ACTIVE LIFT SEAL TECHNOLOGY IMPACT ON WATER INJECTION SERVICES

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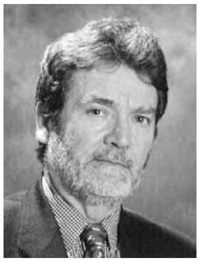

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ABSTRACT

Increasing environmental awareness and the ongoing need for improved reliability has seen an increase in the number of water reinjection installations, both onshore and offshore, and in particular in recent years, the use of double pressurized seal solutions.

While these double seal solutions have presented a generally satisfactory solution, there are notable instances of problems often associated with the reliability of the supporting pressurization system. This has been particularly so in formation and produced water injection installations in the Middle East.

Similarly, in offshore applications, the introduction of comingled service caused by environmental pressures on operators to reinject produced water has caused the traditional single seal solutions to become increasingly unreliable and to lose favor. Until recently, the only available solution has been the pressurized dual seal with all of the additional cost associated with a complex sealing system.

However, by the application of "active lift" technology, originally developed for gas compressors, operators are now seeing the advantage of simple nonpressurized tandem seal arrangements. With these seals, unpressurized barrier fluid is "pumped" across the inboard seal faces into the process fluid using active lift technology, providing a clean environment within which the seal can operate.

These active lift seals have now been developed and applied to a level whereby suction pressures of 70 bar/1000 psi and beyond can be handled, providing all of the benefits of a pressurized dual seal, without the complexity and cost of a pressurized solution.

While active lift technology has been applied to pumps for several years, it has traditionally been associated with low pressure environments. Advances in active lift characteristics have now allowed the technology to be applied on increasingly demanding applications, eliminating the need for complex seal support systems.

WATER INJECTION—
THE STATE OF PLAY TODAY

The extraction of oil and gas is normally accompanied with the extraction of water, often vast amounts of it. This is usually the formation water, or previously injected water, from the structure. As reserves being exploited mature, the volume of water increases. These increases are necessary to maintain pressure and flow. Unless permanent disposal is the primary aim, the quantity of water injected will not only depend on the volume of the oil bearing layer and the rate of depletion, but also on the effectiveness of the containment and confinement layers that are put in place to delimit acceptable injection zones. Figure 1 shows the principle behind water injection.

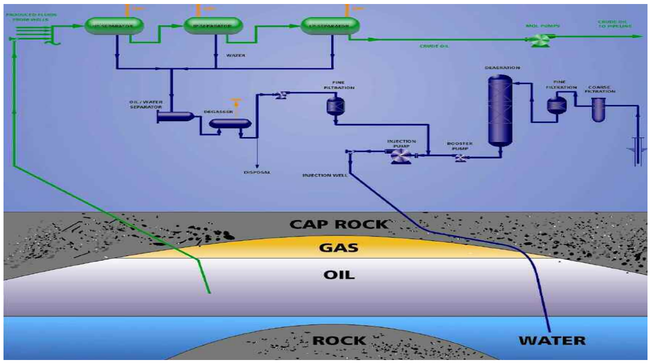


Figure 1. Water Injection Principle.

Water injection or reinjection of produced/seawater improves the recoverable reserves from a reservoir by establishing an external water drive and by maintaining reservoir pressure. Injecting into oil bearing layers or into pressure supporting aquifers for the reservoir sweeps oil out of the pore space and into the production wells. This process can often double the recoverable reserves. The quality of the injection water, be it seawater or produced water, is of great importance to the efficiency of the process. For instance in most applications the injection water must be devoid of oxygen that will cause corrosion of the injection well piping and other associated metal work such as pumps and seals. Injection of poor quality water can lead to reservoir plugging, leading to injection losses, a decline in the injection rate, and a subsequent decline in production. Often an increase in the injection pressure is required to sustain injection rates, instead of well workovers, reperforating the wells, or the drilling of new wells.

It is not always necessary to improve water quality. Some source waters are naturally clean (e.g., most aquifer waters) and some (often high permeability) reservoirs will accept poor water quality without the traditionally assumed injection losses. The skills associated with fracturing or fracture propagation of injection wells can also lead to a relaxation in the water quality specification.

Injection water quality requirements are typically unique to individual reservoirs, and a whole industry exists around the identification, correction, and management of the injection water for producers.

Typical governing factors that influence water quality solutions include:

- Untreated water quality.
- Matrix characteristics of the reservoir rock.
- Fracturing potential of the reservoir rock.
- Any operational treatment constraints.
- Type of equipment employed, helico axial over twin screw setups have greater gas fraction capability.
- Operational or injection philosophy of the operator.
- Compatibility of the injection water with the reservoir rock and the formation water.
- The expected life of the project.

Hence the development and management of the injection water specification, especially over the life of the reservoir as the characteristics change, are of great importance to the efficiency of the well or reservoir.

With many mature fields the water cut increases. In many locations this has been reinjected into the source reservoir, or disposed of into an underground, usually deep, aquifer. However with more stringent international environmental discharge legislation, operators are increasingly obliged to treat produced water to higher standards prior to disposal. For this reason they are increasingly using this water for reinjection into or below the production zone for pressure maintenance/sweep purposes.

This has already demonstrated economic benefits as the produced water has to be treated to a higher degree for simple disposal than for reinjection. Whether the produced water is to be treated for disposal or reinjection, a full understanding of both the chemical and physical properties of that water are essential inputs into any successful treatment solution, especially in terms of minimum capital expenditure, expected or required performance, and solution reliability.

Discharge regulations vary regionally, often according to local environmental concerns or regulatory bodies. Some locations only regulate the oil content of the water. Other areas, often bordering the same reservoir, monitor and regulate many (up to 33) different water quality parameters, including metals, organics, treatment chemicals, radioactivity, and temperature. Actual achievable values are typically dependent on the precise definitions of what is being measured and the techniques used. Globally the methods of analysis are being constantly updated as the commonly used solvents, such as Freon®, become unavailable or forbidden.

Scale Management

Scales form within injection waters when the thermodynamic driving force for precipitation from water overcomes the kinetic factors that inhibit mineral growth. These circumstances can be caused by a number of processes, such as:

- The mixing of incompatible waters.
- Chemically significant pressure and temperature changes during production or injection.
- Changes in pH values due to gas breakout.

The presence of scale in production and injection systems has a number of consequences, all of which can have significant impact on operating cost.

Scale indexes, and the potential to scale at, or within, pump performance operating curves will have a significant impact on mechanical seal performance, and hence the type/style or arrangement of seal chosen on injection duties. Typically uncontrolled (even controlled) scale results in costly and time consuming equipment damage. In the context of the well or reservoir this may also present other problems, such as underdeposit corrosion, further reservoir plugging, and lost production due to the need for workovers. Finally when it is all over, there are high or increased abandonment costs. A major operator in the North Sea has been quoted at spending approximately $12 million per annum on scale management alone. Even then, control is not totally effective and 20 percent of well losses are still attributable to scale elements. The net cost to this operator is estimated at $1/bbl oil produced.

Like all good process management skills, the likelihood of scale formation can be predicted by geochemical modeling. The most often attributable problems with the prediction of scale are that the input of unintentionally erroneous data can lead to costly mistakes. This can occur when measurements are made at conditions unrepresentative of true system conditions, commonly used but inappropriate analytical methods are employed, or simply samples are contaminated.

OVERVIEW OF CURRENT SEALING SOLUTIONS FOR WATER INJECTION

The key objectives of the pump seal for a water injection application are to minimize:

- Maintenance, lower asset operating costs.
- Leakage of seawater, or potentially aggressive produced water, which would otherwise cause external corrosion and increase drainage requirements.
- Leakage of oxygen into the deaerated seawater, which would increase corrosion downstream. It should be noted that oxygen will ingress into the water against the pressure and flow of a leak.

Single Seals

Single seals, as defined in API 682 (2002) as arrangement 1, are the simplest and cheapest method of achieving a seal for a high pressure pump (Figure 2). The single seal takes its seal flush water from a high pressure stage of the process and flushes this across the seal face to a lower pressure stage within the pump. Unfortunately, all mechanical seals leak. When seawater is the process medium, problems of crystallization arise due to the salt content of the seawater. Salt crystals must be expected to become deposited behind the seal and potentially increase the leakage rate.

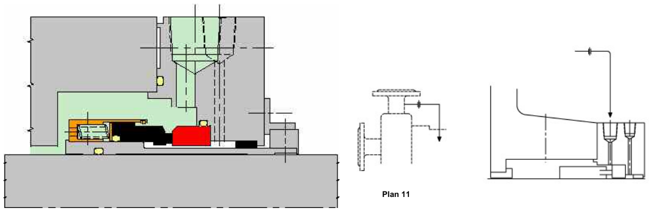


Figure 2. API Arrangement 1 plus Typical Piping Plan.

If crystallization occurs around the face loading springs, these can become fouled-up causing “hang-up” of the seal and accelerating the leakage rate and seal failure. In the event that seawater is deoxygenated upstream of the pumps, one of the undesirable effects of leakage across the seal face is the ingress of oxygen by liquid surface transfer mechanisms. Once oxygen is reintroduced into the system, the corrosion rates within the process will increase, resulting in component hang-up and instrumentation failures due to increased solids loading.

On produced water applications, there is the additional complication of scale formation on both process and atmospheric sides of the seal, formed due to the mineral content of the water coming out of solution. The factors affecting the rate of scale formation are widely documented, and in general seal vendors aim to minimize temperatures and pressure drops in a bid to reduce the rate of scale formation.

Tandem Seals

Tandem seals, as defined in API 682 (2002) as arrangement 2, dual unpressurized seals, as shown in Figure 3, are basically two mechanical seals joined together. The first (inner) seal is flushed in the same way as the single seal but the second (outer) seal system utilizes an unpressurized quench fluid. The outer seal system therefore acts as a buffer and any leakage across the inner seal is absorbed by the buffer fluid and dissipated in a controlled manner. This buffer also prevents harmful oxygen ingress. As the salinity of the buffer fluid builds up it will, however, be necessary to change out the fluid from time to time, depending on inner seal leakage rates.

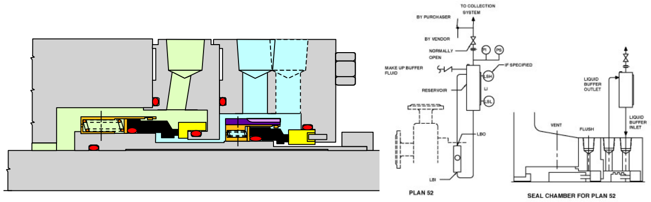


Figure 3. API Arrangement 2 plus Typical Piping Plan.

Double Seals

Double seals, as defined in API 682 (2002) as arrangement 3, pressurized duals, as shown in Figure 4, are again two mechanical seals joined together but the barrier fluid between the two seals is pressurized to a level higher than that at the inner seal. Any leakage across the inner seal face will therefore be inward from the barrier fluid into the process fluid.

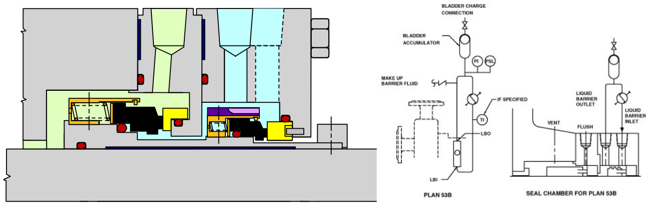


Figure 4. API Arrangement 3 plus Typical Piping Plan.

The main uses for a double seal are for antipollution, safety, or where an outward process fluid leakage will cause problems. This is the most expensive option due to the complications of providing a pressurized barrier fluid system.

In general and until relatively recently, single seals have been supplied in most cases. Where any external salt crystallization has led to hang-up problems, this has usually been avoided with the simple addition of an unpressurized water quench, or in the most serious of applications, the unpressurized tandem approach.

However, with the increasing desire to:

- Prevent ingress of oxygen into the process and
- Reinject produced water,

the pressurized double seal has become the preferred option, often specified at contractor level. While clearly addressing the technical requirements of the service it does add significant cost, and the relative improvement in reliability often falls below expectation.

BACKGROUND TO ACTIVE LIFT TECHNOLOGY

One of the more recent seal interface technologies to be developed is active lift technology or upstream pumping action. This active lift principle uses spiral grooving on the seal faces to produce the same result as the pressurized double seal, without the need for a complex pressurized seal support system.

A spinoff from the noncontacting dry running gas compressor seals, the same spiral groove technology is used to generate hydrodynamic lift. In this case however the active fluid is a liquid rather than a gas and the spiral grooves form the inner portion of one of the seal faces, as shown in Figure 5.

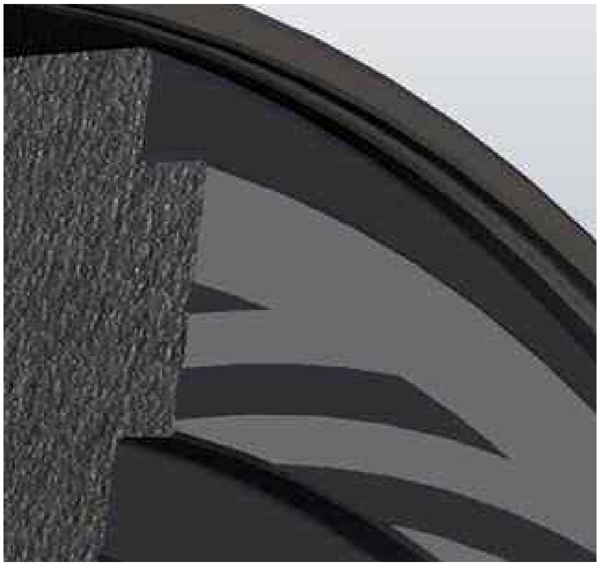


Figure 5. Active Lift 3-D Groove Profile.

With rotation, the spiral grooves take the unpressurized barrier fluid and generate a pressure at the exit of the spirals greater than the pressure in the seal chamber. It is this pressure that forms the active lift. The outer portion of the seal face, between the spiral exit and the process fluid, is a lapped region known as the sealing dam. The pressure differential across this sealing dam determines the amount of fluid flow or upstream pumping action that takes place from the barrier side to the process side. For a given design, as the process pressure increases, the rate of upstream pumping reduces, while maintaining a noncontacting, sealing gap between the seal faces.

Figure 6 shows simply how this technology varies from conventional dual seal arrangements. Here the pressure distribution of an active lift seal can be seen (the pressure profile for the double seal is not shown so it is not being compared here). The barrier pressure is a few psi above atmospheric pressure (due to static head), but significantly below that of the process.

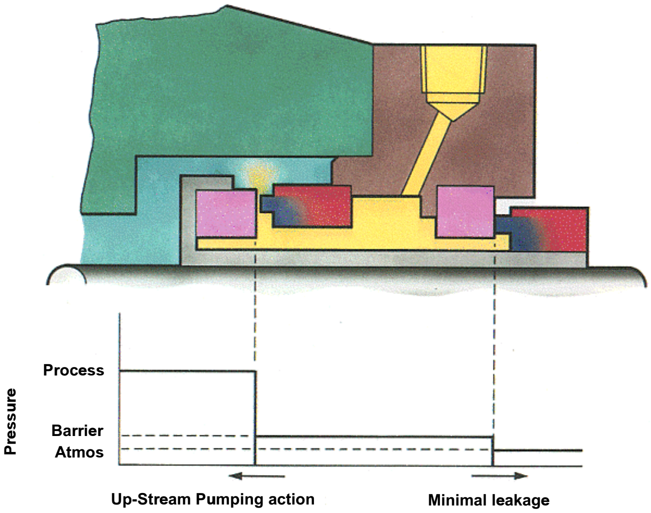


Figure 6. Active Lift Seal Principle.

The pumping action is achieved with the use of very shallow grooves on the hard face element of the seal. These generate significant pressure within the grooves, as shown in Figure 7.

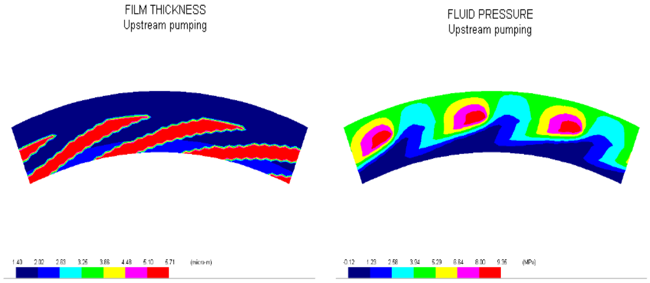


Figure 7. Groove Pressure Profiles.

Figure 8 demonstrates how the pressure is generated through the groove profile, from a groove inner radius of 54 mm/2.125 inches the pressure increases from zero to approximately 55 bar/800 psi at about a radius of 60 mm/2.362 inches, which is the groove root. At this point the pressure decays back across the ungrooved sealing dam to the process pressure at the outer diameter (OD) of the seal, the 63 mm/2.480 inch radius, which is about 40 bar/590 psi.

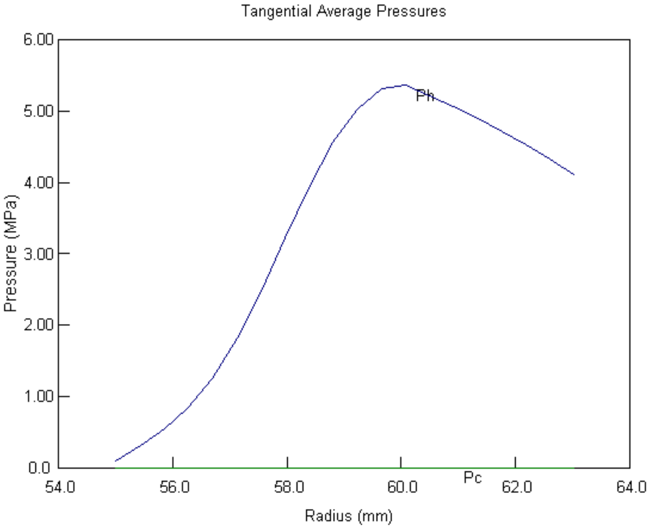


Figure 8. Pressure Profile.

An expected operating condition in this type of application is a pump running against the shutoff valve pressure, when minimum flow conditions occur, hence increasing the operating pressure on the seal. This offers significant challenges in stabilizing seal face presentation over a wider pressure regime. While this often represents an equipment or process upset or even failure condition, in the unlikely event of total loss of the buffer fluid, an active lift seal reverts to operating as a standard single seal. It is the hydraulic balance ratio of a mechanical seal that determines its ability to hold pressure in a given direction, and in this design this is in the region of 80 percent with outside pressure. Figure 9 demonstrates this, the balance ratio being A1/A1+A2—resulting in a net operating closing force.

The same principle applies to a seal that may be subjected to a pressure above the active lift capability of the seal. In this case, once the seal becomes incapable of producing sufficient lift, the seal will operate as a single seal. In general these types of events are short-term and the seal will then revert to normal active lift operation.

Active lift at a seal interface offers several advantages over the traditional double seal approach.

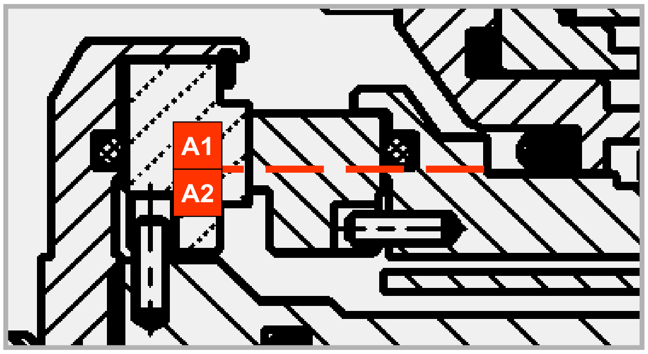


Figure 9. Over Pressure Representation.

- The technology is noncontacting and therefore the usual pressure velocity (PV) limitations imposed by contacting seals and the resultant wear do not apply.
- The power consumed is significantly lower than a double or tandem seal arrangement.
- The positive flow of clean fluid into the seal chamber provides a cleaner sealing environment within the seal chamber.
- Seal leakage to atmosphere is significantly reduced when compared to a pressurized dual seal—where the outboard seal can often operate at considerable pressure.
- The concept allows a simple upgrade of single or multiple seal services, where process changes have rendered the process fluid a poor seal lubricant.
- In services where the process pressure is variable, or where pressure spikes are likely, active lift constantly regulates against this varying pressure, maintaining a sealing gap at all times.

The technology is now also regarded to offer significant operational advantages in subsea scenarios (Figure 10) where high suction pressures are encountered. Barrier pressures can now be controlled using the pressure from the support system, reducing the need to control seal pressures through the umbilical.

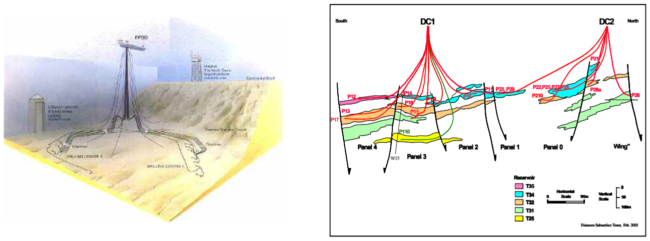


Figure 10. Subsea Diagram.

ENHANCEMENTS IN TECHNOLOGY TO DELIVER HIGHER PRESSURES FOR WATER INJECTION

The key element influencing the seal vendor's ability to develop active lift solutions for higher pressure applications is the availability and integrity of modeling and simulation software. In this respect the finite element analysis/computational fluid dynamics (FEA/CFD) software package used to further develop active lift designs has been crucial to achieving success (Figure 11).

Where a seal design is dependant on some form of hydrodynamic pressure generation, it is vitally important to have a stable design, capable of near parallel face presentation throughout the envelope of operation. Whereas earlier solutions were capable of operation up to process pressures of 10 bar/150 psi, the development of FEA/CFD software has allowed optimization of the seal face design to increase this limit between five and 10-fold.

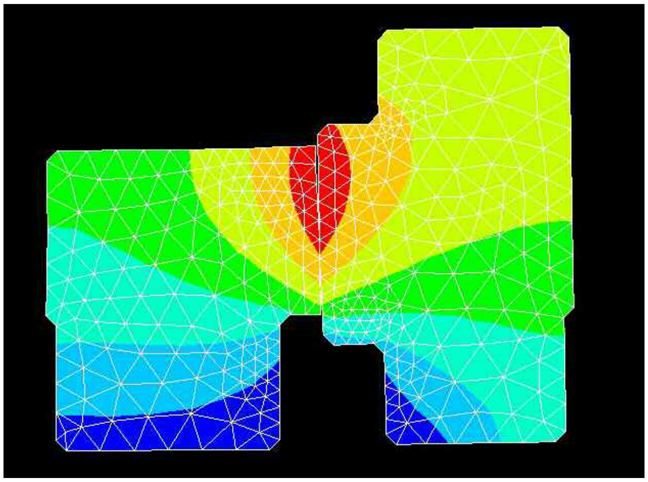


Figure 11. FEA/CFD Software Image.

With any mechanical seal, as the process pressure increases, the distribution and level of pressure influences the degree of pressure rotation of the individual seal rings around their own axes. It is this rotation of the seal ring that causes a change in the face flatness and presentation and every effort is made to reduce this rotation. Face presentations are often described as being “V” or “A” shaped, and the objective with active lift seals is to avoid both of these, establishing a neutral, parallel “II” presentation—as shown in Figure 12.

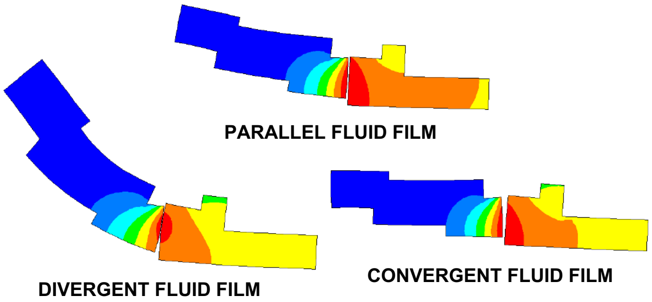


Figure 12. Face Presentation.

Using FEA/CFD software, the seal maker can optimize the profile of the seal face components, can modify the regions exposed to the process pressure, and can vary the ways in which the seal rings are supported within the mating components.

This has been the approach adopted in developing active lift seals for water injection services. The solution involved using pressure neutral symmetrical designs for the seal rings and locating them against cushioned elastomeric supports, as shown in Figure 13. In this way, pressure rotation is near zero and any localized distortion that can be transmitted through the metal sleeve and carrier components are isolated from the critical seal ring components.

As an example, using this tool and method on a 100 mm/4 inch seal exposed to 40 bar/590 psi, resulted in a change of face flatness of a mere half light band—virtually zero. In comparison a standard API seal might deflect up to 10 times this amount.

While stable face presentation provides the foundation for extending the operating capability of this technology, there still remains the small matter of lift generation itself—the optimization of both the lift and the rate of fluid pumpage across the sealing dam.

It has been widely documented within the area of gas seals how the profile, quantity, and depth of any grooved structure on a seal face can influence the degree of hydrodynamic lift. The same is true within the wet seal arena. Whereas, traditionally, significant retesting of alternative structure designs needed to be carried out,

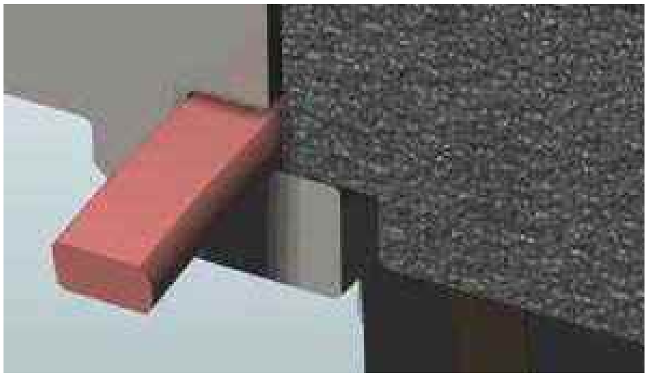


Figure 13. Cushioned Supports.

the recent CFD enhancements within the FEA/CFD software have allowed the optimization of these structures to achieve a balance between ultimate lift and fluid pumpage without the need for extensive test programs.

Within the face design one of the critical features is the dam ratio—the ratio of the area of spiral groove to the total seal face area including the sealing dam. Figure 14 shows how for a given design, a change in the dam ratio results in a significant reduction in the degree of pumpage, while maintaining an acceptable degree of lift and establishing a noncontacting regime.

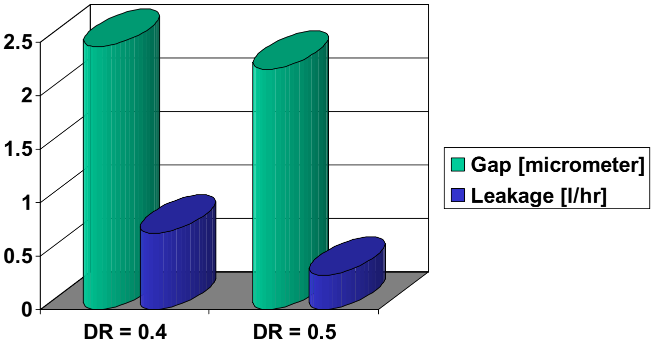


Figure 14. Dam Changes.

An Offshore Platform as a Foundation Technology for Water Injection and Multiphase Sealing

Although this paper focuses on active lift technology applied to water injection services, the first offshore application of this technology was installed on a North Sea offshore platform's test separator pumps. These pumps handle a mixture of crude oil and water with varying concentrations, and also contain large quantities of sand—similar conditions to those found in multiphase and water injection duties.

Commissioned in the early 1990s, the original unpressurized tandem seals on this service grew increasingly more unreliable over a period of time as the sand content increased. Relying on the pumped product to lubricate the seal faces, the seals were suffering from erosion and hang-up—a lack of flexibility, leading to short lifetimes in the region of one to two months.

Although a pressurized tandem arrangement would have been a typical upgrade for such a symptom, recent developments in high pressure active lift seals allowing them to be applied up to 40 bar/590 psi, made this technology more attractive. In particular it was felt that this seal face principle would provide a cleaner environment for the seal to operate in, in addition to providing optimum lift conditions between the seal faces.

The 75 mm/2.95 inch seal design is shown in Figure 15, and was tested under the following operating conditions:

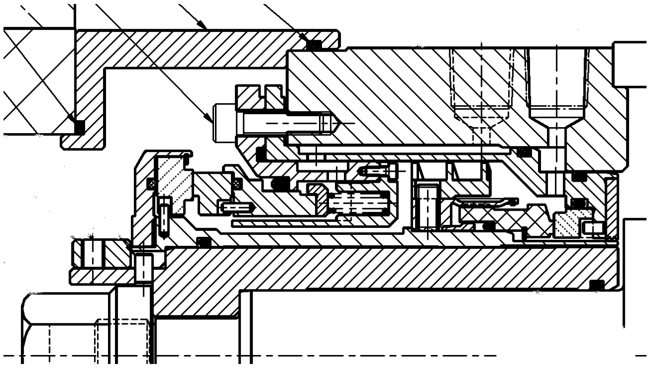


Figure 15. Offshore Platform Arrangement.

- Shaft speed: 3600 rev/min
- Seal chamber pressure: 5 to 40 barg (75 to 590 psi)
- Seal chamber temperature: 70 to 80°C/160 to 175°F
- Process fluid: Water, water/oil/sand slurry (20% wt)
- Barrier fluid: Seawater

Figure 16 shows the condition of the seal components following the slurry testing phase over a 200 hour period. The seal faces appear as new.

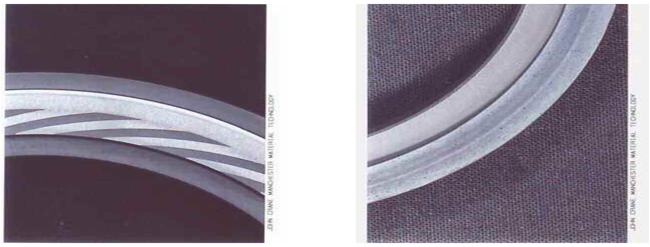


Figure 16. Test Seal Faces.

Following these tests, the first seal was successfully commissioned offshore in October 2003. The seal cartridge was supplied with 7 l/min/1.9 gal of seawater from the seawater ring main via a simple 3 micron/0.00012 inch duplex filter. This flush was then sent to drain through a control valve.

At the time of writing, these seals have operated trouble-free for almost 12 months (compared to the one to two months with the original seals), and the second pump has been upgraded.

Seawater Injection Pumps

A floating production storage and offloading (FPSO) facility operates in the North Sea. The pumps are fitted with relatively simple, single mechanical seals with a single spring located outside the pumped fluid, as shown in Figure 17—an arrangement often used on water injection to reduce the potential of seal hang-up.

For the first few years of operation, the two water injection pumps were giving reasonable performance for this type of service, with typically two failures per year across a population of four seals. In 2002, the service was changed with the introduction of comingling produced water with seawater. In that year the failure rate increased to eight (Figure 18). Examination of the failed components (Figure 19) revealed evidence of hang-up and face damage due to the formation of scale.

The standard solution for improving the reliability would have been the pressurized double seal, but due to limited space available for a complex seal system on the FPSO, it was decided to upgrade the seals to active lift pumping arrangements, again using a simple seawater flush similar to that on the North Shore offshore platform.

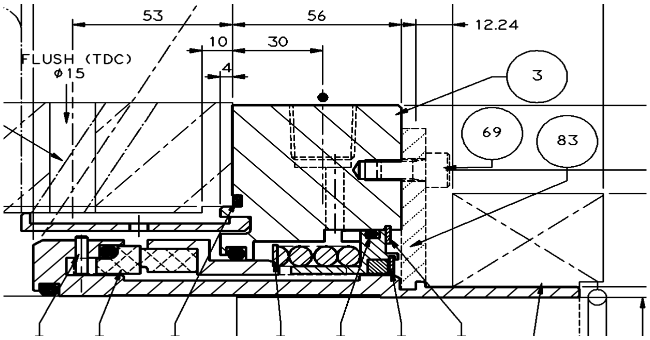


Figure 17. FPSO Arrangement.

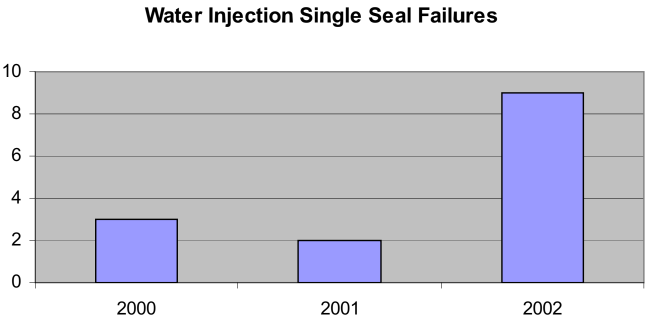


Figure 18. Seal Failure Regime.

Figure 19. Failed Components.

The seals (Figure 20) are the largest produced to date, with a pump shaft diameter of 130 mm/5.118 inches, and operate at 3600 rpm. The stuffing box pressure varies over time due to increasing clearances in the pump wear rings, ranging from 5 to 20 barg/75 to 300 psi.

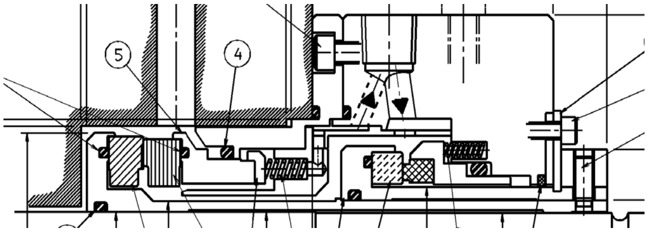


Figure 20. 130 MM Dual Arrangement.

Systems

By nature of the design and operation of active lift mechanical seals, the required support system and complexity are greatly reduced from a conventional dual seal with a full API plan 53 style system (Figures 21 and 22).

The support system for these seals consists of a duplex filter complete with a differential pressure indicator. Downstream of the filter package each supply line to the seals is fitted with an orifice or needle valve and nonreturn valve assembly.

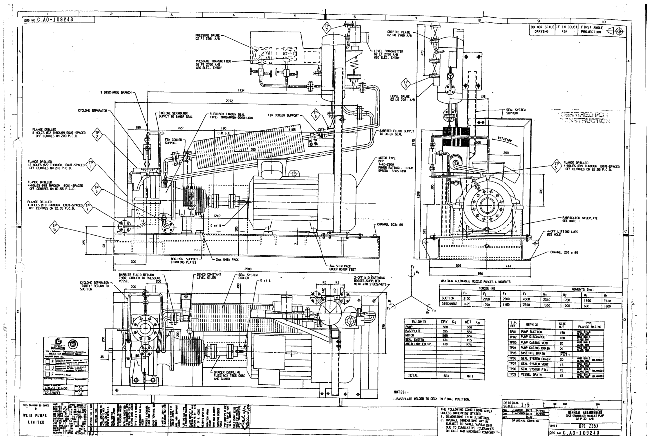
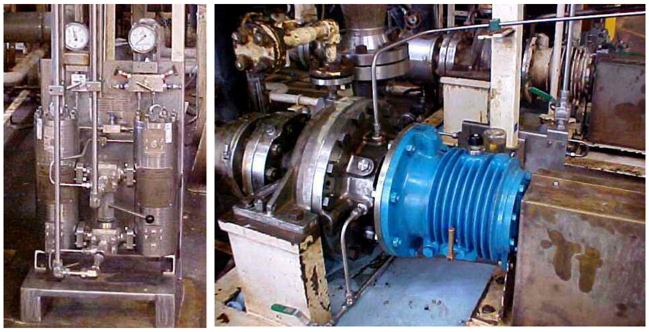


Figure 21. Piping Plan Picture.



Filter Pack

Test separator pump with seawater lines to/from seal & low point drain

Figure 22. Pump with Active Lift Technology Piping.

The seawater passes through the mechanical seal cartridge. Downstream of the seal a flow indicating transmitter monitors the seawater flow rate and a pressure indicating transmitter monitors pressure. A needle valve maintains a nominal back pressure on the seal. Downstream of the instrument panel the seawater goes to drain or overboard dump (Figure 23).

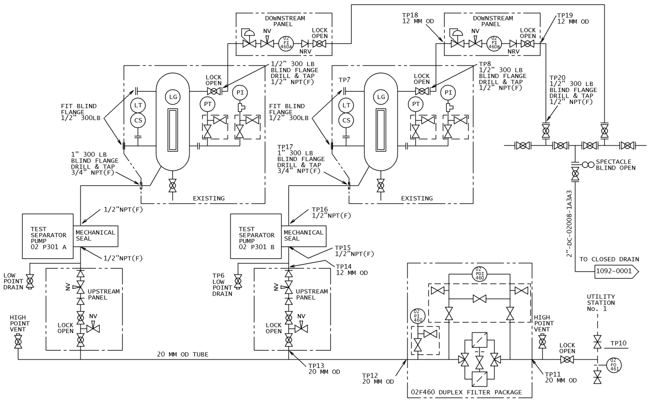


Figure 23. Plan of System.

Costs

The operating cost implications of poorly performing conventional seals on a typical North Sea injection duty can be highlighted in the following case study.

Following the introduction of produced water pumped through the main injection pumps, the reliability of the mechanical seals on the highlighted units deteriorated from what had been good performance when pumping filtered deaerated seawater.

The seals examined had suffered mainly from abrasive wear. Abrasive wear is typical in this application due to the poor lubricating properties of produced water. Dissolved solids precipitate and form suspended solids during the pressure drop across the single seal faces. Produced water can also contain dissolved hydrocarbon gases that come out of solution and both of these symptoms cause damage to the seal faces.

All new pumps supplied into the North Sea for use on produced water have had conventional double seals and seal systems to overcome poor lubrication and other difficulties experienced when sealing produced water.

Existing pumps in the field converted from seawater to produced water service have used modified single seals and have had mixed success. These are still considered on trial. Single seals have been modified and used on produced water as an economical first step for many users. However most seal manufacturers believe single seals are not a suitable long-term solution on produced water applications.

In an attempt to limit the cost impact of conventional double seals, active lift technology seals have been utilized, with suitable support systems. These use filtered seawater from a source downstream of the deaerator as the chosen barrier. The spiral grooves on the inboard seal face pump a small quantity of seawater from the low pressure supply across the seal faces against the process pressure providing the lubrication for the seal faces instead of the produced water. The outboard seal is also lubricated by the seawater as it passes through the seal and goes to the drain/overboard dump.

- Liquid
  - Product: Seawater and produced water
    Filtered down to 80 micron/0.003 inch
  - Temperature: 22°C rated/50°C max (72°F/122°F)
  - Specific gravity: 1.03
  - Vapor pressure: Assumed as water
  - Viscosity: 1.25 cst
- Operating conditions
  - Suction pressure: 5 barg (75 psi)
  - Discharge pressure: 225 barg (3330 psi)
  - Shaft speed: 3570 rpm
- Pump data
  - Manufacturer: United Kingdom manufacturer
  - Shaft diameter: 130 mm/131 mm at seal (5.118 inches)
- Seal design limits
  - Seal design pressure: 20 barg dynamic/30 barg static
    (300/450 psi)
  - Seal design temp: minus 6°C/plus 60°C (21/140°F)
- Site data
  - Temperature: minus 6°C to 18°C (21/65°F)
  - Location: Outdoor/unheated
  - Area classification: TBA
  - Remarks: Marine saline atmosphere
    Water injection deaerated seawater
  - Supply: Deaerated seawater
  - Filtered: 80 micron/0.003 inch

Over a 12 month period three injection pumps suffered eight failures associated with the seals.

• Number of outages:	7
• Pump downtime per outage (days 7+2+2):	11
• Injection water lost (bbl/day):	100,000
• Total injection water lost (bbl):	7,700,000
• Deferred oil (bbl):	5,133,333
• Value of deferred oil (at $4.60 per bbl):	$23,613,331.80

CONCLUSIONS

Active lift seal technology has been available to seal manufacturers in various shapes or forms for many years. However it is only comparatively recently that the technology has been available to allow these designs to operate at pressures and on duties suitable for water injection services.

With the pressures being applied in the industry to clean up these services, reducing the environmental impact of the injection process, improved seal technology is seen as one dimension that could help to reshape how water injection services are dealt with.

- Poor mechanical seal performance in these duties is in most instances a symptom of differing duty conditions as water injection technology and requirements change.

- By focusing on the key areas that effect seal reliability it is now possible for seals to operate for extended periods in these new conditions, which is fundamental to improving asset reliability.

- The cost to operators of adopting such technologies is favorable when compared to the operational losses or deferrals that asset downtime produces.

The relative simplicity of the design and operation of seals equipped with active lift technologies has allowed a significant improvement in not only the reliability, but the operating costs of assets equipped with seals utilizing this technology. As user confidence levels increase, the understanding and development of the technology and the tools and models will push the performance boundaries further.

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