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DEVELOPMENT OF PRODUCTION PROFILING TECHNOLOGIES FOR MULTI-FRACTURED WELLS

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Abstract. Tracer-based production profiling in horizontal wells stimulated with multistage hydraulic fracturing is widely used nowadays both for production monitoring in individual wells and production control across the entire field, significantly enhancing the economic performance of oil and gas producers. At the same time, this method has potential for further improvement in terms of more accurate flow rate estimation for individual frac stages. This paper contains results of a theoretical calculation modeling the long-term production of a horizontal well with two-stage hydraulic fracturing. They suggest that flow rate values across frac stages may be distorted due to uneven washout rate of the tracer-embedded polymer layer exposed to a flowing liquid. A potential pathway for further elaboration of the tracer-based profiling method is proposed, in particular, focusing on achieving better accuracy of each stage flow rate during a long-term production period.

Keywords: tracer studies, multistage hydraulic fracturing, field development modeling, well completion equipment, production profile.

On the back of current challenges facing the oil and gas industry, a tracer-based production profiling technology for horizontal wells stimulated with multistage hydraulic fracturing has seen significant development in recent years [1, 2]. This method involves applying a polymer coating containing tracers either to the proppant (e.g., quartz sand) used to prop the fractures or to well completion components [2]. One of the manufacturers of such equipment is Naberezhnye Chelny Pipe Plant, an enterprise of the TatProm-Holding Group (Figs. 1 and 2). A key and undeniable advantage of this method over conventional production logging tools (PLT) is that it does not require well shutdown and kill operations, costly workover crew services, coil tubing units, and other auxiliary equipment. Consequently, the tracer-based profiling method offers noticeable economic attractiveness.

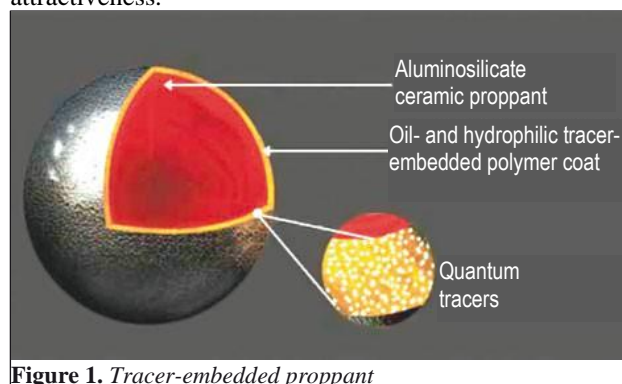


Figure 1. Tracer-embedded proppant

At the same time, according to the authors, the method has potential for further improvement in terms of more accurate flow rate estimation for individual fracking stages during a long-term surveillance period. There are practical and theoretical grounds for this. For instance, the results of tracer-based profiling conducted in individual frac stages show notable variability over a

certain time interval, a phenomenon also observed by other researchers [2, 3]. The causes for such variability, discussed in the publications, have been primarily determined analytically.

Over the well production time, significant volumes of fluid flow through the near-wellbore region containing the tracer-embedded proppant, gradually washing out tracers from the proppant surface [1, 2]. As time passes, the tracer-embedded polymer coating on each proppant particle becomes thinner. Simultaneously, the surface area with the tracer material exposed to the fluid shrinks, resulting in a lesser number of tracers per unit volume of fluid washed out. Each interval (frac stage) has a specific flow rate, so, over time, the aforementioned phenomenon can distort the data on the actual flow contribution from each stage. To illustrate this, we have roughly calculated potential inaccuracy in flow rate distribution across frac stages for a hypothetical case.

The calculation was based on the following initial data and assumptions:

1. The calculation was made for a single proppant particle with a diameter D of 110^{-3} m per one frac stage.

2. Tracers were uniformly distributed throughout the the polymer layer. The initial thickness of the tracer-embedded polymer layer was 1×10^{-4} m (approximately 10% of D). Then, at the beginning of production, the radius of the proppant with the polymer layer, R_0 , is 6×10^{-4} m.

3. The time for the "complete dissolution" of the tracer-embedded polymer layer is 1.5 years at a constant fluid flow rate of 100 m³/day. Alternatively, for ease of calculation, a fluid volume Q_{min} of 5 m³/day, washing the proppant, takes away a layer of thickness $\Delta\tau$ equal to 1×10^{-9} m. We neglected potential layer thinning resulting from its washout due to its insignificance.

4. The calculation was performed for a well stimulated with two hydraulic fracturing stages. The fluid flow rates for Stage 1 (Q_1) and Stage 2 (Q_2) are constant over time and equal to 100 m³/day and 50 m³/day, respectively.

The thickness of the tracer-embedded polymer layer, z_j , m, washed out by the flowing fluid per day for the j -th frac stage is calculated by the formula:

$$z_j = \frac{Q_j}{Q_{min}} \Delta\tau, \quad (1)$$

where Q_j is the actual fluid flow rate for the j th stage, m³/day.

The radius of the tracer-embedded proppant R_n on the n th day, m, is calculated using the formula

$$R_n = R_{n-1} - z_j. \quad (2)$$

The amount of the washed polymer layer with tracers V_n^m for the j th frac stage on the n th day, m³, is calculated as the difference between the amount of tracer-embedded proppant on the previous ($n - 1$) and current (n) days according to the formula

$$V_n^m = \frac{4}{3} \pi (R_{n-1}^3 - (R_{n-1} - z_j)^3). \quad (3)$$

The number of tracers corresponding to a certain frac stage is recorded at the wellhead, as well as the total number of tracers for the well.

The number of tracers is determined by the amount of the polymer layer substance washed out together with the tracer substance. The calculated fluid flow rate Q_{calc} for the j th frac stage on the n th day is proportional to the tracer concentration according to the formula

$$Q_{jn}^{расч.} = \frac{V_n^m \cdot Q_{сумn}}{V_{сумn}^m}, \quad (4)$$

Where $Q_{sum n}$ is the total well flow rate on the n th day, measured at the wellhead by respective measurement instruments, m³/day; in this case, it is constant and equal to 150 m³/day;

$V_{sum n}^m$ is the total estimated amount of the washed marker substance for all stages on the n th day, m³.

Calculations based on the above formulas were performed in MS Excel. The time step is 1 day, the calculation was performed for two years. The calculation results are given in Fig. 3, which compares estimated and actual (as specified in the initial data) flow rates for each stage.

As evident from Fig.3, the difference between the actual and estimated flow rates increases with well production time. The estimated flow rate decreased for the first stage (with the higher flow rate) and respectively increased for the second stage, even though the actual flow rates, according to the problem statement, remain constant. Just prior to the complete exhaustion of the tracer-embedded layer for the high flow rate stage, the calculated difference would be approximately 7 m³/day for each of the two stages. After 1.5 years, tracers from the first stage with high flow rate are no longer detected at the wellhead, which could be misinterpreted as evidence that the flow has stopped.

Naturally, in real field conditions, distortion of flow rates would likely be more gradual and depend on various factors. For instance, a portion of the proppant may be washed out to the wellhead during well backflow and production, and not all proppant may be uniformly exposed to the flowing fluid.

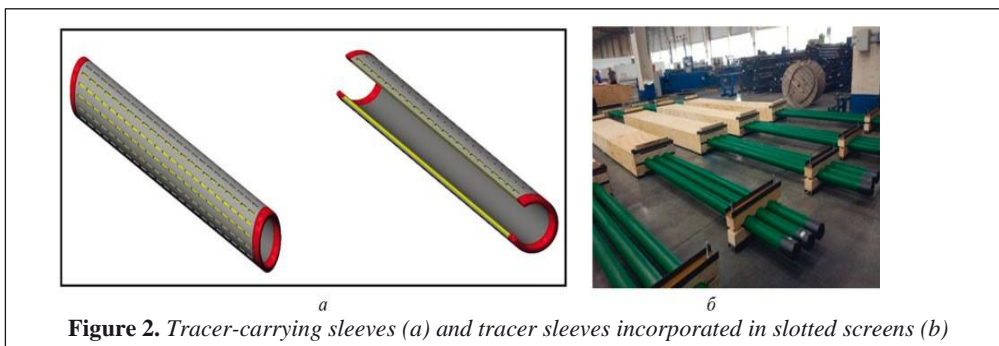


Figure 2. Tracer-carrying sleeves (a) and tracer sleeves incorporated in slotted screens (b)

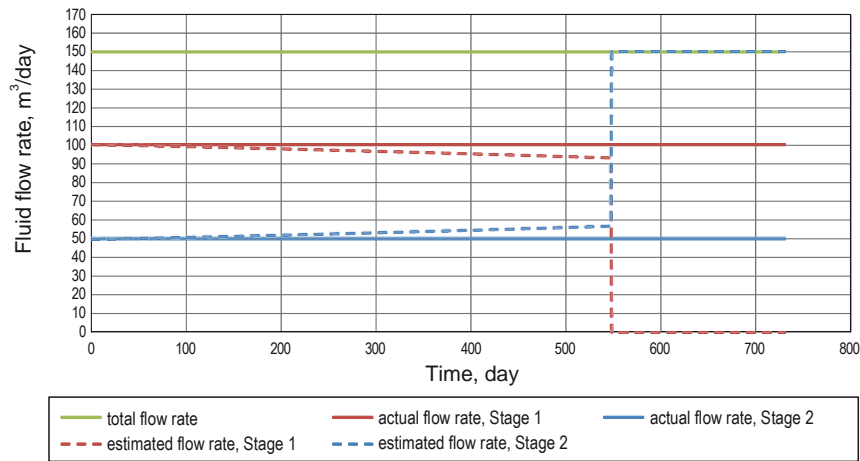


Figure 3. Diagram of estimated flow rate distribution

However, given the high importance of tracer-based production profiling operations at the current level of the oil industry development and condition, inter alia, to address challenges in monitoring and modeling the development of difficult-to-recover reserves and fields with complicated geological conditions [4], the method deserves further development and elaboration.

The authors analyzed the practical results of using the method, which are described in the engineering references, and performed a theoretical calculation modeling the long-term production of a horizontal well with two stages of hydraulic fracturing, on which tracer-based studies were performed. The results of the analysis and calculations suggest that attention should be paid to the appropriate means of processing and interpreting the field data as well as the potential distortion of flow rate values across frac stages due to uneven washout rate of the tracer-embedded polymer layer exposed to a flowing liquid. Consequently, this paper offers a method aimed at enhancing the accuracy of flow rate profiling for individual frac stages.

Conclusion

Upon the analysis of practical results documented in the scientific and technical literature, combined with basic theoretical modeling, a method aimed to advance tracer-based production profiling was offered. This method is specifically designed to enhance the accuracy of production distribution among different hydraulic fracturing stages during a long-term surveillance period.

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