First shale gas experience in Saudi Arabia - lessons learned

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ABSTRACT

Influenced by the success of shale gas production worldwide and to meet requirements for clean energy supply, a multidisciplinary team of petroleum specialists was established in Saudi Aramco. Meeting the growing requirement in industrial consumption and especially electricity production is a driving force for developing unconventional gas reserves. “The initial focus is in the northwest and in the area of Ghawar, where gas infrastructure exists. The company is innovatively combining knowledge and research to maximize gas reserves and production from conventional and unconventional resources in order to meet growing domestic demand (Saudi Aramco. 2010).

During years 2010 - 2011 major international petroleum industry players - Schlumberger, Halliburton and Baker Hughes - were invited to share their experience in a series of workshops held in Dhahran. Exchange of expert ideas developed into appreciation of complexity of the shale gas reservoir and helped to identify the scope of work for the first Silurian Qusaiba shale gas well. The SHALE-1 well was drilled in 2007 as a gas exploration well. Recent drilling and geophysical data obtained in the well were beneficial for detailed sidetrack and fracture stimulation design.

The Multidisciplinary task group was established and positioned in Dhahran. The draft work plan was developed 8 months before actual operations commenced on the well site. Thorough examination of the draft work plan progressed to the final work plan with a number of improvements. The Frac Stimulation design was fine-tuned, involving expertise from Saudi Aramco and Halliburton. The Complete Well on Paper exercise involved over 25 specialists from both companies and helped to rectify remaining completion/stimulation design issues, and put everyone on the same page in terms of the work program. Well site operations commenced in May 2011. All targets set for the SHALE-1 well were successfully achieved and the well was suspended for future utilization as an observation well.

Keywords: Shale gas; unconventional drilling; hydraulic fracturing.

INTRODUCTION

The current world energy situation and the changing outlook of the global market opportunities for energy has put more pressure on existing resources. Increasing energy demands, especially in Asia, have necessitated development of various
alternative strategies and resulted in the exploitation of what is classified as unconventional resources. Notable amongst these is the development of Shale gas plays especially in North America, such as in the Barnett, Haynesville, Marcellus, and Eagle Ford shale plays in the U.S. and the Montney and Horn River in Canada.

Despite significant levels of investment and experience, the realm of shale gas development still remains little understood and evolving. A lot of research and development work has been stimulated within the industry including academic / research institutions. With significant variation in the characteristics of shale plays from shelf to shelf, there is no single solution to the understanding and development of this resource across the board. Shales by nature are very heterogeneous and this significantly impacts the propagation and connectivity of fractures. This is especially important because matrix porosity and permeability in shales are so small and, as such, production from these formations is mainly dependent on fracture connectivity. From this, despite the availability of useful experience from early players, there is still a need to go through a learning curve in the development of any shale play.

Objectives of the SHALE-1 operations were: evaluate the Silurian Shale for reservoir qualities; identify optimal technology to maximize productivity of unconventional low permeability shale gas reservoir; identify completion, perforation, stimulation, and testing strategy; acquire data that will be used to reduce the uncertainties and define optimal field development program; integrate newly obtained data and update simulations and operational models; and execute efficiently the program’s aggressive time line.

A multidisciplinary team began working on the SHALE-1 project in early 2011 (Fig. 1).

![Multidisciplinary team: organizational chart](image)

The Team was made up with a project manager from both Saudi Aramco and Halliburton that were charged with keeping the project moving forward, as all
necessary components needed to come together quickly and efficiently with the rig on location. Resources of Saudi Aramco and Halliburton were allocated to the challenging exploration mission. Over 20 engineers were involved in the well planning, and team work was of utmost importance. Additionally, personnel involved in the planning and execution of the job consisted of more than 10 different nationalities. Language and cultural differences required significant efforts from everyone to overcome natural misunderstandings and allow working as a team. The total test program of two fracture treatments and adequate flow back time was to be completed in 26 days. The complete testing plan along with the special studies performed to identify the shale potential is shown in Fig. 2.

Fig. 2. SHALE-1 Preliminary Test Plan
Every new endeavor is challenged with “cold start” difficulties: exposure to unfamiliar country and company, comfortable technical concepts not necessaraly working in new environment (geological and cultural), and time required for every person to fit into the team. Those and other difficulties created unique challenges apart from the main task of gas exploitation. Primary technical challenge was to design successful fracturing applications in naturally fractured shale formation at depths exceeding most developed shale basins of North America.

While low gas prices set a challenge to developing unconventional gas reserves, Saudi Aramco is prepared to continue work on this front and considers this of strategic importance considering increasing interest and activities in the exploitation of shale gas resources (Mahdi, Wael. 2012).

**WELL DRILLING & COMPLETION DESIGN**

The well SHALE-1 was required to provide a conduit to access and fracture stimulate two intervals in the gas bearing Qusaiba shale formation which had interesting levels of Total Organic Carbon (TOC). These two intervals, the hot shale and warm shale, were considered to be source rock for an overlying sandstone reservoir.

Part of the primary objectives of the project was to carry out all work in a safe manner and at minimum cost. As such, sidetracking from an existing well was determined as the best way to proceed.

SHALE-1 well was successfully re-entered and window cut in 7” liner using a whipstock. An S-shaped 5-7/8” hole was drilled in the direction of minimum horizontal stress to facilitate effective fracture propagation. The sidetrack was drilled with maximum inclination of 25 deg to have adequate step out from the old wellbore to avoid propagating the frac into it. The motherbore had been used to access and test other formations. Electric wireline logs were acquired to gather data. Core samples were also obtained for SEM (Scanning Electron Microscope) and other types of analyses. The hole was cased off with high strength 4-1/2” 15.1 ppf liner using Baker Oil Tools Liner hanger / packer system. Latex cement slurry was pumped to ensure effective isolation of the zones of interest; this was confirmed with cement bond logs. The wellbore was then cleaned out and prepared for completion.

SHALE-1 completion was required to meet the requirements of the hydraulic fracturing design program. This was achieved with a monobore completion
using 4.5” 15.1 ppf tubing and 15,000 psi rated surface equipment to meet high pressure fracturing screen-out conditions.

Baker Oil Tools 15 ft PBR extension with travelling seals was utilized. Since the initial well was drilled 4 years earlier and not designed for fracturing operations, limitations in completion design had to be overcome. Installing a 15,000 psi rated completion inside 10,000 psi rated 7” liner presented technical difficulty which was successfully overcome with BOT Flex Lock hanger system. Combined efforts from BOT, Halliburton, and Saudi Aramco over several workshops and discussions helped to fine-tune the final design. Several options of hanger design were evaluated using engineering simulation software to come up with the optimal equipment selection. This proved very useful and successful.

The original wellhead on SHALE-1 had a 10K psi rated tubing head spool. As such, wellhead for the completion simply involved installation of 10K psi rated lower manual master valve and 4-1/16” 10K x-tree. To meet higher surface pressure requirements expected during frac stimulation a wellhead isolation tool (tree saver) was used to isolate the 10K rated surface equipment and provide 15K pressure capability and pumping capacity up to 40 BPM.

To minimize potential for failure considering tight clearances, it was agreed to limit the number of downhole equipment elements in the completion string. As a result, tubing “R” nipples were not run. Tubing string was successfully pressure tested with “P” prong Mono-Lock plug to 10,000 psi in preparation for the frac operations.

**HYDRAULIC FRACTURING**

One of the main objectives of SHALE-1 well operations was to verify and fine-tune hydraulic fracturing designs for deep shale plays in the Kingdom of Saudi Arabia. Hydraulic fracture stimulation was conducted on two different shale intervals, the hot shale and the warm shale (Fig. 3).
The Hot shale has low clay content and a higher brittle index than the warm shale which is rich in illite clay content (See Fig. 4).

Fig. 3. Equipment set up on SHALE-1 well

Fig. 4 SHALE 1 Type Log with Brittle Index
Due to the differences in clay and brittleness two separate hydraulic fracture design philosophies were utilized to overcome proppant embedment and condensate issues due to the hydrocarbon liquids expected.

The Hot Shale utilized a more conventional design with a 30 ppg borate crosslink fluid and ramping of the proppant to 6 PPG to achieve maximum conductivity at the wellbore to overcome Non-Darcy and multiphase flow damage (Fig. 5).

![Frac Job - Net Pressure Match](image)

**Fig. 5.** Hot Shale fracture treatment

The Warm shale used a more traditional shale fracture design utilizing a hybrid fracture design with a maximum concentration of 2 PPG (Fig. 6).
Frac Job - Net Pressure Match

Observed Net (psi)  
Net Pressure (psi)  
Slurry Prop Conc (ppg)  
Treating Pr (psi)  
Calc BH Pr (psi)  
Slurry Rate (gpm)

Time (min)

Fig. 6. Warm Shale fracture treatment

Prior to performing the hydraulic fracture treatment a full range of diagnostics were performed including a 24 hr Diagnostic Fracture Injection Test (DFIT), rate step-down test and MiniFrac were carried out to obtain data for fine tuning the fracturing treatment design for each interval. The diagnostic tests were critical to determine fracture fluid efficiency and fracture geometry as the shale zones of interest overlay another hydrocarbon bearing reservoir. As such, a temperature log was run after the MiniFrac to determine fracture height growth which indicated the fracture stayed contained in the zone of interest. Due to not being able to use radioactive tracers, a non-radioactive proppant was used to determine fracture generation due to the proppant. A post job neutron log was used to confirm the proppant placement near the wellbore. The use of the non-radioactive proppant in the shale resulted in questionable interpretation due to the high nature of potassium in this shale and the vendor use of a similar marker for interpretation. Future fracturing treatments in horizontal laterals will be monitored using microseismic monitoring to determine fracture length and height away from the wellbore.

Fracuring equipment with about 18,000 horsepower capacity was rigged up and pressure tested to 15,000 psi (See Fig. 3). The lower Hot Shale interval was perforated and stimulated. Early screen out occurred with only about 25% of
the planned proppant volume in place. The treatment plot shown in fig. 3 shows the proppant ramp attempted and surface pressure. As can be seen, the hydraulic fracture treatment experienced a near wellbore screenout due to insufficient fracture width generated to allow the larger proppant into the formation. This was the very first attempt at fracture stimulating a shale formation in the kingdom and provided very useful information and basis for optimization of the second interval frac design. The Hot Shale interval was flowed back / evaluated and then isolated with high pressure, coil tubing drillable composite plugs prior to stimulating the upper zone.

The upper Warm Shale interval was perforated and stimulated according to the revised plan. Slurry design, pump rates and other job parameters were modified for this interval. The result was excellent, about 110% of the planned proppant volume was successfully placed in the formation at about 21,000 psi bottom hole treatment pressure and 35 bpm pump rate. Screen out was reached at about 13,000 psi surface pressure (See Fig. 6). The wellbore was cleaned out and both Hot and Warm Shale intervals flowed back for evaluation. The well flowed gas and liquid hydrocarbon. Further fingerprinting of the gas indicated the shale in this area was oil rich shale vs. gas shale which we were targeting.

Post fracture modeling of the two fractures indicated two independent fractures that tended to grow upwards but stayed relatively contained within the pay zone. The predicted fracture geometries are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Hot Shale</th>
<th>Warm Shale</th>
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<tbody>
<tr>
<td>Propped Length (ft)</td>
<td>134</td>
<td>328</td>
</tr>
<tr>
<td>Propped Height (ft)</td>
<td>90</td>
<td>153</td>
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<tr>
<td>Dimensionless Conductivity</td>
<td>5</td>
<td>101</td>
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Table 1. Hot and Warm Shale Predicted Fracture Geometries

Fig. 7 shows the graphical interpretation of the two independent fractures.
Fig 7.: Hydraulic Fracture Geometry Prediction for Hot and Warm Shale

PROJECT EXECUTION

In the multi-cultural and multi-language environment, new execution approach has played its role from very beginning of the SHALE-1 project. While everyone in the team possessed extensive experience in drilling, completion, well testing, logging, and stimulation areas, synergizing those experiences was a challenge in itself. As well as area of operations: SHALE-1 geographically is located in the low sand dunes area to the North of Rub-Al-Khali desert with driving time of about five hours from Aramco Dhahran base (See Fig. 8).

Fig. 8. Drilling Rig on SHALE 1 in a Low Sand Dune Area
Two satellite channels provided sufficient means of telephone and data communication. Also available was a GSM booster that helped in critical situations when several phone calls had to be made at the same time.

Since the well location was in the soft sand area, having a properly prepared well site was critical. Standard well site dimensions had to be reviewed and fitted with in-scale drawing of rig equipment, frac equipment, and chemical storage. This exercise identified the requirement for a well site expansion compared to a standard drilling site size.

A comprehensive well test program was developed and peer-reviewed in advance of the start of operations. Naturally, no program can be detailed enough to describe every operational step and answer all possible questions. Changes had to be reviewed and captured in a written step-by-step daily operational plan on a regular basis. This operational plan discussed by the well site team served as a supplement to the approved well test program and included deviations, changes, and additional operational steps as required to safely completing the task.

CONCLUSION

The value of detailed planning processes such as the “Completing the Well on Paper” is hard to overestimate and has added great value on this project. Joint meetings with representatives of all involved parties with careful review of upcoming operations identified a list of risks and possible problems, and made everyone familiar with program requirements and upcoming operations. It also helped build a team environment. Regular brainstorming sessions on the well site helped develop in-depth operational plan for every critical job, as well as troubleshooting.

Shale gas in Saudi Arabia has a future. Further exploration will help in identifying best approach to dealing with this challenging new frontier source rock.

ACKNOWLEDGEMENT

The authors wish to thank the technical and operational teams in making this the first successful shale test in Saudi Arabia.
REFERENCES


التجربة الأولى للغاز الصخري في المملكة العربية السعودية

دروس مستفادة

الكسيكوا أ. ف - باردو ك. م - أديبي أ. ي - فراج أ. أو. كامبو سي *

أرامكو السعودية

هاليبرتون **

خلاصة

مدوّنة بنجاح انتاج الغاز الصخري عالمياً ولثيبة متطلبات مصدر طاقة نظيف.. تم
إنشاء فريق متعدد التخصصات من اخصائيين في أرامكو السعودية.

إن تلبية المتطلبات المتزايدة للصناعة وخاصة الحاجة للكهرباء دافع قوي لتطوير

احتياطي "غير تقليدي " من الغاز.

التركيز الأولي هو الشمال الغربي ومنطقة غاوار حيث توجد البنية التحتية للغاز.

المعرفة الأولية المستفادة من تجربة مشابهة في الولايات المتحدة تم استخدامها في
الدراسات التقنية الداخلية وبرامج الأبحاث لمراجعة المشكلات الجيولوجية والهندسية
المتعلقة بالسعودية وتحديد الحقول المخططة لها لعام (2011). تجمع الشركة بين
المعرفة والبحث لزيادة احتياجات الغاز واتجاه من مصادر تقليدية وغير تقليدية لتلبية
الطلب المحلي المتزايد.

في عام 2010-2011 تم دعوة أكبر اللاعبين في الصناعات النفطية: شل، بيرجز -
هاليبرتون - بيكر هيوز لتبادل خبراتهم من خلال ورش عمل في الظهران. تبادل أفكار
الخبراء أظهر مدى تعقيد مخزونات الغاز الصخري وساعد في تحديد مجال العمل في
أول حقل للغاز الصخري في سلوريان- قضية.

الحقل الصخري الأول (شيل - 1) تم حفره في 2007 كنير استكشافي للغاز
الأحفوري والمعلومات الجيوفيزيائية التي تم تحصيلها في البئر كانت مفيدة لتفصيل
المسار الجانبي وتصميم ممانعة الكسر.
تم تكوين فريق أرامكو السعودية - هالبيترتون متعدد القدرات وتمركز في الظهران. هذا الأمر سمح لهم بالتعاون اليومي وجلو لوجه وتطوير أهم أسباب المشاركة والاتصال.

مسودة العمل تمت قبل ثمانية أشهر من البداية الفعلية في موقع البئر. تم التأكد بإسهام من مسودة العمل وتطويره مع إجراء بعض التبديلات. على سبيل المثال:

حلقات "R" تم حذفها من الحفر الأحادي قياس 4,5 أنش سلك التكملة. تصميم مماثلة الكسر تم ضبطه بدقة بواسطة خبراء من أرامكو السعودية وهالبيترتون. العمل الورقي للبئر تطلب أكثر من (25) متخصص من الشركات وساعد في تحسين وامتلاك مواد التصميم المماثل ووضع الجميع في نفس المكان من حيث جدول العمل.

بدأت الأعمال في موقع البئر في مايو (2011). تم إعادة الدخول إلى البئر بنجاح بناءً على قطعية (7) أنش. تم عمل حفرة عمل شكل (S) بالتشارك (7,6) أنش في اتجاه أفقي ذي أقل الضغوط إلى العمق المطلوب بأعلى قيمة (4,5) أنش. باماكن مراقبة المؤتمتر (4,5) أنش من السطح. الفاصل الزمني الحر للقصيبة تم سلخها وتم إنتاج اتباع تصميم الكسر بنتائج مختلطة تم وضع سداد عزل سيراميكي مؤقت فوق فترات السلخ.

فترات القصيبة الدافئة تم العمل بها بمعدل السابق. أخيرا تم إزالة السداد بواسطة (CTU) وتم اتباع الفترتين وكذلك خطوات الإنتاج.

جميع أهداف مشروع (شيل-1) تم تحقيقها وتم إيقاف البئر للاستخدام المستقبلي وكذلك كثير مراقبة وتجارب.