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Knowing a Giant Gas Reservoir with Time

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Summary

Field development of Giant gas reservoirs unlike oil reservoirs is typified with market linked necessities coupled with a compulsory plateau period. Techno-economics of gas reservoirs thus invariably take into cognizance the gas quality/ quantity/ input-pressure needs of the user industry along with delivery commitment period and profitability. Giants are thus developed with care and caution, as fall back for committed sales is rare and mid-course corrections are limited. Initial field development based on the delineation wells fall short in the desired level of characterization and absence of pressure-production history with time limits understanding from reservoir engineering perspective. Knowing the reservoir with time is thus the key and phase development the solution, but integrating the same in the business model is the challenge.

The learning curve generated with time for the giant offshore gas field 'Bassein' in the Western Offshore Basin of India and its effective use in field development in phases ensuring uninterrupted gas supply in accordance with commitments for the last three decades demonstrates the worthiness of the concept. This paper attempts to explain how the concepts pertaining to the geological understanding had to be continuously refined with new sets of data generated and exploitation strategies revised infusing techno-economically acceptable investment to be consistent with the production commitments. The changes in understanding are often radical but given the consequent implications thereof, are convincingly supported by well data/observations. The paper emphasizes, that the perceived development challenges at the appraisal stage are not necessarily the ones that have a considerable bearing in the final stages of field development. The need is thus to have a robust but balanced development plan ensuring operational easiness adequate to accommodate surprises rather than one based on perceived but not so critical issues. The field discussed herein being in reality an oil reservoir of 850+ MMbbl with large (high m value) rich gas cap, complex decision making process are obvious but a combination of market needs-operational easiness-risk mitigations- profitability led to a pragmatic solution search that paid rich dividends both in short and long term.

***Keywords**: Field Development, FZI, Dynamic Modelling*

Introduction

The giant Bassein field in the continental shelf of Arabian sea in the West coast of India at an average water depth of 50m established oil and gas in Mid Eocene and Lower Oligocene limestone through the discovery well SB-1 in the mid-seventies. Subsequent delineation through seven exploratory wells defined the reservoir to be an oil reservoir overlain by a large gas cap with 'm' of about 10 and underlain by a mild aquifer.

On the basis of lithology, age and regional correlation of Bombay Offshore Basin this large limestone reservoir of about 450 m is sub-divided into 'Bassein' Zone of Middle Eocene age , 'Mukta' Zone of Lower Oligocene age and the intervening 'Tight zone' of Lower Oligocene age. Being a saturated reservoir with about 90 m of gas column, 10-12 m of oil column and about 320 m of underlying aquifer, exploitation strategy at the concept level is the key issue considering the high reward in producing rich gas with substantial derivatives in sharp contrast with the associated difficulty in terms of water/ gas coning while producing rim oil. The volumetric estimates on a simplistic hydrocarbon map based on the delineation/ discovery wells could see 'Mukta' Zone hosting about 42 BCM of gas while the underlain 'Bassein' Zone holds around 288 BCM of Gas Cap Gas (GCG) & 116 MMT of rim oil.

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The initial dilemma

The discovery and the quantum of oil inplace volumes generated considerable interest in the field. However, it was soon realised that the exploitation of such an oil accumulation is likely to pose serious operational problems due to gas and water coning restricting oil production through the critical rates. Coning studies in wells SB-4, 7 indicated that a rate of 10 m3/d to 60 m3/d is achievable only for the first couple of years. Similar studies carried out indicated that the local water coning and edge water encroachment effect would be dominant constraint in techno-economically acceptable field development planning. In view of the above, it was felt prudent to go for gas exploitation in the beginning given the high gas cap gas inplace, attractive well deliverability capable of both ROI of high capex and marketing potential needs in the Western part of India, till tailor made technological solutions for exploitation of thin oil column is in place.

Production Performance

The field was put on commercial production from September 1988, gas being the targeted deliverable. Subsequent development campaign based on studies with additional drilling data and pressure-production history at different point in time was initiated to enhance production, optimizing drainage across the geographical spread. The philosophy of 'learn-unlearn-develop' was centric to these campaigns and thus investment for development was in several phases, each phase dovetailing the renewed understanding of the earlier. The historical field performance till March 31, 2011 is placed as Figure-1. It achieved a peak production rate of 32 MMSCMD in 2001-2002. The average production rate during 2009-2010 & 2010-2011 is about 28 MMSCMD respectively. The cumulative production from the field by March 31, 2011 is around 199 BCM and the average field pressure has declined from initial value of 178 kg/cm2 to around 100 kg/cm2 against this production. Currently gas is being exploited through 49 wells spread over 6 platforms with additional 4 horizontal wells targeting the underlain oil rim.

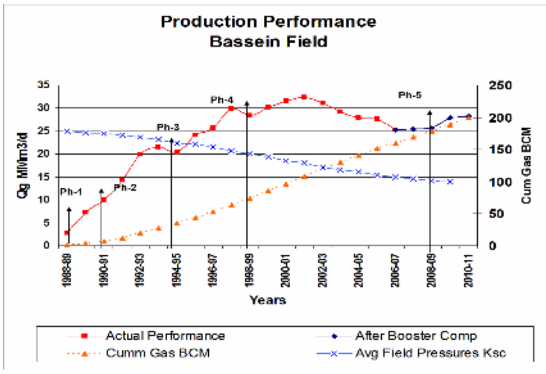


Figure-1: Production Performance of Bassein

Phases of Field Development:

The field has so far undergone 5 major Phases of development. In the first phase two well platforms namely BA and BD and one process platform BPA (capacity 10 MMSCMD) was put in place during 1988-1989. A 36" offshore to onshore Trunk Line was also commissioned during this phase and the field was geared to meet a production of 10 MMSCMD. In the second phase of development two well head platforms namely BB & BC and a process complex BPB (capacity 10 MMSCMD) were installed in 1989. The field was now geared to produce 20 MMSCMD of gas. The steady performance of the field from the northern four platforms brought in third phase which targeted the southern portion of the field by bringing BE platform. The processing capacities of the two process complexes were raised to 12.5 MMSCMD each. Another important aspect of the third phase was commissioning of 42" Trunk line to meet future production level of 30 Mmm3/d. Sustained production led to continued drop in reservoir pressure and it was realised that booster compressor will be a technical necessity to maintain requisite pressure in order to transport required quantity of gas. Under the fourth phase (1999) two booster compressors were installed at BPA & BPB. The production peaked at 32 MMSCMD in 2002. The fifth and final phase was focussed at further development of southern portion of the field by bringing BF platform in 2008. A second stage booster compressor was installed in BPA & BPB during this phase.

History of Inplace Assessments

The revisions of the inplace were necessitated due to improved performance of the field as indicated in Figure-2.

The concomitant pressure drop in the field being less than anticipated from purely depletion drive estimates was suggestive of static model revisits necessity. Several possibilities that could lead to restriction of pressure decline were explored and examined for mathematical and geological acceptability. This included analysis of pressure-production history, seismic and drilled data combine revisits. The last revision was necessitated in 2010 post commissioning of BF platform as well BF-1 (southern part of the field) recorded a pressure of 129 kg/cm2 much higher than the pressures in the northern part of the field (105 kg/cm2). In the meantime satellite discoveries with different contacts and depleted pressures both in the west and east led to the belief of some pressure support possibly transmitted through the underlain connected aquifer.

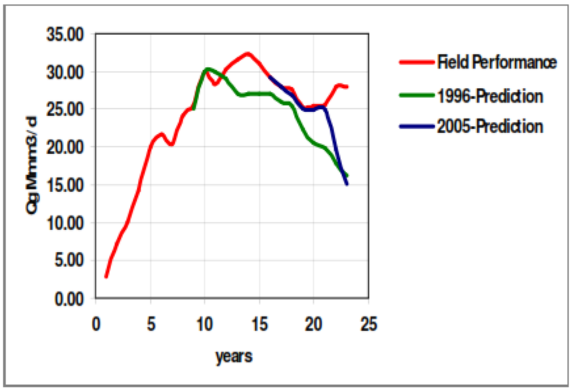


Figure-2: Performance: Plan vs. Actual

The GIIP revision at different time steps with squaring up efforts of Material Balance and renewed G&G understanding is tabulated below.

Year	Mukta (BCM)	Bassein (BCM)	Total (BCM)
2004	34	239	273
2007	34	268	302
2009	41	268	310
2010	41	288	330

The connectivity between Mukta and Bassein pays

The tight zone (TZ) separating Mukta and Bassein formation traditionally has been considered to be some kind of barrier allowing very restricted communication between the zones. This negated the possibility of pressure support from Mukta formation and any kind of participation in production. This, therefore, necessitated a relook into the character of TZ. Revisits of open hole logs of TZ, CBL-VDL, RFT and test data of wells is suggestive of Mukta and Bassein formation to be in locality specific communication, reasoning being downward flow of hydrocarbons through channels and porous chimneys. The RFT pressure of exploratory well SB-10 (February 2001) against Mukta formation shows a decline in pressure to the tune of 160 kg/cm^2 from initial value of 178 kg/cm^2. This is not commensurate with a meagre reported production of 0.323 BCM (<1% of estimated inplace) from Mukta through a couple of wells. The RFT record of SB-10 placed in Figure-3 exhibits the pressure below -1651 mMSL dropping below 152 kg/cm2 and this is an indication of

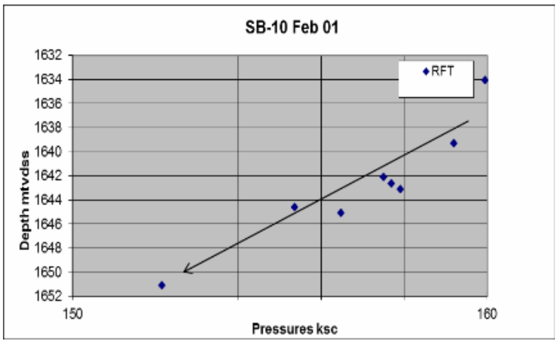


Figure-3: Pressure vs. Depth of Mukta

possible communication. RFT pressure of well BSE-1 in the adjoining satellite discovery in August 1997 also exhibit lowering of pressure (163 kg/cm^2) at Mukta level. A plot of RFT pressure and cumulative production vs. time plotted in Figure-4 indicates that A Zone pressure start to decline after 1995 though there was no significant production from Mukta formation during this time. It is worth mentioning that the SBHP recorded in January 2009 in well BE-7Z which is, currently the only well producing from Mukta formation indicates a pressure of 115 kg/cm^2. MDT of recently drilled exploratory well SBJ also shows a pressure of 105 kg/cm^2 at Mukta level. In light of the above data, it is now comprehensively believed Mukta & Bassein to be in communication and that Mukta is participating towards production through the TZ and accordingly modelled.

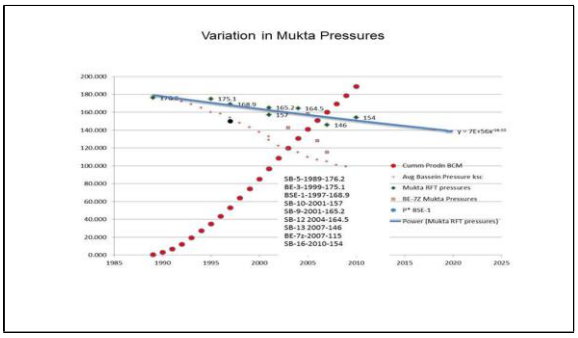
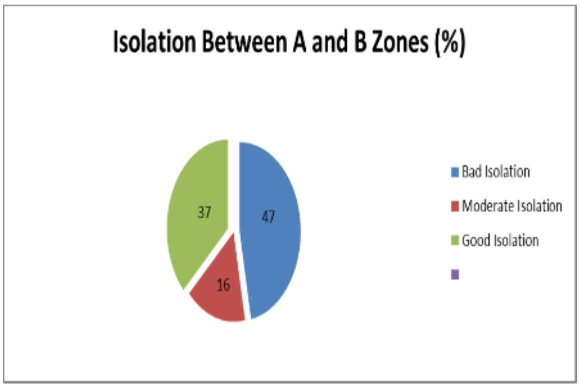


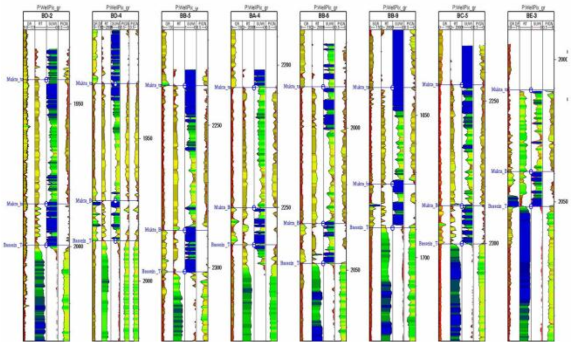
Figure-4: Variation in Mukta Pressures with Time

An exhaustive study of the isolation between zones based on CBL-VDL signatures shows the following distribution.



The above pie chart extends the concept of gas migration from Mukta to Bassein through channelling behind casing phenomenon and since 20 wells (47%) have poor isolation i.e. BA-1,2,5,6; BB-4,5,7,8,9; BD-2,3,4,5,6 and BE-2,5,8,9. Mukta production is understandably in vogue from almost all platforms.

The development of porosity and HC accumulation along North-South direction is depicted below through wells BD-2, 4, 5; BA-4; BB-6, 9 & BE-3.It is also interesting to note that these wells are distributed throughout the field.



Reservoir Characterisation through Hydraulic Unitisation

The fundamental static property of porosity and dynamic property of permeability are two parameters, which have been used extensively by various authors1-5 to uniquely characterize a reservoir through its flow units.

Amaefule et.al, 1993 has presented a simple approach commonly known as flow zone indicator (FZI) for quantification of rock tying. It is based on the following equations:

$$RQI = 0.0314\sqrt{\frac{k}{\phi e}} \quad \text{.................................(1)}$$

$$\phi z = \left(\frac{\phi e}{1-\phi e}\right) \quad \text{..(2)}$$

$$FZI = \frac{RQI}{\phi z} \quad \text{..(3)}$$

Where
RQI : reservoir quality index,
k : permeability (md),
Øe : effective porosity (fraction),
Øz : Normalised Porosity
FZI: Flow zone indicator

Both SB#4 and SB#7 are having continuous core of length 40 and 80 m respectively against Bassein section. This has provided an exhaustive core property data base of 140 and 251 core plugs in SB#4 and SB#7. These porosity and permeability data have been used and 6 hydraulic units have been identified by using equations1 to 3 and have been presented in Figure-5 to 7.

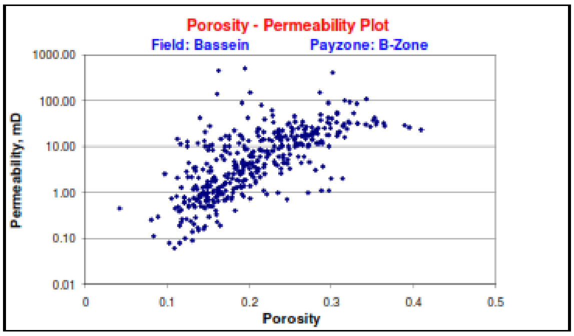


Figure-5:Porosity Permeability distribution

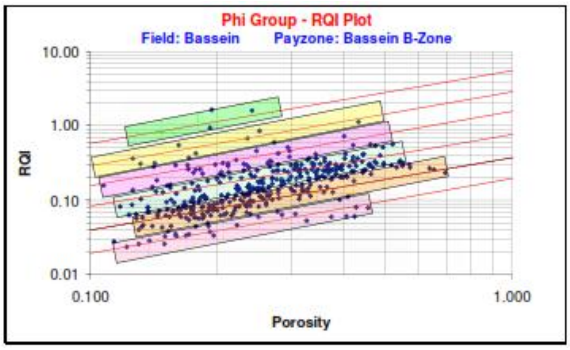


Figure-6: Rock Quality Index

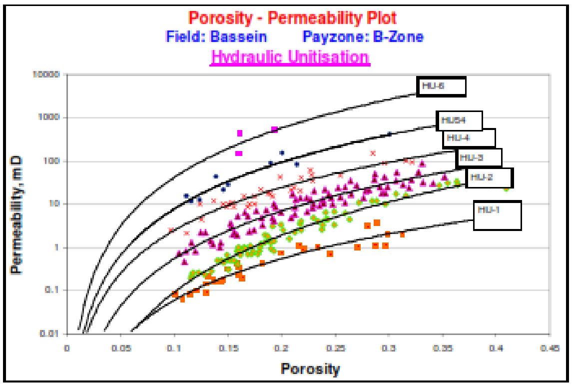


Figure-7:Hydraulic Units-Bassein formation

The Hydraulic Unitisation distinctly indicates that units HU-2 and HU-3 together constitute hydraulic units which contain the major part of the sample population. The data of these two units have been further analysed to arrive at distinctive K-Φ relationship. This data cluster have been further subdivided in to two groups: Φ<0.24 and Φ>0.24. The curve fit analysis is shown in Figure-8 and Figure-9 respectively.

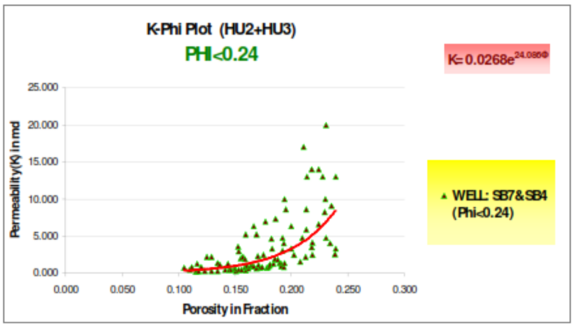


Figure-8:k-phi transform for HU2+HU3

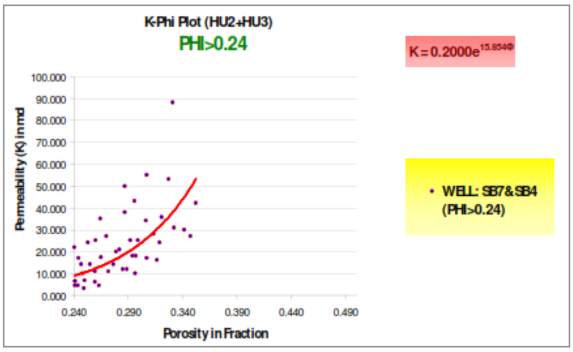


Figure-9

There is very good match between these derived K-Φ transforms and the transform which were used in the earlier phases and was an integral part of the initial FDR on Bassein.

Dynamic modeling

Having recovered almost 57% of in place gas, the final development of Bassein is round the corner. The dynamic simulation thus for the first time is through a giant integrated model encompassing Mukta-Bassein production, Mukta-Bassein connectivity, and modelled ongoing production impact of satellite fields for pressure transmissibility through aquifer connectivity. The geocellular static model (2.4 million cells) was devoid of any upscaling to avoid losing of any characterization and event mapping. Given that Water and pressures to be the key prediction parameters deterministic of additional investment, history matching both at well/platform and field level has been done with utmost care. Study indicates possibility of cumulatively producing around 79 & 81% by year 2023 under 'business as usual' and 'additional development' cases respectively.

Conclusions

- Deliverables of Gas giants need to be strategized in micro-detail as surprises in adversity are in for market turbulence from the recipient side. The phased development approach of Bassein field which is based on the philosophy of learn-unlearn and develop has put in place a robust infrastructure capable of realizing the field potential effectively with all possible value added products.

- Ample evidences with time suggest communication between Mukta and Bassein formation, nullifying the age old apprehension that Mukta will be near virgin at the end life of Bassein and Bassein wells can be transferred to Mukta. Capability of Mukta to deliver obviated the need for conscious monetization attempts with high level of confidence in the final phase of development.

- The FZI approach brings out two dominant hydraulic flow units and robust k-phi transform could be generated for each of these units.

- Dynamic model in the last phase is able to capture all associated events and history not only in the main field but also the hydrocarbon withdrawal effects in the satellite discoveries understandably connected through aquifer. Modelling approach to capture effects of hydrocarbon production from neighbouring fields has its own uniqueness and the fact that it could be effectively history matched spells out the robustness of the model. This was possible because the knowledge of the reservoir matured with time and was adequate to capture unknowns effectively with plausible implications.

- The field in terms of enhancing significant recoveries do not show promise-a key indicator of earlier strategies to be reasonably non-destructive. But accelerating and/or preponing recoveries with additional investment has ample merits and reasoning to be an inclusive part in the field of Bassein hopefully the last phase till abandonement.

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