Introduction

In search of the precious energy commodity i.e. hydrocarbon the world community has entered into the periphery of deep and ultra deepwater. These are relatively new zones of production of hydrocarbons and hitherto posing new challenges. Few of them are structural instability of ocean floor affecting drilling operations, High Pressure and Low temperature at deeper depths causing hydrate formation, Salinity causing corrosion etc. In fact, almost all operation related to surface and sub-surface viz. exploration, drilling, production and transportation are getting affected because of harsh environment of deepwater.

The available technology for shallow water may not be suitable for exploitation of deepwater fields. Further, high cost of operations and concerns related to safety and environment have further added up the challenges and provoked operators to expand boundaries and look for new set of solutions. Due to this, both- Operator and Service providers- worldwide are investing heavily in R&D. They are also looking for innovations and formulating various strategies to overcome impacts due to said challenges. The philosophy of exploitation of deepwater has undergone tremendous changes and has led to a paradigm shift in E&P operations for such areas.

Deepwater: Future Source of Energy

Energy is the basic building block for future growth of any economy. For sustained development, long-term availability of energy from sources that are economically accessible and socially & environmentally acceptable is of prime importance. During last two decades, almost all the countries of the world have witnessed tremendous economic growth and so the requirement of energy has gone up. In future, this trend is expected to go up further. As per International Energy Agency study, from 1990 level, the total energy requirement is going to be doubled by 2030 and tripled by 2050. Though the contribution of fossil fuel in world energy mix
will decrease from 56% to 44% but in real term, it will be more than doubled during the period and will continue to dominate the energy basket.

On supply side, there are many challenges. Conventional and easy oil has now matured and so they are facing inherent challenges associated with it. Moreover, after early 60s, there are not many findings of large oil reserves. Oil demand rate surpassed the oil discovery rate in early 80s and the gap is ever increasing since then. Large onland and shallow water pools of fossil fuels are already discovered and future hopes lie on non conventional sources like deep water. As per Exxon, the contribution from deep water will increase from mere 3% in 2005 to 14% by 2010.

**Changing Philosophy of E&P Industry**

As indicated at figure 1, there is a paradigm shift in E&P activities when one moves from onshore to shallow water and then to deep water. Like technological development in any other industry, E&P sector also witnessed a slow pace of technological development in its early phase. Therefore, development of onshore fields, though considered much simpler now in comparison to offshore, took more time. The technological environment changed once development of offshore fields started. Directional drilling, rigless well intervention, automation and SCADA system and other associated technologies got boost. In both these cases i.e, onland and offshore shallow water (SW), technologies are matured and diffused. Innovations are incremental and modular.

Now, as we move into deeper waters, field development becomes more complex. Most of the technologies, which were very successful till now, suddenly became obsolete in new harsh
environment of deep-sea. Physical capabilities of man and materials became a limiting point. Existing drilling, completion, process, pipeline and other equipment touched their technological and physical limits. This has lead to emergence of newer technologies, many a times radical, and formulation of new strategies. In the beginning of oil industry, we witnessed oil cities on lands, which got extended to sea. Now, we are developing oil city underwater beneath sea.

**Deepwater Activities: Overview**

Most of the deep water activities are taking place in golden triangle of Gulf of Mexico (GOM), Brazil and West Africa which together are holding 35 billion bbls of oil equivalent (BBOE). Another 23 BBOE is estimated to be the reserve in ultra deep water (water depth >1500 m) fields.

Shell, BP, Exxon and Chevron are particularly active in the U.S. Gulf and are concentrating their exploration and development activity on deep water and ultra deep water up to 3300 m.

With regard to drilling depth, before 1996, gradual increase was observed. But, since 1996, the maximum drilling depth has increased rapidly, reaching true vertical depths (TVDs) just below 9,100 m in 2002. The Transocean Discoverer Spirit drilled the deepest well in the GOM to date: Chevron/Unocal’s Knotty Head discovery in Green Canyon Block 512 at a TVD of 10,411m in December 2005. This recent dramatic increase in TVD may be attributed to several factors, including enhanced rig capabilities, deeper exploration targets and the general trend towards greater water depths.

India has also joined this elite club of deepwater E&P operations after the discovery of Dhirubhai field in 2001 by Reliance Industries and some of the recent discoveries by ONGC (KG-DWN-98/2) in the deepwater at East Coast. So far, ONGC drilled the deepest well (well no. K-1X) in India at a water depth of 2678 m under its ambitious deep water endevour “Sagar Samriddhi”. The drilled depth of the well is 7094 m.

**Deepwater: Challenges & Strategies**

Development of deepwater gas fields presents significant technical and commercial challenges. Frequently, discoveries are made in remote locations, and in inhospitable environments, which increases the development capital expenditure. Offshore processing can be prohibitively expensive. In extremely remote locations it may be the only option but, depending on the distance to shore, a subsea development may be the least expensive solution for gas field developments. For subsea developments, the multi-phase production pipeline to shore may provide the optimum development scheme. However, hydrocarbons and water drop-out in the production pipe (export) line has to be considered. The pipeline has to follow the seabed terrain and there may be low sections in the pipeline where liquids may accumulate.

Field development capital costs improve the economics if the gas is ‘wet’ (gas with associated hydrocarbon liquids). Associated liquids (condensate) with the gas may increase the overall economic rate of return as liquids are high yield and provide premium prices. Liquids are also
easier to transport to markets. However, it means perhaps having a processing facility located in
a remote location with either tanker loading for sale to markets or a liquids pipeline to shore.
New offshore floating LNG plants are being considered for exploitation of deepwater gas
discoveries where distance to shore makes the development cost-prohibitive.

![Diagram of sub-surface, surface, and support services]

**Sub-surface Operations**

In deepwater fields, almost all the sub-surface operations whether drilling, completion, testing or
well intervention, are quite complex. Maintaining well integrity in such environment is a real
challenge. The sub-surface architectures of many deep-water reservoirs are not very congenial
for stable drilling. Most of these reservoirs, as the case of West African deep and ultra deep-
water reservoirs, are shallow and thin having larger horizontal extent. These are also located in
unconsolidated and soft recent sediments. Due to which there are difficulties for drilling non-
conventional wells i.e. extended reach wells and multilateral wells. Even in conventional wells, it
causes sand production problems, requiring gravel packing and reducing well productivity. The
hydrostatic head of the mud column during drilling itself may cause damage to unstable
formation of the reservoirs.
Murphy Oil, operator of the Front Runner Field (Green Canyon 338 and 339), expected production about 9,000 BOPD during 2007, significantly below the spar platform’s capacity of 60,000 BOPD and 110 MMCFPD. The field performance was poor than the initial forecasts due to unanticipated reservoir compartmentalization issues and the collapse and shut-down of several wells. Similarly, BP was also struggling with lower than expected production from its Mad Dog spar (Green Canyon 782). They could put only three wells out of a planned 12, on production, with flowing rates significantly below the spar’s capacity of 100,000 BOPD and 60 MMCFPD. Again, here the problems appeared to be related to drilling difficulties. The reservoir is located below 2,000 m of salt and contains “highly mobile tar deposits” affecting the reservoir’s exploitation.

Drilling operations at increasing water depths require larger equipment with extra hoisting capacity, more capacity in terms of mud circulating systems. At a water depth of 3000 m, looking for a target at additional 7000 m below the mud line, earlier generation rigs just can’t be used. They don’t have the size, horsepower or lifting capacity to reach out into those depths.

Further, drilling in deeper water could be constrained by limitations in riser technology. The main problems to be faced by the risers are first the pressure drop in the fluid column, generating systematic degassing and a temperature drop with risk of hydrate formation and/or slugging problems, and second, the low sea water temperature with the risk of paraffin deposition and the requirement for thermal insulation. Flexible risers have been widely used in shallow to medium water depths. They can be used in free hanging (SCR) or lazy wave configurations. Application to ultra deep waters is limited by riser/riser clearance and riser/mud line interaction, global stability and cost increase. Conventional steel rigid riser solutions include Steel Catenary Risers (SCR) and vertical top tensioned risers. The use of SCRs in ultra deep water gives rise to fatigue and dynamics problems. Hybrid risers are solutions dedicated to deep water. Risers can be hybrid by the shape or the profile or by the structure: flexible pipe or steel pipe. As an example, an hybrid riser can be composed of a vertical tower, a sub surface buoy and a flexible jumper connecting to the surface unit.

Petrobras has taken lead for developing completion riser for 3000 m water depth. The purpose is to eliminate technological barriers for production at water depths of 3000m.

Great water depths can increase the problem of the sub sea vibrations known as vortex-induced-vibrations (VIV) that damage pipes and risers, thus shortening their life spans. Shell did the VIV analysis and got is simulated through computational fluid dynamics software. They could reduce the effects of VIV substantially by developing specialized ‘strakes’ and ‘fairings’. These are devices that are fixed around the risers to streamline flow and inhibit these vibrations.

The traditional well intervention costs may be lowered when sub sea wells are designed with continuous, reliable, built-in performance monitoring system. It will also minimize associated risks and maximize performance. This total surveillance can be any combination of multiple acquisition sensors in the well bore, on the seabed or along the flow lines. Sensors – for pressure, fiber-optic distributed temperature, down hole or seabed multiphase flow meters and
fluid property – provide information that allows for decisions such as opening or closing well bore valves, boosting pump output or controlling flow line methanol injection during hydrates treatment. Establishing connectivity between these various measurement devices is important and even they may become a part of the complete sub sea enterprise rather than remaining isolated and discrete. High data rates are required when there are an increased number of devices that need monitoring and control, such as subsea processing and combined multiphase metering and flow boosting.

Managing blowout prevention systems at extreme depths is exceptionally difficult. Shell has addressed the problem with the development of surface blowout preventors (SBOPs) that enable us to transfer blowout prevention from the sub sea stack to the surface. They have used SBOP in Malaysia, Brazil and Egypt.

One possible solution would be to have the drilling rig on the seabed. A drilling rig can be deployed on the seabed and can be operated through remotely placed umbilical cords. The rotary system and everything could be on the seabed and through umbilical cords at the sea coast or some through a floating super structure at the sea surface all drilling operations on the sea bed can be controlled. This would overcome instability risks related to risers and positioning system. Another solution is to have dual activity drilling, dual gradient drilling, slim-bore drilling, high pressure drilling risers with surface BOPs, expandable casing, and free standing drilling risers. Each will provide benefits such as lower day rates, reduced drilling time, reduced drilling consumables, and higher well rates.

Collection and treatment of Geologic, Geophysical, Geotechnical and Oceanographic data for ultra-deepwater is very important for success of such projects in view of high cost of operations. There is a need to obtain, process and interpret geologic, geotechnical and oceanographic data along with information about the seabed and water column which are required for the installation, development and production activities.

Petrobras is currently executing various projects, which are strategically important for their ultra deepwater operations. Few such projects are:

- Developing well control technology to drill and produce safely from ultra-deep water wells
- Intelligent Completion for ultra-deep water which for monitoring and controlling water injection or production of hydrocarbons from multiple zones in a single well or from individual laterals in a multilateral well in real time on site or at a remote base. Intelligent completion not only prevents costly interventions in the reservoirs but also optimizes the performance of the well and maximizes the recovery of the assets and return on capital employed.
- It has also taken up a project for developing new technologies and software for gas lift design and analysis for deepwater satellite wells under flexible risers.
Flow assurance issues are very important as far as surface operations are considered. There are challenges during normal (steady state) operations as well as dynamic (transient) operations. The performance goal for steady state operations is to achieve platform arrival temperatures above hydrate formation temperature and/or wax appearance temperature (WAT) as a minimum. The performance goal for transient, i.e. shut-in, operations is to achieve adequate cool-down time before the pipe contents cool to the hydrate formation temperature after shut-in.

At depths below 500 m, the seabed environment is dark and very cold. Shallower reservoirs too have low temperature caused by the low temperature of the seabed and the small distance between the seabed and the reservoir. This results into high oil viscosity and gravity which consequently may risk paraffin deposition in sub sea flow lines. Moreover, in the presence of high-pressure, low temperature, and sufficient water content, gas forms ice-like crystalline solid compound “hydrates” below dew point. This results into choking of pipelines. Due to immense water pressure, strong sub sea currents and unstable sea floor, reducing system’s pressure below hydrate-prone conditions is difficult. The large external pressures are due to the hydrostatic pressure of the water at the sea floor, where the sub sea production facilities are located. In most cases, the large external pressure does not allow the use of certain easily compressible insulation materials without providing a strong external shield (jacket). These insulation systems are called pipe-in-pipe configurations. Typical wet insulation materials that can be applied directly onto the carrier pipe include neoprene, carazite, polypropylene, syntactic polyurethane, polybrid, and Eccotherm tape, all of which have water depth limitations. Moreover, high pressure at deep-sea requires technicians to work using remotely operated vehicles (ROVs) which poses another challenge.

Another major problem is encrustation and corrosion on equipment. The overall deep-sea conditions are very conducive for corrosion. First start-up at Thunder Horse (Mississippi Canyon 776, 777, and 778), the largest GOM deepwater discovery to date, has been delayed to mid-2008 due to hydrogen embrittlement problem of seafloor production equipment. Due to which, BP has decided to rebuild all these equipment. Further, it has also caused them to retrieve and modify the sub sea manifolds for its Atlantis deepwater development.

The flavour of development for most of the fields located in hostile and remote environments is to exploit sub sea technology with direct export pipelines. Consideration has to be given to the terrain that the pipeline route has to take, as significant changes in topography of the seabed can make development very complicated. The challenges in deepwater and remote locations are immense. In fact, there could be various strategies for evacuation of hydrocarbon. While developing the Na Kika field in the Gulf of Mexico, Shell faced the same challenge of evacuation. They connected these small fields via sub sea pipes to a centrally located semi-submersible host platform, equipped with processing facilities and pipelines for export to shore.
This ‘cluster’ development, with linked fields up to 43 kilometers from the host, made it possible to produce oil economically from a depth of 2300 m.

As another strategy, the Greater Sunrise gas/condensate field having 9 trillion cubic feet of reserves, located in Timor Sea, Australia, considered development using world’s first floating LNG plant. Its remote location from land, as it was almost 450 KM from shore, as well as from markets made it an ideal candidate for development using this innovative idea. In fact, considering the problems associated with long sub sea pipelines, the future lies in floating LNG plants. Once all the safety issues have been resolved, ‘stranded’ gas fields will be developed using this technology.

Shell has carried out lot of research for overcoming various impediments of deep-water development. It has developed new chemicals, based on fish protein, to prevent freezing. They are injected into the hydrocarbons in far lower doses than traditional chemicals, significantly lowering costs. It has lead to saving of millions of dollars in their operations at Gulf of Mexico. For increasing the temperature, Shell also invented pipe-in-pipe heating, using an electric current to warm the oil and gas inside an inner-pipe, which is insulated from the freezing water by an outer pipe.

Petrobras is also working on the concepts of thermal insulation, heating and pigging of deepwater pipelines. The topics included are pipe-in-pipe configurations, heating of subsea pipelines, and the comparative analysis of insulation, heating and pigging. With regard to evacuation of hydrocarbon, they have undertaken project of multiphase subsea pumping systems, the purpose of which is to build the capacity in using multiphase subsea pumping systems in deepwater scenarios.

Going deeper requires new platform designs too. Over a period of time, different deepwater systems have been developed suiting to various requirements. Fixed platform, compliant tower, Tension Leg platform (TLP), spar platform, floating production storage offloading (FPSO) vessel are few of them. In the 1990s Shell used mass production techniques to reduce the cost of tension leg platforms. These platforms, which allow operations at water depths between 500 m to 2400 m, float on the surface and are held in place by vertical, tensioned tendons connected to the sea floor by pile-secured templates. This virtually eliminates all vertical movement of the structure.

Some additional projects undertaken by Petrobras is to develop

- equipment for subsea cable installation at a water depth of 3000 m,
- Mooring cable system for ultra-deep water
- Stationary dry well completion production units under which feasibility of using rigid risers for both drilling and completion will be evaluated.

**Support Operations**
Support services like air/ marine logistics; Contracts & Materials Sections and Human Resource have a play major role for the success of deep-water endeavour of any company. Rig day rate and cost of other operations are very high. Therefore, it is paramount to have a good logistics support to avoid any short of waiting or equipment shortage at the rig. The lead-time of many specialized equipment are long and their availability may also limited. Contract and Materials Sections should work in close coordination with Technical Section and ensure availability of all equipment and services on schedule. For example, in recent past, the industry was facing shortage of offshore rigs and also their day rates have gone up many folds, due to which many operations were negatively affected.

Similarly, for any deep water operation, along with operator company, many services companies are also involved for different activities. Each of these activities may have direct or indirect effect on schedule of the well completion and which may affect the cost of the well. Even a very small increase in efficiency may result into substantial saving. Therefore, both operator company and service providers should work in close association. It is preferred to follow use Multidisciplinary team (MDT) approach involving members from different related domains from both operators and service providers.

Another big issue comes in terms of availability of skilled human resources. As per a study, staff profile of a typical National Oil Company indicates presence of mostly two age group of people: first set is “nationals” in age group of 25-29 years who needs to be trained and gain experience whereas the another set of people is expatriates in age group of 49-56 years who are experienced and going to retire in another 5-10 years. There Human Resource Department has to play a very active role during next 5 years to train young workforce as well as to formulate strategies to fill up the void created at higher levels.

**Safety, Health and Environment**

Deep Sea E&P activities also require safe and healthy environment to work with. Safety standards set for shallow water offshore may undergo further changes to address the safety requirement of deep water activities.

Few other challenges like global warming etc. are forcing us to re-look into processes and preserve the natural environment. Many times, social and political aspects need to be addressed as is the case with most of the African Countries. Oil and Gas exploration and production in Nigeria witnessed a major shift in activities from onshore and near-shore environment to the shallow and deep offshore environment in recent times. This shift was attributed to major exploration successes and discoveries in the offshore environment. As the abundant valuable resource in offshore Nigeria is developed, challenges lie in the management of the environment.

Similarly, oil industry in the past, was notorious as a big polluter. In order to meet environmental challenges, attention must be paid to waste and effluent management. There is growing concern on biodiversity and the need to preserve the deep offshore environment.
Economy

The ultimate challenge for deep water is, of course, the economic challenge. At present, the cost of operations at deep water is very high. Drilling Rig charges, equipment cost, logistics support requirement as well as cost of technology make it a very risky proposition. The average cost of drilling is close to USD 30 million per well. In case of ONGC’s Sagar Samridhhi, more than 40 wells have been drilled and the average cost of drilling was USD 20 million. But, the success rate made it a much riskier venture. In fact, though, ONGC is having lowest ratio of dry well by successful well, but specifically in this case, the success rate was even less than 50%. Further, risks and complexities associated with their future development affects the techno-economic badly.

Once, put on production, keep the wells flowing for a longer duration in deepwater fields is a tremendous challenge. To be economic, wells have to reliably produce oil and gas at high rates without costly intervention. Subsea wellheads, tiebacks and flow lines are susceptible to blockage and corrosion. Even the unconsolidated sandstone of shallow reservoir may stop the well flowing. Perobras faced the same problem at their Campos Basin when their one of the first deep water wells stop flowing after 30 days of production. They carried out open hole gravel pack job. Subsequently, it has become almost a practice to drill build up and horizontal section in one single step with synthetic fluid and then complete the well with open hole gravel pack. Considering the immense cost, even small increase in efficiency translate into huge cost saving. Due to innovative idea of drilling and completing their wells, Petrobras could achieve two things: sustained production for a longer time and cost saving of almost USD 4 million per well by way of reduced drilling time.

As another strategy, Transocean pioneered the use of "dual activity derricks." This new class of deepwater drill ship reduces deepwater drill costs by allowing operations to be performed concurrently rather than sequentially.

Conclusion

The major challenges faced by the E&P community are in deep water exploration and productions are mainly related to high pressure, low temperature, seabed instability, unconsolidated recent sediments and high corrosion rate.

Worldwide, operator and service providers are investing in Research and Development to develop innovative solutions and overcome various challenges. Success in Deepwater would be success of hydrocarbon community in the coming years. With oil prices touching more than USD 100 per barrel, the search for low-cost gas reserves will gain more momentum. Due to environmental impacts like greenhouse effect and global warming, frontier areas will likely to be explored with increased zeal for more gas discoveries. Subsequently, various strategies would be formulated to exploit them at the earliest.
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