Chapter

Experimental Setup for Swellable Elastomers in Cased and Open Holes

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> *It is an essential characteristic of experimentation that it is carried out with limited resources, and an essential part of the subject of experimental design is to ascertain how these should be best applied; or, in particular, to which causes of disturbance care should be given, and which ought to be deliberately ignored.*
>
> *Sir Ronald A Fisher*

Abstract

A full scale experimental setup was designed and commissioned for testing of swelling elastomer seals against a casing (cased hole) and formation (open hole). Actual replicate of wellbore was designed with varying inside diameters and roughness to reproduce the effect of actual formation. The Dynaset packer mounted on a 7-inch tubular was allowed to swell against a 9–5/8-inch casing, while the fast swell packer mounted on a 9–5/8-inch tubular was allowed to swell against the 12–1/4-inch replicated well bore. This one-of-its-kind test setup can demonstrate the way the elastomers swell out and fill the asperities against smooth outer casing (cased hole) or against rough wellbore surface (open hole). Dismantling of the test setup midway through the testing scheme revealed a severely dimpled surface of the swelled elastomer.

Keywords: demonstration setup, elastomer swelling, cased hole, open hole

1. Introduction

In the petroleum industry, packers refer to the components/products which are used to isolate one section in a formation from others, or to isolate the outer section of a production tubing from the inner section, which may be a casing or liner or well-bore itself [1]. They are also called *mechanical packers* because they remain in an oil well during its production life, and are set by some form of tubing movement. In a typical well, a packer is installed close to the bottom end of the production line, just above the top perforations [2]. If a well is connected to multiple reservoir zones, then it is also used to isolate the perforations for each zone. It may also be used to isolate sections of corroded casing, casing perforations, casing protection from undesirable fluids, and complete shut-off of high water cut-off zones. These production packers are further classified into *permanent* or *retrievable* packers [3]. Permanent packers are low in cost and provide better seal, while retrievable packers are expensive but re-usable after repair, and have lower sealing capability [4, 5].

Temperature and pressure can cause changes in the expansion rate of production tubing and packer leading to the development of tensile or compressive or no force conditions [6].

Till the innovative use of swellable elastomers, the most commonly used packers were the ones mentioned above. A swellable packer is much simpler than a mechanical packer because there are no moving parts and it requires no special services. Like a casing, the swellable packers are lowered to the desired depth and allowed to swell before production or injection operations begin [7]. These elastomers swell when they come in contact with different types of fluids and are categorized based on the fluid, such as oil-based swellable elastomer, saline-water based swellable elastomer, etc. The swelling amount of such elastomer depends on the fluid chemistry and the temperature at swell. Typically, the elastomers are vulcanized on a pipe to make a swellable packer. When it comes in contact with a fluid, it starts to swell. The swelling continues until the internal stresses inside the elastomer reach equilibrium, and creates a differentially sealing annular barrier, hence completing the sealing [8].

In field applications, different types of swellable elastomers are used at different depths of the same well, or in different wells. Extensive amount of research has been carried out for material and mechanical characterization of swellable elastomers in its virgin or vulcanized form as well as in bore-hole conditions. The characterizations had been done for some of the elastomers under different conditions of temperature and salinity, using laboratory-size elastomer samples [9–12]. However, the uncertainty remains about the effectiveness of actual sealing done by the swellable packers. Is the packer really effective in terms of providing the needed pressure to keep the unwanted fluid away from seeping into the production tubing? Do these swellables completely cover the random profile of formation in open bore-holes or the roughness of a casing in cased holes? However, no tests have been carried out yet in a replication of the real oilfield scenario: elastomer seals mounted on tubulars in cased or open holes, with or without cementing. This chapter explains the performance of a mix of swellables under these scenarios through the development of an experimental demonstration unit.

This demonstration unit is designed and fabricated using inert and swelling elastomer seals mounted on actual petroleum pipes/tubulars, and housed in a concrete block replicating the open-hole and a casing replicating the cased-hole. The inner-most pipe is a swell packer comprising inert and swelling elastomer segments sealing against a casing pipe, which in turn uses another set of swelling elastomers to seal against the formation, in the form of a concrete block with layers of varying roughness as would be the case in a real formation [13].

The main objectives of this demonstration-cum-test unit were:

a. Life-size demonstration of how a swelling elastomer packer provides sealing against the formation in a well hole.

b. Life-size demonstration of how a swelling elastomer packer provides sealing against a casing in a well hole.

c. Testing the actual behavior of fast-swell elastomer (E1) in near-ambient conditions in a shallow aquifer.

d. Testing the actual behavior of a swell packer elastomer (E2) in near ambient conditions in a shallow aquifer.

e. Testing and demonstration of whether swelling elastomers completely seal off irregular boreholes and geometrical aberrations.

2. Design of experimental unit

Many possible designs were considered for this experimental unit. The following set of criteria reduced the possible designs to only a few:

a. The experimental unit must replicate the formation roughness of typical on-shore oil-field as closely as possible.

b. The casing, production tubing, and swell packers (along with the spacing between these) had to be the same as used in an actual oil-well.

c. The spacing between open-hole and packer, and cased-hole and packer must be filled with fluids that are compatible to specifications of the swellable elastomers used.

d. Swelling behavior of the elastomer must be clearly visible and recordable during the swelling process.

e. The experimental unit must be able to de-swell the elastomer after complete swelling and re-swell again to see the effect of the swell/de-swell/re-swell cycle.

Based on the above criteria, the final design consisted of a half (cutaway) concrete block replicating the formation. Symmetrically cutaway sections of two concentric swell packers were housed inside this concrete half-block. The sealing elements between the two packers and between the outer casing and formation (concrete) were actual inert and swelling elastomers. The semi-circular cavity in the concrete block was to have slight variations in diameter and roughness to reproduce realistic formation conditions. The setup was to be enclosed from the top and

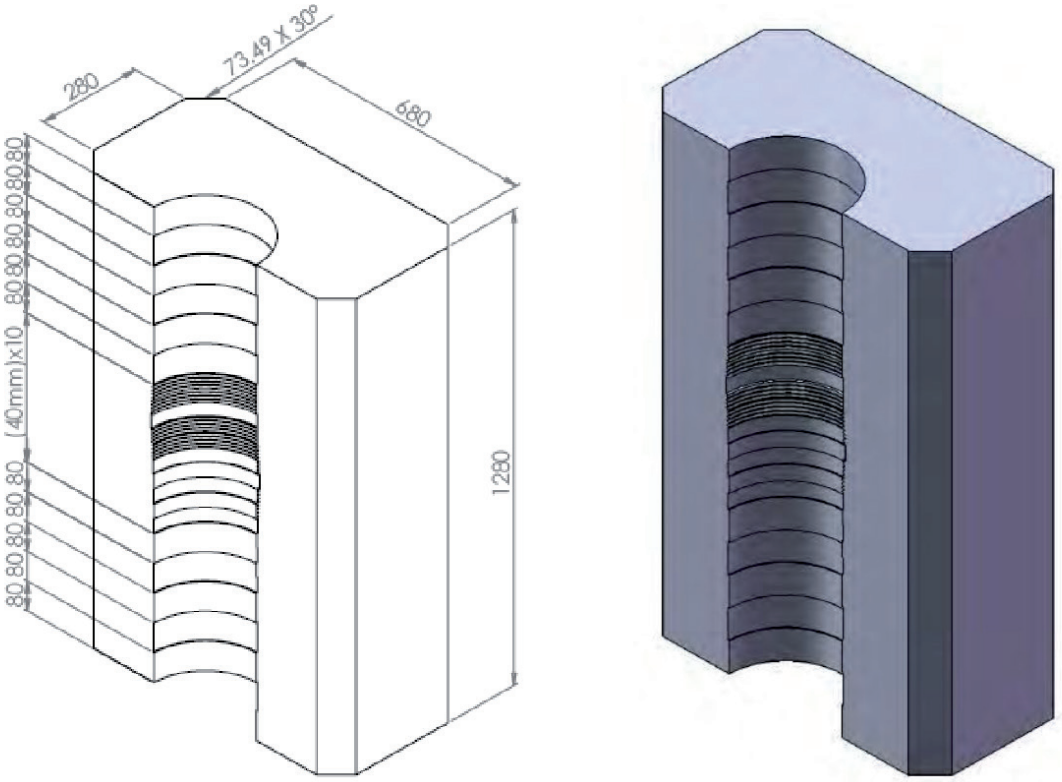

Figure 1.
Concrete block with layers of different roughness to replicate formation geometry.

front with high-strength plexi-glass, to be able to withstand high pressures, and to provide a clear view of the internal arrangement and swelling behavior. The final configuration of the experimental unit is shown in **Figures 1** and **2**.

Major specifications of the final design include the following: Concrete half-block: height 1280 mm; width 827 mm; thickness 427 mm. Semicircular hole in concrete half-block consisting of 80 mm deep sections of varying roughness. Diameter of semicircular hole varying from 311 to 320 mm as per an actual oil-well. Inside packer consisted of two elastomer segments of inert and swellable type; elastomer on 177.8 mm tubular swells against 244.475 mm casing. Outside packer consisted of fast-swell elastomer mounted on 244.475 mm casing that swells against 311.5 mm formation (concrete block). Test conditions included fresh water with almost no salinity, ambient temperature of about 20-degree Celsius, and atmospheric pressure (representing shallow aquifers in actual oil wells).

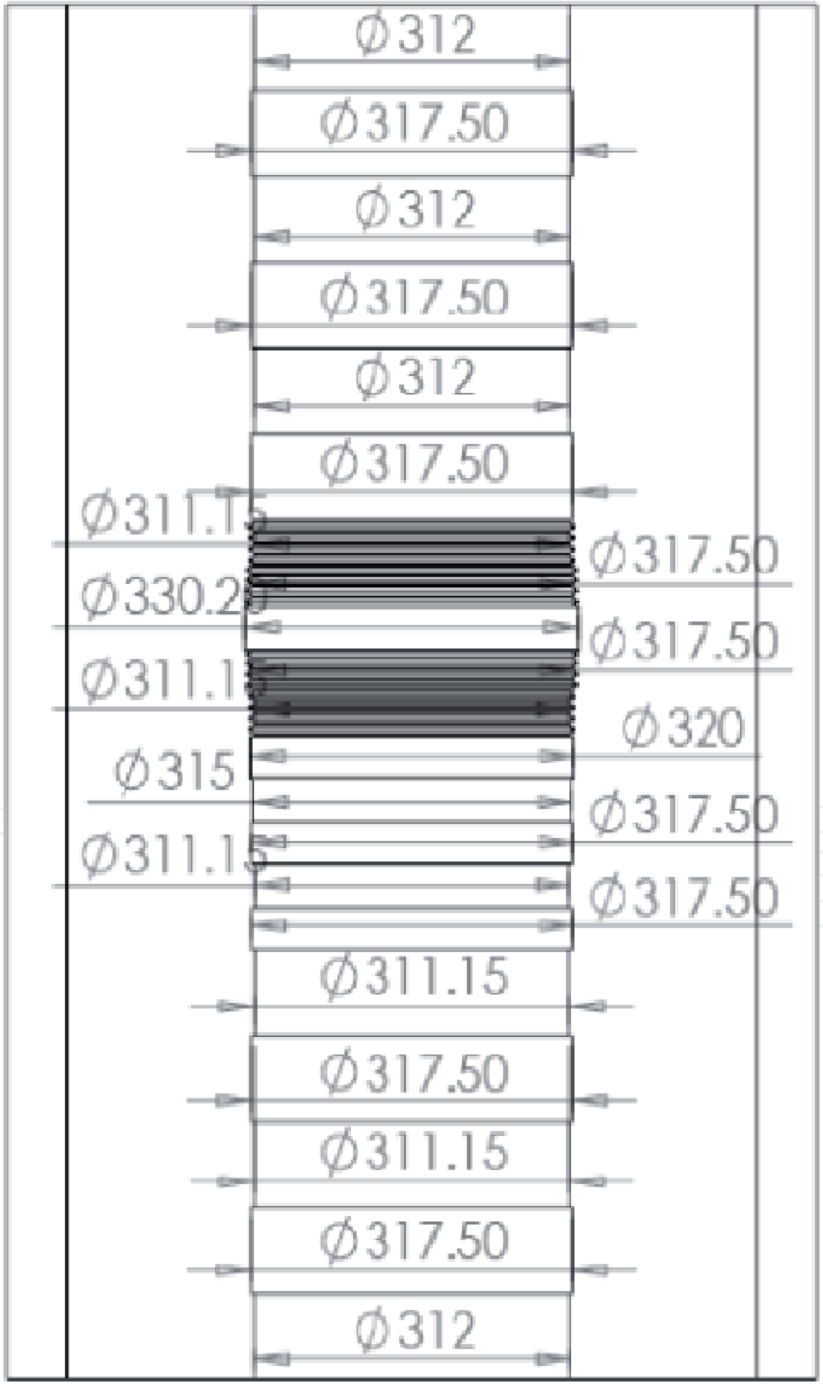

Figure 2.
Different diameters and roughnesses to replicate variations in the drilled formation.

3. Fabrication/assembly of experimental unit

In consultation with oilfield engineers, and following the recommendations of concrete requirement for oil-well cementing jobs, a special concrete mixture was prepared to provide sufficient strength, durability and relatively quick curing time. In order to develop different inside diameters and sections of varying roughness, polystyrene layer of sufficient thickness was mounted on a cylindrical column of a wood pattern. The varying diameters and surface roughness for each diameter were carefully generated on the polystyrene using a long-bed lathe machine. This wood-polystyrene unit was then cut longitudinally into two parts. With this half-cylinder forming a core, the concrete half-block was formed by pouring the special concrete mixture into an already prepared large wooden pattern. After proper curing of the concrete, the wooden pattern was disassembled, the polystyrene core was completely removed, and the block was carefully cleaned. The process is summarized in **Figures 3** and **4**. A close-up view showing the variation of diameter and roughness in the concrete half-block are presented in **Figure 5**. The inside and outside packers were also precision-cut into two longitudinal halves as shown in **Figures 6** and **7**. The tubulars and packers were carefully positioned and fitted inside the concrete half-block, and the assembly was then fitted with plexi-glass front and top walls. A hook-type lifting mechanism was fixed onto the top (**Figures 8** and **9**) to move the full assembly from one place to the other, using overhead crane or other moving/lifting equipment.

The most challenging design task of this experimental unit was to make it leak-proof. Although many common techniques were available, it had to be guaranteed that it will remain leak-proof even after substantial swelling of elastomers, which can exert enormous pressures. A detailed comparative study was carried out about all available varieties of weather-shield paints, and their merits and demerits, but all had to be discarded due to pressure sustainability requirements. Finally, a carefully selected epoxy coating was smeared onto the walls before the plexi-glass sheets were bolted into position. The torque applied on to the bolts fastening the

Figure 3.
Concreting of the half-block with polystyrene half-cylinder carefully placed inside; and curing of the assembly.

Figure 4.
Removing of polystyrene core (left); final shape of the setup with varying roughness and hole diameter (right).

Figure 5.
Close-up showing variation of diameter and roughness in the concrete half-block.

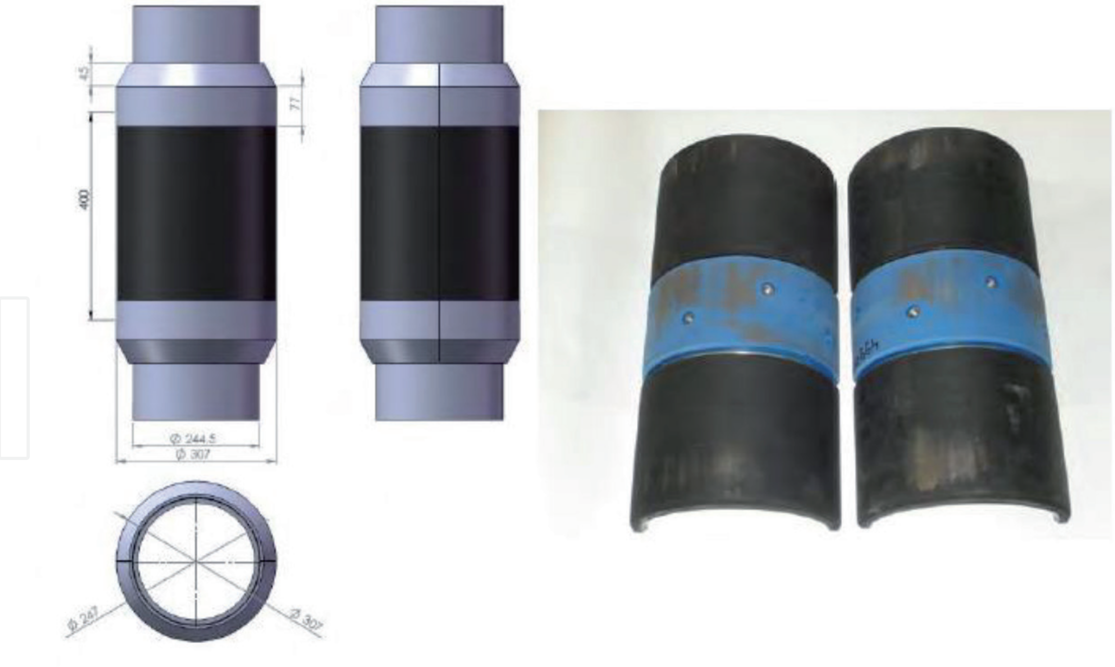

Figure 6.
Dimensions and cut-away sections of the swell packer.

Figure 7.
Half portions of inside swell packer and pipe (left); inside and outside swell packers fitted on respective pipes (right).

plexi-glass and concrete block were calculated using standard procedure outlined in design of fasteners [14]. Similarly, to make it water proof, a combination of Tank Guard 1 and 2 paints from Jotun Marine Paints Division was used so that the concrete half-block could remain water-proof even when submerged with water from the inside for years of use.

At the end, designed-for-purpose screw was removed from the top, unit was filled up with water through a small funnel, and the screws were retightened. An automatic camera was set up on a tripod, focusing on the swelling elastomer region to periodically

Figure 8.
Fitting of the tubular in the concrete block, together with the lifting arrangement (left); fixing of the plexi-glass front wall (right).

Figure 9.
Assembled setup with inner and outer packers, plexi-glass front and top walls, and lifting arrangement.

record the swelling process using its advanced time-step programming module. Manual photographic and video recording was also done at fixed time intervals.

4. Results and discussion

After observing and monitoring the swelling behavior of the packers for a few days, it was found that the steel tubulars and screws/bolts exposed to water had started to corrode. This would have only a minor effect on swelling, but the rust particles diffused into the water and visibility reduced drastically after more corrosion took place as shown in **Figure 10**. To remedy this problem, the water was siphoned off using a portable pump, and the rust stains and particles were vigorously cleaned. This flushing-cleaning of the unit improved the visibility significantly (**Figure 11**). Under actual shallow-aquifer field conditions of around 50 degrees Celsius temperature and 0.5% salinity, 70% swelling had been predicted for the outer packer (elastomer E1) in six hours during swelling tests conducted on laboratory size samples [9, 10], confirming its fast swell character. Fresh water used in test unit behaves almost the same in terms of salinity as the 0.5% brine solution, so this field condition was almost replicated. However, the unit being kept in an air-conditioned lab meant that the test temperature was nearly 20 degrees Celsius, a large difference from the field temperature, which definitely reduced the swelling rate of the elastomer by a significant percent. Also, the packer in the test unit could swell only in the outward direction, and was swelling against a concrete hole of varying diameter and roughness, markedly different from lab-size elastomer samples swelling freely on all sides. It was thus no surprise that it took more than 10 days for the elastomer to fill the irregular cavities in the concrete half-block.

The inside swell packer (E2) was intended for an application with salinity ranging from 12–18%, and working temperature environment of 40 degrees to 90 degrees Celsius environments. This test unit could be classified as a low-salinity and medium-temperature setting. According to earlier lab tests [9, 10], it was estimated to reach 70% swelling in 3 to 4 weeks. This was not too far off as it took the inner swell packer almost 5 weeks to swell against the casing, even though the salinity and temperature conditions were different. There was apprehension about the behavior of this elastomer under fresh water. However, it remained glued firmly to the tubular. **Figures 12** and **13** give an idea of the behavior of fast-swell and inside swell packers before exposure to water, and at different stages after being in contact with water.

There were intermittent leakages from the sides or the bottom, particularly at the interface between plexi-glass and the concrete block or casing or production

Figure 10.
Assembled unit after initial water fill-up (left); rust stains after 8 days of water exposure (right).

Figure 11.
Flushing and cleaning of the unit (left); water fill-up after flushing (right).

Figure 12.
Elastomer seals before exposure to water (left), and after near-complete swelling of the outer packer (right); inner packer has only partially expanded.

tubing. Most of these leakages were completely stopped by applying more torque on the bolts, thus increasing the tightness between the front-end plexi-glass to the concrete block. Also, tubulars and bolts started to rust again after a few weeks, reducing the visibility once more. Periodic flushing-cleaning would not be a good solution if the unit were to be used for long-term duration. It was thus decided to dismantle the entire system for a major unit overhaul.

Figure 13.
Near-complete swelling of the outer elastomer seals against cavities of varying diameter and roughness.

Figure 14.
Demonstration-test unit after disassembly, flushing and cleaning, repainting of different components, and reassembly; partial de-swelling can be observed.

Before disassembling the unit, research was again conducted about the most suitable water-shield paints for steels. Water was drained out from the unit, and it was moved back to the laboratory as quickly as possible, to maintain the same environment as before in order to avoid significant de-swelling of the elastomers. The complete unit was disassembled and thoroughly cleaned using wipes and different grades of sand and emery paper. Some steel bolts were replaced by non-corroding brass ones. Insides

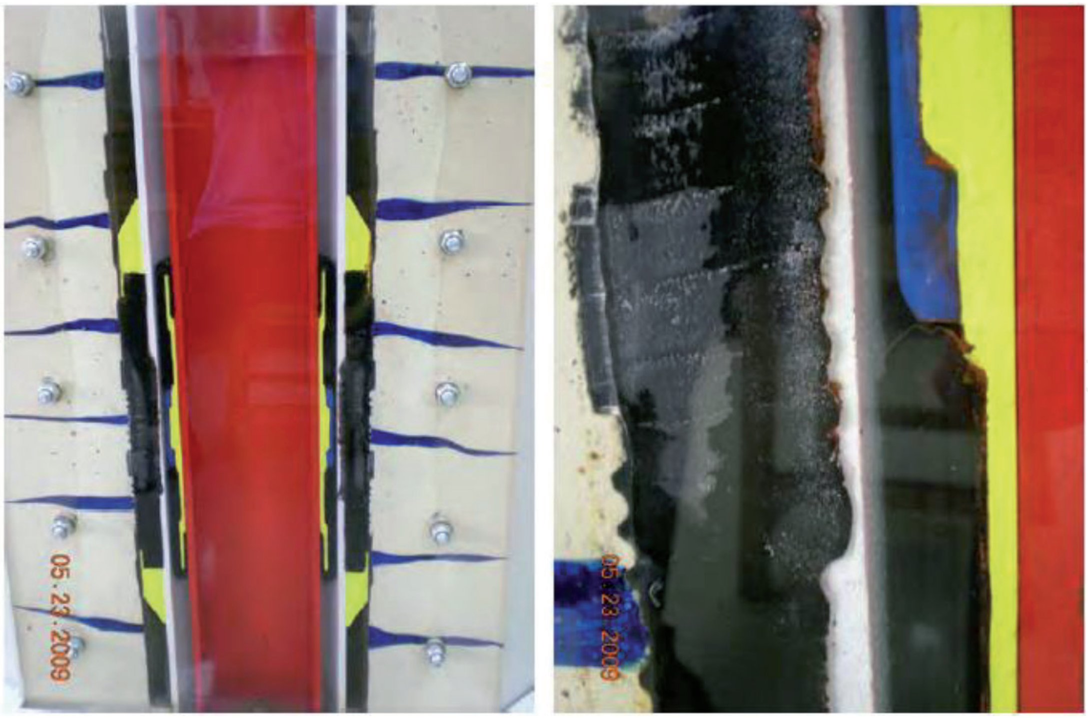

Figure 15.
Re-swelling of the elastomer seals after disassembly, reassembly and water re-fill.

Figure 16.
Experimental unit after one year of re-swell showing the swelling durability.

Figure 17.
Pictures of the elastomer surface that swells against formation (concrete block), after swelling and partial de-swelling.

of the concrete block were repainted with appropriate layers of tank-guard protection. Tubulars and exposed bolts were painted with red oxide primer and weather-shield coatings of different colors, for rust-protection as well as improved identification of different parts. Fresh epoxy coating was applied to the concrete front-wall before fixing the plexi-glass sheets. However, with all such measures, a small amount of de-swelling had taken place during the overhaul process of the experimental unit.

Once assembled and filled again with water, the two swell packers started to swell again as shown in **Figures 14** and **15**. Long-term contact of packers and concrete and metal elements to standing water without any flushing could pose another serious problem. Algae and other biological growth can crop up in the water over time. This can have unseen effects on the swelling setup, and can again reduce the visibility to very low levels. In order to alleviate this problem, a chemical was identified that inhibits bacterial and other biological growth in standing water. When water was filled into the reassembled unit, this chemical was added to the water in measured quantity. With the help of these modifications/improvements, the system exhibited improved visibility and no leakage even after several months of continuous water exposure as shown in **Figure 16**.

Dismantling the system gave a great unexpected benefit. Generally, no one has a clear idea of how the elastomer looks after swelling against the casing or the formation. However, as the system was disassembled, there was a chance to have a close look at the elastomer surface that was swelling against the concrete block. **Figure 17** displays extremely interesting and unique photographs of the almost brain-like elastomer surface that is pressed against the concrete block due to swelling. Further investigation of this behavior could reveal interesting physical phenomena responsible for this pattern after swelling and partial de-swelling of elastomers in general, and of these specific types of elastomers in particular.

5. Conclusions

An experimental-cum-demonstration unit was designed, fabricated and assembled for testing of swelling elastomer seals against a casing (cased hole), and against the rock formation (open hole). A concrete half-block with a semicircular hole was designed and fabricated with varying inside diameters and surface roughness to reproduce the effect of actual formation, with front and top walls made of plexiglass for clear visibility. Smaller packer on 177.8 mm inner diameter steel tubular had to swell against a 244.475 mm casing, while the larger diameter swell packer (fast swell elastomer) on the casing had to swell on 311.15 diameter of formation represented by the concrete block. Given the difference in field and test conditions (0.5% salinity water at 50 degrees Celsius, against fresh water at 20 degrees' Celsius ambient temperature), 70% swelling results were very reasonable. The fast swell packer took about 10 days, while the other swell packer took around 5 weeks to completely fill all irregular surfaces. Modifications and improvements were carried out on the unit to make it reliably water-proof and leak-proof, and to improve and maintain the visibility. This experimental unit also a one of its kind demonstration unit, reproducing the behavior of swell packers in cased and open holes, and providing visual confirmation to the field engineers of the swelling of elastomer seals against casing and formation.

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