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Deployed Smart Technologies Enablers for Improving Well Performance in Tight Reservoirs—Case: Shaybah Field, Saudi Arabia

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Abstract

Intelligent wells are becoming the buzz word in the oil and gas industry. Today the development and deployment of smart technologies are important drivers for improving well productivity and delaying early water or gas breakthrough in tight and challenging reservoirs.

Shaybah field, a low permeability reservoir overlain by a huge gas cap was initially developed in 1996 with one-km single lateral horizontal wells to effectively drain the hydrocarbon while reducing gas coning. A step development approach by increasing the reservoir contact to improve well productivity and performance was the basis for Maximum Reservoir Contact (MRC)[1] concept. Maximizing reservoir contact through MRC wells was one of the measures taken in early 2002 to reduce gas coning and improve recovery. Results to date from 37 MRC wells have indicated a four fold increase in well productivities and a three fold decrease in unit development cost when compared to the one-km single lateral wells.

In addition, several advanced completion technologies such as downhole flow control systems (smart completions), expandable liners, and production equalizers were deployed in Shaybah Field. These technologies have shown major improvements to well performance and recovery. Smart controls assisted in optimizing production from each lateral in a multi-lateral setting in the event of premature gas or water coning. In addition, downhole smart completions improved well productivity in multi-lateral wells through an improved well cleanup process. Production equalizers when deployed in high GOR wells reduced gas coning by 50% and improved well productivity. To date, over ten expandable liners have been deployed as enablers to a workover strategy to convert single lateral wells to Multi-lateral/MRC wells thereby providing the platform for installation of downhole flow control systems. Shaybah Field holds several world records in the area of technology implementation; one of which is for the first MRC window to exit from 5-1/2" expandable allowing the placement of 2-7/8" ICV for inflow control. This paper will highlight how smart technologies have positively impacted field performance.

Introduction:

The mid-1990s witnessed the development of the Shaybah field in southeastern Saudi Arabia utilizing horizontal drilling technology as the preferred development mechanism to drain, produce and sustain a targeted production rate.

The field was initially developed with 106 horizontal wells, each with one km single lateral producing from the Shu'aiba reservoir characterized with an average reservoir permeability of 13 mD. The presence of a large gas cap and a relatively weak aquifer above and below the tight Shu'aiba reservoir (Figure 1) dictated the need to develop this field with horizontal technology to delay and minimize the potential for early gas breakthrough and/or water coning, and also economically produce the field at well rates in excess of critical coning rates for vertical completions.

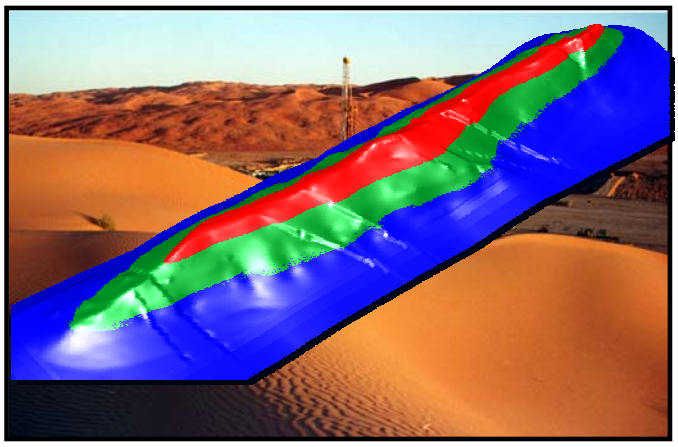

Figure 1- Three-D View of Shu'aiba Reservoir Superimposed on a Picture of the Shaybah Field

The performance of the initial development one km single lateral horizontal wells was as projected by in-house reservoir simulation studies[2]. Assessing the performance of these wells

required a comprehensive testing and logging programs to quantify the effective horizontal well length especially in areas where lateral permeability variations exist[3].

Following the initial development and based on wells and field performance, reservoir contact was gradually increased by drilling 2 km and 3+ km single lateral wells. From 1998-2001 this step approach resulted in significant improvements to well performance in terms of increased PI, lower drawdown, and further delays in gas coning. This success led to the birth of the MRC well concept.

In early 2002, the MRC concept was initiated in Shaybah Field by drilling the first MRC well, SHYB-380 as a tri-lateral well with a maximum reservoir contact of 8.5 km. This well, along with SHYB-378 and SHYB-220 as shown in Figure 2, were drilled with reservoir contacts of 5.8 km and 12.3 km, respectively and were completed as openhole. Drilling and production performances of these MRC wells were summarized in various SPE technical publications [4, 5].

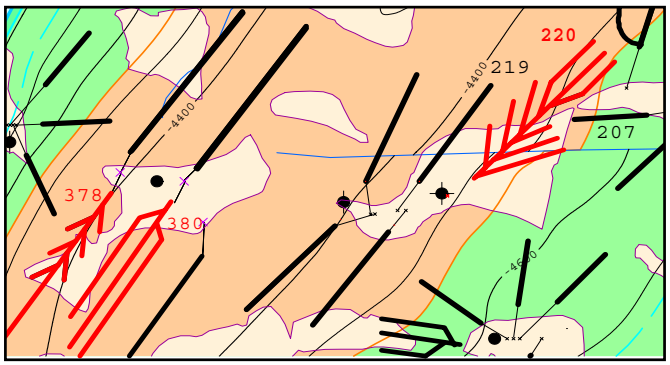

Figure 2- First MRC/Multi-laterals Wells in Shaybah Field

Drilling the MRC wells required introducing new technologies with expected business impact to improve well performance. Several new advanced completion technologies such as downhole flow control systems (smart completions), expandable liners, swellable packers, permanent downhole monitoring systems (PDHMS), and production equalizers were deployed in Shaybah field especially in the last three years to optimize the field development.

This paper will investigate the various intelligent technologies that were deployed in Shaybah Field and their impact on field performance.

Background:

Field History: The Shaybah field, discovered in 1968, in the Rub' al-Khali desert of Saudi Arabia, is approximately 13 km (8 miles) wide and 64 km (40 miles) long. The surface terrain is comprised of salt flat areas known as *sabkhahs* and mountainous sand dunes (up to 200 meters high). Because of its rugged character, the field is developed from the flat *sabkhahs* necessitating highly directional drilling to reach the targets.

The oil in the Shu'aiba formation is Arabian Extra Light with an average API of 42º and a solution GOR (Gas-Oil-Ratio) of 750 SCF/STB. The field went on production in July 1998.

Shaybah Geology and Tectonic Setting: The field is characterized as a gently folded northeast-southwest trending anticline consisting primarily of cretaceous age sandstones, shales and carbonates. The reservoir consists of ruddist build-ups that vary laterally into barrier and shelf slope facies[6]. While matrix porosity is generally high, with an average of 25%, and does not vary laterally; permeability is facies-dependent and exhibits spatial variability. In south Shaybah permeabilities range from 5 to 10 mD, whereas in the north the matrix permeability ranges from 50 to 200 mD. Three-D seismic data show the Shu'aiba reservoir to contain a number of faults. These faults and fractures have been identified from openhole logs and are most prevalent in the northern part of the reservoir.

Implemented Technologies:

Encouraging results from the first three MRC wells and the need to optimize production from each lateral has dictated the need to evaluate and install smart completions, i.e. downhole flow control systems. Furthermore and building on the success of the MRC wells; an aggressive workover program was initiated to convert the existing one-km single lateral weak wells that were drilled during the initial development (1996-1998) to MRC or multi-lateral wells. These wells were excellent candidates for smart completions utilizing a combination of expandable liners or swell packers with downhole flow control systems. The utilization of these advanced completion technologies has further enhanced the effectiveness of the MRC wells in reducing overall development cost.

I. Maximum Reservoir Contact Wells (MRC):

To further address the challenge of producing the low permeability formation and manage the gas cap, the drilling strategy had evolved from drilling single lateral horizontal wells to drilling long reach MRC/multilateral wells to maximize the reservoir contact per well. These maximum reservoir contact wells (greater than 5-km of contact) have resulted in increasing well productivity and reducing unit development cost. Figure 3 reflects the impact of increasing reservoir contact on cumulative production in south Shaybah wells where the permeability averages around 8 mD.

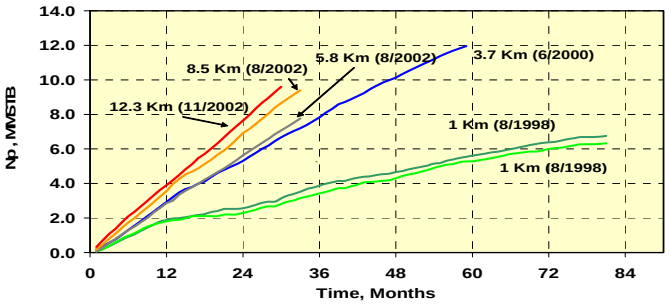

Figure 3: South Shaybah Area: Cumulative Production versus Time at Varying Reservoir Contact (6 Wells)

To date, over 50 MRC wells have been drilled of which 27 have been completed utilizing smart well completion technologies. MRC wells with advanced well completions have been accepted as standard operating practice in Saudi Aramco.

The high flow rate of a typical Saudi Aramco multilateral well requires a mechanism to manage and control each lateral separately so an impaired lateral does not disrupt productive laterals. This can be achieved using smart completion.

II. Smart Well Technology:

Saudi Aramco has successfully installed the first hydraulic down-hole flow control System in Saudi Arabia in March 2004, in Shaybah Field. The objectives of using this system are to improve the reservoir's management, increase the life of the well and to avoid intervention. The first smart completion was installed in a multilateral (tri-lateral) well targeting one reservoir with total reservoir contact of 8.7 km (28,670 ft). The well is located under the gas cap, and wells in such location have a tendency to produce gas and /or water. Smart system in this well consists of 10 choke settings per lateral [including on and off]. This allows to hydraulically flow and test each lateral at a time and/or to completely isolate any of the laterals separately, if needed from the surface (Figure 4).

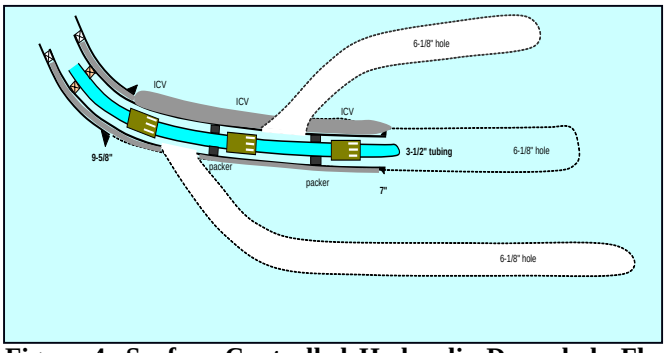

Figure 4: Surface Controlled Hydraulic Down-hole Flow Control System

The well was placed on production in July 2004 at an initial rate of 10 MBOD. The downhole valves are regularly operated and tested after placing the well on production. Table-1 highlights the results from the first test where each lateral was tested fully open while the other laterals were completely closed. In all cases the surface choke was set at 25% opening.

Table 1 shows that at the tested choke settings each lateral can deliver approximately 9 MBOD which confirms the MRC wells simulation predictions and production logging assessment that each lateral will contribute to flow especially in the non-fractured low permeability facies. Furthermore, Table 1 highlights that when all the laterals are opened, the well can deliver a maximum of 16 MBOD at a surface choke of 35%. At this choke setting with all the laterals fully opened the production was limited by the 4-1/2" tubing size. It is worthy to note that the MRC wells in Shaybah Field will be produced at optimum well rates to maximize recovery. For this well the optimum rate (9-10 MBOD) to delay gas coning.

Separate Lateral Testing at 4 Downhole Choke Settings with Surface Choke @ 25%:

Tested Lateral	Downhole Choke	FWHP, psig	Rate, MBOD
Lateral-1	100%	1017	9.3
Lateral-2	100%	1044	8.9
Motherbore	100%	1036	8.7

Combined Laterals Testing (Downhole Valves are Fully Opened):

Tested Lateral	Surface Choke	FWHP, psig	Rate, MBOD
ALL	25%	1086	10
ALL	35%	895	16

Table 1: Smart Well Testing Results

The smart well installation was part of a pilot program to test and evaluate the impact of smart well technology in reservoir management. The success of this installation opened the door widely for additional installations of different types of downhole flow control systems, where applicable, in various Saudi Aramco fields. Over 27 systems have been installed in Saudi Aramco fields with more then 50 new systems planned for installation in 2006. These installations will help Saudi Aramco to better manage its reserves and further maximize the hydrocarbon recovery.

III. Expandable Liner:

In view of the success of MRC drilling in Shaybah field, the concept was also applied by converting the existing weaker single lateral 1-km wells to multilateral/MRC wells using 5-1/2 by 7" expandable liners. The expandable liner is deployed below the existing 7" casing shoe as a means to provide isolation and separation between laterals, and offers the flexibility to run smart completions in the future, if needed (Figure 5). The design challenge was providing the ability to install downhole ICVs inside the post expanded 5-1/2" liners.

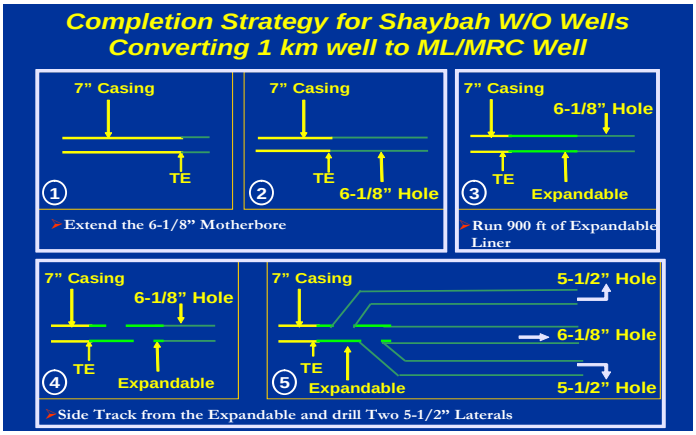

Figure 5: Schematic Showing how to Convert 1-km Single Lateral Horizontal Well to ML/MRC Well

IV. Smart Completion Inside 7 by 5 ½" Expandable Liner:

The world first smart completion in an MRC well exiting from a 5 ½" expandable liner was deployed in SHYB-369 (Figure 6). This well was successfully worked over and converted from 1-km single lateral horizontal well to tri-lateral (MRC) well and completed with smart completion system. During the workover, the original horizontal section was extended by 1.4 km and two additional laterals were sidetracked from the expandable (L-1= 1.5 km and L-2= 2.3 km) for a total reservoir contact of 6.1 km.

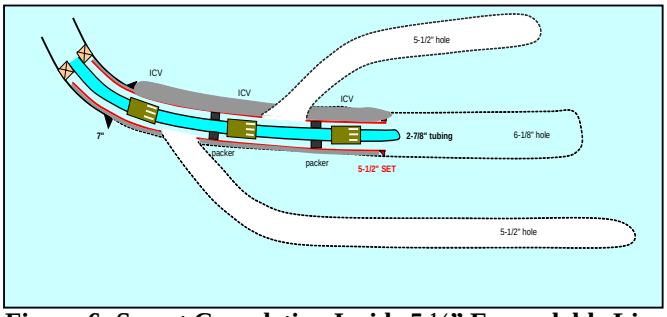

Figure 6: Smart Completion Inside 5 ½" Expandable Liner

V. Open Hole Smart Completion:

In an effort to reduce cost and save rig time, Saudi Aramco ran the world first swellable-packer-smart open hole completion in SHYB-368 (Figure 7). This well was worked over and converted from 1-km single lateral horizontal well to tri-lateral (MRC) well and completed with a combination of swellable packer and smart completion system. The swell packers were used to provide lateral isolation removing the need for the expandable 5-1/2" liner. During the workover, the original horizontal section was extended by 1.0 km and two additional laterals were sidetracked (L-1= 1.9 km and L-2= 2.1 km) for a total reservoir contact of 6.0 km.

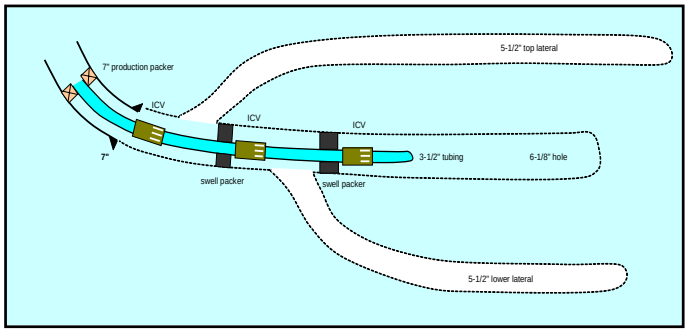

Figure 7: Open Hole Smart Completion

VI. Production Equalizer:

Another advanced completion technology installed in Shaybah Field was the production equalizer which acts as a passive intelligent completion to improve inflow along the horizontal section (Figure 8). The inflow control device (ICD) uses a helical channel as restrictive element to impose a pressure distribution along the entire length of the wellbore. Openhole annular isolation packers are used in conjunction with equalizer to compartmentalize the horizontal section providing passive inflow control. The system was tested in SHYB-257 a high GOR openhole well producing at a rate of 4.5 MBOD and GOR of 6300 SCF/STB. The objective of the equalizer was to reduce the GOR from 6300 SCF/STB to 2500 SCF/STB and improve well productivity. A total of eight external packers were selectively installed along with 20 inflow control devices (ICD) placed along the high permeability sections to control the inflow performance.

Test Date	Choke %	FWHP PSI	Rate MBOD	GOR SCF/STB
Pre-W.O	13	1300	2.2	4000
Post-W.O	14	1100	5.0	2450

Table 2: Production Equalizer Testing Results

Table 2 summarizes test results on SHYB-257. The GOR was reduced from 4000 to 2450 SCF/STB for a net production gain of 3 MBOD.

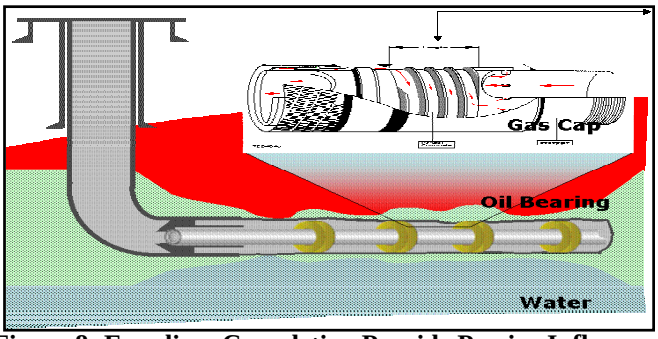

Figure 8: Equalizer Completion Provide Passive Inflow Control

Impact of Intelligent Technologies: Lessons Learned

MRC Wells: Impact and Lessons Learned

Early MRC wells test results have shown a significant improvement in well performance when compared to the offset one-km single lateral wells drilled in similar rock facies. On the average and after three years of production, a 9 km MRC well (tri-lateral) produced at a rate of 10 MBOD compared to the offset 1-km well which produced at an average rate of 2.5 MBOD. Furthermore, the MRC well PI was four fold higher than the 1-km single lateral well (Figure 9). The increase in PI and well productivity has resulted in a reduction in the number of wells required to maintain the field production rate. This translated to a 40% reduction in unit development costs.

Well #	Reservoir Contact, km		PI, STBD/psi		Rate MBOD		Water Cut %	
	Before	After	Before	After	Before	After	Before	After
236	1	5.8	10	92	1.5	6	7.0	2.0
258	1	3.1	12	95	1.5	5.5	3.0	1.0
313	1	4.0	30	116	2	5.5	0.0	0.0
315	1	4.7	22	100	2	5	5.0	1.0
490	1	3.7	20	88	2.5	7	19.0	3.0
249	1	5.4	11	62.5	2.5	5	17.0	2.0
95	1	6.0	6	188	1.5	7	10	2.0
239	1	6.1	7	123	2	7	12	1.0

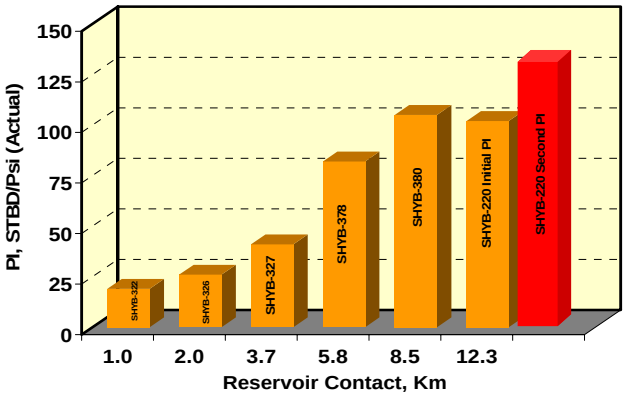

Figure 9: Productivity Index as a Function of Contact

The encouraging results from the MRC wells paved the way for a major shift in the application of MRC wells to reduce development drilling costs. Furthermore, high considerations were given to MRC wells for developing new increments.

Saudi Aramco's aggressive move towards MRC wells utilizing advanced well completion technologies to improve well performance, remotely control the production from each lateral, and thereby maximize well productivity is showing great promise.

Smart completions have proven to be critical, especially for wells where gas coning is a major issue such as the Shaybah wells located near or under the gas cap. The impact of smart completions will be realized with time as these laterals start to cone gas. One major impact was realized during well clean-up where each lateral was flowed for clean-up with the other two laterals being closed. The reservoir energy was concentrated in one lateral at a time allowing each lateral to be fully cleaned. This was apparent form the flowing well head pressure (FWHP) data recorded on the well with smart completion versus an off-set well drilled in similar rock facies with similar reservoir contact without a smart completion.

Expandable Liners: Impact and Lessons Learned

The installation of expandable liners was essential to the success of the Shaybah workover program. The 7 by 5-1/2" expandable liners provided the means to case the first 1000 feet of horizontal section providing lateral separation as needed allowing the deployment of smart completions.

A total of 10 expandable liners were successfully installed in 2005 in Shaybah Field. The success of the workover strategy which was highly dependent on the successful deployment of expandable liners, resulted in reducing the water cut from an average of 9% to less than 2% as a result of increasing the reservoir contact, increasing the PI and thereby lowering the drawdown to produce at optimum well rates (Table 3).

Table 3: Impact of Maximizing Reservoir Contact on Well Performance

Swell Packers: Impact and Lessons Learned

The swell packer technology when installed in tandem with smart technology will eliminate the need to run the expandable liners as the smart completion will be deployed in an openhole environment. This offers major cost savings by reducing rig time and improves well economics. The swell packer-smart completion deployed in Shaybah field was completed in 39 days compared to the offset well completed in 48 days with a combination of expandable and smart completion system.

During the installation of the swell packer-smart completion in the workover well, difficulties were encountered resulting in landing the completion high. It was determined that the completion fell into the second lateral as all laterals were drilled on the low side.

Based on the deployment of the swell packer-smart completion, the following lessons were captured that will enhance future deployments:

1- For existing wells, plan dual-lateral conversions to avoid low side lateral problems.
2- For new wells, plan to drill lateral top down to allow high side kick-offs. This will allow tri-lateral completion success.
3- Application areas need to be selected where the formation is stable; i.e., no risk of open hole instability problem with completion brine, since the completion will require up to three days static time before reaching the target depth.

Future Focus Areas

The successful deployment of the various advanced completion technologies in Shaybah field has opened the door for a wider implementation across other Saudi Aramco fields. Currently, the focus is on additional deployments of smart completions in new wells, especially those MRC wells planned in areas near or under the gas cap and wells completed in the oil rim close to the oil-water contact. Simulation studies as shown in Figure 10 highlights the impact of MRC wells on recovery and sweep. A one-km single lateral well converted to MRC well showed an improved performance in terms of water cut, rate, and cumulative production. Approximately 31 MMSTB were recovered when converting this well into an MRC well.

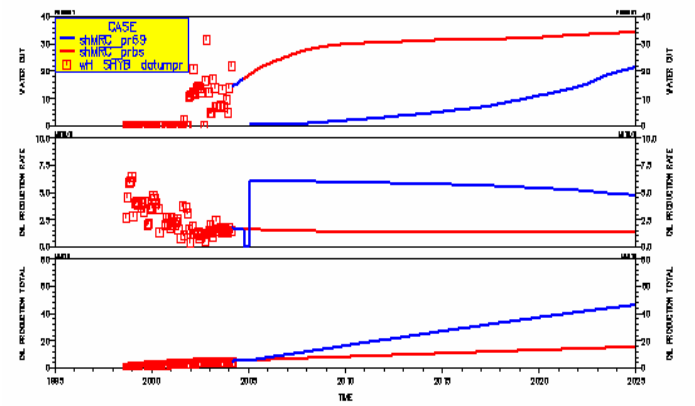

Figure 10: Impact of MRC Wells on Recovery-Comparing 1-km Single Lateral Wells to MRC Wells

For the workover wells, the focus in the near term will be on deploying smart completions in tandem with expandable liners while awaiting the performance of the swell packer-smart completion system. The success of the equalizer deployment in high GOR wells resulted in the selection of two candidate high GOR wells (one-km single lateral wells) for deploying equalizers after running multiphase flowmeters. Equalizer completions will be moved into dual lateral wells allowing increased reservoir contact.

The installation of PDHMS in future wells along with the deployment of several intelligent completions will be the platform to move Shaybah Field to the intelligent-field concept.

Conclusions

1. Deployment of intelligent technologies in Shaybah is at an early stage. Results from MRC wells when compared to single lateral wells have indicated a four fold increase in well productivities and a three fold decrease in unit development cost. To date a total of 37 ML/MRC wells have drilled in Shaybah field since January 2002.
2. A total of 10 expandable liners each approximately 1000 feet long were successfully deployed in Shaybah field as part of the recompletion strategy. Expandable liners are considered technology enablers providing means to install smart completion if needed.
3. Smart completions in tandem with 5-1/2" expandable and swell packers were successfully piloted and tested in Shaybah field.
4. Production equalizers in high GOR wells were deployed and proven successful by reducing the GOR by 50% and improving well productivity.
5. PDHMS are being installed in recompleted and new wells. The permanent downhole monitoring systems (PDHMS) will be the platform to convert the Shaybah Field to intelligent field.

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References

1. Saleri, N.G., Salamy S.P., and Al-Otaibi, S.S, "The Expanding Role of the Drill Bit in Shaping the Subsurface," Distinguished Author Series, JPT, December 2003, p. 53.

2. Saleri, N.G., "Disruptive Technologies and Real-Time Reservoir Management Issues," Keynote Speech, Sixth International Forum on Reservoir Simulation, Salzburg, Austria, September 3-7, 2001.

3. Salamy, S.P., et al., 2002, "Impact of a Comprehensive Horizontal Well Production Logging and Testing Program in Shaybah Field, Saudi Arabia." SPE, Asia Pacific Oil and Gas Conference and Exhibition, paper 77933, Melbourne, Australia, October 8-10, 2002.

4. Dossary, A.S, Mahgoub, 2003, "Challenges and Achievements of Drilling Maximum Reservoir Contact (MRC) Wells in Shaybah Field," 2003 SPE/IADC Middle East Drilling Technology Conference and Exhibition, paper 85307, Abu Dhabi, UAE, October 20-22, 2003.

5. Saleri, N.G, et al., 2003, 'SHAYBAH-220: A Maximum Reservoir Contact (MRC) Well and Its Implications for Developing Tight Facies Reservoirs," SPE, Reservoir Evaluation & Engineering Journal, August 2004, pp 316-321.

6. Hughes, G. W., "Bioecostratigraphy of the Shu'aiba Formation, Shaybah Field, Saudi Arabia." *GeoArabia*, Vol. 5, No. 4, 2000, Gulf PetroLink, Bahrain.