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Adopting Aphron Fluid Technology for Completion and Workover Applications

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Abstract

The literature describes several applications where Aphron fluid technology has been applied in both drilling and re-entry scenarios and includes an extensive description of how this drilling fluid system works. A highly efficient leak-off prevention mechanism makes Aphron based fluid systems beneficial for certain completion and workover applications as well, where formation damage could be avoided by the practical elimination of fluid-fluid or fluid-rock interaction or where simply the workover objectives could be achieved by obtaining the efficient circulation of fluid to surface. Completion and workover applications for this fluid system have not been extensively reported.

This paper reviews three applications of Aphron fluid technology in different completion and workover scenarios. The selected cases were reviewed to present some of the technical and operational lessons learned and to some extent discuss the observed formation cleanup behavior. The following applications were reviewed: use of an Aphron based system as a kill fluid while several well servicing operations were conducted during the completion of a normally pressured formation in a dual string sour gas well and in this case the practically complete prevention of fluid losses even though a well kill fluid was substituted for snubbing operations; the completion of additional zones within a depleted dolomitic limestone formation on two wells where the method of Aphron fluid placement was found to significantly affect fluid losses; and finally, the enabling of the provision of annular pressure support at pressures which approached the hydraulic fracture opening pressure of a shallow zone while hydraulically fracturing a deeper zone down tubing with a packer.

Introduction

The mechanisms by which Aphron fluids operate make the technology a reliable and economic tool for certain completion and workover applications. These mechanisms have been described extensively in literature [1,2,3,4]. The fluid's enhanced rheological properties and the sealing abilities of aphron bubbles have caused low fluid leakoff rates to occur when the system is properly applied. Moreover, the presentation of field performance data for Aphron fluids in drilling and re-entry operations is also commonly published [2,6,7,8,9]. Lessons learned from the performance of Aphron fluids in a wide range of applications have shaped the evolution of a specific profile for the use of this technology. The high low shear rate viscosity (HLSRV) necessary to stabilize aphron bubbles in an Aphron fluid not only provides the proper environment for aphron formation and survival [1] but also provides a high resistance to flow which significantly prevents initial fluid loss to the formation. The creation of aphron aggregates has been shown to be an effective filtrate control mechanism which further reduces fluid loss [1,10] and prevents formation damage. This can be attributed to the majority of inert gas that makes up an aphron aggregate and the limited amount of bulk fluid which invades a leakoff zone. Therefore, when aphrons are used as the filtrate control mechanism the rate of fluid-fluid and fluid-rock interaction is stoichiometrically limited. Simply put, adverse fluid-fluid and fluid-rock reactions are prevented because the completion and workover fluid is not available as a reactant or contaminant.

The sealing mechanism is controlled by the differences in fluid and formation pneumatics and hydraulics [4]. When wellbore pressures exceed formation pressures the aphrons will move with the pressure gradient from the base fluid in the wellbore to the lower pressured formation and form a tight effective seal inside the formation. Aphron bubbles have been observed to move to the leading edge of a migrating fluid front [3]. Sealing is achieved quickly and to the extent necessary to establish a balance between the formation and annular pressures. The seal remains intact and stable until fluid properties or wellbore hydraulics no longer support individual aphron or aggregate aphron seal integrity. If fluid LSRV is lowered to below about 40,000cP the aphrons become unstable and begin to break apart. If the wellbore pressure is lowered to below that of the formation the aphrons will again move with the gradient, from the formation into the wellbore.

The inherent properties unique to Aphron fluids have produced growing interest in using these fluids in certain completion and workover applications. Aphron fluids have been successfully used a kill fluid for producing formations during completion and workover projects. We carefully reviewed several projects in western Canada and have presented three which illustrate the benefits and challenges of using Aphron fluids in completion and workover applications.

Case Studies:

Case 1

For the first case, significant and relatively complex dual string snubbing operations were avoided. This well, represented in Fig. 1, was to be dually completed for sour gas production in two Upper Cretaceous sandstone intervals in the north central foothills region of Alberta. After hydraulic fracturing and initial cleanup flow operations an oil based Aphron completion and workover fluid was used to kill the upper formation in order to enable the well completion to be finished using standard well servicing equipment. After 8 days of service rig operations which included multiple tubing trips, an aggressive proppant cleanout using a mud motor, mechanical bridge plug retrieval and the installation of dual production tubing strings, the full original kill fluid volume was recovered. Nitrogen circulation through the completion tubing was used to expedite fluid recovery and the upper interval immediately resumed the post fracture rate that was observed during the original cleanup flow. Fig. 2 shows the shallow interval gas production rate throughout the completion and cleanup flow operations and Fig. 3 shows the corresponding fluid loading throughout the completion operation.

Fluid properties were not perceived to be optimal for this well servicing application as the fluid was purchased from another operator who had used it as a drilling fluid in a multiple well program. Despite an abnormally high LSRV and the presence of drilling fines gained during its previous drilling service this recycled fluid proved to be suitable for this application and did not damage the well.

Case 2

This well and the next were completed in a Mississippian aged dolomitic limestone gas reservoir having a gross pay thickness of 90 m, estimated reservoir pressure of 6 MPa and a vertical depth to the pay zone top of 1446 m. Both wells were the subject of workovers to increase gas production by completing additional pay sequences which were located amongst the existing completion intervals.

With the depleted reservoir pressure in this field, well servicing operations when conducted using produced water kill fluid have historically incurred continuous losses of 6-8 m^3 per hour with a few hundred m^3 of kill fluid loss over the course of a workover operation having been common. The resulting fluid load would often lead to poor well performance during the early post workover production period and in some cases well performance would suffer for a period of several months. In recent years snubbing has evolved as a preferred well servicing method for intervention work such as these operations because the fluid loss volumes could be significantly reduced.

Case 2a

The first workover was proposed to complete two additional pay intervals. Acid and hydraulic fracturing operations were performed respectively on the two new intervals. Fig. 4 shows the wellbore configuration during and after the workover. The well was killed with a full column of Aphron workover fluid before retrieving the original completion equipment and then perforating and acidizing the deeper interval. The Aphron fluid was circulated out of the tubing and then the tubing was swabbed dry before conducting an acid squeeze. A brief evaluation after the acid job showed poor inflow and then after recovery of the spent acid the zone was re-killed with Aphron workover fluid before being isolated below a bridge plug. Operations continued with the second, shallower interval, which was isolated to conduct a hydraulic fracture using the previously set bridge plug and a service packer. A surface pressure of 3 MPa was applied on top of a full annular column of Aphron workover fluid without inducing losses and the shallower zone was hydraulically fractured, placing only 30% of the planned proppant tonnage in the formation before a premature screenout. Poor inflow was also observed from this zone and it was left loaded with a high volume of stimulation fluid. To this point no observable Aphron volume had been lost to the reservoir.

Operational problems were encountered during oil tool setting, which were attributed to perforating debris and possibly other solids suspended in the fluid column. In an attempt to exploit the stable Aphron seal within the formation, on day 17 as shown on Fig. 5 it was elected to circulate the well to produced water for the remaining well servicing procedures. The Aphron workover fluid was recovered from the well by circulation with produced water and then the packer was unset but was dropped during recovery from the well. While fishing and after a day of well servicing operations the Aphron plug had degraded sufficiently to permit significant enough fluid leak off to cause a substantial loss of the fluid column. A kick occurred during packer recovery and continued gas influx was contained with produced water. In a failed attempt to stabilize the kill fluid column a low volume Aphron pill was squeezed through the tubing from in intermediate depth in the well. An effective and stable kill fluid column was not regained and the remaining operations were executed with significant additional produced water kill fluid loss.

Fig. 6 shows well performance both before and after this workover. Though a production success could not be claimed, significant observations were made which will affect ongoing operations with this fluid. Among these observations are the following items.

- The affect of entrained air on the surface volume of Aphron based completion and workover fluids must be recognized during kill fluid placement and recovery, ensuring that sufficient fluid of an understood weight is placed in the well. Growcock [11] observed a mud weight gradient which reflected Aphron compressibility in the well.
- Wireline tools, including a wireline set bridge plug were deployed without incident.
- A packer setting failure occurred after running a mechanical set service packer through a newly perforated interval. Examination of the failed packer indicated that the fluid bypass area was plugged with perforating debris. It appears that the high LSRV enabled solids in the static fluid column to remain suspended until they were filtered out in the packer bypass flow area. The surface fluid handling process was subsequently improved by adding solids removal equipment to the premix and return tank.
- Upon recovery after a period of 8 days in the well without circulation, the workover fluid rheology properties were stable and Aphron content was consistent with the originally placed fluid. An upper time limit to Aphron stability under static downhole conditions has yet to be defined.
- The failed attempt to place an Aphron pill was made with the tubing bottom 350 m above the top of the pay zone. The Aphron pill and a substantial produced water volume were lost to the formation while recovering the packer and bridge plug and installing the production tubing. The method of fluid placement is a vital factor in the success of placing a stable Aphron seal. For this case it is likely that the stability of the seal in the formation was reduced when surge and swab pressures incurred during fishing and pipe movement contributed to its degradation. With an adequate reserve of Aphron fluid inside the wellbore it is likely that the Aphron seal would have regenerated each time it was destabilized with no significant fluid loss.

The Aphron seal, once stabilized by the packed aphron bubbles is maintained or strengthened by the addition of further bubbles. Conditions for seal maintenance would be enhanced by the continuous circulation of fresh Aphron fluid inside the wellbore adjacent to the seal. Reduced seal stability would be expected with static Aphron fluid in the well at the invasion zone, though this condition was adequate to maintain a long term seal in this case. The lowest seal stability would be expected when a non Aphron fluid was present in the well, especially under unstable, surging bottom hole pressure conditions as occurred in the later stages of this operation. The next case outlines a similar workover application in the same reservoir which was successful.

Case 2b

This well was the subject of a workover to add a new deeper completion, as shown in Fig. 7. Before recovering the original production tubing string, the well was killed by balancing a column of recycled Aphron workover fluid in the bottom half of the well, with a fresh water column to surface. Produced water was left across the proposed new interval and the well was perforated with wireline conveyed guns. A packer was run on tubing without incident and the tubing was displaced to fresh water, pushing the Aphron volume fully into the annulus before setting the packer between the intervals. A surface pressure of 6 MPa was applied to the annulus while pumping the fracture stimulation. Low volume surface Aphron losses which occurred during the hydraulic fracture are noted in Table 1 .

Observation	**Surface Pressure**	**Loss Volume**
1 day prior to the fracture stimulation	6 MPa	0.7 m^3
during fracture stimulation - the noted volume is an initial high rate loss	6 MPa	1.0 m^3
during fracture stimulation - low rate loss while maintaining constant annular pressure	6 MPa	0.4 m^3

Table 1 – Aphron surface injection volumes with increased annulus pressure with an open upper completion interval during hydraulic fracture of a deeper completion interval.

Fluid losses for the complete workover are summarized in Fig 8. All but 0.5 m^3 of the Aphron fluid was recovered by circulation after installation of the completion equipment. The post workover production results, Fig. 9, show the well to be producing at a higher rate and further analysis has suggested that additional reserves are being drained.

Case 3

This case describes two wells in the Cretaceous conglomerate sands of the Deep Basin region in Alberta where Aphron workover fluid was used to provide a means of preventing fluid leakoff under high differential pressures so that a high casing pressure could be maintained during through tubing fracturing operations. In order to accommodate expected high fracture treating pressures, the tubing maximum pressure capacity was increased above its derated internal yield pressure by maintaining a high annulus pressure during the treatment.

Case 3a

For the first well a retrievable casing patch type packer was originally proposed to protect the upper completion interval from the high annulus pressure which was desired during the fracture treatment, however operational problems were encountered with two attempts to install the tool. An Aphron fluid system was circulated into the annulus and the casing pressure was held near the previously observed fracture pressure of the shallower interval. Fig. 10 shows the well configuration during this fracture treatment.

Overall fluid losses during the workover are described in Fig. 11. The shallower sand, which had been hydraulically fractured during the original well completion, acted as a sink for ongoing workover fluid losses throughout the pre-fracture well preparations until the well was circulated to the Aphron fluid system.

Case 3b

As in the previous well, the casing was filled with Aphron workover fluid and the surface pressure was held at a sufficient level to enable the desired fracture treatment pressure to be achieved. The volume of Aphron fluid injected into the upper completion interval before and during the fracture treatment is noted in Table 2.

Aphron Event	Observation	Surface Pressure	Injection Volume	Injection Rate
short duration, one day prior to fracture	continuous injection	25 MPa	2.6 m^3	0.14 m^3/min
3 hour duration during hydraulic fracture	spurt, followed by slow surface pressure bleed off	21 MPa	3.4 m^3	0.02 m^3/min

Table 2. The surface annulus pressure data suggests that the upper completion interval was effectively sealed at 21 MPa. The annulus volume was 17 m^3.

The injection data is plotted in Fig 12. On the original fracture treatment for the shallow zone a bottom hole closure pressure of 49 MPa was observed. For this workover the Aphron pressurized density was 1035 kg/m^3 so for the shallow completion interval at 2883 m, these annulus pressure observations suggest that the shallow hydraulically fractured interval was effectively sealed with Aphron fluid at its full previously observed fracturing pressure.

Both wells in this case experienced productivity improvements under commingled flow conditions however as of publication, isolated testing had not been done of the shallower intervals which were exposed to Aphron workover fluid under a high differential pressure.

Discussion

Through investigating early cases where Aphron fluids were used in completion and workover scenarios, several lessons were learned about how to appropriately apply these fluids in a well servicing environment. The conveyance method for delivering aphrons to an open formation appears to be an important factor towards achieving effective seal stability. It has been found through drilling experience [6,7,8,9] that circulating Aphron fluid across a producing zone, under the right conditions provides an excellent seal with low fluid loss which is consistent with observations made in the present cases. Additionally, it was observed that “bull heading” or squeezing a static column of Aphron fluid will yield various amounts of fluid loss.

Aphron micro-bubbles range in size from 10-100 μm therefore the gross number of aphrons required to form a seal across a previously perforated and hydraulically fractured formation is likely to be large. The number of aphrons that can be supplied to such zones is limited by, among other factors, the volume of Aphron fluid exposed to the zone. The amount of aphrons delivered to a zone of fluid invasion is influenced directly by the amount of Aphron fluid exposed to that zone, which is far greater with a circulating column than it is with a static column.

The HLSRV property of an Aphron fluid will allow it to exhibit a viscous resistance to flow not seen with produced water or other kill fluids. Nevertheless, any practice of applying aphrons through a static fluid column should be avoided when possible since Aphron fluid with HLSRV imbedded in formations may pose well clean up challenges. Additionally, under enough differential pressure, at least for the case of a static Aphron column applied to a previously fractured formation, reinitiation of hydraulic fracturing may be a concern. It should be noted that if an adequate seal is established by circulating Aphron fluids across a producing zone, allowing the fluid column to go static does not result in seal degradation or whole fluid loss to the extent likely with a seal that was established under static conditions. Where the aphron seal was established under circulating conditions stability was maintained for up to 8 days without incurring fluid losses. Though the life span for an aphron seal stabilized by a static Aphron fluid column has not been established, lab based observations [11] of aphron bubble longevity would suggest that there is a time limit.

Another significant observation in field conditions is fluid compressibility when aphrons are exposed to the down hole pressure environment. Aphron microbubbles formed in a HLSRV fluid have been reported to withstand pressures up to 4000psi without collapse[11] and unpublished field data provides evidence that the upper limit threshold for aphron survivability under elevated pressures may be higher than this. The present cases suggest that an effective seal was maintained at bottom hole pressures exceeding 6000 psi. This survivability may be due to the pressure gradient which would exist across a well placed Aphron seal, with formation pressure on the low pressure side and the high pressure existing only on the wellbore side. A model describing aphron survivability in the conditions which are present across a formation seal, at pressures above the laboratory investigated limits is presently not defined in the literature.

Although aphrons can endure in a high pressure environment, Boyle's Law predicts that aphron diameters will reduce with increasing pressure. Consequently, the overall Aphron fluid system is also compressible and at the hydrostatic pressure conditions representative of the depths achieved by most wells would be expected to reduce in volume by values which asymptotically approach the surface aphron volume. Therefore sufficient additional Aphron fluid volume is required to overcome reductions in the surface fluid volume as the fluid is compressed in the elevated pressure environment of the fluid column inside of a well.

Aphron fluids recovered from both drilling and completion operations have been stored, transferred and successfully reapplied in other completion and workover projects. Despite the presence of drilled solids, produced fluids, mill cuttings and other contaminants, recycled Aphron fluids have provided highly efficient sealing performance. This is attributed to the highly effective carrying capacity of the fluid phase of the Aphron system and the fact that the aphron microbubbles move ahead of the fluid front to prevent continued fluid invasion. Fluid borne contaminants are simply not available to producing formations and therefore present no significant risk of formation damage.

The initial costs and high fluid recoverability involved with Aphron fluids in completion and workover operations gives some motivation for the implemention of a coordinated approach to Aphron fluid management. A cost effective method for adapting Aphron fluids to completion and workover applications is to incorporate a system of fluid management which facilitates recovery, storage and reuse. Components of such a system might include the following:

- Reduce - Low fluid loss rates for Aphron fluids in well re-entry operations provide a degree of predictability in requirements and recovery volumes.

- Reuse - Re-entry wells are circulated out with either pressured nitrogen, brine or frac oil and the Aphron fluids are recovered at the surface. The fluids are then stored or transferred to other locations. No challenges with the transfer of these fluids from one location to another have yet been encountered. Furthermore, fluid sharing has significantly offset the initial fluid purchase cost.

- Recycle – In field observations it has been noted that Aphron fluid integrity is similar before and after well servicing operations. Storage of these fluids requires periodic agitation and treatment for prevention of microbiols and where extended storage has occurred, chemical costs for Aphron fluid reconditioning have typically been 25-40% of the original fluid costs.

Systems which have been designed to ease the handling of invert fluid systems have proven to be useful in the loss prevention of Aphron fluids while handling pipe at the rig floor. The small volumes of Aphron fluids that either inter-mix with displacement fluids or remain as residue on rig equipment have been disposed of according to the applicable regulations for fluids from producing wells.

Active solids management is an area which traditionally is not a concern with the clear, filtered brines that are normally deployed in well servicing operations. The rheological properties which help prevent fluid invasion with Aphron based systems also lead to solids suspension in the fluid column, which could interfere with oil tool deployment and retrieval. Solids removal can be addressed on the surface for the entire fluid system with the various types of traditional drilling solids removal equipment and in the wellbore, for specific contaminants like perforating debris, with the various brands of in well filtering tools.

Conclusions

Aphron fluid technology was applied successfully in several completion and workover applications to prevent fluid loss, enabling well operations to be carried out under dead well, static fluid conditions. This has simplified some well servicing operations and has enabled complex operations to be executed with reduced risk.

The compressible nature of Aphron fluids requires recognition when installing and removing fluids from the well and also when applying squeeze pressures on top of an Aphron column. Furthermore, migration of the Aphron stabilized bubbles through these fluids when exposed to a pressure gradient, such as across a formation seal can be expected to lead to an apparent bulk fluid loss with a resultant surface static pressure reduction, when the actual mechanism is the loss of gas containing bubbles from the bulk fluid to the Aphron bubble front at the seal.

The method to achieve an effective and durable formation internal seal must respect the unique properties of Aphron fluids. For well servicing applications it may be helpful to view the sealing mechanism in two phases, the first being a seal building stage which is enhanced by the provision of Aphron fluid circulation inside of the wellbore with seal efficacy largely being determined by the supply of sufficient bubbles to produce a substantial Aphron seal thickness. The second stage addresses seal longevity and recognizes that some degree of seal maintenance is necessary, with a positive balance being required between those factors which both enhance and degrade the Aphron seal.

The observation of an effective Aphron seal at bottom hole pressures which are near the known formation fracturing pressure warrants further investigation to rigorously describe the interaction between the Aphron seal, the pre-existing hydraulic fracture and the near wellbore stress state.

Other potential applications for Aphron fluids may exist where circulation of fluids to surface is required yet hindered by exposed depleted pressure reservoirs. Unreported experience suggests that Aphron fluids may be useful for increasing the likelihood of gaining efficient circulation during primary and certain remedial cement jobs. Employing a modified version of these fluids for hydraulic fracturing may even be possible. Lastly, innovative operational practices such as the pressurized forced air formation of aphrons could permit using these fluids to enable seal formation, even in very high leak off situations.

The authors would like to thank Devon Canada Corporation, operator of the wells in these case studies for permission to publish the information from which these conclusions were drawn and furthermore wish to encourage and invite both the publication of other applications of this technology and a more rigorous examination of the various Aphron fluid behaviors observed in these cases.

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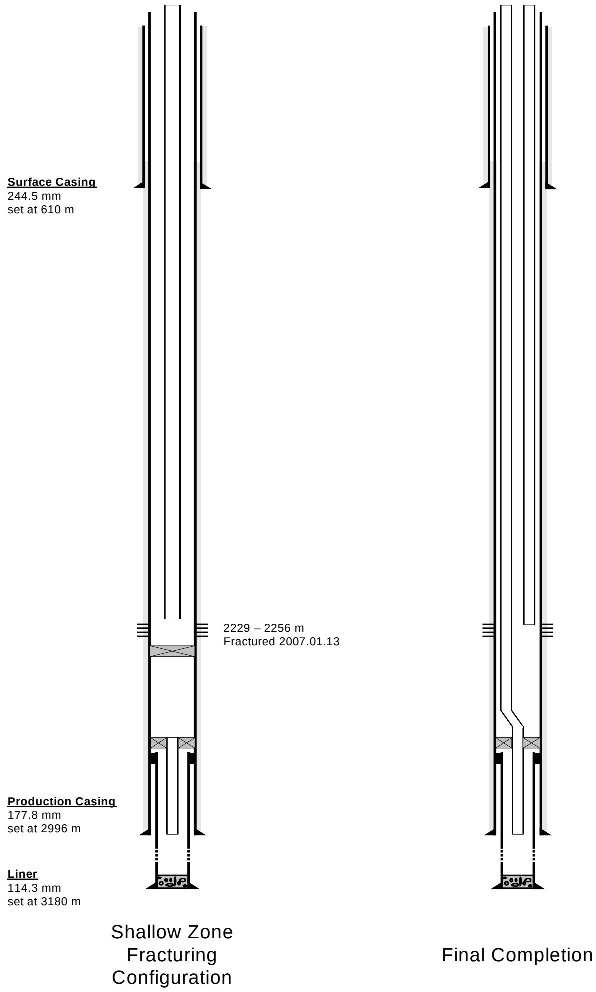

Fig. 1 - Case 1 – **The shallow completion interval was killed using an oil based version of Aphron fluid technology in order to install a dead leg tubing string for hydraulic fracturing and then to configure well for dual string production.**

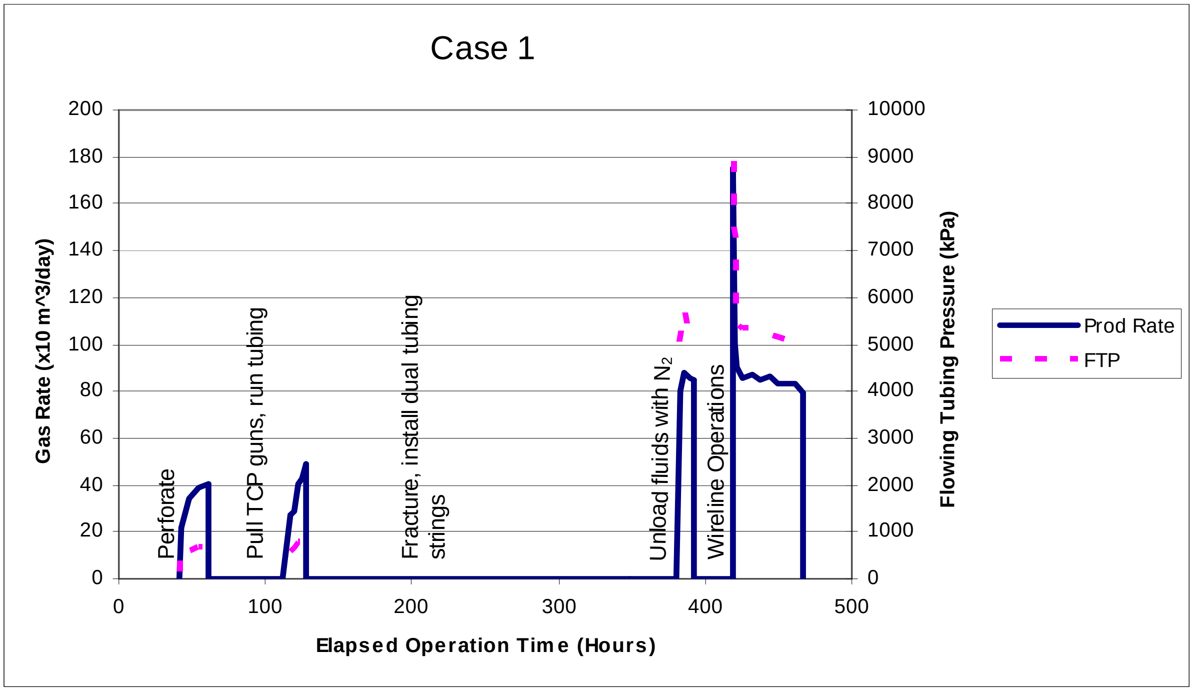

Fig. 2 – Gas production rates observed during the completion operations.

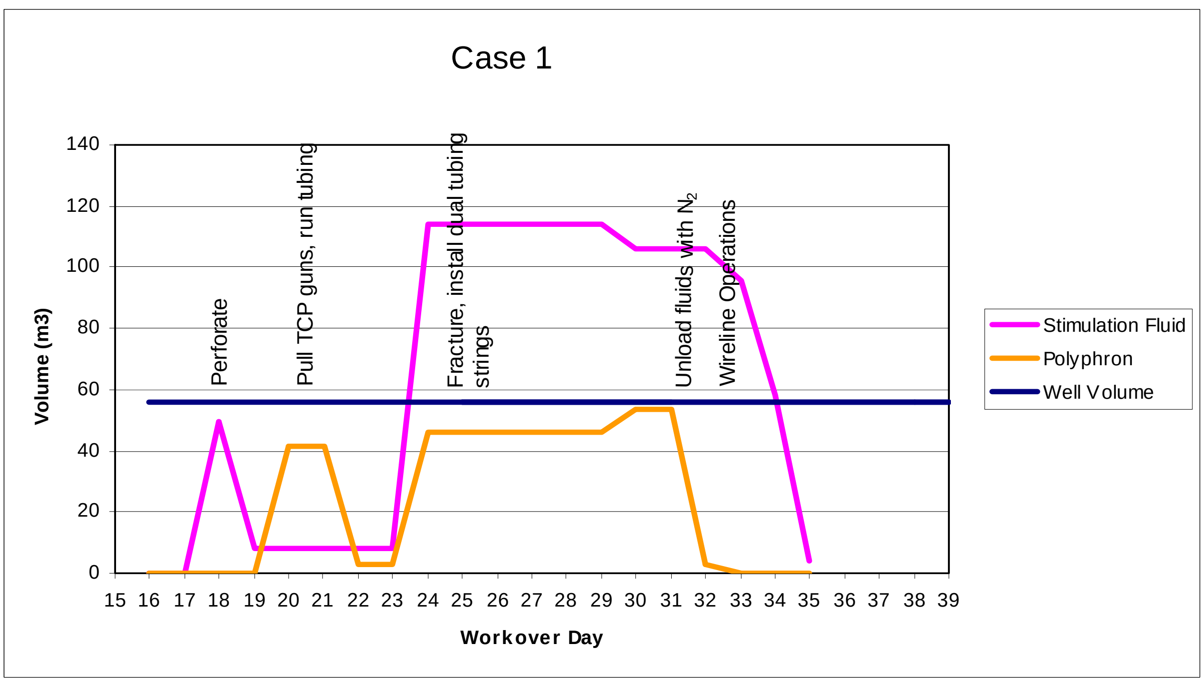

Fig. 3 – Fluid losses are presented by fluid type with the major phases of the completion operation noted.

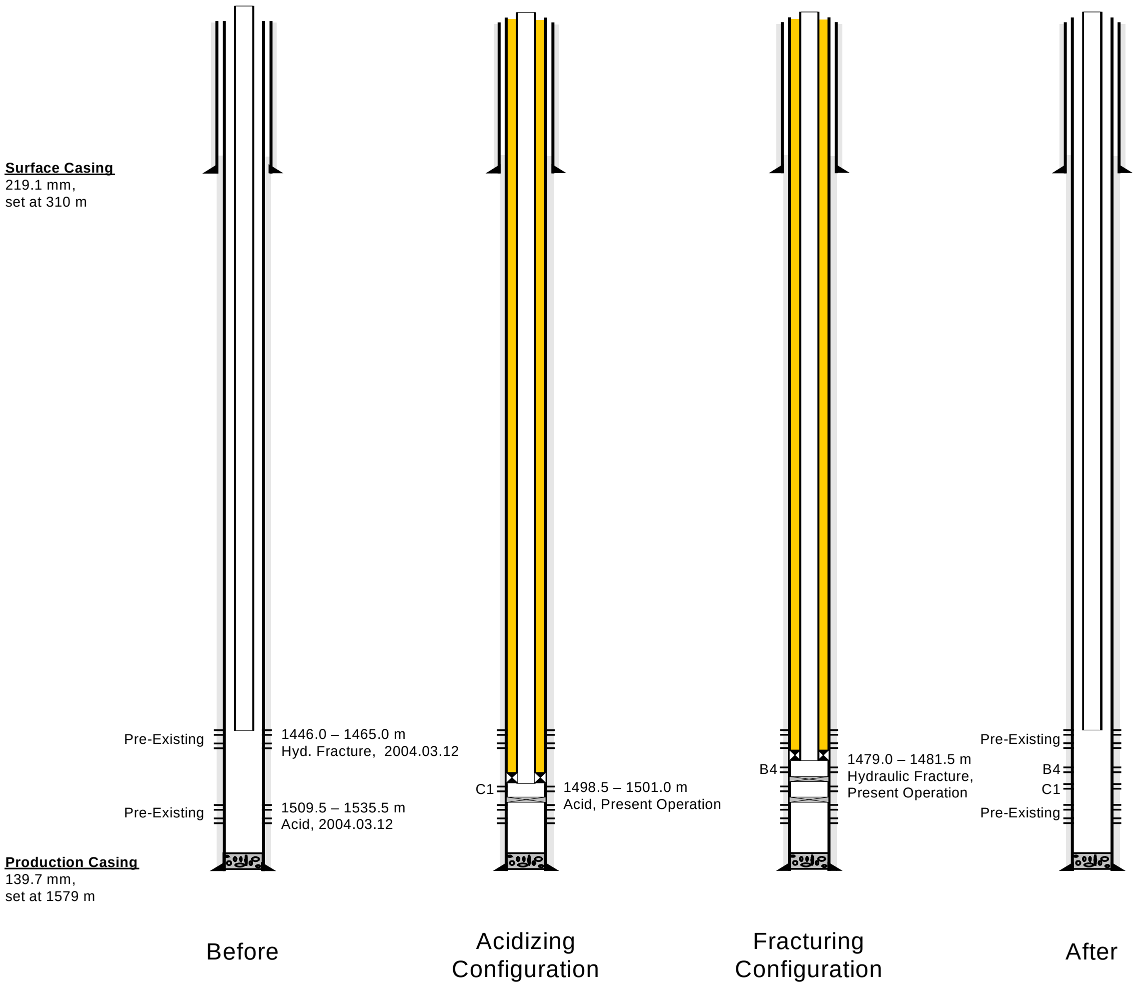

Fig. 4 – Case 2a - Two zones were added, acidized and hydraulically fractured within the existing completion intervals.

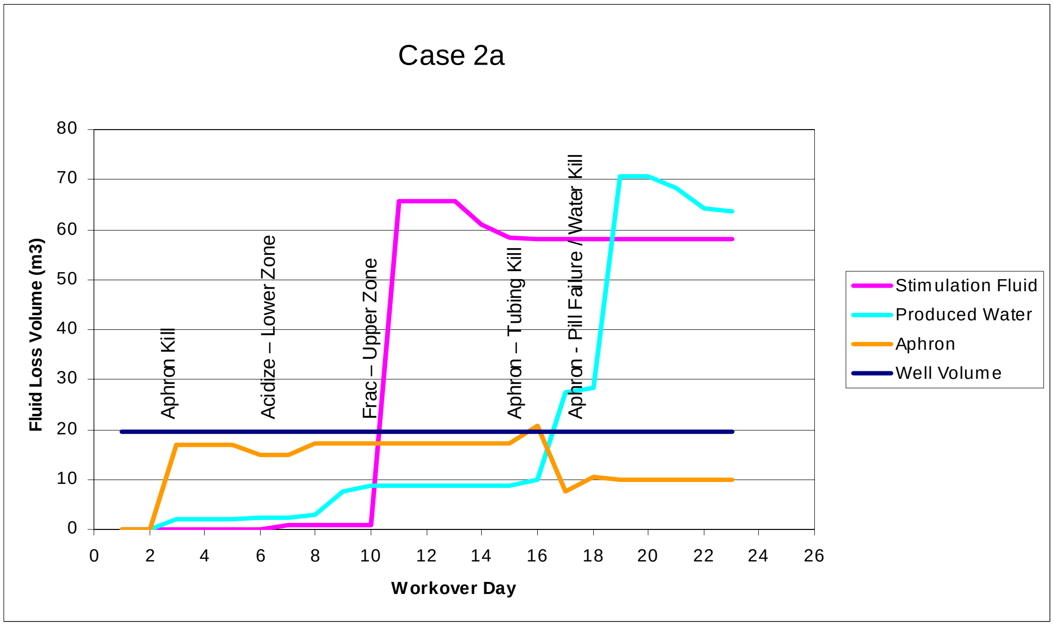

Fig. 5 – Fluid losses are noted by fluid type during the workover operations.

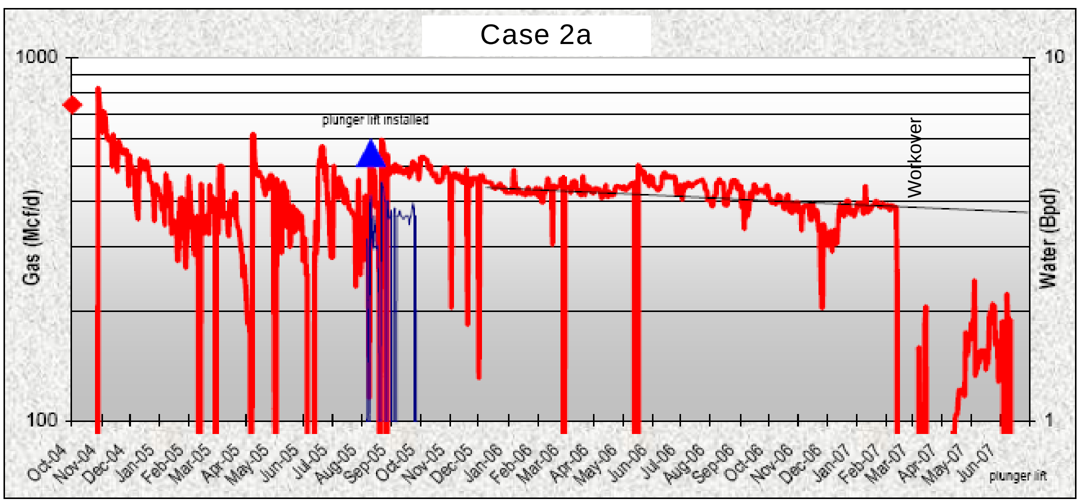

Fig. 6 – Well production pre and post workover.

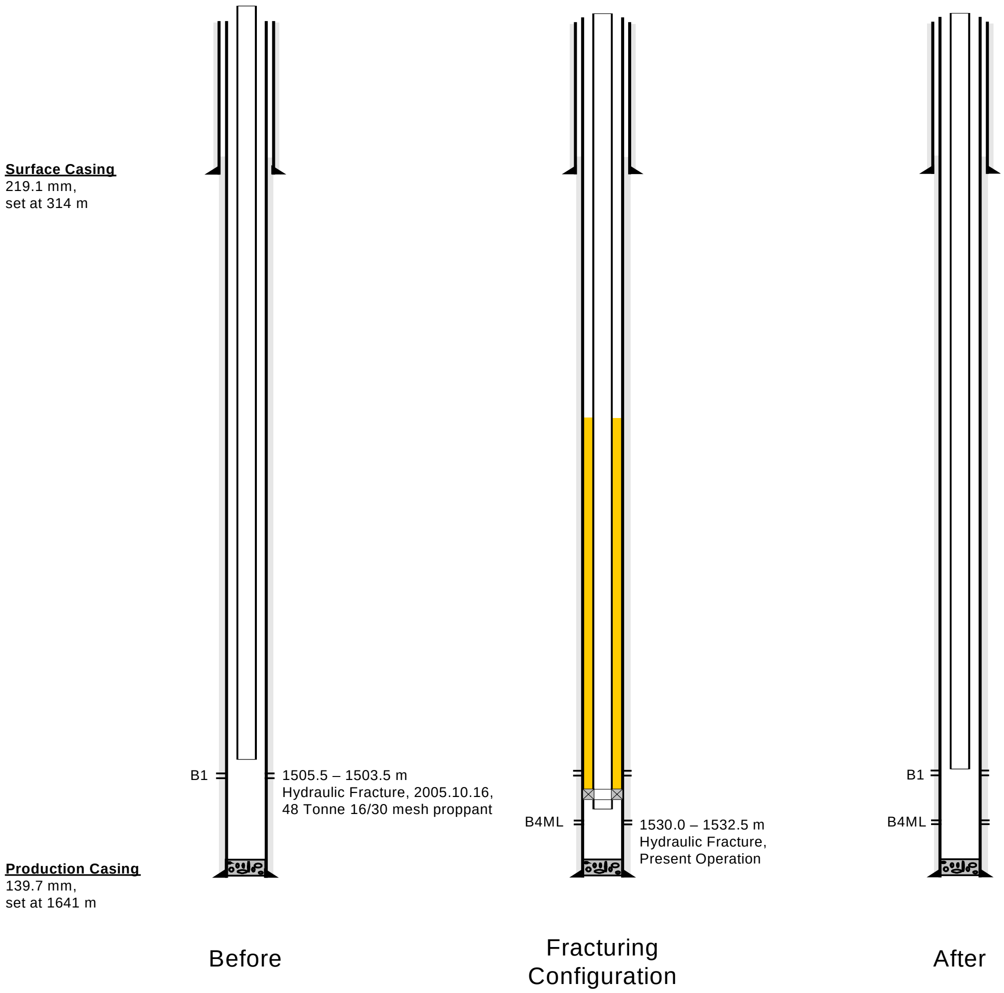

Fig. 7 – Case 2b - A single zone was added and hydraulically fractured below an existing completion.

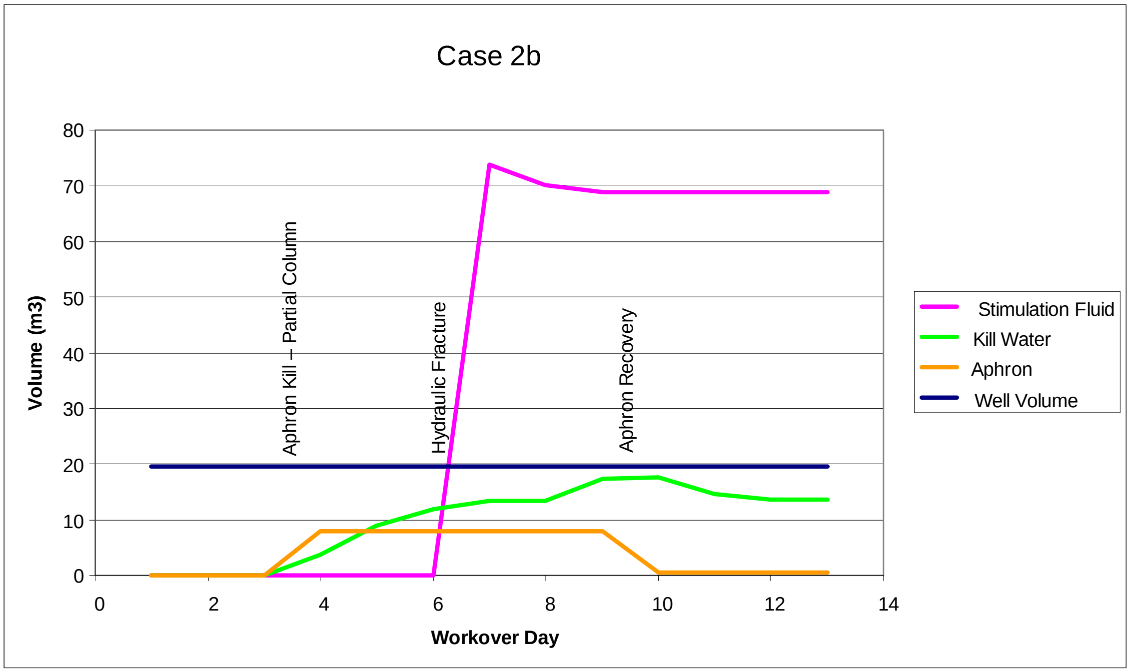

Fig. 8 – Fluid losses are noted by fluid type during the workover operations. A partial column of Aphron workover fluid was used to kill the well. All Aphron fluid was recovered from the well during this operation.

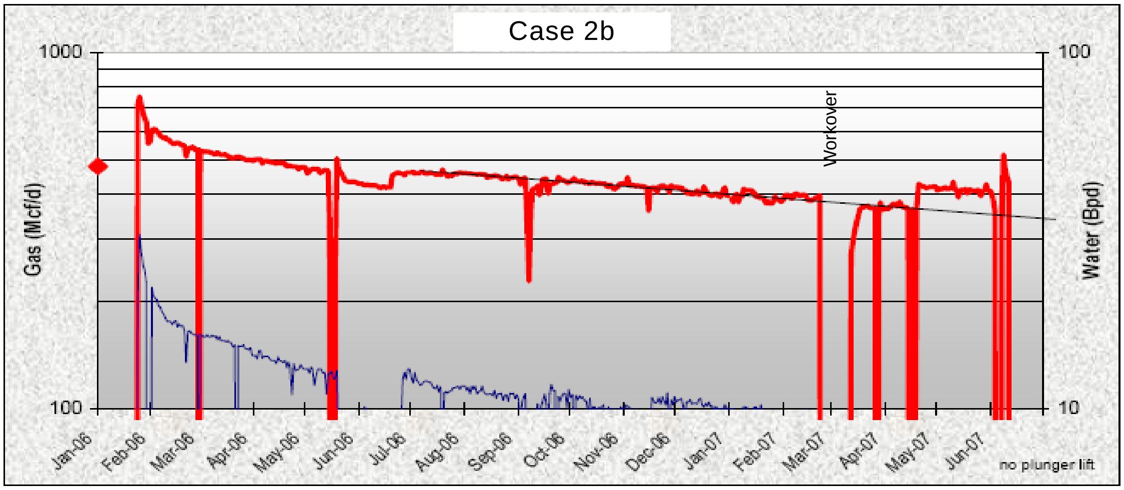

Fig. 9 – Well production pre and post workover.

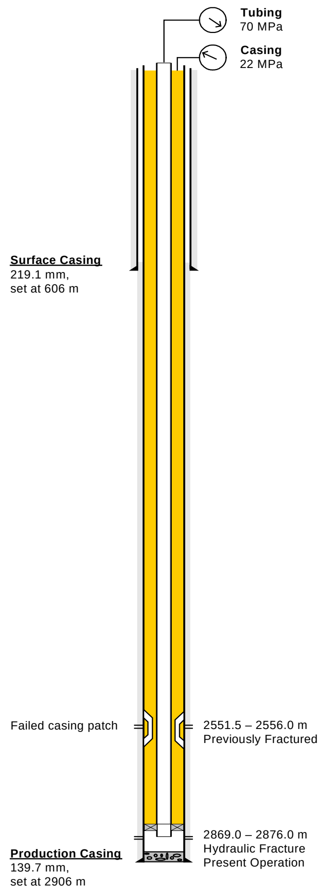

Fig. 10 – Case 3a – A single zone was re-perforated and re-fractured below an existing hydraulically fractured completion interval. Aphron workover fluid was used after a temporary casing patch twice failed to set across the shallower interval.

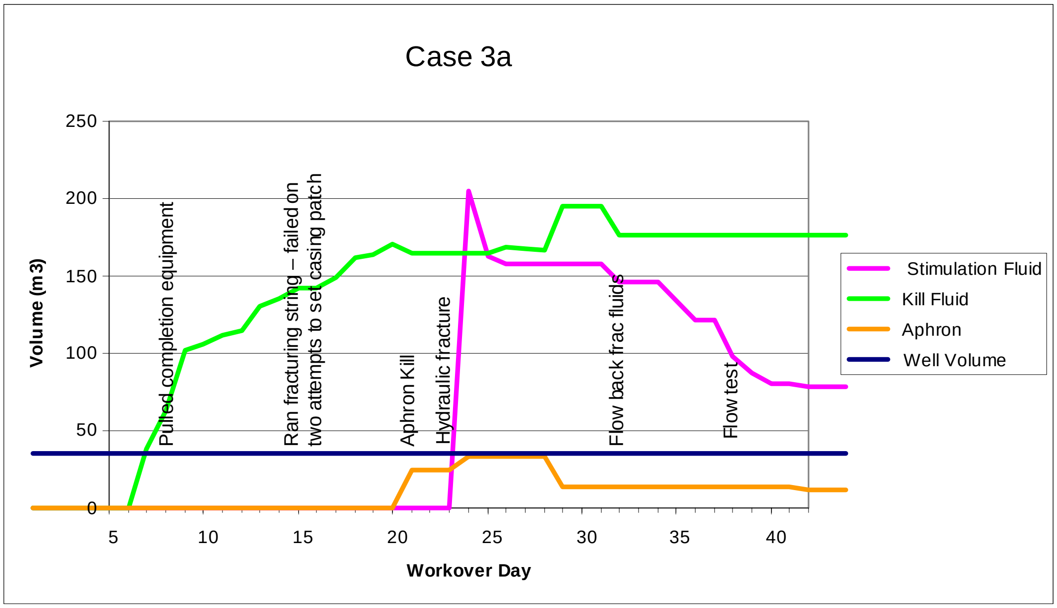

Fig. 11 – Workover fluid losses are graphed by fluid type. High workover fluid losses were incurred until the well was circulated over to an Aphron workover fluid.

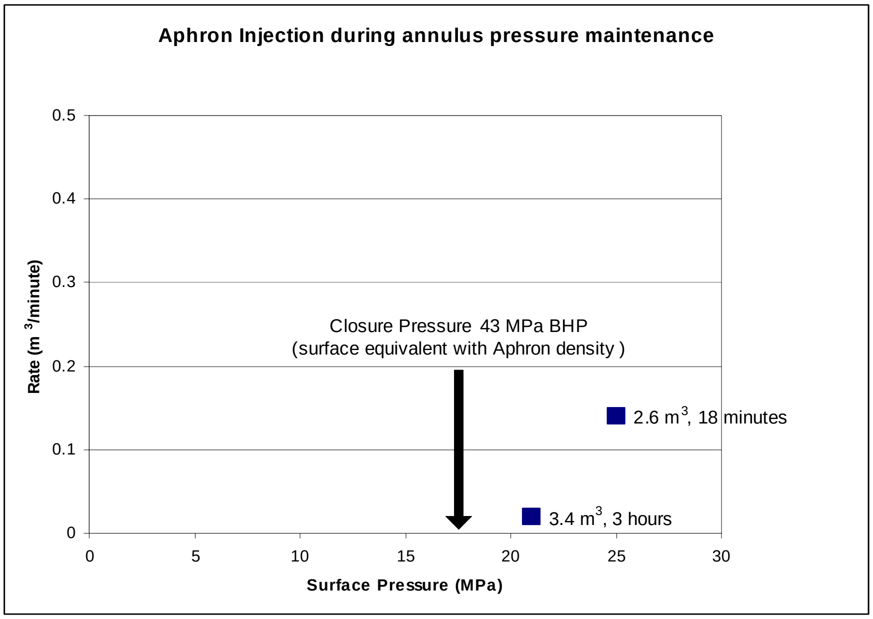

Fig. 12 – These annulus injection pressure observations suggest that the Aphron fluid provided an effective seal up to the previously observed fracturing pressure of the upper interval. Injection volumes and durations are noted.