



## Exploitation Strategy and Drainage Pattern for Low Permeable Layer of Mumbai High field.

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### Summary

*In Mumbai High field most of the wells are completed as commingled multi-layered completions. Layer-wise management is a challenging task for the field. For better exploitation and improvement in recovery, layer-wise drainage pattern is of the utmost priority. The field is in a mature stage of its producing life and has associated problems like increase in water cut and high production GOR. Uneven water movement due to reservoir heterogeneity and permeability differences between the layers has left large portions of the field holding unswept oil.*

*The present paper deals with exploitation strategy and drainage pattern for low permeable (5 to 30 md) ‘C’ layer with focus on quantification of the injected water and oil production on the basis of flow capacity (kh) and its impact on reservoir performance for better management.*

*The exploitation strategy consisted of drilling of new infill drainholes, identification of existing poor producers for side-tracking, conversion of more wells to injectors and commingled to dual injectors for the optimum exploitation of the layer on the basis of analysis using bubble map of oil production & water injection and drainage pattern of ‘C’ layer.*

*Layer-wise management has emerged as a tool in identifying the problems and applicable remedial measures. The strategy resulted in the release of three infill development locations, identification of two sidetracks of existing producers for improving the oil production and recovery factor in different parts of the layer. Conversion of single water injector to dual water injector for focused injection and closure/transfer of high-GOR wells was also carried out for better layer management*

### Introduction

The Mumbai High Field, discovered in 1974 and located 165 km WNW of Mumbai city, is the largest and most prolific oilfield in India. It is one of the most complex fields in terms of reservoir heterogeneity. The most important oil producing reservoir is the Miocene L-III limestone unit which has a thick oil column and a well developed gas cap. The L-III limestone reservoir is a composite of up to twelve hydrocarbon bearing sub-zones in different parts of the field. The sub-zones are separated by shale layers of variable lateral extent. Till date, around 600 development wells (oil/gas producers and water injectors) have been drilled in Mumbai High South.

Low permeable ‘C’ layer of Mumbai High South field is estimated to have held initial in-place oil of about 72 MMt of which 6.6 % (4.76 MMt) has been produced, leaving estimated oil reserves of 4.02 MMt. The expected recovery up to 2030 is 12.9 % (8.8 MMt). The production of the

remaining 4.022 MMt of oil will be more challenging than the first 4.76 MMt. The challenges include unexpected local geological surprises leading to placement of drainholes in areas of poor petrophysical characteristics, encountering low permeability tight facies, low pressure pockets, high GOR and inadequate pressure maintenance through water injection due to insufficient voidage compensation, while aiming for maximizing the ultimate recovery of oil.

The present R/P (Reserves-Production Ratio) of the layer is 23 years. The objective of layer management is to maximize economic oil recovery from the field. For example, recovering the estimated 12.9% of the ‘oil in-place’ in ‘C’ layer will require maintaining a sustained production rate exceeding 1.5 times the present production rate for a period of 15 years.

The main challenges are to increase the oil production rate by sidetracking the existing poor producers as drainholes,



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placing new drainholes through infill drilling, optimization of artificial lift and stimulation of the wells by hydrofracturing. Another important aspect is to maintain the well rates within reasonable limits, in such a manner as to minimize the gas saturation near the wellbore region.

The other main area of reservoir management consisted of conversion of low producers as water injectors and large scale focused injection through conversion of more commingled injectors to dual injectors, enhancing liquid rates and stabilization of reservoir pressure. Pattern water injection<sup>1</sup> is favoured in view of the low transmissibility and areal heterogeneities remain an important consideration especially because it may take longer to see the effects of water injection in terms of pressure maintenance due to the low formation permeabilities.

#### *Layer geology and characteristics*

Development of C layer is mainly in the eastern part of the Mumbai High South field. In general in this area the sub layers B and C are oil bearing, with an OWC at 1369m in C. There is also a GOC observed in A2-IV to A2-VII, at 1330m MSL. Geological model for the C layer is conceptualized on the basis of effective and gross thickness trends emerging from electro-log analysis. The layer is essentially characterized by thin localized development. Broadly, the parameters of the 'C' layer can be quantified as follows:

|                            |                     |     |
|----------------------------|---------------------|-----|
| Porosity                   | 18-25               | %   |
| Permeability               | 5-30                | md  |
| Effective thickness        | 2-7                 | m   |
| GOC (MSL)                  | 1330                |     |
| OWC (MSL)                  | 1369                |     |
| Average Reservoir Pressure | 2000-2200 (initial) | psi |
|                            | 900-1100 (current)  |     |

#### **Methodology adopted for the present study**

For layer-wise management, the well completion history for oil production and water injection is required. As the wells are completed for commingled production from many layers, the contribution of each layer is to be considered<sup>2</sup>. Factor kh representing the transmission of fluid in porous media is calculated for each well and for each layer over the past period where permeability (k) & effective thickness (h) values are taken from the transient test data and log data. For the present study all wells up to September 2007 completed in 'C' layer have been selected and their completion history considered. Contribution of 'C' layer is calculated by the multiplication of contribution factor and cumulative production/injection. Whereas

percentage contribution for 'C' layer is calculated as follows.

$$\% \text{ contribution of 'C' layer} = \{kh(\text{'C' layer}) / \sum kh (\text{all completion layers})\} * 100$$

From the calculated values of oil production and water injection, a bubble map is generated to help understand the overall drainage pattern of the layer (Fig 1).

The second step is to understand the current drainage pattern of the 'C' layer for which the production data of all the wells are considered for the month of September 2007. For better monitoring and improvement in recovery, the current drainage pattern of the layer is very useful (Fig. 2).

The 'C' layer has been developed within 20 platforms and a total of 64 development wells out of which 39 are oil producers and 25 are water injectors. The calculated values of oil production and water injection are validated by the available PLT results in injectors & producers. PLT studies are available for 28 out of the 39 oil producers and 18 out of the 25 water injectors. Though some PLT results for producers are old, they are matching in 70% of the wells. Thirty percent the PLT studies of water injectors pertain to the last four years and the rest were older.

#### **Analysis of the results**

##### *Drainage pattern for the low- permeable 'C' layer*

Development of the 'C' layer is mainly in the crestal part of Mumbai High South field. Most of the wells are completed for production/injection as commingled multi-layered completions. For better exploitation and improvement in recovery, layerwise drainage pattern is of the utmost priority. The average reservoir pressure in the producing area is 900-1100 psi resulting in the creation of pressure sinks near the producers. The average reservoir pressure in the unexploited area is 1800-1900 psi recorded through MDT surveys.



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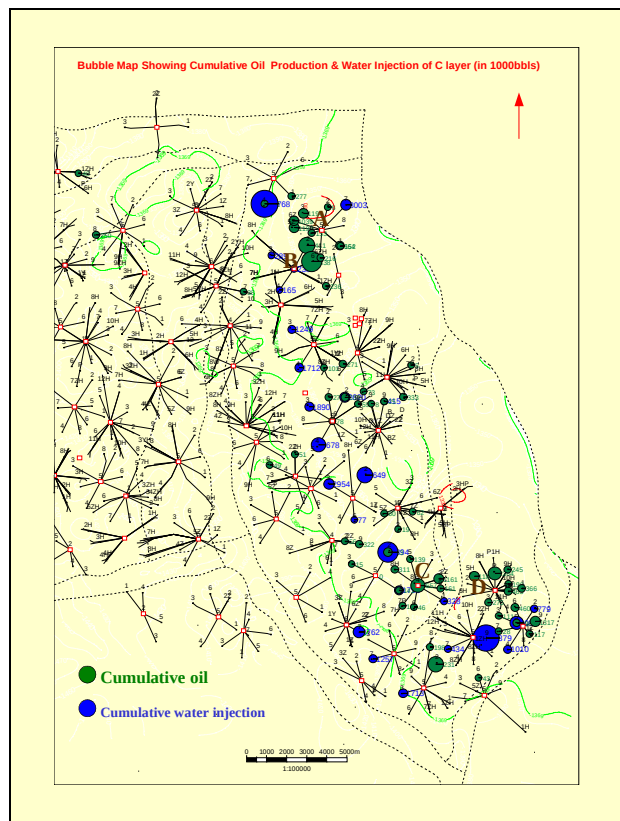


Fig.1 - Drainage pattern for cumulative oil production/water injection in 'C' Layer

The drainage pattern of the 'C' layer (Fig.1) indicates that oil production is more in the northern and southern parts of the layer. In the central part, production is less and water injection is good. Therefore, more water injectors are required in more areas of withdrawal with completions in 'C' layer only. Redistribution of injection is also needed for targeted injection. An analysis of the drainage pattern of the layer shows that 70% of the production is from the four platforms A, B, C & D and 75% of injection is through a set of eight wells, though the total number of injectors is 25. This shows that production/injection is not uniform.

Calculated liquid production is 11,675 b/d and oil production is 3946 b/d through 39 oil producers. The water injection is 21,683 b/d through 25 water injectors. The average water cut is 66% and the GOR is abnormally high at 747 v/v. The current level of VRR is 56%, which confirms that the injection is not commensurate with production and needs to be improved. Out of the total oil production of 3946 b/d from 39 wells, 2878 b/d is from 14 wells completed in 'C' layer and 1067 b/d is from the rest 25 wells completed for commingled production from different sets of layers. The total water injection is 21,683 b/d through 25 injectors, out of which 11,523 bwpd is from

three injectors completed in 'C' layer and 10,160 bwpd is from 22 injectors completed in different sets of layers. The present layer production rates are considered to be quite low, when viewed with respect to realizing the aimed for recovery factors. At the present production rate, the ultimate recovery of 12.9 % would probably be achieved in 23 more years.

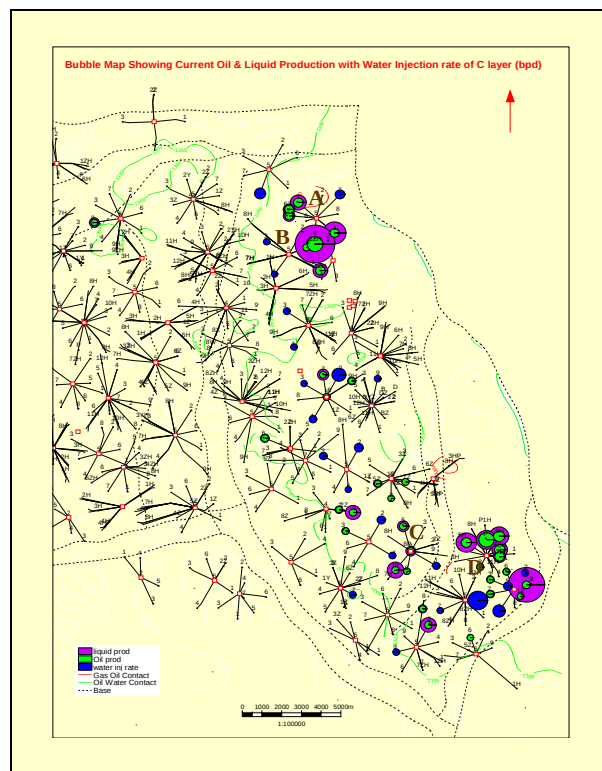


Fig.2 - Current drainage pattern for cumulative oil production/water injection in 'C' Layer

The current drainage pattern (Fig.2) of liquid, oil production and water injection is clearly showing the high withdrawal areas and areas where the water gets injected into 'C' layer. The wells which are producing with high water cut are also clear from the drainage pattern. The current voidage replacement ratio (VRR) on a monthly basis is only about 56 percent which is considered too low to achieve good pressure maintenance and ultimate recovery of the layer. Thus additional water injection is required to make it commensurate with oil production. Due to the reservoir being thin in this area, horizontal injectors may present an alternative for going forward with injection in this portion of the field.

A critical survey of measured pressures indicates that there exist four low pressure pockets in A, B, C & D platform areas. To address such low pressure pockets, conversion and completion of water injectors singly in 'C' layer is



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required. Two water injectors have recently been converted as dual injectors to improve the level of voidage replacement ratio & two other wells need conversion as dual injectors. In structurally higher parts, some wells which are producing with high GOR have been transferred to S1 free-gas reservoir to conserve the reservoir energy of 'C' layer. Stimulation by hydraulic fracturing is planned in producers and injectors to enhance oil production/water injection in such a low permeability layer.

Due to local surprises leading to poor Petrophysical characteristics of reservoir placing of drain hole is very challenging. In the past, for the optimum exploitation of layer four wells were released for drilling in the eastern part, one location is drilled and produced gas because structure came up by 7 m w.r.t. nearby existing exploratory well where 'C' layer was found to be oil bearing on logs, another location indicated high water saturation in 'C' layer and well is completed in upper 'B' layer. Therefore, for low permeable and heterogeneous reservoir of the type seen in 'C' layer, the geological model needs review for better understanding of the performance. Improved geological model will help in appropriately placing drainholes and better performance prediction. Further, two other released locations need relocation to be firmed up on the basis of a review of geological model in conjunction with seismic and updated drilling data. Also, for proper placement of horizontal wells in the future and better understanding of performance of the layer, all geological/geophysical and reservoir interpretations should be merged for analysis of the layer behavior. This can be expected to lead to better production performance of the layer.

More water injection is required near platforms A, B, C & D which are the main oil producers from 'C' layer. Producers and injectors which are completed for commingled production/injection in different sets of layers, including 'C', are not producing significantly from 'C' layer due to permeability contrast and so more producers and injectors are required with 'C' layer completion only<sup>4</sup>. Bottom-hole studies are required in different parts of the layer for performance analysis of the wells.

Production performance of vertical and horizontal wells is analyzed for all the wells completed in 'C' layer. An example of typical production performance of well-AA completed as a vertical well in 'C' layer with average production of rate 400 bopd (Fig.3) and another example of well-BB completed as a drainhole in 'C' layer with average oil production rate of 700 bpd (Fig.4) indicate that the performance of the horizontal well, as may be expected, is better than the vertical. Thus placing more drainholes could be an economical way of effectively accelerating production and limiting the field life cycle. Thus, with the help of analysis, three locations (for drilling of drainholes) have been released and lined up for drilling. More drainholes, however, would be required to improve the recovery further.

Another step is to maximize production from poor producers. Accordingly, it was decided to drill a lateral by sidetracking one and complete it as a drainhole in 'C' layer. Two other wells are also identified for sidetracking and completion as drainholes in 'C' layer. Sidetracking of the available conventional wells instead of drilling fresh horizontal wells would lead to optimum utilization of low producers and will minimize the total drilling cost. Short-radius and medium-radius drainhole (SRDH & MRDH) drilling tools have provided the opportunity to work the existing wells over and convert them from conventional wells into horizontal drainholes in the same drainage area but with higher oil productivity<sup>3</sup>.

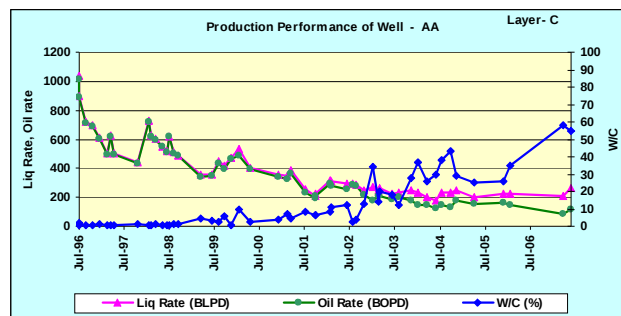


Fig.3 -Performance of a typical vertical well-AA in 'C' layer.

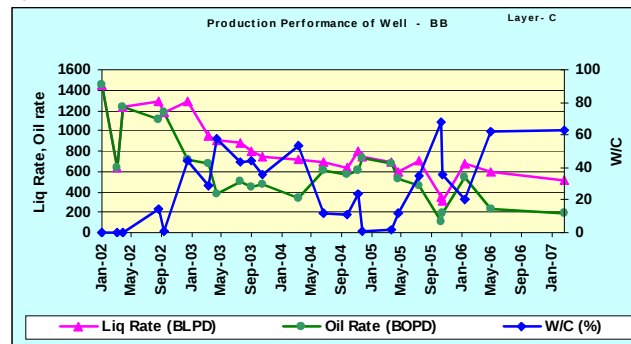


Fig.4 -Performance of a typical horizontal well-BB in 'C' layer.

## Key Reservoir Management Issues, Challenges and Suggestions

- Four locations were released in eastern part of 'C' layer for the further development, two locations drilled, one produced gas because 'C' top came up by 7 m., another location indicated high water saturation in 'C' layer and completed in upper layer. Two locations need review/relocation. Therefore, the present geological model needs review and better understanding for further development of the layer.



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- In the eastern part of the layer as surprises are seen in the oil saturation levels, fine-tuning the exploitation strategy would require a thorough review of all the well logs, previously conducted geological studies, and other available information to arrive at a fresh estimate of the oil and gas in place.
- The contribution of the 'C' layer is not significant in terms of production and injection in wells completed in upper layers together with 'C'. More producers and injectors are, therefore, required in 'C' layer only.
- Reservoir with poor facies, poor petrophysical properties and low reservoir pressure in pockets would be better productive if drilled with low gravity drilling fluid. Prevention of formation damage during drilling would save time and efforts for subsequent activation.
- Transient tests need to be conducted on a regular basis to evaluate the need for well stimulation, as well as for monitoring depletion of reservoir pressure in the layer.
- Stimulation by hydraulic fracturing could be one of the possible ways to enhance oil production in such a reservoir.
- For effective and healthy management of the layer, more and more injectors near the high withdrawal areas are required in the days to come in order to move towards a more organized pattern flooding. The reduced producer-injector ratio would result in better sweep efficiency and conformance factor, leading to improvement in recovery factor.

## Conclusions

This paper has presented a brief overview of the exploitation strategy adopted for the low permeable 'C' layer of the Mumbai High South field, arriving at the following conclusions.

- For low permeable and heterogeneous 'C' layer reservoir, better reservoir description for improving the geological model and predicted performance is the key to correctly placing the drainholes for further development of the layer.
- Larger the volume of data better the reservoir description. The volume of data generation efforts for a fairly homogenous reservoir is quite small in comparison to the volume anticipated in case of a highly heterogeneous reservoir.
- Integration of all geological/geophysical and reservoir interpretations consistent with observed layer behavior would be beneficial.
- The 'C' layer is heterogeneous and of low permeability. Due to this, pressure sink gets created near the wellbore area in the producers, leading to fast decline in liquid and oil rates.

- More horizontal wells can now be planned as infill wells for exploiting the undrained areas of the reservoir. Therefore, three horizontal wells are lined up for drilling for exploitation of the 'C' layer.
- Two poor producers are identified for side-tracking as horizontal drainholes for better productivity to exploit the unswept oil, which will lead to recovery improvement.
- On the basis of the results of transient tests, stimulation through hydrofracturing is recommended to increase the oil production.
- To address the low pressure areas, a large scale and focused water injection is needed for effective and healthy management of the layer. Pattern injection would have better sweep efficiency and conformance factor, which would lead to improvement in recovery factor.

## References

1. Uma Goyal, B.V.Bhushan, Ram Avtar, Lehmbhar Singh, 1997, "Static and Dynamic model to improve pattern water flooding of sand GS-5C of Gandhar field", Paper no.172, National Seminar on Reservoir Management & Exhibition, 6-7 Oct 1997, Baroda.
2. H.B. Bradley, Petroleum Engineering Handbook, printed by SPE, Richardson, TX, USA
3. R.Saxena, Uma Goyal, E.Murugesan, U.B.Singh & S.K.Verma, "Role of Medium Radius Drain Hole (MRDH) & Short Radius Drain Hole (SRDH)-Logging While Drilling (LWD) Technology in Drilling Sidetracked Horizontal Wells in Mumbai High Field"-PETROTECH-2005
4. U.B.Singh, Uma Goyal, R.Saxena, & S.K.Verma, Effective layer management to enhance oil production in multi layer reservoir - *Presented in strategic meet on well flowing wells, 2004 in MH Asset.*

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