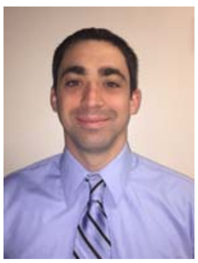
46TH TURBOMACHINERY & 33RD PUMP SYMPOSIA
HOUSTON, TEXAS | DECEMBER 11-14, 2017
GEORGE R. BROWN CONVENTION CENTER

CAUSTIC PROCESSES: APPLICATION AND IMPLEMENTATION OF SUCCESSFUL SEALING STRATEGIES

Kyle Stoner
Regional Engineer
John Crane
Pasadena, TX, U.S.A.

Daniel Grooms
Sr. Process Engineer
Akzo Nobel Functional Chemicals, LLC
La Porte, TX, U.S.A.



Kyle Stoner is a Regional Engineer in the Southern District of the United States for John Crane in Pasadena, TX. He has 9 years of experience with mechanical seals and support systems. His duties and responsibilities include On-site troubleshooting and diagnostic failure analysis, formulating recommendations and seal selections to address problem applications, along with design evaluation of existing and proposed mechanical seals utilizing Finite Element Analysis (FEA) software. He is also responsible for training of both customers and John Crane personnel in both mechanical application and troubleshooting. Mr. Stoner is a degreed Mechanical Engineer with a BSME from LeTourneau University in Longview, TX.

Daniel Grooms is a Senior Process Engineer at Akzo Nobel's La Porte, Texas site. He has over 10 years of experience in the chemical industry, working with various types of pumps, agitators, and other sealed equipment. His experience includes designing seal flush distribution systems, troubleshooting pump failures, and work with pH control systems, including caustic injection. He received his Ph.D. in Chemical Engineering from Texas A&M University in College Station, TX and his BS in Chemical Engineering from Lamar University in Beaumont, TX.

ABSTRACT

Caustic applications have proven to be a common source of concern in almost every industry, and each application in each facility can present different complications due to concentrations, desired purity levels, and even pump design. Just as there are many different types of caustic applications, there are also many different ways to seal it.

This paper addresses the requirements of API 682 for caustic applications that cover seal arrangements and materials, the basis being founded in years of experience along with end user and supplier input. The preference would be to incorporate as many of these defined practices into any application to provide the mechanical seal with the best reliability in a difficult service.

This tutorial will discuss the difficulties in sealing caustic processes, the material compatibility concerns, the different seal types utilized, and the piping plans required to support those seal types. Examples of implemented solutions will be incorporated into the discussion to provide visual explanations for the different options discussed.

INTRODUCTION

An important first step in solving difficult centrifugal pump applications that historically provide poor mechanical seal reliability is to have an understanding of the process you are sealing. Caustic is a process that can be difficult to seal due to its chemical properties both while in a solution as well as in a dehydrated state. Seal manufacturers have developed multiple seal designs and even customized support systems to ensure that the seal will survive the harsh demands placed on them by the pump, the process, and the operating conditions.

COMMON SOURCES AND PURPOSES OF CAUSTIC

Sodium hydroxide, also called caustic soda, is the most common type of caustic due to its widespread availability and low cost. It is commonly used in pH control (industrial waste treatment as well as municipal water systems), manufacture of paper products, and as a cleaner. The pure form is a solid that can be dissolved in water to a maximum of 50% (by mass) at normal temperatures.

Potassium hydroxide, also known as caustic potash, is normally used as a source of potassium or as pH control if there are process compatibility issues with sodium. Some of the common uses that potassium hydroxide has are: fertilizer manufacture, oil and natural gas treatment, refining petroleum fractions, electrolytic stripping baths, as a chemical desiccant, and as the electrolyte in batteries. It is a pure solid like sodium hydroxide and can be dissolved in water up to approximately 55% (by mass) at ambient temperatures.

CHALLENGES OF CAUSTIC PROCESSES

Since caustics are pure solids, caustic solutions will form crystals as the liquid is evaporated and the caustic concentration increases past the solubility point. These crystals can cause concerns for a mechanical seal, which will be discussed in detail in this document, and will lead to a reduction in performance and seal life. Since caustic solubility is directly related to temperature, decreases in temperature can result in crystallization of the pure caustic. Another concern that may exist when sealing caustic processes is material compatibility. Certain concentrations at certain temperatures will react differently with many of the more common materials found in mechanical seals, such as 316 stainless steel and elastomers such as a fluoroelastomer. Caustic fluids are simpler than some other corrosives in that the corrosiveness of the process is directly related to the concentration and the temperature. So as the fluid becomes hotter and/or more concentrated, it becomes more corrosive.

From a seal design standpoint, these properties can compound to increase the chances of failure. For example, a caustic solution in water exposed to elevated temperature can be more corrosive due to the higher temperature. Also, the higher temperature could cause more water to evaporate, concentrating the caustic, also increasing the corrosiveness. Finally, if the situation continues, the concentration of the caustic can increase above its solubility limit, causing it to crystalize and generate solids on the sealing surfaces.

Besides causing general corrosion, caustic fluids can also cause “caustic embrittlement”, a specific type of localized corrosion most commonly seen in carbon steel. Being a localized corrosion, it is frequently not detected by periodic wall-thickness measurements which are aimed at detecting generalized corrosion. Therefore, it is crucial to understand the process conditions both of the bulk fluid and at the specific location of use when working to determine compatibility and specifying materials of construction. Otherwise, mechanical failures can result and cause equipment damage, impacts to the environment, and personnel exposure to hazardous materials.

COMMON SEAL DESIGNS

There are multiple possibilities for seal designs and seal arrangement that can be used, and each has its benefits and drawbacks. Likewise, each application may be different in the type of support system that can be used. Some applications may be sensitive to the addition of an outside source that may be used to improve the seal’s environment, or lubrication, because it may dilute or contaminate the process and cause additional processing costs to remove the added fluid. Older equipment can add additional challenges to making a seal and support system selection due to historically small seal chamber diameters, additional steps in the shaft meant for component seal installations, and insufficient dimensions for modern seal designs.

The most common seal arrangement found in caustic applications is a single seal. Single seals used in caustic applications can be found in all varieties, namely: elastomeric bellows, metal bellows, and pusher styles.

The first two seal types discussed are referred to as non-pusher designs because their secondary sealing elements are static. This means that the element does not move axially with the adjustment of the primary ring, but rather it seals in only one axial location on the shaft after proper working height has been achieved. The seal faces used in the non-pusher seal designs are often very simple geometries. This is because the primary ring itself is short and is affected less by pressure and thermal distortions. The face of the primary ring is typically plain in appearance; although some seal manufacturers incorporate patterns caused by etching or slots and grooves caused by machining to aid in face lubrication.

Elastomeric bellows use a single large coil spring as the load element which applies pressure to close the seal faces at low pressures, an elastomeric bellows to provide a static seal against the shaft and the primary ring with a convolution that enables it to flex and adjust with movement needed in the seal caused by axial movement of the shaft or pressure increases in the process. The advantages of a seal type using a single coil spring, with an elastomeric bellows, stem from its physical design and its adaptability to multiple pump designs. From the purely physical aspect of the seal, one advantage of a single spring is that it resists clogging and corrosion better than a seal using multiple smaller springs. This seal type has a small cross section which allows it to be used in small seal chambers commonly found in older equipment.

On the other hand, one disadvantage of this seal type is that due to its single spring design, it is unable to provide an even force to the primary ring which can lead to uneven face loading. Another disadvantage is the availability of the elastomeric bellows to be formed in a select range of materials which limits its ability to be used in certain process streams. It should also be mentioned that

Metal bellows most commonly use metal plates that have been formed to a desired geometry and are welded together. This procedure provides both a sealing and loading element to the seal. For the static sealing components, this seal design can incorporate either an elastomeric O-ring, or a press-formed graphite packing ring. The choice for the static sealing component is dependent on temperature and process compatibility with the component. API 682 refers to a metal bellows using an elastomeric O-ring as a secondary sealing device as a Type B seal, and those that use graphite are referred to as a Type C seal. This seal design can be used at higher temperatures due to its ability to be used without an elastomer. One advantage of this seal design is that there is no dynamic O-ring, but rather a series of plates that flex providing axial movement to the seal. In a properly installed seal, these plates will provide an evenly distributed load to the seal faces. For high-concentration caustic applications where the caustic could precipitate out of solution, a rotating bellows design is ideal. This is because by spinning the bellows the convolutions between each plate will have a higher probability of remaining clear of debris. Metal bellows seals also have the physical characteristic of having a small cross section allowing them to fit in smaller seal chambers commonly found in older pieces of equipment.

A major disadvantage of metal bellows seal types is that they can be limited by their pressure capabilities. These pressure capabilities can vary between seal suppliers and should be verified before selecting a metal bellows seal for an application. Another disadvantage of a metal bellows seal is that a caustic process stream can create solid deposits on the plates and cause distortion to the seal as the plates are unable to evenly flex. This is a greater concern for stationary bellows and for pumps that can be in an idle state for extended periods of time and/or have a high caustic concentration that can be near the solubility limit.

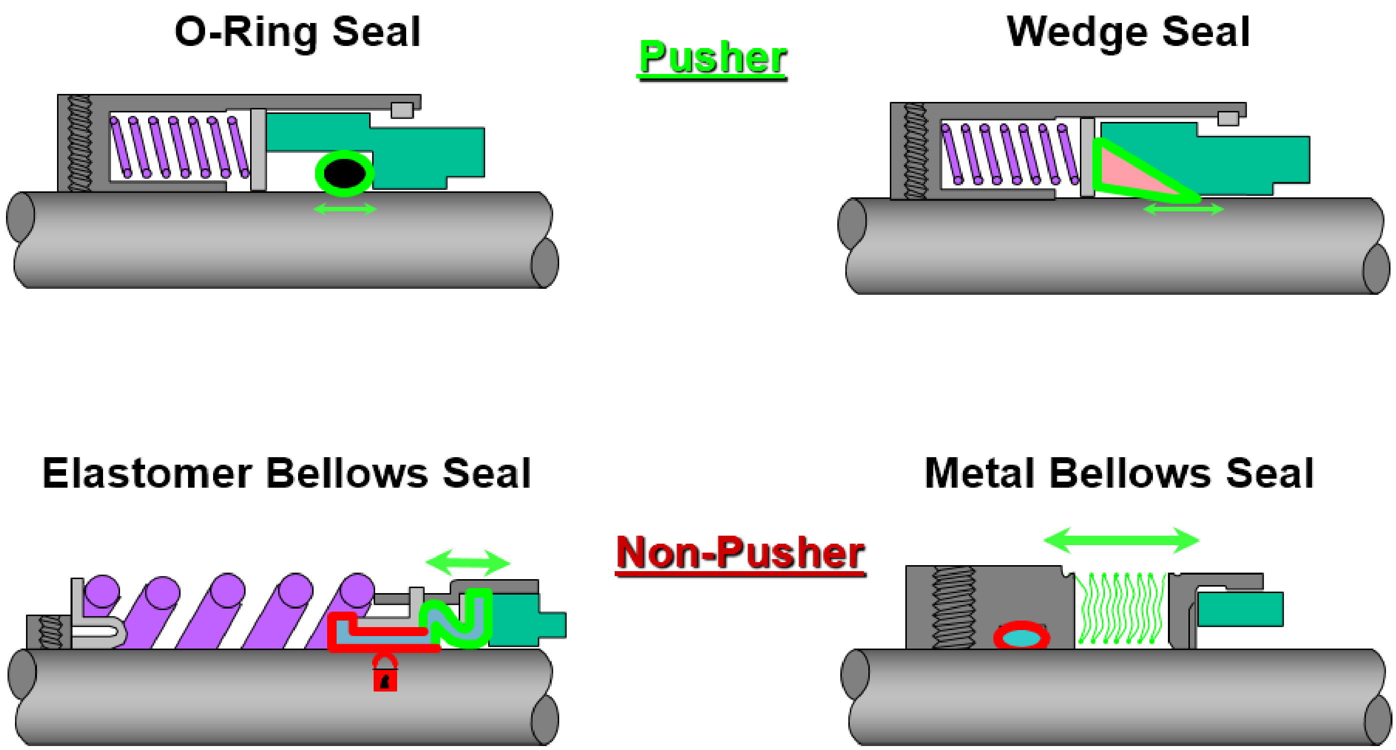


Figure 1: Pusher and Non-Pusher Type Comparison

The next single seal type discussed is referred to as a pusher design. Pusher seals use a dynamic secondary sealing element which adjusts with the axial movement of the primary ring. The seal faces used in a pusher seal design can have a relatively more complex geometry with multiple diameters and lengths. This is because the primary ring of a pusher seal is longer than those of a non-pusher seal and the geometry helps the ring to accommodate pressure and thermal distortions. It is more common to find pusher seals with patterns on the face than it is non-pusher seals.

API 682 refers to pusher seal designs utilizing multiple springs, a balanced insert and is internally mounted in a cartridge configuration as being a Type A seal. The API 682 Type A seal also requires an elastomeric O-ring to be used as the secondary sealing device. According to API 682, this is the preferred seal type for caustic applications. Outside of the API designation for Type A seals, many manufacturers have utilized other secondary sealing materials and designs to accomplish the same task as an O-ring for specific reasons or for specific sealing difficulties.

Pusher seal designs are most commonly designed utilizing an elastomeric O-ring. An O-ring is desirable because of its simple geometry, its ease of replacement, and depending on the material used, its cost. Pusher seal types also have the advantage of having a balance ratio that can be engineered to meet certain requirements of an application. Another advantage of the pusher seal design is that it can utilize a single large coil spring in applications with a lot of particulates that can foul a seal using multiple small coil springs. (While the advantages and disadvantages of a large single spring have been discussed, it is still a viable option for some customers who have a particularly difficult application with minimal support system options.)

Some disadvantages of a pusher seal design utilizing an O-ring are the potential for limited axial movement and chemical attack. Limited axial movement can be caused by particulates accumulating around the O-ring and limiting the ability of the elastomer to slide axially in response to changes in the pump and seal. This inability can be magnified further if the O-ring has become compression set. This refers to the O-ring no longer having a circular cross section but rather a square cross section. This can occur as a result of temperatures approaching the limits of the material, or by time as the O-ring is under a compressive load between the primary ring and the sleeve from the moment it is assembled. This increases the importance of having accurate process temperature data and of having sufficient cooling from the seal flush medium. When particulates accumulate around the O-ring and the sleeve, an additional concern is realized. The particulates can begin to score the sleeve which can lead to a leak path under the O-ring. In addition to limited axial movement of the seal, an O-ring can be chemically attacked. The proper elastomeric material should be carefully considered as the corrosiveness of caustics increase with a rise in temperature or with an increase in concentration.

Other pusher seal designs that do not use a dynamic O-ring instead rely on a more complex geometry and material to accomplish the same dynamic sealing task. Some examples include the use of PTFE (Polytetrafluoroethylene) wedges and chevrons. In seals utilizing the wedge ring, the spring and hydraulic pressure constantly press the wedge into the cone shaped bore of the primary ring which forces the nose of the wedge down onto the shaft or sleeve. There is some allowance for flexibility because the angle on the outside of the wedge ring is different to that in the bore of the primary ring to allow for movement caused by misalignment. The primary ring can move in relation to the wedge ring and still form an effective seal. The other example is the use of chevrons. PTFE chevrons are constantly energised by the spring force and hydraulic pressure transmitted through the metal follower. PTFE cold-flow, which will be discussed, is prevented by using a fully-trapped chevron seal. The chevron ring assembly is designed to fit into the same primary ring as elastomer o-ring seals, which can aid inventory reduction.

Some disadvantages of using such materials and secondary seal designs is that over time PTFE can damage a shaft or sleeve caused by abrasion. This wear can be reduced by incorporating a coating on the shaft or sleeve in the location of the PTFE component, however; this coating can add time and cost to a seal replacement if it is damaged or worn. The previously mentioned cold-flow of PTFE occurs as a result of pressure exerted on the material. This can occur from process pressure or the compressive force placed on it as it is squeezed between the primary ring and the shaft or sleeve. Some major disadvantages of the use of chevrons are that chevron rings provide for less misalignment than wedge seals and a change in pressure will have a direct impact on the energizing and friction forces of the secondary seal.

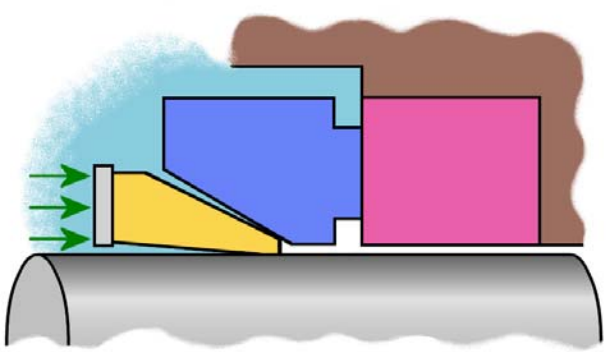


Figure 2: PTFE Wedge

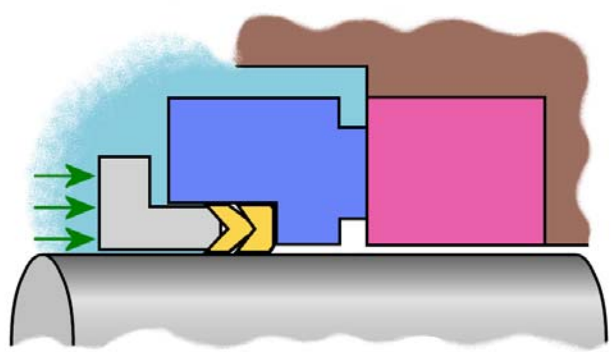


Figure 3: PTFE Chevron

When a single seal is not acceptable in a particular application the next option is to use a dual seal. A dual seal is simply a seal with two sets of seal faces in multiple configurations, and as a result require additional space within the pump assembly. Dual seals can be designed using any combination of the previously mentioned seal designs. API 682 refers to the seal faces that are in the process as the inner seal and the seal faces that are not in the process as the outer seal.

An advantage of dual seal designs is that they can accommodate leakage in a variety of ways. This is dependent on the piping plan used which will be discussed.

More commonly found on pusher seals, but also a possibility on non-pusher seals, certain face patterns caused by etching or grooves and slots caused by machining can be used to enhance lubrication of the seal faces. An example of a face etching is those found on the inner and outer mating ring of a dual gas seal. The purpose of the etching on these seal designs is to create a stiff film of pressurized gas, commonly nitrogen, between the seal faces. This accomplishes a positive seal against the process as well as eliminating face contact which increases potential run time of a seal as there are no wearing parts. An example of machined grooves and slots are those that are often referred to as hydropads. These are most commonly used when sealing a process with a high vapor pressure. The hydropad is machined into the primary ring to an engineered distance across the face in order to force more fluid across the seal faces to improve the lubrication by the process and to reduce the risk of the process flashing which would provide a hard rubbing contact of the seal faces with practically no lubrication. Face patterns and machining have been used successfully when properly supported by the correct piping plan and when a full understanding of the process is obtained.

PIPING PLANS

The life of all seals can be drastically improved with the use of a properly selected support system, more commonly referred to as either a mechanical seal piping plan or a flush plan. The purpose of a piping plan is to provide the best environment possible for a mechanical seal during successful operation as well as managing leakage for environmental and personnel safety reasons. This is accomplished by removing heat that is generated by the seal, providing lubrication to the seal faces, and by diverting leakage to a safe location.

In its fourth edition, API 682 recognizes 32 piping plans. Each of these piping plans are designed to accomplish a particular purpose in supporting a mechanical seal. Some piping plans can be very simple and inexpensive while others can be complex and very expensive. Some piping plans are used to lower the temperature of the process before being injected into the seal chamber to cool and lubricate the seal; while other piping plans are used to provide an external source of fluid to cool and lubricate the seal. While any piping plan can be used when sealing a caustic application, this paper will focus on the plans that are more common and have provided the most success in caustic services.

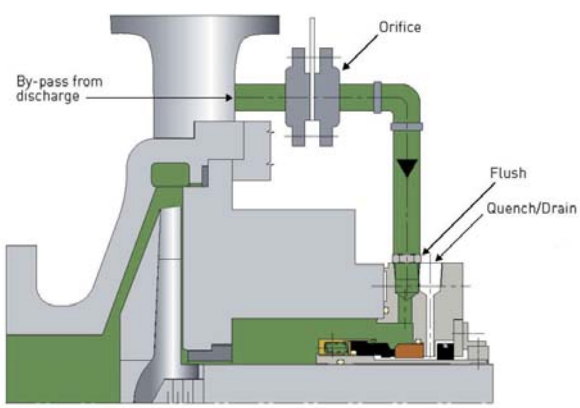


Figure 4: Plan 11

The most common support system found in almost all industries using centrifugal pumps is known as Plan 11, as shown in Figure 4. This piping plan, used in conjunction with single seals as well as dual unpressurized seals, is often desired because it uses the process itself to support the mechanical seal, thereby eliminating any dilution that might occur if an outside source was used. This piping plan takes a stream of process from the discharge of the pump and routes it to the seal chamber. Depending on the pressure differential between the seal chamber and the discharge, an orifice may or may not be necessary. This piping plan is ideal when the process is a good lubricant for the seal faces, which may not be the case for all caustic applications.

One disadvantage of a Plan 11 is that the process itself must contain limited particulates that can cause damage to the seal faces as it migrates across. Seal face damage caused by abrasives can lead to leakage rates that are higher than desired. Using caustic process streams as the seal flushing fluid can be a problem if the stream runs close to the caustic solubility point, especially if the process temperature changes. Another disadvantage of the Plan 11 that is often overlooked, but should still be considered from a lifecycle cost perspective, is that the pump is recirculating a volume of process continually which reduces the overall production of that service.

This can be mitigated by properly designing the system to minimize the circulating flow but if the upstream and/or downstream process pressure fluctuates, the flow will change accordingly. Also, since the flushing fluid comes from the pump discharge, if the pump can be blocked in, that will lead to a quick temperature rise of the bulk fluid. This makes it impossible to adequately remove heat from the seal, likely leading to rapid seal failure. For caustic applications, the higher temperature could lead not only to a seal failure, but to a loss of mechanical integrity due to the increased corrosiveness at higher temperatures.

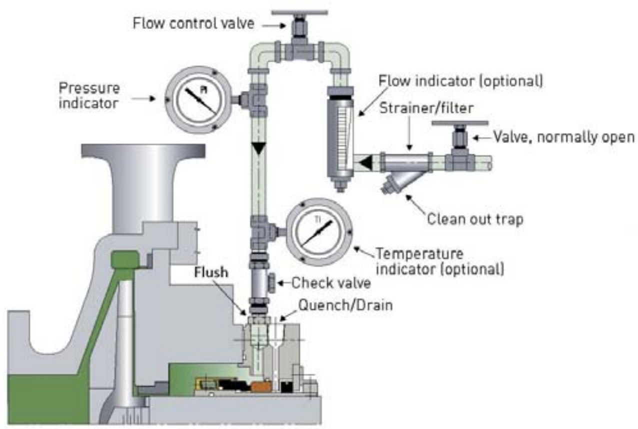


Figure 5: Plan 32

Piping Plan 32 is a support system that supplies an external source of liquid, at a higher pressure than the seal chamber, in order to cool and lubricate the seal faces. A Plan 32 is most commonly used with single seals but it can be used in conjunction with dual seals in particularly hazardous processes or processes with poor lubricating properties. This piping plan is desirable when the external source is a better lubricant than the process. The ideal scenario for using this piping plan is being able to supply enough flush that the seal chamber is void of any process and process particulates that may hinder the successful performance of the mechanical seal. To accomplish this, a close clearance throat bushing is required to aid in limiting the amount of process in the seal chamber and, to some extent, reduce the amount of flush required to remove the undesirable process from the seal chamber. Another advantage of this piping plan is that if properly set up, it will alter the leakage across the seal so that it becomes a mixture of process and external flush, rather than pure process that may be hazardous to the environment or even to the seal upon reaching atmosphere. The external fluid's temperature and flow rate can often be controlled more consistently than the process, leading to more reliable flushing of the mechanical seal.

While Plan 32 appears to be a desirable support system, it does have its disadvantages. The fluid used in this piping plan must be compatible with the process. This can limit the options of a flush source and be further limited based on pressure and temperature requirements for a successful seal performance. Another disadvantage is that this piping plan can dilute or degrade the process. This is a concern as the external flush source may need to be removed from the process at some point if it is not compatible with downstream units. So a cost could be generated with both the injection and the removal of the external fluid.

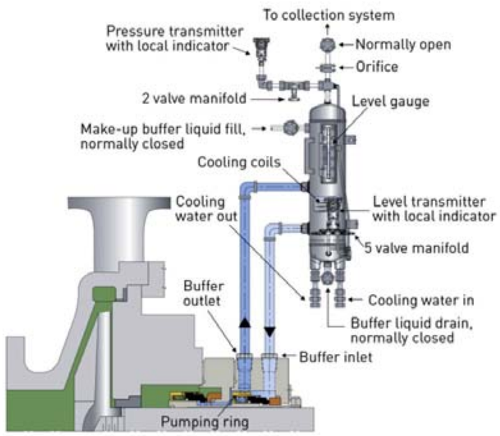


Figure 6: Plan 52

Another common support system used in a variety of applications is known as plan 52. This piping plan is used only with dual seals. Plan 52 incorporates a reservoir containing a volume of liquid that is unpressurized and a vent to a vapor recovery system or a flare system. This fluid should be a good lubricant and be compatible with the process. Since the fluid is unpressurized, it is referred to as a buffer fluid because it serves as a “buffer” between the process and the atmosphere to reduce the amount of emissions from entering the atmosphere. Because the buffer fluid is unpressurized, this means that the process will be used to lubricate the inner seal faces. One benefit of the Plan 52 is that the leakage that crosses the inner seal faces will ideally be swept to the seal reservoir where any light ends in the leakage can vaporize and vent to the flare system.

One disadvantage to the Plan 52, which is often overlooked, is that the buffer fluid will become a mixture that incorporates the process fluid itself. This is a particular concern if the reservoir, and tubing, is not thoroughly cleaned periodically through a preventative maintenance program and during a seal replacement. Contaminated buffer fluid may lead to a string of seal replacements because the buffer fluid is the lubricant for the outer seal. As abrasives collect, or as high viscosity fluids sit in the buffer fluid forming an emulsion, or as processes with a higher vapor pressure than the pressure of the buffer fluid become entrained and contaminate the buffer fluid, a seal replacement is very likely as all of these occurrences can have a very negative impact on the containment, or outer, seal. It is because of reasons such as these that it is strongly encouraged that the entire buffer fluid system, reservoir and tubing, be cleaned and the buffer fluid replaced during each seal replacement at a minimum; as well as at some regular interval. These cleanings and replacements may be require the used buffer fluid to be treated as a hazardous material if the pH increases above 12.5 due to the amount of caustic. Depending on the fluid selected for the buffer, multiple replacements can be expensive over time. Also, in caustic applications, the equipment used in the system must be compatible with the caustic which can require enhanced metallurgy and increase the cost.

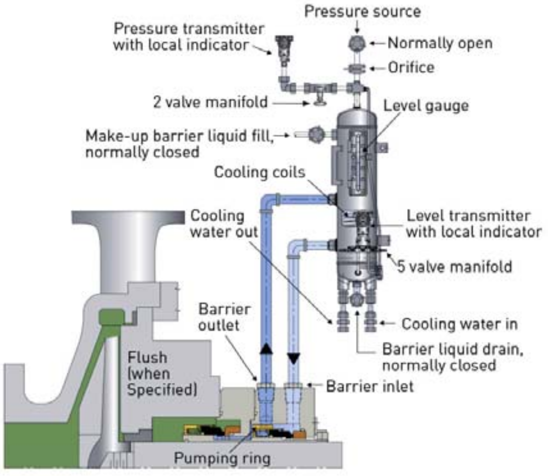


Figure 7: Plan 53A

Similar in physical appearance to a Plan 52 is the Plan 53A. Rather than being unpressurized and vented to a collection system, the Plan 53A is pressurized above the seal chamber pressure. The most common source for pressurizing a Plan 53A is nitrogen which is readily available in many facilities. While the liquid in a Plan 52 acts as a buffer between the process and atmosphere, by pressurizing the liquid in a Plan 53A, a true barrier between the process and atmosphere is created thereby providing a zero emission seal. The most desirable advantage of a Plan 53A is that the pressurized liquid in the reservoir is lubricating the inner and outer seal faces. This is a benefit because with only a few exceptions, both the seal designer and end user can choose a quality, clean, lubricating liquid to seal and to design for. In some processes, the operation of the pump can have an impact on the characteristics of the process, but if a pressurized support system such as a Plan 53A is used, then the fluid lubricating the seal faces will remain constant. Another advantage of the Plan 53A is that in the event of a pressure reversal, meaning the pressure in the seal chamber becomes greater than the pressure in the seal reservoir, then the Plan 53A will become a Plan 52 until the proper pressure differential can be re-established. A pressure reversal can occur due to an upset in the pressurizing supply system or operational issues. It is important that if a pressure reversal is ever discovered then the reservoir and tubing should be cleaned and the barrier fluid should be replaced.

Disadvantages of a Plan 53A are concerned with pressure and chemical compatibility. The Plan 53A can be limited to a maximum operating pressure due to gas entrainment as the pressurizing gas is in direct contact with the barrier liquid in the reservoir. This is dependent on the liquid selected and the seal supplier and liquid vender should be consulted to determine a maximum allowable pressure for the Plan 53A. Another disadvantage of this support system is that the pressure of the barrier liquid should be maintained at a minimum of 20 psi above the maximum seal chamber pressure, according to API 682. This can be a disadvantage because it may not be possible to find a readily available source of pressurizing gas near the application or at the desired pressure. The other notable disadvantage of the Plan 53A is that because the barrier liquid is lubricating both sets of seal faces, a small amount of barrier liquid will leak into the process, and therefore; the barrier liquid must be compatible with the process. A seal failure will introduce a significant amount of the barrier fluid into the process, which could impact product quality even if the normal small leakage does not. Finally, although a less likely requirement than for a Plan 52, the equipment used for a Plan 53A must still be compatible with caustics when used in those applications due to the possibility of process intrusion into the seal reservoir in the event of the barrier pressure dropping below the seal chamber pressure.

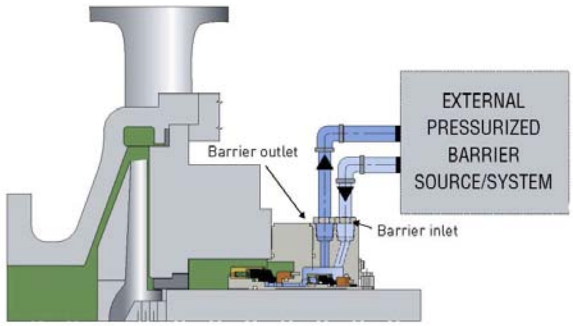


Figure 8: Plan 54

Another pressurized support system that is used with great success on dual seals is the Plan 54. This plan utilizes an external source to provide a clean pressurized barrier fluid to a dual pressurized seal. The Plan 54 system supplying the barrier fluid can range from a process pump in the unit providing clean cool lubricant under pressure to a simple lubrication system with minimal components to an elaborate large system with many ancillary components and redundant systems to safeguard and alarm against malfunctions and process upsets to a controlled process stream. Like the Plan 53A, the barrier fluid of a Plan 54 can be selected specifically for the service to help improve the reliability of the mechanical seal. As long as the pressure of the Plan 54 remains above the seal chamber pressure, the seal will positively eliminate any leakage of harmful and fugitive emissions to the atmosphere. Plan 54 is capable of much higher pressures than a Plan 53A because it is not at risk of experiencing gas entrainment, as the pressure of a Plan 54 is generated by a pump. While a Plan 53A is constrained by size limitations, a Plan 54 can be sized to provide barrier fluid to multiple seal installations which can reduce the overall costs when using dual pressurized seals on multiple applications in a unit. A seal flush circulation system can also be designed with instrumentation to maintain consistent flow and pressures, which can be infeasible on multiple local installations of Plan 53A.

As the Plan 54 is a pressurized system, it can provide the potential for process contamination in the event of a damaged inner seal. Thus, the main disadvantage of the Plan 54 is that if one system is used on multiple seal installations, the failure of one seal can have an effect on all of the other installations unless proper precautions are taken to isolate the failed seal. Furthermore, if one system is used on multiple applications, then without proper instruments and controls, the failure of a particular seal can be very difficult to identify. Another disadvantage of the Plan 54 is that if the circulation of the barrier fluid is dependent on a motor driven pump, then potential seal failures can result if power to the system is lost. Finally, either the seal chamber pressures of the seals on the system should be similar, or additional equipment (such as booster pumps) or instrumentation must be used to control the supply pressures. For most end users, the biggest disadvantage of a Plan 54 support system is the cost involved. The external lubrication system can be very costly compared to other piping plans depending upon the number and type of redundant and safeguard systems utilized.

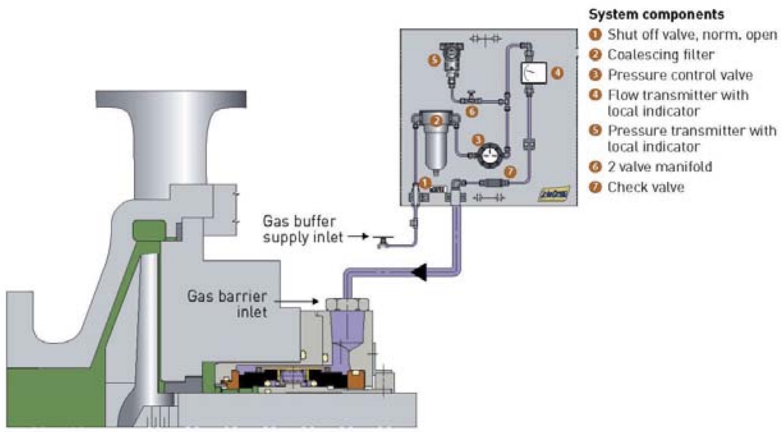


Figure 9: Plan 74

Another common pressurized piping plan for dual seals is the Plan 74 which uses a gas to serve as the barrier. This plan is only used on dual gas seals. This seal design differs from other pressurized multiple seal arrangements in that they do not have circulation of a fluid between the seals, but rely upon an external source of inert gas to pressurize the seal cavity provided by the seal cartridge. Flow into the seal cavity is the result of leakage of the inert gas past both the outer seal faces and to a lesser extent the inner seal faces. Typically the external source is a pressurized nitrogen line within the plant. In some very special cases the nitrogen source can be a nitrogen bottle or a bank of nitrogen bottles. The advantages of the Plan 74 are related to cost, maintenance and reliability. A Plan 74 system costs less than liquid dual pressurized systems, especially for between bearing pumps. In addition to lower system costs, the Plan 74 also has lower maintenance requirements and associated costs compared to dual liquid systems that utilize a pressurized reservoir. The leakage from the inner seal into the process is an inert gas and in many services, such as caustic, is compatible and easily separated from the process downstream. The barrier leakage to atmosphere is also an inert gas which means that the drainage and cleanup is not an issue as with dual liquid systems. With the demand to limit water usage in facilities, the ability to use a gas seal can eliminate the need for cooling water in many applications.

The Plan 74, like other support systems can present some problems in certain circumstances. As with all pressurized systems, the leakage across the inner seal will be the barrier gas, and entrained gas in the pumping system can be a problem with multiple dual gas seals in a particular unit and especially on closed loop systems. Gas entrainment problems can cause pump performance problems on some installations with both low suction head and low flow conditions. If pump performance is degraded to the point that elevated temperatures result, this can increase the corrosion of caustics and result in operating in a corrosion region that the piping system was not designed for, resulting in a loss of mechanical integrity. Furthermore, entrained gas under certain conditions can influence net positive suction head testing at the pump OEM level, which may require the use of a different seal type for the test which can be an added cost. A dual pressurized gas seal may not be recommended for services containing sticky or polymerizing agents, or where dehydration of the process fluid causes solids buildup, such as caustics near the solubility point. One specific disadvantage of the Plan 74 in crystallizing services like caustic is the potential for dehydration of the process around the dynamic O-ring of a pusher seal. This is because there is typically a very minute volume of fluid around the O-ring and as the leakage of the Plan 74 accumulates it can lead to pockets of crystals that can restrict the movement of a dynamic O-ring. Extra attention should be taken when recommending this piping plan in services such as caustic.

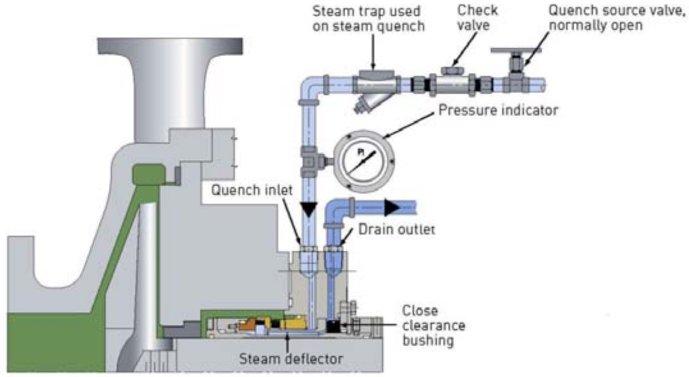


Figure 10: Plan 62

While all of the previously mentioned support systems are used to provide lubrication and cooling for the seal faces, or containment of process leakage, there is another piping plan that is used to improve the environment on the atmospheric side of the seal. This piping plan is referred to as Plan 62 and it is most commonly used on single seal designs. Typically, this is either low pressure steam or nitrogen to prevent coke formation on hot hydrocarbon services or water to prevent the formation of crystalline substances on fluids with solids in solution. The prevention of coke and crystalline formations is accomplished by removing the atmospheric conditions necessary for these formations to occur. It is typically used with a floating or segmented bushing to limit the leakage of the quench fluid to atmosphere, but can be used with a fixed bushing if the application permits. Quenches also provide a small amount of cooling in hot applications. If properly controlled and if the leakage is managed, then a Plan 62 could become a low cost alternative to dual unpressurized seals to improve the condition on the low pressure side of the process seal, but this should not be considered before weighing all sealing possibilities and eliminating a dual seal as an option.

Some disadvantages of a Plan 62 involve the leakage of process, the need for quality steam, and the need for proper control of the quench. Leakage of process past the primary seal is not contained except with the throttle bushing. Any leakage of the process can cross the throttle bushing and go to atmosphere or it can be swept with the quench and go to a drain that is placed in the gland between the seal faces and the throttle bushing. Steam is the most readily available and cost effective source for a quench media in most industries, however; the steam properties necessary for a quality quench in a high temperature application are less common. No matter what fluid is used for a quench media the pressure necessary is commonly less than 5 psig with many applications between 1 and 3 psig. This helps to reduce consumption of the quench, but if not properly managed, it is possible to reverse pressure a mechanical seal with a low pressure quench. Furthermore, too much steam flowing through a mechanical seal has been linked to bearing oil contamination. Water is commonly used in caustic applications as a quench, but to many end users a single disadvantage may outweigh the advantages. This is because many facilities are reducing their water consumption in order to reduce waste. With some additional expense and complexity of instruments and controls, waste can be reduced. Proper control of the flowrate and pressure of a water quench is crucial to the success of the seal and even the bearings in case of excessive leakage past the throttle bushing.

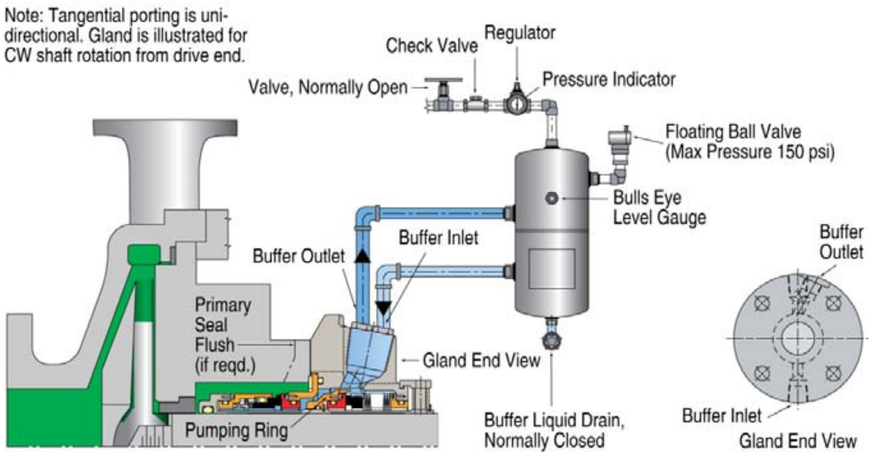


Figure 11: Plan 99

In some applications it may be necessary to design a piping plan for the specific seal design, arrangement, conditions or operating practices of the end user. The plan may require modifications to an existing plan or plans or the creation of a unique piping plan. A Plan 99 is simply an engineered piping plan that is not defined by any of the existing plans.

API 682 does not have any specifications for a Plan 99. It does state that the Plan 99 description and requirements must be clearly defined in specifications outside of the standard. It is not sufficient to indicate "Plan 99" on the seal data sheet or even on a seal layout drawing. A drawing of the Plan 99 and notes about its operation must be supplied.

SEAL SELECTION BASICS

When selecting a mechanical seal for an application, it is important to quickly consider a few key points to ensure a long seal life and a safe operation in the event of a leak. These points for consideration are as follows:

- **All seals fail.** All seals will fail, or leak an undesirable amount, either due to age, operational issues, mechanical issues, process issues, or misapplication of the seal design itself.
- **All seals leak.** All seals require a fluid to cross the faces to provide lubrication and cooling for the seal faces.
- **All single seals leak to atmosphere.** All single seals have limited capabilities to control the leakage that reaches the atmosphere after crossing the seal faces.

The first point is important because a mechanical seal is a wearable component that is operating as a part of a system of other wearable components subjected to outside influences, both natural and manmade. A follow up question that is considered at this point is to determine the environmental and cost impact of a seal failure in each particular service. With this in mind, a seal arrangement can often be considered.

The second point simply refers to the operation of a mechanical seal. A mechanical seal requires a fluid film, either gas or liquid, to exist across the seal faces to provide both cooling and lubrication. The movement of this fluid across the seal faces is driven by differential pressure, passing from highest to lowest. With this in mind, it is important to consider what is acceptable to leak across the seal faces, and whether or not it is it a good, clean lubricant. By considering the second point, a support system can be considered.

The third point is important to remember if a single seal has been selected for an application. As the name suggests, single seals do not have a second set of faces to provide sealing if there is a failure. Therefore, the way in which a leak is contained or managed must be considered.

MATERIAL SELECTION

Like all applications, when sealing caustic processes careful attention to material selection can make the difference between success and failure of a mechanical seal. As previously stated, some caustic services can react differently with certain materials when at varying concentrations. Working with the process / chemical engineer responsible for the service can be a great resource for material selection, but other resources do exist online and in print to guide in material compatibility. Because concentrations and temperatures can change over time, such as in batch services, careful consideration should be taken. Care must be used to select the proper materials to be compatible with the caustic concentration at the expected temperatures. The temperature wouldn't necessarily be the normal process temperature, but the temperature expected at the seal faces – a higher temperature here could create a more corrosive environment than in the bulk fluid stream. During processes such as batch services it is better to consider the worst case scenario when selecting the materials used in a mechanical seal. There are five elements to each mechanical seal that must be evaluated for each application.

The first element is referred to as the Primary Sealing Element. This is simply the primary ring and the mating ring, both commonly referred to as the seal faces. The seal faces must be properly chosen for their durability as well as their compatibility with the service. Seal faces must be capable of withstanding the viscosity of the fluid, any particulates in the fluid being sealed which may be abrasive to a seal face material, as well as the pressures and velocities exerted on them which can all lead to excessive wear. Seal venders have a variety of seal face materials to choose from, but the most common materials are Carbon, Silicon Carbide and Tungsten Carbide. As these materials can be combined in a variety of ways, it is important to consider the best material pairing possible for each service. For caustic services, namely NaOH, API 682 recommends a particular classification of Silicon Carbide known as Sintered Silicon Carbide for both seal faces. This classification of Silicon Carbide is "chemically inert in virtually all corrosive environments" due to its manufacturing process (API 682 4th edition, B.2.3.3). In addition to its chemical compatibilities, it is also a hard material that improves its abilities to handle processes with abrasive particles as well as fluids that crystallize. This material combination is strongly recommended but after evaluation of the process fluid, the seal arrangement and the support system chosen, other material combinations can be selected. In a dual unpressurized seal arrangement, this may be the proper combination of seal faces for both the inner and the outer seal faces as the outer seal will also see traces of caustic process in the buffer fluid that has crossed the inner seal faces. In a dual pressurized seal arrangement, this particular combination may only be necessary for the inner seal as the outer seal will only see the barrier fluid.

The second mechanical seal element to consider is referred to as the Secondary Sealing Element. This element comprises of multiple individual components that seal the process from the atmosphere where ever two components join together. In a mechanical seal, these components are elastomeric O-rings, PTFE components such as wedges, chevrons, etc., metal and elastomeric bellows, press formed graphite foil rings, and gaskets found between the mechanical seal gland and the face of the seal chamber. API 682 suggests using a perfluroelastomer in caustic applications. This classification of elastomer has a wide chemical compatibility range with a broad temperature range as well, but of particular concern to some customers, it is often more expensive than other elastomer compounds. As stated before, with careful consideration of the process and potential characteristics, other less expensive elastomers can be evaluated for use in a caustic service. If an application requires an API 682 qualified seal, then it should be noted that according to API 682 4th edition; "(w)edge, u-cup, or v-ring shaped elastomer or PTFE material also has to be energized by external means, such as a spring, but reliability concerns associated with fretting and increased friction eliminate these as suitable alternatives within this standard."

The third mechanical seal element to consider is referred to as the Drive Element. The purpose of this element is to provide a positive connection between the shaft and the rotating face to overcome seal face friction. This element can be a simple pin that keeps a seal face from rotating, or a retainer that houses a primary ring, or a set screw or key that transmits torque from the rotation of the shaft in to the rotation of a seal face. If these components are not compatible with the process, then they will not be able to properly perform their role in the mechanical seal. These components are often made of a metal that is easy to replace, but some services require the use of exotic materials such as titanium, Hastelloy, or Monel to resist any chemical incompatibilities with the process. For thermal growth concerns and full seal compatibilities, the materials chosen for this element are often used for the remainder of metal components in the seal design.

The fourth mechanical seal element to consider is referred to as the Load Element. The Load Element is used to maintain the minimum prescribed seal face pressure during static and dynamic pump conditions. This element is simply the springs found in a pusher style seal and the bellows of a metal bellows seal. Corrosion of these elements will result in loss of static sealing capabilities in a pusher seal and in the case of a metal bellows seal, this will result in both static sealing and secondary sealing concerns.

The fifth mechanical seal element to consider is referred to as the Adaptive Hardware. The Adaptive Hardware is everything that is used to adapt a mechanical seal to the pump. This includes the sleeve, gland, and drive collar. The sleeve and gland are always in direct contact with the process and may require the use of exotic materials if the process is found to be aggressive with other materials. Both the sleeve and the gland house a Secondary Sealing Element and if these two components are not compatible with the process leading to severe corrosion, then a leak path can be formed by the secondary seals.

All five elements must be equally suited for the process conditions. Corrosion of a metal component or chemical attack of a seal face or secondary seal will result in a seal leak.

SUCCESSFUL SEALS AND PIPING PLANS

Seal manufacturers have been able to successfully seal caustic services with a variety of seal designs and support systems. The following designs and support systems cover a wide spectrum of successful caustic sealing services. Exact process names and conditions will not be provided as they may mislead the reader in attempting to equate their process to one of the applications listed below. When determining the seal design, materials and support system used, the seal manufacturer reviewed the history of the application, material recommendations for the process and consulted with the customer to better understand the chemical makeup of the process.

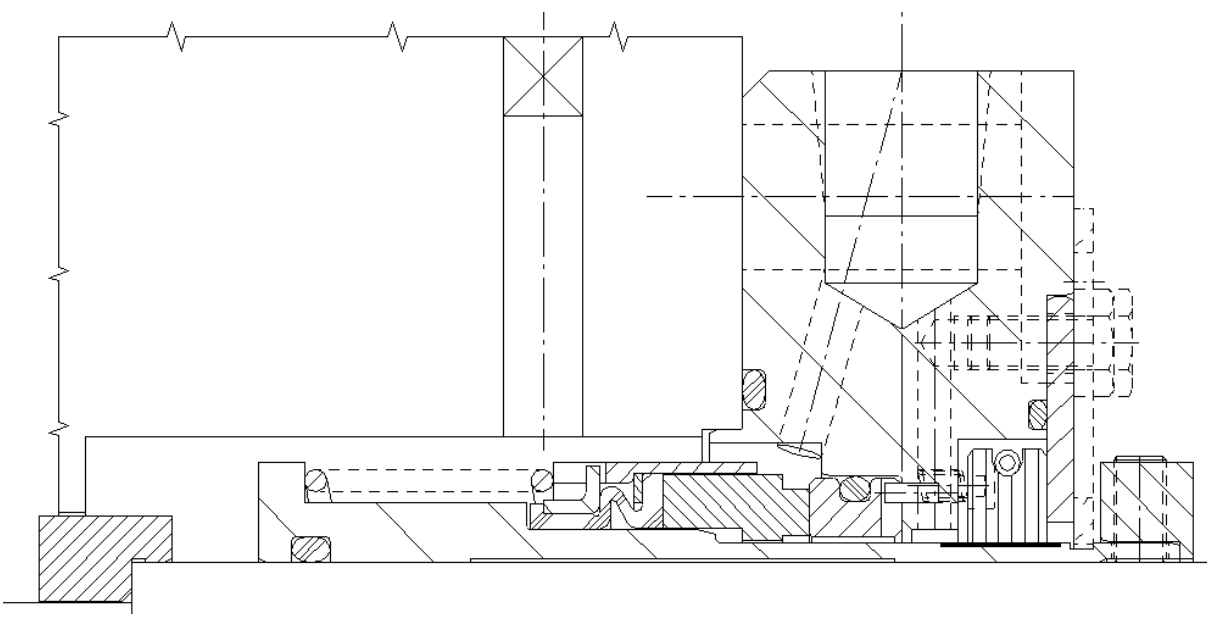


Figure 12: Elastomeric Bellows Seal with a Plan 11 / 62

One successful seal design for a caustic application is represented in the figure above. The application originally used a component seal but was upgraded to a cartridge by trimming the hook sleeve to increase the radial clearance in the seal chamber to accommodate a cartridge seal. This seal design incorporates a single spring with an elastomeric bellows. The piping plan used was a Plan 11 / 62. The Plan 62 used low pressure water to sweep away the leakage from the seal before the caustic crystals could accumulate around the seal faces hindering the axial movement. A segmented carbon bushing, which allows for smaller clearances around the sleeve, was used to control leakage to atmosphere by directing the flush and process leakage to the drain. To accommodate the use of a quench on the atmospheric side of the seal an extra step was incorporated into the sleeve to prevent the elastomeric bellows from sliding due to a potential for reverse pressure. In this particular caustic service; tetrafluoroethylene / propylene (TFE/P) O-rings were acceptable which helps to minimize the cost. The seal faces used were Sintered Silicon Carbide for the primary ring and Tungsten carbide for the mating ring. All of the drive, load, and adaptive hardware were 316 S.S. In order to accommodate the additional wear of the sleeve by the bushing, the sleeve has a chrome oxide coating to prolong the life of the component. While this particular seal is used in a small overhung pump, this design can also be effective in a vertical pump as well by using a Plan 13 instead of a Plan 11. (Though not covered previously, a Plan 13 takes process from the seal chamber and directs it to suction. This piping plan is also useful for venting a seal chamber continuously to prevent cavitation of the equipment.)

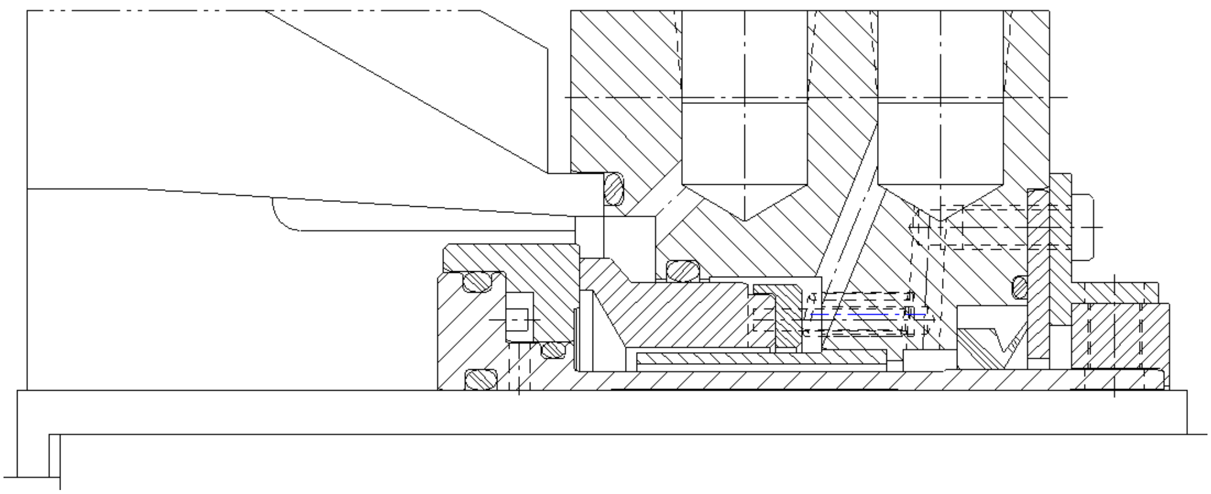


Figure 13: O-ring Pusher Seal with Only a Plan 62

Another successful single seal in an 18% caustic application involved only a Plan 62. The Plan 62 used water as the quench media and to control the quench a V-Ring made of Nitrile was used on the atmospheric side. The cartridge seal was installed on a hook sleeve, which is more common for component seals and packing because it is a replaceable component that is cheaper than replacing an entire pump shaft. The hook sleeve reduces the damage caused by multiple locations of set screws of a component seal and the fretting that occurs from the packing material as it rubs on the shaft. However; in this application, the hook sleeve provides a layer of protection for the pump shaft from the process. The process was made more aggressive due to entrained air in the fluid caused by low suction head on the reservoir supplying the pump. When the process became more aggressive the sleeve and gland were chemically attacked. Because of the aggressive nature of the process the seal contained exotic materials. Sintered Silicon Carbide for the primary ring and Tungsten Carbide for the mating ring. The O-rings used were a special grade of TFE/P. All hardware, drive and load elements were made of Titanium. This seal design incorporates a captured dynamic O-ring on the outer diameter of the primary ring. This reduces the possibility of reduced axial movement that may occur as particulates build up over time around the O-ring. The additional flush port directed at the seal faces is for future use of an additional flush plan if conditions change.

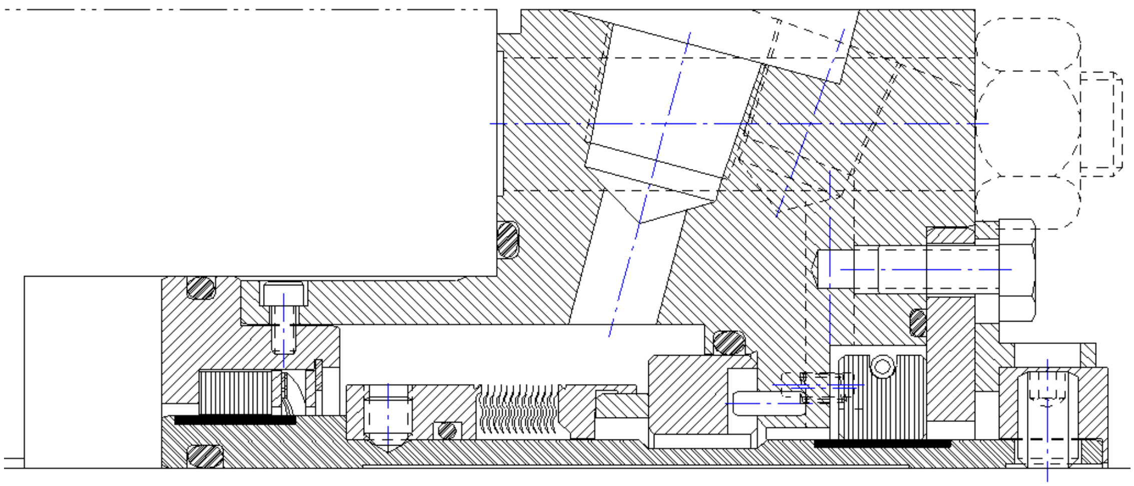


Figure 14: Metal Bellows Seal with a Plan 32 and Close Clearance Throat Bushing

This next caustic application involves a single cartridge seal that incorporates a close clearance throat bushing built into the seal gland to help control the environment around the seal faces. The process fluid is described as a caustic solution with a certain weight percentage of sodium hydroxide. This application was originally successful with a Plan 32, which was water, with no throat bushing. As time went on, process and environmental demands changed requiring the reduction of the injection of the Plan 32 into the process stream. The same seal design, a single metal bellows, was used with the addition of a close clearance throat bushing. The close clearance throat bushing drastically reduces the required flow rate and maintains a high level of fluid cleanliness around the seal faces. In this seal the bellows are made of Hastelloy C with a Sintered Silicon Carbide insert for the primary ring face. The Mating ring is a Reaction Bonded Silicon Carbide. The O-rings are a perfluoroelastomer grade to accommodate the range of possibilities in this caustic solution. The seal gland and sleeve are 316 S.S. and the close clearance throat bushing is Carbon. The seal does not normally run with a quench, but the connection can be used to sweep away any debris from the atmospheric side of the seal if the Plan 32 is blocked in. This is a first attempt for a recovery if the seal shows signs of leakage to atmosphere. It should be noted that the use of a single seal with a Plan 32, even with the aid of a close clearance throat bushing to reduce the volume of flush necessary, the process should be examined to determine what an acceptable level of dilution is for the particular stream. Another important design feature that should be noted is that this application would have also been successful with an O-ring pusher seal in place of the metal bellows.

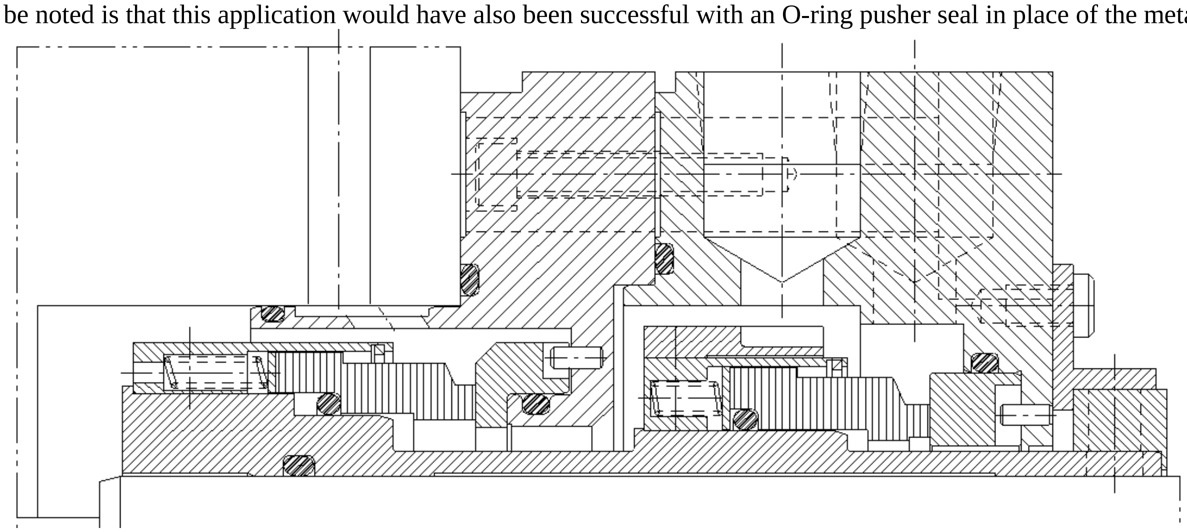


Figure 15: Dual Unpressurized Pusher Seal with a Plan 11/52

Another successful seal in a caustic service involves a dual pusher seal. The application is 25% sodium hydroxide. The seal used is a dual unpressurized seal with a Plan 11 / 52. There were no adequate utilities nearby to pressurize the seal and a dual unpressurized seal was desired over a single seal to provide additional safety to personnel and the environment. This seal was designed to accommodate a pressurized barrier system, such as a Plan 53A, in the future if a sufficient pressure source was made available. If a Plan 54 was made available then it could also be used and at that point the pumping ring could be removed as it would no longer be necessary for barrier fluid circulation. The Plan 11 provided cooling and lubrication to the inner seal faces and kept the process agitated around the inner seal to prevent particulates from accumulating in tight spaces that might hinder axial movement by the seal during operation. The Plan 52 provides cooling and lubrication to the outer seal while providing a quench, similar to a Plan 62, for the inner seal. In this situation, the Plan 52 removes the process and crystals away from the inner seal and keeps it in suspension in the buffer fluid. Over time the buffer fluid will become contaminated by the process and it may provide a poor lubricant for the outer seal faces leading to a leak to atmosphere of a mixture of buffer fluid and process. In this application, with history to support the material selections, both primary rings are Carbon and both mating rings are Sintered Silicon Carbide. The O-rings are TFE/P and all hardware and drive elements are 316 S.S. while the load elements are Hastelloy C.

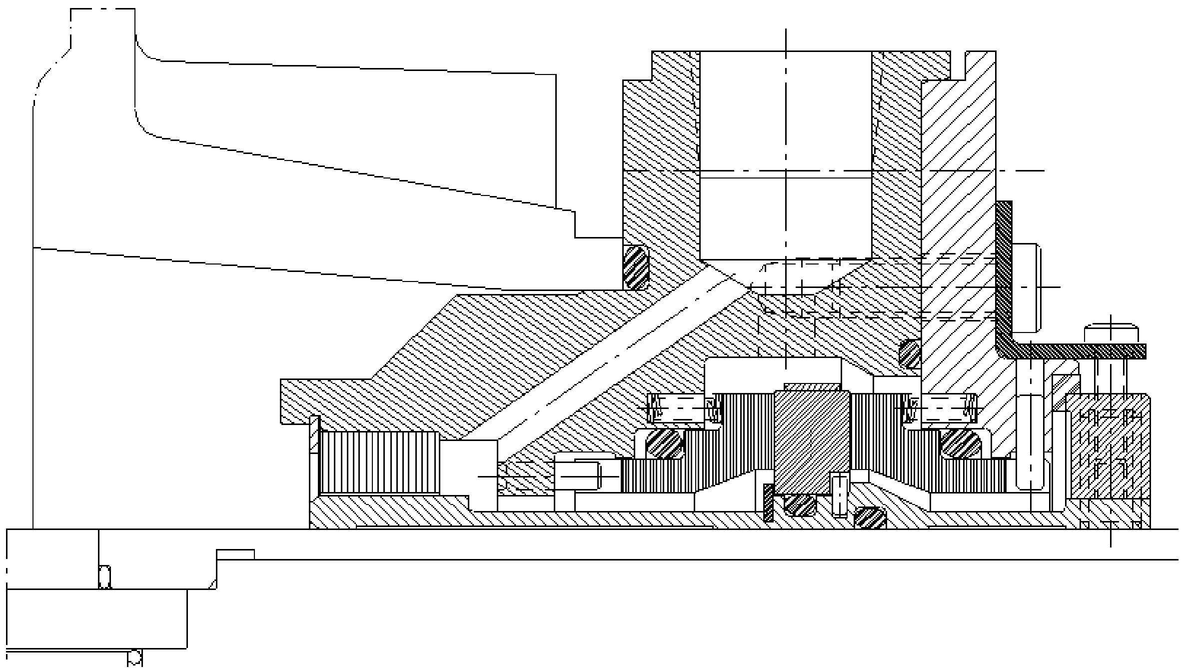


Figure 16: Dual Pressurized Gas Seal with a Plan 13 / 74

The next successful caustic application was sealed with a dual gas seal. The application involved a small low volume pump in a circulation service that had the potential to cavitate easily. A dual seal was required for this service because there was no place to route process leakage and a quench safely. The seal is supported by a Plan 13 / 74. The Plan 74 provided a clean barrier of nitrogen gas to the seal faces for face separation and sealing; while the Plan 13 was used to take any nitrogen that crossed the inner seal faces away from the low volume pump impeller to prevent it from causing cavitation. The Plan 13 was also used to keep the area around the inner seal faces from becoming stagnant by constantly venting process to a high point on the caustic tank that was at atmospheric pressure. This also helps to reduce the risk of dehydration around the dynamic O-ring of the inner seal, which would result in crystallization. The bushing in the process side of the gland is necessary to divert the nitrogen leakage to the Plan 13 vent. In this application the O-rings are TFE/P. Both primary rings are Carbon and the mating ring is Tungsten Carbide. All of the drive, load and adaptive hardware are 316 S.S.

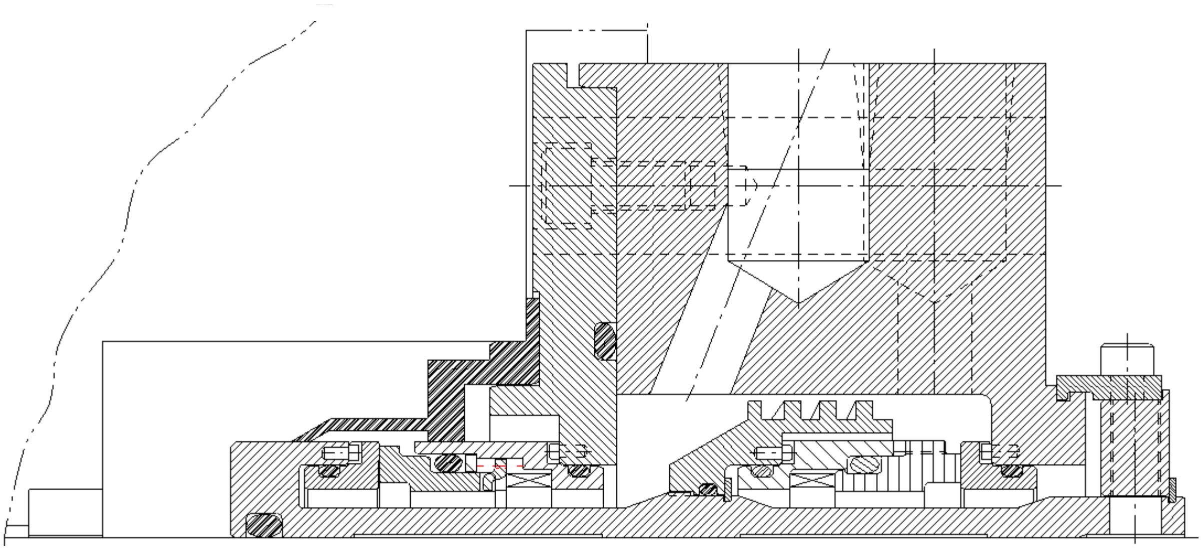


Figure 17: Dual Unpressurized Seal with a Plan 99

Another successful seal design used in caustic services involves a unique technology that is similar to that which is used in the dual gas seal face technology. While the dual gas seal technology requires a nitrogen source at a higher pressure than the seal chamber, this seal technology uses an unpressurized liquid instead of a gas. This seal uses a technology referred to as active lift technology as it takes an unpressurized source of liquid and it draws it into the grooves etched on the mating ring and "pumps" it into the higher pressure seal chamber. This technology provides the benefit of a pressurized seal without the need for pressure giving the end user an alternative to often more expensive support systems. The support system looks similar to a Plan 52, with a supply and return line between the seal and the reservoir, but although the reservoir is unpressurized, the seal does consume a small volume of liquid that is pumped into the seal chamber. As the support system for this seal design is not defined by API, it is labeled as a Plan 99. The below seal uses a Sintered Silicon Carbide primary ring with at Tungsten Carbide mating ring in the inner seal. The outer seal, because it is only in contact with the unpressurized fluid, uses a Carbon primary ring and a Tungsten Carbide mating ring. A perfluoroelastomer was chosen for the O-ring material. The component that is squeezed between the seal gland and the seal chamber and also covers the inner seal is made of a PTFE material. The purpose of this component is to reduce the amount of caustic that can accumulate around the O-rings and seal faces during non-operating periods. As the inner seal slowly pumps the unpressurized fluid into the seal chamber, the caustic available in this area will be reduced. The drive, load, and adaptive hardware are 316 S.S. As a small volume of external liquid is pumped into the process stream, this design may not be acceptable in small batch or finished product services. For more information on active lift technology refer to the proceedings from the 26th International Pump Users Symposium (Mammadov, et al 2010).

CONCLUSIONS

While caustic applications can present challenges to a mechanical seal's reliability; with a full understanding of the possible concerns and potential hazards associated with sealing such a fluid, a proper seal and support system can be selected to achieve an acceptable level of reliability. The solutions discussed in this tutorial are the result of field experience, communications between the process/chemical engineer and the seal manufacturer, and an understanding from the customer on the way in which the equipment was operated.

REFERENCES

API Standard 682, Fourth Edition, 2014, "Shaft Sealing Systems for Centrifugal and Rotary Pumps," American Petroleum Institute, Washington D.C.

Mammadov, V. A., Yusifov, A., and Tacon, K. P., 2010, "Upstream Pumping Technology In Centrifugal Pump Mechanical Sealing Applications – Field Experience With High Duty Sea Water Injection Pumps," Proceedings of the Twenty-Sixth International Pump Users Symposium, Houston, Texas

ACKNOWLEDGEMENTS

The authors would like to thank Alan O'Brien and John Crane for supporting the development of this tutorial.