Applying low emission API compliant sealing technology to mature pump machinery

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ABSTRACT

Many of the developed world's refinery and petrochemical processing plants were built over 30 years ago. The industry, through good maintenance practices, achieves high levels of reliability from pumps and sealing devices. The high cost of replacing pumps and the dependability of existing machines has restricted the wholesale replacement of these mature assets. Consequently, there are extremely large populations of pumps and seals operating today whose designs date back to the 1960's.
The mechanical seals fitted on these old generation machines will, in many instances, no longer meet current regulatory requirements in terms of emissions or best practice in terms of safety. Upgrading these machines to modern sealing devices is becoming an increasing requirement. Many engineers wish to incorporate the API 682 mechanical seal standard in the upgrade process. On paper this sounds relatively straightforward, however in practice, this is fraught with difficulties. The physical size requirement for modern mechanical seals does not lend itself to the installation on old machines. Pump modification or replacement to accommodate modern seals can be at considerable cost and/or interruption to production. The paper will explore some of the areas of difficulty and provide some ideas for potential economic and elegant solutions.

1 MATURE PUMPING MACHINERY

1.1 Age profile
Major oil refineries & petrochemical complexes across the developed world are ageing. A review of the UK's refineries indicates that most were built over 40 years ago. New equipment has been installed in subsequent major expansions programmes. The majority of these newer installations occurred when most of today's engineers were at the beginning of their careers. Table 1 illustrates the vintage of oil refinery installations across the UK. This age profile would be typical of most complexes across the developed world.

1.2 SABIC UK Petrochemicals NE England
The Wilton petrochemical complex in the North East of England was built by Imperial Chemical Industries (ICI) who, at the time, were a giant in this field. The site has had many changes in ownership over the decades, however much of the original rotating equipment installed is still operating today. (Figure 1)

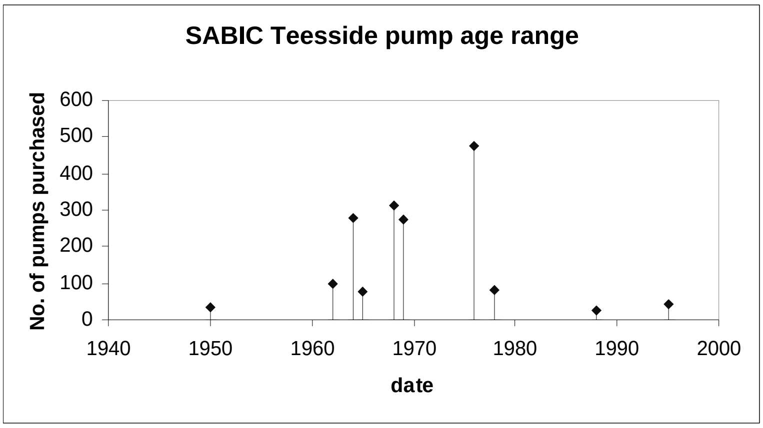
1.3 Pumping technology development hydrocarbon sector
Over the last 50 years, there have been quantum leaps in technology. A typical example being the audio industry where new technologies have emerged that completely replace old formats, rendering them redundant.

Table 1 UK Refineries

UK Refineries	Built	Major Expansions
Dundee	1939	
Grangemouth	1921	1948, 72, 89, 96
North Tees	1966	1971, 86, 96
Killingholme	1966	1981, 86
Coryton	1953	1982, 89
Fawley	1949	1951, 66
Pembroke	1964	1973, 82
Milford Haven	1973	1981
Stanlow	1929	1968, 72, 84
Eastham	1966	1989, 90

There has been no such step change in centrifugal pump technology with the performance ultimately limited by hydraulics and the laws of physics. Pump machinery in the Hydrocarbon sector tends to be well maintained with ultimate life exceeding 50 years. With a high cost of replacement, economic justification of wholesale replacement of older generation pumps is therefore difficult. Efficiency improvements offered by modern machines will often not provide an adequate financial return. Consequently, there are many hydrocarbon-processing plants operating pumps reliably and safely that date back to the 50's, 60's, 70's and 80's.

Figure 1



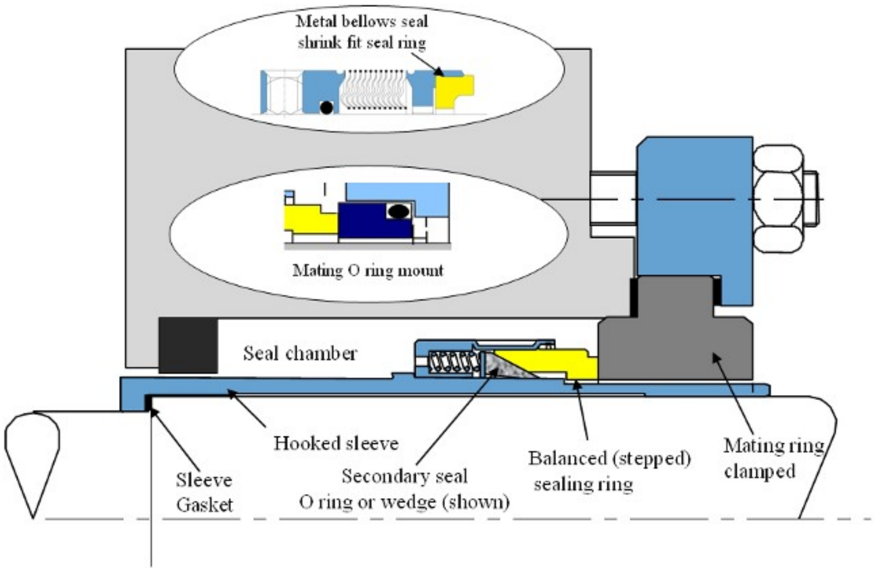
1.4 Sealing technology historically used

Typically hydrocarbon industry pumps would have been furnished with single component mechanical seals where the rotating drive shaft penetrates through a pump casing. These seals are made up of two sealing rings (one rotating one stationary) whose faces are lap polished. Most seals are designed so that the faces operate in a mixed lubrication regime with asperity contact. The spring mechanism allows one of the sealing rings (traditionally the rotating element) to axially float on the shaft, to compensate for 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. Depending on the fluid being sealed the leakage may be in vapour form or visible droplets.

Typically seals were normally fitted over a stepped pump sleeve that provides a reduced area for the sealing fluid acting on the back of the seal. When this area is less than that of the seal face, the seal is termed a balanced mechanical seal. Balanced mechanical seals provide reduced wear and increased life. The sleeve would typically be abutted against the impeller and clamped against a shaft shoulder thus providing drive.

A gasket would normally be installed, preventing leakage. This so-called ‘hooked sleeve’ may also have been designed so that the back of the seal is abutted to a shoulder OD, thereby setting seal length. An O Ring or a PTFE seal would seal the rotating sealing ring to the sleeve. An alternate method would be to use a metal bellows rotary seal with, typically, a shrink fit sealing ring (face). The stationary mating ring would be sealed to the pump case and gland plate by gaskets, so called clamped seat or mating ring, or alternately to the gland plate with an O ring. (Figure 2)
In many cases this type of seal has probably provided old type machines with reliable service over the previous decades. Requirements now in terms of emissions, regulatory or best practice, have changed with traditional seals no longer compliant.

Figure 2



2 STRATEGIES FOR REDUCED EMISSIONS

2.1 Drivers for change
Across the world the containment of hazardous or toxic fluids is an increasing regulatory requirement. Compliance in many parts of the world is strictly policed. With increasing public scrutiny some operators have elected to implement even higher standards illustrating their corporate responsibility & reducing environmental impact. Regulatory bodies include integrated pollution protection and control (IPPC) in Europe & the environmental protection agency (EPA) in the USA

2.2 API 682 designs & adoption
In 1994 the American Petroleum Institute published its first international standard (API 682) written for pump sealing systems in the petroleum, natural gas and chemical industries. One of the primary objectives of the standard was the reduction of emissions to the atmosphere. The standard is now on its third edition and identical to ISO 21049 (2).

API 682 specifies that all seals regardless of type or arrangement shall be of cartridge designs and defaults to carbon versus silicon carbide faces. Traditional hook sleeve arrangements are excluded as they are prone to assembly errors with potential for leakage under the sleeve gasket. According to the standard clamped mating rings are also to be avoided as they can distort under gland plate loads causing flatness issues, thus increasing leakage rates. Resiliently mounted faces utilising FKM O rings prevent this. Pusher seals are preferred to bellows seals for duties <176°C, generally bellows seals have a shrink fit a seal ring. Differential expansion of components in shrink fit designs can cause distortion of the seal ring, increasing leakage.

Whilst the standard is now virtually universally applied on new installations in hydrocarbon services, it has been less widely adopted on old machines, despite this being one of the aims of the standard.

2.3 Field studies

A survey carried out in 1994 (reference 1) by the Chemical Manufacturing Association of America (CMA) and the Society of Tribology and Lubrication Engineers (STLE) concluded that cartridge seals have lower emissions than component seals (Table 2). Lowest emissions of all could be achieved by using double cartridge seals. The survey also concluded that seals furnished with carbon/silicon carbide seal faces & elastomeric secondary sealing components would have lower emissions than other material combinations.

Table 2 STLE / CMA field Study

	N	Leakage gr/hr
Non Cartridge Single	555	3.22
Cartridge Single	31	1.18
Non Cartridge Double	11	0.73
Cartridge Double	33	0.45

N = Number of Tests In Subcatorgory

2.4 Seal arrangements

API 682 defines a single cartridge seal as an ‘Arrangement 1’. Dual seals are defined into two groups

Arrangement 2: Seal configuration having two seals per cartridge assembly, with the space between the seals **at a pressure less than the seal chamber** pressure.

Arrangement 3: Seal configurations having two seals per cartridge assembly, utilising an externally supplied barrier fluid at a **pressure greater** than the seal chamber pressure.

The principal difference between Arrangement 2 and Arrangement 3 is the concept of containment of process fluid leakage (emissions) versus the elimination of process fluid leakage with the arrangement 3.

2.5 Arrangement 2

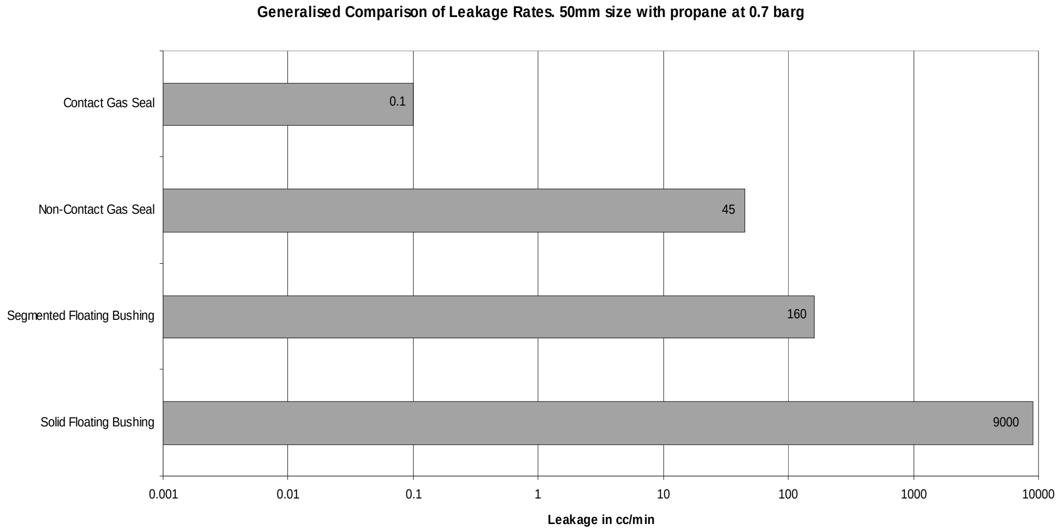
Containment seals were traditionally wet contact ‘tandem seals’. These would normally be connected to a seal reservoir and vented to flare (API plan 52). Over the last decade, the mechanical seal industry has produced a range of dry running containment seals. The containment chamber will be connected to a vapour recovery system (API Plan 76) or a contained drain system (API Plan 75)

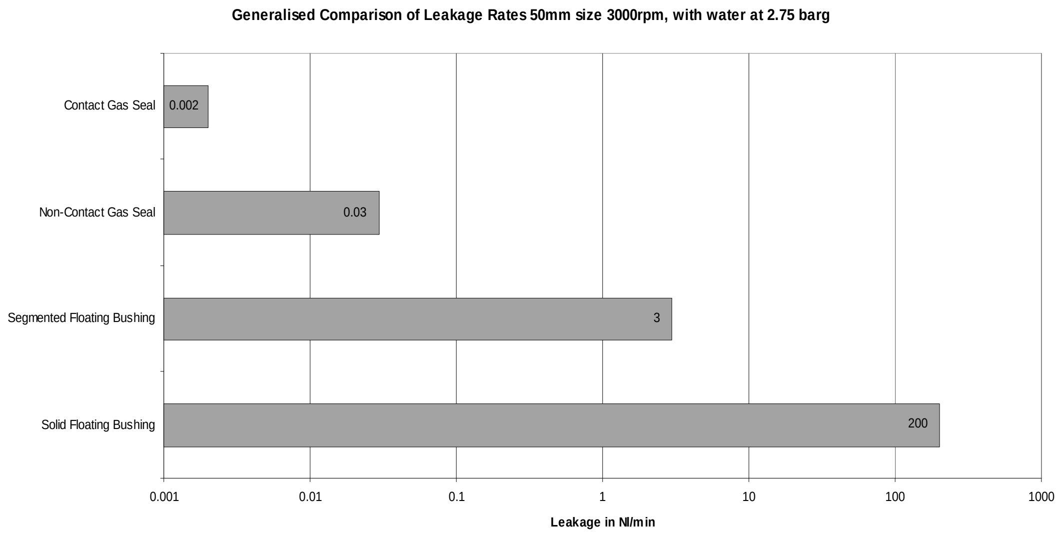
Two variants of containment seal exist, contacting and non-contacting. The latter device has significantly higher leakage rates in normal operation, (reference 1) In the event of a primary seal failure the leakage can be considerable if in a liquid phase. (Figure 3). A nitrogen quench can be introduced (API Plan 76) to help ‘sweep’ normal leakage to flare.

2.6 Arrangement 3 seals

These can utilise contacting wet faces using a liquid barrier or non-contacting faces and a gas barrier fluid. There are several liquid piping plans used to support contacting wet seals but the most common today is probably API plan 53B. This is often selected due to reduced requirement for instrumentation. Non contacting arrangement 3 seals with a gas barrier fluid will use API Plan 74.

Figure 3 Containment seal leak rates (reference 3)





2.7 SABIC Containment seal strategy - Bang for your bucks

The SABIC sites in the NE of England are fairly unusual in that a vapour recovery system is often not available locally to the pumps. When considering seal upgrade options for hydrocarbon pumps, it is very often possible to achieve zero emissions. This can be done using a pressurised double seal with either a liquid or gas barrier, or ultimately with a canned or magnetic drive pump design. The cost of these options is high, especially when the cost of instrumentation, services and cabling are considered. If a modern single cartridge seal can deliver low seal emissions rather than zero seal emissions then the problem is essentially solved. The question at this point becomes: if pump seal leakage can be reduced to the level of valve gland leakage then why spend a great deal of money to reduce the emissions to zero? Taking this approach, the upgrade option of putting in a single cartridge seal with a back up non-contacting containment seal can provide very low levels of leakage. Seal condition can then be monitored with an inter-space pressure gauge giving a very simple system with virtually no “seal system” overhead. This strategy was adopted where single seals had historically proven reliable. If the seal conditions were unfavourable then arrangement 3 seals were selected, to ensure seal face operating conditions could be guaranteed.

2.8 Comparison of different seal arrangements
The relative merits and drawbacks of differing seal arrangements are tabulated in table 3

Table 3 Seal arrangements
advantages & disadvantages

Arrangement 3 Contacting Wet API Plan 53 or 54	
Advantages	**Disadvantages**
Complete barrier	Cost, especially instrumentation
Containment in the event of inner seal failure	Complexity
Protection against poor vapour pressure margins	Maintenance Barrier Fluid Level
Avoids problems with dirt contamination in the process	Increase power consumption
Protection the event of barrier fluid pressure loss or process upset (face to back configurations)	Possible systems footprint on retro fits
Dry running protection	Contamination of process material with barrier fluid (minute)
No flare or vapour recovery connection required	

Arrangement 3 Non Contacting API Plan 74	
Advantages	**Disadvantages**
Complete barrier	Seal failure in the event of barrier gas pressure dip below process pressure
Protection against poor vapour pressure margins	Barrier gas pressure may require boosting
Lowest power consumption	Contamination of process with barrier gas
Dry running protection	Barrier Gas Leakage can cause start up issues pump priming venting
No Barrier Buffer fluid Maintenance	No protection in the event of barrier fluid pressure loss
No flare or vapour recovery connection required	Barrier Gas Leakage may need to be vented out the system downstream
	Barrier Gas consumption need constant supply

Arrangement 2 Contacting Wet API Plan 52	
Advantages	**Disadvantages**
May Offer some protection against poor vapour pressure margins	Containment of Leakage not a Complete barrier
Containment in the event of inner seal failure	Maintenance Barrier Fluid Level
Dry running protection	Possible systems foot print on retro fits
	Limited to use on light HC and connection to flare to prevent buffer contamination

Arrangement 2 Containment Seal API Plan 75 or 76 (72may be used in conjunction)	
Advantages	**Disadvantages**
Lower cost and complexity (Not true for Plan 75 condensing leakage)	Containment of leakage not a complete barrier

No Maintenance (Barrier / Buffer fluid) Not true of plan 75 where pot draining is required	Flare or vapour recovery required
	No Dry running protection
	Emissions monitoring may be required. Leakage detection and repair (LDAR)
Contacting Containment type	
Full Containment in the event of inner seal failure	Will wear over time (25,000hr) min API requirement
Very low levels of Emission	Speed or size restricted
Non Contacting Containment type	
No wear on continuous duties	Limited Containment in the event of inner seal failure, especially with condensing leakage
Can be used at higher speeds and larger shaft diameters (relative to contacting designs)	Higher levels of emissions than contacting type Emissions but can be minimised by use of plan 72 nitrogen quench

Figure 4 Classic approach to API 682 dual seal

Arrangement 2 Containment Seal Non Contacting API Plan 71 SABIC modified	
Advantages	**Disadvantages**
Lowest cost dual seal option and low complexity	Containment of Leakage not a Complete barrier
Containment in the event of Primary seal failure (Contacting type)	Emission limited to the performance of inner seal
No Barrier / Buffer fluid Maintenance	
Simple Leakage detection No Instrumentation	Leakage detection limited to visual No Instrumentation

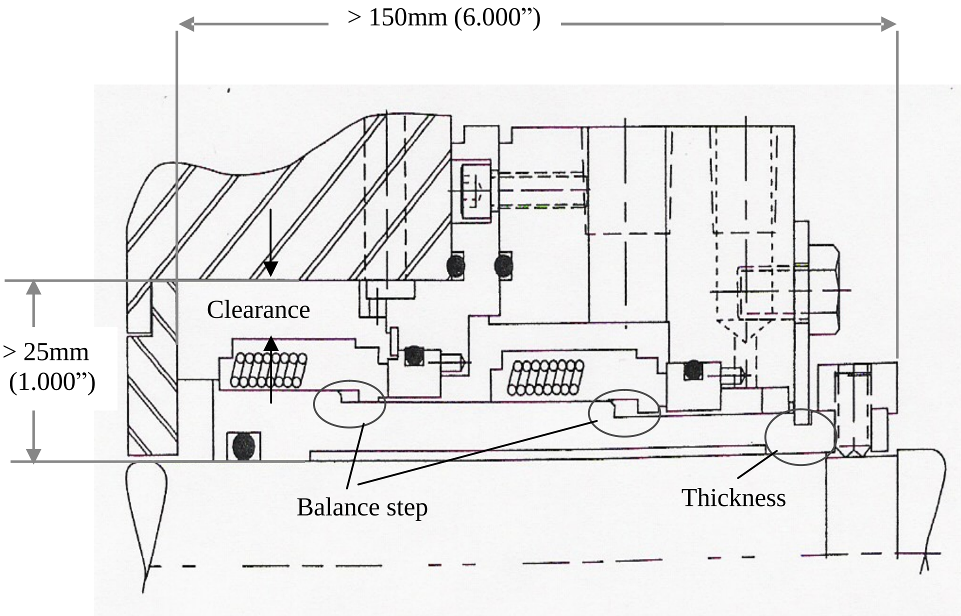
Arrangement 1	
Advantages	**Disadvantages**
Lowest Cost	No Containment in the event of seal failure
Simple Installation	Will not comply with LDAR exemption strategies. Emissions monitoring required (USA)

3 SEAL DIMENSIONS & CONSTRAINTS OF OLD GENERATION PUMPS

3.1 API 682 dual seals – Component seals with adaptive hardware

Traditional rotary component seal technologies have proven reliable in clean liquid services. Classic API 682 double cartridge seals designs have been derived from this ancestry. Mounting two component seals on a common cartridge seal sleeve and held to a gland plate with transport clips they form a seal cartridge. The cartridge seal sleeve and gland are often referred to as adaptive hardware. A typical cross section of a double API682 mechanical seal, (Figure 4) illustrates that the sleeve now has multiple steps in it to accommodate the hydraulic balance of both seals and a minimum thickness of at least 2.5mm. Combined with the requirement for 3mm clearance between the seal and the chamber bore, a minimum 25mm cross section seal chamber will be required. The seal will now have three sets of drive set screws. The first & second set will drive the component seals the tertiary set located on the pump shaft driving the complete assembly. The resultant seal cartridge axial length typically exceeds 150mm.

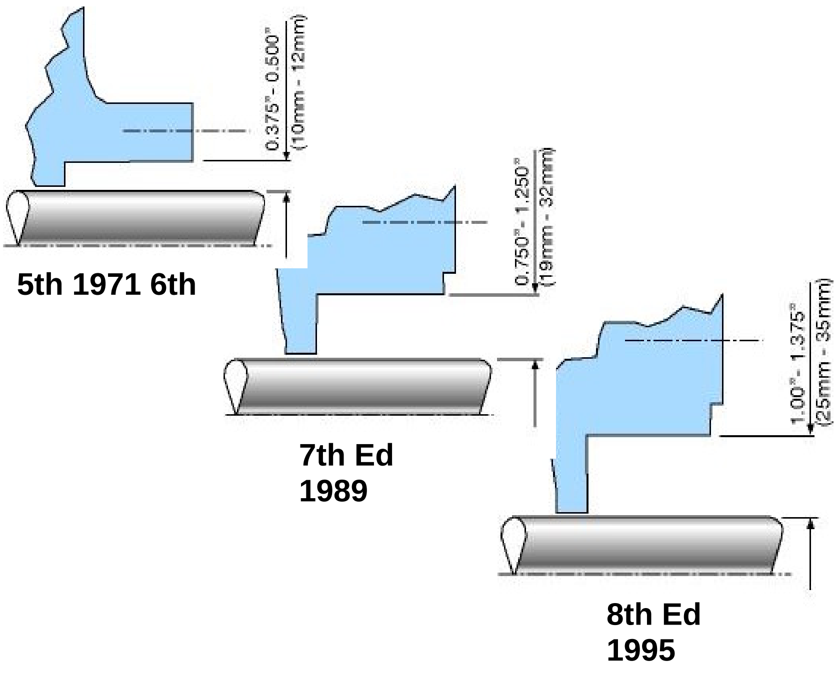
Figure 4 Classic design approach - API 682 dual seal



3.2 Seal chamber dimensions

Modern API 610 pumps are designed with sufficient space to accommodate these 'big' seals however most of this space made available is filled with metal work of the adaptive hardware. Seal chamber cross sections of early editions of API610 pumps will not be large enough to accommodate API682 'big' double seal (Figure 5)

Figure 5 Typical API 610 seal chamber cross sections



3.3 Alternate design approach, fully integrated designs

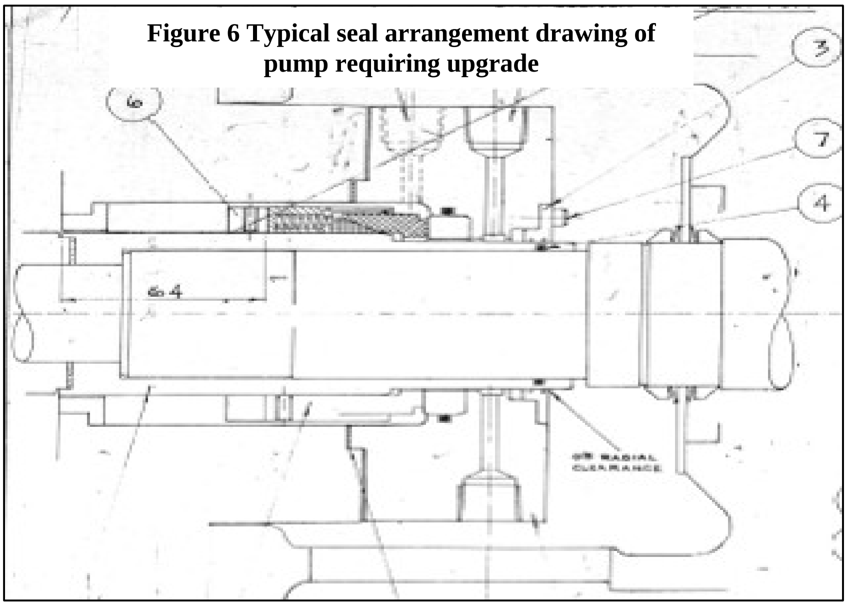
Traditionally seals have been balanced with the O ring on the inside diameter of the seal face. However, an alternate method is to mount the O ring on the outside diameter of the seal face. This has been a common practice in the Chemical Industry for the last 20 years although has as yet to be widely adopted in the Oil & Gas or Hydrocarbon Industries.

The use of modern multi axis CNC machine tools has freed up the designer's hand in that more complex shapes can be manufactured viably in low volumes. No longer is the seal designer limited to mounting component seals to simple turned stepped cartridge sleeves. Fully integrated cartridge seals where the faces

are directly mounted into cartridge components can now be easily made. The mounting of the faces directly into the seal sleeve will save on radial space. The absence of separate clamping arrangements reduces the axial length.

An API 682 Category 2 seal with 0.750" (19mm) cross section can be achieved whilst being compliant with API 682 clearance and sleeve thickness requirements. In extreme applications, seals fitted with API 682 qualified category 2 seal faces can be fitted to smaller cross sections. In these instances some exception will have to be taken to the standard.

Figure 6 Typical seal arrangement drawing of pump requiring upgrade



3.3.1 A worked example

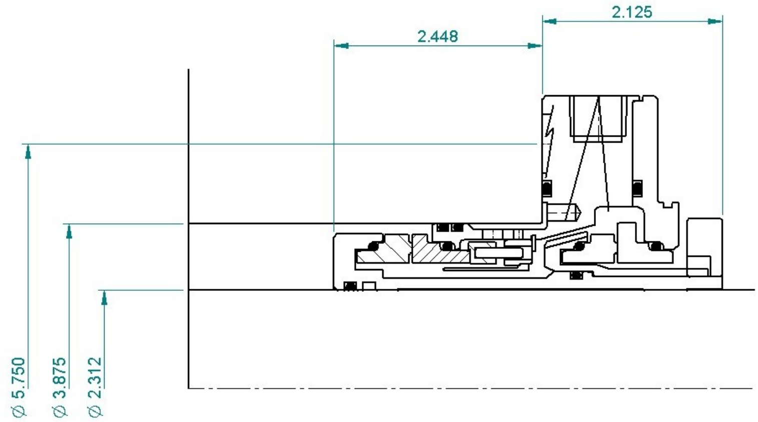
Figure 6 is a typical drawing presented by a user to upgrade to a double API 682 category 2 cartridge seal. Seal chamber bore and axial space available is challenging.

The seal chamber cross-section can be increased by the removal of the existing seal sleeve. The cartridge seal has its own seal sleeve built in so there is often no longer a requirement for a seal sleeve. Indeed, it is bad practice to run a sleeve on a sleeve, as there is a danger of a tolerance "stack up". In many instances with old machines, the end of sleeves also provides a spacer for the pump impeller and so the sleeve was cut back and retained as an impeller spacer. When the shaft sleeve is removed, the cross sectional space available in the seal chamber will typically be 19mm

Classic 'big' API Seals would require boring out the seal chamber. This may not be possible as reducing wall thickness reduces the pressure integrity, or due to proximity of a cooling jacket. Providing replacement big bore seal chamber (if available) may be one option. The axial length requirement would necessitate the expense of a modified power end. In this instance the traditional API seal would not fit, a replacement pump would have been the only option.

The alternate approach is illustrated (Figure 7) with the seal fitting in the confines of the pump seal chamber.

Figure 7 Alternate approach fully integrated API 682 Cat 2 cartridge design solution



4 UPGRADE PROGRAMME

4.1 Traditional approach

Typically a project to upgrade multiple pump seals would be to have a list of seals and then plan to carry out the upgrades to a pre-determined programme. If the aim of the project is to reduce seal emissions then this can defeat the object of the exercise – which is to reduce emissions. Many pumps working on old technology seals will be operating with very low seal emissions – typically less than 200ppm. To carry out an upgrade on such a pump means that the pump is removed from site, given a full overhaul and then recommissioned shortly afterwards. The process of removing a pump causes emissions in itself from the pump purging activities and from the material left in the pump after the purging is complete – particularly on an ambient liquid hydrocarbon pump.

4.2 Alternate approach

With over 150 pumps with Butadiene and Benzene streams requiring upgrade on the SABIC Wilton and North Tees sites a new approach has been applied. The seal upgrade project has been undertaken as part of the pump maintenance programme. At its most stretching, this has involved removing a pump for overhaul and then supplying a new seal in 2-3 weeks, fitting the seal and then re-installing the pump. More typically, the results of the emissions monitoring are used to prioritise the maintenance plan, with seals ordered while the pump is still available for operation. The pump is then declared “failed” and is overhauled by the normal maintenance team with the project stepping in during the seal removal and refitting to install and commission the new seal.

The approach provides a cost-effective way to move to upgraded cartridge seals which can offer lower emissions and better seal life. The two ways that this approach works is that the cost of the seal overhaul is carried by the normal plant maintenance budget rather than the project budget and the highest emitting seals are overhauled and upgraded first. To upgrade during a pump overhaul has been challenging for the seal suppliers, but a challenge, that has been met on several occasions. Table 4 provides details of the contractual requirements of all parties.

Table 4 Upgrade program responsibilities

Target turnaround upgrade	Critical machines 14 calendar days from pump availability
Purchasers responsibility	Provide pump seal sizes (accuracy of information can not be guaranteed)
Purchasers responsibility	Provide drawings seal chamber (accuracy of information can not be guaranteed)
Seal vendor responsibility	Attend site, measure the pump with in 24 hours of availability
Seal vendor responsibility	Deliver the new seal to workshop
Seal vendor responsibility	On delivery attend workshop to supervise the fitting
Seal vendor responsibility	Attend site to witness commissioning
Seal vendor scope of supply	Specify any pump modifications
Purchasers responsibility	Approval for any modification
Seal vendor scope of supply	Arrange and pay for any pump modifications
Seal vendor scope of supply	Supply any other parts required such as seal sleeve
Seal vendor scope of supply	Documentation, dimensioned general arrangement drawing, spares list
Cost over run	seal vendor to meet additional cost due to re-work, modification
Cost over run	seal vendor to meet cost of additional visits due to reworks
Warranty	2 years - cost of the seal overhaul
Warranty	The seal supplier will indicate the “normal” and “maximum” emissions level
Warranty	The seal will be checked for emissions within 4 weeks of commissioning.

5 CASE STUDIES

5.1 J1855 A/B/C

Emissions prior to upgrade were more than 60,000 ppm. Intermittent duty with a tendency to run the pumps dry at the end of the batch meant that the single seals were not able to run reliably. An upgrade to oil pressurised arrangement 3 seal (API plan 53b) was carried out (Figure 8). This has reduced the emissions to zero and improved the reliability (and hence purging losses). When the pumps were first upgraded, a casing leak was identified (poor casing gasket location surface finish) so the initial leak rate from the upgraded pump, with an upgrade dual seal, was 3000ppm! This had been previously masked by the original seal leak. The casing leak has since been rectified.

5.2 J1940 A/B/C

A low-pressure flare system and nitrogen supply was readily available, so a single seal with a dry running outer seal (API 682 arrangement 2) and pressure monitoring was chosen as the sealing option. The seal emissions recorded were low (<100ppm), as the pump is on an infrequent batch (ship loading) duty with the pumps isolated and depressurised when not in use. The seals had failed in normal operation and the maintenance team were replacing the seals. The new seals were installed as part of this maintenance – although with the simple seal harness arrangement, the upgrade is hardly visible.

CONCLUSION

Seal up grades can be successfully carried out on reliable ‘legacy pumps’. API 682 type seals can be applied to smaller seal chambers with little modification to the pump. Arrangement 2 dry running containment seals can simplify the process by removing the need for seal pots and their (top up) maintenance. Upgrading as part of normal maintenance is possible. Success of such a program needs responsibilities to be clearly defined and deadlines adhered too. Reduction in costs and emissions are the principle benefits.

Figure 8 Pump Tag J1855A

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