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Extending Openhole Gravel Packing Capability: Initial Field Installation of Internal Shunt Alternate Path Technology

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Abstract

High angle, openhole completions are often selected to maximize production and reserve capture from several non-homogeneous sand packages in a single wellbore. Many times, the wells will require some form of sand control. Standalone screen applications may often times be the most cost effective and simplest form of sand control, but the formation characteristics may dictate that a gravel pack is necessary. Circulating water packs, alpha-beta gravel packs, have been used worldwide, but may be challenged to achieve a complete gravel pack in certain applications. Alternate Path[®] technology (APT), using the current eccentric two by two (2x2) shunt system, has proven to be extremely reliable in completely packing the openhole annulus and delivering high rate, failure free openhole completions.

Although routinely deployed, the current eccentric 2x2 APT screens have both technical and operational limitations. These limitations may include:

- Maximum shunt system working pressure of 3,000 psi which limits the packable length to ~3,200 ft pumping at 5 barrels per minute (bpm)
- Risk of plugging with two independent shunt tubes extending the length of the completion
- Complexity of rig site connection make-up as oriented connections and cross-coupling jumper tubes are required
- Deployment exposure dictates that an outer shroud must be incorporated in openhole applications to protect the shunt tubes

In order to overcome some of these limitations, while preserving all of the benefits of Alternate Path technology, a new generation of gravel pack screens was developed and successfully run utilizing Internal Shunt Alternate Path Technology (ISAPT). ISAPT extends openhole packable length, increases shunt tube redundancy across the entire interval, improves rig site installation efficiency, reduces deployment exposure, and provides a platform to incorporate specially designed shunt packers to provide true openhole zonal isolation.

This paper will discuss the key differences between the new ISAPT gravel pack screens and the current eccentric 2x2 APT screens as well as validation of key objectives from the first field installation.

Background

High rate, high capacity, long-life wells are essential for the long-term economic success of deepwater developments. Due to the high cost of performing remedial workovers, a reliable form of sand control is desirable. Additionally, applications for longer completion lengths and high angle completions are increasing as the cost to develop deepwater plays continue to rise. In summary, there is a need to produce more hydrocarbons from fewer wells.

When gravel packs are required for sand control, the operator has two options for gravel packing high angle completions, the alpha-beta technique or gravel packing with APT. Alpha-beta gravel packing is used in high angle wellbores and relies on an alpha wave, controlled by fluid velocity, to deposit a gravel bed on the low side of the openhole. Fluid returns are required to ensure a full gravel pack in the annulus as the beta wave packs from the toe back to the heel. Many operating environments do not have sufficient frac margin to allow the beta wave to fully pack back to the heel. In long interval or heterogeneous reservoirs, additional monitoring and control features/programs have been used to achieve the goal of a complete gravel pack, but they also increase the complexity in both completions tools and operations (Pedroso 2005, Pedroso 2008), which are not desirable under rising cost, more remote, or more challenging well conditions. Some operators are satisfied with simply covering the screens. There is evidence that simply covering the screens is not sufficient and could lead to early screen failures. Localized, high permeability streaks may flush away the thin layer of sand covering the top of the gravel pack screens, resulting in direct impingement of formation sand on the screen. Formation sand may also mix with the gravel in a loose pack to reduce the permeability of the annular pack. Potential sanding and reduced permeability risks are not acceptable in high rate, high cost wells when only a few wells are drilled to develop a resource. Alternate Path technology was developed to consistently deliver fully packed, highly productive, and reliable wellbores.

Evolution of Alternate Path Technology

Single Shunt Tube Design - The original shunt tube design includes a continuous ported shunt tube mounted on the outside of a jacketed screen (**Fig. 1**). The shunt tube provides an alternate path for the slurry to bypass any premature bridge that may form in the annulus. The shunt tube remains inactive until the top of the screen is covered with gravel, then slurry is diverted through the shunt tubes to bypass any bridge and gravel packing continues until the annulus is fully packed. This design seemed to work well for relatively short intervals (< 100 ft); however, laboratory testing (Jones 1997) identified the potential to plug the shunt tubes in lengths > 100 ft as gravel concentration increased throughout the shunt tubes due to fluid leaking off through the ports.

Staggered Shunt Tube Design - In an attempt to gravel pack longer intervals, multiple shunt tubes were placed on the outside of the screens and portions of the ports were plugged off in the shunt tubes to allow packing further along the wellbore (**Fig. 2**). The concept would be for each shunt tube to pack a segment length of < 100 ft along the wellbore. If three shunt tubes were used, shunt tube A would have ports only along the top 80 ft, shunt tube B would be responsible for the next 80 ft and shunt tube C the next. This approach had its limitations with the number of shunt tubes that could be placed on the outside of the screens without sacrificing too much of the base pipe diameter. Even with four shunt tubes installed, the overall length one could gravel pack would be less than 400 ft.

Eccentric 2x2 Design - As industry pushed into deepwater developments in the mid 1990's, long openhole completions became more popular, maximizing oil recovery from fewer wells. The current eccentric 2x2 Alternate Path system was designed to ensure complete gravel packs beyond the 400-ft limitation of the previously described system. The eccentric 2x2 system has two types of shunt tubes attached externally to standard screen hardware, (non-ported) transport tubes and (ported) packing tubes. Transport tubes form a continuous conduit along the entire length of the completion and deliver fluid to packing tubes that branch at the top of each screen joint (**Fig. 3**). Packing tubes contain nozzles spaced approximately every 6 ft to deliver gravel slurry to the annulus. After exiting the nozzles, the slurry packs the nearby annulus or continues to pack down the annulus until another bridge is reached. Once the annulus is packed alongside the packing tube, slurry continues down the transport tube until another region of unpacked annulus is encountered. Since shunt packing progresses from top down, leakoff to the formation is minimized and the risk of prematurely plugging the transport tubes is significantly reduced. The rectangular-shaped tubes and an eccentric cross-sectional screen design as shown in Fig. 3 minimize the effective outside diameter of the assembly. An outer shroud covers the entire assembly, providing shunt tube protection during openhole installation.

The eccentric 2x2 system requires the use of timed connections on the screen base pipe to line up the shunt tubes of the two screen joints about to be made up. Once the connection is made, cross coupling jumper tubes are installed to form the continuous conduit from one screen joint to the next screen joint. A shroud is later placed around the connection for protection. The complexity of the connection slows the running of the screen joints at the rig site.

The eccentric 2x2 system has been used to gravel pack wells up to lengths of 3,200 ft in hole angles up to 93° and across hundreds of ft of shale with great success (**Fig. 4**) (Yeh 2008; Jones 1999; Bryant 1995; Tibbles 2000; Hurst 2004; Wilson 2004; Powers 2006; Whaley 2007). However, requirements for longer openhole gravel packs are ever increasing as environments become more challenging. The 3,200-ft limitation is due to the friction pressure associated with pumping through shunt tubes along the entire openhole interval. In-house best practices limit the shunt friction pressure to 3,000 psi to maintain reliability in the shunt packing system.

As the industry continues to drill longer extended reach wells, completing the wells may reveal additional challenges. Historically, short, openhole completions may intersect one or two pay intervals. The long openhole completions associated with many extended reach wells may intersect up to five or six pay intervals. The eccentric 2x2 system is ideal for completing the entire interval, given the length limitation mentioned above; providing unwanted water and gas are not encountered. The lack of zonal isolation capability can begin to minimize the initial benefits of the fully gravel packed openhole completion. Due to these situations and the potential limitations of the eccentric 2x2 design, an alternative solution was required.

ISAPT - A new and enhanced screen design has been developed and qualified (Barry 2007) to further extend the technical limits in Alternate Path gravel packing. The new design is an extension of field proven technology. The ISAPT screens incorporate nine round shunt tubes, six transport tubes and three packing tubes, protected by the wire wrap (**Fig. 5**). The wire wrap is applied using direct wrap screen technology (Moen 2001). The transport tubes are non-ported and run continuous throughout the length of each joint. The packing tubes are closed at the bottom of the screen joint and contain nozzle rings spaced approximately 6 ft apart. At each nozzle ring, 3 discharge nozzles are phased 120 degrees. At the top of each joint of screen, a manifold is present where slurry from the transport tubes of the previous joint is redistributed and can flow into any of the transport or packing tubes of the next joint of screen (**Fig. 6**). The transport tubes and packing tubes are no longer paired together as in the previous eccentric 2x2 design. This coaxial manifold increases shunt redundancy and further reduces the risk of shunt plugging, thereby increasing the probability of a successful gravel pack over the entire length of a completion. This feature is particularly important in completion intervals requiring prolonged gravel packing and allows the bypassing of any localized plugging in a transport tube that may occur when extending gravel pack lengths.

The coaxial manifold not only reduces the risk of plugging a single shunt tube over the length of a completion, but it also simplifies field make-up by eliminating the timed connections and cross coupling jumper tubes of the eccentric 2x2 design. The connection is based on a standard premium connection with a concentric outer sleeve. The connection design facilitates easy rig floor make-up similar to conventional tubing handling operations.

By migrating from rectangular shunt tubes to round shunt tubes, the working pressure of the shunt system increases from 3,000 to 6,500 psi. The shunt system of the new ISAPT screens has been tested to 10,000 psi. With the increase in working pressure, a length of 5,000 ft can now be packed at a rate of 4.5 bpm extending the length limit by more than 50%.

Internal shunt openhole packers, currently under development, will take advantage of the new ISAPT concentric screen design to provide zonal isolation. The openhole packers will be set prior to gravel packing, thereby providing a hydraulic and mechanical seal to the borehole before any gravel can be placed around the element. During pumping operations, once gravel covers the top of the screens, slurry is diverted into the shunt tubes, tightly packing the openhole above the packer, then passes through the packer and continues to pack below the packer via the shunt tubes. Internal shunt openhole packers enable gravel pack completions to gain the current flexibility of standalone screen (SAS) applications by providing future zonal isolation of unwanted fluids with the reliability of a gravel pack completion.

Initial Field Installation

After the completion of an extensive testing and qualification program for the ISAPT screens, the following objectives were set for the first field installation:

- Verify ease of the new screen handling / make-up equipment during field installation of the ISAPT screens
- Assess ISAPT screen make-up times and compare to that of the eccentric 2x2 APT screens
- Verify drag estimates for running a completion equipped with ISAPT screens
- Assure full gravel pack placement using the new ISAPT screens
- Verify shunt tube friction of the ISAPT screens and compare to eccentric 2x2 system field data and ISAPT qualification tests

The operator has extensive experience installing openhole gravel packs around the world, especially in West Africa developments. One such development, offshore Angola, provides excellent case histories with continuous improvements. Angola Block 15 is located approximately 90 miles off of the northwest coast of Angola. The KSJ-103 ST2 well was selected for the first installation of the new ISAPT gravel pack screens. This well is part of the Kizomba B Development and was a sidetrack from an existing wellbore on Tension Leg Platform 'B' (TLP-B). With the 9⁵/₈-in. production casing set at 11,313 ft, the 9⁷/₈-in. hole section was drilled to a total depth (TD) of 13,659 ft with an inclination between 85 and 90°. The openhole interval consisted of 144 ft of 12¹/₄-in. hole below the 9⁵/₈-in. casing shoe, 1,962 ft of 9⁷/₈-in. hole, and 240 ft of 8¹/₂-in. hole to TD. Since a large interval of shale was encountered in the bottom section of the well and the hole inclination was nearly horizontal, a decision was made to install screens

just below the base of the bottom sand at 13,298 ft rather than TD. The lower completion consisted of 54 joints of ISAPT gravel pack screen, two joints of shunted blank and one top joint.

One drawback of the current eccentric 2x2 design is related to the complexity of the rig site connection make-up given the need for oriented connections and the requirement to install cross coupling jumper tubes and shroud. This complexity slows the make-up and running speed of the screens to an average of approximately five joints per hour. The coaxial manifold system of the ISAPT screens eliminates these issues and significantly improves the overall make-up times for shunted screens. This design enhancement required a change in the handling and make-up equipment for the ISAPT screens. Due to the shape of the coaxial manifold system, a conventional bowl and slip arrangement could not be utilized to support the ISAPT screens while hanging in the rotary; therefore, a clam-styled landing spear was designed and tested. Additionally, a load collar was developed to place around a specially designed groove below the outer sleeve of the coaxial manifold to allow the screens to be picked up with conventional elevators. This same load collar is then temporarily used to support the weight of the screens when placed on the landing spear in the rotary.

A single joint compensator was used for each joint to ensure the pin was carefully stabbed into the coupling while not damaging the seal face of the coaxial manifold. Once the joint was successfully stabbed, the connection was made up hand tight with a strap wrench prior to using conventional power tongs and manual backup tongs to make-up to the final torque. The assembled screen sections were then picked up off the landing spear and the load collar on the lower screen section was removed (and subsequently installed on the next available joint of screen waiting on the pipe conveyor). The landing spear was opened and the assembly was lowered through the rotary. As the top of the assembly neared the rotary, the landing spear was closed and the assembly was slowly lowered until the load collar engaged the top of the landing spear. The process was repeated until all of the screens and blanks were run. All of the special running and handling equipment performed as expected.

A total of 57 connections were made up while running the ISAPT screen assembly and a peak run time of 10 joints per hour was obtained. This make-up time is consistent with make-up times of conventional tubing and is a significant improvement over the five joints per hour average for the eccentric 2x2 design. Each joint was successfully made up and no screen joints were laid down due to handling or make-up issues. The peak running time validated the assumption of improved rig site efficiency with the ISAPT design by the elimination of the timed connections and cross coupling jumper tubes of the eccentric 2x2 design.

The design of the ISAPT screens inherently makes the assembly more rigid which could make it more difficult to run to TD on long and highly deviated wells. While the ISAPT screens were successfully being run to the desired depth on 5½-in. drillpipe, pickup and slack-off weights were periodically recorded and plotted versus a range of expected values. A simulation with an overall cased hole friction factor of 0.20 and openhole friction factor of 0.25 was determined to best represent the actual value (**Fig. 7**). This combination of friction factors was found to be comparable to completions utilizing the eccentric 2x2 design on similar wells drilled from the TLP-B.

After successfully running the lower completion to the predetermined depth, the gravel pack packer was set and the well was prepared for gravel packing. The NAFpacSM process (Hecker 2004) was used to gravel pack the well. The open hole was swept with gravel pack gel by placing the fluid into the annulus, shifting the service tool into the gravel packing position and pumping down the casing annulus, through the wash pipe, up the open hole by screen annulus, and into the drillpipe. The service tool was shifted back to the reverse position and the drillpipe was reversed out. While still in the reverse position, 5.1 ppa (pounds of proppant added per gallon) slurry was spotted to the gravel pack service tool and the tool was shifted to the weight down position. The gravel pack pumps were brought back online at 5 bpm with full returns.

After pumping approximately 18,300 lb of proppant below the crossover tool, slurry was diverted through the shunt tubes resulting in a pump pressure increase of 217 psi (**Fig. 8**). **Fig. 9** shows the pressure increase of 217 psi on the bundle carrier reading drillpipe pressure, located one stand above the service tool. In deepwater environments, the production casing shoe is typically set off the bottom of the drilled hole for ease of space out. The productive interval is later drilled, but the larger rathole remains under the casing shoe, typically 15 to 35 ft in length. During normal gravel packing operations with a viscous fluid, the openhole by the screen annulus is gravel packed, toe to the heel, and the larger rathole is typically not fully packed. With APT, slurry is diverted into the shunt tubes after the screens are covered inside the production casing. The 30 to 65 ft of annular space between the screen and casing are typically tightly packed, so the first exit port for the slurry, once it passes through the shunted blank joints and top screen joints, is immediately below the production casing shoe in the larger rathole. The sharp increase in pressure due to pumping through the shunt tubes will decrease slightly at this point as the slurry exits the shunt tubes. The sharp increase in pressure is used to calculate a shunt friction pressure gradient by dividing the initial pressure increase (217 psi) by the length of

shunt tubes from the top of the shunted blank to the casing shoe (135 ft). The shunt friction gradient of 1.6 psi/ft at 5 bpm from the KSJ-103 ST2 compares favorably with the friction numbers seen during pre-job modeling and full scale testing. An additional $\pm 33,000$ lb of proppant were pumped through the shunts, accounting for 64% of the gravel pack job, until a screenout was achieved.

The shunt friction pressure gradient can be used to track the progression of packing through the shunt tubes during the job. **Fig. 10** shows the drillpipe pressure at the bundle carrier increasing with time after slurry enters the shunt tubes. The observed pressure differential divided by the shunt friction results in the packing location. The pressure increase seen in KSJ-103 ST2 suggests the slurry was delivered to the end of the screens prior to screening out. Knowing that slurry was delivered to the bottom of the gravel pack assembly through the shunt tubes and the amount of gravel placed below the service tool equaled the calculated openhole volume required to pack the completion interval, one can feel confident the annular space was fully packed.

Conclusions

The performance of the ISAPT screens and handling equipment met or exceeded all key objectives established prior to the first installation on the KSJ-103 ST2 well. The fit for purpose screen handling equipment performed as expected and the rig crew (with minimal training) was able to demonstrate peak running times comparable to running conventional tubing. The drag profile for running the ISAPT screens experienced similar cased hole and openhole friction factors as the eccentric 2x2 design. The entire completion interval was completely packed after diverting into the shunt tubes. Future ISAPT installations of up to 5,000 ft should be achievable since the actual shunt friction factor replicated laboratory measurements and calculated values.

Utilizing a structured approach, additional ISAPT project objectives will be implemented and evaluated on subsequent wells throughout the operator's worldwide portfolio. Some potential applications being evaluated include:

- Extreme length openhole gravel packs requiring complete gravel packs
- Long interval openhole gravel packs needing zonal isolation
- Stacked pay targets that will require isolation of encountered water or gas intervals
- Multizone openhole completions (frac upper interval, gravel pack lower intervals)

Acknowledgements

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Figures

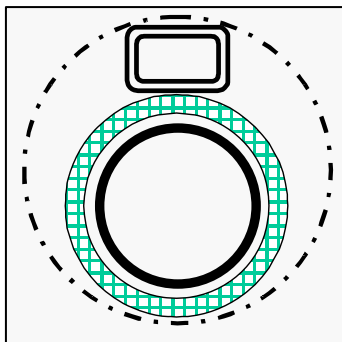


Fig. 1—Single shunt tube design.

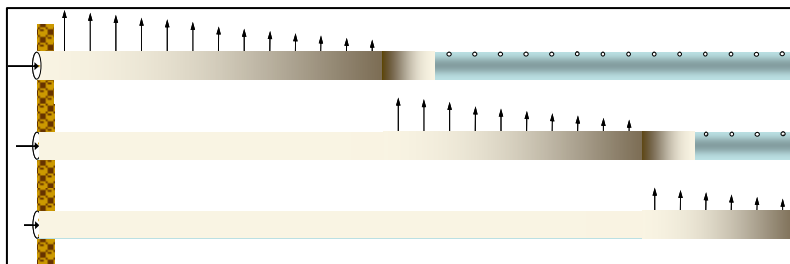


Fig. 2—Staggered shunt tube design.

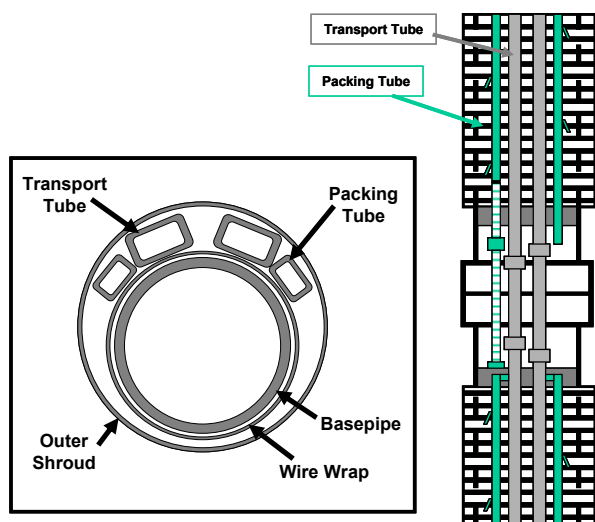


Fig. 3—Eccentric 2x2 design.

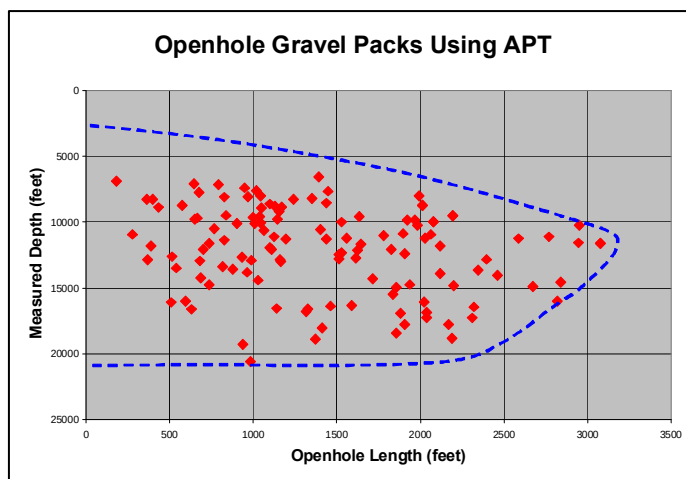


Fig. 4—Openhole gravel pack lengths of APT completions.

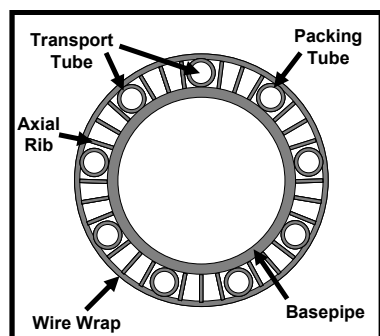


Fig. 5—Cross-Section of ISAPT

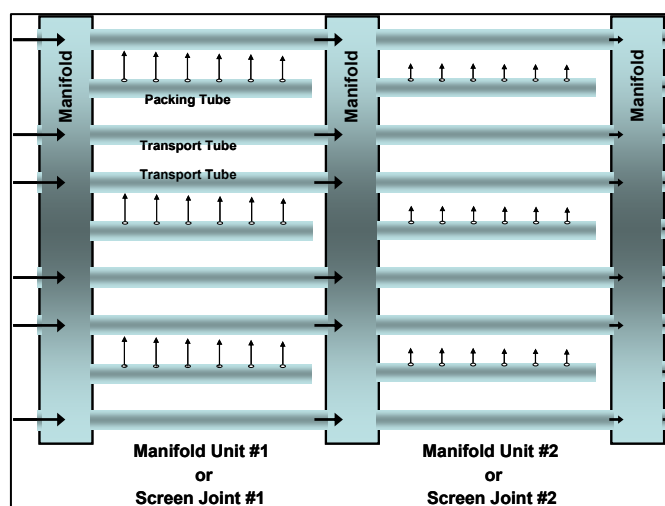


Fig. 6—ISAPT design, multiple-shunt manifold system.

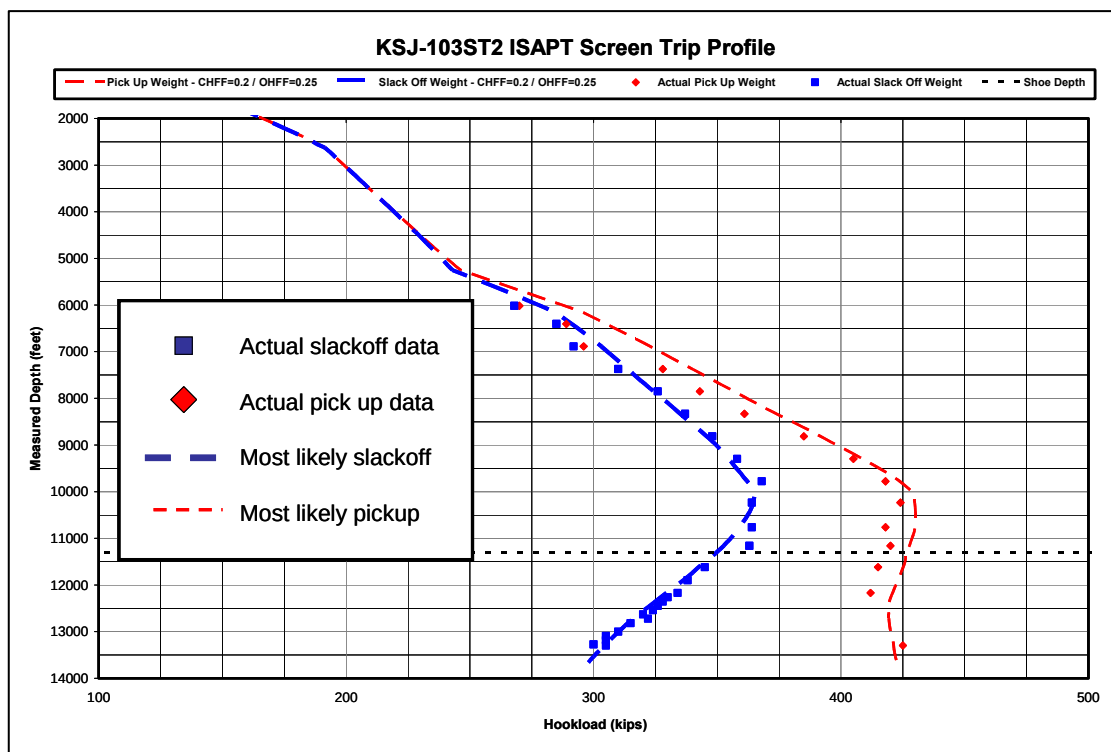


Fig. 7—ISAPT screen trip profile, actual pickup and slackoff data matches predicted numbers.

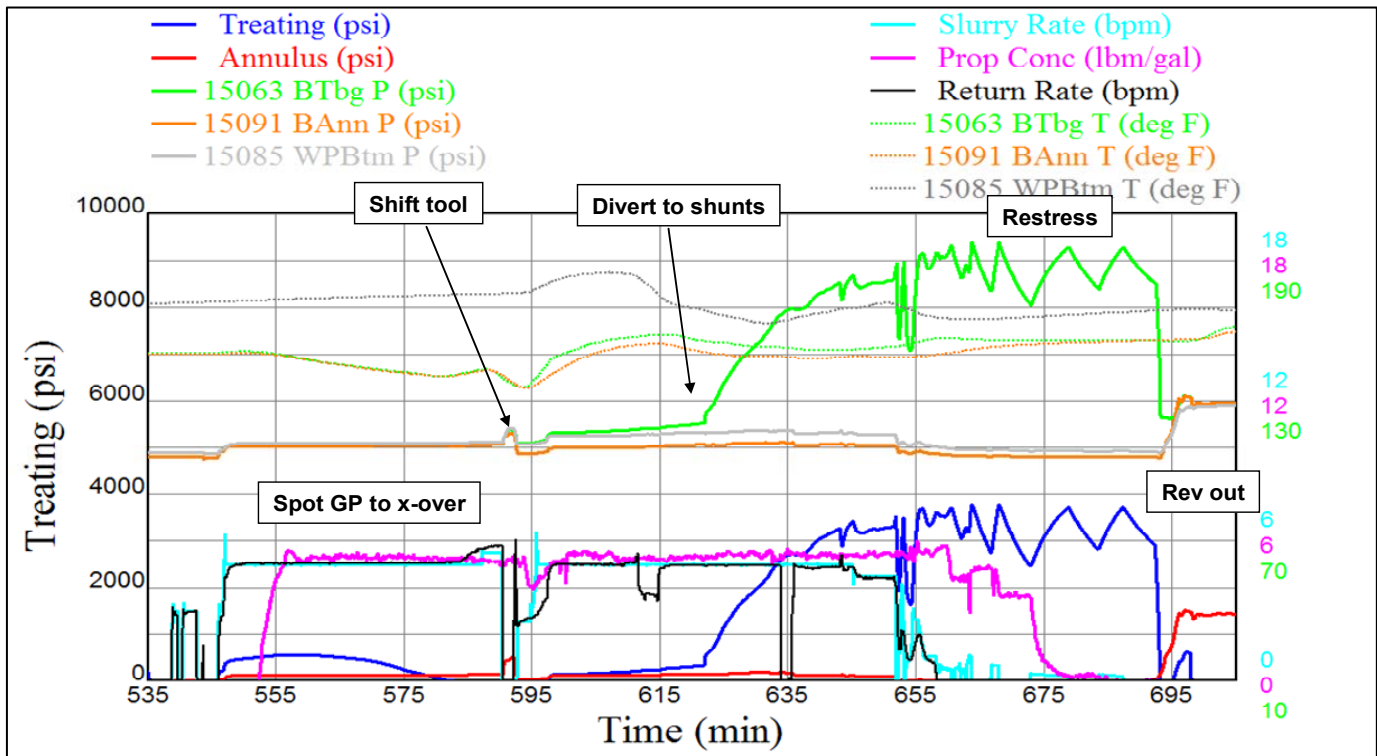


Fig. 8—KSJ103 ST2 pressure and pumping curves from initial ISAPT gravel pack.

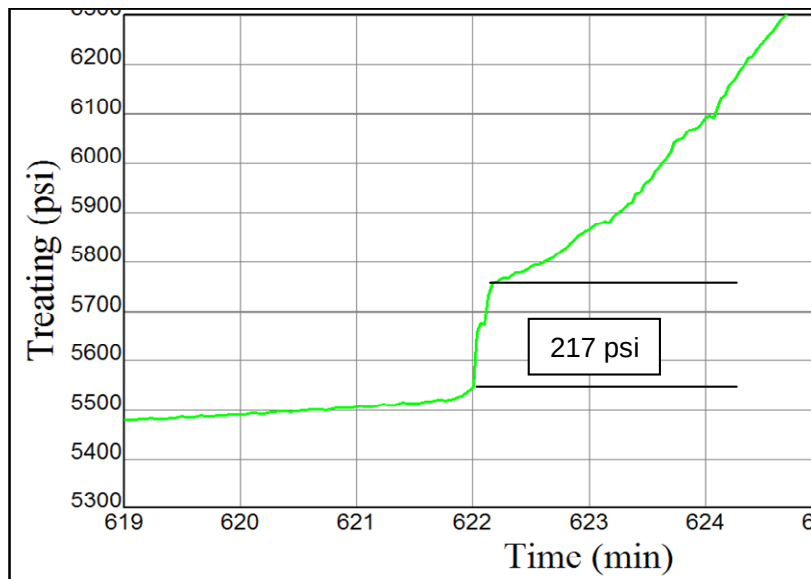


Fig. 9—Pressure increase due to shunt diversion.

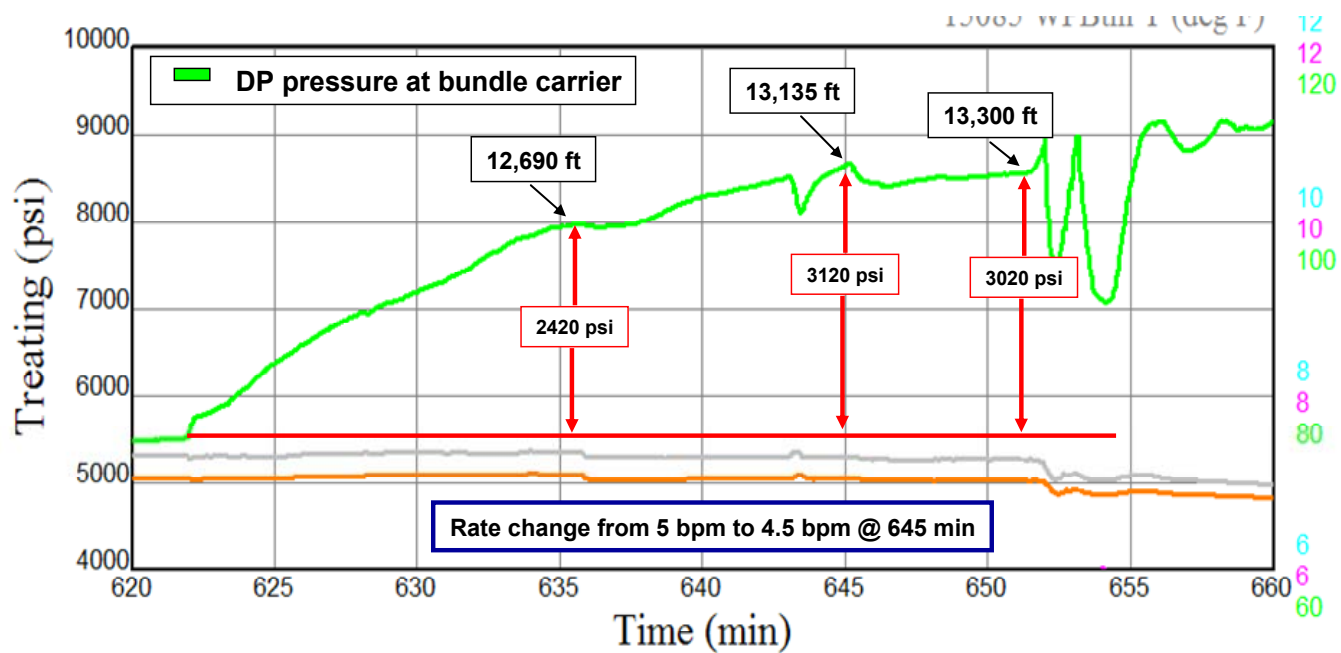


Fig. 10—KSJ103 ST2 progression of shunt tube packing.