A Fit-for-Purpose Geological Evaluation Workflow for Non-Rig Well Work

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Abstract

The depth of geological evaluation involved in non-rig well work (NRWW) can sometimes be under-documented as it tends to be more rigorous in the early phases of maturation of the opportunity. This paper seeks to highlight the geoscientist's role in non-rig well works by presenting a fit-for-purpose evaluation workflow developed in the maturing of five opportunities in the Western Niger Delta shelf. For a large field with over 140 existing wells, the evaluation can sometimes be very complex with conflicting well data. For a geoscientist, understanding spatial location of wells within the reservoirs and the implication of well performance on current reservoir condition are the most important task. In the reservoir of interest, the K-02, it was found that most of the shut-in wells had quit on low tubing head pressure indicating that the reservoir is pressure depleted. This might imply that few opportunities remain in the reservoir, given that this is a reservoir with a large gas cap and about 50% recovery. Pressure data from new drills through the reservoir however shows that the pressure in some fault compartments may be adequate to lift the oil to the surface. Based on geological evaluation, current reservoir conditions indicate that some of the shut-in wells were still within the reservoir oil band and still have the potential to flow simply by adding perforation above current interval. With the intent of using the gas cap as a potential gas lift, the perforation intervals were deliberately optimized to be as close to the current gas-oil contact as possible. Four perforation addition jobs in the reservoir and one zone switch opportunities into a shallower reservoir were proposed for execution. Two opportunities successfully executed led to significant production addition while others are still in different stages of maturation. A major challenge encountered is that with rapid pressure depletion, reservoirs with huge gas caps may ultimately have limited options of lifting oil to the surface, even with large remaining oil in place. Structural compartmentalization was also an issue as it limits how far dynamic fluid and pressure data can be extrapolated away from well control. An important lesson learned is that for a very big field with over a hundred wells, keeping an up-to-date well/reservoir status worksheet is recommended. This easily captures all well and reservoir information that will aid NRWW evaluation in one single repository.

Introduction

Determining reservoir fluid contacts appears to be the single most important task in the NRWW process. Before the decision is made to zone switch out of the producing reservoir, it must be that the zone being abandoned is either gassed out or fully flushed. The intent of the evaluation is to determine whether the reservoirs have remaining economic accumulations and that wells are available to produce the opportunity. A new zone may then be selected that typically have good reservoir pressure and good potential and be structurally well placed within the reservoir (Bates, G. et al, 2012). Additional perforation could be the recommendation if it is found that opportunities exist above current perforation in the same zone. From this effort, those wells that require a zone switch to shallower reservoirs are also determined. The evaluation also helps to verify if reservoir conditions favor any other well intervention such as gas lift, acid treatment or hot oiling before proposing any zone switch.

If zone switch is recommended, the same rigorous evaluation is carried out for the new reservoir of interest to ensure that the reservoir interval in the well falls within the oil band. The geological evaluation basically influences what type of well work – perforation addition, zone switch or other well intervention – to be recommended and determines the initial proposed perforation interval and how much hydrocarbon volume is being targeted.

Reservoir Discussion

The K-02 is a saturated reservoir that has had significant production with peak production of in the 1980s. About thirty well have been completed in the reservoir to date (Figure 1). At the beginning of this study there were only two completions flowing from the reservoir. Material balance analysis indicates that the reservoir drive mechanism is a combination of gas cap expansion and water influx with little contribution from solution gas expansion. This is corroborated by the HGOR and HBSW seen in producing wells, depending on their placement on the structure.

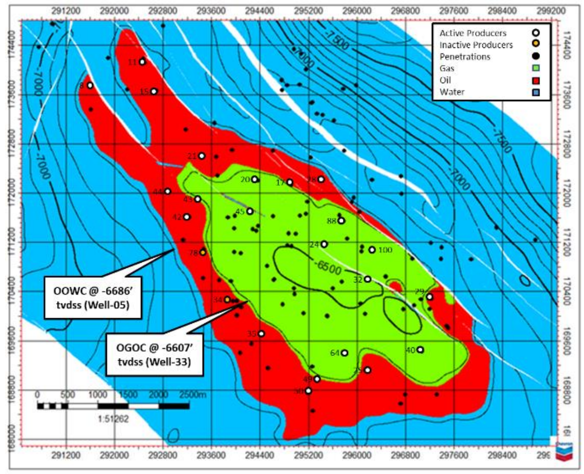

Figure 1: K-02 Original Fluid Distribution Map

The reservoir was initially interpreted as a single flow unit within the hydrocarbon zone and the aquifer. Post-production wells data however revealed the development of differential oil-water contacts as identified by shallower contacts in two recently drilled well in the east of the reservoir than the production interval of the two producing wells in the west. Two distinct oil accumulations are believed to have been segregated due to crestal faulting and are most likely being depleted as separate tanks (Figure 2). The reservoir is however still connected in the aquifer hence the similarity in reservoir pressure across fault compartments.

The reservoir of interest, the K-02 is a saturated reservoir which was discovered in 1964 when the discovery well encountered 20 ft of net oil in the K-02 sand. The reservoir has currently produced 58.1% of its EUR. The reservoir exhibits a four-way faulted dip closure at the crest of the complexly faulted crested fault block (Figure 1). It has a large gas cap with a relatively small oil rim. About 81 wells have penetrated this reservoir to date. The original gas column is 144 ft, with an original oil column of 79 ft. The last recorded reservoir pressure is 1,708 psi representing about 43% decline from the initial recorded reservoir pressure of 2,934 psi in 1965. Most of the wells that produced from this reservoir quit on low tubing-head pressure (LTHP) due to extreme pressure depletion. The pressure challenge implies that even if opportunities still exist in some wells, getting enough pressure to push the oil to the tank appears to be a hinderance to successful execution of any well work.

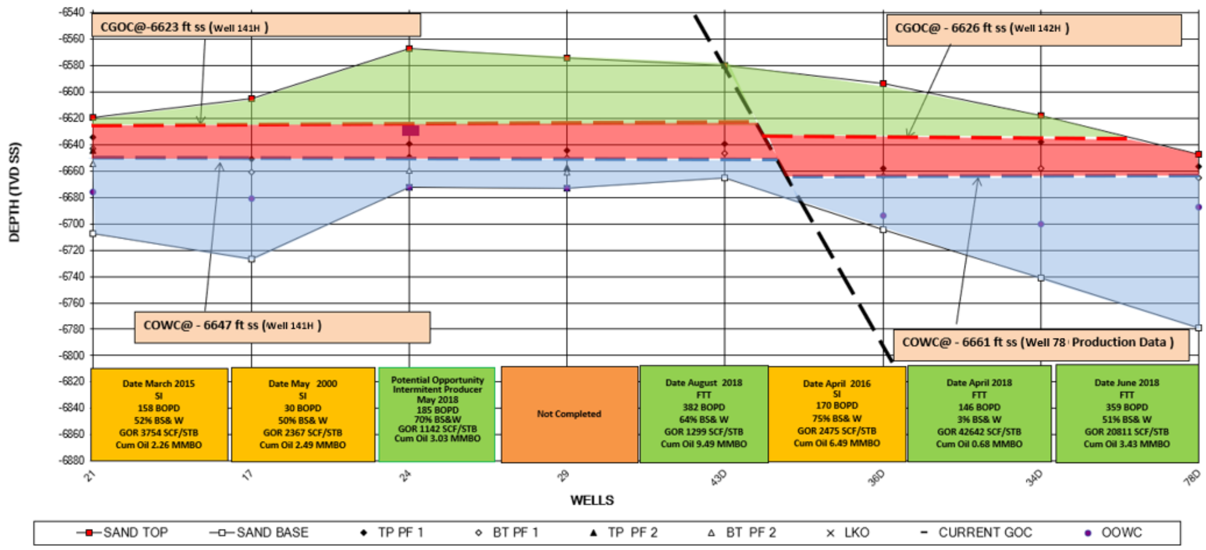

Figure 2: K-02 Reservoir Stick Diagram showing varying fluid contacts across crestal fault. Note that well 78 completed deeper is still producing while Wells 17 and 21 with shallower completions have quit

Reservoir Evaluation Workflow

In a complex field such as this with several producers at different points in the history of the field, a good starting point for geological evaluation is to develop a template that gives all reservoir and well information on a single database (Figure 3). A spreadsheet was developed that incorporated the status of all well strings in the reservoirs such as production status, current rate, water cut, existing non-rig well work plan and if plan is on current barge schedule, on the one hand, and the list of all available reservoirs penetrated by the well on the other.

The different sorting tabs includes:

1. Well status indicates whether well was flowing (ftt) or shut in for various reasons such as low tubing head pressure, high GOR, high water-cut etc.
2. Current production in barrels of oil per day (bopd): any well producing below a set economic limit can easily be identified.
3. Future plan column identifies wells that are already being progressed or matured to prevent duplication of effort.
4. Constrain tab indicates wells that have any sort of mechanical issues such as fish-in-hole, tubing issues, communication issues etc. that would prevent any immediate well work
5. BS&W indicates water cut and give an idea of possibility for gas-lift as an option
6. List of Reservoirs penetrated by each well string, color coded according to the fluid type encountered (gas, oil or

water). Also indicated is the oil and gas column encountered. The current producer can be uniquely color-coded to easily show which are the remaining potential candidate for zone switch to shallower reservoirs.

With this database in place, it was easy to sort by wells that have been shut in and for what reason they were shut in as well as wells that were flowing. Wells that had very low production volume can also be identified early on as future opportunities so that the queue of opportunities is updated for timely interventions.

This might be a tedious exercise for a field with over 200 well strings and will need to be constantly updated to keep well status up-to-date, but the front-end loading exercise provides an evergreen resource that churns out potential well work opportunities and helps focus the geologist’s attention on reservoirs of interest.

In this case, sorting through well status on the field database revealed that the K-02 reservoir had a good number of wells that were shut in on low tubing head pressure even at relatively low water cut. Nodal analysis was carried out and excludes the option of gas lift to sustain and optimize flow in many of these wells.

Next phase was the actual geological evaluation of the reservoir to understand why wells in the reservoir had this unique status. Fluid contact evaluation showed the reservoir still had between 24-40ft of oil in place. Four new wells drilled in 2016 revealed that while Gas-Oil contacts variation was not significant, Oil-Water contacts varied by up to 20ft across the faults. For the eastern flank, current OWC is from one of the wells was -6,647’ tvdss and an OUT at-6623ft. TVDSS. On the western side, another new well encountered an ODT at 6656 ft tvdss and is corroborated by material balance (2018) which puts the COWC in the western flank at 6659ft tvdss.

Along with saturation logs, production data and material balance analysis were also used to estimate fluid contacts for comparison. Contact estimation from water cut information assumes that the percentage of water-cut corresponds to the fraction of the perforation interval covered by water. Water cut could however be affected by coning and could vary significantly in case of a slanting contact. It should be noted that production-based oil-water contacts tend to be more pessimistic than the reality. Formation water is believed to move faster than oil in a bottom water reservoir especially where withdrawal rate is high (Tu, X. et al, 2007)

The challenge to production from the reservoir was the magnitude of pressure depletion that meant that even though there was still up to 60mmbo in place volume in the reservoir, most of this volume could not be brought to the surface. Some of the wells however revealed suspected partial dynamic pressure compartmentalization due to the complex system of crestal collapse faults. It appears that some fault blocks were able to act as partially closed systems with possible lower decline rates with high enough pressure to sustain fluid flow for longer. Several of the wells that had quit were found to still have perforation interval within the oil band encountered in the new drills. The reservoir has a huge gas cap and simply adding perforation at an optimized interval close to the gas cap could be used to lighten the tubing column somewhat to get the oil to the surface. These wells were proposed for additional perforation above existing intervals (Figure 4).

Well Information			Well Status				Reservoir Penetrated					
Well Number	Type	Status	Current Production	Plan to work on current	Constraints	BS&W	E-01	E-03	E-04	E-05	E-06	E-07
1	P	FTT	471	FUTURE NRWO	NO	77	E-01 - 18ft					
1	P	LTHP	97	NRWO	NO	84	E-01 - 20ft					
2	P	FTT	275	NRWO	NO	0					E-06 - 12ft	E-07 - 17ft
3		Abandoned Well										
4	P	LTHP	252	HWOU	NO	5						
5	P	LTHP	78	NRWO	FISH	60	E-01 -15ft					E-07
5	P	FTT	32	NRWO	NO	98	E-01 - 19ft					E-07 - 19ft
6		Abandoned Well										
7	P	LTHP	150	HWOU	NO	0					E-06 - 10ft	E-07 -19ft
8	P	HGOR	350	HWOU	FISH	0						
9	P	HBSW	534	HWOU	FISH	23						
9	P	HBSW	461	HWOU	NO	60						
10	P	LTHP	513	NRWO	NO	1					E-06 - 15ft	E-07 - 27ft
10	P	LTHP	1652	NRWO	NO	15					E-06 - 11ft	E-07 - 21ft
11	P	LTHP	147	NRWO	NO	53						
11	P	LTHP	14	NRWO	NO	93						
12	P	LTHP	24	HWOU	FISH	50	E-01 22ft					E-07 - 25ft
12	P	LTHP	827	NO	NO	50	E-01 - 20ft					E-07 - 28ft
13		Abandoned Well										

Current Producing Reservoir

Figure 3: Non-Rig Work Over Geological Evaluation Data Sheet with well and reservoir information. Database allows integration of all required NRWO information for effortless evaluation

Pressure data taken from some of the new wells revealed that fault compartments do exist with significantly higher pressure that could get the oil to the tank. It was found that withdrawal rate had been higher in the eastern more faulted area at the earlier phase of production and this was responsible for shallower fluid contacts and higher-pressure depletion. When production from this side stopped, it appears the zone had had chance to re-equilibrate baffled, as it were, from the rest of the pool by the fault where production was still ongoing. Wells that had perforation interval still within the oil band in these fault blocks were identified and flow-tested. One of such wells, well 24 came back onstream with about 200bopd production. Other wells in these fault blocks were evaluated for potential perforation addition well work and wells 17, 21, 24 and 36 were thus identified.

Choice of perforation interval is another task the geologist must undertake. Usually the perforation interval would need a compromise with the asset Engineer to be as far from the gas and water as possible but in the K-02 reservoir, the choice was to be close to the GOC to enable some gas into the tubing to lighten the fluid as a form of gas lift mechanism. Water Cut Sensitivity Analysis for well 24 indicates that the reservoir pressure would be able to sustain flow naturally to a water cut of 76% while the well was already at over 70% water cut. The wells were therefore going to need gas lift to continue producing. Getting the optimal perforation interval was important to the expected production increase as the this would determine extended life of the additional production

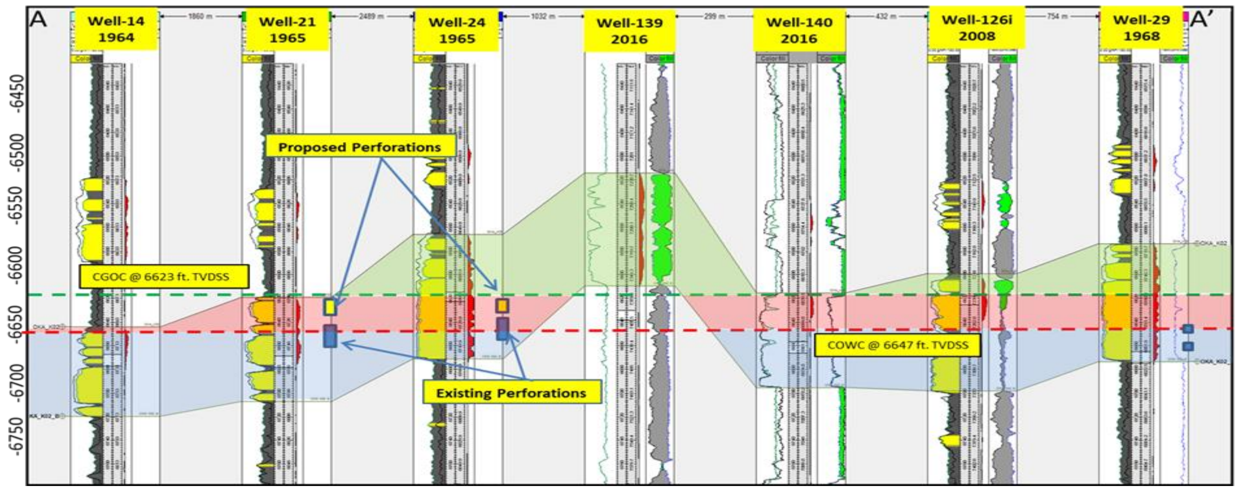

Figure 4: K-02 Structural Cross-section Showing Current Fluid Contacts. Identified perforation addition opportunities are indicated in yellow box

Discussion and Conclusion

The last measured reservoir pressure from a well within the viable fault block was 1,718 psi (June 2016) representing about 43% decline from the initial recorded reservoir pressure of 2,934 psi in 1965. This is significantly higher than the 1250 psi that was recorded before this as part of well surveillance from areas with higher pressure depletion rate

Production add of up to 67% increase on the old rate was recorded in well 24 by adding perforation at an optimal interval within the oil band above current perforation indicating that even in this highly depleted, pressure challenged reservoirs, non-rig well work could still salvage some value. Other opportunities are being matured leveraging the lessons learned from the well 24 well work result. (Figure 5)

An important challenge with this reservoir is that with rapid pressure depletion, reservoirs with huge gas caps may ultimately have limited options of lifting oil to the surface, even with large remaining oil in place. This reservoir had many take points at a time and voidage replacement was not going on. One thing that could have helped was to be more conservative

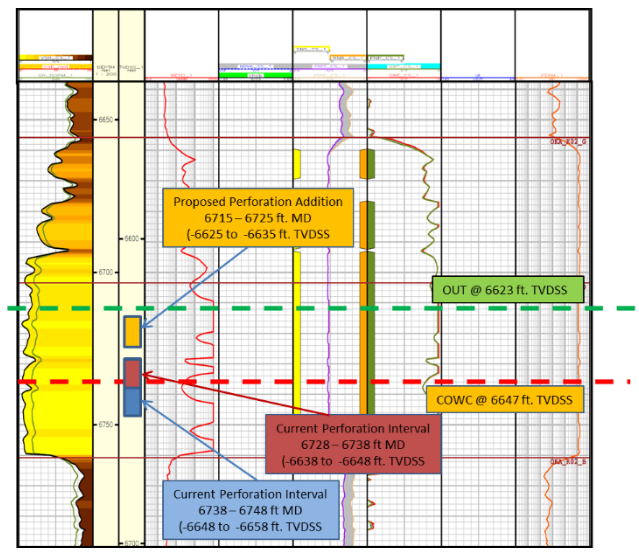

Figure 5: Well 24 Well Log showing Proposed Perforation Addition

in production rates so that the reservoir gets the change to significantly maintain its pressure.

While extrapolating reservoir properties as seen in wells, structural compartmentalization severely limits how far fluid and pressure data can be extrapolated away from well control This often means we do not know if a well is going to behave a certain way or not. In terms of best practices, for a very big field with over a hundred wells, keeping a well/reservoir status worksheet is recommended. This easily captures all well and reservoir information that will aid NRWO evaluation. Well production data needs to be integrated in this database with pressure data and dynamic reservoir characterization to fully assess an opportunity.

An important lesson learned is that teams should be willing to exhaust all available options in producing from a zone before considering zone switching to another. Sometimes with significant pressure depletion, some seemingly viable geological opportunity may not be technically possible to mature.

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