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Application of Fiber-optic Temperature Data Analysis in Hydraulic Fracturing Evaluation: A Case Study in Marcellus Shale

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Abstract

Technology advancement is a key parameter to gain more information, and valuable insight in the area where we lack proper knowledge to make the right decision at the right time. Development of unconventional resources is an area where application of advanced technology can play a significant role in shedding light on many unknowns pertaining to production from these resources.

Fiber-optic is among the new technologies that has recently received more attention in unconventional reservoir development. The data collected through optical fiber running along the horizontal or multi-lateral well, carry vast amount of information, which provides the operator with a near real-time monitoring opportunity.

This work is a part of Marcellus Shale Energy and Environment Laboratory (MSEEL) research, which is a unique multi-disciplinary research program, and aims at achieving a better understanding of the shale reservoirs and the best practices for producing from these resources. Despite the common practice of applying the same hydraulic fracturing design for all the stages of horizontal or multi-lateral wells in shale resources development, at MSEEL different stages of the well have been completed and stimulated with varying parameters. Perforation and hydraulic fracturing design along the lateral was performed based on reservoir characteristics, such as petrophysical parameters, geomechanical parameters, natural fracture density, amount of organic carbon, etc. Microseismic and fiber optic technology were used to monitor different stimulation operations performed on the well. Application of these technologies provided a large amount of information related to the performance of each operation.

This work is focused on the analysis of fiber-optic temperature data, collected from a multi-lateral well in Marcellus Shale. In this study, the performance of different hydraulically fractured stages of the well is investigated through evaluating the temperature changes along the wellbore during various operations. The analysis shows completion designs that lead to a better production from the corresponding stages. Using these results, best practice completion and stimulation plan can be suggested for infill drilling, re-fracturing or further development of the Marcellus Shale.

Introduction

During the last couple of decades, gas production from unconventional resources has grown rapidly. Shale gas is one of the unconventional resources, which is playing a major role in the world energy supply (EIA, 2016).
Due to the characteristics of the unconventional reservoirs (extremely low porosity and permeability) compared to the conventional reservoirs, utilization of hydraulic fracturing is required to make economic production. High volume hydraulic fracturing over multiple stages in horizontal well bores has employed relatively short history in our industry, and therefore there are many unknowns regarding different aspects of this operation.

Application of new technology is significantly beneficial to obtain more information and get more insights into the shale characteristics, fluid flow behavior within the shale formation, and production from multi-stage hydraulically fractured wells. However, the economic burden of utilizing advanced measurement tools on top of the already expensive operation of horizontal drilling, and hydraulic fracturing makes it unappealing to the majority of the operators in shale. Therefore, most of the shale development operations are performed using a simple geometry design for the perforation and hydraulic fracturing, without considering any other parameters, such as the reservoir characteristics at the stage location.

This approach can result in a sub-optimal production from a shale reservoir, and lead to an adverse economic outcome. However, in shale development, the information that is gained through advanced measurements leads to a more insightful completion and stimulation design, which can eventually contribute to improved production rates and higher ultimate recovery from the wells. One of the advanced technologies that can be advantageous in shale development is fiber-optic, which can be applied in high-temperature/high-pressure condition to provide flow profiling and accurate wellbore monitoring (Denney, 2007).

Fiber-optic Technology Overview and Application

Real-time downhole data collected through optical fiber provides a means to greatly improve production management and ultimate reservoir recovery (Kragas, Williams, & Myers, 2001).

The distributed acoustic sensing (DAS) is a fiber-optic downhole measurement sensitive to local vibration around the fiber (Dickenson, et al., 2016). DAS technology is based on the Optical Time Domain Reflectometry (OTDR). A laser pulse travels inside the fiber and will be scattered back encountering natural imperfection in the fiber. The recorded backscatter contains information of local axial strain along the fiber (Parker, Shatalin, & Farhadiroushan, 2014). Distributed temperature sensing is another common fiber-optic measurement sensitive to temperature variations around the fiber. DAS and DTS measurements are often recorded in parallel to provide a more comprehensive understanding of stimulation (Molenaar & cox, 2013).

Downhole fiber-optics was used to provide continuous measurement of pressure and temperature for West Coalinga Field in California (Karaman & Kutlik, 1996). Other applications such as water injection surveillance, leak detection analysis, acid injection profiling, and hydraulic fracturing have been documented (Rahman, Zannitto, & Reed, 2011), (Glasbergen, Yeager, Reyes, & Everett, 2010), (Sierra , Kaura, Gualtieri, Glasbergen, Sarker, & Johnson, 2008), (Holley & Kalia, 2015).

Employing fiber optic distributed measurements can be significantly beneficial in multiple stages of completion, post completion and production of a well.

Study Area

The well is located in Morgantown Industrial Park (MIP) site in the state of West Virginia (USA), and it is a part of the Marcellus Shale Energy and Environment Laboratory (MSEEL). MSEEL is a multi-disciplinary research program that aims at achieving a better understanding of the shale resources to ensure that energy is extracted in an economically efficient and environmentally responsible manner. Application of advanced technology such as comprehensive well logs, microseismic, Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) at MSEEL, provides an opportunity to collect a large amount of data during various operations.

At the MIP site, two horizontal wells (MIP-4H and MIP-6H) were drilled in Marcellus Shale, and have produced natural gas since December 2011. Two new horizontal wells (MIP-3H and MIP-5H) were drilled from the existing pad, and placed on production in December 2015. MIP site also includes a vertical scientific observation well (MIP-SW) drilled approximately one half mile to the northwest between the two new horizontal wells for the purpose of additional subsurface data collection, and microseismic monitoring. The locations of the existing and newly drilled wells are depicted in Figure 1.

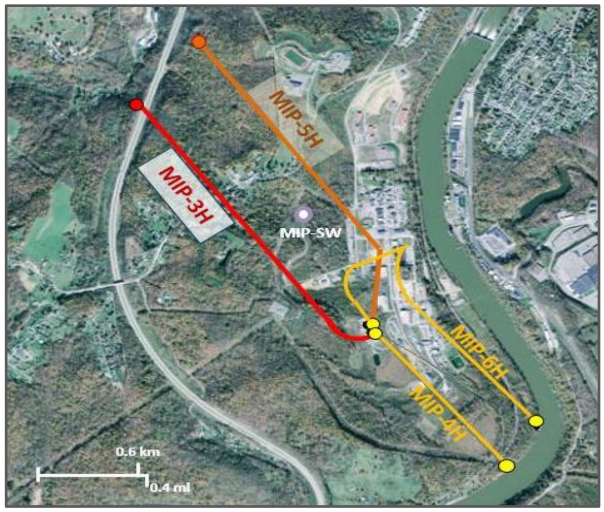

Figure 1. Marcellus Shale Energy and Environment Laboratory (MSEEL) just outside Morgantown, West Virginia, USA. The MSEEL site consists of four horizontal production wells operated by Northeast Natural Energy LLC. (MIP-3H, MIP-4H, MIP-5H, MIP-6H), two pilot holes (MIP-3 and MIP-4), a micro-sesimic and sampled observation well (MIP-SW). Fiber-optic cable was installed in the MIP-3H

MIP-3H Completion Specification

The MIP-3H well was completed over 28 stages in 5 sections from the toe to the heel Table 1. Section A and B are completed using a geometrical approach in which geomechanical parameters that does not account for geomechanical properties, fracture closure stress, fracture intensity. Two types of proppants are used for hydraulic fracturing of MIP-3H: 100 mesh sand and 40/70 mesh white sand. Section A has around 35% 100 Mesh proppants and 65% 40/70 white sand, while Section B has 75% 100 Mesh Sand and 25% 40/70 white sand.

The completion extends to Section C, labeled as Engineered Completion (Table 1). This section is designed by appraising geomechanical parameters from the well logs: each stage is set in a zone with similar fracture closure stress, fracture intensity, and gamma ray (Anifowoshe, et al., 2016). The proportion of proppants varies between stages in Section C: Stages 13, 14, 15, 17, and 19 have 35% 100 mesh while Stage 16 has 67% mesh 100 and Stage 18 around 43% mesh 100. In addition, limited entry approach was undertaken by decreasing the number of shots per clusters to enhance stimulation efficiency (Anifowoshe, et al., 2016).

A new guar-free viscoelastic fracturing fluid known as Sapphire VF® is used in stages 20 and 21(Section D) to maximize the well performance (Schlumberger, 2014). Sapphire fluids are designed to enhance proppants transport, deliver higher retained proppant pack permeability, improve fracture clean up, and lower the treatment pressure. Section E includes stages 22 to 28, which were completed using a combination of engineered approach along with using Sapphire fluid, and an accelerated pumping schedule.

Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) fiber-optic devices are deployed in order to measure, and record high resolution energy band amplitude and temperature data along this well. Fiber-optic data is used for the purpose of well surveillance and long-term performance monitoring of the well bore as well as the reservoir.

Hydraulic fracturing design parameters for different stages of this well are summarized in Table 1.

Table 1.Hydraulic fracture designed parameters for MIP-3H by stage and zone

Section		Stage	Cluster Count	Total Shot Count	Shot Density (shot/ft)	Stage Length (ft)	Pump schedule
E	Best Practice Applied	28	4	40	6	191	A
		27	4	40	6	184	A
		26	5	40	6	225	A
		25	5	32	6	231	A
		24	5	30	6	222	A
		23	5	40	6	237	C
		22	5	40	6	220	C
D	Sapphire VF	21	5	40	5	218	D
		20	5	40	5	240	D
C	SLB Engineered Completion	19	4	32	6	180	C
		18	4	32	8	180	C
		17	4	32	6	181	C
		16	4	26	6	178	C
		15	4	26	6	186	C
		14	5	30	6	228	A
		13	5	30	6	230	A
B	NNE 75% 100-Mesh	12	5	50	5	231	B
		11	5	50	5	232	B
		10	5	50	5	227	B
		9	5	50	5	237	B
		8	5	50	5	222	B
		7	5	50	5	224	B
A	NNE Standard 35% 100-Mesh	6	5	50	5	245	A
		5	5	50	5	234	A
		4	5	50	5	230	A
		3	5	50	5	238	A
		2	5	50	5	223	A
		1	5	50	5	233	A

DTS Data Acquisition

In order to collect temperature data, a strand of optical fiber, running inside the wellbore (outside the casing) sends a pulse of light, and the reflection signal is further processed to obtain the temperature at different locations along the well. Fiber-optic temperature data for MIP-3H are available during three intervals; stimulation, flow back, and production of this well. In the subsequent sections, the temperature distribution is visualized along the entire lateral, during several well operations.

1. Stimulation

Temperature data recorded during stimulation has the highest temporal and spatial resolution. Temperature data is recorded every 30 seconds, with a spatial sampling of 1.5 feet. To generate the temperature distribution an averaging filter, with a window length of 1 hour, was applied to all the stages along the lateral.

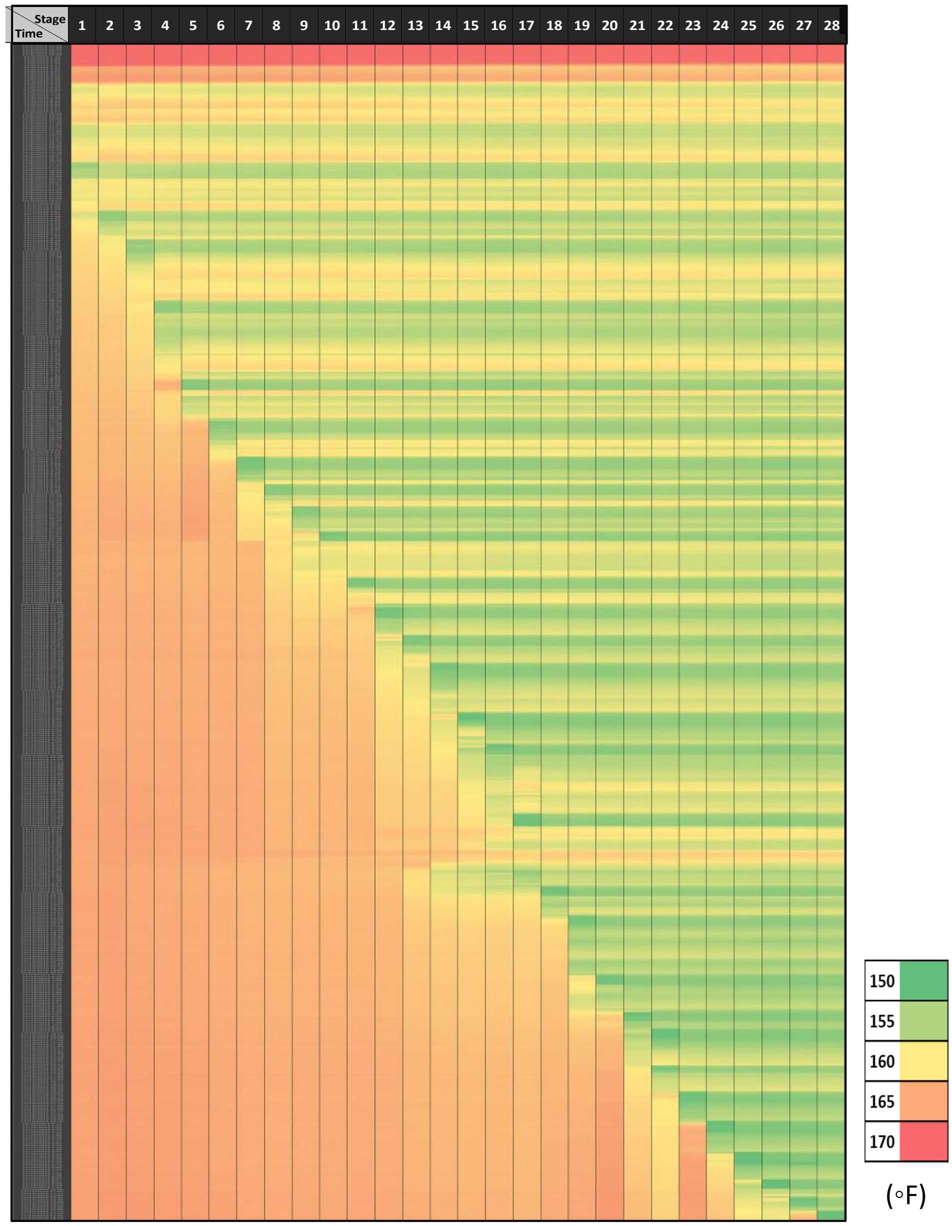

Figure 2. Temperature distribution in degrees Fahrenheit, at different stages of MIP-3H during stimulation. Stages 1 through 28 are shown on the horizontal axis and one-hour increments on the vertical axis.

In Figure 2, the 28 stages of the lateral are demonstrated in horizontal axis while simulation time is shown on the vertical axis. The very early time, with a uniform red color, represents the original reservoir temperature (°F) that is followed by a green color, demonstrating the cooling effect of the fluid which is pumped through the wellbore. The area with darker green, shows the location of the stage which is being hydraulically fractured.

Observing the temperature distribution throughout the well during the entire stimulation operation provides us with valuable information. In some stages, at the time of fracturing, an increase in temperature is observed in the earlier stages (observed in stages 5, 6, 10, 12, 21 and 24). This is an indication of the existence of either a fault or conductive fractures in the vicinity of those stages which are activated by the stimulation operation and ultimately results in communication between the stages (Carr, et al., in press). In some cases, the temperature peaks and then falls back and, in some other cases the high temperature lasts for a longer while. This depends on the time during which generated communication between stages remains accessible.

2. Flow-back

Temperature measurement in flow-back period has time resolution of 5 minutes, and length resolution of 1.5 feet. Temperature values are normalized along the lateral to better demonstrate the temperature distribution along the lateral during the flow-back period (Figure 3).

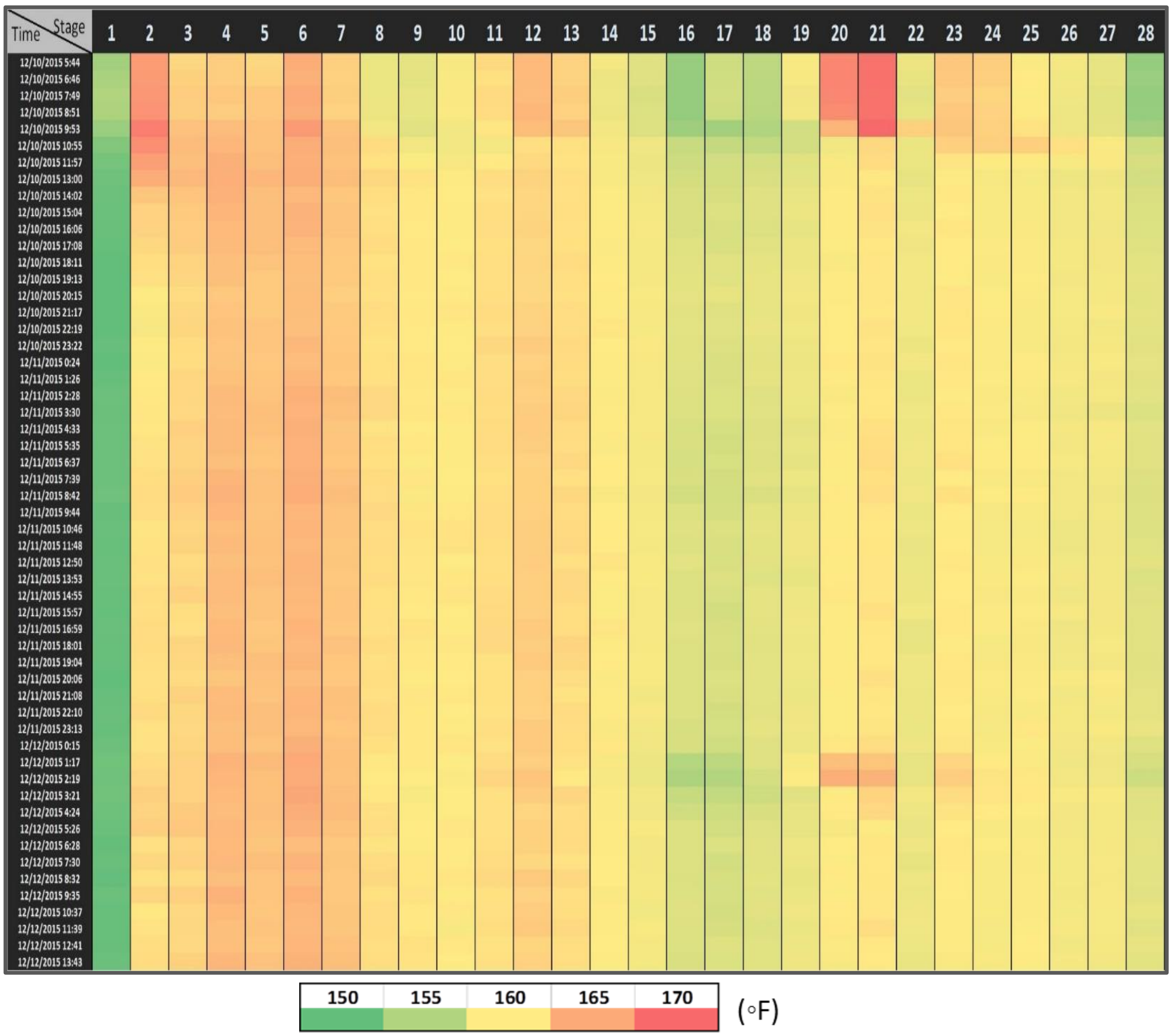

Figure 3. Normalized temperature distribution at different stages of MIP-3H during flow-back. Stages 1 through 28 are shown on the horizontal axis and three-hour increments on the vertical axis.

3. Production

During production a daily, 3-hour average temperature, is recorded at each 13 feet for the vertical section and each 5 feet for the lateral. Temperature distribution during production is presented in Figure 4.

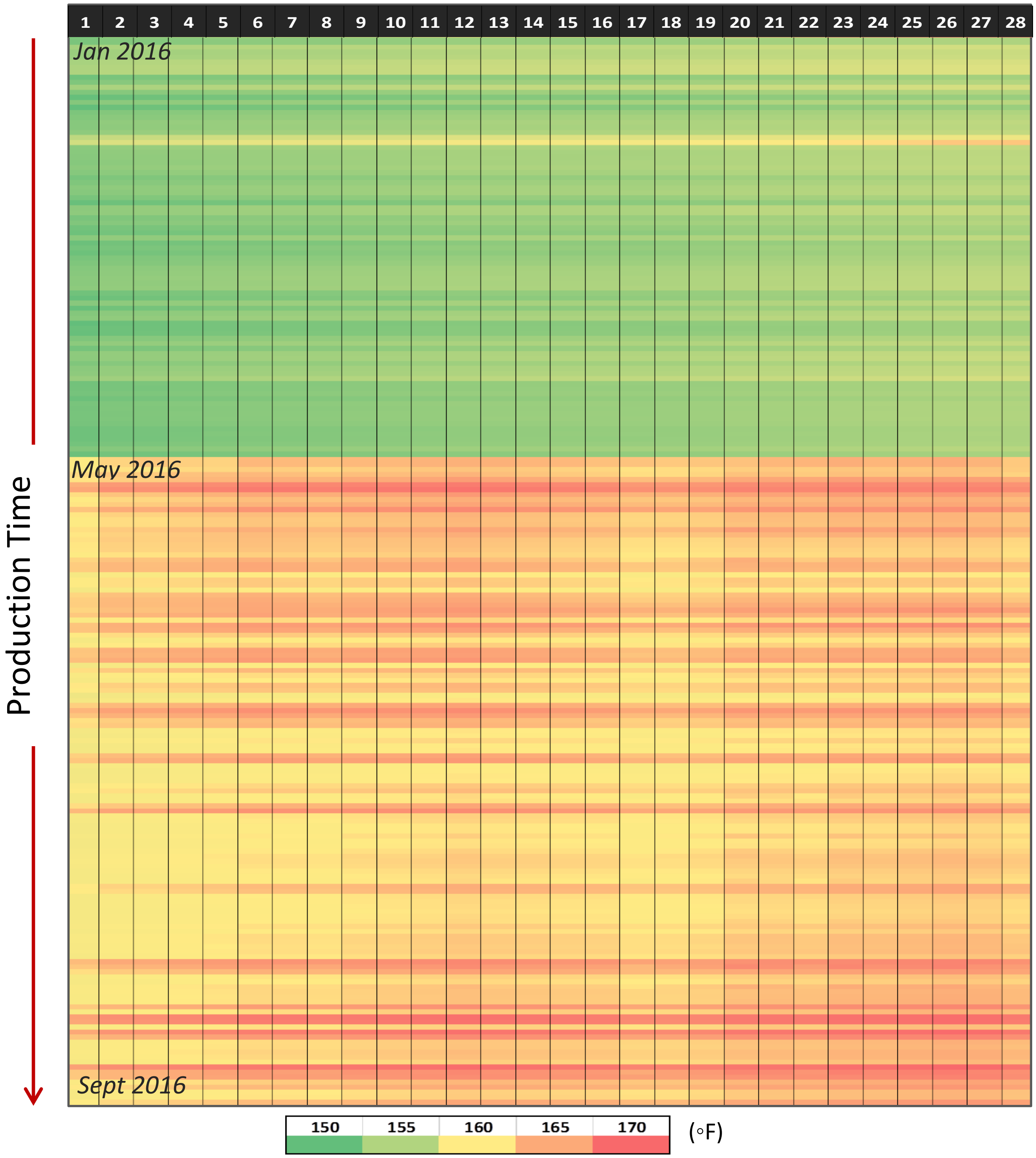

Figure 4. Temperature distribution at different stages of MIP-3H during production. Stages 1 through 28 are shown on the horizontal axis and one-day increments on the vertical axis.

During this time interval, the average daily gas production of MIP-3H is 3.3 MMCF. Minimum temperature at this interval is 150 ºF. From May 2016, gas production rate, due decreased demand from the City of Morgantown, was decreased to about half of the production in the first quarter (average daily gas production 1.7 MMCF). This causes a temperature increase along the lateral and therefore, the minimum temperature reaches to 164 ºF.

Figure 5 illustrates the temperature distribution, which is normalized along the lateral, during the two time intervals of high and low production, separately.

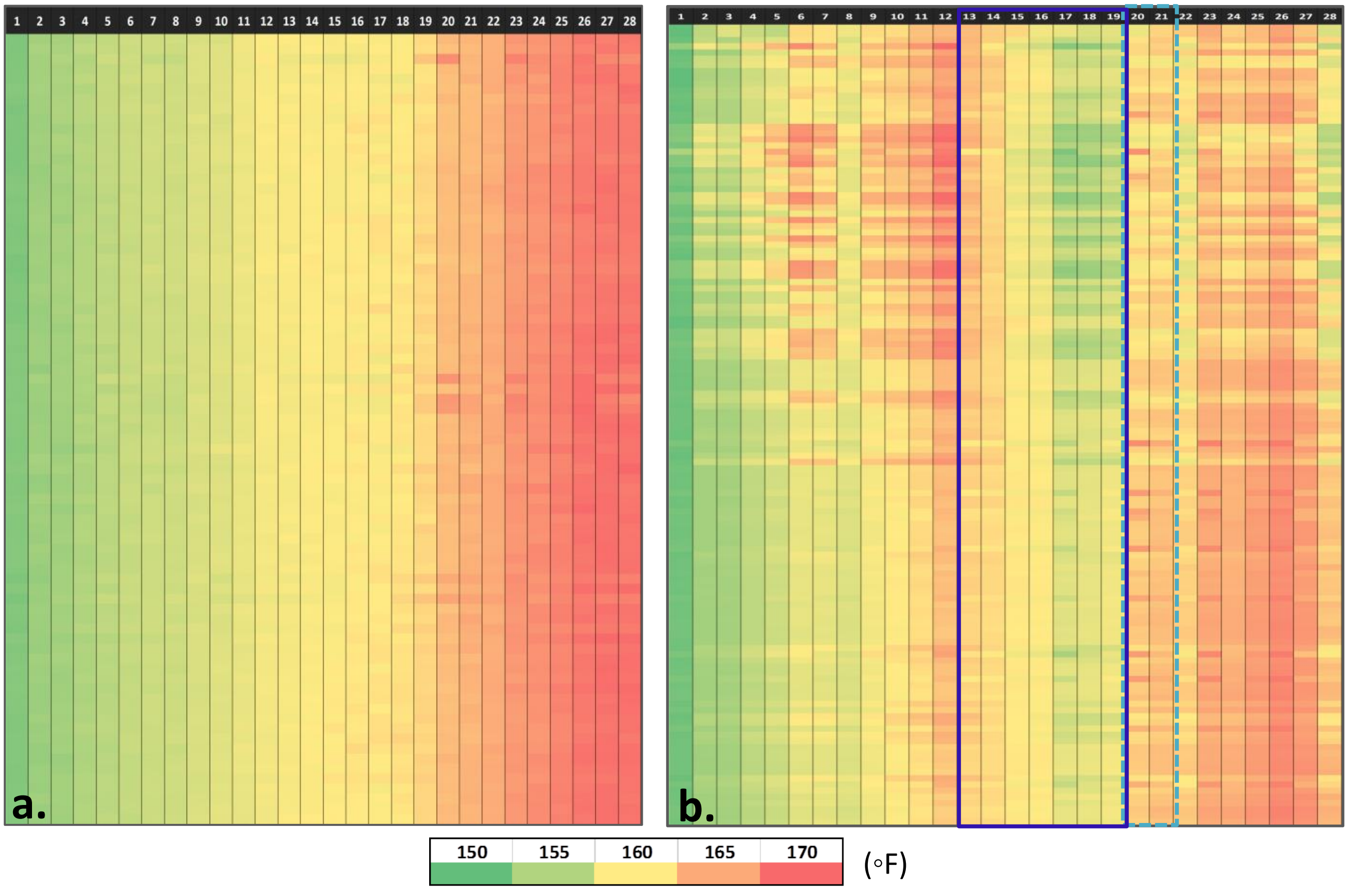

Figure 5. Normalized temperature distribution at different stages of MIP-3H during:
(a) High production period, (b) Low production period

During the high production interval, generally temperature increases from the toe towards the heel and the cooling effect is masked in the stages closer to the heel.

During the low production interval, the general trend of increased temperature from the toe to the heel is not seen due to the low amount of gas, and therefore the higher producing stages show lower temperature.

Summary and Conclusion

This study demonstrates how a different approach to analyzing the collected fiber-optics temperature data, provides us with valuable information. By summarizing and visualizing the data on stage-based format during each specific operation, completion efficiency of hydraulic fracturing are put into perspective.

Hydraulic fracturing of some stages of MIP-3H resulted in an increase in the temperature of the earlier stages. This is an indication of the existence of either faults or conductive fractures in the vicinity of those stages. The faults or fractures are activated by the stimulation operation, and therefore a communication path is generated between the stages.

In the flow-back period a distinct pattern can be observed from the temperature of the differently completed stages (lower temperature between stages 13 to 19, and higher temperature in stages 20 and 21).

Evaluating the temperature data during the low rate production period shows lower temperature in stages 13 to 19 which is an indication of higher production in these stages. It should be noted that although these stages are all included in the section C of completion, with engineered design, they don't have similar performance. Looking more closely to the completion parameters it is observed that they have been completed with different stage length and different number of clusters. In fact shorter stage length, and fewer number of clusters resulted in higher production.

Stages 20 and 21 which are both generated using Sapphire VF® fluid, show a poor production performance. This can be related to the fact that the viscos hydraulic fracturing fluid is not effectively performing in this type of the reservoir.

Acknowledgements

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