: the pipeline and the measuring and pressure instrument should be suitable for transporting the liquid contain low sulfurous and carbon dioxide. The inside surface should be treated with preservatives, and the outside surface should be protect by paint and sacrificial anode.

5.3 overall development ideas – prudent and creative model selection

The most distinctive development idea of Lufeng 22-1 is adopting the production mode without production platform. To estimate with the price of raw materials in 1990's, the cost of construction of a jacket platform with water depth 333 meters is nearly 1.6 billion dollars. Refer to the cost of purchase and refit of Floating Production System (FPS) of Liuhua oilfield 140 million dollars; it was still a considerable prior-period investment. Lufeng 22-1 adopted the new way to service for the oilfield which is renting the FPSO (Floating Production，Storage and Offloading Unit). The rented FPSO was brand-new one, and it cost more than 200 million dollars, and the cost of purchasing and refitting an old one was almost 160 million dollars. The renting plan in the production period greatly reduced the prior-period investment of the project, and it benefits the whole oil field development cash flow (Table 5.3). In other words, the Lufeng oilfield was developed by asking the subcontractor a long-term loan.

Table 5.3 The estimate Investment cost of purchasing and leasing plan. (Sources: COSL)

Investment Projects	Purchase Plan (million dollars)	Lease Plan (million dollars)
Drilling	38.1	38.1
Down hole equipments	27.3	31.1
FPSO purchase	18.1	0
FPSO repair	16.1	0
FPSO refit-communal facilities	11.9	0
FPSO refit- turret and mooring system	41.1	3.2
FPSO update- production module	15.2	0
Offshore transport, installation, test run	15.3	0
Project management, inspection and insurance	18.3	13.9
Operation expenses (development stage)	6.6	6.6
General and administrative expenses	7.1	7.1
Total	215.4	99.9

5.3.1 Cross-industry analysis

Under the situation of the international crude oil stayed low price for a long time, if this small field was developed by constructing huge jacket platform like the U.K North Sea and the Gulf of Mexico did at the same water depth, it was absolutely uneconomical investment. In 1970's the oil price was staying high price period, a 386 meters high jacket platform constructed in the Gulf of Mexico at the same water depth, and it cost nearly 2 billion dollars, and in year 1995, a concrete gravity platform and subsidiary system was constructed in North Sea which cost 10 billion dollars, the water depth was 360 meters, and the height of the platform was 430 meters, which was 50 meters higher than the Empire State Building, New York, USA. Although the oil price was high at that period, and the oilfields both were huge oilfields, it was still affected by the changeable oil price during long term production. With nearly the same depth, the Lufeng 22-1 oilfield adopted the creative technology, only spent less than 150 million dollars on the early stage investment, and only 1.5 years when it was brought on stream which was created a record in the development of a small marginal oilfield.

5.3.2 Development conception

The production and control system and marine system of the Lufeng 22-1 oilfield was designed to be automatic and semi-automatic mode, which can reduce the operating personnel. The FPSO operating team just needs 55 staff, which includes the Catering staff. Compare with the normal configuration of oilfield which contain the platform and the FPSO, the total number of staff is 150, the Lufeng 22-1 can save a lot of personal expenses. All the production and marine necessary spare parts were stored in the FPSO, which different from the common practice (the spare parts were stored in the warehouse in the shore base, when need the spare parts, the base should call for helicopter or ship to deliver). Certainly, it benefit for both the operating costs and production efficiency.

5.3.3 Basic design description

According to the result of economic assessment, the Lufeng 22-1 oilfield adopted the rental scheme, which was to rent a FPSO and mooring system. (Figure 5.3) The lowest storage capacity is 600 thousand barrels. A semi-submersible drilling ship was rented to drill and complete 5 horizontal production wells. After the drilling ship finished running main manifold, X-tree, completion tubing string and retrieving anchor, a installation vessel came and took over the next jobs. Contain laying the sea bed pipeline, power cable and electricity /hydraulic control cable of the booster pump, and then installed the single-point of the FPSO mooring system. When the installation vessel finished those installation jobs, the FPSO finally arrived at the oilfield, and the installation vessel assisted the FPSO to butt joint body and single-point. When connecting the rotary joint, at the same time, the operator installed 5 booster pumps from the FPSO to the X-tree, the booster pump pumping the crude oil to the production module on the FPSO to conduct the whole marine system and production system to pilot run. At last, the FPSO put into production. By using the automatic and semi-automatic production control system and installing the booster pump which had the longest failure-free operation time, to achieve non-workover operation. The Lufeng 22-1 oilfield was successfully put into production 5months in advance than the ODP report approved by Ampolex(Table 5.4).

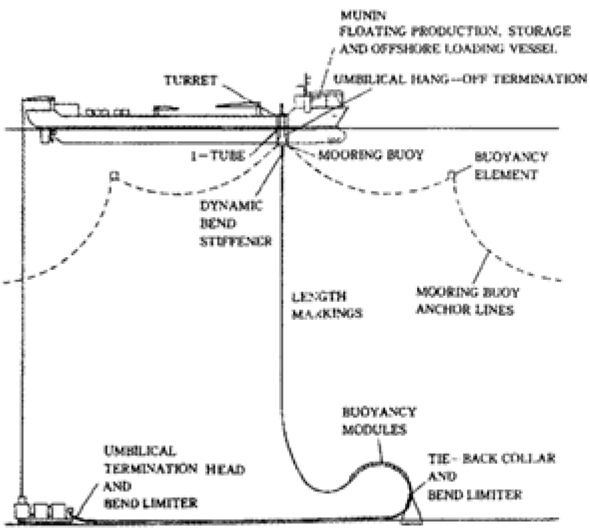

Figure 5.3 The general arrangement of Lufeng 22-1 oilfield.

Table 5.4 The running schedule of main projects of Lufeng oilfield. (Sources: COSL)

Project	Running schedule
Overall development plan(ODP) is approved	1996.03.06
A package of contract (EPIC) award	1996.09.24
Subsea contract award	1996.12.20
Spud in	1996.12.22
Completion of drilling	1997.06.23
FPSO(Munin) arrive at the upgrade shipyard	1997.07.14
Finish completion	1997.10.04
Finish FPSO upgrade	1997.12.01
Finish FPSO installation	1997.12.21
Production	1997.12.27

5.3.4 Creative ideas and advancing technologies adopted in Lufeng 22-1 oilfield

There are eleven creative ideas and advancing technologies were adopted in the Lufeng 22-1 oilfield in total, which are:

a. Assembling FPSO with standard and multi-function process module.
b. Ingenious new type Single point mooring system (SPM) - STP BUOY.
c. Multi-function rotary joint combine with STP-RC module.
d. Folding Hanger Over Subsea Template（HOST）.
e. Vertical gravity connector of the subsea production pipeline.
f. Deepwater suction anchor.
g. Double positioning subsea horizontal tree.
h. Mud line booster electrical pump.

i. Electrical/hydraulic transform remote controlled subsea production system.
j. All wells are horizontal wells, exceed 2000 meters horizontal segment was drilled turn off along the fault.
k. No diving operation.

5.4 The characteristic of drilling and completion technologies

The drilling and completion technologies adopted in Lufeng 22-1 oilfield has its own characteristic due to the special challenges from technology aspect, and some solutions for the system design also will bring new problems into the development process, the detail information will be introduced as follow:

5.4.1 early stage plan

The related personal of drilling and subsea well head operation and involved contractor plan the development of deepwater oilfield together in the early stage. The drilling staffs start to work for the project half year before spud-in, and their task is to optimize the well design.

5.4.2 the effect of the complex geological factors

The Lufeng 22-1 oilfield is a bottom water reservoir, and the depth of the oil-water interface is 1626 m, in order to meet the demand that the height of avoid perforation is more than 10 m during the completion, the depth of the wellbore must less than 1615 m, which bring more difficulties to well path control.

The reservoir is divided and controlled by the fault; the well path must follow the faulty trend. So the horizontal segment must turn.

The well path and the depth of the kick-off point are determined by the depth of the fault. The fault may bring the potential risks of leak and collapse.

5.4.3 The problems bring from the system design

a. The application of folding HOST determines the location of the platform, and also affects the 5 horizontal well paths, drilling footage and drilling operation difficulty.
b. The allowable variation of each horizontal well segment is very limited. It is very hard to control the well path, and easy to form keyway. Meanwhile, it is hard to hit the target. So the high-accuracy measuring technologies are demanded.
c. Due to the risk of well leakage, we should pay more attention on the issues like well clean, wellbore stability and preventing lost circulation.
d. Running the liner also is a hard task for completion.
e. Avoid buckling during the drilling process, and perform sliding drilling also are challenges.

f. The drilling platform implements many subsea equipments installation jobs, and after completion the FPSO need to be installed and connected to the subsea system. All this jobs need to be proceeding in an orderly manner because this process is the key part.

5.4.4 major target

The project batch installed 5 set 30” conductor, and then batch drilled 5 wells with 17-1/2” well segment, and finished drilling and completion. The timeliness of the project was greatly increased due to the effective drilling method and application of advanced drilling technologies, and also saved a lot of money. The total drilling footage was 16221 m, and the average length of the 8-1/2”horizontal segment was 1318 m.

5.5 The model selection of the subsea wellhead system.

There are two models of the subsea wellhead system for the Lufeng 22-1 oilfield, which are the decentralized subsea wellhead system and the centralized subsea wellhead system.

5.5.1 The decentralized subsea wellhead system.

The decentralized subsea wellhead system was adopted in the deepwater oilfield when the flow direction of the surface current, intermediate current and bottom current is the same and keep relatively stable in the operation sea area. The subsea wells are connected together through the flexible subsea pipeline, and connected with the main manifold directly or through the neighboring wells.

The advantages of this system are:
First, There are some installation and operation experiences in other deepwater area.
Second, The accuracy of the installation of wellhead and surface casing may decrease.

The disadvantages of this system are:

a. There is no operation experience in deepwater of South China Sea, and the sea condition is not clear.
b. The cost of the soft pipelines between the subsea wellheads and the special hydraulic connectors is very high, and the installation and maintenance cost also is very expensive. It too inconvenient to perform workover operation that a special work vessel needed to be rented.
c. The current direction is so unstable that the soft subsea pipeline is easy to get twined, which may damage the connector joint part and the middle hanging cable.
d. The single well workover operation may affect the production of other wells, and need to mobilize other support operation vessels.
e. The operation window demand strict sea condition, and the installation period last

very long.

5.5.2 The centralized subsea wellhead system.

The centralized subsea wellhead system was adopted when the current direction of the surface current, intermediate current and bottom current is instable. The well fluid flow into the central manifold through the X-Tree, or utilize the multi-functional integrated umbilical cable, and the range of motion of this cable was limited by the buoy.

The advantages of this system are:

a. The number and motion of the soft pipeline was restricted which may protect the soft pipeline from friction and twining.
b. The single well workover operation has no effect on the production of other wells.
c. Apply the multi-functional weld-shrunk power cable and electrical/hydraulic control cable, which decrease the number of the subsea cables and avoid the cable twining, and reduce the chance of damage under the water.

The disadvantages of this system are:

a. The operation experiences are lack and the sea condition is not clear.
b. Many immature new technologies will applied pioneered in this project, such as the folding drilling template.
c. There is a high demand on the positioning accuracy of the folding drilling template. Especially the deviation of the horizontal level must limit in 1 degree or it will affect the installation of the subsea wellhead system later.

5.5.3 Subsea wellhead model selection of the Lufeng 22-1 oilfield

The Lufeng project subsea engineers chose the centralized subsea wellhead system which cost less and easy to maneuver. The engineering design was divided into two parts. One part is subsea wellhead and wellbore part, primarily responsible for wellhead, soft and hard attachments, running and retrieving tools. Another part is flexible cable hanging system and the mud line booster pump, and the installation and retrieve of the flexible cable and booster pump.

The selected subsea wellhead system was adopted the most advanced technologies and creative ideas in the Lufeng project. The new advanced technologies are first time adopted in the offshore oil industry in the world include:

a. The subsea mud line booster pump
b. Workover operation by ROV on the FPSO.
c. The multi-terminal and multi-functional weld-shrunk power cable.
d. The multi-functional rotary connector combined with STP-RC buoy.
e. The vertical gravity connector of the seabed production pipeline (TDF).

The new advanced technologies adopted in subsea wellhead:

a. Folding integrated drilling template.
b. The double positioning subsea horizontal tree.
c. The multi-functional control central manifold.
d. The application of the wet electrical connector in civil industry.
e. The subsea production system was controlled automatically by the electrical/hydraulic control cable.

Chapter 6. Discussions and conclusions

The thesis identifies the challenges and problems which the deepwater operation in South China Sea faced, from three aspects which are environment conditions, facilities, and technologies. The solutions and advices of some of the challenges and problems are listed out, and the further study areas are also pointed out. And then select the Lufeng 22-1 oilfield as the case study to introduce the development processes of the project to overcome the challenges. The whole oilfield development processes are the excellent representative of the successful deepwater asset management in the South China Sea.

According to the common challenges on deepwater development worldwide and the special challenges on South China Sea, to construct an economically feasible, practicable, environmental friendly and effective project model on offshore deepwater oil and gas development, we must integrated consider the three aspects-environment, facility and technology- in an early stage. And make all the personal involved attended the project preparation and development in advance, especially the key operation team who have a lot of field experiences and can make all the facilities placed and run in a correct and effective way. This thesis provides the experiences for project development as follow:

a. When the common technical solution cannot meet the need of offshore oilfield development, we must adopt the creative concept and technology bravely and carefully to solve the problem. Generally, the positive aspects are more than the negative aspects.
b. For major development projects, sufficiently detailed planning and design must be implemented in order to reduce the risk to a minimum extent, and early intervention of experienced staff in all aspects will bring the programs immeasurable comprehensive income.
c. Sound project management is an important factor for project success.
d. Safety and environmental issues must be considered into the initial stage of the project work, and must give full attention.

And this thesis also provides the technology countermeasures of deepwater drilling and completion in South China Sea as follow:

a. Research on deepwater drilling geological disaster forecast and shallow drilling risk prevention.
b. Research on dynamics coupling mechanism and safety control of the deepwater subsea wellhead riser platform.
c. Research on deepwater drilling unsteady multiphase flow rule and wellbore pressure fine control.
d. Research on deepwater drilling and completion engineering design theory and risk control.

The purpose of writing this thesis is to find a correct and effective way to help the company COSL to well manage the offshore asset – develop the deepwater oil and gas in the South China Sea – by fully indentify the challenges from all aspects and study the successful deepwater development example in South China Sea. But this thesis is limited by my working experiences, academic levels, and professional cognition, some expressions and illustrations are not clear and sufficient enough, all the data and the materials are collected from my company, industry, internet and other scholars and authors, and some data information are not so accurate and timely, because the industry and the technology are still keep developing so fast that I believe there are many improve room in this thesis.

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