Helping Improve Asset Productivity with Near-Wellbore Stimulation Solutions

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Key Words

near-wellbore stimulation, propellants, tubing convey perforating, microfractures

Resumen

Se sabe que las prácticas de perforación y terminación utilizadas actualmente en la industria del petróleo y el gas causan daños a la formación cerca del pozo que generalmente reduce la permeabilidad de la roca del yacimiento. La invasión del fluido de perforación, fluido de cemento y la presencia de revoque de lodo causan daños (a los que se hace referencia como "skin") alrededor del pozo cercano. Debido a estas condiciones comunes (pero difíciles de remediar), la industria ha adoptado técnicas que pueden ayudar a reducir o eliminar la zona dañada que afecta la productividad de los activos o la inyectividad en pozos.
Los métodos utilizados para lograr la estimulación cerca del pozo se basan en una variedad de prácticas de ingeniería, tales como diseños de carga moldeada con forma patentada, diseños de sistemas de pistola, sobre balance extremo, bajo balance dinámico y el uso de dispositivos de adquisición de datos de alta velocidad para capturar eventos dinámicos que hacen posible y medible la estimulación de la zona productora cerca del pozo. Estas técnicas permiten sobrepasar la zona dañada alrededor del pozo dejando una trayectoria limpia que puede proporcionar una producción óptima de hidrocarburos a partir de pozos productores o inyección de fluido para pozos de inyección.
El uso efectivo de estas técnicas de estimulación, y / o una combinación de ellas, ha tenido éxito en varios lugares a nivel mundial. Este artículo discute los resultados alcanzados en los países latinoamericanos.
Debido a la limpieza mejorada, existe una mejor ruta entre el reservorio y el pozo, que ha demostrado una mayor productividad / inyectividad del pozo en más del 50%.
La creación de un flujo dinámico de gas y fluido a través de la roca dañada ayuda a mejorar la limpieza de la perforación y crea una red de micro fracturas que ayudan a mejorar la conectividad del pozo con las fracturas naturales dentro del reservorio.
El uso de estas técnicas es una solución efectiva a un costo razonable que optimiza la conectividad del yacimiento con el pozo para aumentar significativamente la productividad de los activos. Sin embargo, para que esto funcione y cree con éxito las condiciones necesarias para eliminar el daño cercano al pozo, es imperativo que los modelos de software y las simulaciones sean proporcionados por un ingeniero experimentado y bien entrenado y que se utilicen datos precisos para crear las simulaciones.
Estas tecnologías han demostrado un gran éxito en el retorno de la inversión (ROI) de los activos al ayudar a mejorar la productividad de los pozos hasta en un 50%. Además, estas tecnologías facilitan la iniciación de fracturas en operaciones de fractura hidráulica.

Abstract

Drilling and completion practices used currently within the oil and gas industry are known to cause damage to the formation near the wellbore that usually reduces reservoir rock permeability. The invasion of drilling fluid, cement leakoff, and the presence of a mud cake cause damage (referred to as “skin”) around the near wellbore. Because of these common (yet difficult to remediate) conditions, the industry has adopted techniques that can help reduce or eliminate the damaged zone that impacts asset productivity or well injectivity.

Methods used to achieve near-wellbore (NWB) stimulation are based on a variety of engineered practices, such as proprietary shaped charge designs, gun system designs, extreme overbalance, dynamic underbalance, and the use of high-speed data acquisition devices to capture dynamic events that make the NWB stimulation possible and measurable. These techniques enable the operator to

bypass the damaged zone around the wellbore with a clean flow path that can provide optimum hydrocarbon production from producing wells or fluid injection for injection wells.

The effective use of these NWB stimulation techniques, and/or a combination thereof, has been successful in various locations globally. This paper discusses results achieved in Latin American countries.

Because of improved cleanup, there is a better path between the reservoir and the wellbore, which has demonstrated increased well productivity/injectivity by more than 50%.

Creating a dynamic flow of gas and fluid through damaged rock helps improve perforation cleanup and creates a network of microfractures that help improve wellbore connectivity with natural fractures within the reservoir.

Using these techniques is an effective solution at a reasonable cost that optimizes reservoir connectivity with the wellbore to significantly increase asset productivity. However, for this to work and successfully create the necessary conditions to remove NWB damage, it is imperative that software models and simulations are provided by an experienced and well-trained engineer and that accurate data are used to create the simulations.

These technologies have demonstrated great success in asset return on investment (ROI) by helping improve well productivity by as much as 50%. Additionally, these technologies help improve or enhance hydraulic fracture stimulations.

Introduction

The first two cases presented used propellant-assisted perforating technology; the propellant material is potassium perchlorate, an oxidizer that burns rapidly, creating carbon dioxide gas (Almanza, 2007). While the shaped charges detonate, the propellant is ignited by extreme heat from the gun system. As it burns, the propellant generates carbon dioxide gas at high peak pressure typically well above the formation fracture gradient. The propellant assembly is an effective method for mild stimulation (fractures approximately 2 to 9 ft) that treats near-wellbore problems. The propellant assembly could be used for either extreme overbalanced or conventional underbalanced perforating. The hardware used for either system remains the same aside from added protection using centralizer rings to protect the brittle propellant material.

The third case presented uses dynamic underbalanced perforating achieved by applying special fast-opening surge vents, atmospheric chamber assemblies, and a dynamic wellbore simulator to accurately model and predict the effects of pressure transients during the perforating event (Fernandez, 2009).

The first case refers to a well within the Caguán-Putumayo Basin near the border with Ecuador, which has been explored for several years and has produced both oil and gas wells. Further, it was believed to be a good candidate for unconventional exploration because of its proximity to the Oriente Basin in Ecuador.

The second and third cases refer to a well within the Llanos Basin, which has been drilled and developed for 79 years. The Llanos Basin is one of the largest sedimentary basins in the country and has been the target of oil and gas exploration since the 1940s. The basin covers more than 220,000 km^2 and is oil-prone, containing multiple giant medium and heavy oil fields, such as Cusiana, Caño Limón, and Rubiales (Figure 1).

Case 1: Injector Well Using Extreme Overbalance Perforating – Propellant-Assisted Perforating

Well A was drilled and completed during 1988 within the Caguán-Putumayo Basin in Colombia. After evaluating the formations with a drill stem test (DST), the field was inactive for almost 14 years. During 2002 and 2003, extensive tests performed within the well exhibited unstable production behavior and low potential compared to the remaining wells. Between 2004 to 2013, the well was a producer from two different formations: Unit A1 and Unit A2, which exhibited unstable production behavior despite the different interventions performed and methods of artificial lift evaluated (Figure 2). The formations have the following characteristics:

- Depth [true vertical depth (TVD)]: 9,000 to 9,500 ft
- Porosity: 15 to 18%
- Permeability: 150 to 220 mD
- Formation pressure: 3,600 to 3,700 psi
- Rock unconfined compressive strength: 10,000 to 15,000 psi

During the first part of 2016, it was decided to convert the well to a water injector to address the problem of water produced within the field. During October and November 2017, a workover/intervention service was performed to modify the completion string and perforate additional intervals. By January 2018, an injectivity test was performed to evaluate injection capabilities. The results (Figure 3) were not satisfactory because the low injectivity rate only reported an average of 1,500 B/D at 3,100-psi injection pressure; however, the injection rate was not stable, and it decayed with stable wellhead pressure. Production logging tests were performed to identify the injection profile within the well; the log confirmed than 56% of the intervals do not admit water during the injection test (Figure 4).

After well evaluation, propellant perforating was selected to workover the well and increase injectivity—well design consisted of only reperforating intervals blocked with a 4 5/8 in. × 12 shots per foot (SPF) deep-penetrating (DP) gun system chosen to increase flow area downhole and propellant sleeves to generate microfractures and bypass near-wellbore damage. The perforating operation was performed in a static underbalance condition to increase the effective perforation tunnel and shockwaves software used to help determine behavior of the technology and help prevent failures in a bridge plug set to isolate lower zones (Figure 5).

Operation results included an increase from 1,500 to 3,800 B/D at 4,000 psi and constant flow (Figure 6); it allowed an additional stimulation technique with an acid treatment to meet the operator's objectives for the well and increase the injection rate to 8,000 B/D.

Case 2: Producer Well Using Extreme Overbalance Perforating – Propellant-Assisted Perforating

Well B, located within the Llanos Basin in Colombia, is a producer well type J where the production zone is drilled in angles greater than 80°. The formation has the following characteristics:

- Depth (TVD): 7,200 to 8,200 ft
- Porosity: 11 to 16%
- Permeability: 700 to 1,000 mD
- Formation pressure: 2,000 to 2,200 psi
- Unconfined compressive strength: 8,000 to 10,000 psi

The first intervals perforated in the well were opened during 2012; later during 2014, the remaining potential intervals were perforated to complete 873 ft of active intervals and an associated production of 184 B/D at 1,231 psi Pwf. Production analysis and well history from the drilling process exhibited skin associated with near-wellbore damage because of the drilling fluid invasion and an associated skin of +27.0.

Propellant-assisted perforating was proposed to optimize production because of the generation of microfractures to bypass near-wellbore damage with microfractures generated during propellant sleeves combustions. Only 50% of the opened intervals were selected, according to petro physics, and interventions were performed using a 4 5/8 in. × 6 SPF DP gun system.

Different models were simulated to help determine the behavior of the technology. The first iteration was performed with a portion of the 80% of propellants compared to the loaded intervals to be perforated, because of the amount of energy generated within the system. The software anticipated a potential failure in the string (Figure 7). A second iteration was loaded with 50% of the propellants compared to the loaded intervals to be perforated. This iteration was successful and helped predict microfractures of 4.61 ft and a reduction of skin to values close to +2.1 (Figure 8).

The operation was performed during 2015 with the tubing conveyed perforation (TCP) technique without any problems or affectations within the components of the completion string or wellbore. The initial production test was close to the production calculated during the design analysis (Figure 9) with an incremental production of 130%. For this operation, high-speed pressure and temperature recorders were used to register the perforating/stimulation event so that simulated and actual data curves could be compared for accuracy. The matching of the data sets enables continuous improvement with the software and training programs.

Because of the results obtained for this well and others within the field, the operator implemented this technique within the field and has performed more than 80 wells with connectivity problems to bypass the near-wellbore damage and increase production.

Case 3: Producer Well Using Dynamic Underbalance Perforating

Well C, located within the Llanos Basin in Colombia, is a deviated well with the target formation at 4,000 to 4,100 ft. It produces from a formation with the following characteristics:

- Depth (TVD): 4,000 to 4,100 ft
- Porosity: 21 to 27%
- Permeability: 700 to 900 mD
- Formation pressure: 1,200 to 1,500 psi
- Unconfined compressive strength: 4,000 to 4,900 psi

The well was completed during January 2016 using 4 1/2 in. × 12 SPF BH guns to generate sufficient flow area downhole to reduce fluid velocities and help prevent sanding. A second perforating run was performed with 4 1/2 in. × 5 SPF DP charges to bypass the near-wellbore damage and optimize production. Using this perforating strategy, the well gets an associate production of 308 B/D with a skin of +12.53. To optimize production within the well (and because of the unconsolidated sand to be perforated within the well that does not allow techniques such as propellants), the dynamic underbalance perforating strategy was evaluated to bypass the near-wellbore damage. The intervention was designed using 4 5/8 in. x 5 SPF DP charges with surge vents to generate dynamic underbalance to clean the perforating tunnels and remove the crushed zone generated by the perforating jet. A simulation was performed to design the proper length of the surge vent to generate a sufficient surge to clean and remove the crushed zone without generating sand within the well (Figure 11).

The well was reperforated during February 2016 with the dynamic underbalance technique using wireline with surge vents; well production increased 100% with an associated production of 631 B/D and a skin of +6.31 (Figure 12). Because of the results obtained for this well, the operator implemented this technique within the field and has performed more than 15 wells to bypass the near-wellbore damage and increase production.

Conclusions

By designing a proper plan between the operator and service company before operations, vital success factors were achieved. Using a near-wellbore stimulation technique made it possible to:

- Help improve well production and injection rates by reducing skin damage caused by fluid invasion and perforation damage
- Reduce workover operations, helping prevent matrix acidification
- Reduce water production, not fracturing the water/oil contact

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Andres Felipe Diaz is a Petroleum Engineer from the National University of Colombia with 9 years of experience in oil industry. Andres has been working in different positions within Halliburton, all focused on completion and perforating, beginning as a field operator, supervisor and currently technical advisor for all kinds of perforating services performed for different companies in Colombia.

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Federico Rios is a Petroleum Engineer from "Universidad Industrial de Santander", Bucaramanga – Colombia (2003). He joined Halliburton in 2005 and currently he is the Global Advisor for Tubing Conveyed Perforating (TCP), supporting global field operations and he is an SPE member.

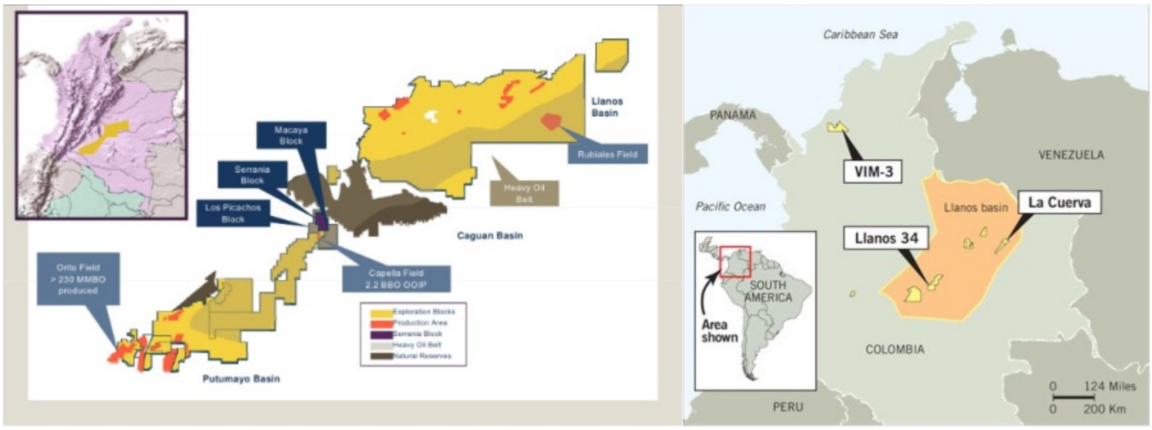


Figure 1—(Left) Caguán-Putumayo; (right) Llanos Basins.

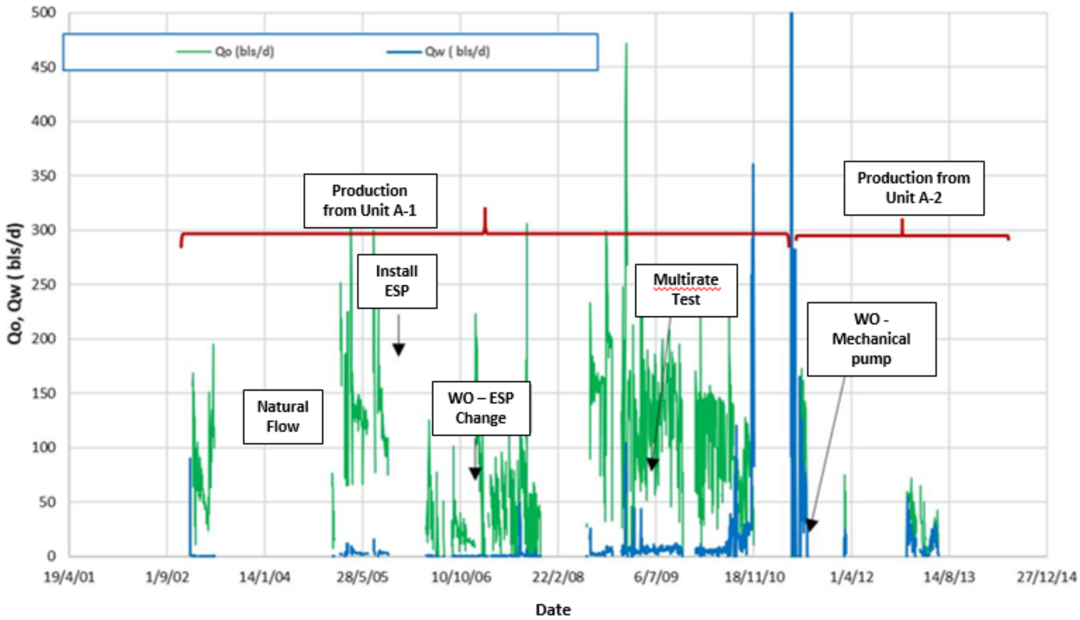


Figure 2—Case 1: production behavior before changing the well to water disposal.

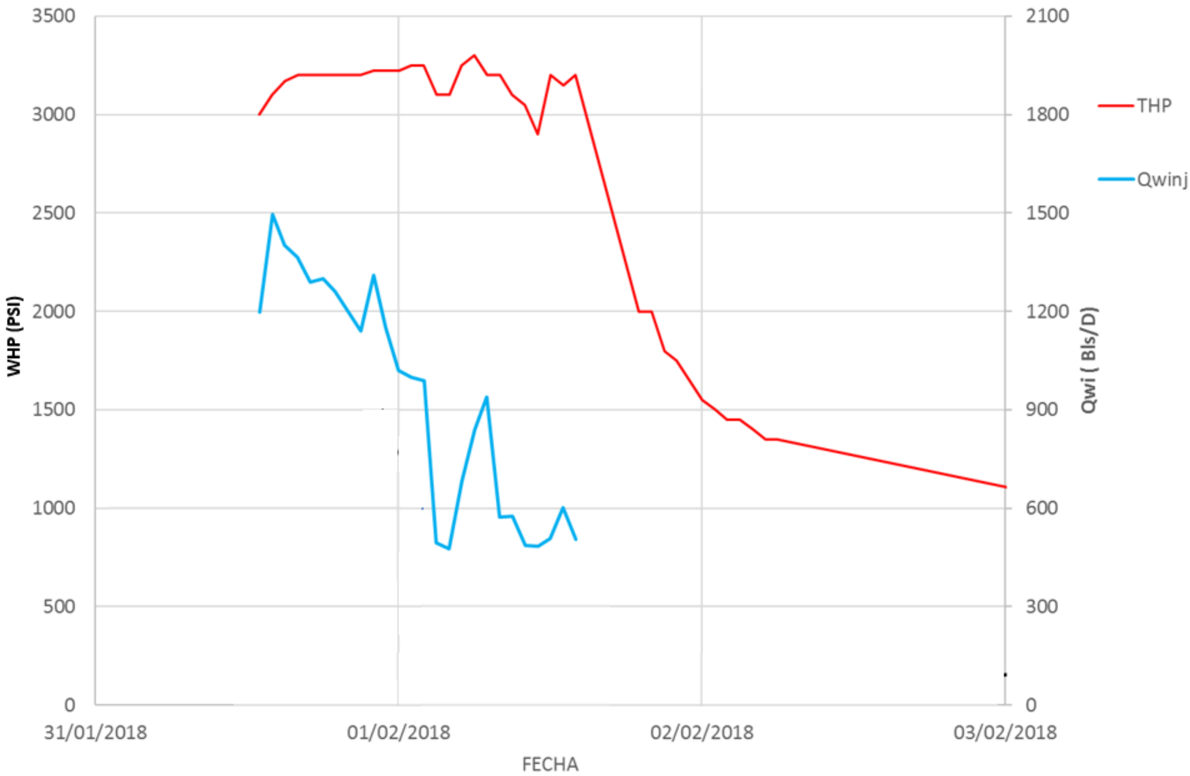


Figure 3—Case 1: injection test after workover to change the well to water disposal.

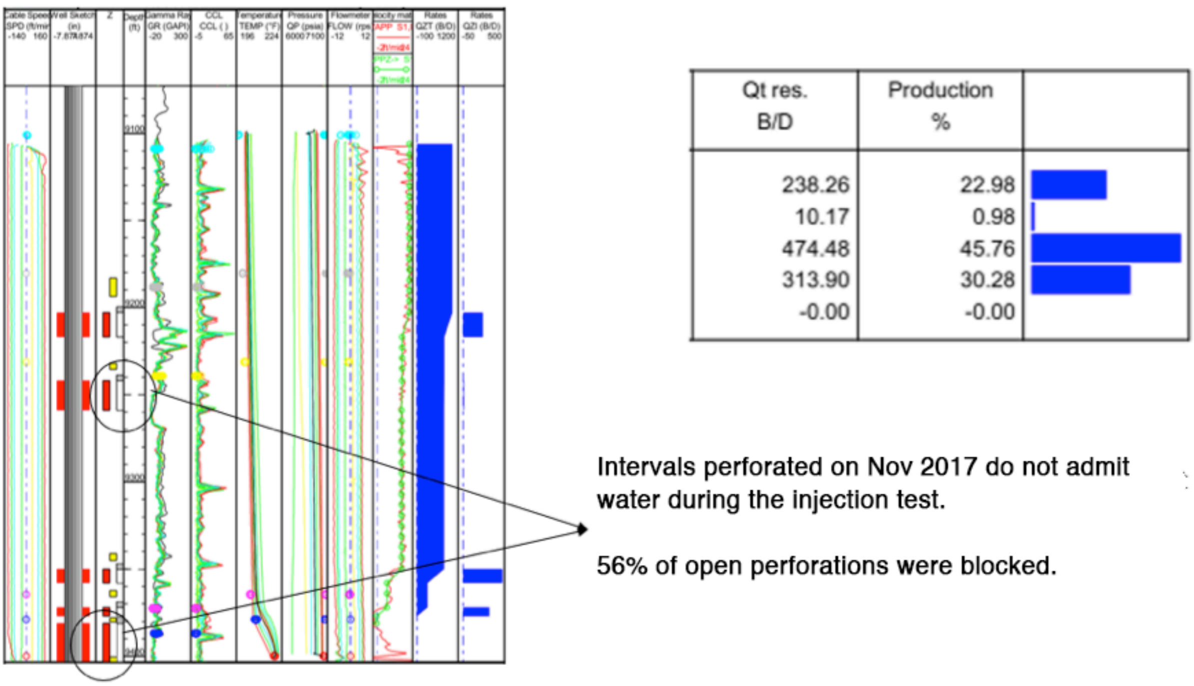


Figure 4—Case 1: PLT analysis during injection test.

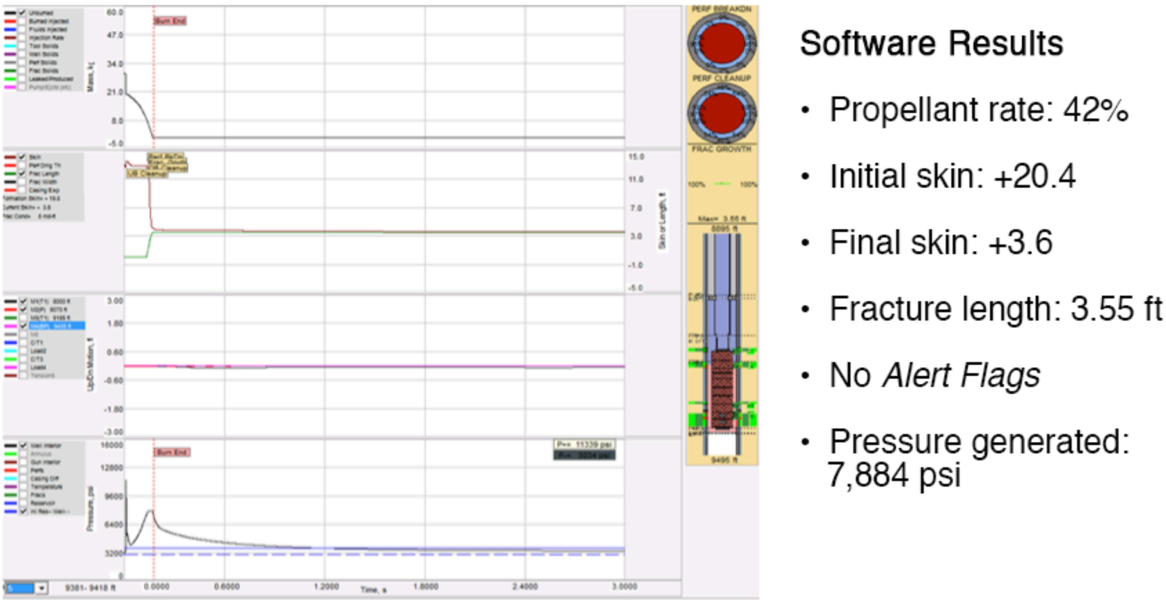


Figure 5—Case 1: shockwave simulation during perforating event with propellants.

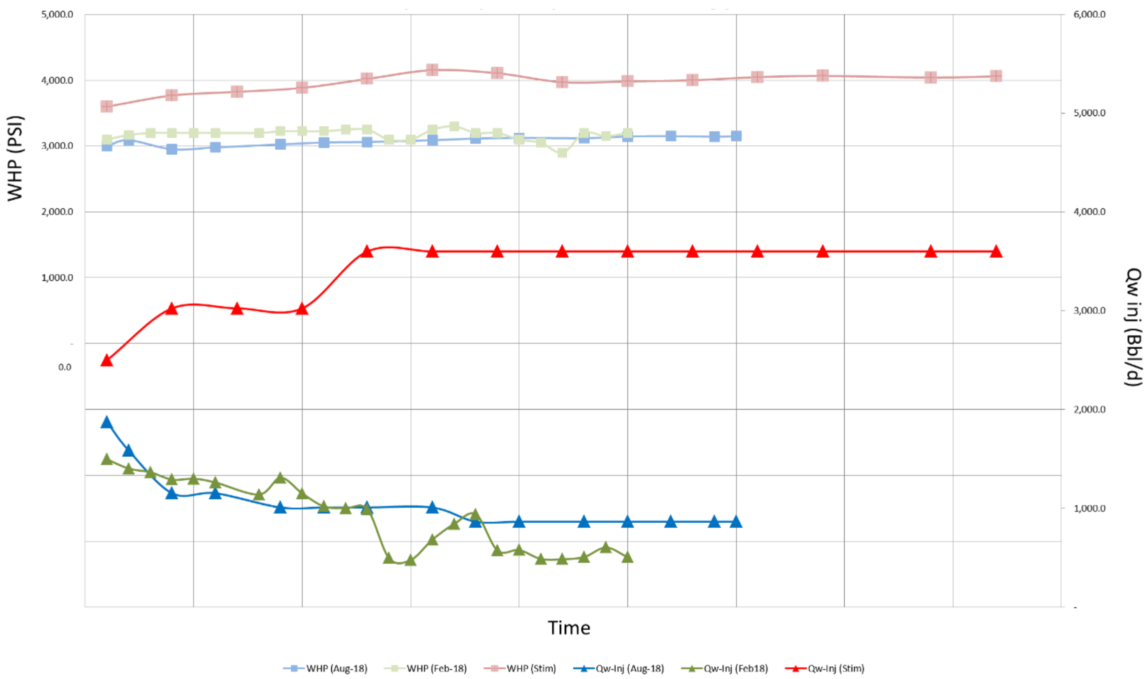


Figure 6—Case 1: injectivity test before and after the propellant-assisted perforating job.

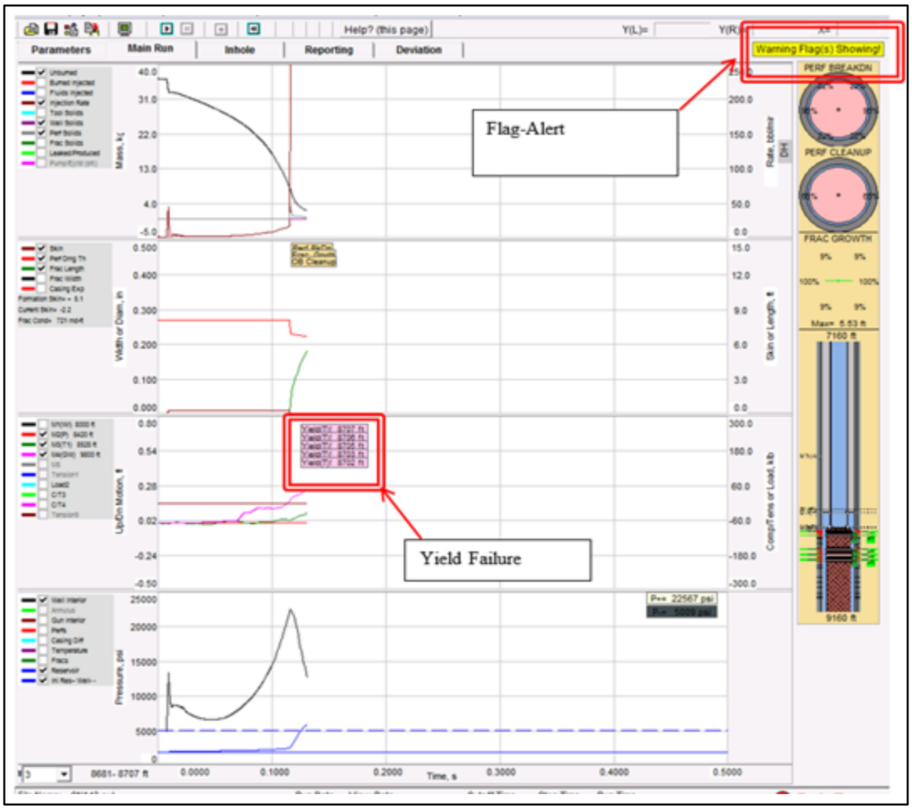


Figure 7—Case 2: first shockwave simulation with 80% ratio of propellant compared to perforating guns.

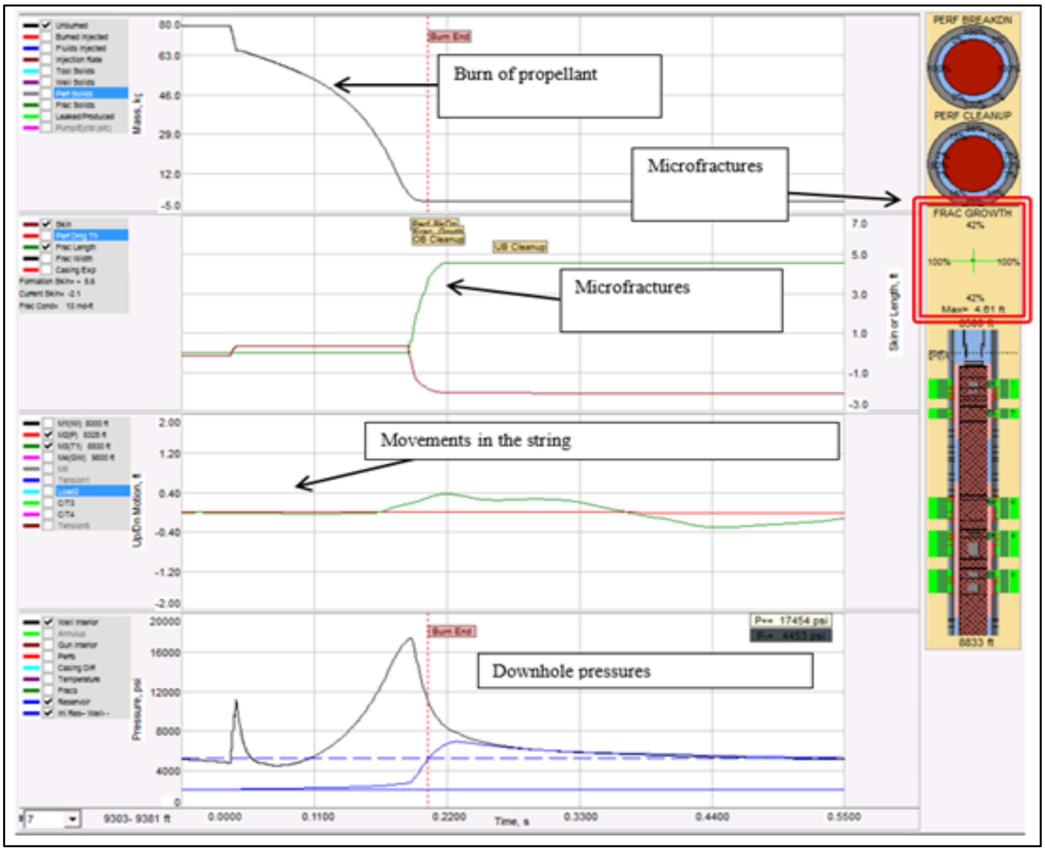


Figure 8—Case 2: final shockwave simulation with 50% ratio of propellant compared to perforating guns.

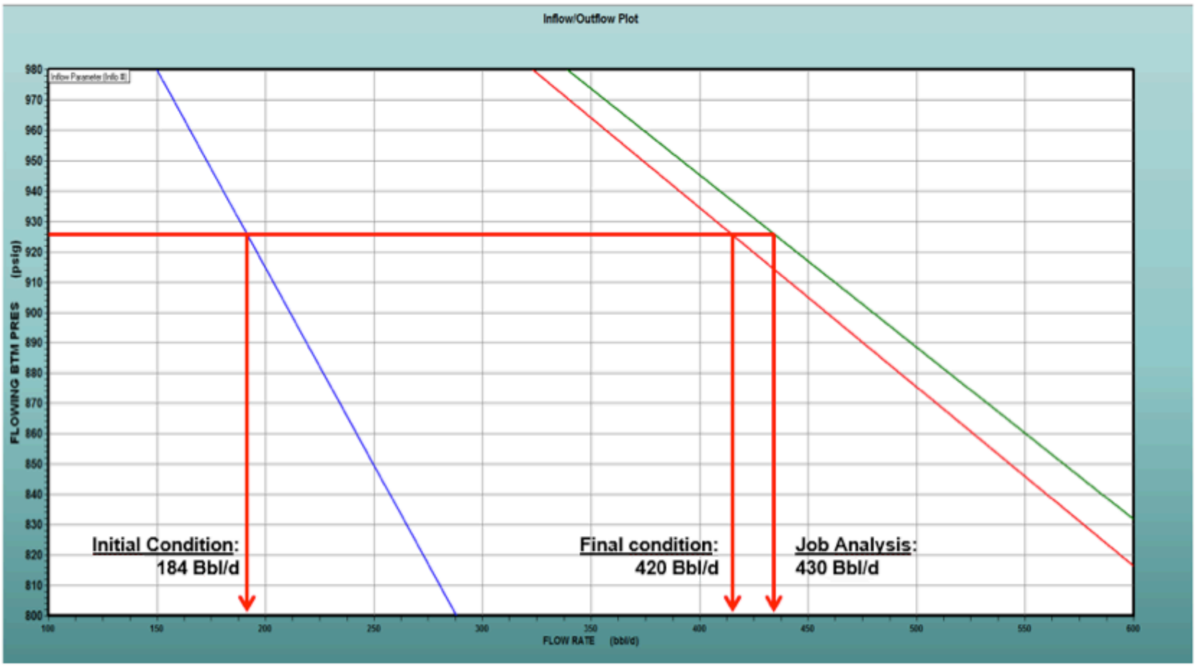


Figure 9—Case 2: comparative inflow performance relationship for Well B.

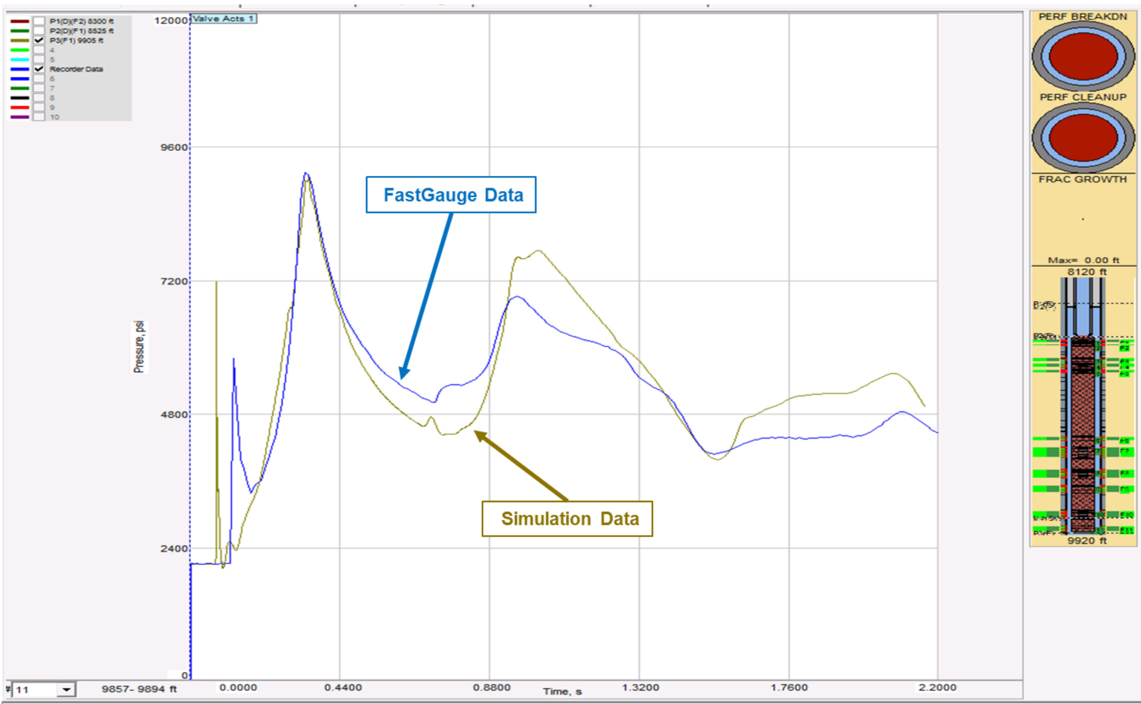
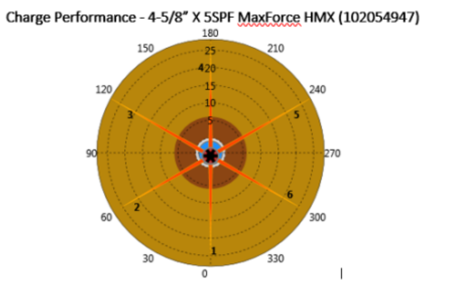


Figure 10—Case 2: match FastGauge data and simulation data.



Shot	Orientation (deg)	Clearance (in)	Formation Penetration (in)	EHD (in)
1	0	0	25.1	0.33
2	60	0.34	25.09	0.33
3	120	1.22	27.37	0.3
4	180	1.74	27.15	0.25
5	240	1.22	27.37	0.3
6	300	0.34	25.09	0.33

Charge Information	
Charge Type	MaxForce
Powder	HMX
Part Number	102054947
Phase Angle	60 deg
Bank Angle	60 deg
API Target Strength	5513 psi

Gun Information	
Gun Size	4.625 in
Gun Position	Eccentered
SPF	5 SPF
Shot Pattern	Spiral
Rotation	0 deg
Clearance	0 in

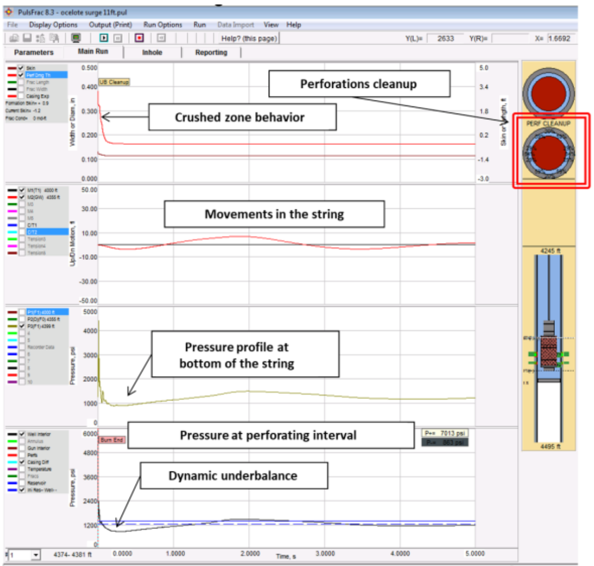


Figure 11—Case 3: simulations of charge penetration and dynamic underbalance perforating events.

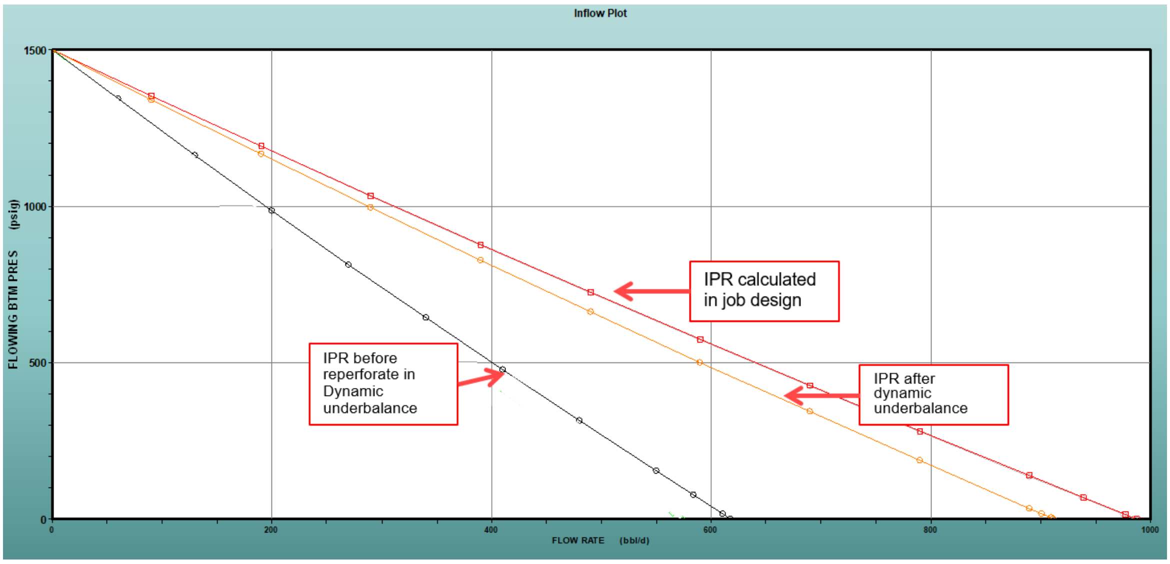


Figure 12—Case 3: comparative inflow performance relationship for Well C.