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## Opportunities for recovery enhancement through IOR strategy - A case study of brown field redevelopment

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### Summary

Most of the mature major oilfields worldwide are characterized by declining production with concomitant increased water cut. A need is thus felt for any reservoir midway through its lifetime, to look beyond conventional well drilling and completion techniques for exploiting the bypassed and left-over mobile oil for maximizing recovery, techno-economics being the single most important parameter to optimize the investment size.

The performance analysis of a 3000 m depth active water drive reservoir of Rudrasagar field in Assam, North East India, exemplifies the above scope, present water cut of about 80% being the only deterrent. The reservoir is in the nascent stage of brown field development and has produced about 23% of its in-place. The well performance is not entirely related to its absolute pay levels, but with increasing cum. Oil production (Np) the bottom water encroachment overtakes the edge water activity, particularly in locales of high well density and drainage, resulting in premature flooding of the pay-zone at relatively structurally higher levels. Albeit in a few cases, wells with large cumulative production allows coning and cusping phenomenon to take centre stage resulting in undesirable water production levels. Operative under a moderately strong bottom aquifer support, the thinning of the 30-35 m oil column due to rise in oil-water contact (OWC) is a natural phenomenon, warranting induction of high tech drilling in the form of laterals to serve the twin objective of reducing drawdown and increased contact area.

Focused challenges for the reservoir is oriented in limiting the water coning and channeling process coupled with effective sand control and bottom water movement measures, all of which restricts the drawdown applicable. Additional inputs, whose arrivals retard the decline pattern, could be married to high technology for manifold increase in benefits. However, usage of Horizontal well technology though beneficial needs to be restricted in numbers because of large costs usually dominated by higher depths. Alternatively, absorption of drain hole, Ultra short radius drain hole (USRDH) through side tracking technology of the non flowing wells could maximize the optimum usage of existing well inventory thereby reducing CAPEX substantially. The optimum placement could be in the top part of the sand, guided essentially by the CHFR logs. Dynamic modeling aspects, wherein fluid movement could locate the by-passed oil with a reasonable degree of certainty, has been resorted to, so that a technology intensive rejuvenation programme could be scheduled towards maximizing oil recovery and profits.

This way forward vision was translated through construction of a fine scale simulation model through which multiple development realizations have been generated by considering a judicious mix of hi-tech horizontal wells, USRDH, High angle wells and Side Track wells. Non-flowing and suboptimal wells have also been made to good use for production for cost optimization.

As an outcome of this robust study, the incremental recovery of 4.4% of Proved oil in-place through 9 additional hi-tech wells would be achieved from a Base recovery of 30% of OIIP. This dramatically reduces the R/P level to 26 from a higher value of 70 years. Some of the proposed wells already drilled; showed the initial testing results were as per expectation.

This paper is emphatic on the need of additional inputs of hi-tech wells for operating a reservoir in an economic friendly environment. More importantly it underlines marriage of technology to reservoir specific needs for front loading of economic profiles.

**Keywords:** BMS, BCS-1, OIIP, Horizontal, USRDH, Side Track, Porosity, Permeability, Saturation, R/P



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## Introduction

Rudrasagar field<sup>3</sup> is situated in upper Assam, around 15 km North West of Nazira town (Figure-1). The field discovered in 1960 and put on production in 1966, has four pay sands, of which BMS is the main producing zone, occurred at around 2980 m MSL depth.

The structure is a broad anticline with longitudinal axis trending ENE-WSW. Seismic surveys have indicated a major fault with considerable displacement on the northern flank of the structure. Well data indicates a throw of around 100 m. Further North to this main fault, the structure flattens out. Thus Rudrasagar field is found to be a composite structural feature developed on the hanging fault of Rudrasagar main fault.

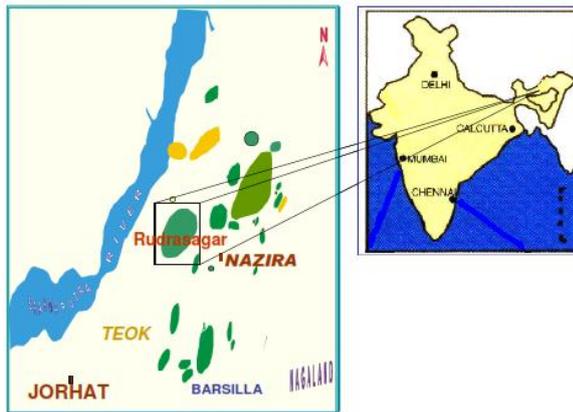


Figure-1: Location Map of Rudrasagar field

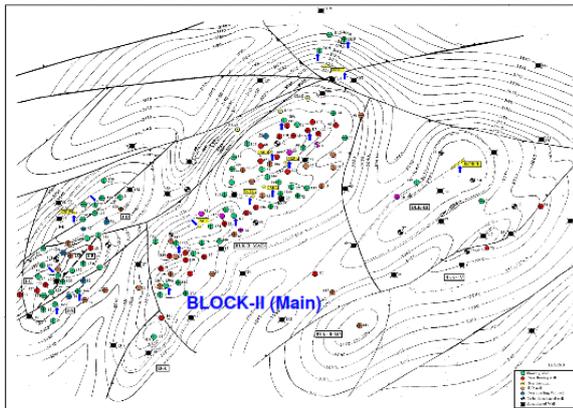


Figure-2: Rudrasagar Field

Faults have divided the field into different blocks and each one is acting as independent reservoirs (Figure-2). The Block-II, presented in this paper is designated to be the Main block and the reservoir has good bottom water aquifer from southern side.

Pay zone wise, the main oil and gas reserves are confined in Barail main group. The Barail group of Oligocene is overlain unconformably by Tipam sandstone and underlain by Kopili formation. The Barail group is recognized by two distinct litho- logical units referred to as arenaceous unit (BMS) and the younger coal shale unit (BCS). The thickness of the arenaceous unit varies from 150 to 180 m and the coal shale unit from 190 to 260 m.

## Sand Geometry

**Barail Main Sand:** The arenaceous unit is designated as Barail Main Sand (BMS). The hydrocarbon accumulation is mainly confined to the top most part of the BMS. In general, there is coarsening upward sequence except in selected areas where it is fining upwards. The sand is deposited in a lower deltaic distributary channel system.

In general, there is improvement in the character in the reservoir towards upper part. In some places, it is difficult to separate the immediate overlain unit. BMS unit comprises of predominantly sandstone and occasional layers of shale and siltstone, streaks of carbonaceous clay and calcareous matter. The Shale in between are very thin and impersistent in nature and therefore the sands have been taken to be one unit for exploitation purpose. The rock matrix is composed of chlorites, argillaceous and sericitic material and rock flour. In general, these sandstones are devoid of cement. Carbonate cement is present in considerable amount. The OWC is established at -3028 m MSL depth.

The initial reservoir pressure estimated to be 312 ksc at 3028 m (MSL) and permeability lies in the range of 10-50 md in southwest part & 50-150 md in northwest part of the reservoir. Porosity and hydrocarbon saturation varies in the range of 17 to 26% and 45 to 78% respectively indicating need to model lateral heterogeneity for reservoir simulation exercises.



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## Performance Analysis

The cumulative recovery from the reservoir (BMS) is around 28% of the proved oil in-place. The oil rate of the main block has been declining from a high of 1255 m<sup>3</sup>/d to the current level of 175 m<sup>3</sup>/d over a period of 20 years with steady increase in water cut from 50 to a maximum of 82% (Figure-3). The performance plot shows that the oil rate was increased rapidly during late eighties to around 1255 m<sup>3</sup>/d (1989-90) due to infill drilling (number of wells increased from 21 in 1985-86 to 36 in 1989-90). The oil rate drastically reduced to 377 m<sup>3</sup>/d by 1996-97 due to ceasure of large number of wells with increased water cut associated with sand production problem. The oil rate was restored to some extent during 1997-1999 due to successful work-over (water shut-off job through polymer injection, sand control job). However, again the oil rate declined in the successive years mainly because of increased water cut and ceasure of good producers (new wells).

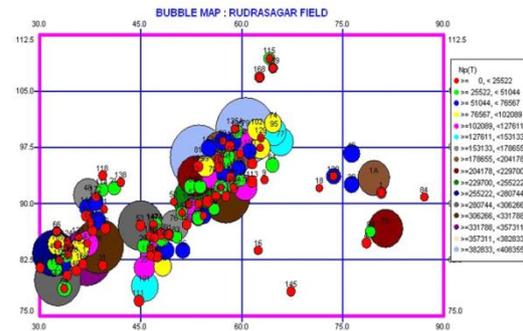


Figure-4: Bubble Map

The Gas-Oil Ratio (GOR) trend of this block indicates an almost steady value till 1972. During this period the GOR has remained in the range of around 80 to 120 v/v. Thereafter, the GOR has exhibited wide fluctuation, increasing to 480 v/v by March 1980, and then gradually maintained at around 250 v/v. The high GOR values observed in eighties may be partly because of contribution

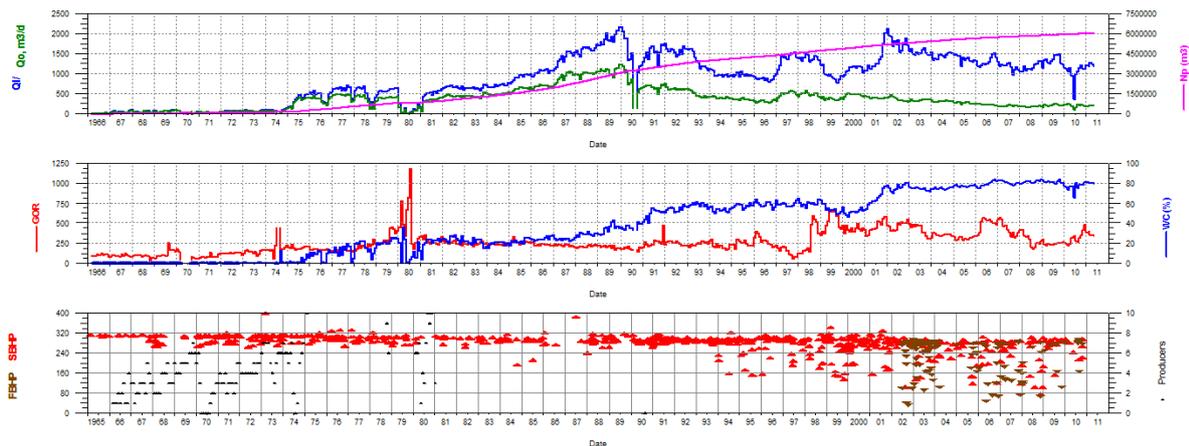


Fig.-3: Performance Plot: Main Block of Rudrasagar Field

As evident from the bubble map (Figure-4), maximum oil production has been obtained from wells located in northern part of the block near the fault. The reservoir has started producing water from 1975 and then increased to around 23% by 1980. Thereafter it remained constant till 1987. But due to increase in withdrawal rate in 1987-89 there was rapid increase in water cut from 23 to 40% after which the water cut increased steadily. Currently the water cut of the sand is around 80%. At present, 16 wells were flowing with water cut above 80%, 5 wells between 50-80% and remaining flowing wells have water cut less than 50%.

from the overlain gas bearing layer of BCS-1. The current GOR is around 350 v/v. PVT analyses however indicate the bubble point pressure to be 270 ksc in the NE part and 194 ksc in the SW part.

The current average reservoir pressure is hovering in between 290 to 300 ksc in the Northern part and 260 to 270 ksc in the Southern part of the block from an initial level of 312 ksc, after a cumulative oil production of 28% of proved in-place, shows the aquifer is moderately strong in nature and the reservoir is still in under-saturated state.



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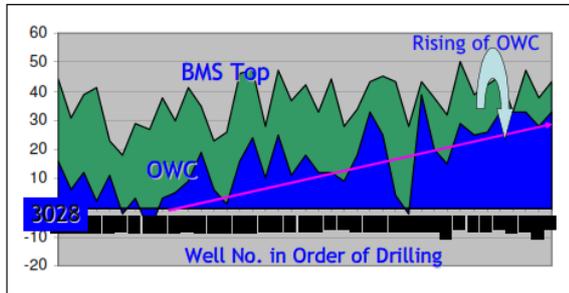


Figure-5: Rising of OWC

### The Study

This paper basically emphasizes the need of additional inputs in terms of infill Hi-tech wells and liquidation of non contributing wells / poor producers, for targeting higher recovery from the current base recovery of 28% of OIIP over a span of 40 years and consequently reducing the high R/P ratio from 70 to 26 years.

Matrix analysis, with the help of different variables was carried out for spatially for prioritizing brown field activities. The approach included identification areas of high current oil saturation, low cumulative production and, good Productivity Index (PI). Well wise pressure-production performance analysis was added. Classical reservoir engineering techniques along with fine grid simulation study were used to identify water movement and to determine areas of left out oil. A multidisciplinary approach to describe the reservoir and review production history led to identification of the unexploited and/or bypassed area. Detailed reservoir studies, log analysis and micro correlation exercises were carried out to identify layers contributing high water production. Log interpretation of recently drilled wells helped in estimating oil-water contact rise. Rising OWC and Reducing Oil Column in the recently drilled wells in this reservoir still hosting around 50% of the Balance Oil Reserves is shown in Figure-5.

### Reservoir simulation

The geological model of the overlain gas bearing sand and BMS were constructed using geo-statistical technique to achieve better quantitative 3-D geological model. The spatial distribution of porosity, gross thickness and oil saturation distribution were generated through statistical

technique, using “Gridstat” software, on the basis of log and well data. The entire block was divided into rectangular grids of dimension 200 m by 200 m in ‘X’ and ‘Y’ directions respectively. For spatial distribution in the ‘Z’ direction initially the values available at every 0.15 m interval for all the wells were considered for generating a spatial distribution of the properties. The ‘Z’ interval was up scaled to 2.5 m thereby resulting in 54 layers from BCS-1 top BMS bottom. The same was adopted for building the reservoir model.

The permeability data from available build-up studies were used to generate a Phi-K transform. Rock and fluid data generated in laboratory based on the actual core and well fluid sample, have been used in the model. The residual oil saturation in the range of 15% to 20% has been incorporated in the relative permeability tables used in the model.

Well wise monthly oil, water and gas data was used as inputs for history matching. The plan envisages only one prong strategy viz. Brown field development through existing wells and infill new wells. Under this strategy, the major areas of focus are enhancing the production through i) drilling new infill horizontal well in the areas of low cumulative production and ii) from non-producing or sub-optimally producing wells by sidetracking and USRDH drilling. Wells were sidetracked and converted to horizontal drain holes and suitably placed in better oil saturation area mainly in the structurally upper part of the sand. After obtaining a good history match, several simulation runs were made for optimizing the placement of the drain-hole section of the wells. Wells were placed based on i) the sand facies development available from the logs recorded and ii) the oil saturation observed in the model. The simulation results have helped in actual placement of the wells.

### Reservoir Management

The main block is currently producing oil @ 175 m<sup>3</sup>/d through 28 wells. Out of these wells, there are about 23 wells which are producing oil at a rate < 10 m<sup>3</sup>/d (PI: 0.43 to 2.7 m<sup>3</sup>/d/ksc), 4 wells are producing between 10 & 20 m<sup>3</sup>/d (PI: 2.75 to 6.0 m<sup>3</sup>/d/ksc) and 1 well is producing at a rate > 20 m<sup>3</sup>/d (PI: 16.0 m<sup>3</sup>/d/ksc) As far as water cut is concerned, there are about 4 wells which are producing oil at a W/C < 30 %, 4 wells are producing between 30 to 80 % and 20 wells are producing at a W/C > 80 %. Under



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Brownfield development, wells which are producing sub-optimally & with high water cut and have potential are taken up for sidetracking / Drain hole drilling them towards better saturation areas (left over oil saturation) and completing them as drain holes for enhancing the production.

In areas having low density of wells as well as untapped (left over oil saturation) hydrocarbons, new horizontal wells are preferred (Figure-6) over the conventional wells for attaining higher production through larger reservoir contact area with lesser drawdown and hence delaying the water production. The envisaged gain in cumulative production is given in Table-1. The existing non flowing wells (because of well complication like fish in the well etc.) are also planned to be drilled as side tracked drain hole (Figure-7) in the rejuvenation plan, to obtain economic advantages of early revenue. Also, these resources are to be used as low risk opportunities to test technologies in geologically risky areas. New drilling and completion technology could be inducted early in the project life to derive maximum economic benefit. Coning has been observed in patches in some of the wells.

Sand incursion was observed in one or two wells in the central part of Main Block & in the block of #115. Application of Gravel pack or sand screen in wells may adversely affect the productivity and requires frequent WOJ. Hence horizontal wells are planned to produce with lesser drawdown & to avoid sand cut. It was recommended in 'Performance Review of Rudrasagar Field3 for proper placement of horizontal drainholes in particular direction where lesser in-situ stress is expected to generate during drilling & recording of DSI log (dipole shear sonic imager). Modeling process has taken cognition of that. Sand cut phenomena4 in few wells has limited the prediction process to a control drawdown in modeling.



Figure-6: Placement of Horizontal well & SRDH

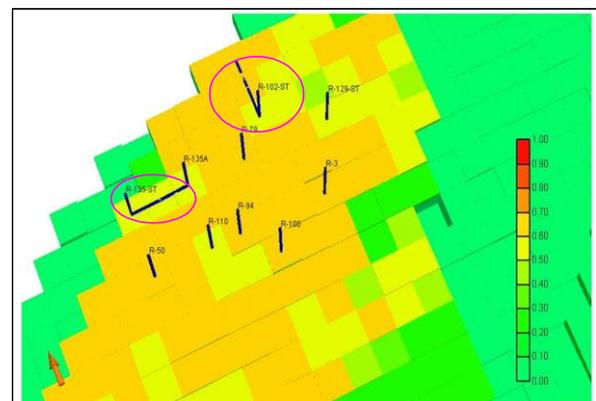


Figure-7: Placement of Side Track wells

Under Brownfield development several simulation runs were made under different boundary conditions. Infill locations are optimized and the following are planned. Horizontal drain hole completions are either cased hole or slotted liner or barefoot depending on the drain hole length and formation characteristics.

- Drilling of 4 infill horizontal well (H1, H-2, H-3 & H-4)
- Side tracking of 4 wells from existing non flowing wells (ST-1, ST-2, ST-3 & ST-4)
- SRDH drilling in 1 well having high water cut (DH-1)

With the phased implementation of above inputs, the oil production was expected to be enhanced from the then level of 175 m<sup>3</sup>/d to 560 m<sup>3</sup>/d by the year 2011-12. The R/P would come down from a higher value of 70 years to a minimum of 26 years and Exploration Index (EI) would go



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up from a current level of 0.35% to a maximum of 0.78 % of OIIP per year. The cumulative oil recovery would become 35% of OIIP from the existing level of 28% with the terminal water cut of 86%.

The envisaged / resultant gain in cumulative oil production in some of the major wells over a period of 15 years and the actual gain in the initial oil production rates observed after drilling are given in Table-1.

- All calculation has been carried out in post-tax scenario.

### Conclusions

Based on the left over oil saturation as determined through fine grid simulation studies, the following inputs have been identified

Table-1: Production gain of proposed wells

Wells	Initial liq. Rate, m <sup>3</sup> /d (envisaged)	Initial liq. Rate, m <sup>3</sup> /d (actual)	Initial oil. Rate, m <sup>3</sup> /d (actual)	Cum. Oil Prod., MMm <sup>3</sup> (envisaged)	Remarks
H-1	80			0.252	To be drilled
H-2	80			0.262	Under drilling
H-3	70	40	40	0.218	Lower bean size
H-4	70	48	44	0.205	Completed
DH-1	60			0.070	To be drilled
ST-1	60	72	72	0.139	Completed
ST-2	40	48	46	0.082	Completed
ST-3	40	43	43	0.096	Completed
ST-4	40	20	20	0.047	Completed

### Project evaluation

In order to evaluate the project, the standard industry practice relies on discounted cash-flow techniques. The investment decision is mainly on the basis of how large is the net present value of the project. Financial analysis has been carried out considering the oil prices between USD 70 per bbl and gas price of Rs. 3200 per 1000 m<sup>3</sup> (local market price) and at an exchange rate of 1USD = Rs. 44. The incremental projected production profile has been considered for economic evaluation. Further, 98% of oil and 100% for gas have been considered for revenue purpose to take care of the transportation losses. The discounting rate adopted is 10%. For an oil price of USD 70 per bbl and gas price of Rs. 3200 per 1000 m<sup>3</sup>, the IRR and NPV estimated as 96.03% & Rs. 342.56 Crores respectively for the incremental oil & gas.

- The viability analysis has been carried out on completion cost basis considering an escalation of 6% p.a. in Capital cost & Operating cost has been escalated @ 8% p.a.

- 4 Side-Track wells are identified for the idling wells having casing & X-mass tree damage/ fishing / GP retrieval problem
- 1 Drain hole is identified for the poor producer having high water cut because of localized coning phenomena.
- 4 Horizontal wells are identified as laterals are better suited due to their longer reach as well as achieve higher productivity with less draw-down

Recovery of 35% of OIIP is likely to be achieved through implementation of scheme compared to 30% of OIIP in Business As Usual case.

The investment is economically attractive. In fact the economic scenario is suggestive of more infill drilling which could be identified based on the results of the wells proposed.



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Rotary steering drilling of shale section, use of LWD, SRDH, USRDH, Whip-stock, Extended Reach wells with horizontal drain holes are some of the new technological initiatives are being undertaken in Rudrasagar field under brown field development. As per the simulation model results to these technologies has been encouraging in terms of improving well productivity and techno-economic viability.

All the wells except one, drilled so far came up as per expectation in view of production testing results.

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