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Modern Approaches for Measuring Production in Partially Completed Wells

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A B S T R A C T

Partially completed wells continue to challenge petroleum engineers due to their limited contact with reservoirs and incomplete perforation zones, complicating precise production estimation. Traditional evaluation methods, mainly designed for fully completed wells, frequently overlook extra pressure drops, irregular flow patterns and the combined effects of formation damage with partial penetration. Building on core principles such as skin factor and flow efficiency, contemporary strategies integrate pressure transient testing, production logging instruments, inflow performance relationships (IPR) and numerical reservoir simulations to enhance the accuracy of production forecasts. Advanced approaches-including pseudo pressure modelling for non-Darcy flows, coupled wellbore-reservoir simulations and stress-informed inflow models-allow more precise predictions of flow behavior, pressure profiles and well productivity. This study emphasizes combining classical well-test interpretation with modern computational methods and digital monitoring systems. Results indicate that these contemporary methodologies not only improve production assessment but also provide guidance for optimized completion designs and operational strategies in complex oil and gas reservoirs.

Keywords: Partially completed wells; Production measurement; Skin factor; Inflow performance relationship (IPR); Pressure transient analysis; Pseudo pressure modelling; Reservoir simulation; Production logging; Non-Darcy flow

Introduction

Wells that are partially completed continue to present significant challenges in petroleum engineering because their interaction with the reservoir is limited and perforation intervals are incomplete. These conditions make it difficult to precisely evaluate production rates[1]. In contrast to fully completed wells, where conventional evaluation methods provide reliable predictions, partially completed wells often display irregular flow patterns, additional pressure drops and variable formation damage, which can result in misleading production estimates[2].

Reliable assessment of these wells is crucial for enhancing production strategies, improving reservoir management and guiding the planning of future well completions[3]. Traditional techniques, such as standard pressure transient analysis (PTA) and basic inflow performance relationships (IPR), often fail to adequately account for the complexities associated with partial penetration and non-uniform flow, underscoring the importance of advanced measurement and modelling approaches[4].

Recent advancements combine production logging instruments, digital monitoring systems, numerical reservoir

simulation and pseudo pressure modelling to provide a more accurate understanding of the dynamic performance of partially completed wells[5,6]. Integrating field observations with computational models allows engineers to better estimate well productivity, identify underperforming zones and design targeted interventions to maximize hydrocarbon recovery[7].

The objective of this paper is to examine contemporary methodologies for measuring production in partially completed wells, focusing on the combination of classical well-test interpretation with modern computational techniques and digital monitoring systems. The insights presented aim to enhance production forecasting and inform strategic decisions for optimizing well completions in complex reservoir settings[8-10].

Methodology / Theory

Accurate production estimation in partially completed wells requires a combination of field measurements, analytical techniques and computational modelling[1]. This section describes the methodologies used to evaluate well performance, including well testing, production allocation techniques and mathematical/numerical models.

Well testing methods

Pressure Transient Analysis (PTA): Pressure transient analysis is widely used to assess reservoir characteristics and well productivity. PTA monitors pressure changes in the wellbore over time following flow alterations, such as well shut-in or step changes in production. This allows estimation of key parameters including permeability, skin factor and well productivity index[2].

In partially completed wells, the apparent skin factor includes:

- True skin - caused by formation damage around the wellbore.
- Apparent skin - resulting from incomplete reservoir contact.

The total skin factor is expressed as:

$$s_{total}=s_{true}+s_{apparents}$$

Radial flow into partially completed wells can be approximated using the Hawkins equation[3]:

$$\Delta P=\frac{q\mu}{2\pi kh}\ln\frac{re}{rw}+s_{total}\frac{q\mu}{2\pi kh}$$

- q = flow rate
- μ = fluid viscosity
- k = reservoir permeability
- h = formation thickness
- re_ = drainage radius
- rw= wellbore radius

Drill stem test (DST): DST provides direct measurement of formation pressure and production capacity. The test isolates the target formation using packers, while pressure gauges record bottomhole pressure during flow and shut-in periods[4]. Advantages include direct assessment of formation productivity and validation of simulation and PTA results. Limitations include high operational cost and limited long-term production evaluation.

Production allocation techniques

Material balance approach: This method calculates fluid production relative to reservoir pressure depletion, allowing estimation of individual interval contributions:

$$\text{Cumulative Production}=N(1-\frac{P}{Pi})$$

Where:

- N = original oil in place
- P = current reservoir pressure
- Pi = initial reservoir pressure

Tracer tests: Tracers are injected into selected reservoir zones to determine the contribution of each section to overall production. Tracer concentration in produced fluids provides a direct measurement for allocation[6].

Nodal analysis: Nodal analysis evaluates pressure–flow relationships at discrete points along the wellbore and reservoir. By integrating wellbore hydraulics with reservoir inflow models, this method offers detailed understanding of production performance[7].

Mathematical and numerical models

Darcy's law

Darcy's Law governs single-phase flow through porous media:

$$q=\frac{kA}{\mu L}\Delta P$$

Where:

- q = flow rate
- A = cross-sectional area
- L = flow path length
- ΔP = pressure difference

Inflow performance relationship (IPR): IPR defines the relationship between bottomhole flowing pressure and production rate:

Where

PI is the productivity index:

$$PI=\frac{q}{\Delta P}$$

Pr- average reservoir pressure

Pwf- bottomhole flowing pressure

IPR curves are particularly useful for partially completed wells with reduced effective perforated intervals[9].

Vogel equation

For solution-gas drive reservoirs, Vogel's empirical correlation estimates oil production as:

$$\frac{q}{qmax}=1-0.2\frac{Pwf}{Pr}-0.8(\frac{Pwf}{Pr})^2$$

Where:

qmax = maximum production at zero flowing pressure

Pr = average reservoir pressure

Integration of methods

The most reliable production estimation combines well testing, production logging, allocation techniques and numerical modeling. Typical workflow involves:

- Collecting field data using production logging tools (PLTs) and well tests.
- Estimating total and apparent skin factors.
- Allocating production among perforated intervals using tracer tests or nodal analysis.
- Applying IPR or Darcy-based models to predict overall production.
- Validating predictions against measured production and adjusting models accordingly.

By integrating these methods, engineers can maximize reservoir exploitation, minimize uncertainties and develop robust strategies for partially completed wells.

Results & Discussion

The combined use of well testing, production logging, allocation methodologies and numerical simulations provides a comprehensive evaluation of partially completed wells[1-3]. Modern techniques offer improved insights into flow distribution, pressure behavior and overall well productivity, allowing engineers to make more informed decisions.

Well testing observations

Pressure Transient Analysis (PTA) effectively identifies formation damage and evaluates skin factors in partially completed wells[4]. Studies indicate that apparent skin often increases in wells with limited perforation intervals, highlighting the necessity of adjusting traditional interpretations to account for non-radial flow and restricted reservoir contact. Drill Stem Tests (DST), while operationally intensive, deliver direct measurements of formation productivity and validate PTA and simulation results[5]. Combining PTA and DST enhances confidence in reservoir parameter estimation and facilitates identification of underperforming zones.

Production logging and allocation insights

Production logging, including flow profiling and tracer studies, enables precise evaluation of contributions from individual perforation intervals. Tracer-based allocation provides more accurate assessment of zonal performance compared to purely theoretical approaches[6]. Nodal analysis integrates wellbore hydraulics with reservoir inflow, enabling detailed modeling of pressure–flow relationships along the wellbore. This method is particularly valuable in partially completed wells, where certain intervals may underperform.

Mathematical and numerical model evaluation

IPR curves, calibrated with field data, offer reliable predictions of overall well production, accounting for reduced effective perforated intervals[7]. Reservoir simulations incorporating pseudopressure modeling and coupled wellbore-reservoir analysis enhance predictive accuracy by considering non-Darcy flow, heterogeneity and stress effects[8]. Integrated numerical approaches accurately forecast flow distribution and bottomhole pressures, supporting strategic completion planning and production optimization[9].

Comparative effectiveness of techniques

Evidence shows that combining production logging, well testing and numerical simulations delivers the most accurate assessment of partially completed wells. PTA alone provides key reservoir parameters but may overlook partial perforation effects. DST validates these measurements but is costly and operationally demanding. Production logging, tracer studies and nodal analysis offer detailed interval-level insights, while numerical simulations provide predictive capability under various operational scenarios. Together, these methods reduce uncertainty and enhance hydrocarbon recovery[10].

Implications for field applications

Integrating traditional and advanced techniques enables data-driven optimization of well completions. Engineers can:

- Identify low-performing intervals
- Estimate total and apparent skin factors
- Allocate production accurately
- Apply IPR or numerical models for overall performance prediction

This integrated approach minimizes operational uncertainty, improves production forecasts and informs targeted interventions such as selective stimulation or recompletion in partially completed wells[1-10].

Conclusions

The analysis of partially completed wells demonstrates that precise production estimation requires an integrated methodology combining well testing, production logging, allocation techniques and numerical modeling[1-3]. Key conclusions from this study are as follows:

- **Well testing insights:** Pressure Transient Analysis (PTA) and Drill Stem Tests (DST) remain essential for evaluating formation characteristics, skin factors and overall well productivity. PTA provides crucial reservoir information but may underrepresent effects of partial perforation and non-radial flow when applied alone. DST complements PTA by offering direct measurements, enhancing confidence in productivity assessment[4,5].

- **Production allocation accuracy:** Production logging tools, tracer studies and nodal analysis allow detailed interval-level evaluation, facilitating identification of underperforming zones. These methods significantly improve production allocation and guide optimization of completion strategies[6,7].

- **Mathematical and numerical modeling:** Inflow Performance Relationships (IPR) and reservoir simulations-including pseudopressure and coupled wellbore–reservoir models-enable accurate prediction of flow distribution, bottomhole pressures and overall well productivity. Calibration with field measurements ensures reliability of predictions, particularly in partially completed or complex reservoirs[8-10].

- **Practical implications:** Combining these techniques provides a comprehensive framework for field application. Engineers can optimize completion design, accurately allocate production across perforated intervals, detect formation damage and implement targeted interventions such as selective stimulation or recompletion. This integrated approach reduces operational uncertainty, enhances hydrocarbon recovery and supports efficient reservoir exploitation[1-10].

- **Future research directions:** Emerging technologies,

including remote monitoring, smart wells and automation, offer substantial potential for improving production measurement in partially completed wells. Integration of digital sensors, real-time data acquisition systems and automated control can facilitate proactive well management, optimize performance and reduce reliance on manual operations. Future studies should focus on combining these innovations with traditional measurement techniques, refining predictive models and enhancing operational efficiency in heterogeneous and challenging reservoirs.

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