WASTE WATER INDUSTRY PUMP RELIABILITY

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Abstract

Modern process industry has become increasingly focused on the installed life of pump machinery. Reliability of these assets has a significant effect on business performance in terms of profitability and safety.

The paper evaluates wastewater industry pumping equipment life with pumping equipment from other different industry sectors. Comparisons are made with both aqueous and hydrocarbon industries. The methods of life measurement that process industry has adopted are discussed. These methods have driven improvements but have limitations.

Comparison is made with both wet and dry well installations. The disparity between modern process industry reliability and the waste water industry is discussed. An Achilles heel of waste water industry pumps is identified. Solutions are offered along with commercial justification.

1 Introduction

Users of large populations of pumping equipment have, over the last three decades, recognised the importance of pump reliability. Pumps are critical pieces of rotating equipment. Their failure can have significant consequences in terms of cost and safety. There is significant information in the public domain (Reference 1) to assist users to adopt 'best practices'. Many of the strategies have now been adopted across many industry sectors.

2 Reliability Measurements & Benchmarking

2.1 Mean time between failure

The oil refining industry was perhaps the first sector to actively measure pump life. The most commonly used measure has been Mean Time Between Failure (MTBF), today in our more politically correct society it is often now referred to as Mean Time Between Repair (MTBR). Classically MTBF is expressed in months, this measure effectively records the in-service life of a pump. With historical data collected across a large population of pumps a plant wide MTBF can be used as a benchmark to provide overall measure of pump reliability. Globally oil refineries have used this standard to directly compare performances of different refineries.
MTBF is most commonly measured as total number of pumps divided by total number of failures, multiplied by review period.

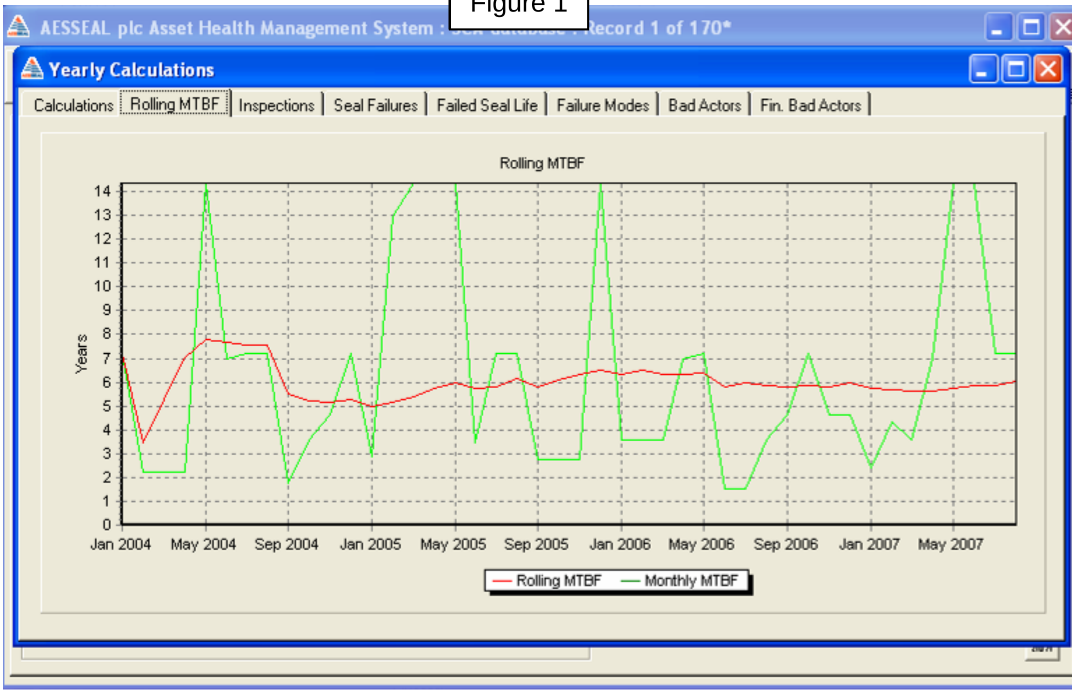
(No. of Pumps / No. of Failures) X Time Period

This method is perhaps overly simplistic, as it takes no account for the actual running hours of pumps. The oil industry sector, for example, typically will run pumps in spared operations (duty / standby). Care needs to be taken when making comparisons, (Reference 2) in other industries such as the pulp & paper industry where pumps are run continuously with no installed standby unit.

2.2 MTBF – What is achieved by modern process industry

Recent published data (Reference 3) illustrates that refineries in Western Europe and North America regularly achieve 80 months MTBR. Depending on the level of spare installed pumping equipment, the industry is enjoying 30,000 hours life from their pump equipment. A more relevant comparison to waste water industry is the pulp and paper industry, where the pumped media is aqueous fibrous slurry with air entrainment. Pumping and sealing equipment face similar challenges. The Paper industry has not universally engaged in reliability measurement. However, many modern plants have adopted these principles; these tend to be best in class & regularly exceed 60 months MTBR. Figure 1 illustrates a UK recycled paper plant rolling MTBF, where pump reliability has reached a plateau of 72 months. With no standby pumps and only 20 down days a year, this particular plant is enjoying 50,000 hours running life from its equipment.

Figure 1



2.3 The Water Industry,

With a pump population spread over a wide geographical area and pump asset register often not complete the industry has not adopted similar reliability measurement.

The water industry increasingly discusses life cycle costing (LCC) when purchasing new pumping equipment. Formulae for LCC (Figure 2) have been developed and widely published (Reference 4). Consideration is made for future maintenance and repair costs for equipment so to some extent reliability is dialled in from new. However, whilst this approach has much value, it too has its limitations. Future maintenance costs are predictions or estimations. The author is not aware of any retrospective studies of the LCC approach and the estimated maintenance and repair coatings have not been properly tested. Implementation of this philosophy has not been universal within the water industry (Reference 5).

Reliability measurement of machines in the water industry is behind most other industry sectors. The author is not aware of any published data on statistical of pumping equipment or industry sector benchmarks.

3 Generic Pumping Equipment

3.1 Submersible pumps

The wastewater industry has adopted two types of generic centrifugal pumping equipment. Submersible or immersible pumps are close-coupled pumps where the pump impeller shares common bearings with the electric motor. Normally, the units are designed so that the electric motor runs continuously submerged in the process fluid. Modern adaptations of this technology now allow the electric motor to run, in some instances, either submerged or surface mounted so this technology can be applied to both dry & wet well pumping stations.

3.2 Traditional long coupled pumps

The other sort of pump commonly found in wastewater pumping stations are long coupled pumps where the pump impeller spindle is supported by its own bearing arrangement. A separate motor, drives the pump unit and the motor is a conventional electric motor that is not designed to run submerged. Traditionally, these pump sets used primitive packing glands. Failure of packing seal glands was a common occurrence and dry well flooding was a risk.

Figure 1

HI / Europump Guide definition

$$\mathbf{LCC = (C_{ic} + C_{in} + C_{e} + C_{o} + C_{m} + C_{s} + C_{en} + C_{d})}$$

➔ic = Initial cost, purchasing cost
(pump,accessories,piping,electrical equipment, electronics, etc...)

➔in = Installation and start up costs

➔e = Energy consumption cost

➔o = Operating cost (regular maintenance labour)

➔m = Maintenance and repair cost

➔s = Loss of production related cost

➔en = Environment impact cost

➔d = Dismantling or return of goods value cost

As a consequence of the risks associated with packed glands, many of these pumps were installed with electric motors mounted at the surface. A prop shaft spindle or line shaft drive would be used to drive the pump at the bottom of the well. In the late 1980's many of these mature pump machines were very successfully converted to cartridge mechanical seals. Pump manufacturers adopted this sealing technology, incorporating it in new machines.

3.3 Traditional long coupled pump reliability

There is very little published data on the reliability of such combination of long coupled pumps with modern cartridge seal technology. However, the author's company has supplied significant populations of seals to this type of equipment, on both installed mature machines and new machines. A survey at one major UK water authority of seals returned in the repair cycle was made. Serial numbers of seals were examined to establish date of supply and it is was not uncommon to find that seals had been in the field in excess, in many instances, of 10 years and on average, well over 8 years. It is therefore safe to assume that dry well, long coupled pumps installed life probably exceeds 25,000 hours, even assuming an intermittent duty and stand by installation or 30% utilisation.

3.4 Submersible pumps reliability

The data available for installed life of submersible pumps is also extremely imprecise. The author has no knowledge of any studies being published. However, two sources from different UK water companies have both reported very similar results. 36 months appears to be the accepted industry norm for installed pump life. This well exceeds manufacturer's warranties of 12 months. However considering a typical intermittent duty, standby operation this would indicate an estimated life of less than 8,000 hours. This is by far behind other modern process industries and also water industry, long coupled pump sets.

Over the last two decades, submersible pump populations have steadily increased. Many factors have influenced this such as, simpler pumping station design and simplified replacement of old pumps. Repair of submersible pumps being a complete unit is easily outsourced; this has also motivated users towards this technology.

However, the installed life and run time of these pumps has not been challenged. A three-year life expectancy is accepted as a norm. Pumps are more frequently returned the Original Equipment manufacturers (OEMs) for repair and there is an increasing trend for the OEM's to provide replacement, rather than repair. The author is not aware of any major user who is implementing a strategy to break this cycle, improve installed life and reduce pump costs.

3.5 Submersible pump populations waste water industry

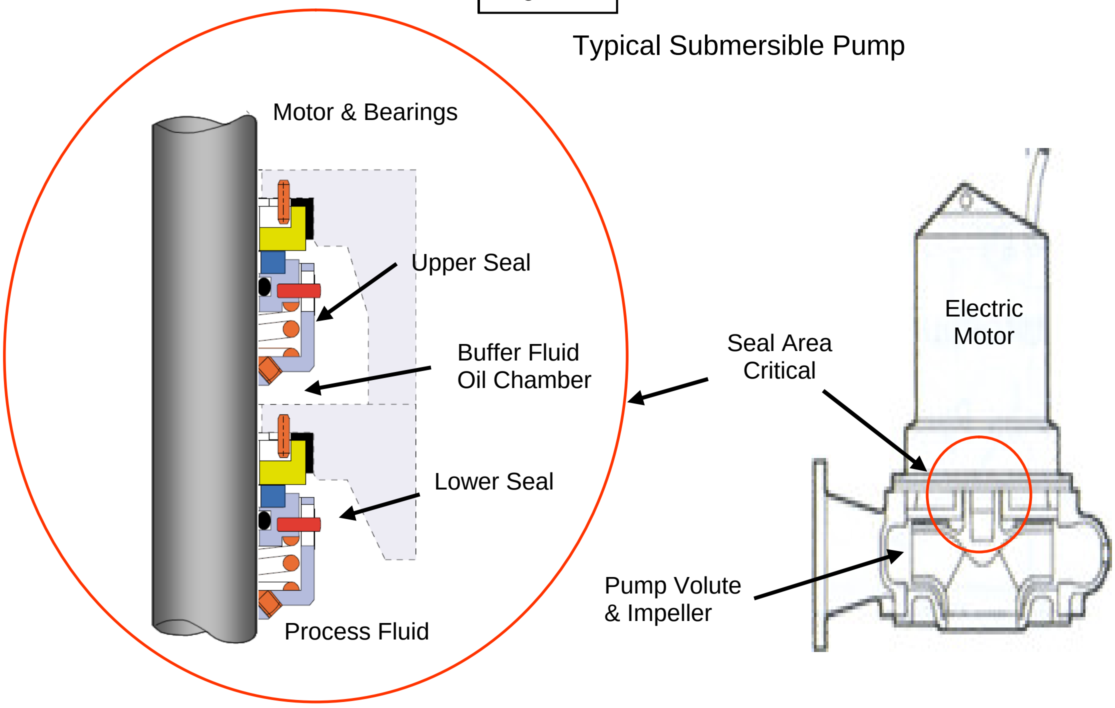
There is little data available or published on the installed population of submersible pumps. The author's own estimations are that in urban areas, submersible pump populations are approximately equivalent to 800 units per million head human population. In more rural areas, typically smaller units are employed with perhaps 1800 pump units per million population served.

3.6 Root cause of premature failure of submersible pumps – Sealing devices

The majority of pumps are removed are due to water ingress into the motor windings. Damage can be, in some instances, limited to just an electrical grounding. Sometimes the failure can be catastrophic where electric motor bearings have seized due to water contamination & consequently damaging many other pump parts. Therefore, it is fairly obvious that the most critical component within a submersible pump is the device that prevents water ingress into the electric motor, the mechanical seal (figure 3). Increase the life expectancy and performance of this component and the life expectancy of the entire machine will be improved.

Figure 3

Typical Submersible Pump



3.7 Consequential costs of seal failure in submersible pumps

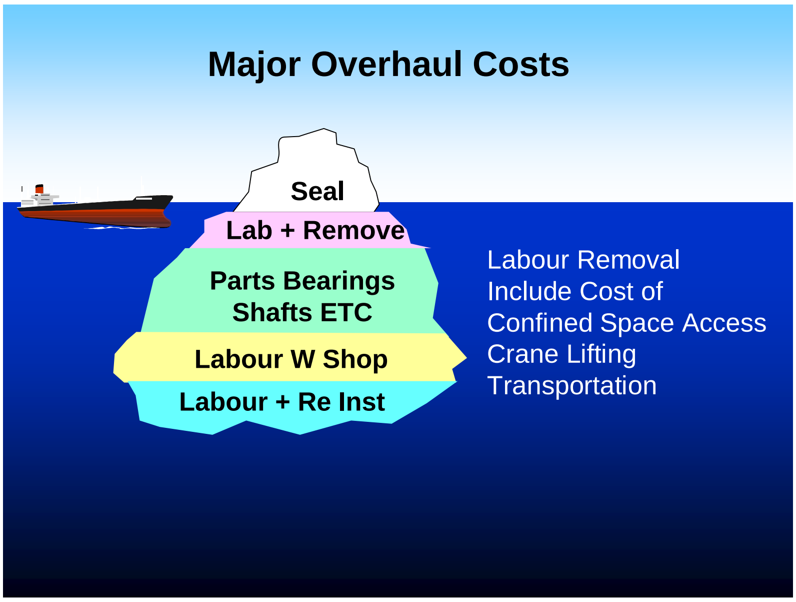
The cost of the sealing devices used in a submersible pump is relatively small with the component price being perhaps a few hundred pounds. However, the consequence of a seal failure is very significant. Costs include removal of pump from a hazardous area, transportation of the pump back to a central workshop or central contractor, stripping & removal of damaged components, replacement of damaged spare components, re-assembly, pressure testing, transportation back to site and then finally installation and commissioning of the repaired unit. The cost of the seal is the tip of the iceberg (figure 4).

3.8 Industry Standards

It is surprising that little reference is made to the submersible pump sealing device in any industry specifications or standards. The industry standard 'Sewers for Adoption' (reference 6) makes reference to bearing life of submersible pumps but no reference to expected seal life. There is little relevance to any standard specifying 100,000 running hours for bearings when seal life is likely <10% of predicted bearing life.

By comparison the American Petroleum Institute (API), which is the standard's body for equipment in the Oil & Gas industry, has a very exacting (185 page) standard for pump sealing devices. API standard 682 (reference 7) has now been adopted in an ISO format, ISO21049 (figure 5). The standards objective is a seal design life of 25,000 running hours.

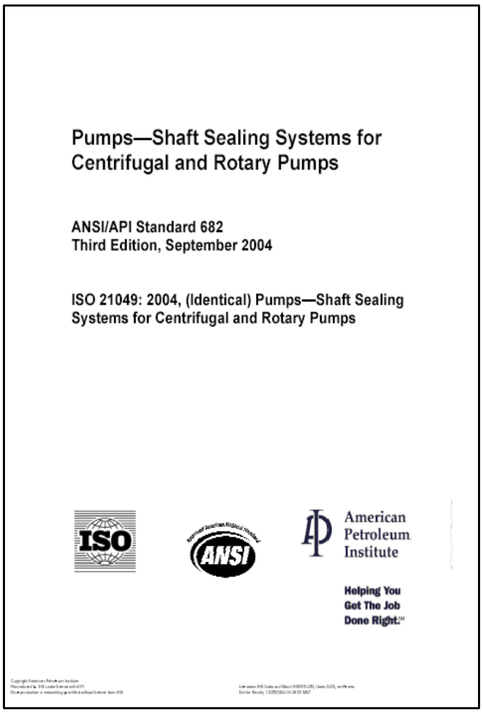
Figure 4



3.9 Industry Complacency or lack of true competition

The question has to be asked that because the water industry sector does not attend to this level of detail on critical components in pumping equipment, then has the industry got its

Figure 5



Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps

ANSI/API Standard 682
Third Edition, September 2004

ISO 21049: 2004, (Identical) Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps

ISO ANSI American Petroleum Institute

Helping You Get The Job Done Right.

costs under control? Competition in other industry sectors has forced pump users to improve pump reliability, thereby providing lower cost goods to the market place. With the lack of competition in the water sector, does the customer base enjoy the most competitive rates?

4 Strategies for improved sealing performance.

4.1 Understanding the Achilles heel can lead to improvements.

Sealing devices are the critical component, understanding how the device functions is paramount to understanding or exploring methods of improving the device. Mechanical seals are used where the impellor drive shaft penetrates through a pump volute casing. A mechanical seal is made up of two

sealing rings (one rotating one stationary) whose faces are lap polished. The sealed fluid will form a film between the two faces; most seals are designed so that the faces operate in a mixed lubrication regime with asperity contact (figure 6a). A spring mechanism allows one of the sealing rings (traditionally the rotating element) to axially float on the shaft, to compensate for face wear or shaft movement due to bearing clearances. A very small amount of fluid will pass across the sealing rings so all mechanical seals leak to some extent. On surface mounted pumps in water services the leakage will be in vapour form.
An O ring, or similar elastomer, seals the rotating sealing ring to the sleeve. The stationary mating ring would be similarly sealed to the pump casing (Figure 6b)

In a submersible pump, two seals are used in tandem (see figure 3). The chamber between the two seals should be filled with oil (buffer fluid). This serves two purposes, firstly to lubricate the seals in the event of a pump running dry and secondly, to form a liquid barrier between the process fluid and the electric motor. The lower seal is sealing process liquid under pressure and the upper oil buffer fluid un-pressurised.

Figure 6a

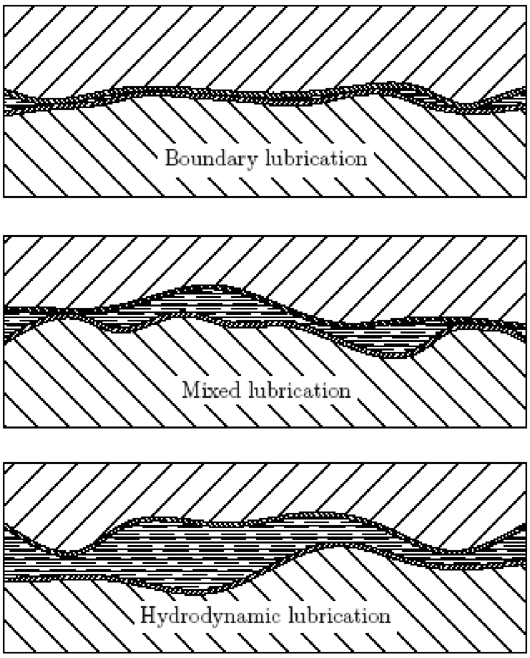
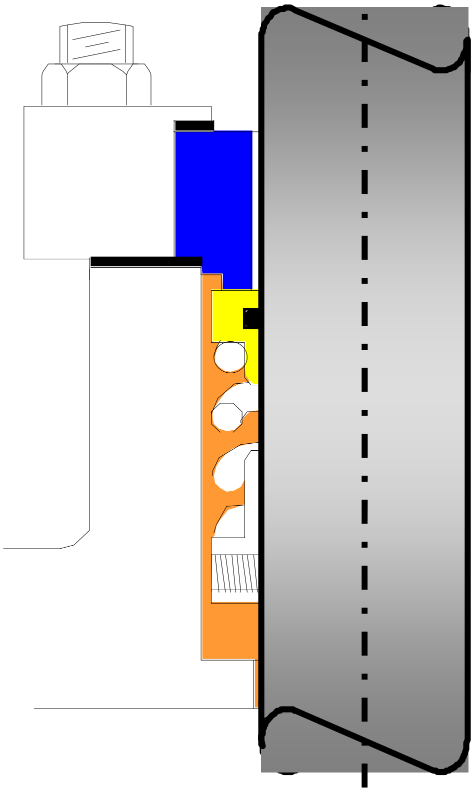


Figure 6b

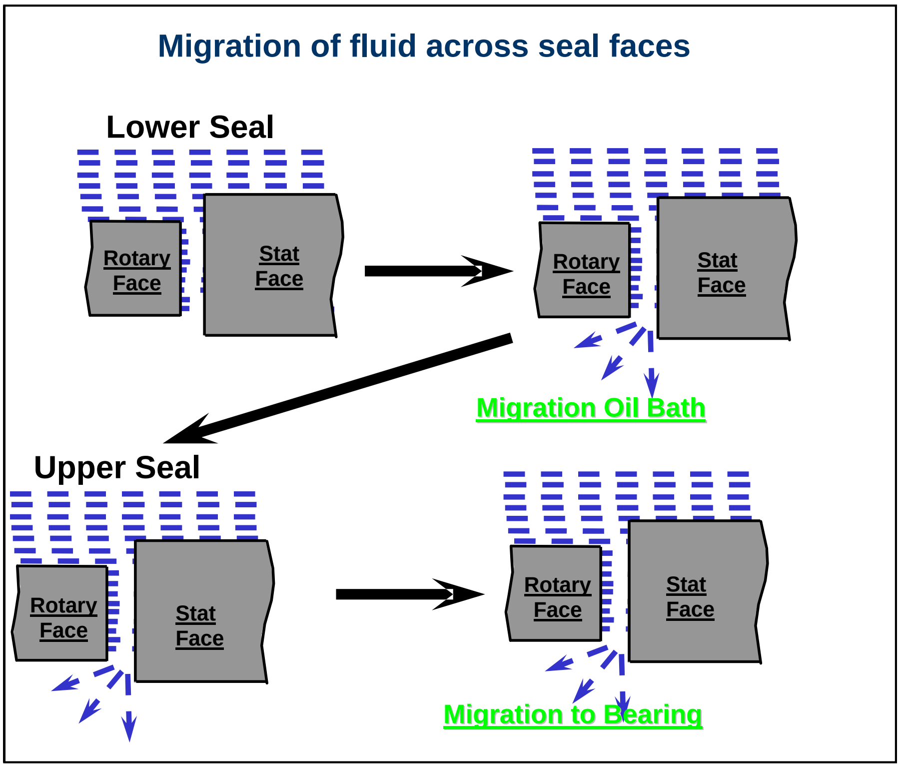
Basic Seal



Over time migration of the process fluid across the inner seal contaminates the seal and eventually the contaminate oil becomes pressurised as well. This contaminated oil then starts to migrate across the upper seal and into the electric motor and bearing chamber (Figure 7). This is a slow process, however, over time, migration will occur. Many submersible seal designs are designed to work on reduced fluid film conditions, or boundary lubrication, this reduces leakage however significantly increasing wear rates. Contaminated water oil mix entering the electric motor will eventually cause failure.

Many manufacturers of submersible pumping equipment state that in their maintenance manuals, pumps should be lifted periodically and the oil in the chamber replenished with fresh oil. Typically, this period is 12 months and an analogy could be made to changing the oil in the engine of your motor car on a regular basis. However, it is apparent that this best practice is widely ignored. Reduced manpower in water companies and remote locations of many pumping stations make the cost of this maintenance extremely high.

Figure 7



4.2 Strategies for improved sealing performance – materials.

Mechanical seal technology continues to develop with better understanding of the dynamics of fluid film under the seal faces. Many of the existing submersible pumps sealing devices are of relatively simple designs. Single coil spring housed in plastic holders with seal faces of relatively low cost unsophisticated face materials. Single coil springs do not provide optimum seal face loading around the circumference. Improved seals would use a nest of multiple springs. Plastic hardware is prone to mechanical failure especially on arduous stop start duties, Reverse rotation can occur if pump non-return valves are not installed on the discharge. Damage to plastic drive mechanism is common, causing the springs and seal faces to hang up increasing leakage or in extreme case complete loss of seal face drive. Stainless steel or similar hardware will eliminate many of these issues (figure8).

Low cost face materials are commonly used to keep the overall cost of the complete pump sets down. Many submersible pumps are bought on a price basis; therefore there is little motivation for pump manufacturers to spend any more on these components than is necessary. The only motivation is to exceed the warranty period, or achieve the accepted industry norm for life.

Stainless steel hardware is specified in other industries for mechanical sealing devices. Robust drive mechanisms increase seal life and prevent failure. Modern carbide face materials are readily available. More sophisticated materials will provide improved life in marginal fluid film lubrication regimes. Multiple sprung sealing devices will have a significantly more controlled spring rate, again improving seal face fluid film conditions in marginal lubrication regimes. Improved seals have been on the market now for many years, there have been many recorded example of improved life.

Figure 8

Typical seal plastic hardware

Alternative design with heavy duty stainless steel

4.2 Back to back testing

Testing has been undertaken to benchmark the performance of an advanced alternate AESSEAL® T05GT 20mm seal against that of the original equipment manufacturers (OEM) seal for a common

Table 1

Product:	Water	**Run type:**	Bi-Cyclic		
Temperature:	40°C (max)	**Parameters**			
Pressure:	4 Bar g (max)	**Forward rotation:**	30 sec	**Pause:**	5 sec
Speed:	3,400 RPM	**Reverse rotation:**	30 sec	**Pause:**	5 sec
Daily runtime:	7.0 hours	**Total test duration:**	417 hours		
Daily cycles :	360	**Total N$^{o.}$ of cycles:**	21,445		

submersible pump. The test objective was to determine specific performance characteristics 'head-to-head'. In terms of construction, the alternative product includes all-metallic materials for the drive and housing component whereas the OEM design has plastic parts (housing and drive). The alternative design also has (as standard) Solid Tungsten Carbide (STC) versus Silicon Carbide (SiC) as the face combination, where as the OEM seal utilised ceramic versus ceramic.

Testing was carried out on a purpose built test rig (Figure 9) with the OEM seal mounted on the drive end (DE) of the test rig and the alternate design mounted on the non drive end (NDE). Test parameters (detailed in table 1) were generic for the 3 individual tests undertaken, which included cyclic bi-directional rotation and conditions to simulate accelerated wear, and totalled +400 test hours. The test media was water, albeit no solids were introduced (due to the nature of the test equipment).

Figure 9

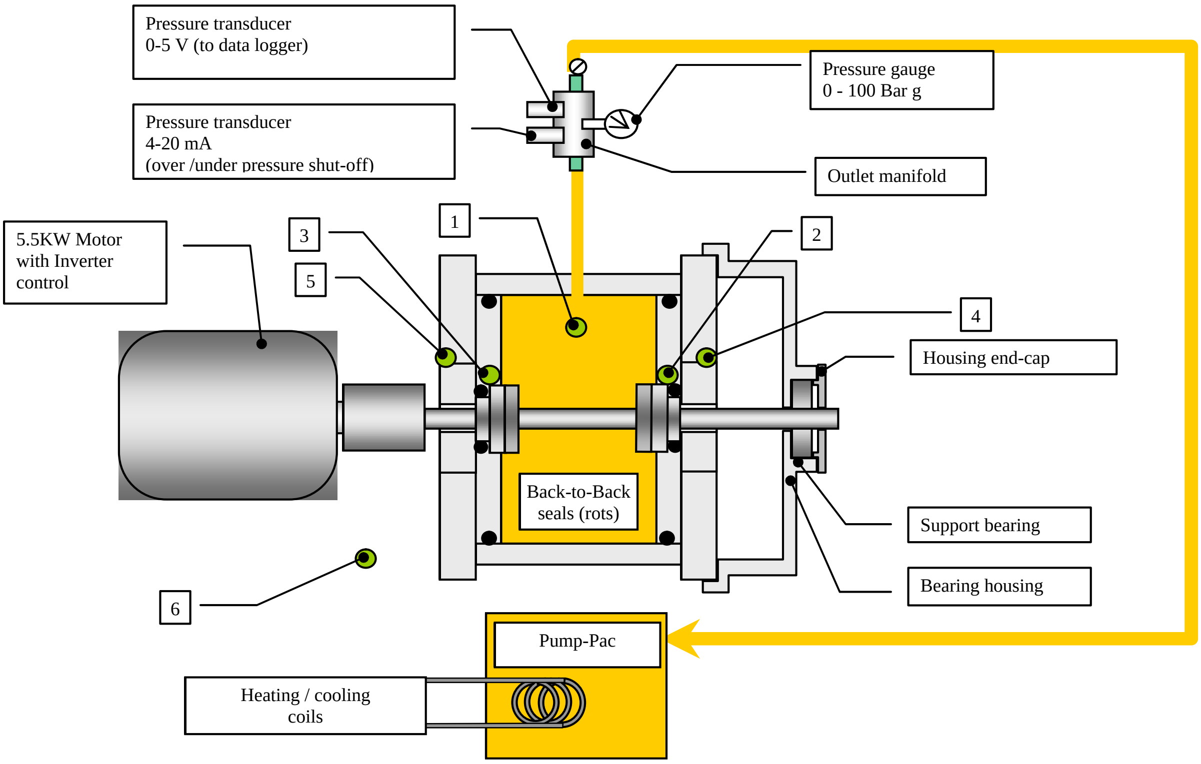


Figure 10a

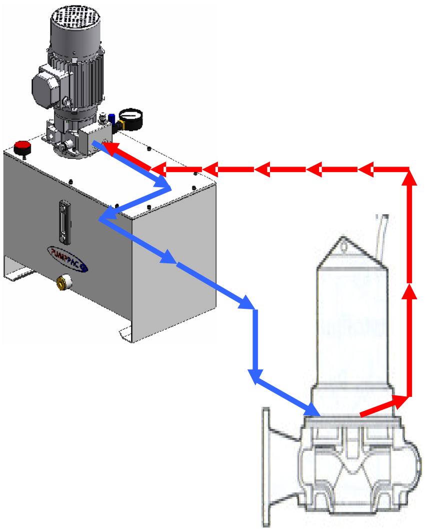
Figure 10b

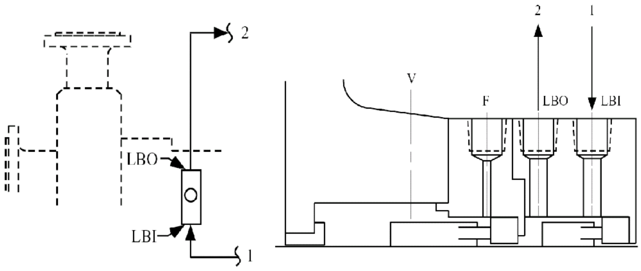
Figure 10c

4.3 Test Results Summary

Steady leakage of ‘ceramic slurry’ was observed (on one test after two days figure 10a) from the DE seal set and continued throughout the duration of the tests. Examination of seal faces post test exhibited extreme wear (average wear 0.7mm figure 10b) and loss of surface finish. The NDE seal set remained *leak-free* throughout the duration of the test and on examination of faces revealed minimum wear (figure 10c).

Figure 11





API Plan 54
Pressurised external barrier fluid reservoir or system supplying clean fluid to the seal chamber. Circulation is by an external pump or pressure system.

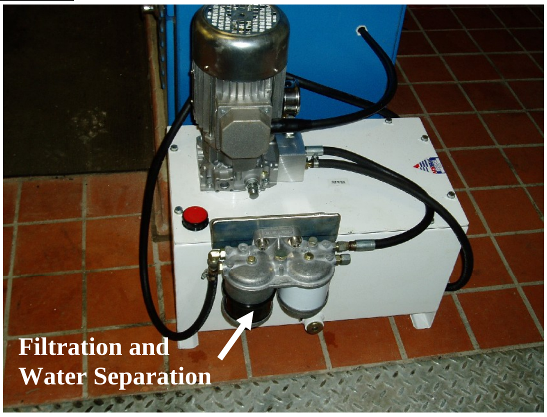
4.4 Strategies for improvement - continual monitoring & replacement of oil.
Contamination and pressurisation of the oil chamber is the primary cause of pump failure. If the oil can be changed regularly, then it is possible to extend seal pump set life. With pumps used on the surface on a conventional process plant, the oil or ‘buffer fluid’ would be circulated through a separate reservoir. This would be known as an API piping plan 54 and the international standard recognise that this arrangement can provide the most reliable systems. The condition of the buffer fluid can then be monitored and replaced via the reservoir relatively simply.

Figure 12

A similar result can be achieved on a submersible pump set by connecting the oil chamber through flexible hosing to a surface mounted reservoir (figure 11). Hosing would be conveniently clipped to the existing umbilical. The surface mounted reservoir or tank would have a self contained circulating pump. The oil buffer fluid volume will be significantly increased from a couple of litres, to 25+ litres. With an oil filter and water separator fitted in the circuit, then the circulated oil in the seal chamber will be cooled and uncontaminated. This is an idealised seal environment. Any oil migration from the low pressure oil chamber through the upper seal to the motor will be clean fresh oil and therefore, pump life will be extended. Replenishment or changing of the oil can now be undertaken at the reservoir on the surface thus simplifying maintenance. Monitoring of the oil condition and filtration can be undertaken on the surface. However, with such a large volume of oil now in the reservoir, oil replenishment or oil changing will probably be unnecessary.

4.5 Case study oil circulating reservoir system
The proposed system has been installed to a submersible pump in a UK water company. Historically, the pump had been continuously problematic. Figure 12 illustrates the condition of the oil chamber when the pump was initially stripped for rebuild, clearly water ingress has occurred. Removal of the pump was frequent with a typical installed life of less than 6 months. There were frequent issues with warranty claims with the pump repairer and with high costs both to the pump repairer and the water company.

Figure 13



An oil circulating reservoir system and upgraded mechanical seals were fitted to the pump (figure 13). The reservoir and circulation system was located on the surface next to the control panel. The pump and reservoir system has now been in service for 18 months. There has been no failure of the pump set and the package, as a whole, has performed faultlessly during this period. The costs of this upgrade retrofit are relatively low with virtually no increase in costs on the upgrade of seals and reservoir circulation system costing less than £2,000 installed. The investment is low. The cost of removal and stripping and rewinding and replacing this pump exceeds the cost of the investment. Therefore, in this particular example payback has been within 12 months. It is envisaged that any problem pump area payback for such an upgrade would be very short.

5 Cost benefit – a macro view.
For every million human population served, an estimate of submersible pump population would be 1200 pumps. With an average installed life of three years, 400 pumps will be requiring replacement or repair. With total costs for removal, repair, replacement, re-installation, re-commissioning being £1,500 per unit, the repair bill would probably exceed £600,000. A simple doubling of pump installed life will reduce the repair bill by 50%. This will amount to several pounds per head of population. Doubling of pump life from 8,000 hours to 16,000 hours is possible and does not represent a quantum leap. 16,000 hours is still, by modern industry standards, a poor life for pump machinery. The saving potential available to any large water company with several thousand submersible pumps may well exceed £1,000,000.

6 Conclusions
Performance measurement, techniques of rotating equipment within the water industry can be improved to assess the reliability of plant. Improved methods and measurements will identify problem areas of plant. Technology exists for making significant improvements particularly in problem plant areas. A significant improvement is possible which will have a dramatic impact on operating costs of water businesses. Consequential savings go straight to the bottom line. Other benefits include safety due to a reduction in activity in hazardous areas; also increased pump life will reduce flooding risks to industry upon multiple pump failure.

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