# DESIGN AND APPLICATION OF DUAL GAS SEALS FOR SMALL BORE SEAL CHAMBERS

by

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## ABSTRACT

Since the release of dual gas lubricated seal technology for process pumps over three years ago, this technology has provided a more versatile, efficient, safe, and less costly alternative to sealless pumps and traditional dual seals, primarily in the process pump market. In the past, to utilize this gas seal technology, the pump had to be fitted with an enlarged seal chamber, thus limiting its use on existing equipment and applications. Dual gas seal technology is now available for small bore seal chambers, allowing existing equipment to be retrofitted without any modifications to the pump. Discussed herein is the design, the analytical tools used in the development along with the features and benefits of the seal. Also discussed are several applications utilizing dual gas seals on small bore process pumps.

## INTRODUCTION

The impact of legislation limiting allowable emission levels from plant equipment is far reaching. Maximum achievable control technology (MACT) standards have been issued for a number of source categories in the United States, such as synthetic chemical manufacturers industry (SOCMI) and petroleum refiners.

Reduced leakage standards apply to pumps, compressor, flanges, valves, and other equipment handling volatile hazardous air pollutants (VHAPS). Controlling process plant emissions has been, and will remain, a key focus to improve the environment. Environmental regulations are striving to bring down levels of plant emissions on a global basis. Conventional single seals have proven to be very effective in controlling volatile organic compounds (VOC) emissions. On certain services, dual mechanical seals are required to reduce or eliminate fugitive emissions on rotating equipment. Up until three years ago, there were two sealing solutions preferred to meet or exceed government regulations; pressurized and nonpressurized dual mechanical seals and sealless pumps.

Pressurized dual mechanical seals require the careful selection of a barrier fluid and a costly support system to ensure proper barrier pressures and levels. Conventional pressurized dual seals operate in a "contacting" mode resulting in high energy dissipation and face wear.

Nonpressurized dual mechanical seals, or tandem seals, are used when the product cannot be released to the atmosphere and the buffer fluid cannot mix with the process. They require the nonpressurized outboard or secondary containment seal to handle full process pressure in the event of an inboard seal failure and be inline with a vapor recovery system or a closed loop system to contain the contaminated buffer fluid.

Sealless pumps are limited to fluids of medium viscosity and low solids content. They may require expensive monitoring equipment to guard against upset conditions and are incapable of running in an upset condition for more than extremely short periods.

Both solutions are still used with success, but with the introduction of dual gas lubricated seals for process pumps, a third option is now available. Over the last three years, gas seals have provided an alternative solution to conventional liquid contacting seals for controlling emissions while extending the mean time between planned maintenance (MTBPM). Gas seals offer the

safety of a pressurized dual arrangement while reducing the life cost of running the equipment.

To effectively apply spiral groove technology in process pumps it is necessary to have sealing faces of significant radial cross section. The application of this technology will, therefore, favor the use of big bore seal chambers, such as ANSI big bore and DIN 24960 Version C. Here, the seal chamber allows for, in many cases, twice the radial cross section of the standard bore seal chamber. In North America, the use of big bore seal chambers is growing at a much faster rate than in Europe, but the majority of installed pumps continue to employ narrow or standard radial cross section seal chambers. Investigation of the standard cross section bore pumps revealed more radial space outside the seal chamber or in the pump seal well. A noncontacting pressurized dual seal has been successfully designed to fit into this space while providing product containment and zero product emissions to atmosphere.

## GAS SEAL TECHNOLOGY

Satisfactory life for any mechanical seal depends on the ability of the design and the materials of construction to minimize the effects of contact friction. Without the proper design and material considerations, a seal will fail due to the thermomechanical effects of contact friction. For gas seals, the noncontacting design eliminates the contact friction allowing the seal to be used where energy levels are too high to run dry running contacting seals [1].

There are several different designs to achieve the noncontacting feature of a mechanical seal, such as spiral grooves, T-slots, and V-grooves. Mechanical seals are discussed utilizing spiral grooves to achieve face separation.

Hydrodynamic gas seals ride on a gas film generated by the spiral grooves while the shaft is rotating, as shown in Figure 1. Spiral grooves are recessed into the harder face material as it is easier to control the manufacturing process. The sealing dam is the area from the inner diameter of the spiral groove to the inside diameter of the face of the opposing ring.

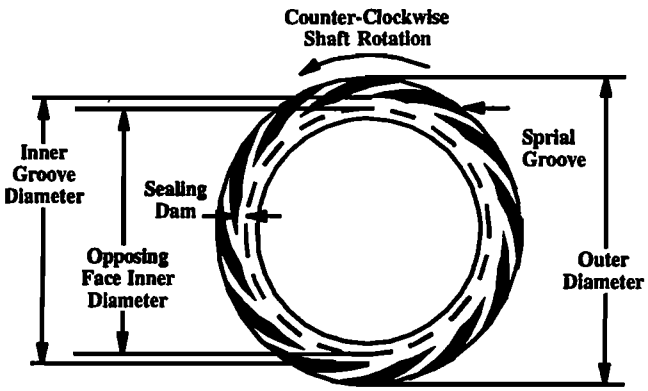



*Figure 1. Typical Stationary Spiral Groove Sealing Surface.*

Spiral groove seals operate by using the principles of fluid mechanics. As the seal rotates, gas flows into the spiral groove by a viscous shearing action and is compressed. At the sealing dam, gas is expanded. The combined film pressure results in an opening force greater than the closing force that separates the faces approximately 100 μ/in. At shutdown, hydrostatic forces along with the spring load act to close the faces. Seal balance and the design of the spiral grooves prevent damage to the faces at startup and shutdown prior to separation [2].

The sealing dam plays an important role in the performance of a gas seal. It restricts the barrier gas passing across the sealing faces and creates the pressure drop of the barrier gas. The pressure profile of a gas seal is illustrated in Figure 2. At $P_3$, maximum pressure is achieved, but a linear pressure drop across the sealing dam occurs reducing the gap and pressure differential and, thus, reducing leakage. In reverse pressure situations (discussed later), the sealing dam restricts the product from entering the barrier chamber. Illustrated in Figure 3 is the theoretical prediction of interface pressure generated by spiral grooves.

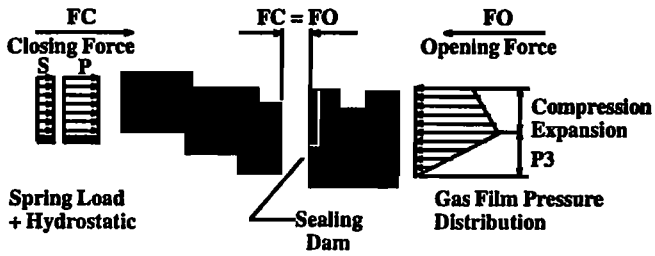



*Figure 2. Pressure Profile of a Gas Seal.*

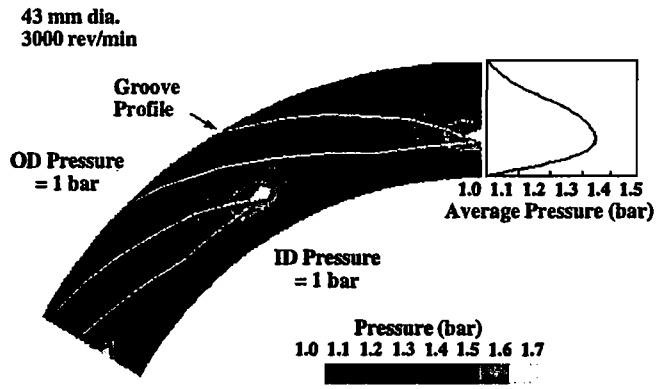



*Figure 3. Theoretical Prediction of Interface Pressure Generated by Spiral Grooves.*

Spiral grooves are designed to correspond to shaft rotation and pressure location. The spiral grooves face illustrated in Figure 1 has grooves located on the outer diameter (OD) of the ring, which indicates the higher pressure will be exerted onto the OD of the ring. The grooves are also unidirectional, meaning the grooves are designed to handle a specific shaft rotation. There are bidirectional groove patterns, but they have proven to be less efficient at lower speeds.

The sealing face incorporating the spiral groove pattern can be rotating or stationary. A stationary sealing face is illustrated in Figure 1. For stationary spiral grooves, the direction of the grooves is the same as the shaft rotation (i.e., clockwise shaft rotation uses clockwise spiral grooves). For rotating spiral grooves, the direction of the grooves is opposite of the shaft rotation. The easiest way to determine the direction of the spiral groove is, using the top groove on the sealing face, follow the gas into the groove. As it flows toward the sealing dam, which direction is it going? Down and to the right would be clockwise spiral grooves (Figure 4) and down and to the left would be counterclockwise grooves (Figure 5).

## BENEFITS OF NONCONTACTING GAS SEALS OVER CONTACTING SEALS

Eliminating contact friction on mechanical seals has many advantages, such as reduced face operating temperature, reduced horsepower consumption, and increased seal life. Figure 6 is a chart showing face temperature rise of a gas seal *vs* a conventional

contacting seal. With a 150°F temperature rise of a contacting seal, a lubrication system is required to supply coolant to the seal and remove carbon wear of the faces. When sealing light hydrocarbons, a 150°F temperature rise may result in flashing across the interface resulting in carbon ring damage, higher leakage rates, and premature seal failure.

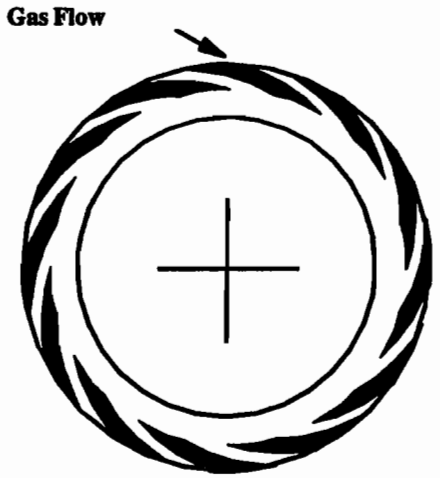



*Figure 4. Clockwise Spiral Grooves.*

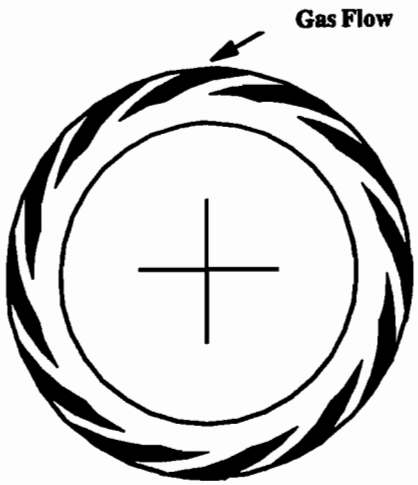



*Figure 5. Counterclockwise Spiral Grooves.*

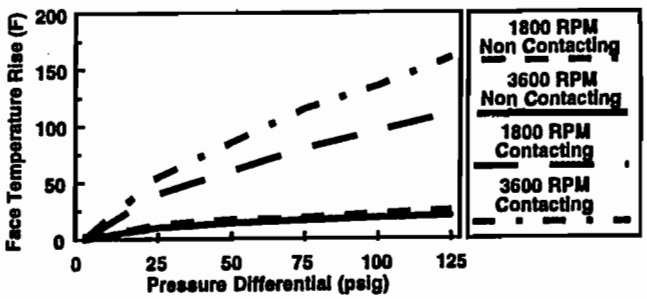
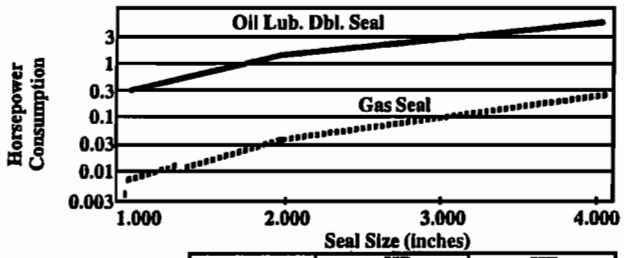



*Figure 6. Face Temperature Rise Comparison Between a Double Liquid Seal and a Double Gas Seal.*

Gas seal face temperature rise has been measured at 10°F to 20°F, at the interface. Temperature probes are located 0.062 in away from the interface into the stationary sealing face. The only temperature being created at the interface is due to the viscous shearing action of the barrier gas. This heat is dissipated through the materials of construction and by the small amount of barrier gas being pumped across the face.

Figure 7 is a chart showing the energy comparison of a dual pressurized liquid seal and a dual pressurized gas seal. Eliminating contacting friction reduces the horsepower consumption of the mechanical seal. The horsepower consumption of a dual pressurized gas seal is a fraction of a dual pressurized liquid seal. For any liquid seal, there are frictional losses that can be calculated based on friction and face velocity. There are also horsepower losses due to the viscous drag of the sealing fluid being sheared between two closed areas. For a pump this can be one to four horsepower (hp). This is called parasitic horsepower, since it is a direct drain on the main driver. Gas seals consume a small percentage of the power of a contacting seal as far as parasitic horsepower. In addition to parasitic horsepower, for pumps that have seal support systems where the reservoir is at atmospheric pressure, there is another horsepower loss, that of the pumps needed to bring the barrier fluids to the proper sealing pressure.




| Qualifications Double Seal at 200 psig 3600 RPM | Size | HP Wet Dbl. | HP Gas Seal |
|---|---|---|---|
| | 1.000 | 0.3 | .006 |
| | 2.000 | 1.4 | .040 |
| | 3.000 | 3.0 | .100 |
| | 4.000 | 5.5 | .260 |

*Figure 7. Energy Comparison of a Double Liquid Seal and a Double Gas Seal.*

A simplified barrier support system is another advantage to using a gas seal over a conventional liquid seal. The standard control panel for a dual pressurized gas seal is shown in Figure 8. Inert gas is connected to the panel and is then filtered through a coalescing element to remove moisture. The gas is then regulated and measured by two flowmeters, a high range and a low range. A low pressure alarm is incorporated to warn of the loss of barrier pressure. A high flow switch can also be incorporated to warn of a seal failure. Most plant nitrogen or air supplies are at or below 120 psig. If higher pressures are required to achieve the recommended 30 psi pressure differential, an amplifier can be added to the panel that is capable of a 4:1 pressure increase. If an additional backup system is required, an accumulator or reservoir can be incorporated into the panel to supply pressure, in the event of loss of barrier pressure, to the seal for a given period of time.

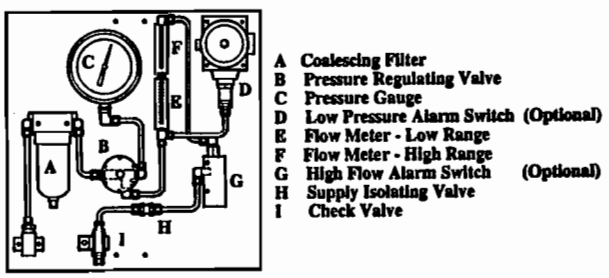



*Figure 8. Standard Control Panel for a Gas Seal.*

## DUAL PRESSURIZED GAS SEALS FOR STANDARD BORE SEAL CHAMBERS

As mentioned earlier, dual pressurized gas seals have been applied to big bore seal chambers for over three years. Although the current design covered the majority of the new pumps being installed in North America, there still remained a global market to cover existing standard ANSI and DIN bore equipment. The design challenge for meeting this new market was fitting the narrow radial cross sectional chamber while still achieving lift off or face separation.

The cross section of the sealing faces plays an important role in the performance of a gas seal. Having a larger face cross section, compared to a convention liquid seal, allows for larger spiral grooves, thus increasing pressures or loads to overcome face closing forces. Standard bore seal chambers were originally designed for the use of packing rings, hence the name stuffing box (now referred to as seal chamber). Standard seal chambers have a radial cross section around 0.375 in, while efficient gas seal will require a face cross section of the same value. Outside the seal chamber or in the seal well of the pump, there is additional radial space that allowed the seal to be designed to fit this envelope. Even though there is additional radial space, axial space is very limited.

Figure 9 is a cross sectional view of a gas seal for a standard bore seal chamber. The standard bore gas seal is a spring loaded, O-ring, double opposed mechanical seal utilizing a rotating mating ring. A single rotating mating ring is used to reduce axial space. The mating ring has the spiral grooves etched onto each side of the face and has a metal band around the outer diameter to prevent the ring from separating in the event of mechanical failure. The band is shrink fitted to OD of the silicon carbide ring. The mating ring can also be supplied in tungsten carbide. Carbon graphite is used as the standard primary ring material, but silicon carbide has been successfully applied to obtain fluid compatibility. The secondary seal material is based on fluid compatibility.

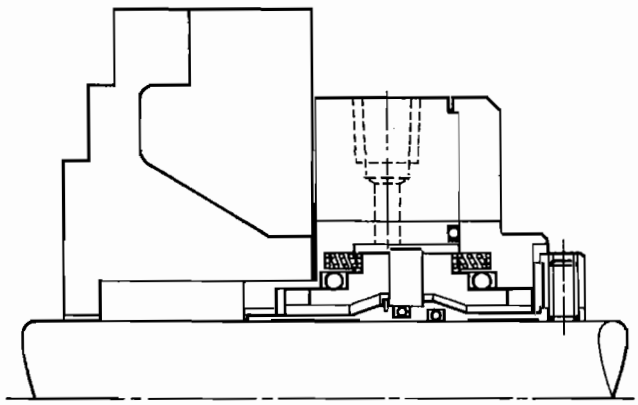


*Figure 9. Cross Sectional View of a Gas Seal for a Standard Bore Seal Chamber.*

An inert gas is pressurized between the two seal faces (barrier chamber) at 30 psi above the maximum seal chamber pressure. An inert gas is used because a small amount of the barrier gas not only enters the process, but is also released into the atmosphere. This barrier gas provides the barrier between the process and the atmosphere. As long as this pressure is present, the process will not be released to the atmosphere. If barrier gas pressure is lost, the inboard seal will close and ride on a fluid film at the sealing dam due to a balance shift in the closing forces. A normal running condition with a positive barrier pressure is illustrated in Figure 10. A reverse pressure condition with loss of barrier pressure is illustrated in Figure 11. The fluid in the reverse pressure condition exerts a closing force on the faces to the OD of the O-ring bore, which is above the groove ID. This balance shift results in 100 percent of the process pressure acting to close the seal faces, thus protecting the environment from the product. The spiral groove will act as a pumping device to keep the product from penetrating the grooved portion of the face.

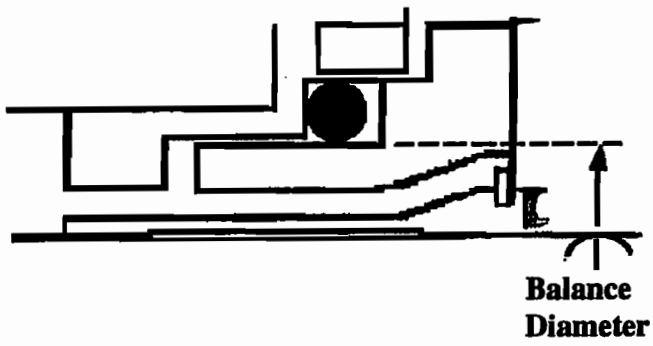



*Figure 10. Normal Running Condition with a Positive Barrier Pressure.*

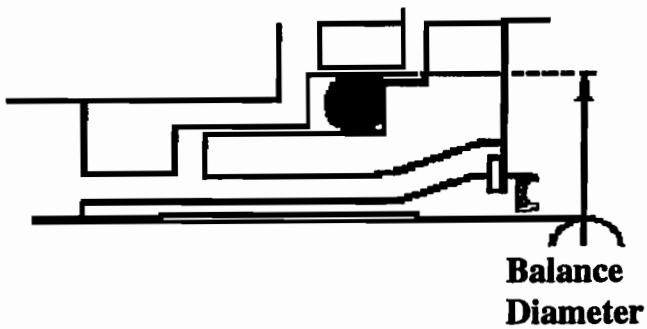



*Figure 11. Reverse Pressure Condition with Loss of Barrier Pressure.*

CSTEDY™ was used to optimize the seal design. CSTEDY™ is a proprietary finite element analysis (FEA) computer program that predicts gas seal load support and leakage. It takes into account the combined effects of pressure, temperature, materials of construction, fluid sealed, and spiral groove geometry. The program predicts the face profile and film thickness. It also predicts gas consumption, stress and distortion due to temperature and/or pressure. CSTEDY™ program files were created for three test sizes, 25 mm, 43 mm, and 100 mm. The tests were used to verify predicted computer program results and seal performance. Testing included normal operating modes and reverse pressure conditions. Water was used as the process fluid while nitrogen was used as the barrier fluid. Barrier consumption rates were measured by recording the total consumption minus the outboard leakage. Outboard leakage was measured by containing the outboard cartridge with an opening through a flowmeter to the atmosphere. Interface temperatures were recorded by placing thermocouples at the sealing faces. A chart of the test results showing various speeds and barrier pressures and the resultant leakage rates is shown in Figure 12. A chart showing the correlation of the outboard seal leakage to the computer program model results is shown in Figure 13. Leakage is proportional to seal size, differential pressure and speed of the shaft. Once a proven model is achieved, it can be used to optimize the seal geometry and face pattern. Over 10,000 hr of testing have been completed on the current design. The seal has been tested for reverse pressure compatibility to ensure proper sealing in the event of gas barrier failure.

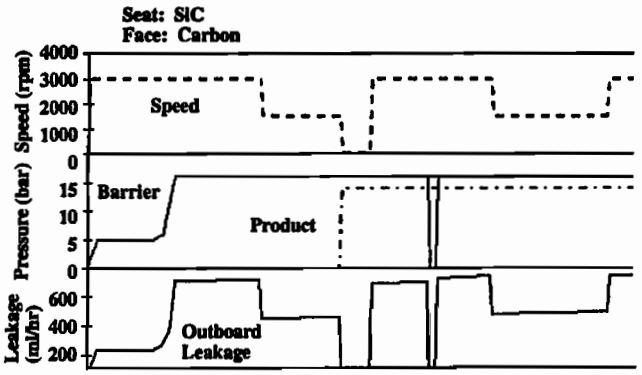



*Figure 12. Test Results at Various Speeds, Pressures, and Leakage Rates.*

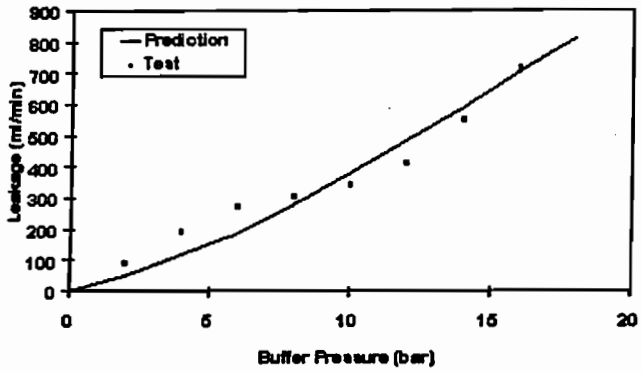



*Figure 13. Correlation Between Test Results and Computer Program Results.*

The current operating range for gas seals for standard bore seal chambers is speed up to 5000 fpm, barrier pressure to 230 psig, and a temperature range of −40°F to 500°F. Temperature limitations are due to the O-ring material. The nitrogen consumption chart for standard bore gas seals is shown in Figure 14.

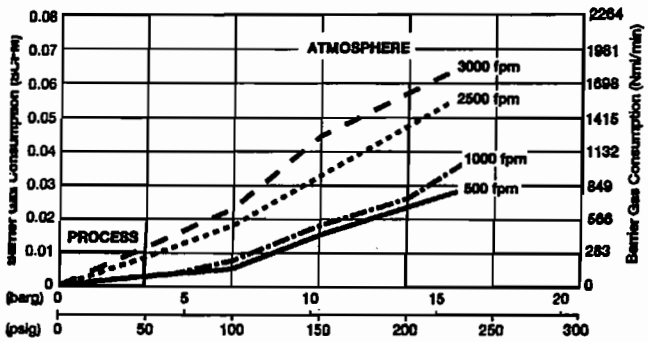



*Figure 14. Nitrogen Consumption Chart for Standard Bore Gas Seals.*

## FIELD EXPERIENCE

To date, over 500 seals have been successfully installed into a range of operating conditions and fluids, which equates to over 1,000,000 hr of operation. The first seal installation was in August 1994 at a plant in South Wales, United Kingdom, on a benzene service and is still running successfully. The company has several locations scattered around the United Kingdom and they specialize in benzene and bitumen derivative products. Their process typically uses overhung pumps with single seals or packing. Emission legislation had a part to play in selecting gas seals. Her Majesty's Inspectorate of Pollution (HMIP) visited the company and advised them to reduce fugitive emissions from their plant or be shut down if no action was taken. HMIP recommended they switch to mag drive pumps across the whole plant. To install all new pumping equipment would have been very costly, so the company decided to run a comparison test between a new mag drive pump and an existing pump fitted with a dual gas seal. The test was on a 20 year old pump which runs 24 hours a day, seven days a week. The seal installation is shown in Figure 15. The process fluid was 70 percent benzene with toluene, xylene, and other trace chemicals. A 1.125 in gas seal was fitted with a 30 psig process pressure and 60 psig nitrogen barrier pressure. Speed was 2900 rpm and the process was at ambient temperature. To date, the seal is still running without problems and the plant has since expanded the use of gas seals to reduce their emissions. The gas seal was a simpler and less costly solution compared to the mag drive pump and provided zero product emissions to atmosphere.

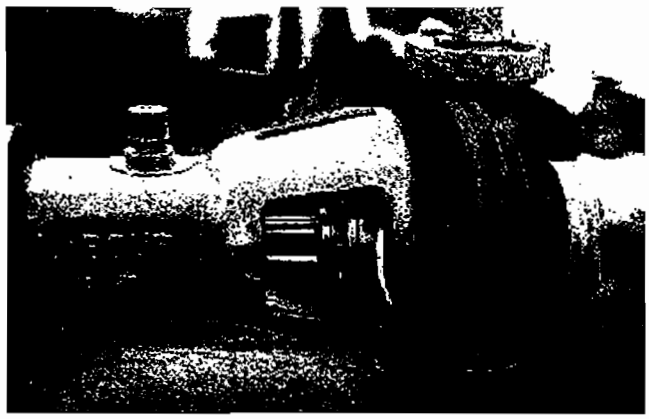


*Figure 15. First Standard Bore Gas Seal Installed on a Pump in South Wales.*

In June 1995, a standard bore gas seal was installed at a chemical plant in Northern England by the plant maintenance manager on a chlorine service. The company encountered two challenges with their chlorine operation while part of their ongoing quest for optimized production and an exemplary safety and emissions record. The engineering team examined all of their worst case operating scenarios and rapidly came to the conclusion that, maybe under a given set of circumstances, the current level of emissions control would not contain every mishap that could theoretically occur. The first course of action was clear to the engineering team, a second scrubber had to be added.

The most immediate hazard is the inevitable occurrence of wet chlorine gas which collects within the system from various parts of the process. This gas is blown into the scrubbers by two centrifugal fans. One fan is operational while the other is on standby.

The second challenge involved the centrifugal fans, which they felt were inadequate in terms of size, along with their current sealing devices. There was also a great deal of dissatisfaction about the life of these seals, which were currently controlling emission levels on one of the most critical parts of the plant. The average life expectancy of these existing seals was in the region of three months. So MTBPM was also an important issue, along with safety and the recurring downtime.

The fan OEM located in Halifax, England, was chosen as the supplier of the new larger fans, but an off-the-shelf solution would not be possible. The material of construction for the fans and the seal hardware would have to be titanium and the fans would have to be capable of zero emissions of process to atmosphere. This

OEM recommended the use of gas seals after reading of their success on big bore process pumps.

The operating conditions for this application were chlorine gas at 180°F on a 1.312 in shaft rotating at 2900 rpm. Nitrogen barrier pressure would be set at 30 psi above the maximum process pressure. A special feature within the barrier support system was the addition of two inline nitrogen accumulators with nonreturn valves in case of barrier gas failure. The gas seal installed on the fan is shown in Figure 16 and the two inline nitrogen accumulators are shown in Figure 17.

In June of 1995, the fans were started, have performed exemplary ever since, and have increased their MTBPM by five times.

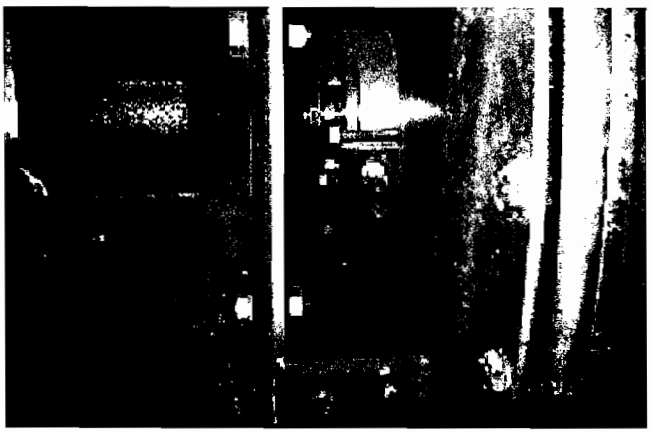


*Figure 16. Gas Seal Installed on a Centrifugal Fan on a Chlorine Service.*

*Figure 17. Two Inline Nitrogen Accumulators on a Gas Seal Installation.*

In September 1995, one of the first standard bore gas seals in North America was installed at a company in Baltimore, Maryland, on a "sofasets" service. Sofasets is a generic term for a very troublesome acid soap solution. The location was a beta test site for the newly designed seal. The customer chose a gas seal, as wet seals were failing in short order, because even light leakage of barrier liquid into the process results in crystallization of the product at the sealing faces. The crystals are corrosive and continue to form with added cooling from the leaking inboard seal. MTBPM was recorded as a few weeks, resulting in seal replacement and hazardous waste disposal problems. This gas seal design was chosen because it fit the standard ANSI seal chamber and the small amount of nitrogen passing into the process does not have the cooling effect that a liquid barrier does. The 1.750 in seal was started in September 1995, on the sofasets at five psig process and 30 psig barrier pressure, 138°F, and 1750 rpm. The root cause of previous failures was eliminated and the seal continues to operate as designed.

On February 1, 1996, a gas seal was installed on a 1.875 in (shaft) standard bore ANSI pump at a company in the United States, on a mixed solvent and weak acid ($H_2SO_4$) solution; toluene, xylene, and methanol. The lead mechanic for the company chose the gas seal for this application, because it was on his emission problem list. In the past, the company used single seals that were failing to control emissions at startup. The process fluid was flashing across the sealing faces resulting in high leakage rates and seal damage. A water flush could not be utilized because of the weak acid. The mechanic heard of the success of gas seals on big bore seal chambers and decided to apply the technology to his problem application. His maintenance personnel found the cartridge design to be user friendly and the barrier support system easy to set up. Since the pump was an emissions problem, it required frequent monitoring, but if they were able to demonstrate an increase in technology to solve the problem, the pump could be removed from the list after a few successful readings. Since startup (February 1996), the pump has been monitored monthly and zero leakage has been recorded. Monthly visual inspections are still required, but as the mechanic mentioned, "That's one less piece of equipment we have to monitor or worry about." He is confident he has chosen the right technology and has plans to install addition gas seals in the very near future.

## CONCLUSION

An innovative dual pressurized gas lubricated cartridge seal has now been designed, developed, and successfully applied on a global basis to standard bore rotating equipment. It is primarily directed at the narrow radial section seal chamber on rotating equipment to the ANSI and DIN standard used within the chemical processing industry, but has broader application potential.

The product was designed using an advanced design tool and its performance was extensively verified in the laboratory at two separate global locations under simulated pump operation, including upset conditions.

Successful field experience to date equates to over 1,000,000 operating hr and has allowed plant operators to comply with local emission regulations all over the globe. In addition, the product offers simplicity in installation and operation, along with low life costs and significant savings in energy consumption.

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