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Productivity Comparison of Different Completion & Stimulation Strategies with Underbalanced Coiled Tubing Drilling in Gas Carbonate Reservoirs

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Abstract

Gas condensate reservoirs often require special completion and stimulation techniques to maximize productivity. Workovers performed due to well integrity issues often lead to formation damage which can severely impact the production potential from these wells. Some of the most commonly used well completion techniques are conventionally stimulated vertical wells, Multi-Stage Fracturing (MSF) with ball drop systems or plug and perf systems. More recently, these completion systems have been challenged by Underbalanced Coiled Tubing Drilling (UBCTD), which has proven to yield high. This paper aims to compare the post-completion production performance achieved with these completion techniques with special emphasis on UBCTD while factoring in reservoir characteristics that contribute to such results.

Furthermore, to thoroughly assess the productivity index associated with each well type, an extensive review was conducted on the advantages and limitations of UBCTD, MSF wells, and conventionally stimulated vertical wells. The review focused on the various factors that influence productivity, such as relative comparison of reservoir properties, wellbore stability, drilling fluid selection, and completion techniques.

This paper introduces a novel integrated approach to evaluate the PI of gas wells drilled using UBCTD technology, MSF wells, and conventionally stimulated vertical wells. Specialized plots were developed which helped in comparative assessment of the different completion types and also understand the differences. The proposed method combines the analysis of normalized field data, numerical simulation and a comprehensive review, offering a more reliable and accurate assessment of well productivity and the reasoning behind exhibited results. Furthermore, the paper highlights the importance of considering various factors, such as drilling fluid selection, and completion techniques, in optimizing the PI of gas wells. This study provides valuable insights for reservoir engineers, drilling engineers, and decision-makers in selecting the optimal well configuration and drilling technology to maximize hydrocarbon production.

Introduction

Completion technology has been the focus of reservoir management engineers, and petroleum engineers in general, to develop hydrocarbon reservoirs in the most efficient and productive manner. In gas condensate reservoirs, arriving at a completion method that achieves maximized and sustainable productivity is of the essence. Especially with the continued production from these reservoirs entailing severe production restricting tendencies such as depletion-attributed liquid dropout leading to liquid loading within the wellbore.

Horizontal drilling started back in 1929 with the drilling of a horizontal well in Texas to achieve higher reservoir contact than vertical wells aiming to maximize productivity. For further productivity enhancement, horizontal wells across gas reservoirs are fractured utilizing Multi-Stage Fracturing (MSF) completions – inducing transverse fractures along the wellbore to maximize reservoir contact and remove formation damage while drilling. In mature carbonate reservoirs, formation damage is an essential aspect that may result in hindering well ability to produce commercial rates.

Underbalanced Coiled Tubing Drilling (UBCTD) Overview

UBCTD technology involves a coiled tubing reel hooked to an injector inside which the coiled tubing pipe is fitted. The coiled tubing pipe is fitted with a drilling Bottom Hole Assembly (BHA) containing a slim 3-5/8″ bit and Measurement While Drilling (MWD) capabilities.

The defining feature is the hydrostatic of the wellbore being at a lower Bottomhole pressure (BHP) than reservoir pressure, inducing underbalanced conditions while drilling. The rig includes separators and a testing package capable of handling significant gas production while drilling – flowing gas and its liquid byproducts to processing facilities while drilling and during subsequent flow testing.

Gas and measured BHP are used to calculate Productivity Index While Drilling (PIWD).

$$PIWD = \frac{q}{\left(p_{wf} - p_r\right)}$$

The laterals, ranging from 3 to 5 laterals per well, are placed following geological correlations, PIWD interpretation of previous wells, laterals, or drilled footage within the same lateral. Furthermore, geological bio-steering techniques and improvement in slim hole Logging While Drilling (LWD) are utilized to insure proper placement within heterogenous reservoir environments.

The drilled footage being drilled in underbalanced conditions, pumping only water and a small percentage of additives e.g. friction reducers, results in virtually formation damage free footage drilled within the most prolific interval in the reservoir. Nitrogen is often pumped to insure hydrostatic remains below reservoir pressure to sustain underbalanced conditions. This results in wells being ready to produce post-drilling without the need of stimulation technologies or stimulation-tailored completions to be implemented.

The lack of completion to be ran adds to the flexibility while drilling UBCTD laterals resulting in significantly higher Dog-Leg Severity (DLS) and inclination angles along the trajectory of the laterals. Insuring that a high percentage of the footage drilled is placed within the prolific target development in a heterogonous reservoir environment.

UBCTD vs. Conventional Stimulation Examples

Two examples provide a very good comparison and benefit of utilizing Underbalanced Coiled Tubing Drilling (UBCTD) with conventional stimulated wells.

Well-A was a commercial gas well which required to be sidetracked due to mechanical issues in well completion. The reservoir pressure had dropped below the dew point with production over time causing liquid dropout inside the reservoir. The initial sidetrack performed by twinning the well with high inclination to maximize reservoir contact and completed with a cemented liner. The well was perforated in two intervals utilizing data from the initial vertical well. The well was stimulated with energized acid fracture stimulation utilizing 485 barrels of 26% Hydrochloric Acid and Nitrogen. Post-stimulation the well was opened for flowback to cleanup but despite the use of energized fluid the well did not gain productivity.

This was followed up with Nitrogen lifting to unload the well which did not yield any improvement in well performance.

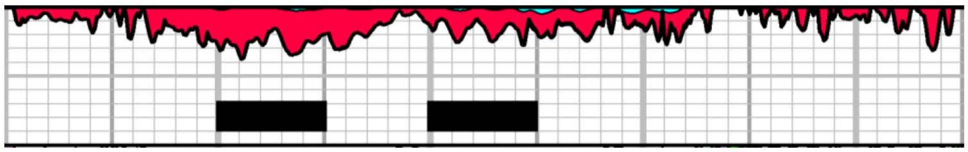

Figure. 1—Openhole Log and Perforation Intervals of Well-A

Well-A was then attended with UBCTD. The initial sidetrack was performed with a rig on location drilling the 5 7/8″ hole which was to preset the lateral above the reservoir and completed with a 4 ½" liner. After the preset, the well was attended with a UBCTD rig which drilled three laterals in the direction of the maximum stress each with a total footage of 2,500 ft. for a total footage of 7,500 ft. for the three laterals. While drilling, Productivity Index and Productivity Index / Footage was monitored with bio steering to ensure placement of the laterals in the zone of interest. Since coiled tubing drilling was performed in underbalanced conditions, the pressure was maintained to allow well to produce which increased with drilling of multiple laterals and reached commercial gas rate towards the end of the third lateral.

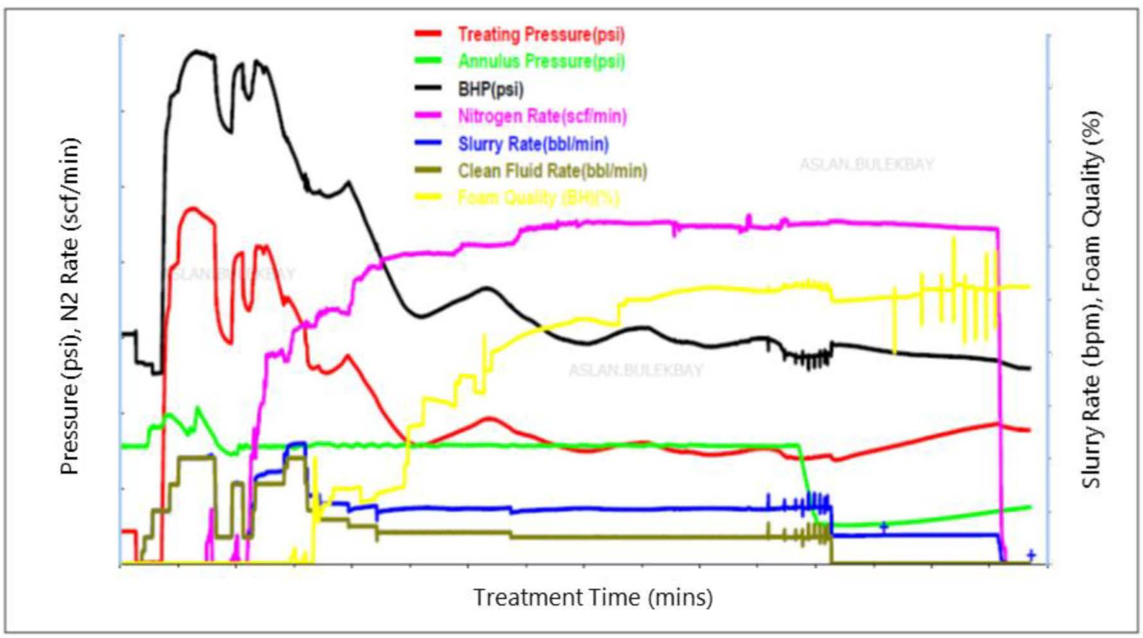

Figure. 2—Energized Acid Stimulation of Well-A

Post-UBCTD flow test showed excellent results with an excellent gas rate of at sustainable FWHP. The well was put on production and continues to show excellent productivity. A pressure buildup test acquired during later showed linear flow in the early time region and excellent transmissibility with very low geometrical skin.

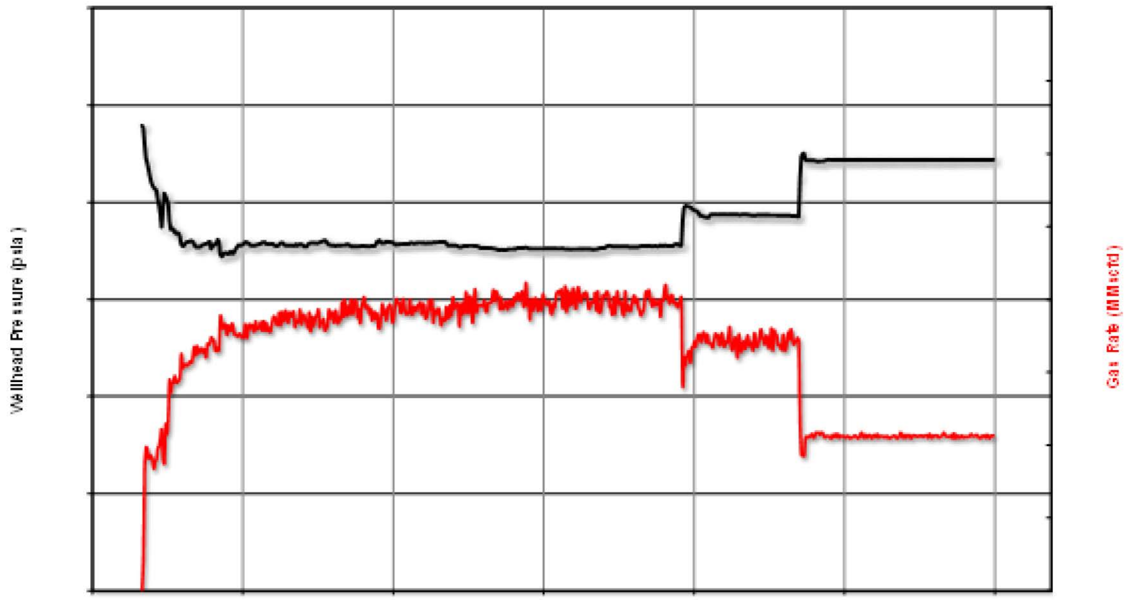

Figure. 3—Well-A Post UBCTD Flowtest

Well-B was drilled and completed as a vertical well in a high-pressure carbonate reservoir. Unlike Well-A, this well was completed at pressures above the dew point pressure but the development was less prolific than what was observed in Well-A. It was stimulated conventionally with approximately 12,000 gallons of 28% Hydrochloric Acid. Post-stimulation the well was opened for flowback but the well productivity declined within a few hours of production and the well died. Despite efforts to unload the well with Nitrogen lifting the well could not improve productivity.

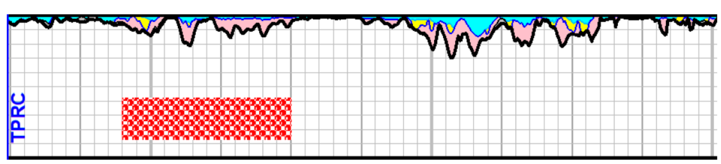

Figure. 4—Well-B Openhole Log

After initial results not achieving expectations, Well-B was sidetracked with a rig to preset for UBCTD. The preset lateral was placed on top of the reservoir and completed with a 4 ½" liner. After the preset, the well was attended with a UBCTD rig and three laterals were drilled with total footage of 7,000 ft. Post-UBCTD flow test showed well production exceeding that of Well-A with an excellent stabilized rate with sustainable FWHP. It is believed the well penetrated into natural fracture system since due to its proximity with a fault.

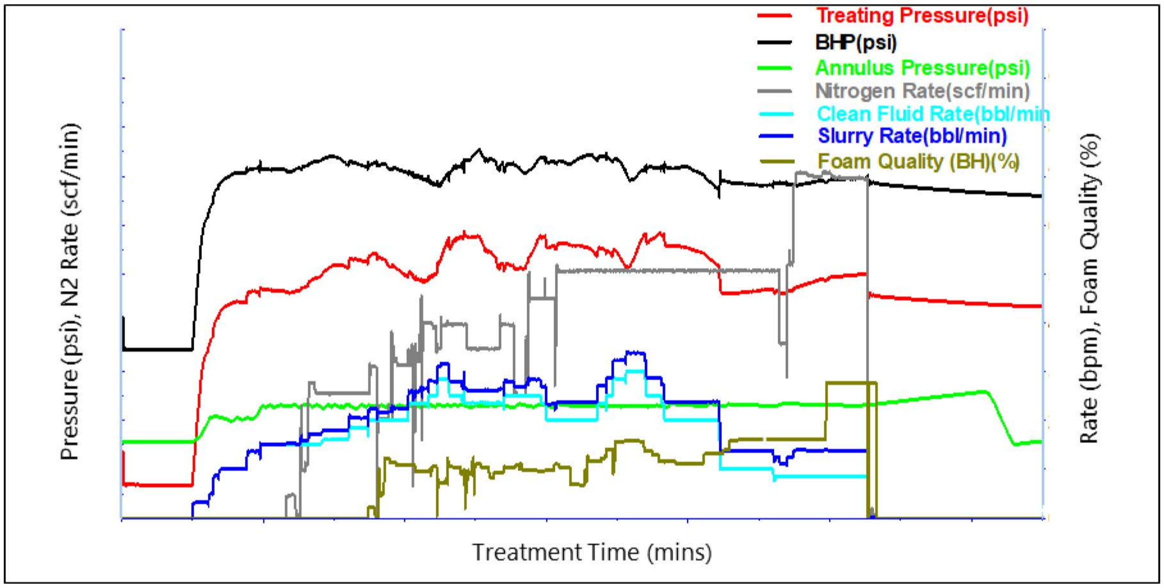

Figure. 5—Well-B Acid Fracture Stimulation Treatment

Reviving Complex Wells with UBCTD

Both the two examples show how Underbalanced Coiled Tubing Drilling (UBCTD) was utilized to revive production in complex well environments. In the first example, the technique was used to utilize its non-damaging environment to access high permeability reservoir and yielded excellent results despite the low reservoir pressure environment. This is one example from many and it has allowed UBCTD as a completion of choice for reviving old or drilling new infill wells in low, sub-hydrostatic pressure environments.

The second example shows the superiority of UBCTD technique in accessing natural fracture system with its long horizontal multi-laterals compared to vertical wells where limited reservoir connectivity may not allow benefit of production from natural fractures.

UBCTD vs Conventional Stimulation – Analytical Comparison

Sound reservoir engineering and well completion decisions require a comparison between different well types to evaluate most optimum well completion decisions. Several plots were used to assess and compare productivity from different completion types. Following completion methods were assessed: (a) single-stage vertical wells, (b) multi-stage horizontal wells completed with OH packers and ball drop system, (c) multi-stage horizontal wells completed with cemented liner (plug and perf), (d) multi-stage horizontal wells completed with Cemented Liner and stimulated with surgi-squeeze (slotting/hydra-jetting and acid stimulation with Coiled Tubing), (e) Underbalanced Coiled Tubing Drilling.

The most convenient comparison between different completion types is to compare the normalized stabilized gas production rate and normalized Flowing Wellhead Pressure. Though this plot is raw and does not explain causes for a completion's advantage over the other, it is a good assessment of all completion methods within a field. Fig-6 shows this plot which affirms that wells drilled with UBCTD have produced at rates higher than any other completion types. While horizontal wells (type b, c and d) have shown good performance, for the same normalized FWHP range, wells completed with UBCTD have shown higher normalized gas production rates. Vertical wells have shown most wide range of production variation but the high rate tests from vertical wells are in areas of prolific reservoir development as well as high normalized reservoir pressure. Vertical wells have performed poor in areas of tight development and/or low normalized reservoir pressure. In these areas horizontal drilling or UBCTD is much needed for a commercial producer.

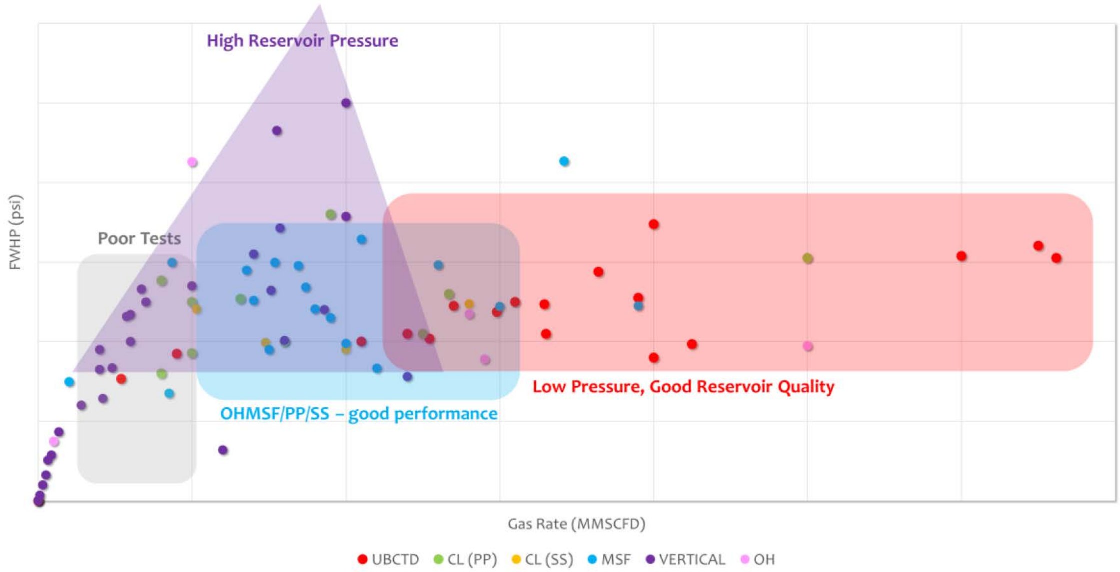

Figure. 6—Normalized FWHP vs. Gas Rate for different completion types

For a more qualitative assessment, wellhead productivity index was generated to compare performance from different completion types. Though the concept of Productivity Index (PI) may not strictly apply for gas wells, in the absence of an actual deliverability or pressure buildup tests for all the wells, the wellhead productivity index (WHPI) is the most practical approach to compare performance of a large group of wells. The wellhead PI is calculated for the maximum stabilized gas rate achieved using the following equation:

$$WHPI = \frac{q}{\left(p_{ws}^2 - p_{wf}^2\right)}$$

Fig-7 shows normalized WHPI plotted against reservoir pressure to assess performance variation with respect to changes in reservoir pressure. Assuming all variables are the same, it is expected that high reservoir pressure would yield higher gas rates. As observed in the plot, the UBCTD wells (plotted in red) outperform all other completion types across all ranges of reservoir pressure. Between conventional horizontal completions, the OH completion with packers and ball drop system has clear advantages over cemented completions. The OH completion system has the advantage of a large footage of reservoir rock exposed between the packers for stimulation and flowback. This type of completion allows access to secondary porosity features that contribute positively to production. In the absence of special image logs in horizontal wells, these features may be missed by perforation intervals that are targeted selectively.

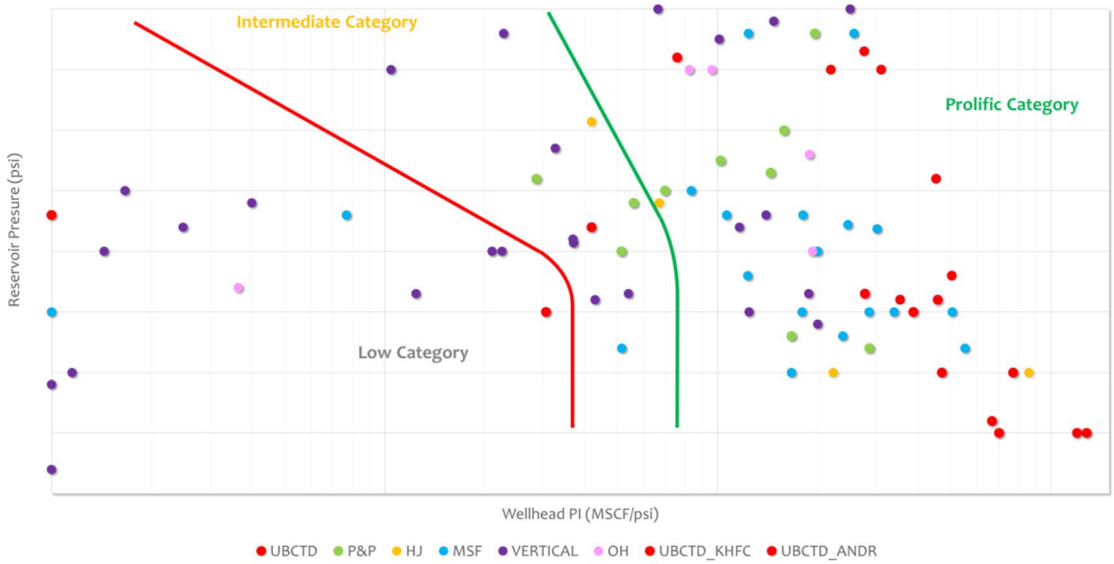

Figure. 7—Normalized FWHP (psi) vs. Gas Rate (MMSCFD) for different completion types

Modeling UBCTD Performance with Reservoir Simulation

A commercial 3D reservoir simulator was used to model UBCTD well performance under different reservoir environments. The reservoir properties used in initialization are listed in Table 1. For simplicity, dry gas was used. Two laterals each with a length of 1000 ft. was input in the model. Target rate was set at a constant gas rate for all the cases.

The model was run under different conditions of permeability and well spacing to analyze the effect of these parameters in analyzing productivity and ultimate recovery.

Parameter	Type	Arbitrarily Set Value
Reservoir Pressure	Fixed	5,000 psi
Vertical Thickness	Fixed	50 ft.
Layers	Fixed	5
kz / kr	Fixed	1
Permeability	Variable	45, 4.5, 0.45 md
Reservoir Area	Variable	2, 1, 0.5 $km.^2$

Figure. 8—Arbitrary Reservoir Model Properties

Fig-9 shows the theoretical impact of well spacing (or contacted reservoir volume) for different values of arbitrary reservoir permeability. At higher permeability values, the model shows sustainable production at plateau of arbitrarily set 20 MMSCFD for larger reservoir areas. This is well understood as permeability has a high influence on total recovery. For lower permeability values, it was observed that the target rates were not sustainable and production decline was observed earlier for lower reservoir areas. Despite lower cumulative production volumes were observed for larger reservoir areas, the recovery factor was higher for lower reservoir area or tighter well spacing. This explains the need for having longer, multiple laterals or closer well spacing in tighter reservoirs for improving recovery.

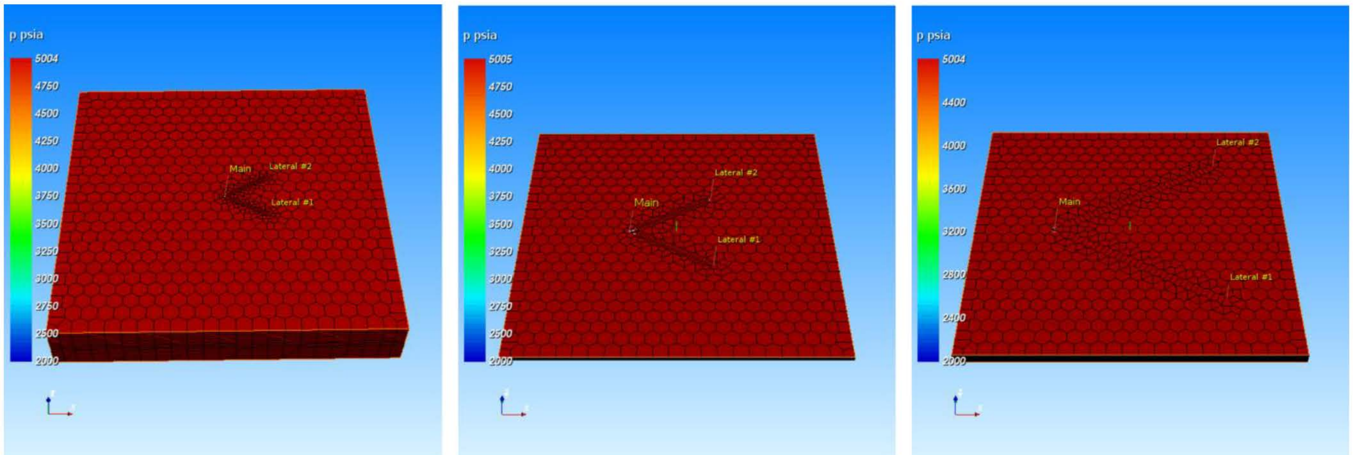

Figure. 9—3D Reservoir Model with UBCTD Properties for different reservoir areas

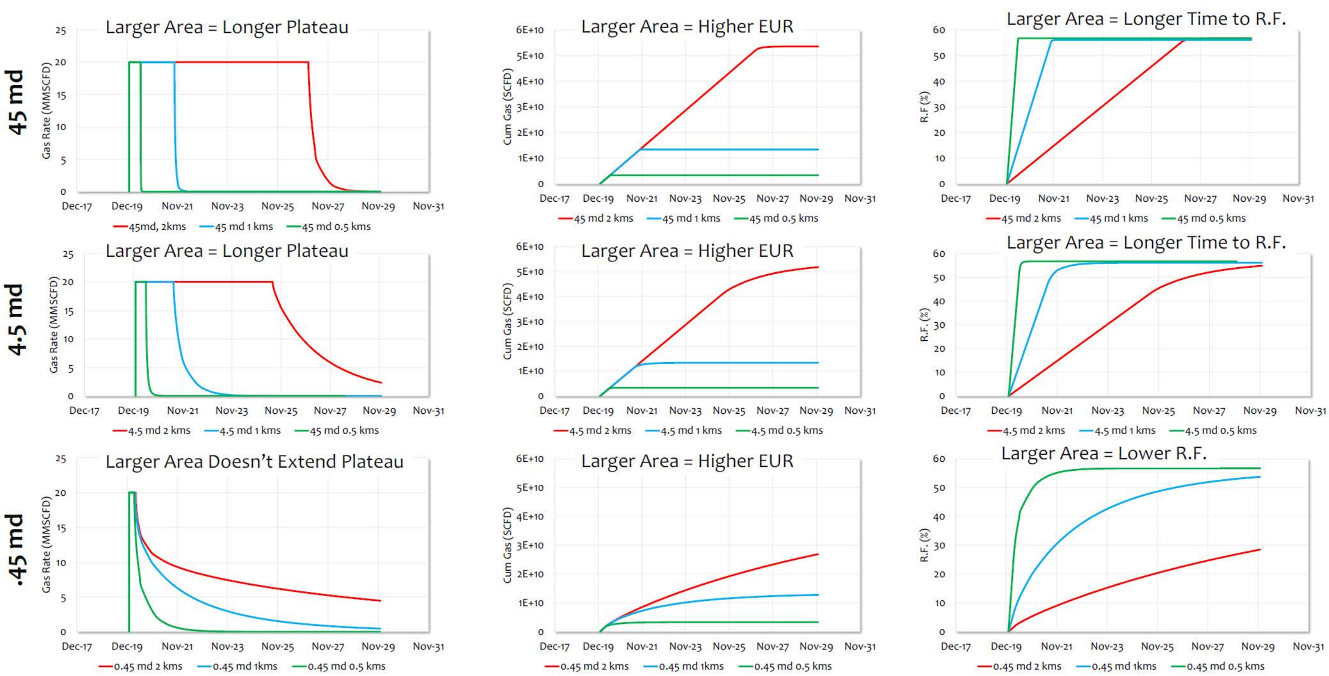

Figure. 10—Theoretical Reservoir Simulation Results of Arbitrary Perm vs. Arbitrary Area Sets

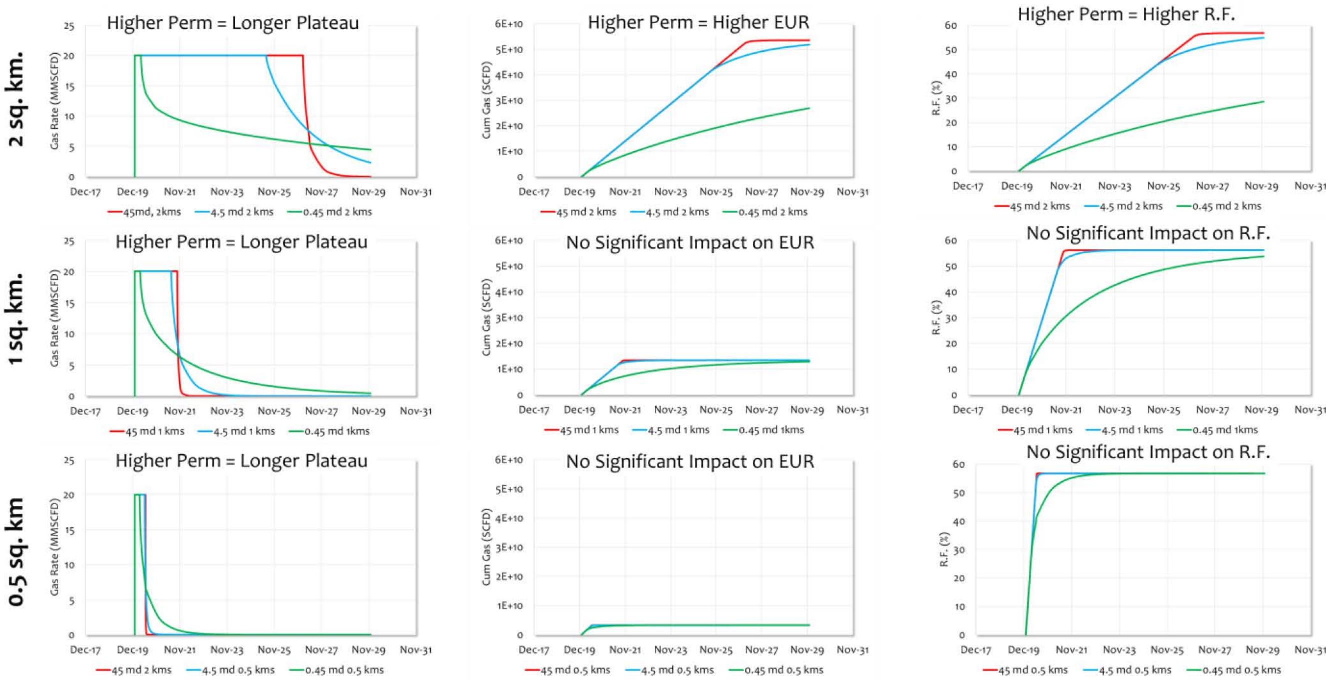

Figure. 11—Theoretical Reservoir Simulation Results of Area vs. Arbitrary Permeabilities

Conclusions

The Underbalanced Coiled Tubing Drilling (UBCTD) provides a competent completion technology often surpassing well performance other completion types in tight as well as relatively low reservoir pressure environments.

The key factors contributing to the superiority of UBCTD include the following after consideration of reservoir characteristics and numerical simulation are as follows:

1. Eliminates Reservoir Damage: UBCTD eliminates formation damage caused by the invasion of drilling fluids. With the use of nitrified water as the base drilling fluid, invasion of filtrate and solids into the formation is practically non-existent, leading to minimal formation damage and higher PI.
2. Increased Reservoir Contact: UBCTD allows drilling highly deviated or horizontal wellbores with minimal Dogleg Severity (DLS) limitation due attributed to the open-hole completion nature of UBCTD wells, significantly increasing reservoir contact and drainage area. This increased footage often results in connectivity with fissures and fractures which results in a higher PI compared to MSF wells and especially vertical wells.
3. Optimized Completion Technique: UBCTD technology allows for a relatively smooth simultaneous drilling and completion operation. In comparison, MSF wells and vertical wells typically require multiple interventions and complex completion operations, which may negatively affect well performance.

Nomenclature

UB : Underbalanced
CT : Coiled Tubing
UBCTD : Underbalanced Coiled Tubing Drilling
DLS : Dog-Leg Severity
MSF : Multi-Stage Fracturing
P&P : Plug and Perf

OH : Open Hole
WH : Wellhead
FWHP : Flowing Wellhead Pressure
MMSCFD : Million Standard Cubic Feet per Day
PI : Productivity Index
PIWD : Productivity Index While Drilling

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