Integration of Production Communication and Hydraulic Fracture Connection in DJ Basin

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Abstract

This study compares the hydraulic fracture connection during stimulation with that during the production period by leveraging the low-frequency Distributed Acoustic Sensing (LF-DAS) signals and the production data. The four-square-mile study area is located in the Hereford Field of the northern Denver-Julesburg (DJ) Basin, close to the Wyoming-Colorado state line. 23 horizontal wells were drilled in four pads, as shown in Fig. 1. Seven wells are Codell wells, and the remaining are Niobrara wells. Niobrara wells have a typical spacing of approximately 650 ft while Codell wells have a larger spacing of 1270 ft to 2400 ft. The LF-DAS signals were acquired from two fiber wells: the Codell well P3Bf and the Niobrara well P3Df.

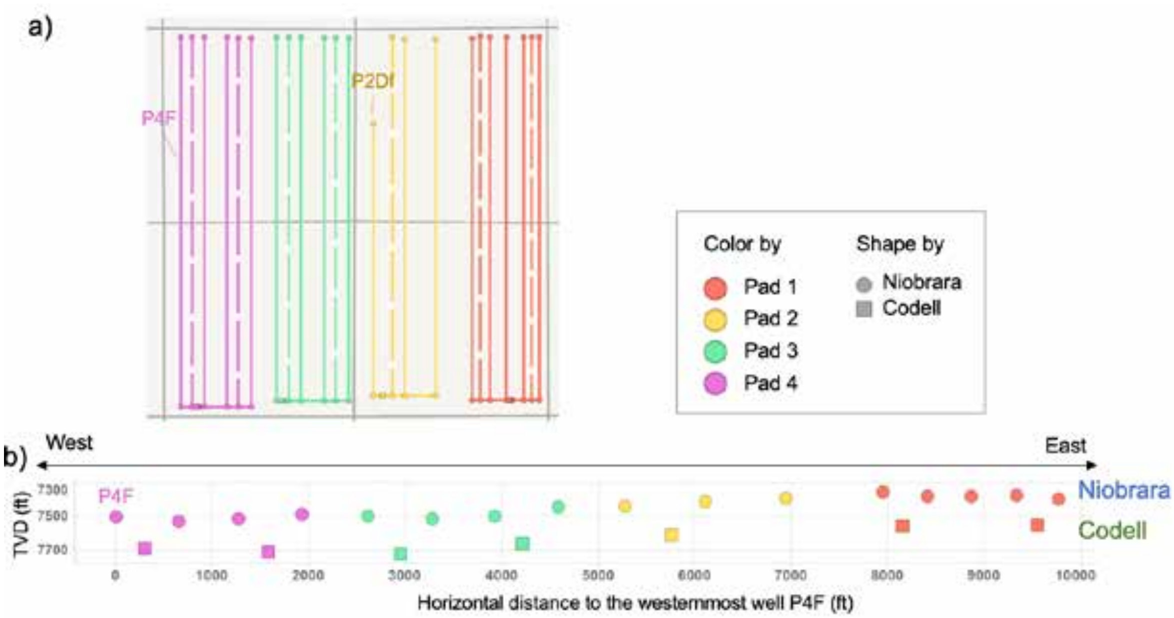

Figure 1-a. The four-square-mile study area includes 4 pads and 23 horizontal wells; b) in the gun barrel diagram, each dot represents one well. The wells are colored by pad number. Niobrara wells are shaped by circles. The underlying Codell wells are shaped by square boxes.

Production interference is caused by random shut-ins or similar operations in the study area. Production interference is analyzed based on the daily production data of all 23 horizontal wells. To quantify the impact of well interference, the decline curve was estimated for each well using the production data of the undisturbed period. The curve is matched using the Arps equation as shown in Eq. 1. Here, q_t is production rate at time t (unit bbl/day), q_i is the initial production rate (unit bbl/day), b is dimensionless decline exponent, D_i is the initial decline rate (unit: days^{-1}), t is time in days.

$$q_t = \frac{q_i}{(1+bD_i t)^{\frac{1}{b}}}$$

The well interference observed on Pad 3 is shown here as an example. Fig 2 b) shows that Pad 3 has four Niobrara wells and two underlying Codell wells. Niobrara wells have a spacing of 450-700 ft while the two Codell wells are 1270 ft apart. Fig. 2 a) divides the production curves into four stages: Stage 1 (08/01/2019-3/1/2020) when the choke size changes over time; Stage 2 (3/1/2020-4/10/2020) when choke size remained constant and production declines following the Arps equation; Stage 3 (4/10/2020-8/1/2020) when abnormal production rates occur due to operation or well interference; and Stage 4 (8/1/2020-1/10/2021) when production gets back to the original decline curve. The production data in Stage 2 and Stage 4 are collected to fit Eq. 1 with a goal of estimating the Arps parameters to achieve a production match. The blue dots and the orange

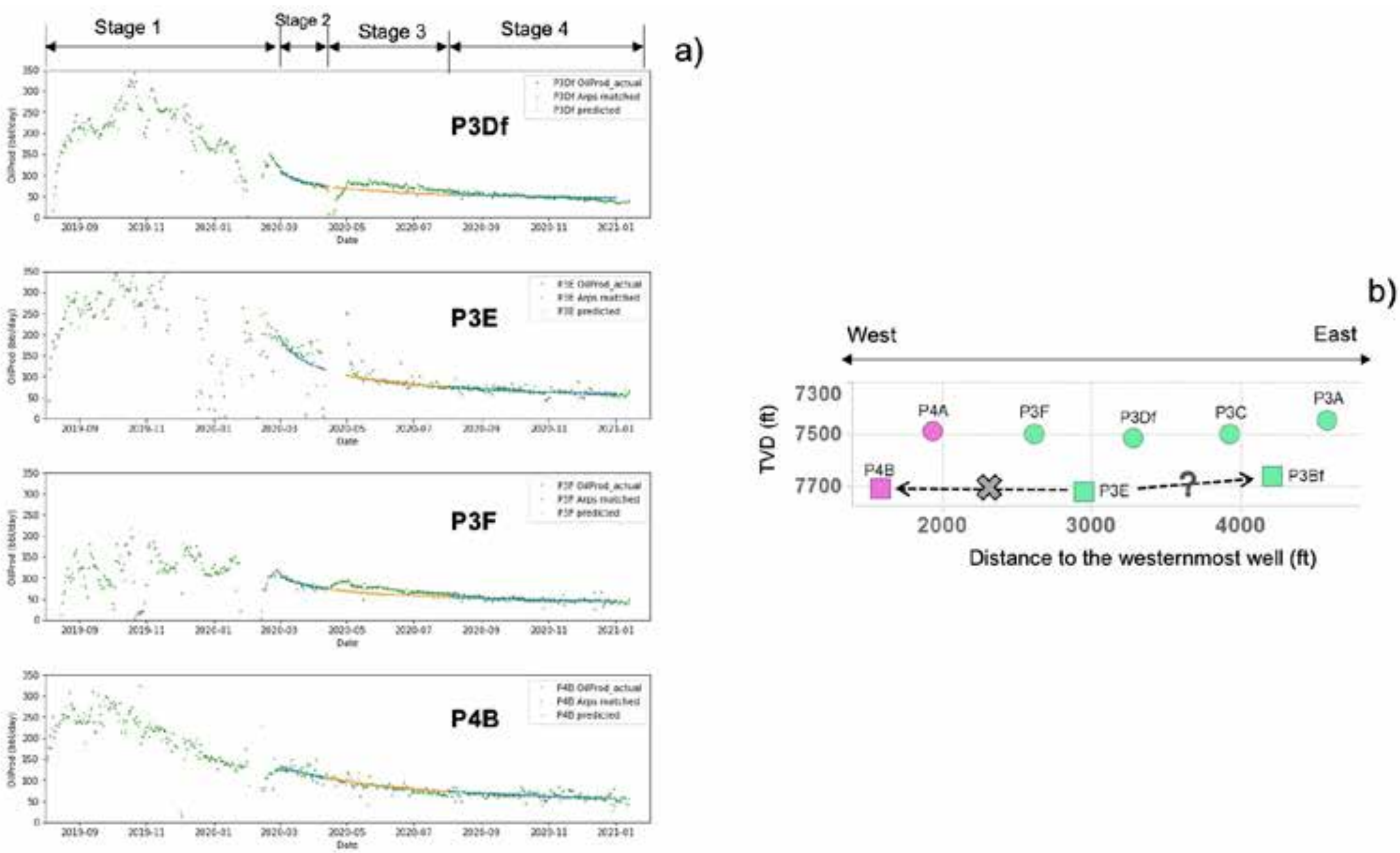

Figure 2-a. Shut-in operation of P3E improves P3F's production but does not affect P4B that is located in the same formation; b) there are four Niobrara wells and two Codell wells on Pad 3. Strong cross-formation communication is observed.

dots represent the production values that were calculated by the estimated Arps equations.

During the shut-in period of Well P3E, the nearby Codell well P4B's production continued following the decline curve, revealing P4B is not disturbed by P3E shut in. The gas lift system in another neighboring Codell well, P3Bf, was lowered around April 2020. Thus, it is difficult to distinguish whether P3Bf is influenced by the shut-in operation of P3E. All these observations are summarized by the black dash arrows in Fig. 2 b).

During Stage 3, when P3E was shut-in on 4/10/2020, P3F showed continuous production increase after that day, as indicated by the blue arrow in Fig. 3 a). It shows that P3F's production was affected by P3E shut in. P3Df's oil rate showed a weak disturbance for two days, which was then interrupted by the operation of lowering gas lift system and dropping plungers. The production disruption of P3Df was followed with a short buildup, which could be a function of coming to equilibrium with the new operational set up. Because P3Df had its own operation during the same time period, it is difficult to attribute P3Df's production change to the shut-in operation of P3E.

On 5/2/2020, P3E was re-opened and showed temporary high oil production. Accordingly, the oil rate of P3F showed a sudden drop from 95 bbl/day on 5/2/2020 to 85 bbl/day on 5/4/2020, and then kept decreasing. This further validates the production communication between P3E and P3F. P3Df showed erratic oil rate in May 2020, which might be caused by noise or the continuing effect of P3Df's own operation. It cannot demonstrate production communication from P3E to P3Df, as illustrated by the question mark in Fig. 3 b).

The orange dash arrow in Fig. 3 b) presents that P3E affected the production of P3F. Due to the operation synchronization of P3Df and P3E, no available data can establish the impact of P3Df on P3F. This is represented by the question mark in Fig. 3 b).

Fig. 4 compares the LF-DAS signals recorded from two fiber wells. During the pumping schedule of P3E, Fig. 4 a) shows the LF-DAS signals recorded along the Niobrara fiber well P3Df, whereas Fig. 4 b) presents the LF-DAS signals acquired along the Codell fiber well P3Bf. Fig. 4 c) summarizes the observation of fracture hit from P3E. In Fig. 4 a), the newly opened fractures (red color) start

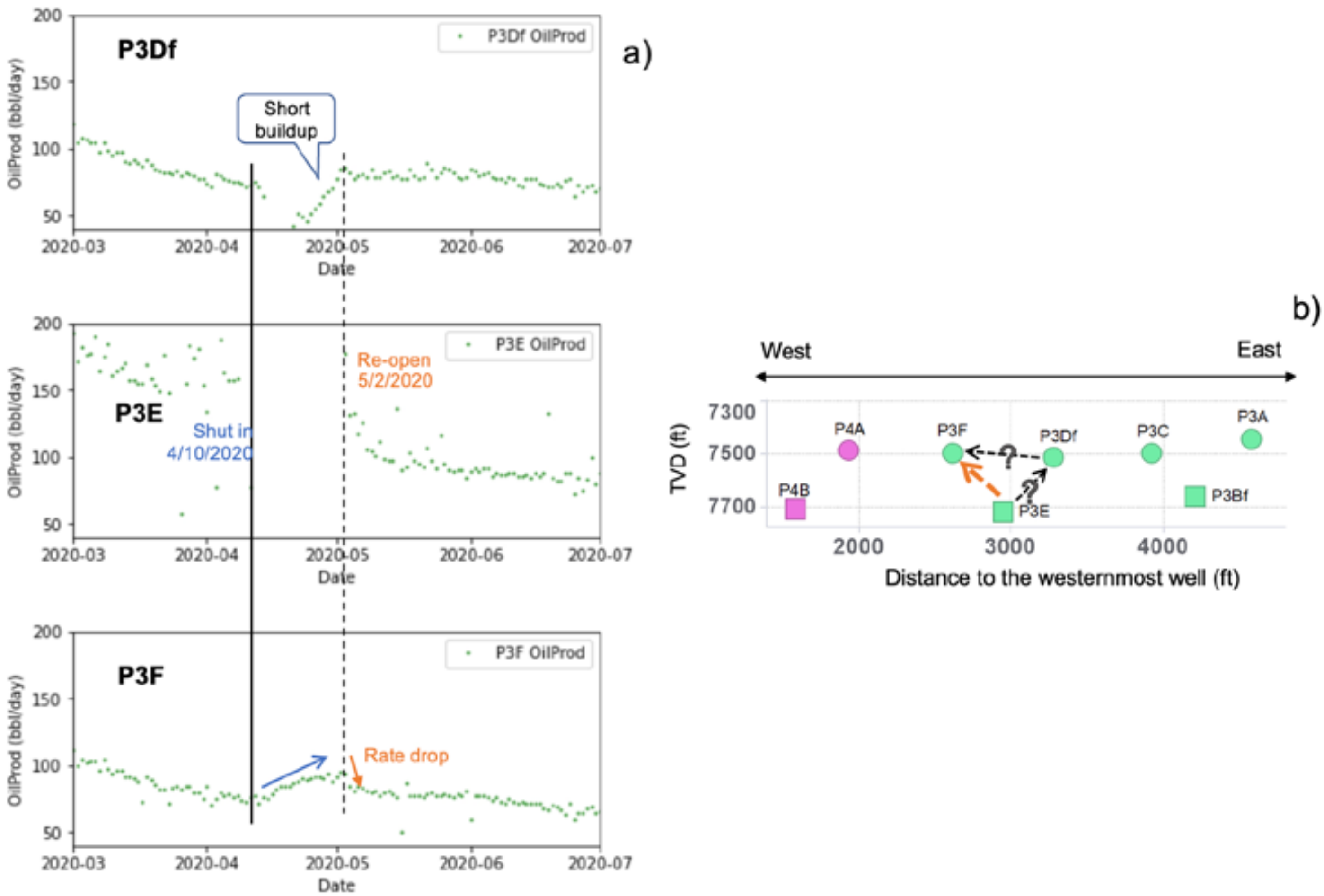

Figure 3-a. The production increase and drop of P3Df and P3F is related to P3E's shut-in and re-open operations. b) Production communication existed from P3E to P3F.

to close while the compressing area (blue color) relaxes immediately after pumping stops. This phenomenon is referred to as polarity flip. The fracture hits from the Codell well P3E to the Niobrara fiber well P3Df indicate hydraulic fracture connection exists between Niobrara and Codell. In Fig. 4 b), the fracture hits from P3E to the Codell fiber well P3Bf show fracture connection within Codell. There are two differences between Fig. 4 a) and b). First, during the 1.2 hours of P3E's pumping period, when the first fracture hit was observed in both monitoring wells (P3Df and P3Bf), Fig. 4 b) illustrates a later fracture arrival time than Fig. 4 a), as shown by the blue vertical dash lines. Second, opposite from Fig. 4 a), Fig. 4 b) shows that there is no signal polarity flip after pumping stops, indicating fractures at the monitor well location P3Bf have already lost connection to the injector P3E during stimulation.

The earlier fracture hit time and polarity flip in Fig. 4 a) correspond with strong connection between Niobrara and Codell formations during stimulation. When compared with later fracture hit, earlier fracture hit means hydraulic fluid propagates for a longer period, hence it creates a hydraulic fracture much longer than the current well spacing. When assuming the hydraulic fracture filled with proppant is a constant percentage (e.g., less than 10%) of the entire hydraulic fracture filled with fluid, earlier fracture hit implies a longer proppant-filled hydraulic fracture. With a greater percentage of the well spacing is filled with proppant, the two wells that are connected by this hydraulic fracture are more likely to interfere with each other during the production stage. These wells are more likely to interfere with each other during the production stage.

The following conclusions are drawn from this study.

- Polarity flip and earlier fracture hit time indicate strong inter-formation communication between Niobrara and Codell during stimulation, which is consistent with strong well interference during production.
- Within Codell, fractures are connected during stimulation but not in production. The observation of no polarity flip and later fracture hit time in LF-DAS signals is related to no communication during production.
- Within Codell, fracture connection during stimulation indicates the stimulated fracture half-length of Codell wells is greater than 1270 ft.

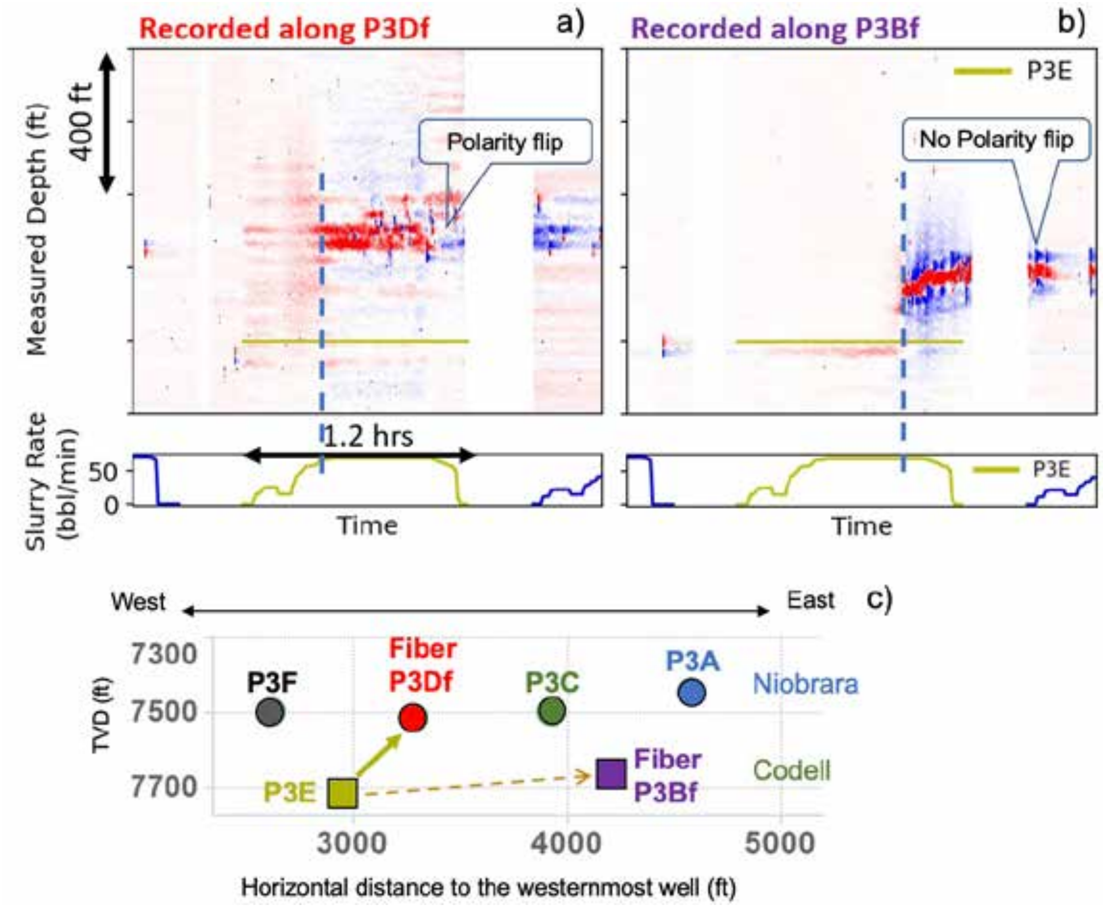

Figure 4-a. The Niobrara well P3Df's LF-DAS data shows fracture hit signals from the Codell well P3E (yellow), implying Niobrara-Codell communication; b) the Codell well P3Bf's LF-DAS data identified fracture hits from the Codell well P3E, showing connection within Codell; c) the connection summary is illustrated in the gun barrel diagram of Pad 3 wells

Acknowledgment

Special thanks to Civitas Resources (previously HighPoint Resources) for the field data and the permission to publish this work. We are grateful to the Reservoir Characterization Project (RCP) consortium sponsors at the Colorado School of Mines for supporting this research.

Speaker's Bio

Yanrui Ning is a research fellow at Colorado School of Mines. With a Ph.D. degree in Petroleum Engineering and a minor in Geophysics, she worked in the oil industry as a Reservoir Engineer for two years. Her current research interests focus on reservoir simulation, machine learning, distributed acoustic sensing (DAS), and Distributed Temperature Sensing (DTS), focusing on hydraulic fracturing optimization, enhanced oil recovery (EOR) in unconventional reservoirs, as well as carbon capture, utilization and storage (CCUS).