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Using Down-Hole Control Valves to Sustain Oil Production From the First Maximum Reservoir Contact, Multilateral and Smart Well in Ghawar Field: Case Study

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Abstract

This paper describes a case-study detailing planning, completion, testing, and production of the first Maximum Reservoir Contact (MRC), Multilateral (ML) and Smart Completion (SC) deployment in Ghawar Field.

The well was drilled and completed as a proof of concept. It was completed as a trilateral and was equipped with a SC that encompasses surface remotely controlled hydraulic tubing retrievable advanced system coupled with pressure and temperature monitoring system.

The SC provides isolation and down hole control of commingled production from the laterals. Using the variable positions flow control valve, the well was managed to improve and sustain oil production by eliminating water production. Monitoring the rate and the flowing pressure in real time allowed producing the well optimally.

The appraisal and acceptance loop of the completion has been closed by having this well completed, put on production and tested. Approval of the concept was achieved when the anticipated benefits were realized by monitoring the actual performance of the well.

Leveraged knowledge from this pilot has provided an insight into SC capabilities and implementation. Moreover, it has set the stage for other developments within Saudi Aramco.

Background

Haradh forms the southwest part of the Ghawar oil field located about 80 kms onshore from the Arabian Gulf, in the Eastern Province of Saudi Arabia (Figure-1). Haradh field consists of three increments where the initial production started in May, 1996 from Increment-1 followed by Increment-2 and 3 in April, 2003 and January, 2006, respectively.

Increment-1 was initially developed using mainly vertical wells while Increment-2 was developed with horizontal wells. The subsequent MRC, ML wells and Smart Completion installations in Increment-2 were part of a proof of concept project to test and evaluate the impact of these technologies on reservoir, well performance and overall reservoir management strategies. As a result of the proof of concept project, Increment-3 was developed with MRC, ML wells with SCs.

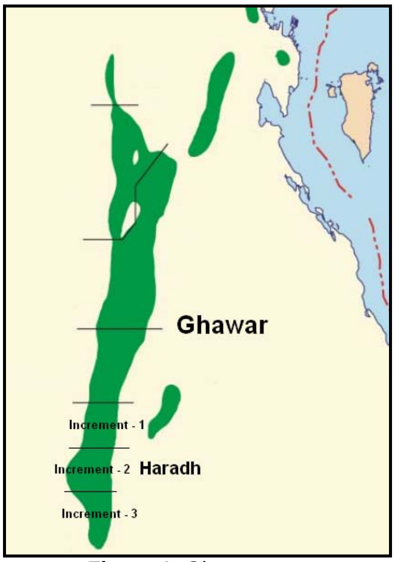


Figure-1: Ghawar map

Modeling was extensively used to illustrate the potential benefits of the incremental expenditure of MRC, ML wells with SCs versus conventional completions[1, 2]. Several authors quantified potential gains from using such wells and completions in fields' developments [5, 6].

HRDH-A12 is the first MRC, ML well that was equipped with SC in Ghawar Field. It was drilled and completed as a trilateral selective producer with surface controlled variable multi-positional hydraulic controlled system.

This paper discusses a closed-loop approach that led to efficient realtime production optimization. The evaluation loop of the technology was closed by having the well completed, put on production and tested. Approval of the concept was achieved when the anticipated benefits were realized by monitoring the actual performance of the well. This paper describes a case-study detailing planning, completion, testing, and production. It concludes with impact and lessons learned for future SCs.

General Geology:

The producing horizon at well location belongs to the lower member of Arab-D formation which is characterized by a complex sequence of anhydrite and limestone events with varying degrees of dolomitization. This particular well is located in the west flank of Haradh Increment–2 in an area characterized by heterogeneity in reservoir rock properties, salinity and fluid movement. Fluid mechanism in this specific area is highly influenced by the presence of fracture corridors and strataform super permeability. The motherbore of this well (L0) extends to the vicinity of the projected flood front while the other laterals extend away from the flood front (Figure- 2).

The location dictated drilling a well that can capture realtime data, maximize control, optimize production, and increase well value.

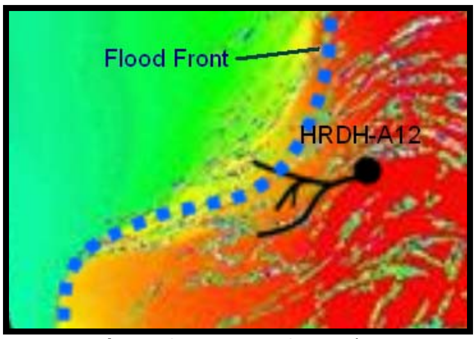


Figure-2: HRDH-A12 Location

Completion Strategy:

After analyzing the reservoir data, SC solutions were sought in consideration to meet reservoir and production main objectives but not limited to:

- Sustain well productivity
- Improve sweep
- Selective control of multiple laterals
- Manage water production
- Minimize production interruptions

Completion Design:

Haradh-A12 well was drilled in April, 2004 and was completed with a 7" liner set horizontally into the Arab-D producing interval. A 6 1/8" horizontal open hole was then drilled out from the bottom of the 7" liner. Due to heavy losses while drilling L-0, a 4-½" liner was set covering part of this open hole section. Two 6-1/8" horizontal sidetracks (L-1 & 2) were then drilled from the 7" liner completing the tri-lateral well. The well was initially completed and put on production from bare-foot laterals. A year later, the well was worked over to install a SC

The SC using three variable down hole flow control valves was designed to provide control of the inflow from each open hole section of the well (Figure-3). These valves operate as downhole chokes to restrict or completely shut off production from any interval with increasing water cut overtime.

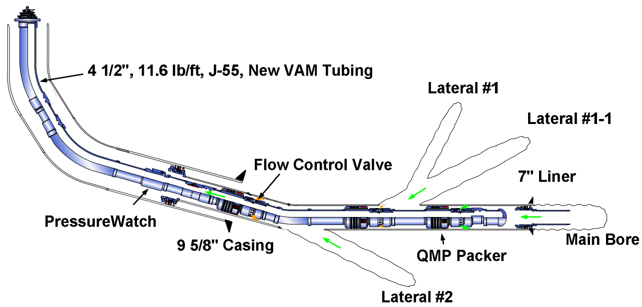


Figure-3: Haradh-A12 Smart Completion Schematic

Nodal analysis and production simulation were conducted to design and optimize choke sizes. In turn this enabled the optimum downhole control setting during the production life of the well (Figure-4).

The completion was designed to meet the following key objectives[7]:

1. Individual zonal production control with a remotely controlled hydraulic flow control valves.
2. Real time reservoir pressure & temperature data.
3. Zonal isolation between the three laterals.

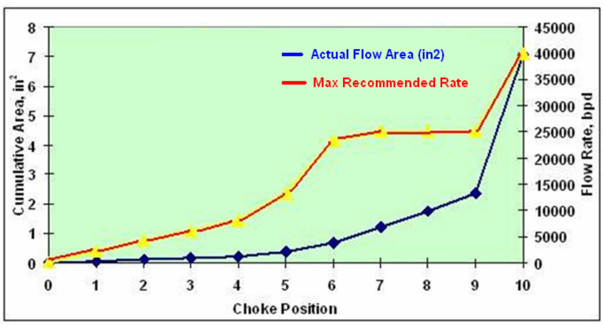


Figure-4: Downhole Choke Valve Flow Area and Recommended Flow Rate

Equipment was qualified for the production life of the well. Permanent Downhole Monitoring System (PDHMS) was selected to be placed above the top packer to monitor flowing and shut in pressures and temperatures. Flow control valves are equipped with 11 positions, of which one is fully closed and one is equivalent to the tubing flow area. The flow areas of the remaining 9 positions where individually designed to represent the most optimum choke settings for the life of the well. The flow control device was successfully qualified with 1,320 individual cycles and multiport packers were used for this installation (Figure-5).

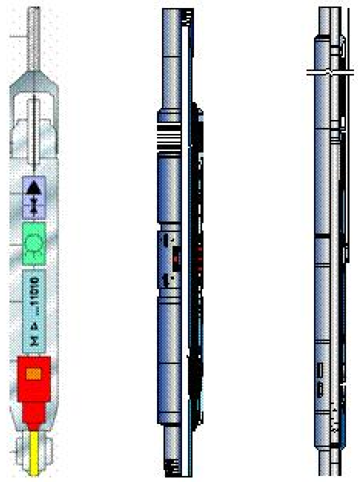


Figure-5: Gauge, Mulitport packer and Flow control valve

Drilling and Geosteering:

The well was drilled across the top ten feet of the Arab-D with a total reservoir contact of 5.6 km (Table-1) and average porosity of 18% which was accomplished through real-time geo-steering.

Lateral	Length
L0	7125’
L1	4042’
L-2	7200’
Total	18367’

Table 1: Lateral Lengths

During the drilling phase, the plan was revised regularly based on actual zone depths. Due to sudden changes in formation dip, a few deviation from the plan occurred. Among the changes were placing the motherbore and Lateral-1 lower in the reservoir. Lateral–2; however, climbed to tight Anhydrite above the Arab-D and was steered back into good porosity by having a sidetrack. During drilling, total loss of returns was encountered in all three laterals.

The design of this tri-lateral honored the objective that calls for having the proper separation between laterals to avoid interference[3].

Completion Performance:

A multidisciplinary team consisted of reservoir, drilling, completion and production engineers as well as the vendor’s experts was formed in order to assure smooth and successful operation. The team applied a project management approach to the design, planning and installation processes.

The SC was subsequently installed in early April, 2005. During the equipment testing, installation and subsequent flow testing of the well, each of the valves were actuated through more than 10 complete cycles (110 position changes) which is equivalent to several years of typical operation. As a precautionary measure and to ensure the functionality of the Downhole Control Valves, the valves were tested downhole prior to setting the packers.

During testing of the well once the completion was installed, a multiphase flow meter provided three phase flow rates measurements. This data along with the downhole pressure and temperature measurements were transmitted in real time for instantaneous analysis and subsequent decision.

Well Performance:

Prior to the installation of the SC, the well was put on production from bare-foot laterals. The well was tested at a rate of 18 MBD dry oil at a choke setting of 95/64. The analysis of the transient test that was conducted on June 19, 2004 indicated a productivity index (PI) of 350 BPD/psi as compared to 17 or 31 BPD/psi for offset vertical or horizontal wells. The well test indicated the presence of anisotropy which is in good agreement with the image log results and loss of returns while drilling which indicates the presence of fractures/faults intersecting the horizontal well.

Within two months of production, the well started producing water. The last test prior to the workover indicated a water cut of about 23% at an oil rate of 8 MBD.

Laterals Pressure Transit Testing:

During the testing the well post SC installation, short duration build ups were performed on each lateral. The productivity testing for each of the laterals was accomplished by testing an individual lateral whilst the other two laterals were closed. Build-up tests were conducted following the production rate tests by shutting-in the well using surface valves.

This was done to determine the PI of each lateral which helped to decide which downhole choke setting to use for each lateral when the production is commingled.

Details of the initial productivities of the laterals are shown in Table-2:

Transient Test Results	
Lateral	**Productivity Index (PI) (BPD/psi)**
L2	165
L1	60
L0	80

Table 2: Build up Test Results

If it were not for the Smart Completion and PDHMS capabilities, conducting individual lateral transient test in a multilateral well would not be feasible and would require intensive intervention.

Optimization of Downhole Chokes Settings:

The well started producing water after two months of production. After five months of production at an average oil rate of 8.0 MBD, the water cut has increased to 30%.

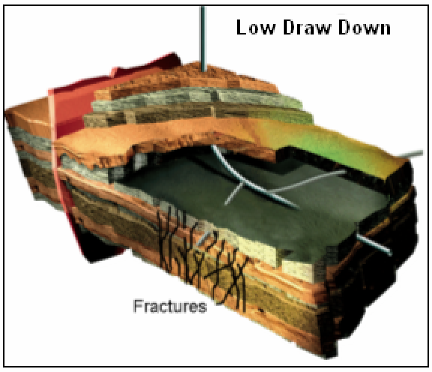
Upon that, a comprehensive rate test was done on the well. The testing involved several downhole choke settings combinations with an objective to come up with optimized settings that honor the production strategy for the well and the area (Table-3).

Test results indicated that L0 was completely wet while the production rate and water cut from L1 were choke sensitive which is a possible indication of the existence of coning through vertical fractures. The impact of natural fractures on dominating production in L1 was controlled by using the downhole flow control technology. For instance, when the lateral operates at higher drawdown (i.e., higher downhole choke setting), water cut increases as water elevates via vertical fractures (Figure-6). The final configuration was adjusted to have L0 closed, L1 open at choke setting of 3 and L2 at choke stetting of 2 (Test# 7). Using the surface choke, the total withdrawal of the well was restricted to an oil rate of 5 MBD and 0% water cut. Since then, the well has been producing at this rate with no water production.

Optimization of SC downhole chokes' settings resulted in a significant improvement in well performance. Nodal analysis was conducted to optimize Downhole Choke settings. Production optimization tools can be used as a step towards intelligent and integrated application of SCs[5].

Test	**Downhole Chokes Setting**			**Rate (MBD)**	**WC%**
	L0	**L1**	**L2**		
1	5	3	2	7.7	22
2	5	0	0	1.0	97
3	0	0	5	3.5	65
4	0	0	2	3.5	0
5	0	3	0	3.9	0
6	10	10	10	Dead	-
7	0	3	2	6.0	0

Table-3: Rate Test Results at variable downhole chokes settings



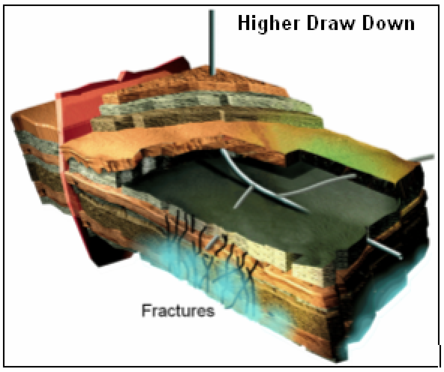


Figure-7: Higher drawdown triggers water production through vertical fractures.

Impact and Lessons Learned:

Leveraged knowledge from this experiment provided an insight into SC capabilities and implementation; moreover, it set the stage for other increment developments (i.e., Haradh Increment-3). Several lessons learned of high impact can be identified, most notably:

- Quality control of the system is a priority for successful implementation. This can be illustrated by function testing the completion in hole prior to setting the packers.
- HRDH-A12 could have been dead without smart completion.
- Realtime surveillance and control capabilities permit proactive measures.

- Downhole flow-control can alleviate natural fractures impact on dominating production.
- Smart Completions have demonstrated potential to reduce well interventions[4].

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