INDUCTION OF EMERGING TECHNOLOGIES IN GIANT OFFSHORE FIELD AND ITS IMPACT

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ABSTRACT

Mumbai High field is the largest offshore oilfield of India. The field has development and production history of over thirty years. A major redevelopment programme was taken-up during last seven years to enhance production and recovery from the field. Large variety of techniques and technologies has been applied in Mumbai High and these have put the field production on the ascending trend.

The improved understanding of reservoir complexity through use of new generation tools, integration of geo-scientific data, refined reservoir simulation and 3D immersive visualization have provided higher degree of confidence to assess the potential reserves of by-passed oil. Recovery of difficult oil beneath the large gas cap has been possible through horizontal wells with advanced technology of the LWD-Geosteering. The thin sweet zones are now being targeted successfully with multilateral configuration with quantum increase in productivity. The inter and intra platforms locales of the unswept / undrained oil in the various sub-layers of the reservoir have been targeted with complex well trajectories guided by real time monitoring.

Poor producers have been relocated by side-tracking for better reservoir drainage. Introduction of advanced tools like rotary steerable system, expandable tubular, whipstock, synthetic mud system have provided encouraging solution for drilling through the problematic shales and differentially depleted pay-zones. Advanced well completion like segmented completion and level3 completion has been tried.

The redevelopment experience has provided the confidence in use of new technologies to achieve even higher recovery in the next phase of development of Mumbai High field.

KEY WORDS
Parallel processing, concurrent modeling, 3D visualization, horizontal wells, multi-laterals, real time operation monitoring, auto-track rotary steerable system, extended reach drilling, low toxic oil base mud, level-3 completion, clamp-on, bridge connected platform, side-tracking, logging tools, ESP.

INTRODUCTION

Crude oil and natural gas-play a pivotal role in powering industrial growth and development activity. India is today the world’s second fastest growing economy. Average growth rate during tenth Plan (2002-07) was 7.64%. During 2006-07 the growth rate has been 9.4% and the trend is likely to continue. To sustain a high growth rate, energy is an important component. Oil and gas account for nearly 45% of India’s total energy requirement and their consumption is increasing annually and nearly three fold increase in oil demand and four fold increase in gas demand by 2025 AD is projected. To meet the increasing demand, the Government of India has launched several rounds of exploration lease to attract and encourage international players into the high risk game. The efforts have been very rewarding as several new discoveries, particularly on the east coast, have been made and are being put on stream. The country’s national oil company ONGC has too geared up to contribute in fueling the country’s growth through aggressive exploration and production programme apart from overseas acquisitions/ joint ventures through its OVL segment.
In order to enhance production and improve oil recovery of the existing fields, an improved oil recovery (IOR) campaign was launched for the major fields during the late nineties. The IOR programmes considered use of then available cost effective technologies and field rejuvenation campaigns. However during the course of implementation of the redevelopment programmes, several emerging technologies were tested and advantageously inducted. The present paper discusses the case of the giant offshore field Mumbai High, where new technologies have been widely used. These technologies have impacted the IOR programme in a big way and helped to achieve high performance.

Mumbai High field is the largest offshore oilfield of India and is located about 160 Km west-north-west of Mumbai city in the Arabian sea at a water depth of about 80m. The field has an areal spread of about 1200 sq.kms. The field was discovered in 1974 and put on production in May 1976. The multilayered carbonate reservoir, L-III, is the main producer. The structure is a gently dipping anticline. The northern and southern sectors are divided by an east-west impermeable shale tongue. The field has been developed through various field development schemes drawn and implemented at various stages. Water injection initially through peripheral row of injectors was initiated in 1984 in North and in 1987 in South, after a brief phase of natural depletion. Injection was later augmented through central and up dip row of injectors.

During late eighties, oil production level of 18 to 20 MMTPA had been maintained (Fig.1). With rise in water-cut and gas-oil ratio, the production level dropped to nearly half the peak level by end of nineties. Several performance improvement endeavors such as accelerated plan of production, additional development, additional oil recovery project, gas-lift facilities, enhanced oil recovery project etc were undertaken to control the declining production trend and to improve the reservoir performance. The field development has been a challenge due to large areal spread with shallow water depth. The large overlying shale above L-III reservoir, gas-cap and depleted zones pose drilling problems. High degree of heterogeneity has led to differential depletion and uneven movement of the injected water in different sub-layers affecting reservoir performance.

**REDEVELOPMENT PROGRAMME**

In the effort to improve reservoir performance, the most significant initiative for Mumbai High has been the massive redevelopment programme launched during 2000-01. The objective of this programme was to control the production decline in short term and to enhance recovery factor in the long term. A two year preparatory phase preceded the launch. The services of international consulting company was hired for firming the work-plan and overall approach. A number of multi-disciplinary teams (MDTs) were formed to accomplish the task of data assimilation, analysis, comprehensive study and planning. Pilots were conducted to assess the potential of by-passed oil areas and feasibility of draining oil from untapped sectors of the field such as below the gas-cap and peripheral areas. A redevelopment plan aimed at better reservoir drainage through additional wells was drawn considering technoeconomically viable options.

The inputs in terms of new platforms, wells and pipelines envisaged under this programme have been completed in April 2007. A noticeable turn-around in field performance has been achieved. This has been possible mainly through improved understanding of the sub-surface, improved layer management, application of emerging drilling technologies and revitalization of sub-optimal wells.

Under the redevelopment process during last seven years, about 210 new wells have been added and over 150 wells have been relocated with horizontal drain holes in better potential sub-layers. The field had touched a production level of 265,000 bopd during early 2005 and, inspite of constrains due to north process platform accident in July’05, the field presently is producing about 260,000 bopd through nearly 700 producing strings. Water injection of the order of around 10,00,000 bwpd is being done through 252 injection strings The current GOR and water cut are 270 v/v and 62% respectively. Now over 45% producers are with horizontal/ multi-lateral drainholes.

Till March 2007, around 22.9% of IOIP has been recovered from the field. The oil rate versus cumulative oil plot (Fig.2) shows that the redevelopment programme has been successful in adding reserves and improving oil recovery from Mumbai High.
IMPROVED RESERVOIR MODELING

The main strategy of the redevelopment programme has been locating undrained oil and targeting them with suitably placed wells. Identification of bypassed/undrained oil areas in the multi-layered carbonate reservoir has been the main challenge. The highly heterogeneous character of the carbonate sub-layers has led to differential flooding leading to early water-breakthrough as well as bypassed oil. Faults have also affected the flow of injection water not only in terms of communication but also in fast water movement along the fault plane.

To have an understanding of the drainage pattern at sub-layer scale improved geological modeling and reservoir characterization was achieved through integration of available geo-scientific data. To have better control of inter well variations in structure and properties, 3D seismic data was acquired during 1997, processed and the Post-stack time migrated data was interpreted. Petro-physical reprocessing including electro-facies analysis was carried out. The team of geo-scientists made a fairly detailed geological model incorporating the complex reservoir features of sub-layered structure, major faults, heterogeneity and fluid distribution. This model was used for reservoir simulation and redevelopment planning.

To have better resolution and understanding of the reservoir, separate simulation models for Mumbai High North and Mumbai High South L-III reservoirs were constructed. To optimize the hardware, software and manpower resource requirements, the modeling job was divided between Institute of Reservoir Studies (IRS) and Mumbai High Asset. The north simulation model consisted of 90x90x16 cells while the south model size was 166x192x14. These models were considered fairly large when they were constructed in 1998-99 and the simulation model run parameters were optimized to have reasonable run time. During the course of the study parallel processing option was acquired which helped to reduce the run time considerably and provided the simulation engineers more flexibility and opportunity to incorporate improvements in the models as more and more performance history became available.

During the course of implementation of redevelopment plan, continuous up-gradation of the model was done with drilling data and production behavior. Some of the faults considered insignificant during initial model building were re-scrutinized and reinterpreted. This approach helped to improve the understanding of the structural framework and led to necessary precautions in fine-tuning the placement of wells. At this stage, when the 3D visualization center was set up, the model was quality checked and refined. During drilling in less control areas, a ‘concurrent modeling’ approach was adopted in order to reassess the enhanced potential of the sector and to re-orient the development approach within the available timeframe.

It needs to be mentioned that the development team well understood the inherent limitations of the simulation model and the decision making involved the multi-disciplinary team and took into account the strengths and weaknesses of the model apart from updated G&G interpretation and classical reservoir data analysis.

ADVANCED DRILLING TECHNOLOGY

Although horizontal well technology was tested as back as 1986 in L-II reservoir of Mumbai High, the multi-layered L-III reservoir continued to be developed with conventional wells. Use of horizontal wells to develop the peripheral area was experimented early on and use of horizontal well was considered to a limited extent in the original plan. With horizontal wells, the undeveloped reserves of an area with thin pay zone have been successfully developed. With initial results being very encouraging, the use of horizontal wells was extended to tap the oil in lower layers in gas-cap area and for targeting the unswept oil in sub-layers even near the injectors. The technology to expose the large reservoir formation area with horizontal drainholes was extended to have more than one drainhole. Multi-laterals with three or four drainholes and fishbone type completion has led to economic development of thin layers, particularly in the fringe area with sweet zone as low as 3m.
In Mumbai High, given the small thickness of the sweet zones, proper placement of the drainholes, is very important and challenging. The trajectory planning of the complex geometry wells is carried out in conjunction with the sub-surface data but the uncertain characteristics of the carbonates and variations in structural picture keep the well placement team on alert. Real time operation (RTO) monitoring with logging while drilling (LWD) data provides better interface and faster decision during drilling, resulting in rig cost optimization. The data from the rig is transmitted via satellite to the monitoring center where the assigned team continuously checks the streaming data and advises course corrections if any. The real time mode Test runs for real time updating of the model have also been conducted successfully and is expected to further improve the drainhole placement.

Several new tools and technologies have been inducted in the drilling area. Notable among these are the extended reach drilling (ERD) technology, auto-track rotary steerable system (RSS) and low toxic oil base mud (LTOBM).

With the development of extended reach drilling (ERD) technology, undrained oil in the inter-platform area is being reached by drilling highly inclined wells with angle of inclination ranging from 60° to 85°. Initially ERD wells were drilled with horizontal drift of 1800m to 2000m. Within the field area a number of ERD wells have been drilled to optimize the platform cost. The ERD technology has been extended to drilling of ERD-Horizontal wells and more recently ERD sidetracks have also been carried out. With extended capability of over 2500m, ERD technology has provided an opportunity to reach long distance isolated areas.

Use of RSS and LTOBM in combination has helped to efficiently drill the problematic 12 ¼" long shale section above the L-III zone and problems of shale collapse, caving, hole enlargement and pipe stuckups have been controlled to a great extent. This has been very useful not only in drilling of problem prone ERD wells but in also reducing the drilling time. Improvement in penetration upto almost four times with better control on trajectory and shale problem has been observed.

After success of multi-lateral drilling, a higher level of completion involving drainholes in two or more zones (level-3) is being attempted as a cost effective completion technology for multi-layered reservoir.

The movement of injection water in the sublayers has not been always as expected and segments of high water saturation are encountered in the drainhole. Segmented/ intelligent completion using predesigned sleeves and external casing packers (ECP) has been used to reduce unwanted fluids and improve oil productivity.

Large volume of bypassed oil is estimated in the relatively tighter parts of the pay-zones. Stimulation of horizontal drainholes is a specialized technique and is planned with expert service providers. Special non-damaging mud in pay zone is used for drilling the payzone to minimize the ‘skin’ around the well bore resulting in better productivity.

With indution of above technologies considerably improved performance of new wells has been achieved.

**NEW WELL SLOTS ON OLD PLATFORMS**

The maximum number of wells that can be drilled in an offshore field is governed by the number of slots available for drilling on the well platforms. During initial development mostly 4-slot platforms were installed in Mumbai High. The subsequent platforms were 9-slot. Very recently 12 and 16 slot platforms have been installed. With the approach of infill drilling for better reservoir drainage, the need for more slots became evident. Installation of independent wellhead platform is expensive, particularly the number of wells to be drilled is limited. The technology of installing clamp-ons on existing platforms has been used as a cost effective option. Two to three wells could be drilled from each clamp-on. During the redevelopment phase, 14 clamp-ons in north area and 16 clamp-ons in south area have been installed.
Another cost effective technology has been the installation of bridge connected platforms wherein new platforms have been connected to existing platforms. This option was found useful where more than three well locations were required to be drilled near the existing platform and also where the existing platform was structurally unsuitable for clamp-on installation. This technology has been used on three platforms of Mumbai High North for additional development of the peripheral area where A1 layer was found to contain significant volume of undrained oil. Bridge connected platforms have cost saving in terms of minimum new pipeline requirement of sharing of some existing facilities.

REHABILITATION OF SUB-OPTIMAL WELLS

With continued production, the oil productivity of the well declines due to depletion of the area and/or watering out of the sub-layers. Workover jobs water/gas shut-off jobs and zone transfers were common in conventional wells. With introduction of sidetracking technology, poor producers have been relocated for better well productivity and improved reservoir drainage. Side tracking is successfully achieved through window cutting/section milling and using whipstock. Besides normal side-track, long drift side-track (LDST) and short drift side-track (SDST) have been carried out by milling the 7” liner section, or 9⅝” or 13⅜” casing. In some cases the 13⅜” and 9⅝” casings have been retrieved to facilitate drilling of new wellbores from the old slots.

Side-tacking of wells to lower layers usually amounted to reduced well size in production zone. Use of expandable casing has been made to achieve the desired hole size and well productivity. Although this technology was originally planned for sidetracks in lower layers, the technology has been advantageously used in new wells also to have the option of additional casing in case of heavy mud loss and also in case of short landing of casing.

With successful implementation of horizontal well technology, side-tracking of conventional wells into horizontal drainholes has also become common now. Some of the existing wells have been side-tracked into ERD horizontal wells. Medium radius drainhole (MRDH) has been used to place a drainhole in the better sub-layer of the existing well. In order to avoid interference of overlying zones, short radius drainhole (SRDH) drilling which requires lesser vertical clearance than MRDH, has been more extensively used for converting sub-optimal conventional wells of Mumbai High into better producing horizontal wells.

NEW GENERATION LOGGING TOOLS

Apart from conventional well logging tools, several new tools have been used in Mumbai High. The use of cased hole formation resistivity (CHFR) tool has been effectively used to evaluate the current saturations and decide the target layer for placement of drainholes in old wells. CMR (Combinable Magnetic Resonance) tool has been used for rock porosity estimation and fluid typing. Cased Hole Density tool (CHDT) has been used for obtaining porosity information of cased holes.

Open hole MDT (Modular Dynamic Tester) tool has been used to measure reservoir pressure and sample the formation fluid during drilling phase itself. In order to understand the flow performance of horizontal drainholes, tractor driven Production Logging (tractor PLT) has been carried out successfully in selected ERD / horizontal wells.

Feasibility of evaluation and incorporation of horizontal wells’ petrophysical data in the model is an area to be worked on with industry experts.

OTHER NEW TOOLS AND TECHNOLOGIES

To build a refined, more representative reservoir model, the seismic data has been reprocessed in depth domain and studies for using the data for better resolution and characterization of the sub-layers have been initiated. Attempt to characterize the fractures and account for them in the simulation model are also in progress. New chemicals and mud systems to improve drilling are being tried. To control drilling cost against rising daily rates of conventional jack-up rigs, modular and platform mounted rigs
are being planned. Improved well designs and completion techniques for better productivity and low cost are being examined. Advanced dispersible plug system for wells’ activation is planned to be tested to improve operational time over the presently used surge plugs.

On the operations front, smart instrumentation, and integrated management of surface facilities has been taken-up. To improve artificial lift efficiency and to limit the future requirement of gas for artificial lift, electrical submersible pump (ESP) is being planned for the non gas-cap area. Performance of five wells put on ESP has provided good learning and confidence. Multi-phase pumps, meters, and downhole pressure gauges are some areas currently in focus.

CONCLUSIONS

Mumbai High field even after thirty-one years of production has responded favorably to new technologies inducted in various areas of field development and reservoir management. Induction of new technologies has helped in targeting the potential locales of bypassed / unswept oil zones and has reversed the production decline trend. Hi-tech in-fill drilling with new generation tools and improved mud system has helped in management of the drilling complexities. Use of horizontal wells and multilaterals has helped to produce economically oil below the gas cap and from the large but limited thickness peripheral area. The inventory of low performing wells has been significantly reduced by relocating the wells through sidetrack and by converting them into horizontal drainholes. Induction of technological advancements in modeling, drilling, completion, engineering, is likely to further improve the recovery from the heterogeneous multi-layered carbonate reservoir of Mumbai High field. The blue print for next phase of redevelopment is already under preparation.

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References


Fig 1: Western Offshore and structure map of Mumbai High

Fig 2: Historical Production Performance of Mumbai High Field
Fig 3: Integrated G&G studies for understanding drainage pattern and bypassed oil

Fig 4: Placement of drainhole in thin zones using real time logging
Fig 5: Oil rate vs Cumulative oil production of Mumbai High field

Fig 6: Impact of redevelopment – increased oil production