Coiled-Tubing-Assisted Hydraulic Fracturing of CBM Wells in India Using CT-Deployed Hydrajet Perforation Technology*

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Abstract

By the beginning of the third quarter of 2010, multiple coalbed methane (CBM) wells had been fracture stimulated using a pinpoint technology in West Bengal, India. The well parameters that contributed to the high success rate of the technology were the shallow depth of the wells and multiple-zone to be treated per well. This technology was introduced to the well operators when a need arose to increase the number of treatments completed per day.

The Pinpoint technology used here pioneers a specific technique wherein target zones are selectively hydrajet perforated by pumping abrasive fluids through a specifically designed coiled-tubing (CT)-deployed bottom hole assembly (BHA) to perform perforating by abrasive jetting. This provides an economical and efficient method of perforating, which is immediately followed by fracture stimulating the interval without removing the CT. This is achieved by pumping the fracturing fluid down the casing-CT annulus. The fractured zone is then isolated after the fracturing stage is complete by means of a wellbore sand plug, immediately followed by individually hydrajet perforating, then treating, and setting a sand plug for multiple additional zones in a similar fashion. This is all performed without having to pull the CT completely out of the well. With sand plugs being the primary mode of zonal isolation, an attempt should be made to achieve a proppant packoff using higher concentrations of sand in the final stages of each fracturing treatment (except the top one).

This pinpoint stimulation method involves the synergistic integration of CT and fracture stimulation disciplines of well services. This paper highlights the lessons learned from both operational and engineering standpoints of CT applications during the process of executing a CBM fracturing campaign in the Raniganj Field of West Bengal, India. The discussions within this paper focus on engineering best practices, optimization of resource utilization, incrementing the number of treated zones per day, and reduction of non-productive time (NPT).

This treatment technique provides an easy and economical method of achieving depth correlation. The small seam thickness of the CBM zones to be fractured makes it imperative to achieve a precise depth correlation technique to help ensure that the perforations are placed within the target seam. A mechanical casing collar locator was employed in this process, which helps correlate the CT depth to the wireline depth. This is why the success of this tool, to a major extent, depends on the accuracy of the wireline logs supplied by the well operator, to

which the collar depths are correlated. This paper also discusses the optimization of this tool, which resulted in an increase in the tool life and reduction of downtime caused by unnecessary roundtrips of CT, consequently reducing total fatigue on the CT string.

A prominent feature of this treatment method is the hydrajetting technique, which uses abrasive sand jetting to cut perforations through the casing, through the cement sheath, and farther into the formation. It provides a cleaner and more economical method of perforating compared to conventional perforating techniques. This can result in reduction of entry friction and larger perforation diameters, leading to enhanced communication to the reservoir and lowering of fracture initiation pressure. While perforating the CBM formation, several parameters were manipulated to augment the technical and operational efficiency of the entire process, which are discussed in this paper. Once the perforations are cut, acid is displaced down the CT to clean the cement remains and debris from the perforation area. An inherent advantage of using CT in this process is acid being spotted directly into the perforations, causing a more effective cleaning of the perforation set, often characterized by reduction in treating pressure during fracturing stages.

Introduction

The environmental, technical, and economic advantages of CBM have made it a global fuel of choice. With the energy demand/supply gap predicted to further increase, India has intensified its efforts in exploration of unconventional hydrocarbon sources, especially CBM. Having the fourth largest proven coal reserves and being the third largest coal producer in the world, India possesses significant prospects for commercial recovery of CBM.

The key geological difference between conventional gas and unconventional gas is the way it is stored in the reservoir. Conventional gas is trapped under pressure in the pores of a relatively permeable formation, whereas unconventional gas is stored by adsorption to the matrix, which generally has a very low permeability. To produce unconventional gas, it becomes imperative to release it from the matrix, which demands the use of stimulation techniques. Hydraulic fracturing is one such technique that helps achieve this purpose with utmost efficiency. With the advent of multistage fracturing techniques in the past decade, it has now become possible to produce gas from unconventional reservoirs in more economic and efficient ways.

In 2010, conventional fracture stimulation of CBM wells was being performed in the Raniganj Field of eastern India. However, the speed at which the wells were treated could not nearly meet the production demand deadlines of the operator. In the fourth quarter of 2010, a service company introduced a sophisticated fracture stimulation technique, which was a single-trip alternative for completing the candidate wells. It involved completing wells by hydrajet perforating using CT, fracturing down the annulus, and wellbore isolation for the following zone treatment, with a single CT trip, by starting at the lowest zone and working up to upper-most zone, both perforating and treating each zone on the way up is accomplished. One advantage of this technique is replacement of wireline with CT for perforating, eliminating the time required for alternate rig-up/rig-down of wireline and fracturing equipment. It also eliminates the need for additional wireline trips in and out of the hole required before each fracturing operation. This equates to a considerable reduction in the time required to stimulate a well, with a consequent reduction of NPT for the well operator.

Candidate Wells

The candidate wells to be initially treated were vertical cased wells with average true vertical depths (TVD) of around 1,000 m. In the later months of 2011, deviated wells with 45° deviation were also treated with average measured depths (MD) of 1,300 m with 5 to 10 target zones per well and reservoir coal seam thicknesses ranging between 1 and 5 m.

Because of the presence of multiple thin seams requiring selective treatment, depth accuracy was another concern with respect to narrowing the cycle time and flexibility to correlate depth under a diverse range of scenarios. Apart from that, as zonal isolation (the mainstay for effective multistage fracturing) was required with seams placed closed to each other; the process had to be versatile with minimum CT trips into the well. Thus, the requirement was to adopt a job procedure considering the stated challenges and design the job focusing on cost and process efficiency.

As compared to one to two fracture stimulations performed per day with conventional methods, this new technique treated an average of four treatments per day, with a maximum of six treatments performed in a day with a 12-hr work shift (Figure 1).

Multistage Fracturing

Multistage fracturing, using pinpoint stimulation, facilitates stimulation of multiple zones in a single trip in unperforated vertical, deviated, and horizontal wells, maximizing near-wellbore (NWB) conductivity. It allows treatment of individual zones by using sand plugs as a medium of isolation. It is essentially comprised of depth correlation with CT, hydrajet perforating, hydrajet fracture initiation, hydraulic fracture stimulation through the annulus, proppant packing NWB, and CT cleanout of casing.

Depth Correlation

Depth correlation is one of the critical aspects of using CT integrated with perforating and fracturing. The correlation system employed was the mechanical casing collar locator (MCCL) tool. The MCCL tool is critical for depth correlation when zones are thin. It indicates the casing collars and, in turn, helps correlate the depth shown on the CT unit depth meter to the wireline depth. One issue encountered when using this tool in the initial days of operation was the considerable wear on the MCCL keys that latch on the lip of the casing collars.

The angle of the MCCL tool keys (facing the collar) and the speed of pulling out of hole (POOH) while locating the collars were two factors that had to be considered together (Figure 2). Additionally, experience with a specific casing design and zone depth must be gained locally. Initially, the MCCL tool used to display collars on the weight graph worked efficiently for only four to five perforation sets, with the spacing between the perforation sets ranging from 30 to 50 ft. This was later attributed to the excessive wear on the MCCL tool keys as they were flattened out during the run. Moreover, there were added issues locating the collars in shallow depths (less than 600 ft). This caused additional CT trips to replace the keys. The springs used, however, lasted the entire duration of the well (about 18 perforating stages). To resolve this issue, the service company experimented with the MCCL tool keys, deriving the following observations.

Angle of the MCCL Tool Keys

Changing the angle of the MCCL tool keys was one method used. However, when the keys were set to work well at the deeper zones, problems occurred at shallower depths where the tool could not read the collars. If the angles were made too aggressive, the wear on the keys would increase significantly, thus reducing their life span. A good practice is to decide the angles at which the keys must be redressed based on the situation at hand.

It was determined while working at depths from 1,500 to 3,000 ft that one angle would provide good results; while, if the depths were shallower (below 1,000 ft), the best angle would be more aggressive. These changes are not possible once the tool is inside the well, but are beneficial when deploying the tool in the hole. Before operations begin, one should always assess the situation and adjust the angles to be more or less aggressive, accordingly.

After several trials, a method was developed to improve performance at all depths and reduce overall wear. This method involved both how the keys were set and altering the speed of pulling the CT; this proved effective. Following these practices, there was a noticeable increase in the efficiency of locating collars. The keys, once installed, lasted about eight to 10 perforation sets, and a clearer indication of the casing collars was observed on the weight graph.

CT Speed

The speed at which the CT is POOH while locating collars is a crucial factor that determines the prominence of the weight spikes shown on graphs, and thus must be carefully manipulated to suit different situations. When MCCL tool keys were new, certain pulling-speed ranges provided good indication of collars. This also applied when the CT was deep in the well. For shallower depths, speed was reduced. When the keys began wearing out (after being pulled uphole through a few hundred feet), lowering the speeds slightly helped provide better results.

There were special cases where only a few zones were left to be treated in the well. If, during one of these, the collar indications were not observed on the graph, the CT was POOH to replace the tool. This accumulated unwanted fatigue on the CT string and resulted in lost time. In such a situation, precise control of pulling speed proved helpful. It was found that a very low pulling speed was beneficial. This process was able to produce a clear weight spike on the graph, thus indicating the collar, even when keys were considerably worn.

Hydrajetting

The hydrajetting process was the method used to make perforations in the casing. It is based on the Bernoulli principle of conservation of energy for flowing liquids. Bernoulli's principle says that a rise in pressure in a flowing fluid must always be accompanied by a decrease in the speed, and conversely, an increase in the speed of the fluid results in a decrease of the pressure. During the hydrajetting process, an abrasive, such as sand, is mixed with fluid and is forced through nozzles under sufficient differential pressure to attain jet velocity. The targets (casing, cement, and formation) are cut away by the action of the erosive jets. One common function of the hydrajet is that its highpower energy is concentrated on a very small target. The benefits of the process for reducing NPT were readily apparent, along with considerable decrease in number of screenouts during fracturing stages.

Compared to the conventional methods of shape charge perforating, which were employed previously for the project, hydrajetting was found to be advantageous in multiple ways, some of which are listed next.

- Can create all perforations in one trip.
- Reduces NWB tortuosity problems, thus making it easier to fracture the zones with lower treatment pressures.
- Leaves formation around the perforation tunnel in tensile mode, where conventional perforating leaves it in compressive mode.
- Hydrajetting creates a clean non-damaged tunnel within a few minutes, reducing the initiation pressure when compared to conventional perforating. Conventional perforating creates a radial zone of damage surrounding the tunnel from extreme pressures and temperatures, and plugs the tip of the tunnel with formation debris and metal fragments (Figure 3 and Figure 4).
- An entire multiple stage fracture treatment can be completed with only one trip in the well.
- Allows performing fracturing treatments within minutes of hydrajetting the perforations.

The hydrajetting procedure includes pumping fluid at 3 to 3 1/2 bbl/min down the CT, achieving circulation, and followed by pumping abrasive fluid with additives. The hydrajetting process was executed downhole with a specifically designed hydrajetting tool, which involves three carbide nozzles placed planar at 120° phasing. The tool has challenges, like erosion of tool surface caused by splash back of sand and nozzle wear with extensive sand pumped through them, which, at times, might result in insufficient pressure drop across the nozzles required to make perforations.

Figure 5 shows a typical hydrajetting job. As the treatment fluid enters CT, the surface pressure (sum of friction pressure and pressure drop across nozzles) begins decreasing because of the decrease in friction pressures caused by the less turbulent nature of gelled fluid. As the fluid reaches the hydrajet BHA (green arrow), the pressure increases as the abrasive slurry has higher density; this indicates the start of the hydrajet perforating process. After full casing penetration has been achieved (Flag 3), the pressure declines only slightly as tunnel erosion is occurring and the casing perforation enlarges while pumping rate is constant. . After hydrajetting for the required amount of time, sand and additives are taken offline (Flag 4) and a rise in pressure is observed because of the increase in fluid friction in the CT and the decreasing hydrostatic head.

Over time, and as experience was gained, the hydrajetting process was optimized for the CBM formation and the following knowledge was gained in some key areas.

- *Annulus backpressure*: The process demands pumping fluid down the CT and taking fluid returns to the surface during hydrajetting perforations by means of the annulus. It was observed that, if no backpressure was maintained on the annulus, the sand plug isolating the current zone from the already fractured bottom zone would become unsettled, causing problems with fluid leaking off to the bottom zone, resulting in significant reduction in fracture propagation of the current zone. Conversely, maintaining high backpressure caused clogging of the perforations because of perforating sand (abrasive) settling, resulting in loss of injectivity during fracturing.

After several attempts, an optimum solution was reached to maintain the annulus backpressure at 500 psi. This provided the best results.

- *Monitoring the returns*: A good determination of the progress of the hydrajetting process can be made by observing the fluid returns taken through the annulus. A sudden loss in the rate of the fluid returns clearly indicated a breakdown while hydrajetting, attributed to the Bernoulli's effect. This is caused by the combined effect of stagnation pressure (caused by the high-velocity impinging jet stream out of the jet nozzles) and the pressurized annulus stream, causing a low-pressure region to be created in the annulus. Once this is observed, the returns are shut and the fracturing breakdown can be initiated through the annulus with CT flow path shut-in.
- *Standoff*: Standoff refers to the straight line distance between the jet nozzle and the casing wall. As the hydrajetting process takes place, there is a splash back of sand particles from the casing onto the jet body, which erodes the surface of the hydrajetting tool. This is one of the reasons for possible hydrajet tool failure. With a 4.76-in. drift ID of the casing, initially tools used had an OD of 3.66 in., which gave a life of 20 to 25 perforations. After decreasing the OD of the tool to 3.06 in., the standoff of the tool life was drastically increased to 60 to 70 perforations before it failed. In the end, this helped reduce CT trips in and out of the hole. Reducing CT fatigue and the cost of jetting tool replacement helped make the process more efficient (Figure 6 and Figure 7).
- *Hydrajetting time*: The typical hydrajetting time to cut perforations is around 5 to 10 min. It depends on various factors, like jet standoff from casing, casing grade, thickness, jetting differential pressure, jet diameter, cement sheath thickness, abrasive type and concentration, and jetting fluid type. Figure 8 is representative of some of the variance in jetting time as per the desired penetration length. Initially, the jetting time was set at 10 to 12 min., depending on CT pressure response, and the minimum required pressure drop across the nozzle was ~2,300 psi. As more experience was gained by changing critical parameters, such as gelled fluid viscosity and pumping rates, it was observed that increasing the fluid rate to 3.8 bbl/min from the initial 3 bbl/min showed a noticeable increase in the pressure drop gained across the nozzle, which in turn increased the jetting velocity and thus the efficiency of the perforating process. This helped when experimenting with the hydrajetting time required to successfully penetrate the formation to the required tunnel length. It was inferred that a jetting time of 7 min with the increased flow rate would provide better results, leading to optimization of the process by reducing the exposure time of splash back on the tool, thus increasing the jetting tool life.

Acid Spotting

Acid spotting across the perforations is another advantage of employing CT for fracturing. Once the perforations are made, 15% HCl acid was pumped down the CT and jetted across perforations to clean the cement damage and other debris in the perforation area. Involving CT for this process provides better control over jetting acid at perforations. Moreover, in cases where injectivity is not achieved after perforating, CT provides the flexibility to travel back down to the perforation depth and respot acid across the perforations. This has yielded positive results in the past by helping achieve injectivity into the formation. The effect of cleaning the perforations with acid is distinctly observed in most cases, as it decreases fracture initiation pressures by 500 to 1,000 psi (Figure 9).

Hydraulic Fracturing

The hydraulic fracturing sequence is initiated once the acid effect is observed and a formation breakdown is achieved. Breakdown is generally observed during the hydrajetting stage because of Bernoulli's effect. If breakdown was not achieved during hydrajetting, additional pad volume (clean fluid) is pumped until fracture initiation occurs. The zone is then treated as per the designed fracture design by pumping sand in gradually increasing concentrations.

Once the fracturing treatment is completed, an additional volume of sand at high concentration is pumped with an attempt to set a sand plug in the wellbore. This volume is calculated based on the size of proppant particles, casing volume per ft, and the height of the column of sand needed to isolate the fractured zone from the next zone above to be fractured. Once the proppant plug is pumped, this sand is allowed to settle to let the plug become more firm, which helps prevent fluid leakoff while treating the new zone above, thus providing zonal isolation

Reverse Circulation

Reverse circulation is another unique feature of the process, which allows receiving fluid returns on surface while pumping upward through the CT. This is facilitated by the presence of a ball and cage sub in the CT BHA, which acts like a check valve, allowing fluid flow only in one direction—from the annulus to the CT. While pumping down the CT, the ball presses against a tapered seat, creating a positive seal and not allowing flow of fluid out the bottom of the tool into the annulus. This creates the pressure drop by forcing all fluid across the jet nozzles required for hydrajet perforating. This process also provides a dynamic control over the placement of sand plugs. If the sand slurry pumped is higher (more shallow) than the designed height, it is possible to quickly cleanout the unwanted sand volume by reverse circulating—opening the CT to returns and pumping clean fluid through the annulus to push the additional sand up the CT to the surface. This is also applicable in cases of a screenout where additional sand could remain in the wellbore. This process can be performed without pulling the CT out of hole and thus saves considerable time. It also eliminates the requirement of a workover rig, thus making the process more economical. If the sand slurry is not pumped in adequate amounts, additional sand can be pumped in the wellbore through the CT.

In the case of deviated wells, the pumping rate through the CT size (1 3/4 in.) was limited and was insufficient to carry the abrasive cutting sand out of the well after hydrajetting. If not cleaned, this sand could reenter the perforations, thereby plugging them and not allowing any injectivity into the formation during fracturing. This problem too was addressed by using reverse circulation, which allowed cleaning the perforation sand out of the well by pumping through the annulus and receiving returns through the CT.

Conclusion

The service company was the first to introduce this technology to the Indian CBM market. With more than 500 fracturing treatments executed in a span of two years, pinpoint multistage fracturing has created a milestone in the Indian CBM market, proving to be extremely effective and beneficial to the well operator. Use of this technology has augmented the fracturing process efficiency by reducing operational costs, eliminating considerable NPT, and significantly improving production results for the well operator.

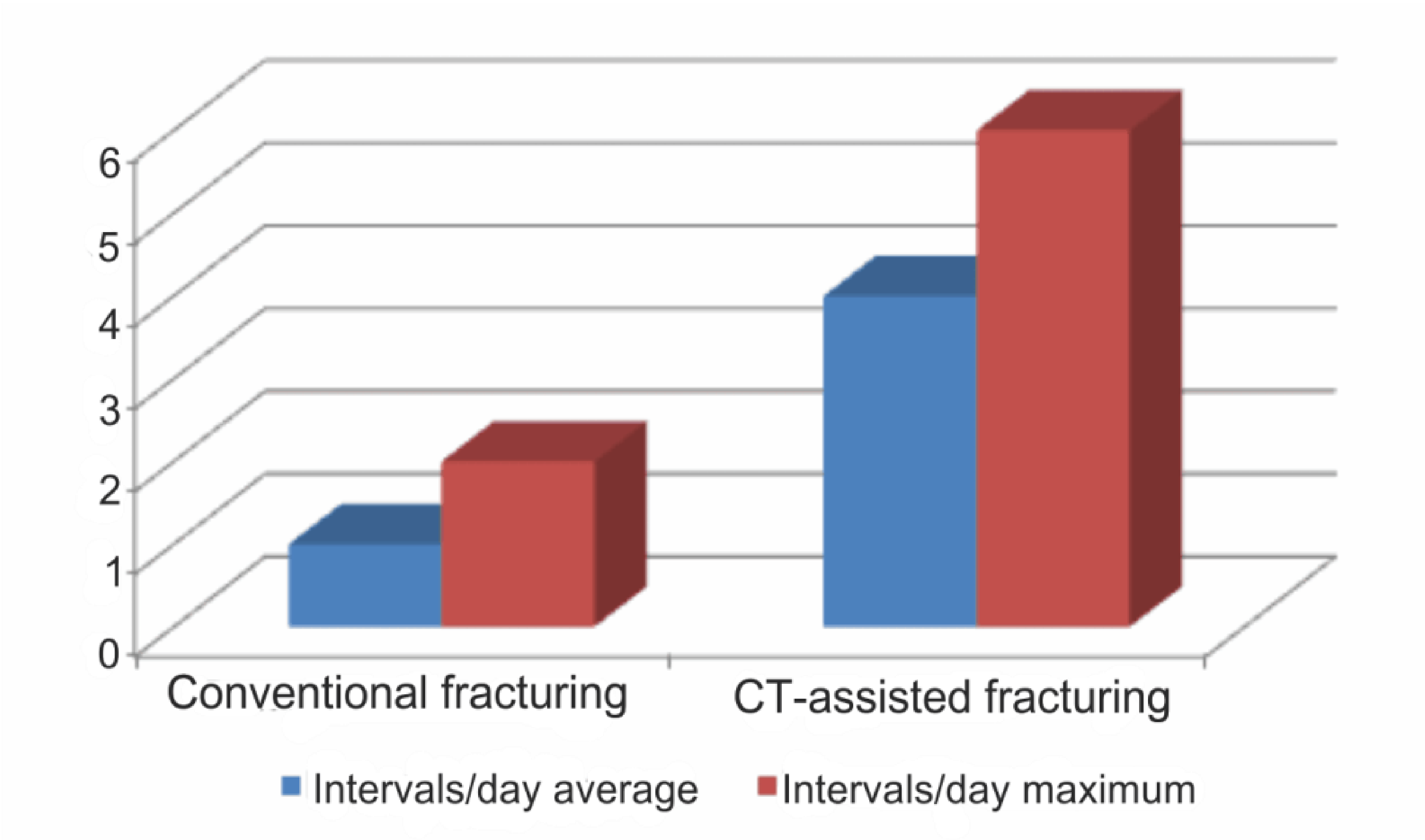

Figure 1. Intervals per day using conventional fracturing vs. CT-assisted fracturing.

Figure 2. Collar locator tool key.

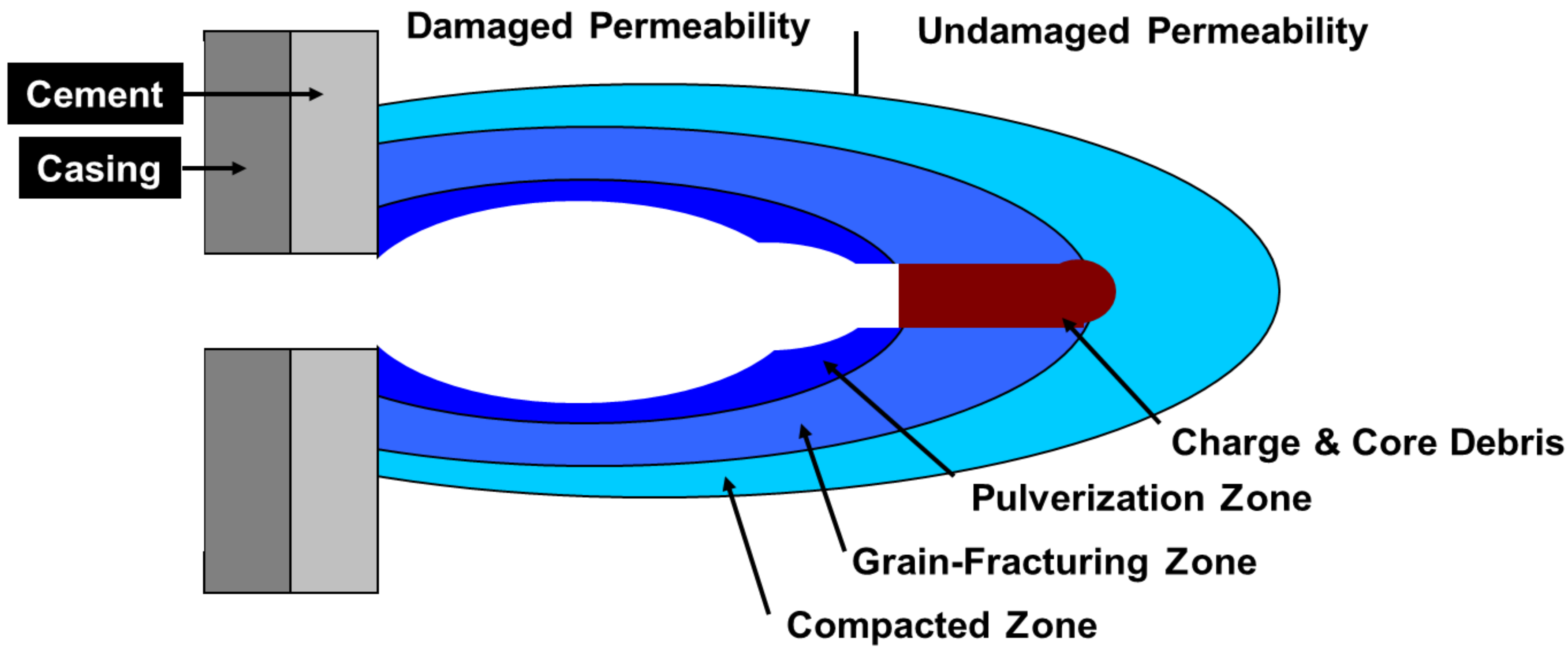

Figure 3. Damage caused by conventional perforation.

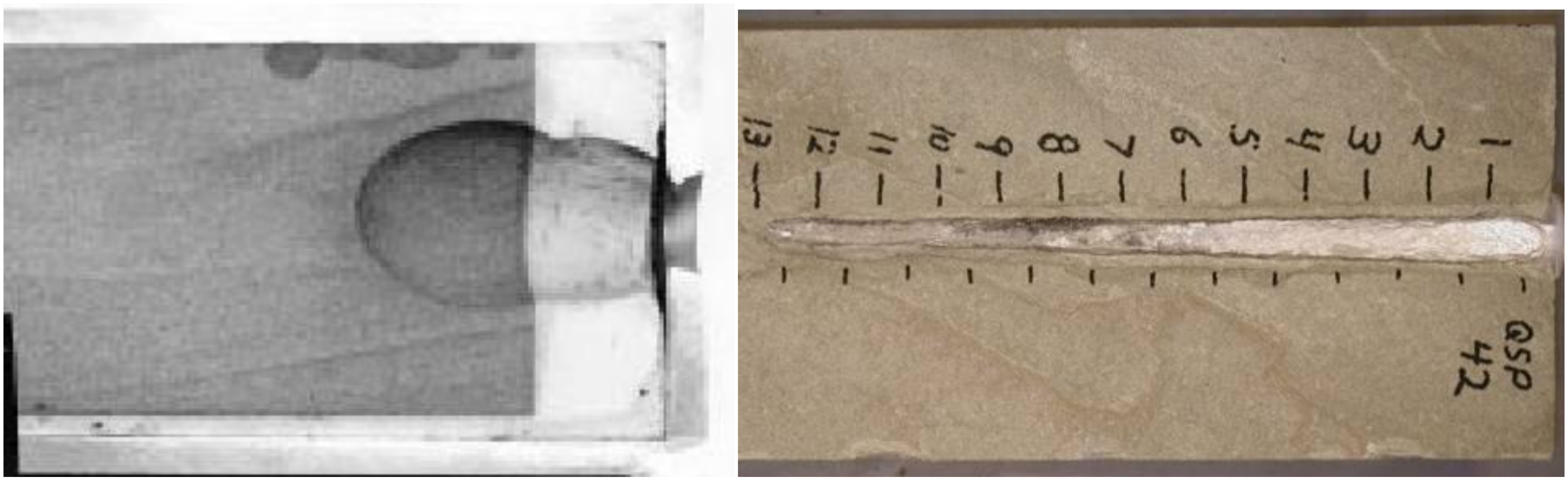

Figure 4. More tunnel diameter, larger entrance hole, and cleaner perforation when hydrajetting (left) compared to conventional shape charge perforation (right).

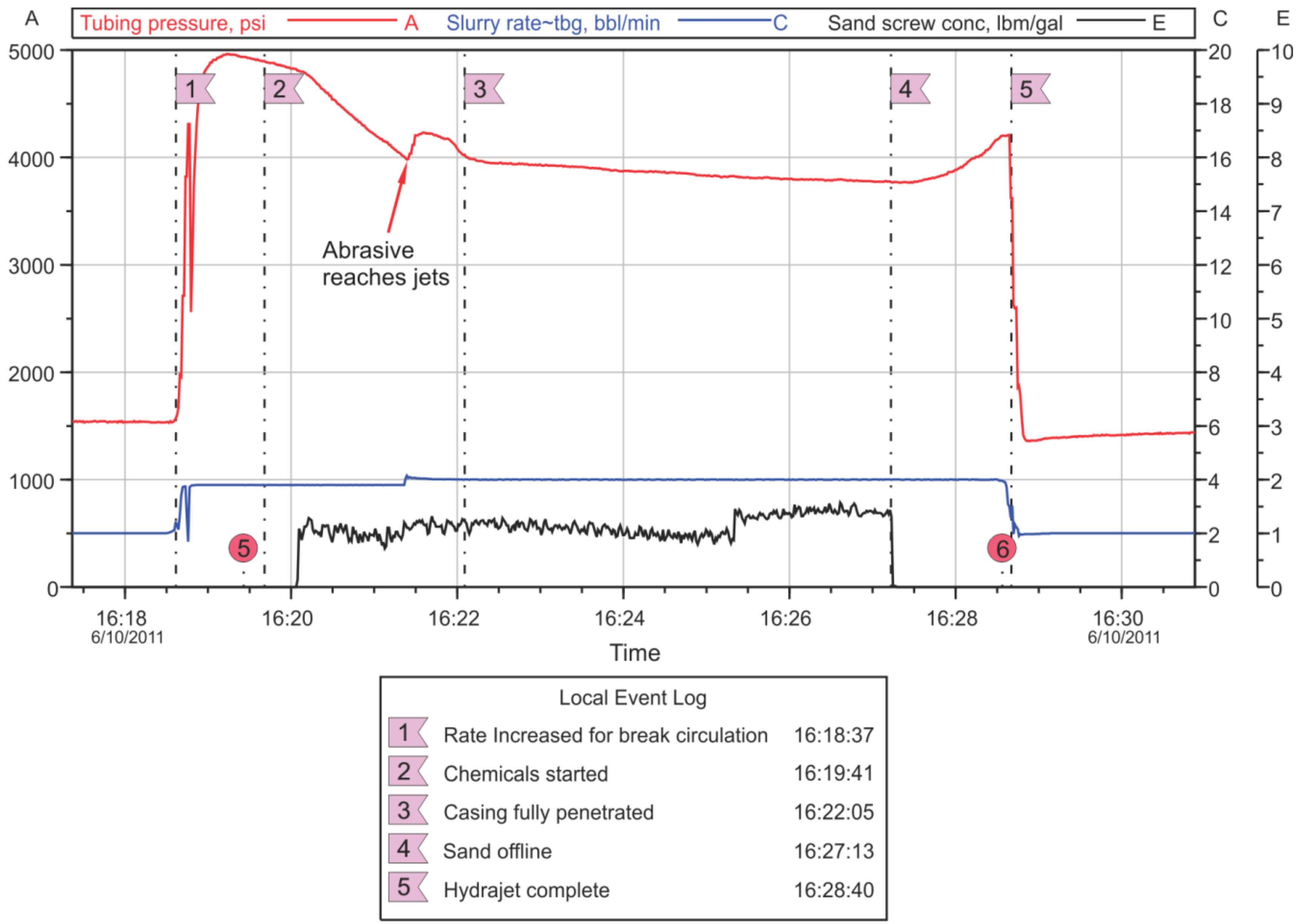

Figure 5. Hydrajetting graph.

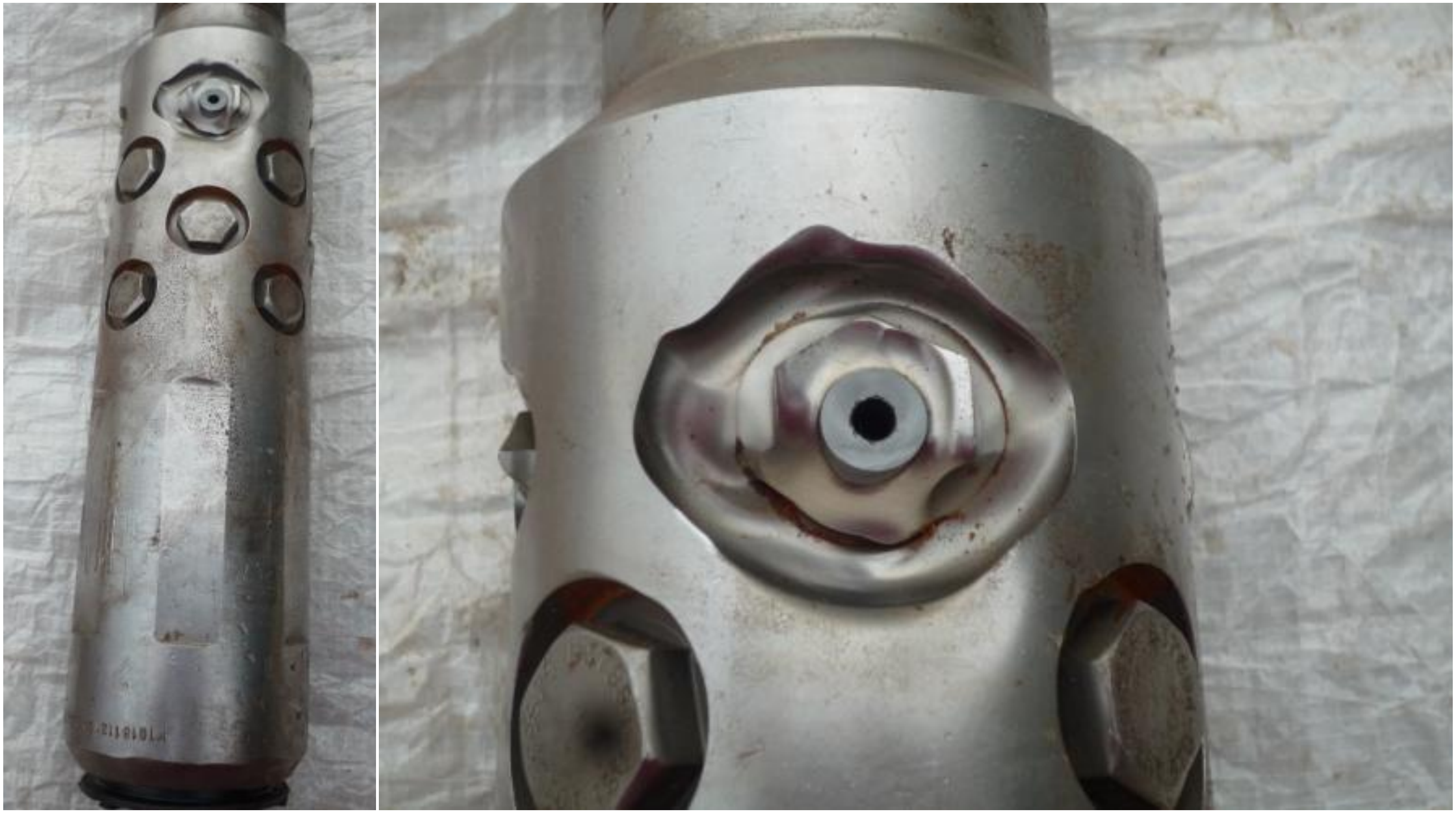

Figure 6. Jet body erosion after 22 perforations performed with 3.66-in. OD.

Figure 7. Jet body erosion after 62 perforations performed with 3.06-in. OD (only the enlarged hole is a nozzle).

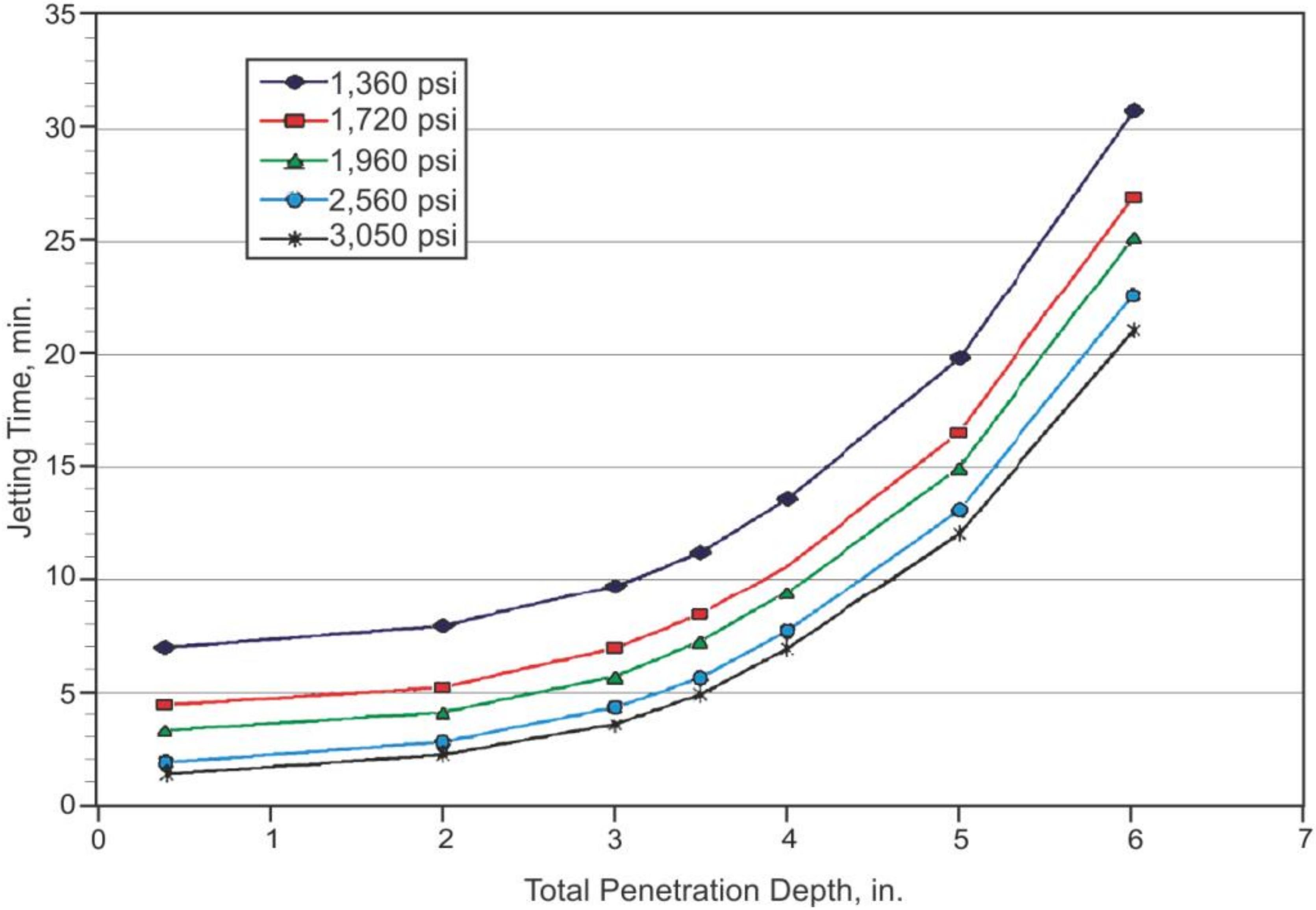

Figure 8. Hydrajetting time vs. penetration depth.

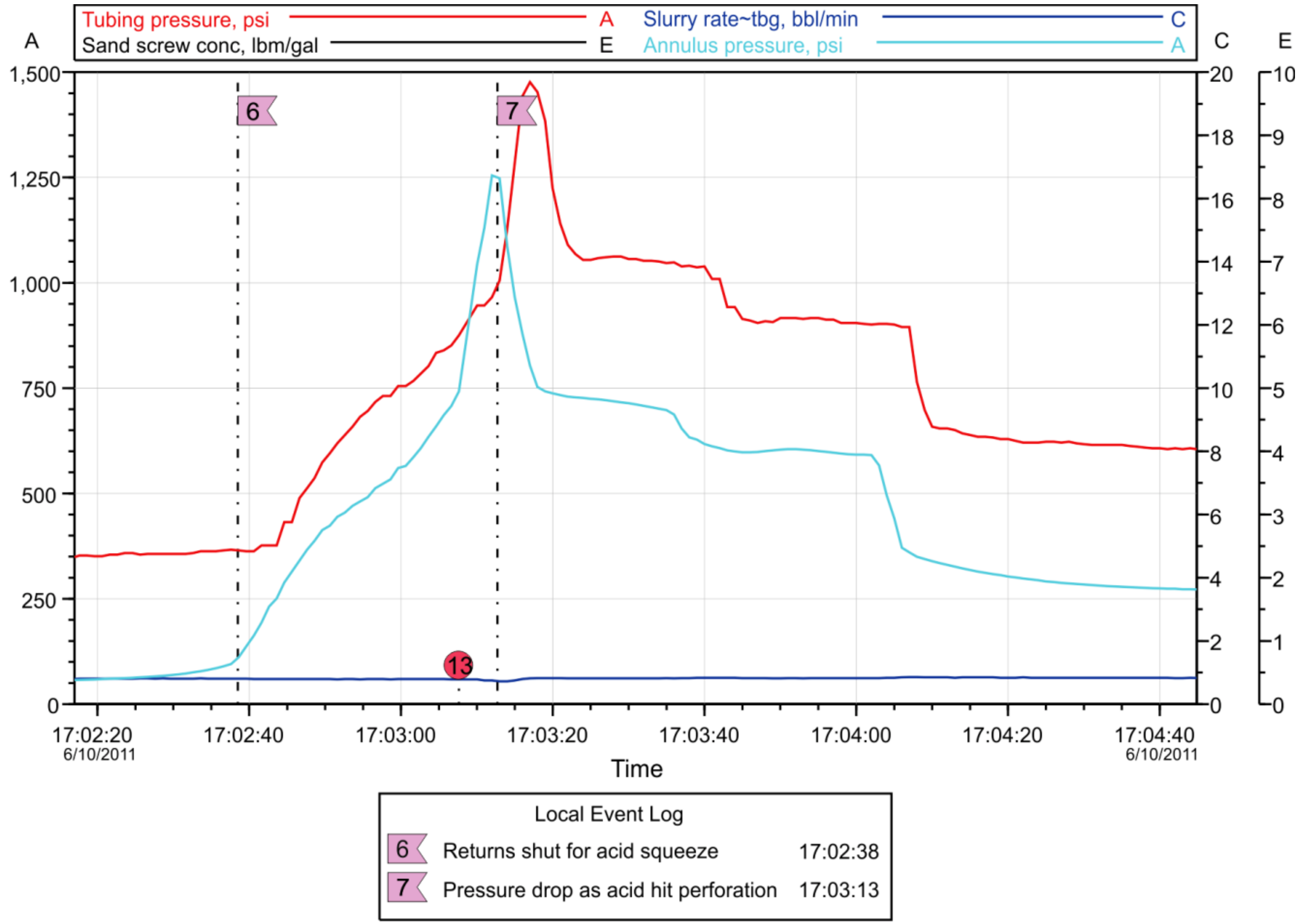

Figure 9. Example of decrease in pressure when acid hits perforations during acid squeeze.