Chapter

Long-Term Integrity Testing of Water-Swelling and Oil-Swelling Packers

Sayyad Zahid Qamar, Maaz Akhtar and Tasneem Pervez

> *An experiment is never a failure solely because it fails to achieve predicted results. An experiment is a failure only when it also fails adequately to test the hypothesis in question, when the data it produces do not prove anything one way or another.*
>
> *Robert Pirsig*

Abstract

As easy oil in many fields is dwindling, there is increasing stress worldwide on innovative enhanced oil recovery (EOR) techniques. One forward-looking EOR approach is the workover method. It tries to convert currently weak horizontal wells to maximum reservoir contact (MRC) wells, or abandoned vertical wells to horizontal ones or power water injectors. Where conventional techniques fail, swelling elastomer seals and packers provide effective water shutoff and zonal isolation in even very complex environments, resulting in significant savings in rig time and development cost. One major issue of interest is the service life of elastomer seals and packers. It can be attempted to predict the probable working life based on the theory of accelerated testing. However, this forecast will not be very dependable for swelling elastomers as the material performance is substantially different from other rubber-type polymers. A full-scale test rig (one of its kind in the world) was therefore designed and fabricated at Sultan Qaboos University (SQU), in collaboration with a regional petroleum development company, for long-term service life assessment of actual full-size water-swelling and oil-swelling packers.

Keywords: Swell packers, in-situ longevity testing, water-swelling, oil-swelling

1. Introduction

As easy oil in many fields is dwindling, there is increasing stress worldwide on innovative enhanced oil recovery (EOR) techniques [1–6]. One forward-looking EOR approach is the workover method. It tries to convert currently weak horizontal wells to maximum reservoir contact (MRC) wells, or abandoned vertical wells to horizontal ones or power water injectors [7, 8]. This is done to maximize well production and to achieve total oil recovery. This requires the placement of smart systems in the well for controlling of flow from each lateral. This type of zonal isolation is built around expandable liners and swell packers.

Intelligent and multilateral wells form another strategy for maximum hydrocarbon recovery. Efficient zonal isolation and reservoir compartmentalization are the keys to success for these well systems. Where conventional techniques fail, swelling elastomer seals and packers provide effective water shutoff and zonal isolation in even very complex environments, resulting in significant savings in rig time and development cost [9]. One major issue of interest is the service life of elastomer seals and packers [10, 11]. As yet, no data is available from service providers, designers, or manufacturers about the durability or long-term endurance of swell packers under actual well conditions. It can be attempted to predict the probable working life based on the theory of accelerated testing [12]. However, this forecast will not be very dependable for swelling elastomers as the material performance is substantially different from other rubber-type polymers. A full-scale test rig (one of its kind in the world) was therefore designed and fabricated at Sultan Qaboos University (SQU), in collaboration with a regional petroleum development company, for long-term service life assessment of actual full-size water-swelling and oil-swelling packers [13].

These packers are of different elastomer materials, kept in crude oil and saline solutions at different temperatures, and exposed to high pressures. The design process went through the typical stages of specifications development, concept design and evaluation, detail design, and assessment for reliability and manufacturability. The test setup was built around some important modules: thermal system with capability of maintaining elevated temperatures continuously over a 5-year period; recirculation system to keep salinity at the requisite level; arrangement to pressurize the packers after sealing has been achieved through elastomer swelling, and maintaining it for several years; and a complex system for temperature and pressure measurement on both upstream and downstream sections in all packers. This unique long-term reliability assessment study is expected to provide helpful pointers to field engineers and application designers in appropriate selection of swell packers and in packer design enhancement.

2. Specifications

Published literature and information from vendor websites were critically reviewed. Focus was on works related to deployment of water-swelling and oil-swelling elastomers in oil and gas wells, new development and remediation efforts, and relevant well conditions (salt concentration of brine, type of crude oil, and in-situ temperature and pressure). After a series of discussions with local and regional field engineers, proposal for a test setup for long-term durability assessment of swell packers was agreed upon. Following were the key specifications. There will be ten units, including nine actual packers placed inside actual steel casings (as in real wells). One display unit will have a transparent Perspex outer pipe, so that internal details could be clearly seen which are not visible in the actual units because of the outer steel casings. Outer casings will be real 7-in steel tubulars. Packer nominal diameter will be 3½-in for four tubes, and 4½-in for the other five. Six units will have water-swelling elastomers, and 3 units will be of the oil-swelling type. Salt water solutions will be of two concentrations: 0.5% in two units, as in low-salinity wells; and 12% in four tubes, to represent high-salinity wells. Oil-swell packers will have actual crude oil from two different regional wells. Two test temperatures will be maintained: room temperature to typify shallow-aquifer type wells; and 50°C representing medium-depth wells. After sealing, four packers will be subjected to a pressure of 1000 psi, characteristic pressure range in many of the well types being studied. Tests will continue for a 5-year duration.

3. Test rig design

Several feasible concepts were developed, followed by thorough design evaluation. Significant features of the selected design are described in this section. A circulation system was needed to maintain water salinity at required levels; without it, salt would precipitate out and salinity would go down. Its main components were water heaters and containers, circulation pumps with control units, and circulation pipes. A thermal system was necessary to continually heat selected packers to 50°C for five years. It consisted of thermal blankets, insulation, control system, and temperature gauges. A pressurizing unit was needed to apply and maintain high pressure in the packers after sealing was achieved through swelling. Its critical components were a pressure-manifold (connected to all packers), high-pressure source, high-pressure pipes and connections, and pressure gauges. A monitoring system was required to observe temperatures and pressures in all units, between the packer and the casing, and inside the inner tube. A detection system had to be there to signal the completion of sealing in each packer, achieved by swelling of the elastomer against the outer casing. A second detection system was needed to indicate any seal failure (after seal completion). A sturdy frame was required as a support and housing for all the test and demo units. Concept evaluation was done using Pugh's basic decision matrix method. Overriding criteria were safety, reliability, and a minimum of 5-year service life. All components (including valves, fittings, and welded joints) were required to have a minimum rating of 100 bar pressure, to provide a safety blanket for the design pressure of 70 bar (about 1000 psi).

Figure 1 schematically shows the arrangement of the different test units. An identification number is assigned to each unit, and brief descriptions are

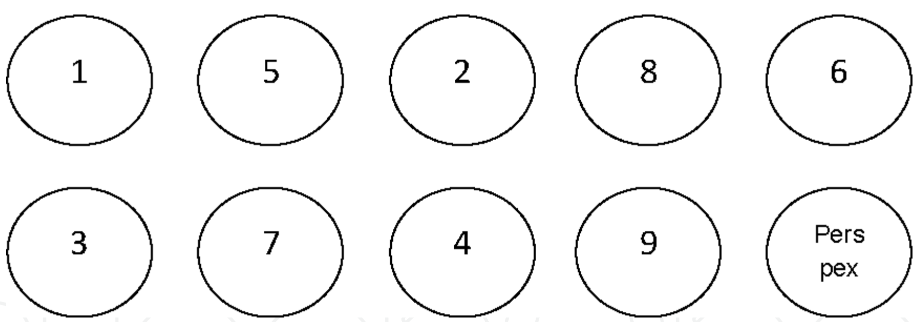

Figure 1.
Layout of the longevity test setup.

Unit #	Elastomer Type	Swelling Medium	Temperature	Unit #	Elastomer Type	Swelling Medium	Temperature
3½-in swell packer inside 7-in casing				**4½-in swell packer inside 7-in casing**			
1	W2	12% brine	Room temp	5	W2	12% brine	Room temp
2	O1	Crude oil	Room temp	6	O1	Crude oil	Room temp
3	W2	12% brine	50°C	7	W2	12% brine	50°C
4	O1	Crude oil	50°C	8	W1	0.5% brine	Room temp
Perspex demonstration unit				9	W1	0.5% brine	50°C
10	W1	—	Room temp				

Table 1.
Elements of the longevity test setup.

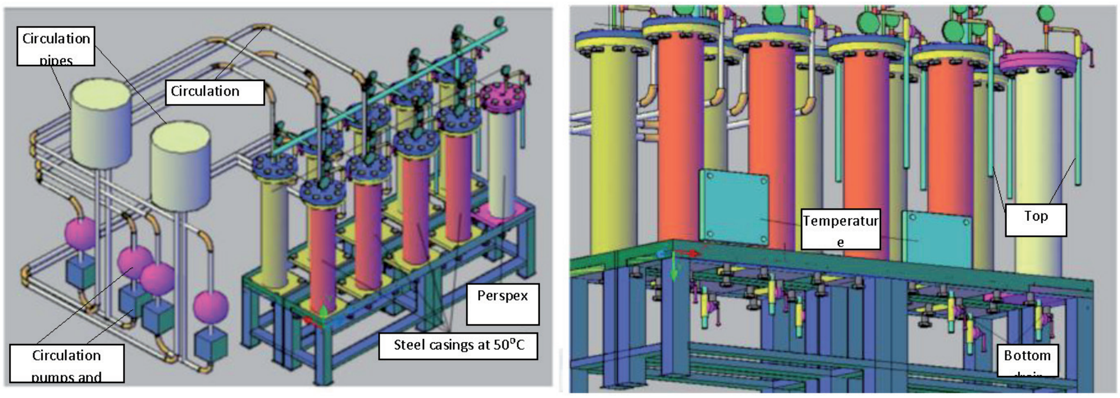

Figure 2.
Schematic diagram of the test facility showing test and demonstration units; circulation system (tanks, pipes, pumps, and controllers); thermal system and controllers; top and bottom drain systems.

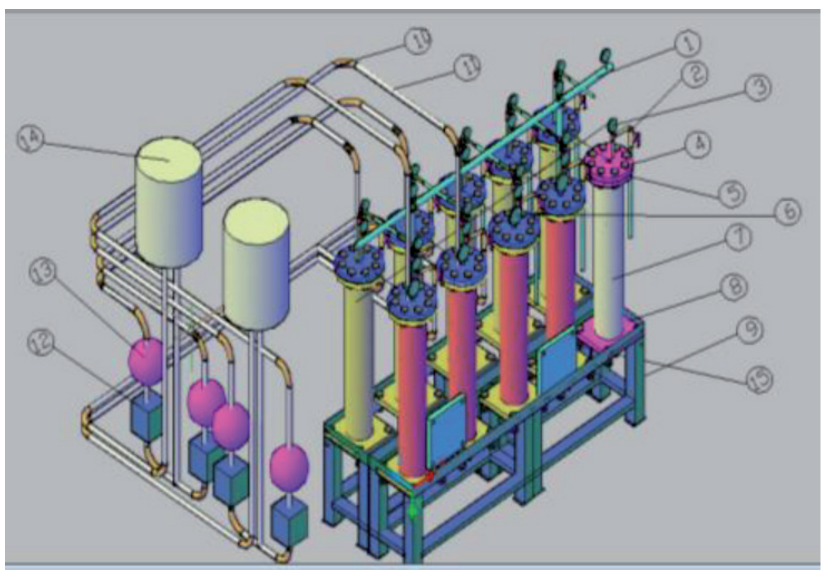

Figure 3.
Schematic assembly drawing of the longevity test setup. 1. Pressure manifold; 2. Drain system; 3. Pressure gauges; 4. Nuts and bolts; 5. Flanges; 6. Temperature gauges; 7. Casing tubulars; 8. Bottom plates; 9. Base frame; 10. Elbow joints; 11. Circulation pipes; 12. Circulation pump controllers; 13. Circulation pumps; 14. Water heaters/tanks; 15. Temperature controllers; 16. High pressure system; 17. Perspex demonstration unit.

summarized in **Table 1**. **Figures 2** and **3** are schematic drawings describing configuration and layout of all components of the test rig.

4. Fabrication and assembly

Swelling elastomer pipes and outer steel casings were provided by a regional petroleum development company. Elastomer sections were mounted on steel tubulars, different ones for low-salinity and high-salinity water, and crude oil; **Figure 4**. Sections of one-meter length were cut out from these tubulars, followed by sizing and trimming to get the swell packers and outer casings. Beveling was required for welding operations to be carried out at one end of the packers, and both ends on the casings; **Figure 4**.

Flanges, blind flanges, and bottom end plates were fabricated for the packers and the casings. Pitch circle bolt-holes (8 in number) had to be drilled in the flanges for joining the casings to the packers. Drilling of corner holes (4 in number) in the bottom plates was needed to fasten the casings to the base frame. Threaded holes

Figure 4.
Full-length elastomer tubulars (left); sizing and beveling of elastomer packers (right).

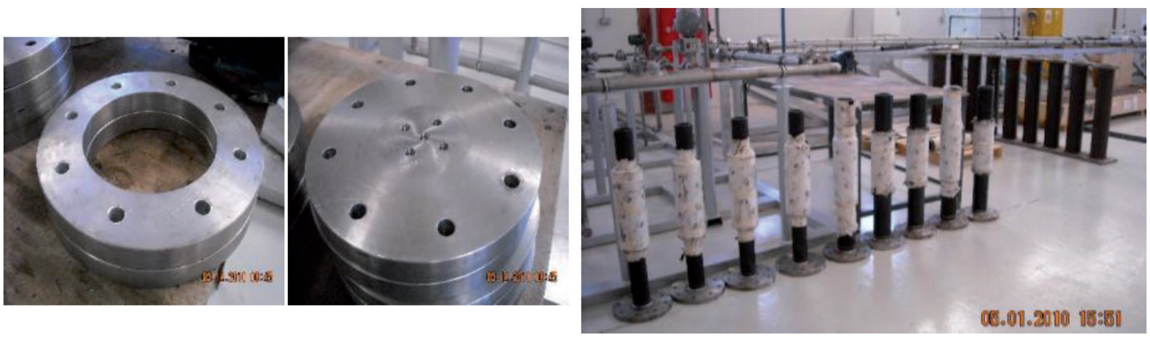

Figure 5.
Fabrication of flanges (left); welding of flanges and bottom plates to packers and casings.

Figure 6.
Fixing of drain valves to bottom plates (left); base frame to hold the test units (right).

Figure 7.
Fixing of casings to base frame (left); placement of packers inside casings (right).

(6 in number) with proper spacing were drilled in the top flanges to house the pressure and temperature gauges; **Figure 5**. Welding of top flanges and bottom plates to packers and casings completed this step of the assembly; **Figure 5**.

Each bottom plate had a single hole drilled in the center, to attach the drain valve. Drainage lines were fixed at the bottom of each unit, with stainless steel (SS)

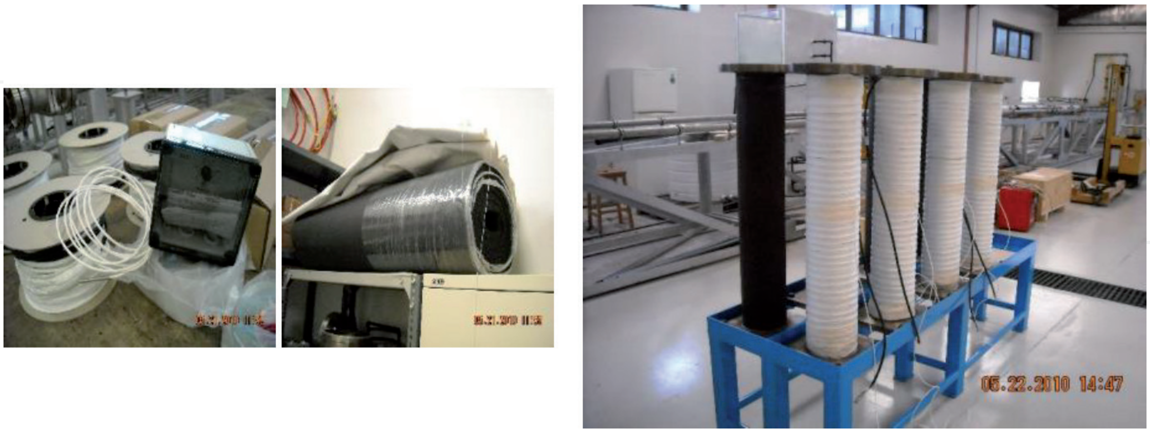

Figure 8.
Thermal system components (left); winding of thermal blankets on casings (right).

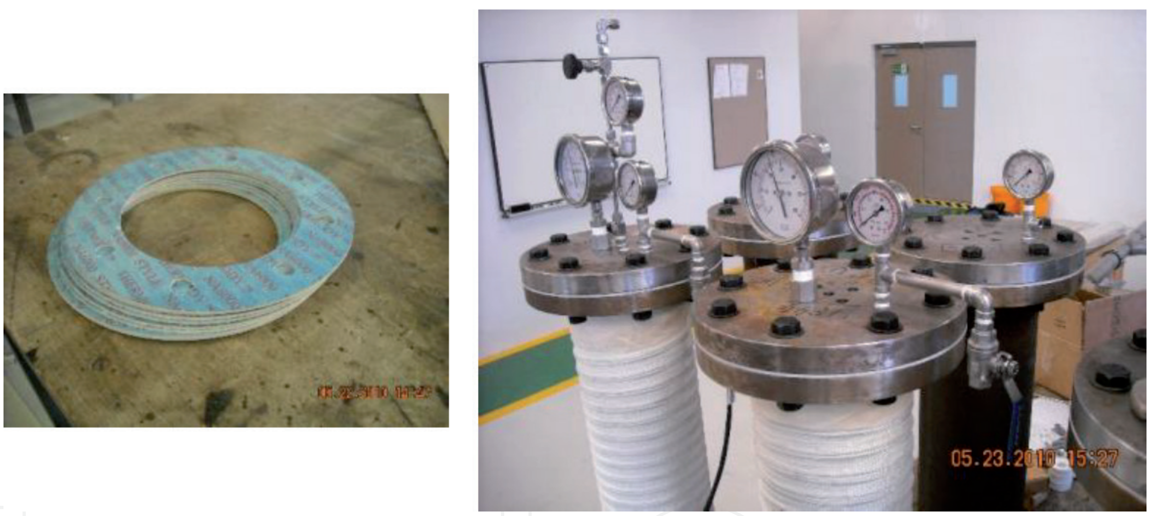

Figure 9.
High temperature–pressure gaskets (left); joining of packer and casing flanges, and fixing of pressure and temperature gauges (right).

Figure 10.
High-pressure manifold with connections to test un its (left); pressure regulator to control high pressure flow into the test units (right).

ball valves and plugs; **Figure 6**. Upper drainage lines were also fitted through the top flange of each of the ten units, together with SS high-pressure (100-bar) ball valves and pressure gauges. A base-frame was fabricated from steel channels etc. to provide housing and support to all packer units; **Figure 6**. Casings were attached to the base frame using bolts, and packers were fitted inside the outer casings; **Figure 7**.

Thermal blanket system was imported from a company that specialized in custom-designed heating units. Assembly was done in-house and the thermal units were installed on four high-temperature packers; **Figure 8**. Joining of packers to casings was done flange-to-flange, with custom-built pressure seals in between. Pressure gauges were fitted on top of the upper flanges for all units, and temperature gauges for the four 50°C units; **Figure 9**.

Figure 11.
Perspex demonstration unit showing internal construction of other test units.

Figure 12.
Ambient and hot water circulation system (left); complete assembly of the longevity test setup.

A manifold system was fabricated and installed, using special valves, to apply and maintain high pressure when needed; **Figure 10**. Main part of this manifold system was a SS pipe that was to be later connected to a high-pressure nitrogen gas cylinder. It had nine specially-fabricated outlets, hooked up to the test units, containing SS high-pressure (100-bar) needle valves and pressure gauges. High-pressure multistage gas regulator and related fittings were affixed to the nitrogen cylinder, to control the flow pressure in the manifold and the packer units; **Figure 10**.

Detail and assembly drawings for the demonstration unit were sent to a specialist facility for fabrication, the outer casing and the blind flange to be made of transparent Perspex. This see-through unit had all the components and was assembled to exactly match the other functional test units; **Figure 11**.

A circulation system was fabricated and installed on the four water-swelling packers, to maintain the salt concentration. It consisted of two water heaters (50-ltrs), three circulating pumps, and four each of pressure controllers, non-return valves, filling ports with valves, air vents, and running-time meters. All of these were connected together through copper lines; **Figure 12**.

Dedicated units were installed on all nine packers to carry out salt-water and crude-oil filling, and to check whether swell packers had sealed against the outer casing or not. This system included special SS ball valves at inlet and outlet ports.

All the components and sub-assemblies were finally assembled together; **Figure 12**. Cutting, trimming, beveling, drilling, threading, bending, and welding were some of the major fabrication operations. SS and PVC pipes, flexible hoses, valves, pressure and temperature gages, circulation and heating system, etc. were fitted at required locations. Forty sets of M16 x 100 and 80 sets of M16 x 80 hexagonal bolts (together with nuts, washers, and spring washers) were employed for different types of connections: packer blind flanges to flanges on outer casings; bottom end plates on casings to base frame; etc.

5. Commissioning and preliminary testing

Various stages of the fabrication, construction, subassembly and assembly work were described above. After that, pilot tests were run for working inspection of the water circulation system, the thermal blanket system, and the high-pressure manifold system. After several rounds of these trial runs, the longevity test rig was ready for commissioning.

Approximately 25-ltr of saline water was required to fill out each packer unit: complete filling inside the swell packer, and then up to a requisite height above the elastomer section in the annular space between the packer and the outer casing. This necessitated the preparation of a very large amount of distilled water: 25 liters per unit for six water-swelling units. This was done with the help of the water purification setup in the Environment Lab of the College of Engineering. Using this distilled water, salt solutions of 0.5% and 12% salinity were prepared, in enough quantity to be stored in 25-ltr storage canisters for initial filling of the tubes, and for intermittent later re-fillings due to possible leakages etc. Proper packaging and transportation to the test rig of a large quantity of crude oil (25-ltr for each of the three oil-swelling units) from two local oilfields was also a formidable task. An important requirement was that testing had to begin simultaneously for all water-swelling and oil-swelling packers, to have the same swelling time. Full commissioning and testing were the next steps.

6. Initial problems

Certain unique problems were encountered in the first couple of weeks of commissioning of the test facility, and were successfully resolved, before the system could be declared fully functional.

6.1 Water filling

Four tubes were to be filled with 12% brine solution, and two units with 0.5% saline water. Manual filling was initially attempted, but proved to be very time consuming. In case the filling took a few days, elastomer seals in some tubes would swell and seal before the other units. Suitable pumps were therefore utilized to accelerate the process and achieve simultaneous filling of all water-swell units.

6.2 Oil filling

It was almost impossible to do oil filling manually, as the viscosity of the crude oil was too high to easily pass through the filling ports under normal pressure. Use of regular water-type pumps could not work easily for pumping of such extra-thick crude oil. It was required to repeatedly re-prime and re-fill the pumps throughout the operation. Not only was the filling process slowed down, but three pumps were burnt out before oil filling could be completed.

6.3 Circulation system problems

As mentioned above, a circulation system was needed to maintain salt-concentration in the 4 high-salinity (12%) units. Small leakages repeatedly occurred in various portions of the circulation system, causing salt deposits on pipes and fittings. Water leakage and salt deposition also caused rusting of the tubes, flanges, and other fittings; **Figure 13**. The system had to be monitored on a daily basis, and clean-up, re-tightening and re-sealing operations had to be frequently carried out. Salt leakage also meant that water salinity would change. So salinity checks and refilling of tubes was also needed occasionally.

Intermittent shutting down of circulation pumps was another problem, caused by the formation of air gaps in the system due to small leakages. Urgent refilling and bleeding were needed to solve this problem, to avoid any notable downtime in the

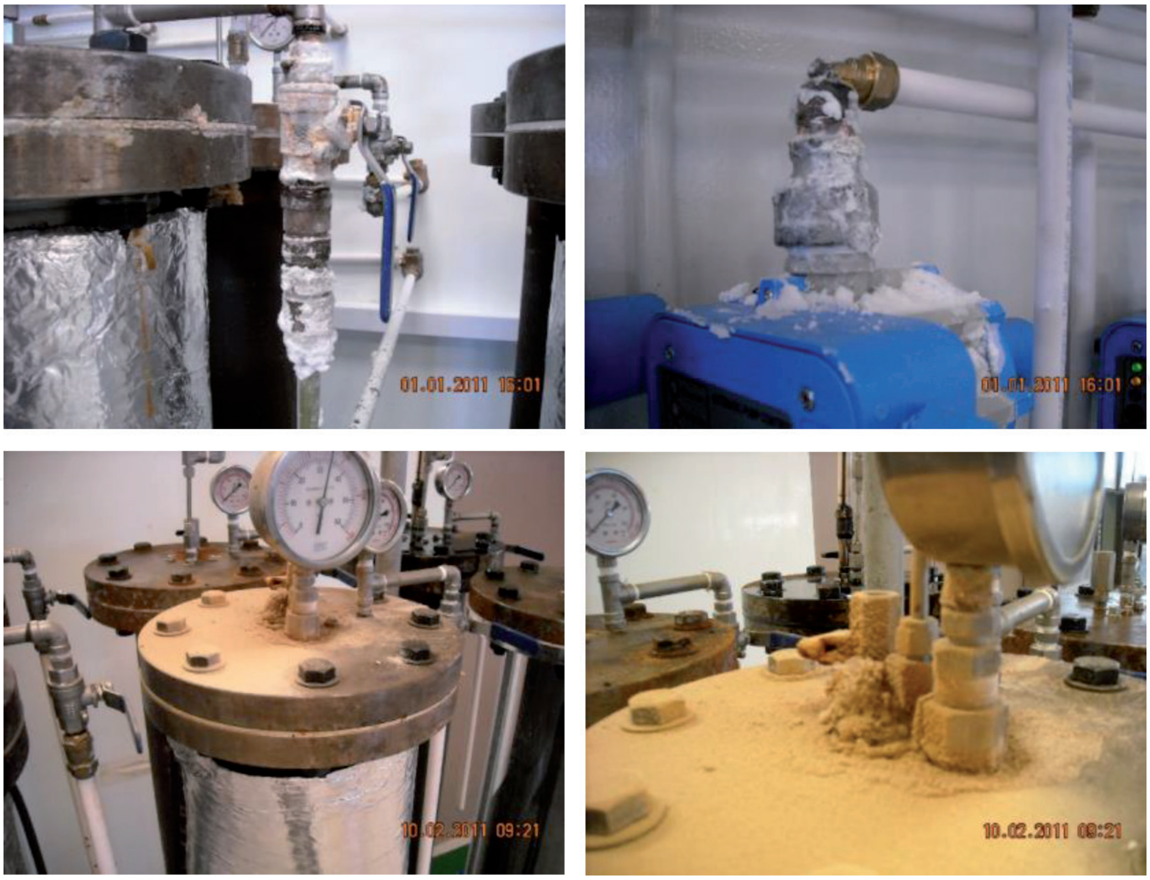

Figure 13.
Salt deposition on pipes, fittings, and pump units due to water leakage (top); corrosion of pipes and fasteners due to water leakage and salt deposition (bottom).

circulation system; otherwise salinity levels could not be maintained. Careful daily monitoring of the test rig was therefore kept up.

6.4 Maintaining temperature

The thermal blanket system was fitted with automatic control units to keep temperature in hot tubes at a constant value of 50°C. However, because of small thermal leakages to the base frame and the surroundings, temperature in some tubes dropped a little from time to time. Close scrutiny of the temperature gauges was required (on a daily basis), together with minor adjustments of the temperature-setting dial.

7. Testing and monitoring

Detailed log of temperature and pressure readings on all tubes, and of any uncommon occurrences was maintained throughout the five-year test period. This was done on a daily basis initially, then every two days, and then once per week.

7.1 Seal check

Initially, daily checks were carried out to see if any tube had sealed. Based on previous experience of material-testing for a variety of swelling elastomers, earlier sealing was expected in low-salinity water, then in high-salinity water, and then in oil. Also, faster sealing was expected for the higher temperature units [10, 11]. After some time, when quick sealing was not observed, the seal-check duration was changed to two days. Circulation pump would automatically stop for a tube once it was sealed; seal check was therefore carried out every time a pump stopped. When it was found that sealing was not complete, and the pump had stopped only because of an air gap, refilling and bleeding were carried out to re-start the pump.

7.2 High-pressure testing

The initial plan was to pressurize all four high-pressure tubes to 1000 psi simultaneously. However, it was observed that some of the tubes did not seal even after a few months. A decision was thus taken to pressurize each of these tubes as they sealed. This required connecting a high-pressure nitrogen cylinder to the pressure-manifold. Seal integrity was re-checked for the tube to be pressurized. If found intact, the high-pressure inlet valve on the manifold for this tube was opened and pressure was carefully increased in steps of 10 bar, as a safeguard against possible sudden seal failure. After reaching the full pressure of 70 bar, the tube was observed for about 20 min before the manifold valve was closed and the unit was disconnected from the nitrogen source. Pressure maintenance in this unit was guaranteed by the one-way valve. A drop in pressure of 10 to 20 bar was observed in the pressurized packers over the next few days. Re-pressurization to 1000 psi was then carried out. Absorption of some nitrogen into the salt solution (or into the elastomer material) may have caused this pressure reduction.

8. Results, observations and discussion

Some notable observations during the first few months, and through the 5-year test period, are mentioned below. It should be noted that 'W1' is a low-salinity fast-swelling water-based elastomer, 'W2' is a high-salinity medium-swelling water-based elastomer, and 'O1' is an oil-based elastomer. The gap between elastomer and the 7-in outer-casing is larger for the 3½-inch packer as compared to the 4½-inch packer; elastomer would have to swell an extra half-inch for sealing to be completed in the 3½-inch units.

8.1 Sealing time

Sealing times, in sequence, for the nine test tubes (swell packers) are summarized in **Table 2**. Of special interest is tube-5 (W2 elastomer; 4½-inch packer; 12% salt solution; room temperature) which sealed in 134 days, de-sealed after roughly 6 months, and re-sealed sometime after draining and re-filling of the brine solution.

8.1.1 Discussion

Let us recall some major findings from earlier studies [14–17] on swelling elastomer testing and characterization, and performance evaluation of elastomer seals and packers, conducted by the authors. Elastomers swell more in low-salinity brine than in salt solution of higher salinity. Water-swelling elastomers swell more and at a faster rate than oil-swelling elastomers. Higher amount of swelling takes place at higher temperatures. Elastomers developed for lower salinity may not perform well in higher salinity environment. If packers were stacked in open yards for long time, their performance seriously went down due to exposure in comparison with fresh packers; smaller amount of total swelling, and at a much slower rate.

In view of these earlier experimental conclusions, most of the observations listed in **Table 2** are as expected, and have rational explanations. Tube-9;

Tube Number	Sealing Time (Days)
9	8
8	43
3	62
7	115
5	Sealed in 134 days; de-sealed after 6 months; re-sealed after some time
4	166
1	178
2	206
6	Did not seal

Table 2.
Sealing times for the nine test tubes (swell packers).

fast-swelling elastomer (W1), low-salinity brine (0.5%), small elastomer-casing gap (4½-inch packer), and higher-temperature (50°C). Naturally, it was the first to seal (8 days). Tube-8; fast-swelling elastomer (W1), low-salinity brine (0.5%), small gap (4½-inch packer), room-temperature; second in seal completion (43 days), as expected. Tube-3; medium-swelling elastomer (W2), low-salinity brine (0.5%), larger gap (3½-inch packer), higher-temperature (50°C); third to seal (62 days). Though gap was larger, low-salinity and high-temperature combined to yield faster swelling. Tube-7; medium-swelling elastomer (W2), high-salinity brine (12%), small gap (4½-inch packer), higher-temperature (50°C); fourth to seal (115 days). While the gap was smaller than tube-3, much higher salinity (12% compared to 0.5%) resulted in slower swelling rate. Tube-5; medium-swelling elastomer (W2), high-salinity brine (12%), small gap (4½-inch packer), room-temperature; fifth in sealing (134 days). As expected; slower swelling rate for combination of higher salinity and lower temperature. Tube-4; oil-swelling elastomer (O1), crude oil, large gap (3½-inch packer), high temperature (50°C); sixth in sealing (166 days). Predictable; oil-swelling elastomer sealed later than both water-swelling elastomers, but before other oil-swelling units due to higher temperature. Tube-1; medium-swelling elastomer (W2), high-salinity brine (12%), large gap (3½-inch packer), room-temperature; seventh in sealing (178 days). Important to note; medium-swelling elastomer seals later than oil-based elastomer if all other conditions are unfavorable (higher salinity, larger gap, lower temperature). Tube-2; oil-swelling elastomer (O1), crude oil, large gap (3½-inch packer), room temperature; eighth to seal (206 days). As expected; longest sealing time for combination of all unfavorable factors: oil-based elastomer, large gap, and lower temperature. Tube-6; oil-swelling elastomer (O1), crude oil, small gap (4½-inch packer), room temperature; did not seal. Unexpected behavior; should have sealed before tube-2; all other parameters were same while gap was smaller. Either elastomer material on this packer segment was sub-standard from the beginning (small manufacturing defects do happen in the best of products), or material degradation due to exposure was much more severe on this segment in comparison with others.

8.1.1.1 Note-1: Long sealing time

One serious anomaly appears to be common in all of the above cases. Except for tube-9 that sealed in a reasonable time (8 days), all other tubes took much longer than expected to swell out and complete the seal. Wells are designed and developed with the target of going into production as fast as possible; production delays translate into significant losses. In an earlier study [17], effect of exposure (to sun and other atmospheric elements) on performance of swelling elastomers was studied. It was found that *performance of packers which were stacked in open yards for several months seriously went down in comparison with fresh packers; smaller amount of swelling, and at a much slower rate*. Packers included in the current longevity study had the same problem; they had been stacked in open yards for very long periods; thus the much slower swelling rate, leading to very long sealing time. This can be the source of a very useful advice to field engineers and procurement personnel. *There should be maximum effort and planning to use almost fresh swell packers. Care must be taken not to order too many packers than actually expected, as old ones will not perform as well. If stacking must be done (to avoid procurement delays), packers should be kept in covered yards, to minimize exposure to the sun and the elements*.

8.1.1.2 Note-2: Multi-segment packer design

In an actual application such as zonal isolation or water-shutoff, there may be water incursion in which water-swellable elastomer would be needed. There can also be oil exposure, needing oil-swelling elastomer. *Alternate segments of water and oil-swell elastomers* are therefore used in practical design [18], as shown in **Figure 14**. Also, if one segment (or more) does not perform satisfactorily due to any material issue, the *series of seal segments guarantees that the region still remains isolated*. Under-performance (no sealing) of tube-6 would not be critical if such multiple-segment design is employed. However, *in the case of single-packer system, operational issues would arise if the packer material misbehaves and does not achieve sealing.*

8.1.1.3 Note-3: De-sealing

Tube-5 had sealed after 134 days (4½ months). Roughly 5½ months after sealing, it de-sealed (almost one year of exposure). After replenishing the saline water, the tube re-sealed in a couple of weeks. One reason for this outlier behavior (de-swelling) may be the loss of water through evaporation from minor leakages, or adsorption of water into the elastomer and gradual water loss from elastomer into air. Another reason, as pointed out in chapter-3, may be the two-way transport of salt and water in an elastomer-brine system, or the breaking and re-forming of polymer crosslink chains. Swelling sometimes decreases a little before building up again. However, from a seal performance viewpoint, it is good to know that *after de-sealing, the elastomer eventually re-seals if exposure to water continues*. *Also, as*

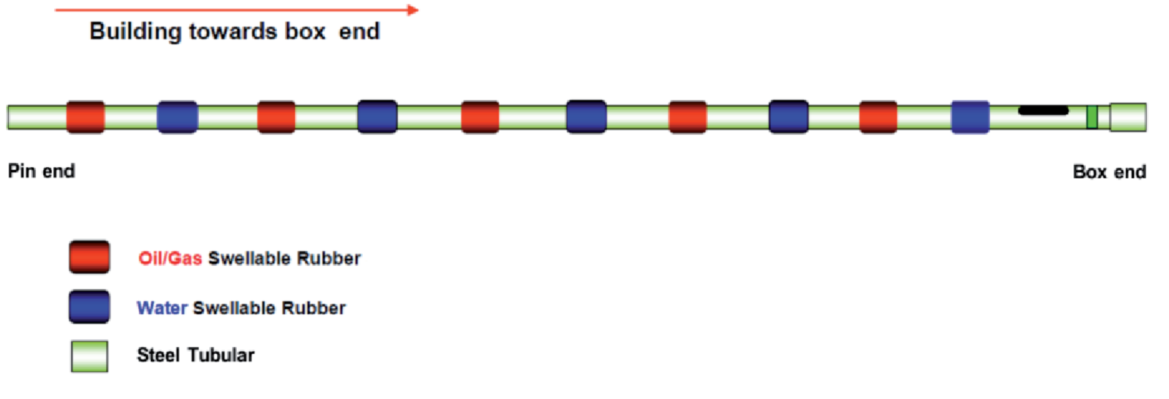

Figure 14.
Hybrid swell packer design; alternate water-swellable and oil-swellable segments on the same steel tubular.

mentioned above, multi-segment approach is a good fail-safe design as it will cover for underperformance of any one elastomer segment.

8.2 Behavior after pressurizing

As described above, four tubes (2, 3, 7, and 8) were gradually pressurized to 1000 psi after they sealed. This was done after a significant post-sealing time in each case, to make sure that the seals were fully intact before pressurizing. Tube-8 was pressurized first, as it was the first one to seal. After observing it under pressure for about 2 weeks, tubes 2, 3, and 7 were also pressurized. By design, pressurization was done on tubes representing all the different test parameters: two packer sizes (3½" and 4½"); three elastomer types (W1, W2, and O1); three swelling media (low and high-salinity water, and oil), and two temperatures (room, and 50°C).

Tube-7 de-sealed within a day of pressurizing to 1000 psi. Pressure was removed from the manifold side. About 2–3 weeks later, the tube re-sealed under atmospheric pressure. After two weeks of resealing, it was pressurized again to 1000 psi. The seal broke again. Later on, after resealing again, it was pressurized to a lower value of 600 psi (40 bar). The tube de-sealed once again. It was not re-pressurized during the remaining test period.

Seals in the other three tubes (2, 3, 8) remained intact after pressurizing to 1000 psi. As mentioned above, a 10–20 bar pressure drop was observed in these tubes within a few days of pressurizing. They were re-pressurized to 1000 psi. The process had to be repeated from time to time.

After about two years of pressurizing, all three tubes de-sealed one after the other. Pressure was initially removed until the tubes re-sealed (about three weeks). When manifold-side pressure was gradually increased, it was found that the sealing withstood a pressure of about 40 bar (600 psi), but not more than that. After about a year (total three years of pressurizing), the seals broke even at this pressure. After another round of de-pressurizing and re-sealing, sealing in tube-2 and tube-3 remained intact at a pressure of about 20 bar (300 psi), but tube-8 de-sealed even at this low pressure. However, it re-sealed once pressure was removed.

8.2.1 Discussion

Performance of tubes 2, 3, and 8 is encouraging for deployment in actual small-to-medium-depth wells, where differential pressure does not exceed 1000 psi. Packers 2 and 3 remained sealed under the full pressure of 1000 psi for two years, then again at 600 psi for one more year, and finally at 300 psi during the last year. Packer-8 performed similarly except for the last year, when its seal broke under pressure. However, it re-sealed when pressure was removed; healthy performance overall.

Behavior of tube-7 was disappointing; it de-sealed every time it was pressurized, even to lower values. Material and condition wise, tubes 3 and 7 were almost similar: W2 rubber, 12% salt solution, 50°C temperature. Tube-7 was a 4½" packer, so the packer-casing gap was smaller, and the seal pressure generated should be higher than tube-3, which was a 3½" packer. All other parameters being the same, if any tube were to de-seal under pressure, it should be tube-3. This anomalous behavior re-strengthens the observation that one individual elastomer segment (of the same material) may underperform due to an outlier issue such as material inconsistency, manufacturing flaw, vulcanizing defect, or some other reason. This also endorses the multi-segment design approach mentioned above; even if one elastomer segment underperforms for any reason, a *serial arrangement of elastomer segments ensures overall sealing*.

9. Chapter summary

This chapter reports the design, fabrication, and commissioning of a test setup for damage assessment and longevity testing (over a 5-year period) of water-swelling and oil-swelling elastomers being used in regional oilfields. Sections of actual packer were placed inside actual steel casings. Sealing performance under low and high-salinity brine and crude oil was investigated at two temperatures, mimicking in-situ conditions in shallow-aquifer type wells and medium-depth wells in the region. Out of ten units in the test facility, nine were actual swell packers inside actual casings, and one transparent Perspex unit was for demonstration purpose. Tube diameter was 3½-in in four 4½-in in five packers. Outer casings were 7-in diameter steel tubulars in all units. Six of the units had water-swelling elastomers, and three had oil-swelling ones. Water-based units were filled with salt-water solutions of low and medium-high salinity (0.5%, and 12%), while the remaining tubes had actual crude oil. The rubber elements in the packers were built up of two different water-swelling elastomers and one oil-swelling elastomer. High pressure (1000 psi) testing was carried in four selected packers, to replicate medium-high well pressures.

Regular log of readings was maintained over the five-year study period. Packers exposed to low salinity and higher temperatures sealed earlier. Water-swelling elastomers sealed faster than oil-swelling ones. Pressurized tubes either retained sealing the whole time, or re-sealed after removing of pressure or reducing it to a lower value. Results obtained are generally in line with swelling elastomer behavior observed in earlier studies. Some failures that have occurred can provide helpful pointers to field engineers and application designers.

Author details

Sayyad Zahid Qamar[1]*, Maaz Akhtar[2] and Tasneem Pervez[1]

1 Mechanical and Industrial Engineering Department, Sultan Qaboos University, Muscat, Oman

2 Mechanical Engineering Department, N.E.D. University of Engineering and Technology, Karachi, Pakistan

*Address all correspondence to: sayyad@squ.edu.om

References

[1] Al-Douseri KMM, Barnes C, Young D, Smith PE (2010) "Swellable Packers Provide a Brownfield Water Management Solution in Open and Cased Hole," *SPE Oil and Gas India Conference and Exhibition 2010, OGIC*, Mumbai, India, 20-22 January 2010

[2] Qamar SZ, Pervez T, Akhtar M, Al-Kharusi MSM (2012) "Design and Manufacture of Swell Packers: Influence of Material Behavior," Materials and Manufacturing Processes, 27 (7), 2012, p 727-732, IF 1.629 Oct-2015

[3] Mahrooqi MA, Hinai G, Marketz F (2007) "Improved Well and Reservoir Management in Horizontal Wells Using Swelling Elastomers," SPE Paper # 107882, SPE Annual Technical Conference and Exhibition, 11-14 November 2007, Anaheim, California, USA

[4] Rogers H, Allison D, Webb E (2008) "New Equipment Designs Enable Swellable Technology in Cementless Completions," SPE PAPER # 112302, IADC/SPE Drilling Conference, 4-6 March 2008, Orlando, Florida, USA

[5] Cooper K, McVey A, Schafer D, Cox JD, Hilleary N, Parker D, Crooks J (2008) "Completion of a Horizontal Well with Swellable Packers to Control Water Production," SPE PAPER # 116263-MS, SPE Annual Technical Conference and Exhibition, 21-24 September 2008, Denver, Colorado, USA

[6] Qamar SZ, Hiddabi SA, Pervez T, Marketz F (2009) "Mechanical Testing and Characterization of a Swelling Elastomer," Journal of Elastomers and Plastics, Vol. 41, No. 5, September 2009, p 415-431

[7] Kamal MS, Sultan AS (2019) Enhanced Oil Recovery, in: Jafar MM, Sheardown H, Al-Ahmed A (eds) Functional Polymers, Polymers and Polymeric Composites: A Reference Series, Springer

[8] Zeidan AA, Redha RA, Williams DD, Montero JE (2018) "Implementing WRFM Well, Reservoir, Facility Management and Smart Field Best Practices for EOR Optimization," Paper # IDSPE-193693, SPE International Heavy Oil Conference and Exhibition, 10-12 December 2018, Kuwait City, Kuwait

[9] Hembling D, Salamy S, Qatani A, Carter N, Jacob S (2006) "Swell Packers: Enabling Openhole Intelligent and Multilateral Well Completions for Enhanced Oil Recovery," Proceedings IADC/SPE Asia Pacific Drilling Technology Conference, 13-15 November 2006, Bangkok, Thailand, SPE Paper # 100824-MS

[10] Roland CM (2009) "Vagaries of Elastomer Service Life Predictions," Plastics, Rubber and Composites, 38:8, 349-354

[11] Achenbach M (2000) "Service Life of Seals – Numerical Simulation in Sealing Technology Enhances Prognoses," Computational Materials Science, 19 (1-4), 15 December 2000, p 213-222

[12] Gillen KT, Clough RL (1997) "Prediction of elastomer lifetimes from accelerated thermal-aging experiments," Elastomer-service life prediction symposium, 14-15 Sep 1997Akron, Ohio, USA

[13] Qamar SZ, Pervez T, van de Velden M, Sanchez FJ (2012) "Design and Fabrication of Test Facility for Longevity Testing of Elastomer Seals," ASME-2012 International Mechanical Engineering Congress and Exhibition

(IMECE-2012), Houston, Texas, 9-15 November 2012

[14] Akhtar M, Qamar SZ, Pervez T, Al-Jahwari FK (2018) "Performance Analysis of Swelling Elastomer Seals," Petroleum Science and Engineering, 165 (2018), p 127-135

[15] Qamar SZ, Pervez T, Akhtar M (2016) "Performance Evaluation of Water-Swelling and Oil-Swelling Elastomers," Journal of Elastomers and Plastics, 48 (6) 2016, p 535-545

[16] Qamar SZ, Akhtar M, Pervez T, Al-Kharusi MSM (2013) "Mechanical and Structural Behavior of a Swelling Elastomer under Compressive Loading," Materials and Design, 45 (March 2013), p 487-496

[17] Pervez T, Qamar SZ, van de Velden M (2011) "Comparison between Fresh and Exposed Swelling Elastomer," Journal of Elastomers and Plastics, 44 (3), May 2012, p 237-250

[18] Patel H, Salehi S, Ahmed R, Teodoriu C (2019) "Review of elastomer seal assemblies in oil and gas wells: Performance evaluation, failure mechanisms, and gaps in industry standards," Journal of Petroleum Science and Engineering, 179 (2019), p 1046-1062