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A Decade of Developing Unconventional Resources in Middle East: A Retrospective

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Abstract. The requirement of tapping new hydrocarbon resources has pushed the Middle East region, which typically produces hydrocarbon in conventional ways, to develop its unconventional resources. The Middle East region started to boost its unconventional resource exploration and appraisal in 2009 targeting multiple tight gas formations and source rocks. Different approaches and concepts were applied based on the exploration data and on adopting the best practices from other regions, such as North America and Argentina.

Adopting the best practices from other regions and integrating comprehensive surveillance data help to define the processes and practices for developing the unconventional resources in the Middle East region. Understanding the reservoir, hydrocarbon, and the fracability of the formation is critical during the exploration phase of the field. During this phase, a full range of log and surveillance data and subsurface analysis are required to understand the fundamental characteristics of the reservoir. Moving to the appraisal phase, additional studies focus on the drilling and completion design to select the best approach as basis of design of the field and confirmation of well productivity. Details and confirmation of field development plan are required to ramp up from the appraisal phase to the development phase to be commercially viable. Furthermore, as successful unconventional resource development is characterized by having the lowest cost of well delivery and maximum productivity, optimization of well cycle is required to ensure the economics of the project.

During the more than 10 years of unconventional resource development in the Middle East region, we acquired many typical field development lessons learned that could be applied in the different unconventional resource plays. Our observations cover different aspects, from both the operator and the service company perspectives. They range from the strategy of field development organizational structure to the operation execution and third-party management throughout the exploration, appraisal, and development phases.

Case studies from Middle East region will be presented for each field development phase and include completion optimization, hydraulic fracturing strategy, surveillance strategy, and operational efficiency.

Keyword(s): Unconventional resources, Hydraulic Fracturing, Source Rock, Full Field Development Plan

1 Introduction

The global energy demand is predicted to continue its current increasing trend. Despite the massive development of the new energy, oil and gas will remain the main energy source through the coming decade (bp 2022). This demand will be the main driver of the exploration for new sources of oil and gas.

The easy conventional resources of the past, for which the extraction cost and the technology demand are low, are rarely available. The current available resources are already tapping into unconventional resources, which require high investment and massive technology deployment. The current unconventional resource development ranges from tight reservoirs to the source rock, including shale.

The massive development of unconventional resources started in North America about two decades ago. After successful development of unconventional resources in North America with horizontal wells and hydraulic fracturing technology, many countries around the world began to follow a similar path, including in the Middle East.

The Middle East region started to boost its unconventional resources exploration and appraisal in 2009 targeting multiple tight gas formations, mainly low-permeability gas, and oil formations across the Arabian Peninsula. Because of low permeability, the development of these reservoirs requires horizontals well with multistage fracturing to be able to produce above the economic threshold. Despite the challenges of tectonic influence and laminated reservoirs, many fields in Oman and Saudi are currently under full field development plans to exploit the hydrocarbon potential (Clark et al. 2011; Al Shueili et al. 2016).

Unlike tight formation development, source rock development in the Middle East region started a decade ago with Jafurah exploration in Saudi Arabia. In the source rock development, because of the nanodarcy permeability, significant reservoir contact is required to be able to extract the hydrocarbon at economic rates. Therefore, a longer horizontal well with more stages is required in the development.

The successful development of source rock requires a minimum well cost delivery and maximum production and estimated ultimate recovery (EUR) of the well. Learning from North America, there are several enablers of the successful development, such as the following:

- *Optimum efficiency*. The optimum efficiency of a drilling and fracturing operation is achieved by the learning curve experience of both operator and service company.
- *Readily available resources*. In North America, the resources, including personnel, products, and equipment, are available across the country with a minimum lead time.
- *Logistic support system*. The logistic support system includes the transportation/mobilization of resources and the government regulations.
- *Well availability*. The learning curve of development requires a persistence mindset in which failure contributes to factor elimination. A massive job with many stages is required to prove the conceptual optimization plan through technology deployment.

2 Challenges

Different approaches and concepts were applied in the Middle East based on exploration data and adopting the best practice from other regions, such as North America and Argentina. However, understanding the unique challenges is the first step toward selecting a fit-for-purpose solution. Table 1 indicates the challenges across the Middle East for the unconventional resources development compared to conditions in North America.

Requirement	Middle East	North America
Tectonic influence	High tectonic influence	Less to medium tectonic influence
Lamination	Highly laminated reservoir	Less lamination
Reservoir Pressure	Overpressure formation	Normal reservoir pressure
H2S	Contain relatively high H2S	Mainly sweet reservoir
Equipment availability	Limited	Highly available
Infrastructure	Desert without proper infrastructure	Available
Fracturing product	Imported	Available
Water	Scarce	Available
Knowledge/Manpower	Limited	Available

Table 1. Unconventional challenges in the Middle East compared with conditions in North America.

Integrated work between operator, government, and service providers is required to overcome the challenges in each of development phase.

2.1 Exploration Phase

Prior to the exploration phase, a pre-exploration phase is required to set up the objective and strategy of the exploration phase. The general pre-exploration plan after seismic data acquisition is as follows:

- *Reservoir*. In this phase, the confirmation of the reservoir and hydrocarbon is the main objective. Upon the confirmation, knowledge of basic reservoir characteristics and resources obtained through the deployment of an integrated surveillance system is required (Clark, 2011). This includes rock analysis, core evaluation, geochemistry, PVT, and many other methods to determine reservoir properties.
- *Drilling*. In the drilling operation, understanding the challenge of drilling a horizontal well will be required for the optimization and design of the technology deployment.
- *Completion*. Understanding the fracability and the geomechanical challenges is the main objective during the completion phase.
- *Production*. A baseline of the production pre- and post-fracturing is required to understand the economics of the project.

2.2 Appraisal Phase

An appraisal program is developed after the exploration phase. During the appraisal, studies, trials, and selection of the strategy introduced in all well cycles are performed to confirm the well productivity. In this phase, a trial of formation response to different development scenarios is the main objective from the reservoir, drilling, and completion strategy. In this phase, a detailed solution to every challenge of field development plan is introduced and evaluated toward project economics. A confirmation of well productivity performance and EUR against different strategies and different locations in the field are evaluated using an extended well test. Upon the project economics confirmation, a detailed road map of logistics and ramping up activities will be required before shifting to the full field development plan. Generally, in appraisal phases, most the completion problems in unconventional wells are revealed. As an

example, post-fracturing completion damage is the main issue that is observed during appraisal phase. On the logistic side, the deliverability of the material can raise issues due to many varieties of the material to be tested at relatively higher volume compared to conventional treatment.

2.3 Development Phase

In the full field development phase, all the drilling and completion activity is conducted in the factory mode, in which the efficiency is the key to reducing the well delivery cost. A continuous technology improvement will also be needed to optimize the well productivity and EUR.

3 Case Study

3.1 Jafura Field

A project in Jafura Field started the exploration of unconventional resources in the Middle East in 2013. The project started with the drilling of three vertical wells targeting the Tuwaiq Mountain, Hanifa, and Jubaila (Al-Mulhim et al. 2014). The Tuwaiq Mountain is the main interest as it shows high total organic carbon (TOC), low clay content, good matrix permeability, high gas saturation, and effective porosity. The log shows the potential for a thick sequence of source rock that may suggest the possibility of commercially viable unconventional play. Further integrated study showed that Tuwaiq Mountain is organic rich, and the pore system is predominantly confined to organic matter in the lower section (Al-Sulami et al. 2017).

The first proppant fracturing in 2013 had the objective to define the geomechanic calibration points such as breakdown pressure, stress contrast, and fracture gradient. An additional objective was to measure the proppant placement capacity to identify the stimulation volume. From this fracturing treatment, it was noticed that the fracture was confined within the Tuwaiq Mountain thickness, and it accepted approximately 100,000 lbm proppant using a hybrid design at 55 to 60 bbl/min.

From this stage, the field development plan immediately aimed towards evaluating the production capability of the Tuwaiq Mountain formation. During this advanced exploration phase, the main objective was to derisk the field development plan (Al-Mulhim, 2015). In parallel with that, the completion design, including the fracturing design, was optimized on both technical and cost efficiency. As an example, the objective changed to design the completion fit for fracturing purpose instead of only production (Sadykov et al. 2018). For fluid optimization, slickwater with a diversion system was introduced to support the feasibility of the project (Sadykov et al. 2019; Kurdi et al. 2020).

On the logistics side, to support the field development plan, a large amount of materials, different sources of water, and different propping agents were investigated. From the water standpoint, treated sewage effluent was utilized and proved sustainable to be used as a water source for fracturing treatment (Al-Taq et al. 2018). For the propping agent, local sand was introduced to later replace the ceramic proppant. There were balancing strategies between having high conductivity but expensive proppant versus the more economical low-conductivity sand (Bartko 2017).

Seven years after the first exploration well, Jafura field has been developed into an early phase of development in which the surface efficiency plays critical role on the economical equation.

3.2 Khaleej Al Bahrain

Bahrain discovered a major unconventional resource in Khaleej Al Bahrain in the regional unconventional source rock group of the Tuwaiq Mountain formation. This discovery extended the confirmation of viable unconventional resources on the northern side of Jafura Field. The exploration phase was conducted in the offshore location by drilling a vertical pilot well, which was subsequently completed with a horizontal side-track with a 20-stage plug-and-perforation design in a 3,000-ft lateral. As the exploration occurred in the offshore environment, logistics and delivery were the major challenges. Due to the constraints, the fracturing treatment had a limit of 150,000 lbm proppant per stage with a 30 to 35 bbl/min pumping rate. Of the 20 stages, 16 were placed successfully (Alansari 2019). Completing the horizontal well from the same vertical pilot hole confirmed the production capability of the unconventional resource; this occurred confirming the fracture geometry from a single stage in the vertical well, which information was used to verify the fracturing parameter and lateral landing.

As a result of this exploration, the appraisal phase is targeting mainly the logistical challenges and delineating the extents of the basin. Furthermore, in the development phase, it will be possible to divide the field development plan based on onshore setup, hybrid operation (reclamation islands) setup, and shallow water offshore setup.

3.3 Abu Dhabi Basin

Unconventional resources in Abu Dhabi are divided into gas unconventional resources and oil unconventional resources. Exploration is in the Diyab formation as the gas unconventional resource and the shallower Shilaif formation as the oil unconventional resource (Taher 2010).

Unconventional resource exploration history in UAE started in 2011 by exploring the deep unconventional gas resource followed by exploration of the shallow tight oil formation in the following year. Fracturing treatment was planned as a major requirement to obtain geomechanical data and place the fit-for-exploration-purpose fracturing design. The main challenges for fracturing were lack of experience in many aspects and lack of technologies and fracturing equipment suitable for unconventional resources (Hegazy et al. 2015)

In recent years Abu Dhabi National Oil Company (ADNOC) has been developing unconventional resources with the Ruwais Diyab (unconventional gas) concession to cover the unconventional gas activities for an onshore (6,150 km2) in West of Abu Dhabi. Efforts have also been deployed in developing the Shilaif unconventional oil play. Both the unconventional gas and unconventional oil recoverable resources represent, respectively, 160 TCF and 22 billion STB (Mangha and Lazreq 2021).

Diyab gas unconventional resource exploration started by drilling four vertical exploration wells. The objective of these wells was to assess the fracturing treatment possibility on each subformation of Diyab source rock (i.e., Jubaila, Hanifa, and Tuwaiq Mountain). From these exploration wells, it was decided to move on to the appraisal phase exploring Diyab formation with the horizontal well to assess productivity of the source rock (Pourpak et al. 2021). After concluding the exploration phase, the appraisal phase immediately began with a zipper-fracturing operation in 2019 that used high-viscosity friction reducer to evaluate the operational efficiency and test the logistic support (Wu et al. 2021). During this early appraisal phase, the project encountered post-fracturing completion damage, coiled tubing milling challenges due to

extreme high pressure, and high H2S concentration that requires a sweetening unit and closed-loop system (Wu and Newby 2019).

Shilaif oil unconventional resource exploration started in 2012. The Shilaif oil source rock has different characteristics across the Abu Dhabi onshore basin. Integrated study was conducted to provide insight for hydraulic fracturing pilot well completion based on the vertical pilot exploration well. The approach taken for the Marcellus shale in United States was adopted as preliminary approach for multistage hydraulic fracturing design (Lazreq 2020). The utilization of a temperature log to calibrate fracture propagation was frequently demonstrated for the lateral landing evaluation. Up to more than 30 stages per well have been placed on each Shilaif horizontal unconventional well at the time of writing this paper.

4 Conclusions

- The development of unconventional resource plays is a journey with the single objective of making the production from the asset commercially viable. Low well cost delivery at the optimum production and EUR are the key of development.
- Unconventional activity in the US, Canada, and Argentina can be referenced as a starting point to explore the methodologies to develop unconventional development with some notes on the uniqueness of each formation around the world. For example, most of the unconventional plays in the Middle East refers to the Eagle Ford Shale as it shows similar petrophysical data. However, the Middle East unconventional source rock rather has greater stress complexity compared to source rock from the North American continent from geomechanics perspective.
- Although more details must be gained from subsurface study, well construction and completion study of any unconventional field development plan can start from the latest approach in the Middle East to shorten the learning curve.
- Resources and logistical challenges are identified as the main barrier to efficient operations, mainly during the appraisal and early development phases.

5 Recommendations

The Middle East has undergone the process of adopting methodologies, approaches, and technologies from western hemisphere and adjusting them to fit to local basins, especially for the unconventional resources in Jurassic deposits. Some of the recommendations coming from the last 10 years of unconventional work are as follows:

- Build a long-term field development plan for the unconventional resource covering all three phases (i.e., exploration, appraisal, and development/production).
- An integrated geo engineered approach (drilling-to-fracturing, fracturing-to-production and production-to-recover) strategy is mandatory.
- Extended well test with integrated surveillance is a must to undertint the project economics.
- Moving to the appraisal phase, it is critical to study the well completion aspects in addition to further subsurface study, for example, studies to evaluate a multiwell pad, lateral length sensitivity, fracturing design, and so on. The study can start from the last approach described in this paper. Although it is important to know so parameter sensitivities, it is also important to optimize parameter change to avoid any biased result.

- During the further study on the completion aspect, logistics and the supply chain play extreme important roles to support the availability of the materials. So many supply chain processes are required to adopt to the large amount of materials that may not be available in the specific area market.
- During the appraisal and development phase, selective study is recommended to shorten the learning curve. Any studies that have been done for similar unconventional resources can be used as a starting point for a new study without repeating the work in the new resource.

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