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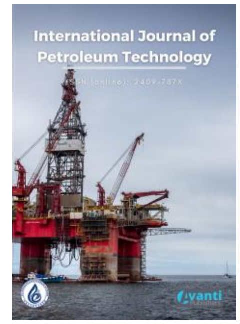

A Novel Approach by Needles in the Payzone of Heterogeneous Tight Carbonate: A Case Study for Offshore Marginal Field

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ABSTRACT

The new Fish-bones Completion & Stimulation approach by needles in the pay stack aims at addressing heterogeneous tight carbonate by increasing flow area in the lower permeable streaks, which is efficient as hundreds of tunnels drain connecting the borewell to the body of the reservoir to increase well productivity and oil recovery. The initial plan includes selecting the best ones from Stair step horizontal well, Dual Lateral well, five lateral fish-bone drilling, and horizontal drilling along with hydraulic fracture. Considering the lessons of failure to clean internal tubes, the modified 4-1/2" Liner is installed in the lower two sub-layer by jetting subs combing with production subs for matrix acidizing in the upper one sub-layer as per modified Fish-bones Completion Design. In addition, special acid-releasing float shoes and new fishing baskets are applied to avoid those previous problems with this well technique. The candidate well shows good oil test and production, which improved by three times at 2000bbl/d with respect to the initial plan in the B field. This paper describes the technology background and characteristics, design factors, modified design, execution, well test, and lessons learned during implementation.

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1. Introduction

ADNOC Al Yasat plans to develop heterogeneous tight carbonate marginal reservoirs as part of ADONC 5 million barrels per day, producing a growth strategy in 2030. An offshore Field B is one of the South West Fields that is to develop after this pilot appraisal well, as shown in the below picture.

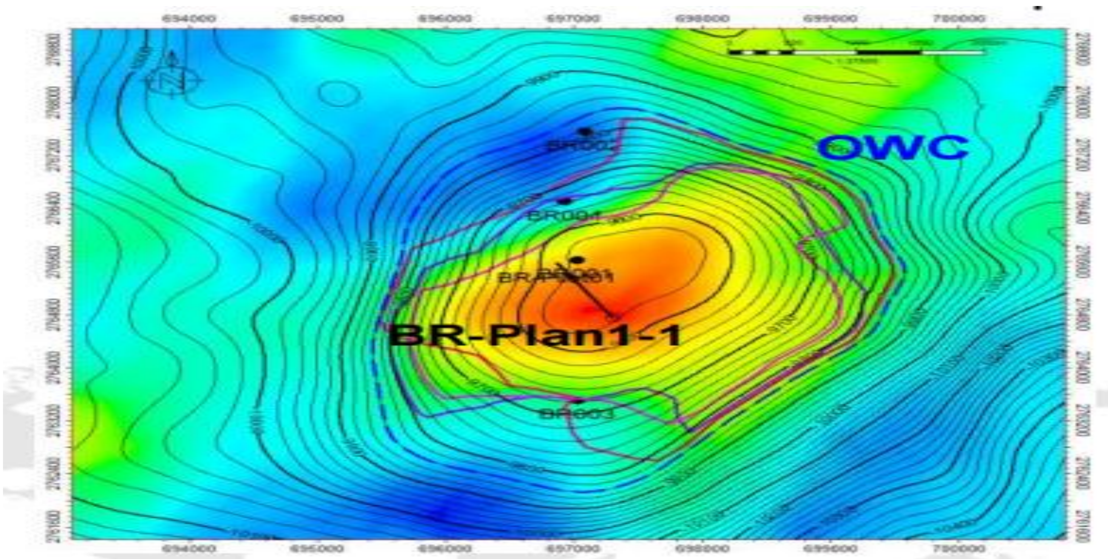

Figure 1: Reservoir distribution map and location based on structure map in Field B.

The challenges for developing Field B come from Reservoir D, a heterogeneous tight marginal field with low permeability ranging from 0.2--5md by different sub-layers where porosity is from 10%--15%. There are five sub-layers from D1, D2, D3, D4, and D5, where D5 is water bearing sub-zone, as shown below.

Table 1: Pay zone sub-layers for Reservoir D in Field B.

Layer	Oil-Bearing Km^2	H ft	Ave. φ %	Ave. K mD	Ave. SW %
D1	16.5	13.2	12	4.33	27.8
D3	14.8	37.5	11	0.23	40.9
D4	11.9	50.1	10	0.30	52.0

From the above table, the sub-layers are as follows:

1) Arab D1: Average porosity, 12%, Average permeability, 4.33mD, Average SW, 0.27.8.

2) Arab D3: Average porosity, 10.9%, Average permeability, 0.23mD, Average SW, 0.409.

3) Arab D4: Average porosity, 10.4%, Average permeability, 0.30mD, Average SW, 0.520.

All types of rocks in the reservoir have stable distribution and good continuity; limestone develops in Arab D3 & D4. Thus, Arab D1, D3, and D4 are drilled in the horizontal well, menawhile D3 and D4 need stimulation.

Based on appraisal well data, the average production rate is around 500 BOPD. The major challenge of Reservoir D is the huge difference between D1 and D3/D4, although those are low permeability.

It is undoubtedly recommended that drilling a horizontal well can lead to increased well productivity in Reservoir D thin bed formation. However, utilization of multilateral well is declined because of their higher cost and complexity offshore.

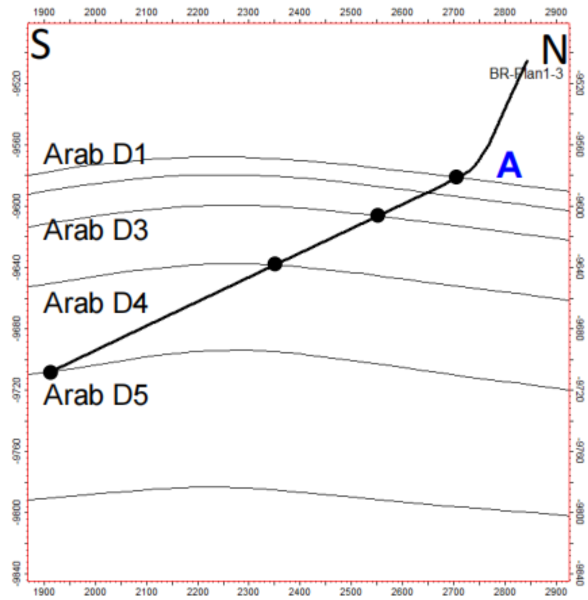

Figure 2: Pilot well path section.

The best well stimulation techniques will be screened and evaluated. Firstly, general stimulation techniques used to address near well damage, such as matrix acidizing, might be available for the D1 sub-layer. It has been proven that conventional and even advanced stimulation techniques might be short-lived and have a minimal impact on D3/D4 tight sub-layer.

The initial design is acidizing fracture as it is commonly used as a well stimulator for low permeability reservoirs to increase flow area for more productivity. There are five stages of acidizing fracture to get two times of oil production, as shown in the figure below.

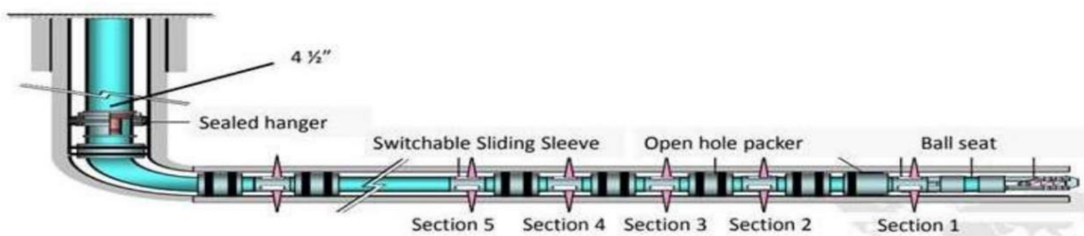

Figure 3: Multi Stage Acidizing Fracture design in Reservoir D.

Based on the core test result, the fracture pressure of D3 reaches 14398psi, which is a big challenge for acidizing fracture in an offshore field as it doesn't have enough equipment and experience in Abu Dhabi.

Table 2: Core lab test result.

NO.	Minimum Principal Stress, Psi	Maximum Principal Stress, Psi	Biot	Pore Pressure, Psi	Tensile Strength, Psi	Fracture Pressure, Psi
1	8874	9559	0.784	4799	870	14166
2	8931	9620	0.763	4798	899	14398

Each well stimulation technique has its pro and cons. Fish-bone stimulation is fit-for-purpose and pilot application in reservoir D as it is installed with a liner and placed in the potential pay zone by connecting the sub-layer with jetting tube(needles).

2. Fish-Bones Completion & Stimulation Technology

As we know, it is very confusing for drilling & completion engineers as Fish-bone technology is regarded as one of the drilling approaches to maximize reservoir contact by several laterals in the pay zone. Therefore, we rename Fish-bone Technology to Fish-bones Completion & Stimulation technology (Abbreviated FCS technology) hereby.

Well stimulation technology is favored in low-quality reservoirs of mature fields because it revitalizes lots of oil & gas wells in a relatively short period of time as shale boom in the world. However, it is not always the best solution when it is heterogeneous tight carbonate with different sub-layers in an offshore field. The current practice of Fish-bones Completion & Stimulation in a thin layered carbonate reservoir has proven to be more effective and efficient as hundreds of tunnels drain connecting the wellbore to the body of the reservoir to increase well productivity and oil recovery.

FCS is a special lower completion string combined with an acidizing solution to effectively drain the reservoir by drilling only one mother bore well but having many oil flowing channels created by unique Fish-bones jetting needles. The lower completion liner of several subs consisting of Fish-bone needles create four multilateral tunnels by each sub to the main well and penetrate different layers by jetting acid within Fish-bone needles, and then oil circulates back through the Fish-bone annulus.

Figure 4: Fish-bones jetting Technology.

Fish-bone Technology started the first jetting installation in November 2013 and finished the first Fish-bones Drilling installation in July 2015. Total application of Fish-bones technology has been reached to more than 50 wells in the world and targeted over 100 installations in the near future after this technology got the ONS Innovation award, OTC spotlight on new technology, and Gullkronen Award [1].

The main advantages of Fish-bone compared to hydraulic fracturing are as below:

- The pressure drop in the Fish-bone fracture tunnel is negligible.
- Less operating time and installation equipment.
- Water/Gas coning is easier to avoid due to limited but sufficient needle height.
- Fish-bones simulation is easier to predict as a hydraulic fracture with more uncertainty for conductivity area.

3. Initial Plan and Re-Design

The initial plan for this heterogeneous tight reservoir is a multistage acid fracture, significantly improving productivity without complicating drilling and well completion [2-4].

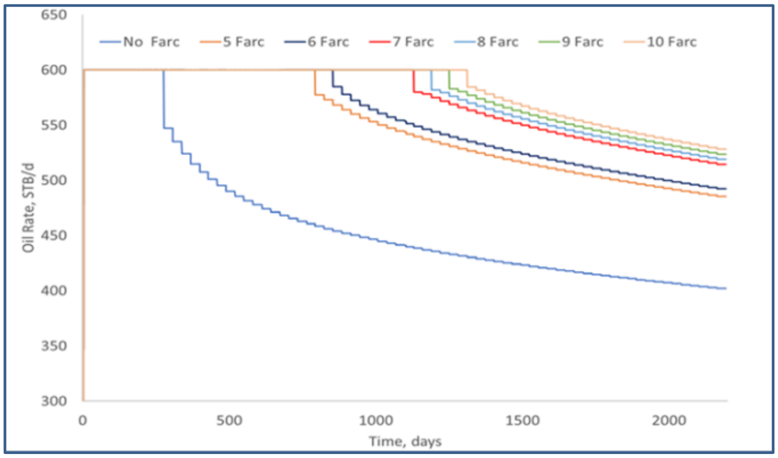

Figure 5: Stage Assessment for Multistage acid fracture.

As normal acid frac job and up to 10 MSF stages were assessed, the result shows us that the stable production period did not increase much after the number of stages exceeded 7.

In addition, there are two challenges as below:

(1) Material and operational readiness can be a challenge on offshore platforms.

(2) Fracture pressure of D3 reaches 14398.5psi, which is a higher operation and HSE risk.

The Pilot work plan is as below:

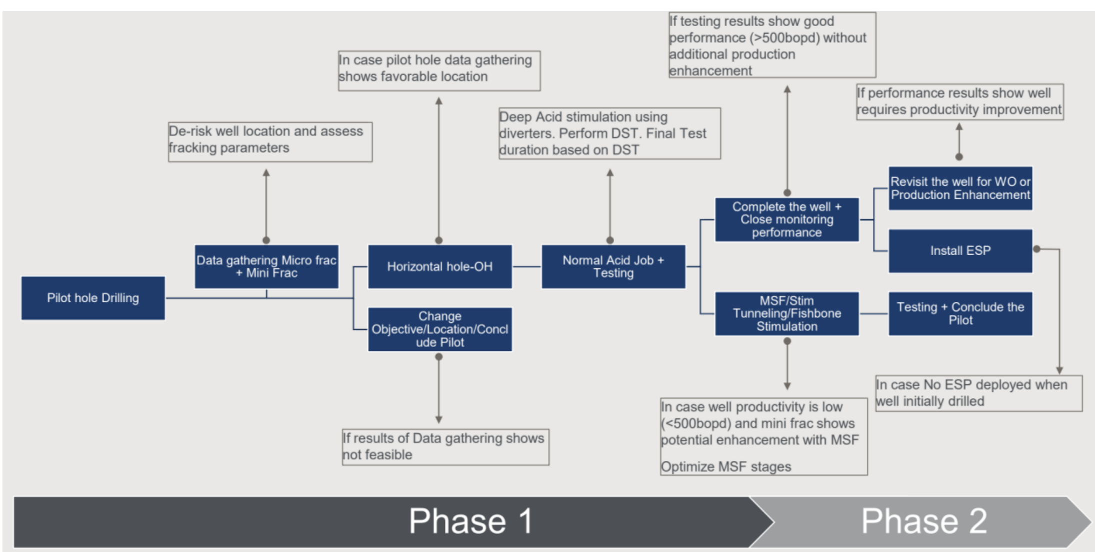

Figure 6: Pilot decision process for different approaches.

Another method to increase well productivity of the D pay zone in Field B is drilling stair step horizontal or dual lateral well, even using fish-bone well technology –five laterals (100m length).

3.1. Option A, Stair Step Horizontal Well

The engineering is relatively simple, and the oil drainage area is increased to some extent with more high-quality reservoirs penetrated. However, this lowered productivity compared to other options. Well completion is relatively complex. This is similar reservoir situation in MIS field case [5].

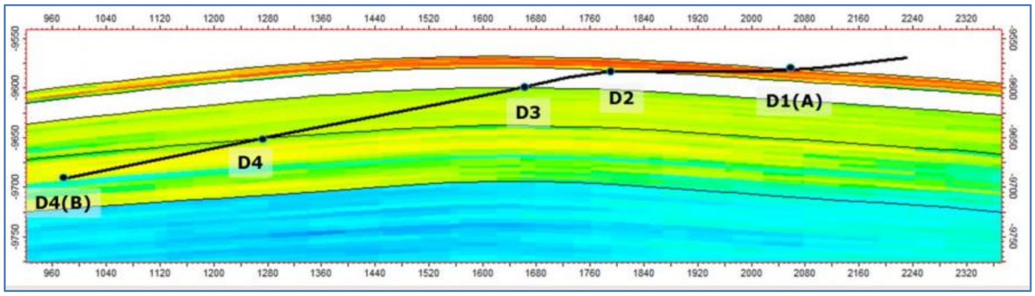

Figure 7: Well Trajectory of Option A.

3.2. Option B, Dual Lateral Well

Design can be considered as 1st Lateral Target: D1, D3, and 2nd Lateral Target: D1, D4.

The advantage is a larger oil drainage area and an increased production rate (reflected in an extended plateau). However, well drilling and completion are complex. ESP deployment difficulties. The most dismaying con is the high cost for TAML Level4.

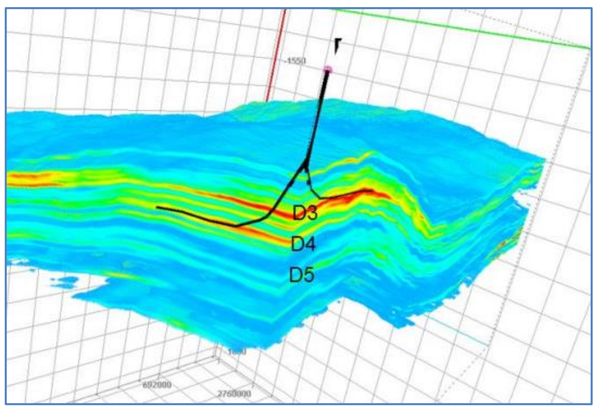

Figure 8: Well Trajectory of Option B.

3.3. Option C, five lateral Fish-bone Drilling

Multiple options of different numbers of Fish-bone laterals were considered at different angles of deviation from the mother hole. The optimum option is five laterals, 100m in length, at 40-50 degrees from the Main hole. So the oil drainage area is relatively large, causing higher production rates. Nevertheless, well completion is relatively complex. Incremental recovery is not as high as other options [6-9]. Engineering feasibility requires further demonstration. Not available for deep stimulation or Acid Frac also.

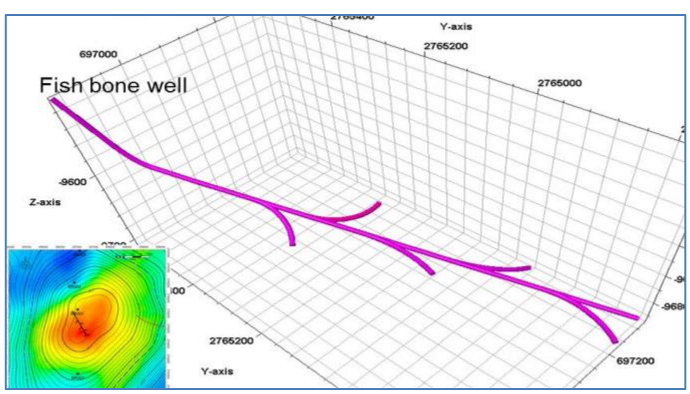

Figure 9: Well Trajectory of Option C.

All of those design scenarios are not satisfied till SHs got a good practice of Fish-bones Completion &Stimulation Technology has been successfully applied in another Field A, the Onshore field of Abu Dhabi.

3.4. Option D, Fish-bone Completion& Stimulation Technology

FCS feasibility study is the first step before making a final decision for reservoir D of Field B. Core test with its needle combined by acidizing.

The testing was performed at the Fish-bones A/S facility in the lab following the standard Fish-bones process to assess different formations. Although this test will be performed on small-scale samples, full-scale testing has confirmed this testing method as effective for the qualifying process. Fish-bones have verified that it is possible to penetrate the formations from which the samples originate with its Jetting technology.

All samples reacted well with the 15% HCl acid blend (including additives as per the recommended recipe). Overall, the samples had a generally high dissolution rate. Acidizing design also refers to reservoir characterization and wellbore stability [10-14]. An average dissolution rate of 0.86 g/min was achieved across all the samples in the test. Sample 9 had the highest rate of 1.40 g/min, while sample 8 had the slowest rate of 0.64 g/min.

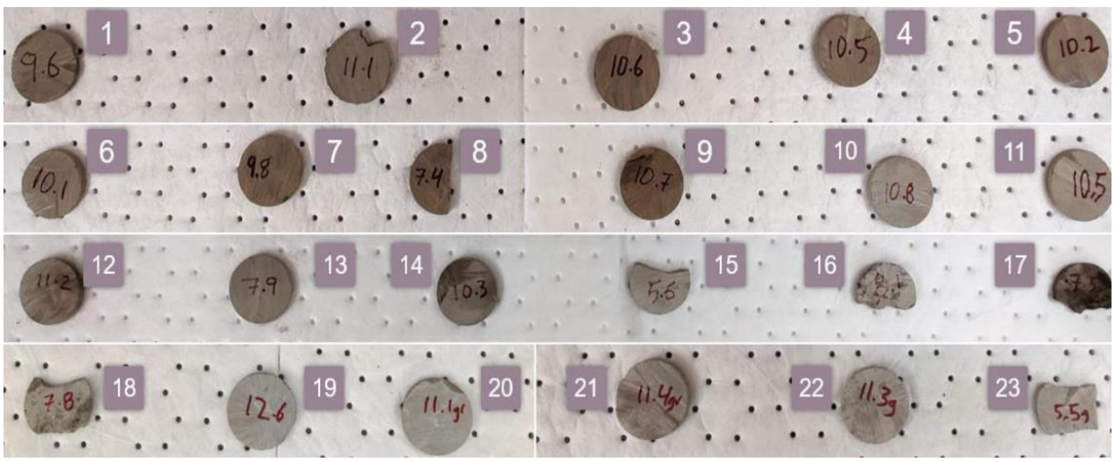

Figure 10: Demonstration of core sample chips prior to a dissolution test.

Remarks: The number written on the core sample denotes its weight.

A complete overview of the results is shown in Fig. **11** below.

Figure 11: Jetting test result in the lab.

FCS Acid jetting technology is recommended for D reservoir application due to the reactiveness of the formation when exposed to acid, as per the lab report.

The initial FCS design is to install all subs from D1 to D3 and D4. However, there are two factors to be considered for re-design. One is that severe losses happened based on FCS experience in the field [15-20]. Another is a significant risk for fishing basket needle recovery as it is failed case [21].

Therefore, the modified 4-1/2" Fish-bones stimulation system was installed in the lower two sub-layers combing with the production sub for matrix acidizing in the upper one sub-layer.

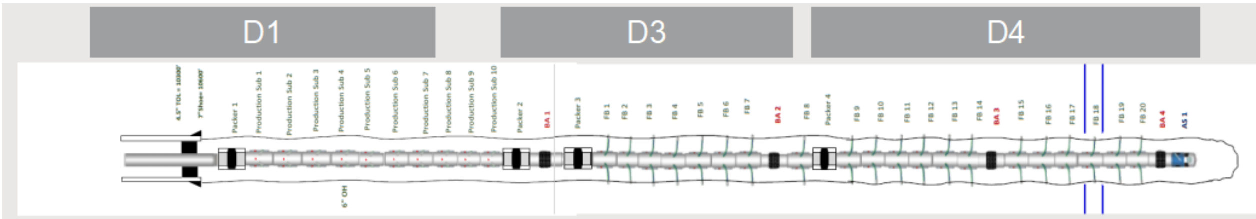

Figure 12: FCS design in D reservoir of Field B.

The plan is to run lower completion with 4 1/2" liner deployment with a Fish-bone Jetting system of 20 Fish-bone subs creating 80 laterals in addition to 10 Fish-bone subs for the production of reservoir section D1 swellable packers for zonal Isolation.

Considering the lessons of failure to clean internal tubes after completion of the Fish-bones System in the other wells, the modified 4-1/2" Liner is installed in the lower two sub-layer by jetting subs combing with production subs for matrix acidizing in the upper one sub-layer.

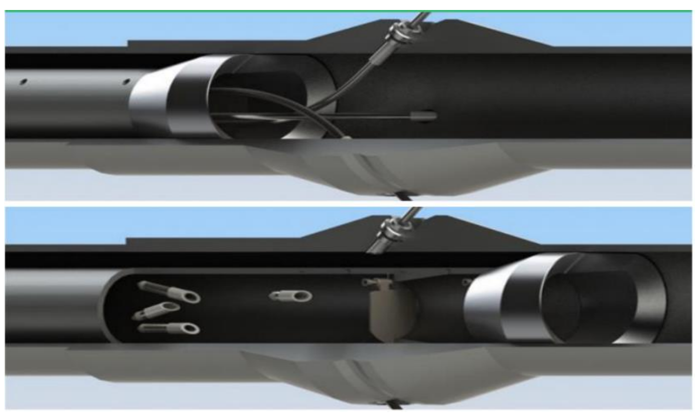

Figure 13: FCS fishing Basket after modification design.

In addition, special acid-releasing float shoes and new Fishing baskets are applied to avoid those previous problems with this well techniques after many discussions and workshops with vendors.

4. Execution

FCS project schedule is as below after feasibility and re-design alignment with SHs.

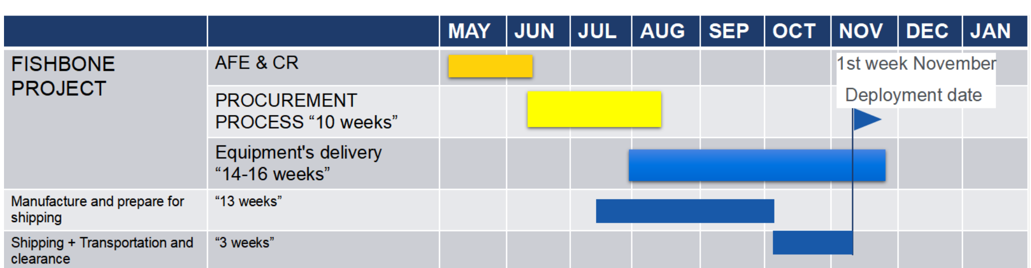

Figure 14: Fishbone Project Schedule.

Well B00X Lower completion summary

• 4 ½" Completion with 10 production sub + 20 Fish-bone subs + 4 anchors along with 5 oil swellable packers

• Each Sub includes : 4 needles (40 ft. each) + 2 Production ports (7mm) + 2 way ports (7 mm)

Figure 15: Needle Cutting during Fish Basket.

Acid strength – the HCL acid strength of 28% was initially recommended as per injection well of B Field to achieve maximum efficiency of improving formation penetration. However, as the FSA jetting system not only uses the dissolving properties of the acid, but also the mechanical jetting properties of the fluid, the recommendation for the stimulation is 15% HCL because this is standard for FSC jetting system.

Acid volume – 3000 bbls acid volume(5.8-6.3 bpm) was discovered to be excessive after the fact, as we now have a better idea of how the specific formation reacts to the stimulation process.

After completion of the acid job, upper completion was run in a hole with 3 ½" tubings (ESP will be deployed in the near future). Subsequently, the cleaning job was conducted to cut and remove the left-out needles in the liner. Five fish basket runs were completed to clean the 20 subs (80 needles). Based on the lengths of needles recovered, the depth of penetration of each needle was established. Below Figure **15** shows the penetration length of each needle:

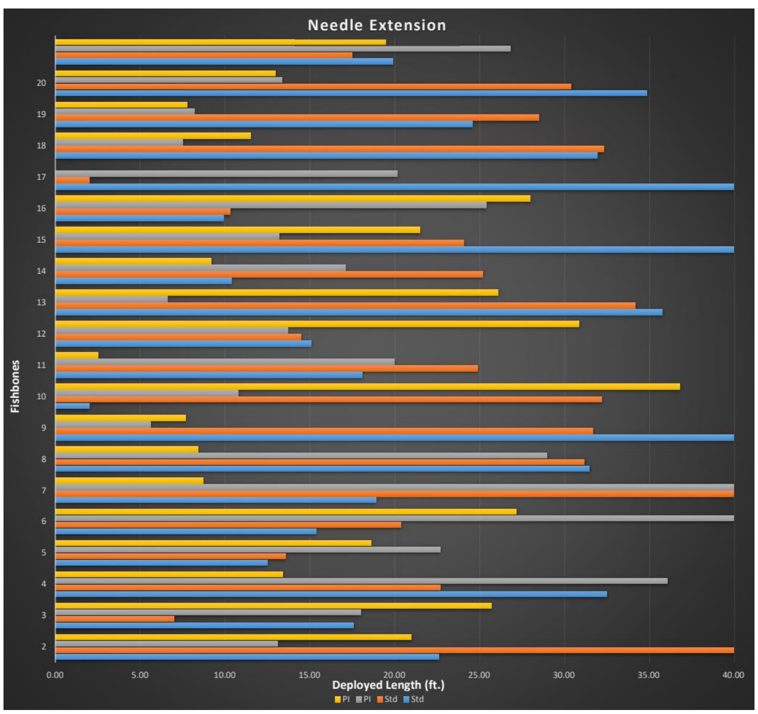

Figure 16: Needles penetration summary.

Deployed length is 1684ft in D formation, occupied by 53%. Meanwhile, seven needles have 100% deployed length. The completion fluid is 10.1ppg filtrated inhibited brine CaCl2 even though there are 14,141 bbl severe losses after deployment of FCS.

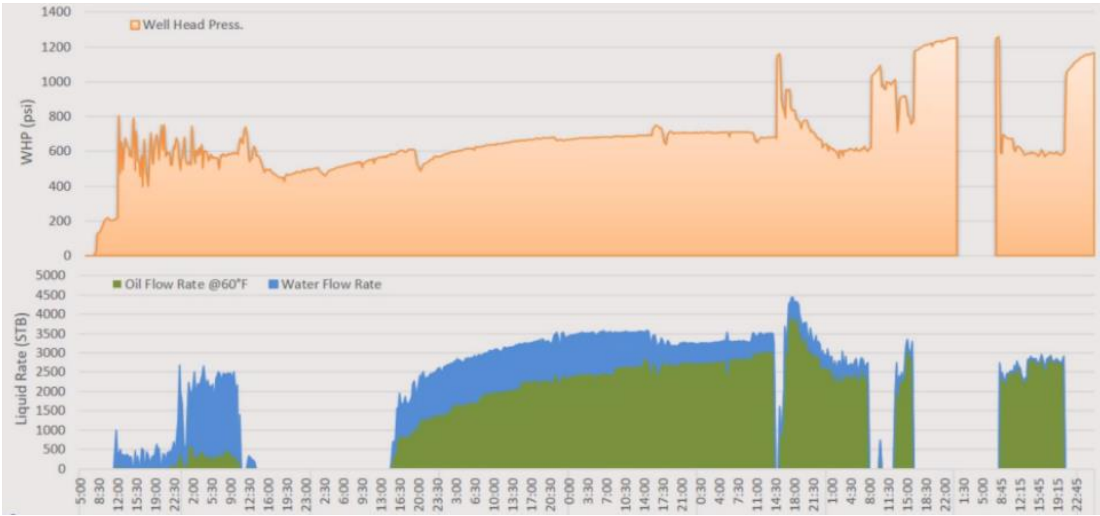

Figure 17: Well test performance of FCS well.

Liquid rate 2924BPD within 2895bbl oil plus 29 bbl water when BSW reaches 1%. Total 11200bbl oil recovery during N2 flow test.

5. Lessons Learn

Although it is a very successful application in field B, there are some lessons to be gotten as below.

Table 3: Lessons learn.

No.	Lesson Learned / Issue Encountered	Proposed Possible Corrective Action
1	Needle serial numbers are not visible	Find a better solution for marking on Inconel strainers.
2	Documented lab acid tests with a recipe	Implement a new proposed procedure for lab testing.
3	Post Fish-bones job, losses were observed	Used a Hi-viscous pill to cure the losses.
4	Official note to follow FB procedure through all job	Stress importance to the customer, improved communication to the customer
5	Rack back of 2 7/8" tubing rig Capacity	Confirm the capacity of the rig to rack back 2 7/8" before assigning rig; fish-bones to highlight early in the planning process.
6	Timing for pumping SLB Acid pill	The pill should be made to react with Spent Acid; plan to pump directly after stimulation operation.
7	Section of perforated joints included in Fishbasket not enough to circulate viscous gels	Increase the length of perforated joints or Run Improved Fishbasket design in future operations.

6. Conclusions and Recommendations

Successful application of this technology is a game changer for tight carbonate productivity enhancement, and will be the implementation of other pilots is in progress. Some conclusions and recommendations as below:

- Fish-bone stimulation helped to improve the well test productivity by 4.5 times compared to the initial estimation of 1.5 times and improved production rate by two times, i.e., 2000 BOPD compared to normal well with conventional stimulation during initial testing.

- In the near future, long sustainability of the pilot well will be established by continuously producing the well for six months before deploying ESP. The sustainability outcome will be used to optimize new wells drilling in the next phase of reservoir B development.
- Successful pilot implementation in B00X well proved the applicability of the technology for tight reservoir development with low permeability and poor vertical communication.
- This technology will further reduce the drilling and tie-in costs as part of new development. Since Fish-bone, technology can achieve the same objective of drilling two or more wells to target different sublayers.
- Fish-bone completion will be used as one of the lower completion designs as part of the ADNOCAL Yasat strategy to reduce barefoot open hole completions with more acid volume in the future.

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Abbreviation

SW	=	Saturation Water
mD	=	Millidarcy
BOPD	=	Barrels of oil per day
ONS	=	Offshore Northern Seas
OTC	=	Offshore Technology Conference
ESP	=	Electrical Submersible Pumps
TAML	=	Technology Advancement of Multi Laterals
FCS	=	Fish-bones Completion & Stimulation technology
ADNOC	=	Abu Dhabi National Oil Company
CNPCI	=	China National Petroleum Corporation International

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