CHARACTERIZATION OF MUKTA & BASSEIN PAY CARBONATES RESERVOIRS USING A SYNERGISTIC APPROACH - A CASE STUDY OF A BROWN FIELD OF MUMBAI OFFSHORE BASIN, INDIA

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ABSTRACT

B-173A is a small field lies in Heera-Panna-Bassein Block of Mumbai offshore located 25 km north of Neelam field. The structure has a roughly NNW-SSE trend except the producing central part, which has an oblique trend in NNE-SSW direction. The structure has a rising trend in NNE direction. Mukta Formation of Lower Oligocene age is gas bearing and Bassein Formation of Middle to Upper Eocene age is both oil and gas bearing.

A petrophysical model was generated & validated using multi-well cross plots, core, cuttings and other relevant geo-scientific data and this model has been successfully used in petrophysical evaluation. The outcome of this analysis were integrated with all the available geo-scientific inputs including production test data, core study data e.g. XRD, core porosity, grain density & permeability etc.

This integrated approach lead to identification of a new oil bearing layer of 5.6m pay thickness and a gas bearing layer of 19.8 m pay thickness in Bassein & Mukta Formations respectively in a well which was earlier declared dry and abandoned. Based on these new findings, the north-western part of the field becomes promising from hydrocarbon point of view and can lead to significant reserves accretion. As a consequence, an appraisal cum development location is released and is likely to be drilled shortly to firm up the new potential.

In another dry & abandoned well, belonging to the north-eastern block of this field, 16.2 m new gas pay thickness has been identified in Mukta Formation which is also likely to increase the reserves.

This synergistic approach has opened up new area for exploration / exploitation in this brown field which will facilitate in increasing oil & gas production as well as reserve accretion for Mukta & Bassein pays.

INTRODUCTION

B-173A is a small field (Figure-1) lies in Heera-Panna-Bassein Block of Mumbai offshore located 25 km north of Neelam field. Mukta Formation of Lower Oligocene age is gas bearing and Bassein Formation of Middle to Upper Eocene age is both oil and gas bearing. Out of seven exploratory wells (well A to G) two wells i.e. B & E are oil bearing in Bassein Formation and well no. F shows oil indication where as wells no B & F flowed gas from Mukta Formation after acidization. Subsequently, the field is being developed with five producers completed in Bassein Formation only and producing oil@ 1882 bopd with GOR & W/C of 125-150 v/v & 86% respectively as on Aug 2011.
GEOLOGY AND STRATIGRAPHY

B-173A structure is in Panna-Bassein-Heera Block which lies in the eastern central part of Mumbai Offshore Basin. The structure has a roughly NNW-SSE trend except the producing central part, which has an oblique trend in NNE-SSW direction. Two small culminations are observed around wells B and E. The structure has a rising trend in NNE direction towards wells A and F. The SSW part has been dissected by a fault west of well G and structure has gone down by about 30m.

The Deccan basalt constitutes the technical basement and the sediments ranges from Late Paleocene / Early Eocene to Recent age (Figure 2) overlie it. The Late Paleocene / Early Eocene sediments are represented by Panna Formation which comprises of claystone, shale, and siltstone and at places very fine grained sandstone.
The overlying Bassein Formation is characterized by thick foraminifera and algal wackestone, packstone and occasional grainstone facies. Core with typical Bassein limestone (Well no. A) characteristics is shown in Figure 3. Extensive karstification observed in this core. Partial sparitisation of matrix and skeletal grains are common.

The Mukta Formation, which unconformably overlies the Bassein Formation, is characterized by presence of fossiliferous limestone with shale intercalations. Typical core of well no. A belonging to Mukta formation is presented in Figure 4. The core is dominated by algal-foraminiferal, coral-foraminiferal wackstone to packstone facies with argillaceous content and shale. Vuggy porosity is observed in the upper part of the core in packstone facies. Lower part is comparatively sparitized and vugs / channels are filled with calcite. The fossil grains are highly sparitized, which led to porosity and permeability destruction. At places pyrite coating on grains are also observed.

The Alibagh Formation of Upper Oligocene to Basal Miocene is overlying the Mukta Formation which is separated by an unconformity and consists of greenish gray splintery shale interspersed with thin limestone bands. Bombay Formation of Lower Miocene age consists of thick limestone interspersed with thin shale and unconformably overlies the Alibagh Formation. Mahim and Tapti Formation are successive younger formations present in this area.
METHODOLOGY & RESULTS

Sub-division of Mukta and Bassein Formations

Based on log characteristics Mukta and Bassein Formation have been subdivided into two (unit-1 & 2) & three (B-upper, B-middle & B-lower) sub layers respectively. A typical log of well no.C is shown in Figure 5. Entire hydrocarbon bearing zone of Bassein formation is developed in B-upper only. Therefore, in addition to the Mukta Formation this study focus on B-upper only.

The subdivision of Bassein formation was made possible due to the presence of two consistent markers picked up by electro log correlation. The Marker-1 is the very first low porosity carbonate zone developed below the Bassein top whereas the Marker-2 is an argillaceous type of carbonate developed between Marker-1 & Panna top.
Development of Petrophysical Model

For B-upper, multi-well Z-plots of Neutron-Density (Figure 6) and M-N (Figure 7) with GR on Z axis have been generated to identify the minerals. Dominance of calcite mineral along with minor dolomite in the reservoir is noticed.

Similarly, in the Mukta section, Neutron-Density (Figure 8) and M-N (Figure 9) multi-well Z-plots with GR on Z axis indicates major lithology comprising of calcite with dolomite. These plots show lot of scattering due to the heterogeneity involved within the formation. At few instances it is reflection of bore hole rugosity.
X-ray diffraction (XRD) studies of well no. A, (Figures 10 & 11) also show calcite as the dominant carbonate mineral with subordinate dolomite as the mineralogical composition of the carbonates and authigenic clays of Mukta & Bassein formations. In addition presence of Kaolinite type of clay is also reported (Ref. 1 & 3). Presence of pyrite mineral in Mukta & Bassein formations is depicted in conventional cores of Well nos. A & H, sidewall core of well no. E and cutting samples collected during drilling (Well no. B).

Therefore, ELAN Plus model for volumetric computation is developed by comprising minerals like Calcite, Dolomite, Kaolinite, Illite & Pyrite with possible fluids like Gas & Water for Mukta and Oil & water for Bassein formations respectively. Appropriate values for the various parameters associated with different minerals and fluids have been used to create a more meaningful and robust model which is used for ELAN Plus processing.

Integration and Validation of ELAN Plus output with the core & testing data

Core derived porosity & grain density data of the well no. A, F, G & H were compared with the ELAN derived porosity (PIGN) & matrix density (RHGA) respectively for the Mukta & Bassein formations. A fairly close match is found between these parameters & typical match for well no. A& F are presented in Figure nos.12 & 13. This validates the petrophysical model chosen for the ELAN Plus processing.

In addition to this, ELAN Plus output data were also integrated with the testing data, side well core / conventional core mineralogy, cutting samples during drilling and RFT/SFT data of the respective wells.
Estimation of Permeability

An attempt has been made to estimate continuous geochemical permeability (KINT) in well nos. A, F & G by calibrating it with core derived permeabilities. The results are shown in Figure no. 12 & 13. It should, however, be borne in mind that k-lambda permeability estimation works best in clastic environment where permeability is mostly governed by pore/pore-throat shape and size (and hence surface-to-pore volume ratio). The presence of vugs, fractures and solution enhanced features in carbonates makes the situation complicated and therefore permeability does not remain a function of surface-to-pore volume ratio alone.

Discussion of Key Wells

Well no. A: (Figure 14)

Status of the well: Dry & Abandoned.

This is the first vertical exploratory well drilled during the year 1989 & lies in north eastern part of the field. The well is drilled up to a depth of 1680 m to explore the hydrocarbon prospects in Mukta & Bassein formations. Formation wise interpretation/analysis is given as below;

Mukta Formation:

Testing results

Obj-II (Intervals 1381-84 and 1388-90 m), No activity observed, concluded as dry object.

Log data interpretation & Analysis

- The Mukta top (H-3-A) has been encountered at 1362.5 m (~ 1328.8 m msl) depth.
- ELAN plus processing shows low average water saturation (67%) and good porosity (20%) within the pay zone interval. This pay zone is extending up to unit -2 of Mukta formation & the total thickness of the pay is 16.21 m. The $h \times \Phi \times S_g$ value works out to be 1.06.
- All the porous & permeable intervals right from top of Mukta i.e. 1362.5 to 1401 m depth are interpreted as gas bearing. However, the top part from 1362.5-1371 m could not be interpreted as the bore hole is highly caved affecting the logs data severely.
- The ELAN processed output matrix density (RHGA) and porosity (PIGN) matches closely with the core grain density and core porosity values supporting that proper petrophysical model has been chosen for the ELAN processing.
- Core data (CC#1 & CC#2) shows strong positive cut and patchy fluorescence within the cored interval 1379-1395.3 m.
- Total gas shows are reported to be 1.5-2% at 1372 m depth during drilling. Gas/oil oozing has also been reported from CC-1 & CC-2 core data. All these observations substantiate ELAN results.
- Based on the log evaluation and above observations, the GSC (Gas Shale Contact) has been placed at 1401 m (~1367m msl) depth.

Comments on Testing: Object-II (Intervals 1381-84 and 1388-90 m) was tested only for 15 minutes and there was no flow observed during the testing. The core permeability data (CC#1) shows very low order of permeability i.e. <1 md, supporting no flow from this object. Injectivity test also shows nil injectivity & this object was concluded as dry without carrying out any acid job. Where as in all the other gas flowing wells of Mukta formation viz well nos. F, H & B, these wells flowed gas only after carrying out acid jobs. Therefore testing of well no. A (Obj-II) appears to be incomplete.

Inference: Requires re-testing followed by acid job to firm up the hydrocarbon potential.
Bassein Formation:

This formation is interpreted & tested as water bearing.

Well no. C: (Figure 15)

Status of the well: Dry & Abandoned.

This is an exploratory well drilled for the delineation of the Bassein pay developed in well nos. B & E and is located in NW direction of oil well E. The well is drilled up to a depth of 2166 m and terminated in fresh basalt. The well was abandoned without lowering the 9 5/8” casing and the status of the well is dry. The log interpretation/analysis of Mukta and Bassein formations is given as below;
**Mukta Formation:**

The Mukta top has been encountered at 1446m (~1415.5 m msl) depth. Based on the following observations hydrocarbon has been interpreted against the interval 1446-1478.2 m in Mukta formation with GTC (Gas Tight layer Contact) placed at 1478.2 m (~1447.7 m msl) depth.

- As per ELAN processing results the pay zone is characterized by low water saturation (56%), moderate porosity (16%) and the pay thickness of 19.82m. The estimated $h\times\Phi\times S_g$ value is 1.44.
- Neutron-Density cross over is seen at many places indicating presence of light hydrocarbons (track 3).
- Reversal of resistivity profile (LLD>LLS>MSFL) has also been observed with in the pay zone at many places indicating presence of hydrocarbons (track 2).
- At 1473.5m depth a RFT sample was taken, collecting 50ml of mud filtrate showing GYF.
- Patchy to specky fluorescence with moderate to poor cut has also been observed in Mukta formation during drilling.

**Inference:**

This formation needs testing to know the type of fluid contained with in porous & permeable zones. As the permeability is quite low therefore acidization & proper activation is required to follow the perforation job.

**Bassein Formation:**

This well has penetrated Bassein top at 1493.3m (~1462.5 m msl). Based on the following observations this formation has been interpreted as oil bearing with FWL (Free Water Level) at 1499.3m (~1468.7 m msl):

- As per ELAN output the pay zone is characterized with low water saturation (55%), good porosity (21%) and pay thickness of 5.64 m. The estimated $h\times\Phi\times S_o$ value is 0.53.
- Abundant GYF with strong positive cut has been observed towards Bassein top during drilling.
- Tendency of reversal of resistivity profiles similar to that of Mukta formation is also noticed in the interpreted hydrocarbon bearing zone where as in the water bearing zone below the FWL the resistivity profile remains normal.

**Inference:**

This zone needs testing to firm up the log interpretation and is likely to produce oil. As this well is not located in the crestal part of the structure therefore it is very likely that pay thickness and hydrocarbon potential will increase towards up dip direction and hence will open a vast area for reserve accretion. As a consequence of this study, an appraisal cum development location is released and is likely to be drilled shortly to firm up the new potential.
Well no. E: (Figure 16)

This well is located in NW of well no. B and SE of well no. C. The objective of the well is to explore hydrocarbon potential in Mukta and Bassein Limestone. It is drilled up to 1630m. The log interpretation/analysis for Mukta and Bassein formations is given as below;
Mukta top has been encountered at 1415m (−1387.3 m msl). Upper part is interpreted as gas bearing with GTC (Gas Tight layer Contact) at 1437.3 m (−1409.56 m msl).

- The pay zone is characterized by low water saturation (61%), moderate porosity (16%) and net pay thickness of 15.39m.
- The side wall core data and cuttings samples during drilling also show the presence of hydrocarbon with in Mukta pay zone.
- As per perforation plan, two objects; Obj-II: 1437-33 m and Obj-III: 1430-27.5m were identified in Mukta formation but these objects could not be tested as the rig had to moved to the next location before the onset of Monsoon.

**Inference:** Requires testing followed by acid job to firm up the hydrocarbon potential.

**Bassein Formation:**

This formation is interpreted & tested as oil bearing.

**Mapping of the properties and identification of prospective areas**

Based on the comprehensive petrophysical evaluation, structure contour and Ø x he x So/Sg maps have been prepared for Mukta and Bassein formations. The Ø x he x So/Sg maps are presented in Figure nos. 17 & 18. The identified prospective areas from hydrocarbon point of view have also been indicated. However detailed seismic study is required to firm up the prospectivity.
CONCLUSIONS & RECOMMENDATIONS

- Present study has brought out two & three distinct sub layers in Mukta and Bassein formations respectively. Identification of these sub-layers will facilitate in better reservoir management.
- Identified new oil bearing layer of 5.6 m pay thickness and a gas bearing layer of 19.8 m pay thickness in Bassein and Mukta Formations respectively in a declared dry and abandoned well no. C. This has led to, a new prospective area for exploration towards north-western part of the field.
  
  As a consequence, an appraisal cum development location is released for drilling to firm up and estimate the new potential. An accretion of OIIP 1.76 MMt is envisaged for the Bassein pay only, from this block.
- In another dry & abandoned well no. A, belonging to the north-eastern block of this field, 16.2 m new gas pay thickness has been identified in Mukta Formation which is also likely to increase the reserves.
- From Mukta pay, an accretion of GIIP 2262.4 MMm3 is envisaged from the field.
- Due to poor permeability of Mukta pay, wells need proper testing to firm up the hydrocarbon potential and upgradation of the estimated reserves. On the basis of present study, to fulfill the purpose, a development location has been proposed for drilling & prolonged testing.
- The area north to well no. E is a good locale for exploitation in this fault block.
- Detailed seismic study is required to firm up the prospectivity of Mukta and Bassein pays.

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