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Emerging Technologies in Offshore

Advancing Production Flow Profiling With Subatomic Fingerprints and Big Data Analytics

This paper describes a smart-tracer-portfolio testing and design solution for multistage hydraulic fracturing which will, write the authors, enable operators to reduce operating cost significantly and optimize production in shale wells. The technology combines recently developed smart tracers with advanced subatomic measurements in an automated process with stringent quality control that assures precise tracer addition onsite and provides accurate and actionable completion diagnostics results at a fraction of the cost of production-logging testing, distributed temperature testing, or distributed acoustic sensing.

Introduction

Multistage hydraulic fracturing operations costs—including high-pressure pumping, proppant, and fluid—ranged from $2.9 million to $5.6 million per well in a typical US shale well in 2018, representing close to 60% of the total drilling and completion cost for each well. Yet industry studies reported that up to 50% of the clusters and stages and up to 40% of the fracture networks do not produce in the current geometric factory-mode-completion approach, leading to estimates that up to 40% of the drilled and completed shale wells in North America alone could be uneconomical.

Additionally, interactions between fractures in adjacent horizontal wells, and the costly negative effects of these interactions, have become the focus of much discussion and debate within the technical community. The impetus for this attention has been the effect of these interactions on productivity and the mechanical integrity of the parent wells.

These issues drive the need for oil and gas operators to have more-accurate, affordable, and timely data on the performance of individual fracturing stages, measured intrawell communication, and temporary and long-term frac/frac connections to enable improved decision-making and optimization of multistage hydraulic fracturing operations as well as overall field development.

The complete paper describes smart tracer technology, including a patented portfolio and fracturing-/completion-optimization work flow; laboratory testing and performance analysis; and integration with completion diagnostics.

Smart Tracer Technology

To control the effectiveness of multistage hydraulic fracturing stimulation treatments, it is essential to use special tracing methods based on the addition of the labeled substance to the proppant, water, or gas, and monitor the release of tracers with flowback water and produced oil and gas from the current well or nearby observation wells. Currently, conventional water- and oil-soluble chemical substances with fluorescent properties and ionic, organic materials, or radioactive isotopes, are used as the tracers. Tracers with fluorescent properties and ionic and organic materials are high-cost, limited to chemical-measurement techniques at a molecular level, and often have reported false-positive results for long-term communication. Environmental regulations in many countries prohibit the use of radioactive tracers (i.e., radioactive isotopes) because they pollute the environment and could contaminate subsurface layers.

The authors, in collaboration with a nanotechnology partner, developed and commercialized a portfolio of smart tracers based on proprietary particles developed from low-cost materials. The technology uses advanced subatomic spectroscopy-measurement techniques to map the distribution of well production, the performance of each fracturing stage, crosswell interference, and environmental containment. The complete paper presents a description and illustration of the work flow.

Laboratory Testing and Performance Analysis

To provide quantitative and qualitative interpretation, all smart tracers undergo rigorous laboratory testing and validation. Each smart tracer is tested for thermal and pressure stability, settling time, particle size distribution, reservoir static, and dynamic adsorption, as well as other characteristics during the testing process.

The next step is to align and refine each smart tracer design with preplanned fracturing design and estimated well-completion-flow profile. This is required for performance testing of the smart particles' recovery efficiency for minimum and maximum flow rates at stage level. For this paper, a shale operator provided a typical completion design for smart-tracer-performance

This article, written by JPT *Technology Editor Judy Feder, contains highlights of paper SPE 196172, "Unleashing the Power of Smart Particles for Completion Diagnostics: Advancing the Production-Flow-Profiling Technology With Subatomic Fingerprints and Big-Data Analytics," by* ***Talgat Shokanov****, SPE, and* ***Pavel Khudorozhkov****, QuantumPro, and* ***Adilkhan K. Shokanov****, Abai University, prepared for the 2019 SPE Annual Technical Conference and Exhibition, Calgary, 30 September–2 October. The paper has not been peer reviewed.*

verification testing at the following downhole conditions.

- Well production rate: 4,000 B/D
- Well fracturing stages: 40 stages per well
- Flow rate per stage: 100 B/D
- Perforation clusters: three clusters per stage
- Minimum flow rate (6-in. perforation): 0.5 gal/min
- Maximum flow rate (6-in. perforation): 3.0 gal/min
- Proppant pack: 40/70 fracturing sand

The assumption for these conditions is that the shale well has averaged 1.5 open perforations per cluster during the period while the well is producing at 4,000 B/D or higher. In reality, the production rate may fall off quickly, so long-term monitoring of smart tracer recovery would also rely on smart particles being able to move at a much lower rate. Additionally, the performance of moving the smart tracer in the horizontal section of the shale well is considered. If the stage closest to the toe is producing 100 BLPD (or 0.0486 gal/sec) with 4½-in. liner, the fluid is moving at 0.0814 ft/sec.

To accomplish such flow profiling and smart-tracer-recovery testing, a special unit was designed and deployed under expert supervision for a dedicated study of each smart-tracer-flow profile by simulated hydraulic fracturing with fracturing sand and at downhole wellbore conditions using different flow-profile rates at each stage. The complete paper presents a detailed discussion of the testing unit and procedure.

The smart tracer recovery was tested using an actual shale well completion design provided by an operator assuming 400,000 lb of 40/70 fracturing sand per stage. The projected flow velocity at the cluster level ranged from 0.1–3.0 gal/min, and detection limited up to 1 ppm from the milligram sample collected from the testing, as shown in **Fig. 1.** The results indicated a very good volume of smart tracer recovery from the first run with 9.2% at 3 gal/min and with 6% at 0.1 gal/min. These results were then verified using subatomic instruments for fingerprinting identification.

Integration With Completion Diagnostics

Completion diagnostics is a complex, multidisciplined task that requires knowledge of formation evaluation, geologic and geomechanics modeling, reserves estimation, hydraulic fracturing pressure analysis, and dynamic simulation. It is required to identify the reasons for good or poor performance in horizontal well stages determined through smart tracer diagnostics and to verify each stage's contribution to the total well production rate.

As with conventional fields, shale well stage production rate is defined by the presence of hydrocarbon in place, formation quality (brittleness, porosity, and permeability), and completion efficiency (perforation strategy and hydraulic fracturing-treatment design). Hydrocarbon presence in shale formations can be characterized by total organic content. Formation organic content is normally determined in the laboratory by kerogen extraction from the core sample and its further analysis. In the field, organic reach intervals can be found using resistivity, spectral gamma ray, and mud logs.

Unconventional fields often are not well characterized by subsurface data needed for formation evaluation and limited modeling for accurate geological and geomechanical assessment. Nevertheless, the industry has accumulated a huge amount of subsurface data. More than 2 million wells have been drilled in the US alone, and most currently developed basins are covered with seismic, well logging and core data, geological, and tectonic information. These legacy data are used to understand geology, correlations, and trends of rock distribution in studied areas to construct reliable models and predict well-production potential.

The complete paper discusses the role of formation evaluation, geomechanics analysis, diagnostic fracture injection testing, and fracturing pressure diagnostics and their importance to analyzing and optimizing hydraulic fracture performance, completion-design efficiency, and well productiv-

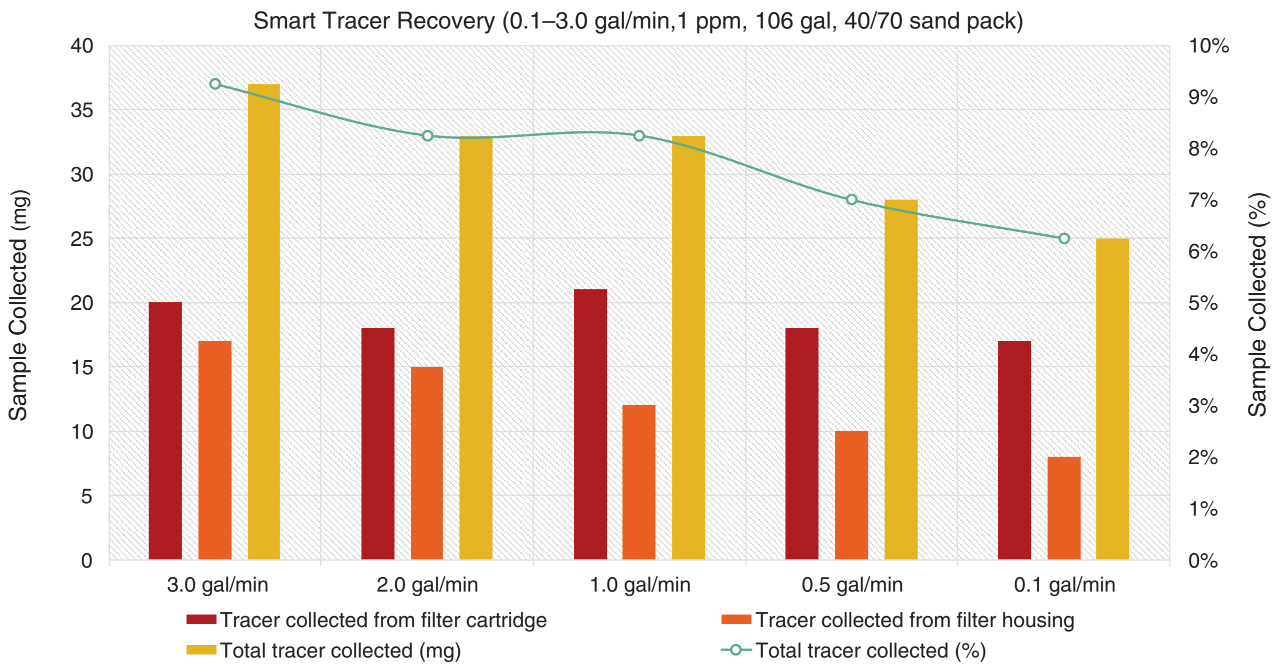

Fig. 1—Smart tracer recovery using flow-loop performance testing.

ity. According to the authors, legacy information and new insightful learning gained from different types of geologic data need to be combined in one reliable solution, but the correlations between these types of information can be highly complex and not always analytically clear. The future of shale-formation characterization is deep machine learning and big data analytics employing different kinds of neural networks, a biologically inspired programming approach that enables computers to learn from observational data. **JPT**