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Attic Oil Zone Redevelopment to Improve Oil Recovery in Almost Watered-out Reservoirs

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Abstract. The A&B reservoir is a giant, complex, very mature carbonate reservoir undergoing waterflood. Given long history of production and waterflood, the main focus in the development philosophy of this reservoir was to maximize the oil recovery from existing wells. Many of these wells had zones with significant oil saturation behind casing, especially in the attic zone. The key to improve the recovery factor of the mature reservoir was through the redevelopment of the attic zone by shift-up and change-layer workovers. The campaign was started with a saturation logging job which was successful in locating the attic oil zone which then gave high oil rate after the zone was opened. This success was then followed by a comprehensive geological, petrophysical, and engineering review of hundreds of the existing wells. To boost the oil gain, ESP upsizing was programmed for wells with sufficiently high productivity. Several wells have been identified for the campaign. To date, seventeen jobs have been conducted successfully. Overall, the campaign could unlock the attic oil and resulted in significant oil gain. One well with saturation logging prior to the workover experienced notable watercut reduction. The production of the well with big-size ESP was boosted four times, while the watercut was reduced rather than increased. In other wells, oil production increase was obtained while the watercut being relatively unchanged. Further evaluation is needed especially to determine the minimum attic zone thickness and minimum up-shifting distance from the existing producing intervals that would result in economical oil gain. This paper discusses the results of the past two years of the attic oil redevelopment campaign conducted in the A&B reservoir. The approach presented in this paper is applicable to mature fields at very high watercut stage.

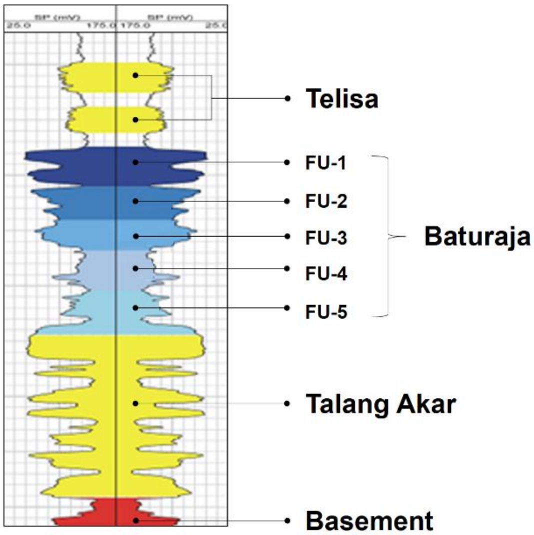
Keyword(s): Attic oil, workover, fractional flow, mature field

1 Introduction

The reservoirs highlighted in this work are the Baturaja Limestone Formations (BRF) which are parts of the K and S fields. The two fields are located in South Sumatra. A typical log of wells in K and S fields is shown in Figure 1(a). The BRF of the K and S fields can be regarded as twins as the two have similar properties and are located very close to each other although they are not hydraulically connected. For simplicity, the two reservoirs will be considered as one reservoir in this paper and will be named A&B. The average reservoir properties of A&B are shown in Figure 1(b). This limestone reservoir is a giant in size with a maximum thickness of 180 ft and has a high degree of vertical heterogeneity as indicated by the existence of different flow units. Based on current interpretation, the reservoir has five flow units: FU-1, FU-2, FU-3, FU-4, and FU-5. Between each flow unit, there may or may not be low permeability baffles that act as barriers which could block cross-flow between flow units.

Primary recovery in the A&B began in 1997. Two years later, in 1999, pressure maintenance via peripheral water injection was established. Oil production peaked at a flowrate greater than 40 MBOPD in 2001, since then the production has been declining. Secondary oil recovery via waterflood was implemented in 2005.

Prior to this work, this reservoir had reached a recovery factor of 38% with the majority of producers reaching watercut of 97% or even higher. Given the long history of production and waterflood in this reservoir, and as the mature reservoir had stepped into very high watercut stage, the main focus in the development philosophy was to maximize oil recovery using the existing wells. Considering the oil recovery and the well-work history in each well, many of these wells were predicted to have significant oil saturation behind casing, particularly in the attic zone. Therefore, the redevelopment of the attic zone was critical to the recovery and future of the A&B reservoir.



(a)

Depth (ft)	2,700
Initial Reservoir Pressure (psia)	1,240
Bubble Point Pressure (psia)	1,240
Current Reservoir Pressure (psia)	800 - 900
Initial Temperature (°F)	181
Specific Gravity (°API)	38
Viscosity at Bubble Point (cp)	0.83
Solution Gas-Oil Ratio	308
Initial Oil Formation Volume Factor	1.212
Effective Porosity (%)	20
Permeability (mD)	74
Heterogeneity Coefficient	0.77

(b)

Figure 1. (a) Typical log of wells in K and S fields; (b) average reservoir properties of the A&B

2 Methods

2.1 Shift-up Workover

The development strategy that had been implemented previously was to complete the wells bottom-up. This means that the deepest flow unit will be completed first and after this flow unit has been depleted or watered-out, it will be isolated, and the perforation will be shifted to the upper flow unit. This process continues until the top flow unit (*i.e.* FU-1) is completed. Prior to this work, many wells in this reservoir had reached a very high watercut level of about 97% or higher but the top flow unit in these wells had not been completed. Therefore, the top flow unit or the attic became the zone of main interest as it might hold relatively high oil saturation resulting from the combination of: (1) the original oil reserve of that zone that has not been recovered, (2) oil that is pushed by the waterflood, and (3) oil coming from the lower flow units that moves upward due to buoyancy and accumulates there.

There are several methods to increase the attic oil recovery. These include the use of horizontal wells (Langaas, 2020) and assisted gas-oil countercurrent technique with waterflooding assistance (Ma, 2020). Drilling horizontal wells was considered expensive while the novel flooding techniques have not been proven commercially and thus both methods were not preferred. The objective of this work was to improve the oil recovery from this mature reservoir through the redevelopment of the attic oil zone with an economical method, namely by conducting a shift-up and change-layer workover campaign in wells whose top flow units had not been completed. Shift-up workover in this case means workover within the same reservoir that is conducted by adding perforation above the existing open intervals. Depending on the production before the workover, the existing open intervals may or may not be isolated during the shift-up workover. In addition, to help identify the attic oil accumulation, saturation logging was also planned for some candidates. Sporadic identification was applied to select the saturation-logging candidates, rather than campaign approach, to test the reliability of the technology.

2.2 ESP Upsizing

As a very mature reservoir, A&B had reached a very high watercut of ≥97%. As such, there was arguably no proven technique that can reduce the field watercut significantly. Enhanced oil recovery might potentially decrease the water production, but this method is not only complicated and expensive, but also not readily executable. The promising approach to boost oil production at this condition is not by reducing the watercut, but instead by increasing the gross liquid production or “gross-up” which will result in the simultaneous increase of oil production.

Figure 2 shows the fractional flow curves of six rock types of A&B reservoir. Watercut is strongly dependent on the flowrate when the reservoir is at the steepest part of the fractional flow curve (red-dashed-line) occurring in water saturation range of about 20% to 65%, depending on the rock type. At this section, a significant change in flowrate will result in significant saturation change which in turn will markedly change the watercut as indicated by the steep slope of the watercut vs. water saturation plot. However, at water saturation above 50%-65%, or at watercut greater than 90%, the rate of change of watercut with respect to the change in water saturation, and hence, flowrate, becomes smaller as expressed by the gentle slope of the fractional flow curve (blue-solid-line). In other words, at high watercut conditions, watercut increase becomes less sensitive to flowrate increase. If, for example, a candidate well is producing at 1500 BLPD, 96% WC, 60 BOPD and its production is boosted four times with a big-size ESP but at the same time the watercut increases to 98% due to increased production, then the final rate will be 6000 BLPD, 98% WC, 120 BOPD, or a satisfactory oil gain of 60 BOPD. This situation is typical in the A&B reservoir and the oil gain is achievable which makes this initiative technically and economically promising.

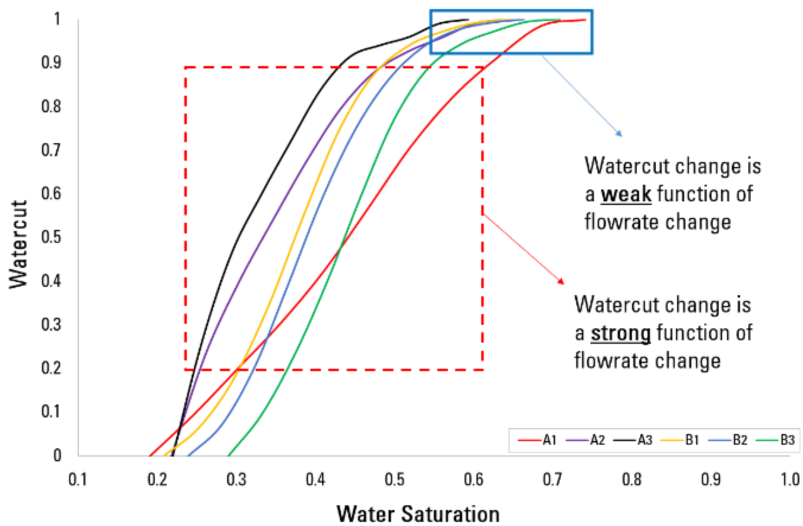


Figure 2. Fractional flow curves of six rock types of the A&B reservoir

Based on this consideration, together with the shift-up workover, ESP upsizing was planned to increase the production in candidates with adequate productivity. The term "ESP upsizing" means that the existing ESP installed in the candidate-well will be replaced with a bigger pump. ESP upsizing and shift-up workover will complement each other where ESP upsizing will increase the liquid production, and possibly the watercut, but the shift-up workover will arrest (if not reverse) the watercut increase by allowing the attic oil to flow. The harmony between the two well-works was the key to maximize the oil gain.

3 Results

Several wells were identified and planned for this campaign. To date, seventeen jobs have been executed with encouraging oil gain. The following subsections will highlight some of the key findings.

3.1 AB-0188

Prior to the workover, this well had been watered out and shut-in for more than three years. Throughout this long period of static condition, the gravity force in the area surrounding the well was predicted to be more dominant than the viscous force which allowed the oil to move upwards and re-accumulated in the attic zone. Considering this hypothesis and the fact that the top flow unit of this well had not been opened, it was expected that economical oil reserve existed in the attic zone. The activities in AB-0188 began with a saturation logging job which was successful in locating the attic oil accumulation. The saturation log interpretation is depicted in Figure 3. During the workover, the existing interval at lower FU-2 was squeeze-cemented. The perforation was then shifted-up to open the attic zone, 44 ft above the existing interval. The thickness of the attic zone was 47 ft and the completed interval of the attic was 10 ft. The results was surprising. Initial well test after the workover resulted in oil flowrate of 233 BOPD with watercut of only 23% (watercut reduction of 77%). It was initially thought that this result would be short-lived but it has been eighteen months since the workover and the current watercut at the time of this writing was still around 68%. Long-term average oil gain recovered at this well exceeded 120 BOPD.

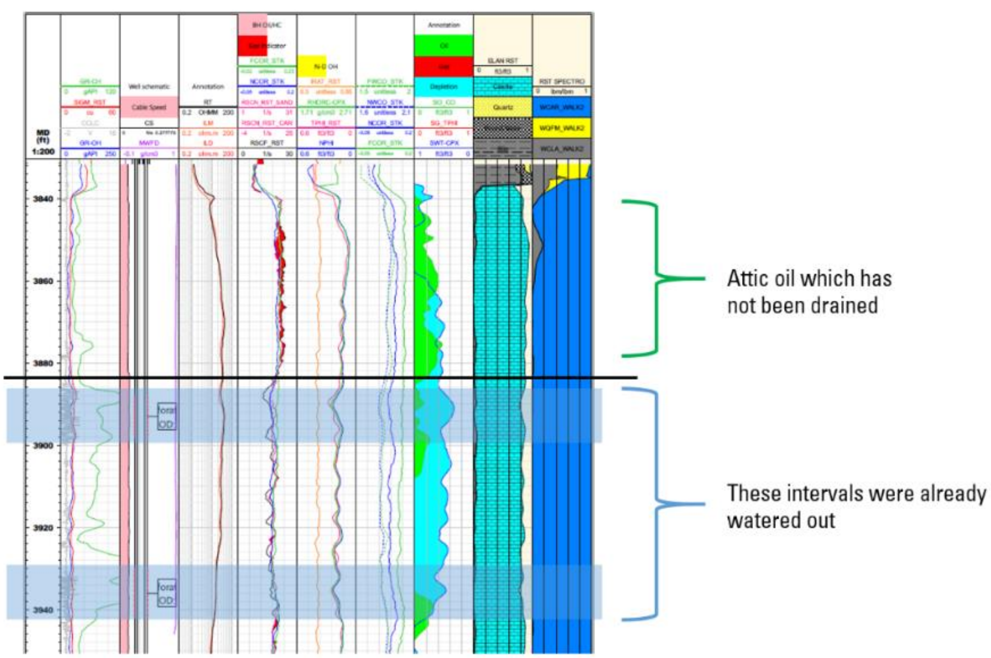


Figure 3. Saturation log interpretation of AB-0188

3.2 AB-0225

Before the well-work, this well produced oil at a flowrate of 20 – 30 BOPD with watercut reaching 99%. Although the watercut was very high, the oil rate was still economical and hence the existing interval was kept opened. ESP upsizing was also planned at this well as the productivity index was sufficiently high. The attic oil zone was relatively thin with thickness of only 12 ft. However, the openhole log indicated the presence of permeability baffle between the attic zone (FU-1) and the producing zone (FU-2). Although interpreted as a non-sealing barrier, with sufficient tightness and thickness, this baffle could effectively minimize the influence of drawdown occurring at FU-2 on the attic zone. Thus, even though the distance between the two flow units was very close, crossflow between them could be hindered by the baffle. In other words, the baffle helped to preserve the attic oil.

The workover results in this well was another major success. With a big-size ESP, the gross production could be multiplied more than five times. Perforating the FU-1 unlocked the attic oil which contributed to reducing the watercut to 97%. After eight months of production, the average oil gain obtained from this well was 216 BOPD and the watercut was relatively stable without any significant increase in watercut. The experience in this well provided a very important lesson to be learned. Firstly, this finding supported the hypothesis that at watercut above 90% (*i.e.* top-right section of fractional flow curve) watercut increase is less sensitive to increase in production rate. Secondly, the existence of permeability barrier can help preserve the attic oil from being drained by the lower producing intervals. Candidates with similar log signatures indicating a permeability barrier would then be prioritized. Openhole log interpretation and the well diagram of AB-0225 highlighting the opened intervals are shown in Figure 4.

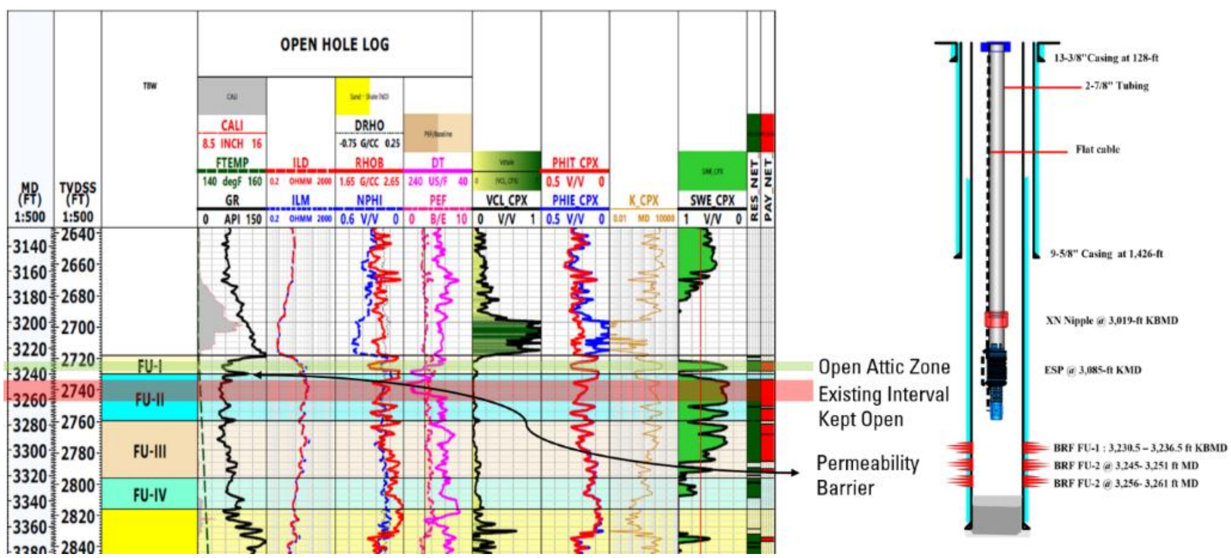


Figure 4. Openhole log interpretation and well sketch of AB-0225

3.3 AB-0037

Before the shift-up workover, this well was an active producer with an average rate of 50 BOPD at an average watercut of 98%. It was previously a taboo idea to rework a well with such a high oil rate as there will always be risks associated with well-works. However, given the good success ratio of the ongoing shift-up workover campaign, and the fact that the attic zone (FU-1) in this well was relatively thick (35 ft), the risk was worth taking. The existing producing interval at FU-2 was not isolated as it was still productive. The attic zone was fully perforated to maximize the productivity. AB-0037 has been producing for three months since the execution. A watercut reduction of 1% could be maintained which resulted in an average oil rate of 100 BOPD or 100% oil gain.

3.4 AB-0222

The last well reported in this paper is AB-0222. Prior to the job, this well produced oil at an average flowrate of 70 BOPD with an average watercut of 97%. As the existing producing interval still produced high oil rate, it would not be isolated. In addition to the shift-up workover, this well was also planned for ESP upsizing considering the high productivity. Reservoir analysis for this well was challenging as complete logging package could not be acquired due to loss circulation problem at the time of drilling. Resistivity log and neutron log were not available in this well. Gas reading data was also not available. The main indicator that supported the analysis was the gamma-ray log that showed the location of the attic zone (upper FU-1) and the presence of permeability barrier between upper FU-1 and lower FU-1. The baffle is made of mudstone as interpreted from cutting samples. The thickness of the attic zone was 15 ft with 15 ft up-shifting from the existing interval.

The results from AB-0222 workover was phenomenal. The watercut decreased dramatically from 97% to 53% which resulted in an initial oil gain of more than 1200 BOPD. This watercut level lies on the central part of the fractional flow curve and thus was sensitive to changes in production rate. At the time of writing, the watercut profile was under close monitoring and it showed an increasing trend. Consequently, although big ESP has been installed in this well, the production gross-up was still maintained at approximately 1.5 times the original flowrate to delay the watercut increase. Considering the very mature state of this reservoir, if eventually the watercut in this well has reached >90%, higher production gross-up will be applied to boost the oil production. The lessons learned from this well was very important. It further strengthened the concept that permeability baffles could effectively prevent crossflow across flow units thereby preserving the attic oil from being drained by the lower completions.

3.5 Overall Results

The results of the ongoing campaign is summarized in Figure 5. In general, the campaign was considered successful in locating and unlocking the attic oil which resulted in reduced watercut and significant oil rate improvement. There are positive correlations between the attic zone thickness and the up-shifting distance on the oil gain. Two wells that have baffle between the attic zone and the lower producing zone gave the highest oil gain, namely AB-0222 and AB-0225. These findings were consistent with the idea of attic oil conceptualized in this study. Sufficient up-shifting distance and the presence of permeability barrier below the attic zone help preserve the attic oil from being drained by lower producing intervals. This will result in higher oil gain when the attic zone is opened. Also, thicker attic zones are likely to have greater remaining attic oil reserve and higher productivity. ESP upsizing proved to be effective in improving oil production rate with relatively low risk of fast watercut increase when used in wells with watercut greater than 90%. To date, seventeen jobs have been executed. Further evaluation is needed especially to determine the minimum attic zone thickness and minimum up-shifting distance that would result in economical oil gain.

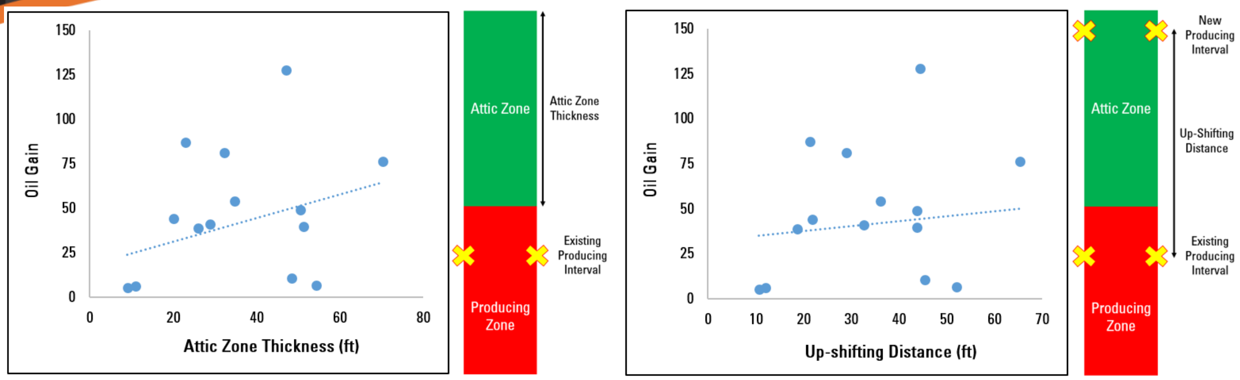


Figure 5. Positive correlation between the attic zone thickness and oil gain (left) and between up-shifting distance with oil gain (right)

4 Conclusions

This paper reports on the success stories and lessons learned from the ongoing attic oil zone redevelopment campaign in the A&B reservoir, a giant, very mature, waterflooded carbonate twin-reservoirs that are almost watered-out. At very high watercut, watercut increase becomes less sensitive to increase in flowrate and thus oil gain can be obtained by increasing the gross production without having to worry too much about rapidly increasing watercut. Permeability baffles exist throughout the reservoir, although not continuously, and they can be effective barriers that separate the attic zone from the lower flow units. These baffles help to minimize the influence of drainage occurring in lower completions on the attic zone thereby preserving the attic oil reserves. Although the reservoir has reached a very high watercut, economical attic oil reserve still exists at the top of the reservoir. Unlocking the attic oil accumulation can reduce the watercut at well-level, and potentially at field-level, and increase oil production. Tapping the attic oil through workovers proved successful for the redevelopment of the attic oil zone at high watercut stage.

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