Identification of Bypassed Oil For Development In Mature Water-Drive Reservoirs
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Abstract
An integrated bypassed oil identification methodology was developed and successfully applied to identify and quantify the presence of bypassed oil opportunities in mature water-drive reservoirs in an offshore field in Malaysia.

A 3D reservoir static model was first built as part of the geological review. Reservoir performance review was carried out in conjunction with material balance and average fluid contact movement calculations to understand the drive mechanism and to estimate the current fluid contacts. Performance matching was carried out with an analytical 1D 2-phase Buckley-Leverett model to assess the potential scope of recovery with additional development. Together with dynamic production data animation on 2D maps, a good view of the production-drainage–water influx pattern progression with time was obtained enabling a first pass identification of bypassed oil opportunities. Well performance data were then used to estimate the likely local fluid contacts in the area or sand layers of the completions. The inferred fluid contacts defining the identified bypassed oil were further calibrated with fluid contacts seen in recent wells and crosschecked with 3D seismic features where possible. Bypassed oil-in-place volumes were calculated using the saturation-initialized 3D static model.

The methodology had been successfully applied in reviewing 14 highly matured water-drive oil reservoirs with small to large initial gas caps. The emphasis of this paper is to describe how it can be applied to locate bypassed oil. Although the field concerned had undergone 8 previous phases of development campaigns, application of the approach had led to identification of a substantial number of potential recovery opportunities for further development consideration.

The approach can be applied for systematic identification of bypassed oil opportunities in water-drive reservoirs where detailed dynamic simulation is not justified. It furnishes a comparatively quick fit-for-purpose approach to identify further development opportunities and furnish input for the planning of detail dynamic simulation where the remaining opportunities scope is large.

Introduction
The objective is to identify the location of bypassed oil development opportunities in and to estimate the potential recovery scope without resorting to detailed dynamic simulation. In the field studied, full dynamic simulation was considered too resource intensive in view of the large number of reservoirs involved, long production history and potentially low remaining reward, as the cumulative recovery efficiency attained has exceeded over 90% of technical ultimate recovery. The results of bypassed oil identification, however, may lead to recommendation for full dynamic modeling where the scope is substantial and risks are considered too high without simulation.

Most previously published bypassed oil identification techniques relied mainly on a combination of reservoir characterization and observation of oil in open hole or through casing logs. This paper described a systematic approach, which integrates analysis and inferences from a few techniques to locate bypassed oil in mature water drive reservoirs. They comprise conclusions drawn from average reservoir fluid contact movement calculations, calibration with logged contacts, estimation of local area contacts from performance, and animation of production data to locate bypassed oil. The robustness of the approach lies in the integration and use of collaborative evidences from different techniques to come to a conclusion on the location and extent of bypassed oil even in difficult cases where petrophysical fluid interpretation is ambiguous. The deduction from any single method is insufficient.

The application of detailed dynamic modeling for locating bypassed oil in the field studied had a number of inherent problems. They include uncertainty in initial fluid contacts due to incomplete early field appraisal data, uncertainty in production data particularly gas production data, and complexities arising from commingled reservoir production. The need for very detailed and accurate static model features representation suitable for
modeling of bypassed oil is apparent. In view of the above, the integrated methodology presented in this paper provides a practical approach to locating bypassed oil in such situation.

Definition of Terms

**Bypassed oil**: It is defined here as the mobile oil that cannot be produced by existing wells and will be left undrained if nothing is done. It can be produced by water or gas displacement or by improved connection to a wellbore through infill drilling or re-completion.

**Residual oil**: It is the oil remaining in the pore space swept by natural or injected water or gas displacement processes. It is trapped in the reservoir by capillary and viscous forces.

**Reservoir unit**: A reservoir unit refers to the reservoir or sand unit or group of sands for which reservoir geological characterization and hydrocarbon volumetric can be clearly defined in conjunction with reasonably accurate production (injection) allocation for production monitoring and reservoir management purposes.

**Integrated Bypassed Oil Identification Methodology**

The methodology comprises a systematic analysis of the location of bypassed oil using collaborative evidences from reservoir performance, performance history matching with an analytical model, material balance study, average contact movement simulation, animation of production data, observed fluid contacts in more recent drilled wells, contacts inferred from well performance (WC, GOR) and 3D seismic indication.

**Reservoir Performance Review**

A good understanding of the reservoir performance (Figure 1) and the underlying drive mechanism of a reservoir is an important pre-requisite to locating bypassed oil in a mature reservoir. The process involved is well known. It is briefly mentioned here to show its relevance to locating bypassed oil. Key items in reservoir performance review could include material balance study to understand the drive mechanism and analyzing well and reservoir performance with the help of production plots and display of key production parameters in bubble maps and color contour maps. The performance information and data are analyzed in the context of reservoir sand development characteristics and the reservoir static model with initial and possible current fluid contacts in mind.

**Analytical Matching and Potential Recovery**

A preliminary estimation of the potential recovery scope of the reservoir studied is made. An analytical 1-D 2-phase model was used for performance history matching and estimation of overall potential recovery scope with additional development (Figure 2). The analytical model assumptions are:

1. The dominant reservoir recovery mechanism is water drive. The overall recovery process and the technical recovery limit can be approximated by oil-water displacement process.
2. 1-D 2-Phase Buckley-Leverett fractional flow calculations form the basis of analytical calculations and forecast.
3. The effect of reservoir heterogeneity and drainage pattern is incorporated in the reservoir volumetric sweep efficiency factor (SE).

The analytical performance history matching process involves matching the overall reservoir cumulative production, recovery factor (RF) and water-cut (WC). Basic 1-D 2-phase model parameters including PVT, pseudo relative permeability curves represented by Corey model and volumetric SE are required input and the input data can be tested for sensitivities. The current SE is obtained by matching the upper boundary of the reservoir recovery data with the analytical model (Figure 2). The preliminary incremental recovery scope for the reservoir is calculated by assuming a target higher SE and abandonment water-cut which might be achieved with additional development (Figure 3).

**Observed Fluid Contacts**

Fluid contacts or fluid types logged or observed in wells provide the important source of information for locating bypassed oil. Cross section and log panel showing fluid contents in the reservoir unit under study is a commonly used technique to identify bypassed oil (Figure 4). The main difficulty with using this technique alone lies in the lack of sufficient strategically located wells with recently logged fluid contents, which would enable unambiguous identification of location and area definition of the bypassed oil.

In the field studied, petrophysical interpretation particularly gas oil differentiation was difficult due to factors including laminated sands, very low resistivity pay, limited density neutron coverage, large washouts affecting density / neutron log, relatively large uncertainties remain in the field regarding both fluid contact identification and fluid typing, gas oil differentiation was often ambiguous and it was necessary to use other collaborative information for fluid differentiation. In this study, early well performance data, the water-cut and GOR performance in conjunction with the completion interval was successfully used to estimate the initial fluid contacts in relation to the perforated production intervals.

More recent development wells drilled in the field during the further field development campaigns over 1993-1999 period provided some useful fluid information on the presence of bypassed oil (Ref.1). In this study, selective observed fluid contacts data, which were considered reliable, were used for calibrating and for comparison with the simulated average fluid contacts movement study and sensitivity matching. Figure 6 shows the use of fluids contact information observed in wells to compare with the simulated average contacts.
Production Data Visualization
In a large mature field with many reservoirs and wells with long production history, performance analysis will necessarily involve manipulation, analysis and interpretation of an enormous amount of production data. The relevant data and derived parameters include oil, gas and water production, water cut and GOR. These data need to be analyzed in order to understand the performance. Efficient retrieval and presentation of data in color pictures for analysis can facilitate the understanding of reservoir and well performance. Some commonly used visual presentation includes well production bubbles and gas-oil-water pies on reservoir map (Figure 7). Selected production data can be more easily understood when presented in color production grid map. The data can be animated through time to identify production patterns and trends (Figure 8).

The production data are generated for plotting using numerical interpolation techniques between wells to create the iso-lines. The software tool divides the base geological map into small grid cells and uses the numerical techniques to populate values in all the cells for plotting.

Average Fluid Contacts Movement Simulation
To obtain a broad indication of the average fluid movement in the reservoir unit, a tank model simulation of average oil-water and gas-oil fluid contacts movement is carried out. A material balance software package widely used in the industry has been used. The model assumes a non-uniform tank geometry, which is described by pore volume versus depth relationship. Basic input for the contacts movement simulation are the material balance matched reservoir and aquifer parameters, initial fluid contacts and saturation, pseudo relative permeabilities, production data and volumetric sweep efficiency. The simulation results show the vertical depth interval of the average remaining oil column in the reservoir unit at a specific time during the production life under the prevailing displacement mechanism (Figure 6). The simulated average contacts are broadly matched with observed fluid contacts or well performance by adjusting the model input, primarily the volumetric sweep efficiency and the relative permeability curves.

Where possible, fluid contacts movement simulation should preferably be carried out at the detail sand unit level. However, re-allocation of production data in commingled reservoir sands with long production history into individual sand unit can create greater inaccuracy. It is not recommended if the production data at the sand group level is already not accurate. Gas production data in commingled reservoirs with gas lifting are prone to substantial error. In the field studied, gas production volumes exceeding in place volumes are sometimes observed.

The simulated contacts represent average rise in oil-water and gas-oil contacts in a reservoir. The local area contacts rise are expected to vary in different parts of the reservoir unit in line with reservoir characteristics. Local area coning, cusping and differential breakthrough can dominate completion performance. This would need to be delineated from interpretation of other data as explained below.

Local Area Current Contacts from Well Performance Data
The fractional water-cut at a well is related to the position of average local current oil water contact in the vicinity of the well completion on the reservoir unit. Current OWC values estimated from the water-cut level in a number of producers are used to create a sketch of contacts across the reservoir unit.

The calculation takes into consideration the depth interval of the completion and the fractional water-cut level (Figure 9). Knowing $f_w$, the net thickness of the water-flooded interval, $H_w$, is estimated as a function of the total net formation thickness, $H_t$, and the end point relative permeabilities, $K_o$ and $K_w$ as follows

$$f_w = \frac{Q_w}{(Q_o + Q_w)}$$

$$H_w = \frac{K_w H_t (\mu_w B_w)}{K_o H_t - K_w H_w}$$

$$H_w = \frac{K_w H_w (\mu_w B_w) + K_o (H_t - H_w) (\mu_o B_o)}{1 + K_w \mu_o B_o (1 - f_w) / (K_o \mu_w B_w f_w)}$$

The depth of the oil-water interface at the completion can thus be calculated. Approximate adjustments are then made to obtain the average oil water current contact in the vicinity of the well. An adjustment was first made to correct for coning effects related to the production rate. This could be based on coning heights versus gross rates correlation where available. If a completion had been closed in for several years and the current contact in the vicinity of the completion is needed, a correction is also made for the time-lapse effects on contact movement since closed. This adjustment is based on the calculated average contact movement versus time in the reservoir unit.

It is recognized that there are many complexities, which could complicate the contact calculation, for example, relating to completion across multiple sand units and preferential layer break-through. The calculated fluid contacts are therefore considered as one source of data, which could be used to analyze in collaboration with contacts information from other sources. They include logged contacts, simulated average contacts of the reservoir unit and well performance. It provides an approximate mapping of local area contacts in the vicinity of producers and as calibration with other sources of contact data. In the reservoirs studied, this technique was particularly useful as there were substantial ambiguities in fluid interpretation from petrophysical logs. Many intervals
logged in the relatively recent 1993/1999 wells were of low resistivity zones, which did not allow clear differentiation of hydrocarbon and water.

Figure 9 shows an example of the local area oil water contacts estimated from well water-cuts.

Integrated Analysis to Identify Bypassed Oil Location
The overall interpretation of the location of bypassed oil opportunity is based on collaborative evidences drawn from the various techniques described above. Each technique on standalone basis provides some information, which is not sufficiently definitive. The integrated approach enabled a more definitive identification of the location and the boundary of the bypassed oil in the reservoir.

Bypassed Oil Volume and Potential Recovery Scope Estimation
The volume of the prospective bypassed oil identified in a reservoir as described above is calculated using the 3D static model built for the field. A polygon is drawn to define the outline of the bypassed oil identified (Figure 11). A range of current fluid contacts reflecting uncertainties is input for the bypass oil volumes computation. The scope of potential recovery is then estimated. Analytical calculation based on Buckley-Leveret 1-D 2-phase recovery performance matching in the reservoirs studied showed that the target technical recovery factors at abandonment water-cut level of 95% could typically reach 40-65% of OIIP. In view of the short remaining oil columns and other uncertainties, a more conservative average RF of 40% was used for the potential recovery scope estimation. In some cases, it is more convenient to define a bypassed oil polygon that include remaining developed oil that could still be produced from existing producers. The developed oil reserve is subtracted from the potential recovery scope.

Field Studied
The field is located offshore Sarawak in water depth of 70 –100 ft. The structure consists of a 30,000 by 90,000 ft elongated anticline and comprises a series of stack reservoirs in the depth range of 4000 – 9500 ftss (Figure 10). The reservoirs were deposited some 20-23 million years ago during Cycle V of the late Miocene in a lower coastal plain to coastal environment. Shore face deposits dominate the sequence, which also includes some channels and associated bar forms. Reservoir sands are loosely consolidated, fine to very fine and inter-bedded with layers of silts and clays. Average reservoir porosity ranges from 14 to 26 % with a field-wide mean of 20%, permeabilities are in the order of 50 to 300 mD, average net-to-gross is 0.62 and net sand thickness is generally less than 30 ft, with most sands around 10 ft thick.

The field was discovered in 1966 and brought on production in mid 1968. Following the initial development, the field had undergone 7 follow-up phases of further field development campaigns to improve production and recovery. With the exception of a few shallow reservoirs, the field mainly contains light oil with low oil viscosities. The reservoirs have experienced strong aquifer drive with less than 10% reservoir pressure decline. In line with good reservoir qualities and sand continuity, the presence of strong natural water influx, and implementation of many followup phases of infill completions, which improve the volumetric sweep coverage, the reservoirs generally have attained relatively high recovery efficiencies. Overall field oil recovery factor is about 48% of currently carried OIIP. Cumulative oil production as at 1.1.2006 had reached about 45 % of the field OIIP.

The integrated bypassed oil identification methodology described had been successfully applied to review the presence of bypassed oil in 14 mature water-drive reservoirs in the field. These oil rim reservoirs have initial oil column of 30- 200 ft and are overlain by gas-cap of various sizes and have strong peripheral aquifers. The initial gascap size ranges from very small to very large. In the following sections, an example reservoir is used to illustrate how the methodology was used to locate bypassed oil. To improve the clarity of explanation, a relatively simple example reservoir is presented below

Bypassed Oil Review In An Example Reservoir
Reservoir Description
The example reservoir occurs at between 5096 and 5405 ft tvdss with gross thickness varying between 29 and 94ft. No faults are observed in seismic or in the wells. The reservoir is subdivided into three sub-units. There is no field-wide shale separating the three units and they are believed to be in communication. Reservoir quality is moderate with modeled porosity of around 16- 25%, average N/G of 48-51%, and average oil saturations of 62 - 80% and permeabilities from well test are 48-600 mD. The property model had been calibrated with log to core matches and initialized with matched saturation profiles at wells. The three zones are similar in gross thickness and contain moderately good sands, which are distributed fairly evenly across the field. They all consist of a series of stacked sands intercalated with silts and shales, giving the logs a serrated appearance. Sand character varies somewhat across the field but most individual sands can be traced laterally. The individual sands amalgamate over parts of the field to form a thicker sand body.

Development Overview
There were a total of 11 completions / re-completions on the example reservoir (Figure 7). Initial development was by Well-11 completion in the NE flank in 1968 followed well re-completions in Well-14 (1974) and Well-15 (1974) in the central near crestal area. Well-14 (1974) and Well-15 (1974) produced mainly gas. Other completions were furnished during subsequent phases of infill development campaigns, most of which took place during the 1990-1993 period.
Reservoir Performance Analysis
The reservoir produced at maximum production level of about 2000 bopd in 1974 with high initial GOR and rapidly rising watercut (Figure 1). It was mostly closed-in from 1977-1986 until infill completion in Well-16S1 (1987) followed by the main infill development from 1990-1993 when the reservoir was producing at a peak of about 1500 bopd. Since then production level was mostly 200-1000 bopd at 40-70% watercut. At end 2005, there were only 3 remaining completions producing from the northern near crestal area of the reservoir at about 132 bopd with 72% watercut and low producing GOR. The bulk of production came from the near crestal area in the northern portion of the reservoir. A number of completions in the central sector of the field like Well-15 and -14 did not perform well due to perforation intervals either near to water or close to the gas-cap. Reservoir cumulative GOR rose from about 2000 scf/stb initially to about 6800 scf/stb in 1975/76 due to gas cap gas production. Post 1987, cumulative GOR declined gradually to the current level of about 1500 –2000 scf/stb which shows that the initial gas-cap gas has largely been produced.

Material balance calculations showed that the reservoir experienced strong aquifer support, which constitutes over 80% of drive energy (Figure 5). Sensitivity analysis showed that the OIIP range could be 9.5-12.5 MMStb in combination with a small initial gas-cap size factor of 0.18 - 0.22.

Analytical performance matching showed that the volumetric SE of development to-date is 70% (Figure 2). Assuming a target SE of 80% could be achieved with additional development and abandonment water-cut of 95%, the total scope of potential recovery from the reservoir is about 0.95 MMStb.

Locating Bypassed Oil In Example Reservoir
Application of the integrated methodology to locate the bypassed oil is illustrated below using the example reservoir.

Animation of Production- Water Influx Pattern
Figure 8 shows a projection of production-water influx pattern base on well production data on to the top contour map at end 1995 and 2005. It is observed that the reservoir is least drained around the crestal area in the central and the southwest. This gives the first pass indication of the likely location of any bypassed or remaining oil opportunities.

Average Contacts Movement Simulation
The initial observation based on production pattern animation is supported by average contacts movement simulation. Figure 6 shows the simulated average fluid contacts movement with time in the reservoir unit. The reservoir unit originally had a small initial gas-cap, which had been produced. With production and strong water influx, the remaining oil column had been displaced to the crestal area of the reservoir unit. The simulated average contacts movement is compared with the calculated contacts from well watercut and the logged contacts.

Local Area Contacts Estimation
The evidence obtained from production-water influx animation and average contacts movement simulation as described above indicated that the bypassed or remaining oil opportunity is likely located around the reservoir crest. To improve the definition of the local area current OWC’s around the crestal area, estimation of the OWC’s in the vicinity of 3 existing near crestal wells are made (Figure 9). The calculated contacts are plotted on reservoir map and compared with contacts logged in the relatively recent wells (Figure 11). Taking into consideration contact changes with time due to production, the calculated local area contacts are considered to be in line with the logged contact data.

Observation In Recent Wells
The fluid contacts observed in 3 relatively recent wells are used to calibrate and compare with calculated contacts (Figure 11)

3D Seismic
There was no earlier 3D seismic shot in the field and so identification of bypassed oil using 4D seismic interpretation technique would not be possible. A study was made to identify possible fluid contacts in the field from the 2005 3D seismic data interpretation. In the example reservoir shown, due to the lack of seismic continuity within the reservoir interval, the top reservoir has been constructed by interpolating from the reliable higher and deeper markers. Consequently the RMS window extraction is not based on a seismically meaningful loop. The weak amplitude brightening in the hydrocarbon bearing area matches poorly with the initial OWC (Fig.12). The sudden strong amplitude reduction at the very crest is probably not representative of the current re-saturated volume around the reservoir crest. Quantitative interpretation work covering the AVO response for oil and gas suggests the presence of strong distortion effects due to seismic absorption caused by overlying gas intervals. Away from crest the RMS amplitude generated, broadly represents possible lithology trends in the vicinity of a higher reservoir. In the crestal region, the amplitude brightening may contain a strong imprint of the hydrocarbon effects within the higher marker interval, thus masking any effects from the reservoir under study. It was concluded that no conclusive deduction of fluid contacts could be made.

Bypassed Oil Location and Scope
Based on production performance behavior, it is concluded that the small initial gas-cap gas in the example reservoir had mostly been produced. Oil and some water down dip had been displaced upwards to the reservoir crestal area. Taking into consideration of the calculated local area contacts and the existing completions depths, it is concluded that the bypassed or
remaining oil opportunity for further development is located above 5120-5140 ftss in the northern crest and above 5130–5150 ftss in the southern crest (Figure 11). The calculated prospective oil-in-place volume is in the range of 0.8 – 2.2 MMstb. Potential recoverable oil estimated is about 0.3 – 0.9 MMstb, which is within the scope evaluated based on analytical performance matching. As the scope is small, it is recommended to develop the bypassed (remaining) oil by future re-completion of existing wells near the crest in the central and southern area.

Reservoirs Reviewed and Development Opportunities

The integrated bypassed oil identification methodology presented has been applied to review 14 developed reservoirs in the field studied. They are of a variety of accumulation configuration. These reservoirs had initial oil columns ranging from 30 ft to 200 ft. The oil accumulations are associated with initial gascap ranging from zero to very large gascap size. Bypassed oil opportunities have been identified in nine reservoirs. They include un-drained oil in their original location, oil that has migrated into an originally gas bearing area, and remaining oil rim located between gas and water. The total potential recovery scope of 14 bypassed oil targets identified is in the range of 4.4 (low) – 7.1 (base) –10.2 (high) MMstb. Potential recovery per drainage point is therefore relatively small, and it is envisaged that further development will be characterised by work-over or sidetracking of existing wells. Existing wells that could potentially be re-completed to access identified infill opportunities were tentatively identified. These candidate wells were selected based on the identified bypassed oil locations and reservoir sand development; therefore their locations represent drainage locations where potential oil reserves could be captured most efficiently. However, optimal selection of wells for work-over/ re-completion or completion from new sidetracks will need to be further reviewed taking into consideration latest operational factors and economics.

Production Performance Expectation

Due to the advanced stage of development and production in the field studied, the bypassed or remaining oil opportunities identified are mostly contained in short remaining oil rims. Production from future drainage points located to produce these bypassed oil is expected to be accompanied by high producing water-cut and in many cases also high producing GOR. The bulk of potential oil recovery will most likely be produced at water-cut level of higher than 50% to 95%. Early or immediate water breakthrough should be expected and oil reserves will be recovered with increasing water-cut. Those with remaining gas-cap will also likely produce at high GOR. Those targets associated with blown-off gas-cap will also produce at high GOR initially due to the presence of remaining mobile gas.

Recovery Challenge and Risk

Significant uncertainties in potential oil recovery volumes are associated with reservoir static model and fluid contacts uncertainties. The identified bypassed or remaining oil opportunities are based on inferences and approximations that are inherent to the analytical approach taken. Dynamic models from other studies were available in a few reservoirs. The bypassed oil locations predicted are in general agreement with the integrated analytical approach. However, as the dynamic models were not purpose built for bypassed oil study, they carry pitfalls in detailed identification of remaining oil at some locations. It is recommended to mitigate these risks by confirming the remaining high oil saturation intervals by logging prior to confirming the final completion intervals.

Bypassed oil or remaining oil opportunities comprising oil that has migrated into an originally gas bearing area could potentially have low conformance of oil re-saturation and higher than expected residual gas saturation level of 5-10%. Recovery from oil rims located between gas and water will suffer from gas and water coning, and therefore high water-cut and GOR production should be expected.

Further improved oil recovery in highly mature water drive reservoirs could be achieved by increasing gross pore volume throughput to sweep out remaining mobile oil at higher water-cut. In the field studied, success in increasing oil recovery will therefore also be dependent on success in enabling the whole integrated production system to produce at higher gross production levels to cater for higher water-cut and gas handling capacity. Complementary field activities required for such improved oil recovery would include well productivity enhancement, increased availability of lift gas, gas lift optimization, lower surface backpressure and higher gross handling capacity.

Conclusions

1. An integrated methodology suitable for the identification of bypassed oil opportunities in water-drive reservoirs is presented. The approach comprised identification of bypassed oil based on collaborative evidence drawn from reservoir performance analysis, performance matching and forecast with an 1-D 2-phase analytical model, material balance, average contact movement simulation, animation of production data, observed fluid contacts in wells drilled, local area contacts estimated from well performance data; and 3D seismic indication.

2. The strength of the approach presented lie in the integration and use of collaborative evidence derived from several different methods that indicate the presence of bypassed oil. This enabled a more definitive identification of the location and extent of the bypassed oil for volume calculation, which would not be possible otherwise.
3. The methodology presented has been successfully applied for the review and identification of bypassed oil development opportunities in 14 reservoirs in a mature water drive field.

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Nomenclature
AVO = amplitude vertical offset
Bopd = barrel oil per day
Cumoil = cumulative oil production
Cumwater = cumulative water production
Cumoilwater = cumulative oil and water production
Cumgasboe = cumulative gas production in barrel oil equivalent
COWC = current oil water contact
CGOC = current gas oil contact
LRUT = logged low resistivity up-to depth (water invaded)
ODT = oil down to
OWC = oil water contact
POWC = possible oil water contact
OIIP = Oil initially in place
MMstb = million stock tank barrel
Mstb = thousand stock tank barrel
GOR = gas oil ratio, scf/stb
WC = fw = fractional water-cut
RF = recovery efficiency, fraction of OIIP
SE = volumetric sweep efficiency
Hw = water invaded net formation thickness
Ht = total net formation thickness
Kw = end point water relative permeability
Ko = end point oil relative permeability
Qw = water production rate, stb/d
Qo = water production rate, stb/d
Bo = oil formation volume facto, rb/stb
Bw = water formation volume factor, rb/stb
ρo = reservoir oil viscosity, cp
ρw = reservoir water viscosity, cp

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Fig. 1: Reservoir Performance Plot.

Fig. 2: Analytical performance history matching and potential recovery forecast.
Fig. 3: Analytical performance history matching. Potential recovery forecast input data and results.

Fig. 4: Log panel showing fluids observed in recent wells.
Fig. 5: Material balance match showed the presence of large peripheral aquifer. Aquifer influx contributed over 80% of drive energy.

Average Contacts Calculation:
CGOC: Gas-cap produced
COWC: around 5120-5140 ftss

☐ Near Crestal well 8S1 (5110-5190 ftss) high GOR initially; later produced at low GOR ~ 950 scf/stb; WC ~ 50%

Local COWC from well WC’s 5137-5188 ftss

Fig. 6: Production simulation showing average reservoir contacts movement. Logged contacts and calculated local area contacts are shown for comparison.
Fig. 7: Oil-water-gas production bubbles and cumulative oil production grid map showing areas of high and low production.

Fig. 8: Animation of cumulative production data on map. In water drive reservoir, it is indicative of flood pattern as water influx replaced production.
Fig. 9: Local area fluid contacts calculated based on well performance data.

![Fig. 9: Local area fluid contacts calculated based on well performance data.](image)

Fig. 10: Schematic cross-section of the field studied.

![Fig. 10: Schematic cross-section of the field studied.](image)
Fig. 11: Calculated current contacts and logged contacts shown on net oil map (So.Phi.H) map. Wells completed on the reservoir were mostly close in or abandoned (ab). Identified bypassed oil at near crestal area in the central and SW.

Fig. 12: Reservoir contour map with 3D RMS amplitude map and original contacts.