JOURNAL OF PETROLEUM TECHNOLOGY • FEBRUARY 2008

JPT

Drilling Technology

Offshore Facilities: Construction and Design

Well Testing

DISTINGUISHED AUTHOR SERIES
Coalbed and Shale-Gas Reservoirs

GUEST EDITORIAL
Private Equity, Energy, and Resources

MANAGEMENT
E&P Production Information Management

Q&A
Shri Niladri Kumar Mitra
Director, Offshore, ONGC

COVERAGE
International Petroleum
Technology Conference

Official Publication of The Society of Petroleum Engineers • www.spe.org

Wireline Pressure Measurements Improve Reservoir Characterization in Tight Gas Formation

Improving recovery in tight gas reservoirs typically requires infill-drilling programs. Characterization of reservoir-pressure depletion and sand-body continuity is fundamental to determining the economic viability of these projects. In tight gas reservoirs, new wireline tools that use precise pretest mechanisms can achieve the required data-acquisition objectives. However, wellbore conditions and data-acquisition procedures can greatly influence the quality and limits of data application.

Introduction

The Wamsutter field is a large, continuous tight-formation gas accumulation in the Washakie and Red Desert basins of the Greater Green River basin in southwest Wyoming. Discovered in the 1950s, it encompasses 1,700 sq miles and is one of the largest tight gas resources in North America. The field area has produced 2 Tcf from more than 2,000 wells since discovery in the late 1950s. The primary productive interval is the Almond formation of the Mesaverde group, comprising shallow marine sandstones deposited along the western margin of the Cretaceous seaway.

This article, written by Technology Editor Dennis Denney, contains highlights of paper SPE 109565, "A Case Study: Using Wireline Pressure Measurements To Improve Reservoir Characterization in Tight-Formation Gas—Wamsutter Field, Wyoming," by ***R.A. Schrooten,*** *SPE, BP America;* ***E.C. Boratko,*** *SPE,* ***H. Singh,*** *SPE, and* ***D.L. Hallford,*** *SPE, Schlumberger; and* ***J. McKay,*** *BP America, prepared for the 2007 SPE Annual Technical Conference and Exhibition, Anaheim, California, 11–14 November.*

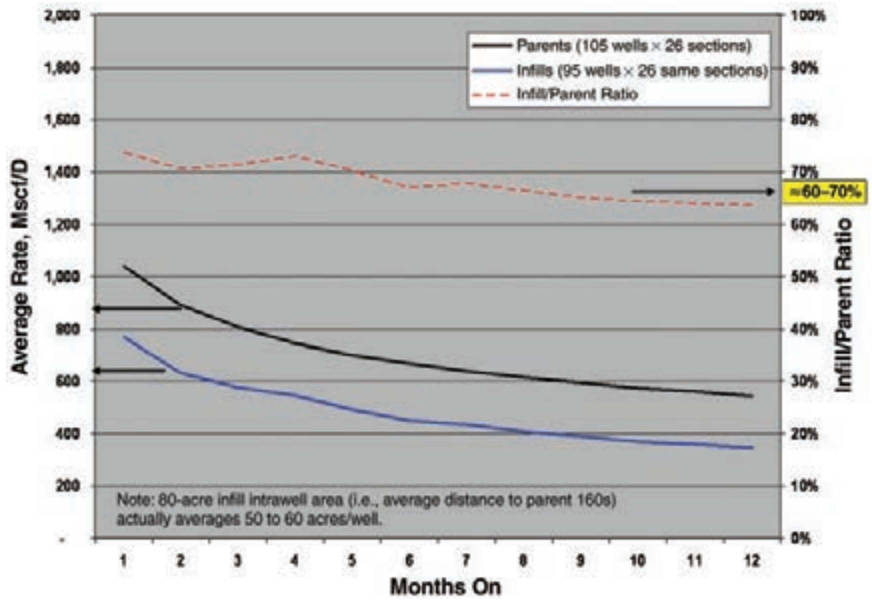

Fig. 1—Wamsutter 80-acre-infill performance: parent 160-acre-spacing vs. 2005/2006 80-acre-infill rate comparison.

Improving recovery in tight gas reservoirs leads to tight well spacing, driven by reservoir connectivity, permeability, well costs, and gas prices. These fields typically go through multiple rounds of downspacing on the basis of development pace, well-performance maturation, increased reservoir-characterization information, and technology advancements. This process can lead to less-than-optimal spacing and completions.

An elusive challenge with tight-formation spacing studies has been to gather fit-for-purpose pressure data in these reservoirs. A typical Wamsutter well will encounter a 500-ft gross (100-ft net) interval in the Almond, comprising 10 to 20 sands each averaging less than 10 ft in thickness. The result is a high level of heterogeneity. The historic inability to adequately or accurately sample individual-sand pressures throughout the productive interval while infill-developing mature producing areas has relegated historic drainage and recovery characterizations to overly simplistic and overly homogeneous tank-type material-balance solutions. The lack of dynamic layer-by-layer depletion detail can lead to erroneous modeling or poorly constrained recovery predictions and equally flawed claims for well-spacing requirements.

Objectives

Encouraging early-term 80-acre well performance coupled with still low recovery-efficiency predictions led the operator to undertake an in-depth 40-acre infill-potential evaluation. As part of that 40-acre-spacing analysis, it was realized that an improved understanding of mature-producer drainage inferred by interwell deple-

For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.

tion would be critical to improved reservoir characterization and modeling. Reservoir pressures were collected throughout the field. No significant reservoir-pressure data had been collected in Wamsutter since early field development in the 1970s and 1980s, and those data had been collected only in a highly permeable and limited portion of the field by use of conventional downhole pressure-buildup-analysis methods.

Many of the 80-acre infill wells are drilled directly offsetting mature producers by as little as 40 acres. In addition to targeting these select proximal infill wells for data collection, three four-well 40-acre pilots were drilled in mature producing sections to gain even further downspacing-performance insights. As a result, more than 180 pressure tests were performed on 24 wells spanning a 500-sq-mile area.

Pressure-Data Collection

A new generation of wireline tool was used. It is a pressure-only tool that is combinable with standard openhole-logging tools.

Pressure Gauges. This tool can be equipped with up to three gauges. A primary sapphire gauge monitors wellbore hydrostatic pressure continuously. A second sapphire gauge monitors the flowline pressure, and an optional quartz-crystal gauge can monitor the flowline pressure.

Pretest Mechanism. An electromechanical motor is coupled to a planetary roller-screw mechanism and high-reduction gearbox. This system provides precise control of the pretest rate and volume. The downhole tool-control and command functions improve response time and enable pretest volumes as small as 0.1 cm^3.

After a pretest rate is specified, all pretests are programmed to increase the flow by a desired volume or to increase the flowline volume until a desired flow pressure is obtained. The pretest piston will stop when either of the two criteria is met. Multiple pretests are possible at the same depth without resetting the tool. The user can draw down the flowline pressure below the sandface pressure multiple times to verify the measurement.

Universal Tight-Formation Gas-Testing Challenges

All probe-type wireline formation testers measure sandface pressure, the pressure at the borehole wall where the tool's probe is pressed, not necessarily formation or reservoir pressure. Many factors (e.g., formation permeability, mud properties, near-wellbore damage, overbalance, or underbalance) determine how the measured sandface pressure relates to the true formation pressure.

In any given application, the required accuracy of the pressure data must be determined such that the data are fit for purpose. Usually, pressure data are used in reservoir models to determine the optimum well spacing for fields. If many pay zones are stacked, which will require multiple fracture stages, the pressure data may be needed to optimize the staging of the fracture treatments and determine if any zones should be passed over or energized.

It also is important to consider conditions under which a sandface pressure can be obtained and relate it to true formation pressure. In a low-mobility formation, supercharging must be considered, and there is no definite way to identify or quantify it. However, the sandface pressures can be used with conditions.

Obtaining and Maintaining a Packer Seal. A seal with the formation is necessary to isolate the tool flowline from the hydrostatic mud pressure. The pretest volume must ensure that the flowline is drawn down below the potential formation pressure. When a very-low-mobility zone is tested, a large pressure differential across the packer element can make maintaining a packer seal difficult. Control over pretest rate and volume enables management of the flowline drawdown. Excessive flowline drawdowns are avoided, resulting in a minimum pressure differential across the packer element.

Minimizing Buildup Time. In very-low-mobility formations, excessive flowline-pressure drawdowns result in unnecessarily long buildup times. For a specific formation mobility, the time required for the pressure to build back to the sandface pressure is determined primarily by the pretest volume, not the rate. The ability to control the pretest volume and to terminate pretests on the basis of volume or pressure limits enables the control needed to minimize pressure-buildup time while ensuring the flowline was drawn below the formation sandface pressure.

Supercharging. Supercharging occurs in an overbalanced-drilling situation in which the mud-filtrate-leakoff rate exceeds the formation's ability to accept and dissipate the fluid freely. The result is a localized pressure buildup at the wellbore sandface that exceeds the true formation pressure. The effect is amplified in low-mobility formations for which the mud system never achieves reasonably low mud-cake permeability.

Supercharging is primarily a function of the ratio of formation-to-mud-cake permeability, the mud system, and the time/magnitude of overbalance to which a formation is exposed. The ability of the mud system to reduce filtration is key in maintaining supercharging at an acceptable level. In general, oil-based-mud systems seem to perform better than water-based-mud systems in reducing or eliminating the presence of supercharging.

Quality Control. When performing wireline formation tests, there are two basic criteria that must be accomplished. The first is to make sure the flowline pressure has been reduced below the sandface pressure. This action allows formation fluid to flow into the tool, recompressing the flowline and building up to the sandface pressure. The second is to wait long enough for the pressure buildup to stabilize. The level of pressure stabilization depends on the application and the accuracy needed. To aid in the determination of when to end a buildup, pressure-derivative curves are available for monitoring in real time. If the buildup is allowed to stabilize long enough, the actual flow regime, spherical or radial, can be identified. Identifying a flow regime verifies that fluid has indeed flowed from the formation into the tool, demonstrating that the flowline was drawn below sandface pressure.

In tight-formation gas wells, there is seldom time to allow this level of stabilization and consequent flow-regime identification. Additionally, in the presence of supercharging, flow-regime identification may not be possible. Therefore, a second, confirmation drawdown/buildup can be taken. Subsequent drawdown/buildup tests, in which the stabilized pressure repeats, also confirm that the flowline was drawn down below sandface pressure. In this case, derivative curves are used only to verify that a test has progressed beyond simple flowline recompression and is beginning to transition to a formation-flow-regime response.

Wamsutter-Specific Testing Challenges and Procedures

Wamsutter drilling practices were modified to improve the prospects for acquiring quality pressure information. Drilling at or near balance to prevent supercharging the formation was the most important drilling-practice delivery. The formations above the Almond are normally pressured, and the Almond sands are low-enough permeability to facilitate drilling at or near balanced without posing a major drilling risk. There also was concern that use of an even slightly underbalanced mud weight could prevent developing sufficient filter cake for the tool to seal, and allow near-wellbore gas entry and potential de-pressurization (i.e., false low pressures). Because many of the test intervals demonstrated some depletion, good filter cake and pressure isolation were achieved for most of the tests. After drilling the first few wells with traditionally high mud weights, it was determined that the final mud weight could be reduced further by not drilling into the Ericson formation (just below the Almond and typically used as rathole).

In addition to drilling with a lower mud weight, wiper trips and short trips across the Almond were kept to a minimum to prevent supercharging. Because the time necessary for supercharging to dissipate in the tightest zones is likely well beyond the openhole-logging period, it was felt that filter cake should be deposited and maintained as long as possible before logging.

Pressure-Data Analysis

Pressure-testing locations were chosen by selecting wells being drilled on approximately 40-acre offsets (1,320 ft) from existing mature producers. Twelve of the 24 wells were drilled as 40-acre pilot tests, with the remaining 12 test wells drilled as 80-acre infills meeting the 1,320-ft-offset requirement. The entire pressure-testing program also strived for comprehensive geographic coverage of the entire Wamsutter development area.

More than 180 successful tests were performed on these 24 wells. A post-program data-quality review resulted in approximately 60 tests being eliminated because they did not meet the quality-control criteria (i.e., buildup shape, final build slope, and derivative beyond storage domination).

How often and to what degree supercharging affected the data set was investigated, not so much to improve upon the 40% of the tests that showed obvious depletion, but to attempt understanding how much depletion the supercharging could mask on the remaining 60% of the tests deemed undepleted. To attempt supercharge quantification, injection fall-off tests were performed on a small sampling of the same sands tested with the new pressure tool, and on wells with contrasting (balanced vs. overbalanced) mud weights.

These duplicate pressure measurements were performed on five sands from four different wells. Tests on wells in which mud weights were kept near-balanced throughout the drilling and testing process gave remarkably similar reservoir-pressure results. Tests taken on wells drilled slightly over-balanced (which is more like the normal operation) indicated approximately 500-psig higher reservoir pressures with the new-generation pressure tool than from the injection fall-off test. Those wells demonstrating supercharging were drilled with an average 12-lbm/gal mud weight, while those showing minimal pressure-test difference were drilled with an average 10.5-lbm/gal mud weight. This mud-weight difference equates to approximately 800 psi at testing depth, agreeing reasonably well with the 500-psig-supercharge estimate observed from the injection fall-off vs. new-generation-pressure-tool crossplot. Therefore, the 40% of the wireline pressure tests that exhibited lower pressures than their respective mud-weight pressures are likely both the "minimum" percent connected sands at 40-acre spacing (to their offset producers) and their minimum depletion.

Performance-Related Depletion Corroboration

A select sampling of sections that had been infill drilled on 80-acre spacing during a 2-year period was compared to their same-section offset 160-acre mature-producer performance. The typical comparison section had four mature 160-acre parent wells for which the average early-term performance could be compared directly to the average performance of the four new same-section 80-acre infill wells.

Fig. 1 shows the early-term rate performance for the 80-acre infill wells. The average rate for the entire 80-acre infill-well data set (95 wells on 26 sections) during the first 12 months performed at 60 to 70% of the comparative initial average rate for their offset 160-acre parent-well data set (105 wells on same 26 sections). This performance ratio was consistent for most of the analyzed sections and provided strong corroborating performance evidence that supports the partial-depletion conclusion that was based on pressure measurements from the new testing tool.

Conclusions

This study demonstrated collecting fit-for-purpose pressure measurements in tight-formation gas reservoirs.

- Drilling practices can affect pressure-testing results greatly and must be managed to optimize hole conditions and minimize wellbore influence on the sandface pressures.
- Testing procedures should be designed for the expected formation mobility, anticipated depletion level, and time limitations with the goal of acquiring pressures useful for the intended purpose. These techniques are not necessarily designed or expected to quantify absolute reservoir pressures. They can, however, be designed to observe the presence, magnitude, and frequency of pressure depletion.
- Supercharging must be acknowledged, with the associated pressure data interpreted within the limits of applicability.

Useful information for characterizing pressure depletion and reservoir connectivity in infill programs such as Wamsutter can be achieved, provided statistically sufficient sampling is done. **JPT**