MECHANICAL SEAL APPLICATION — A USER'S VIEWPOINT

by

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INTRODUCTION

The purpose of this paper is to present some user guidelines for the selection, operation, and maintenance of mechanical end face seals in chemical, petrochemical, and petroleum operations. Though the exact seal requirements for a similar service may differ between the authors, we are all looking for a means of improving our mechanical seal reliability. For the majority of services, there are several seal vendors and installation schemes that will work equally well for that service, while for certain services, only one seal vendor may excel with a limited installation scheme variation. The reasons that a particular plant uses a certain seal for their general plant service relates more to the local service representative, parts availability, materials offered, seal arrangement or seal type. Conversely, your plant should not be stuck in the dilemma that the plant preferred seal has to fit all applications because of spare parts or "maintenance know-how to work with this seal." Every seal design has strong and weak design points. Learn what they are and know how to best apply and maintain your plant seals.

PROJECT SEAL SELECTION

Mechanical seal technology has improved considerably during the last several years and has resulted in major improvements in seal design, application, and materials. In spite of these improvements, failures of mechanical seals continue to be a major problem with pump reliability. Leaking seals have caused major fires, toxic material releases, unit downtimes, pump damage, and excessive maintenance costs. The blame for poor seal performance is generally placed on operations or maintenance, depending on who has the strongest hand. But there are other parties involved which are also responsible for poor seal performance. Too few plant people realize that the influence on seal performance begins at the *design* stage with the selection of the seal, seal environment, controls and equipment. More times than not, especially at small or new plant sites, seal selection is taken for granted or independently selected by the contractor with little guidance from the seal vendor. People that have not been involved in seal selection get the idea that selecting a seal is like a visit to the doctor — information is given and out comes a prescription (seal specification) that cures the ills (sealing the process fluid around the shaft). Toxic and pollution requirements have changed the concept of seal selection in the last several years and will continue to change it. Seal and the seal environmental system selection on larger numbers of pumps are becoming more complex and time consuming than the selection of the pump. Yet, most engineering contractors still spend 10 to 35% of the allotted pump engineering time on the mechanical seal system. A de-escalation of pump engineering time is not intended, rather *more* emphasis on seal selection should be given.

Observed from the plant level, it is often difficult to understand the method used by the project to select the total seal system. It is important to understand the methods of selection so that the plant can be an effective influence with its knowledge and experience. All selection methods cannot be covered, but some typical selection methods and organization will be dicussed.

Equipment Vendor Selection

Generally, the least reliable and poorest performance is obtained by such terms in the pump specification or equipment sheet as "Vendor Standard," "with seal or packing," "balanced seal — plant preference," or "seal, yes." One should not expect the optimum and most reliable selection because of the competitive nature of the equipment supplier. The best one can expect is very competitive hardware (usually cheap) which will satisfy the general pump specification and hopefully make it through the start-up period. Only in services where the equipment manufacturer has shown an accepted expertise in the particular seal applications, such as cryogenic services, should this seal selection method be used.

Corporate Standards Selection

The use of seal standards is another method of detailing the seal specification on the centrifugal pump specification sheet. This description may be from guidelines in the corporate standard or in local design guidelines from the field. These guidelines can be a valuable aid to the young project engineer if the guidelines and specifications are kept up to date. Guidelines such as "no pressed carbons," "seal gland to be piloted," "use of 'O' ring in shaft and stationary seal packing is preferred," do not get out of date. Specifications such as "Unless otherwise specified, single mechanical seals shall be supplied for chemical and hydrocarbon services within a pumping temperature range of minus 150°F to plus 600°F" are always out of date and of little help to the project engineer. A number of the present projects have young project engineers that have little practical mechanical experience responsible for mechanical design. Seal selection is often hurried through with little advice. This does not say that inexperienced project engineers are the problem; in fact, some work harder because they want to do a good job and gain experience. Most of the problems with inexperienced engineers are cuased by project time schedules, not knowing if the information is sufficient and their lack of immediate knowledge.

Seal Vendor Selection Using Full Disclosure

A third approach, sometimes called "full disclosure" consists of supplying all information to the seal manufacturer such as: complete product composition; crystallization temperature; size of the entrained solids; solid agglomeration tendency; metallurgy requirements from past plant data; complete process conditions at the pumping point; and EPA or suspected EPA requirement on leakage; etc. The availability and description of any alternate external flush stream should be listed for consideration. The seal vendor should have the latitude to supply his own gland design. It is usually a more optimum design than the general-purpose gland supplied by the pump vendor. The method of operation should be discussed along with any type of unusual start-up or shutdown conditions.

Seal manufacturers are aware of the problems encountered in the application of their designs. Many support extensive research and development programs and have published many of their results for general use. Know where your particular seal has limited application, i.e., don't accept a recommendation for a metal pusher type seal on a Teflon coated shaft. "Full disclosure" has generally produced good results. The equipment supplier may or may not be involved, depending on the equipment. At best, he should assist the seal vendor on specific requirements for installation and flusing.

"Full disclosure" can be objectionable because of process security reasons. If that is the case, pilot plant or laboratory data may be used to aid in the ultimate selection. If there are questions in the user's mind about the process properties in the stuffing box or at the pump, extra provisions should be included in the equipment, seal arrangement, and seal environment.

Selection Using In-House Expertise

"In-house expertise" is another method used to influence seal reliability. It can be and often is coupled with one of the above methods. In fact, "full disclosure" and "in-house expertise" are similar in several important respects. Both methods recognize that only the user is in possession of the information required for proper review and application. The involved individual may be at the plant, division, or corporate level, but the method generally works best when the plant has an input. "In-house expertise" resolves some of the reluctance and ethical problems that engineers have in discussing the merits of an application with the pump and seal vendor before writing the centrifugal pump specification. Vendors can be a tremendous help with ideas, if they are just used. Remember, the seal specification that is initiated by the user, hopefully with the help of the vendors and plant experience, is the user's only control over the quality of the application.

SEAL FUNCTION AND ARRANGEMENT

When referring to mechanical seals, most people discuss seal design (balanced or unbalanced) or seal arrangement (single or double seal). Regardless of the design or arrangement, they have one thing in common — most leak. In order for a seal to function properly, four sealing points must function as shown in Figure 1: 1) the stuffing box face must be sealed; 2) leakage down the shaft must be sealed; 3) the mating ring in the gland plate must be sealed in a floating design; 4) the dynamic faces (rotary to stationary) must seal.

The force arrows acting on the unbalanced seal in Figure 1 keep the sealing faces together. Box pressure also assists in keeping the shaft packing forward and sealing. Note the compressive force A of the spring plus the hydraulic force B of the box pressure acts on the rotary seal ring axial projected area (looking towards the mating ring). This is opposed by force C acting on the area between the mating ring face O.D. and the O.D. of the seal ring and force D results from the average pressure gradient acting on the face contact area. If the fluid in the box can maintain a film over the faces, then a reasonable service can be expected. If the resultant unbalance force on the seal ring becomes extremely high from high box pressure, face damage will occur.

Figure 2 illustrates the common part names as designated by A.S.L.E. Various seal manufacturers still use trade names for their component parts, therefore, one has to learn to recognize parts by their function. The balanced seal shown in Figure 2 has been described as an unbalanced seal over a step in the shaft which by hydraulic forces applies a degree of balance to the seal ring. Both force A and B still exist with B being a smaller force than in Figure 1. The value of force C is larger since it will oppose and help balance out force B. Force D is again the average pressure gradient acting on the face contact area.

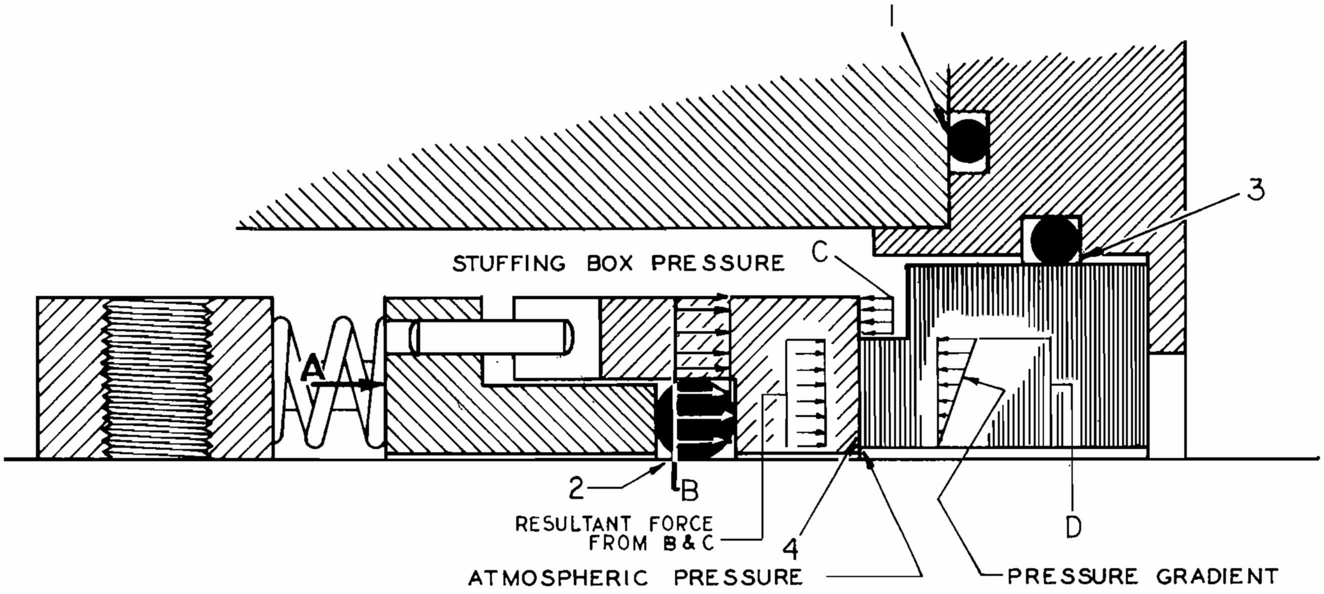

Figure 1. Unbalanced Seal.

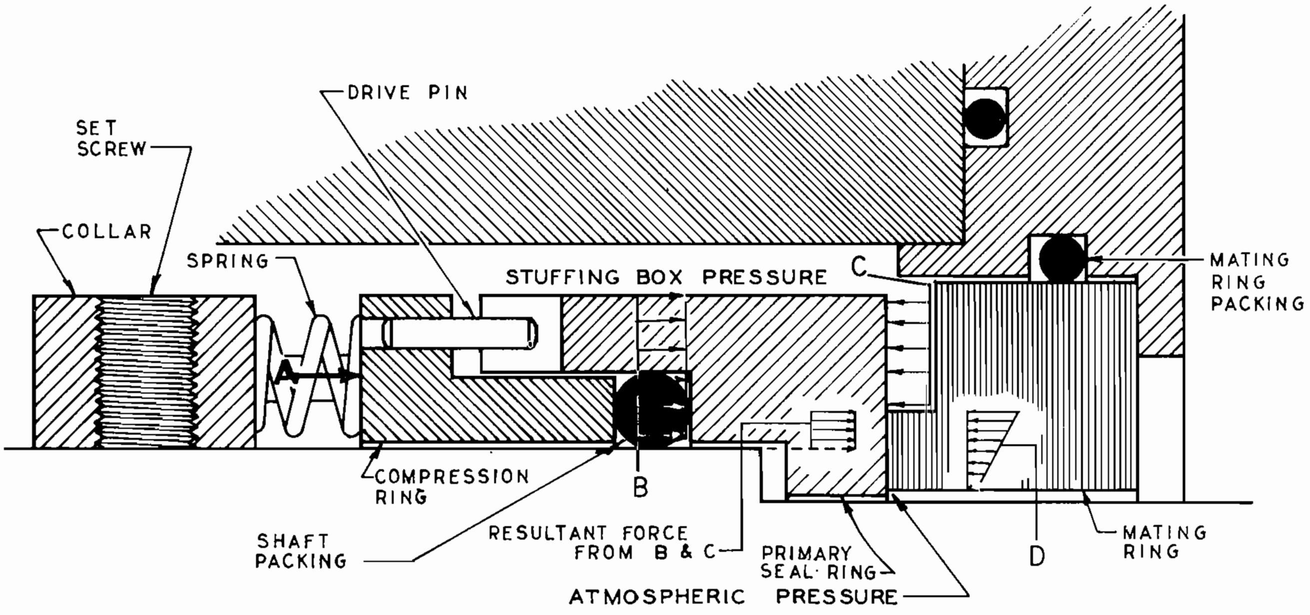

Figure 2. Balanced Seal with Step in Shaft.

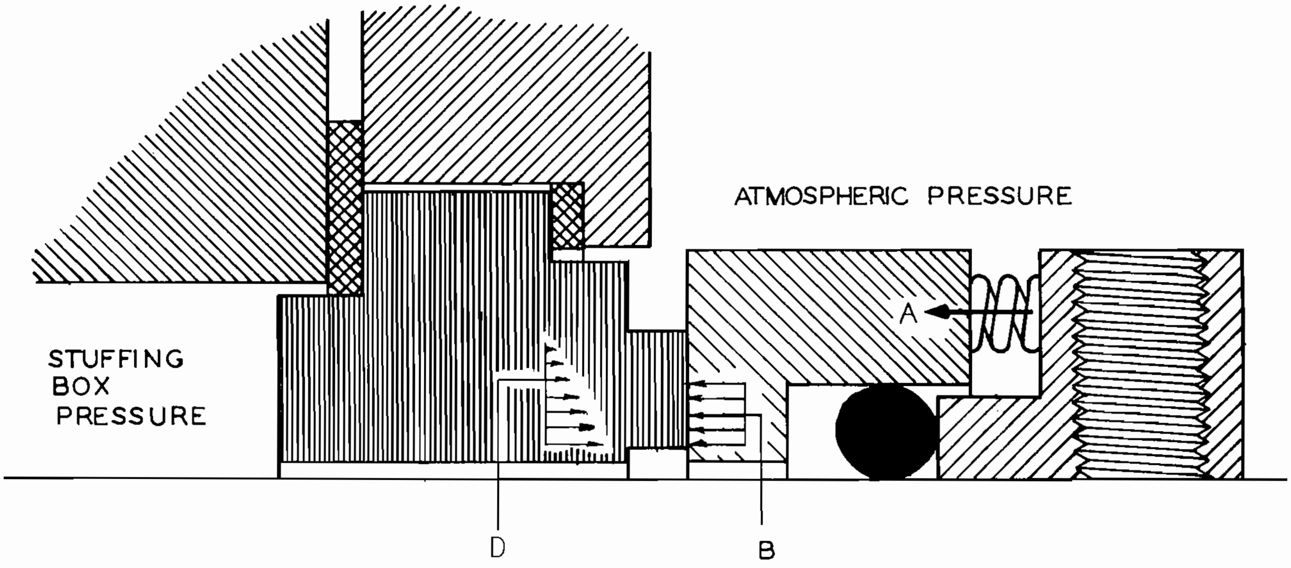

Figure 3. Outside Balanced Seal.

Figure 3 shows a balanced outside seal. Forces are again figured in the same manner as before. The resultant forces are shown. One can see that the outside seal is sensitive to overpressure, thermal changes and pressure surges.

Figure 4 shows a double unbalanced seal back to back. A separate fluid is used between the faces. The fluid is generally circulated through the box. Dead-head installations will work providing adequate jacket and gland cooling exists.

Figure 5 shows a typical tandem seal arrangement. This arrangement is found in unattended installation and on designs requiring a fail-safe condition. A balanced seal is normally used on the inside. The outside seal can be balanced or unbalanced depending on the requirements. The lubrication between the inside and outside seal is normally oil, but other compatible products that have lubricating properties are used. Cooling is generally accomplished by thermo-syphon. Alarms and pump shutdown can be activated by a pressure switch in the seal fluid pot.

As previously discussed, seals can be grouped by their arrangement or their design. Figure 6 shows a general picture of the choices available on a common seal design. No attempt is made to make a chart inclusive of all special seal components and glands that can be used. The chart follows a similar logic used by Crane Packing in *Engineered Fluid Sealing*.

Figure 7 shows a typical balanced stationary seal found, for example, in Sundyne pumps. The application of a stationary seal is well suited for high speed sealing applications. It also eliminates many of the problems that plague the rotating pusher seal.

SEAL SELECTION AND APPLICATION

Plant personnel involved in the review of equipment specification sheets and mechanical seal specifications can increase their contribution to seal reliability by understanding the considerations used in the seal selection. For example: The maintenance foreman noticed that Viton A was called out as the shaft packing in a seal specification. He remembers using a

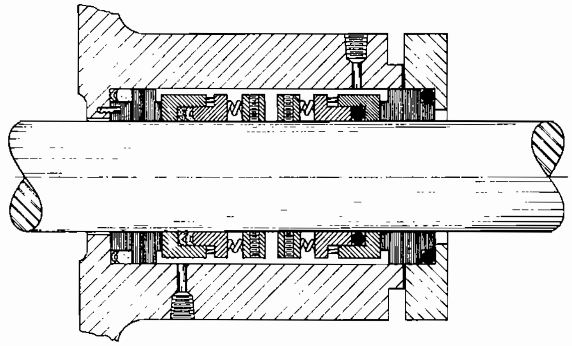

Figure 4. Double Unbalanced Seal — Back to Back.

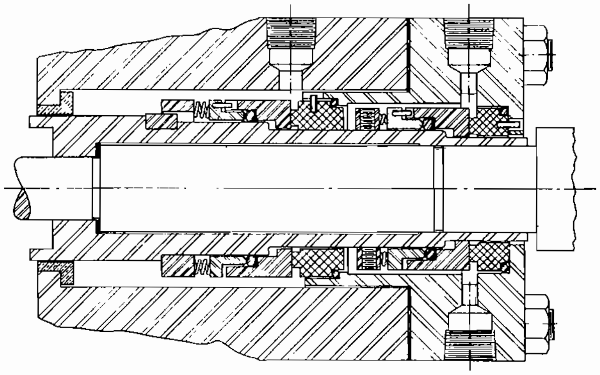

Figure 5. Balanced Tandem Seal.

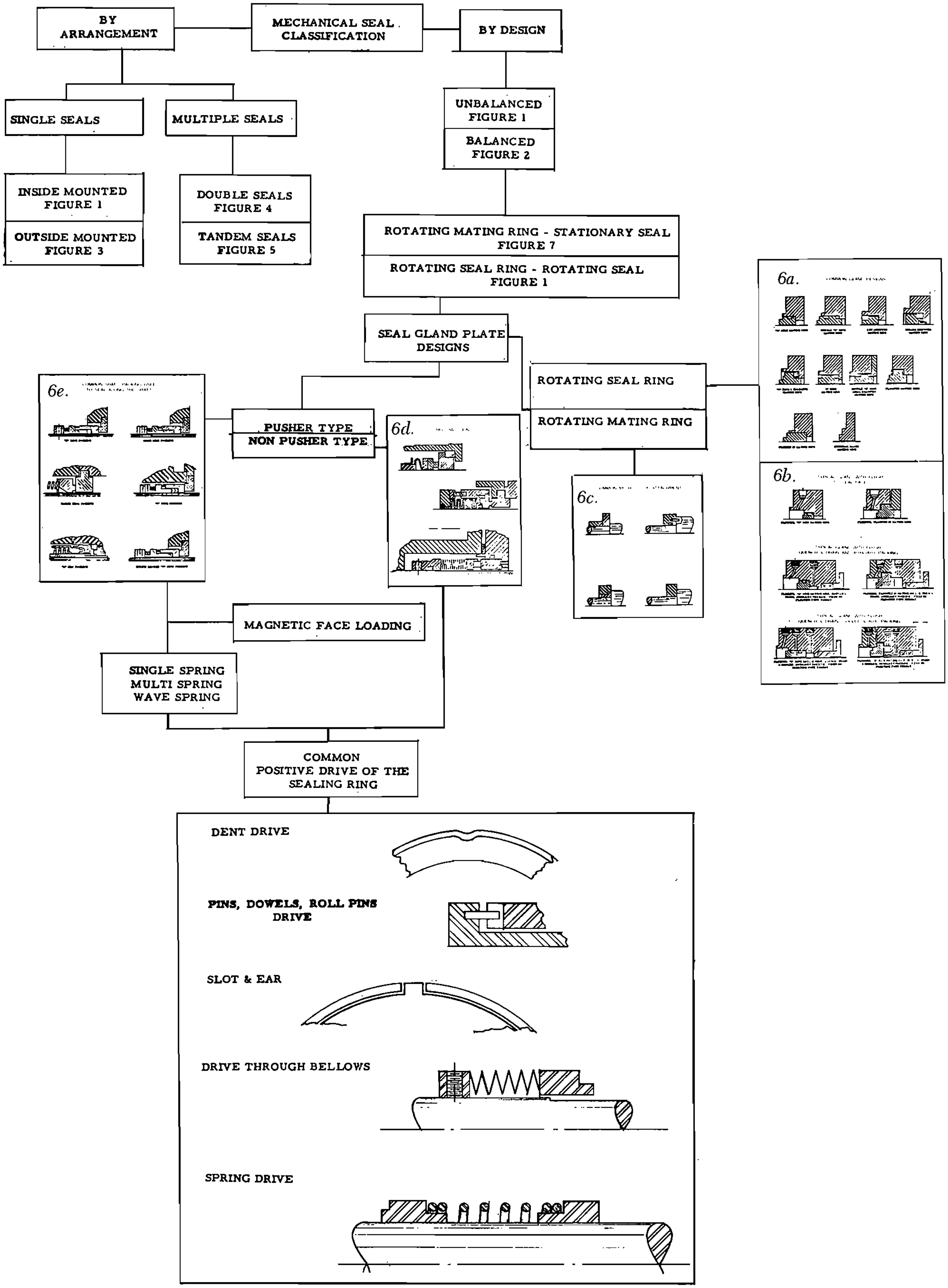

Figure 6. Mechanical Seal Classifications.

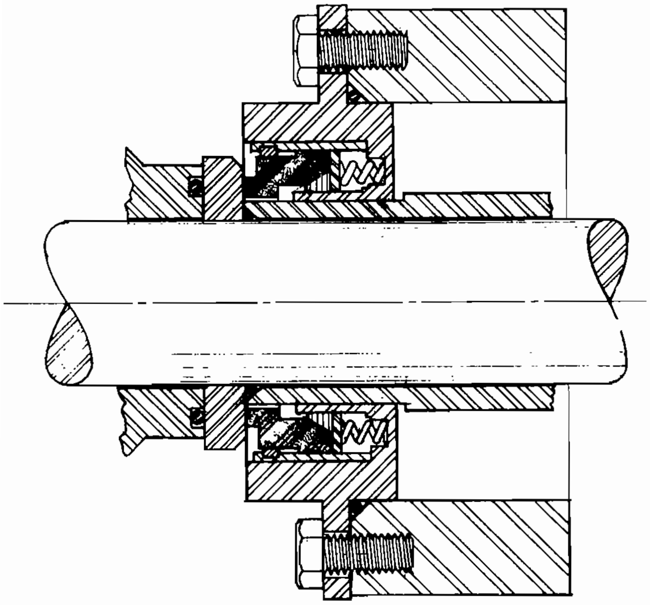

Figure 7. Balanced Stationary Seal.

Viton A "O" ring process filter gasket and how it swelled and cracked. He communicates this information to the project.

When reviewing pump and seal specifications, it is often helpful to list the factors that must be considered in the evaluation. Many seal problems can be resolved on paper by the systematic review of possible areas where problems occur. Once these areas of concern are properly identified, designs can be selected that will give an acceptable performance in that service. Below is a list of factors that have proven helpful in seal system design and selection. Each factor will be discussed in detail.

1. Product
2. Seal Environment
3. Seal Arrangement
4. Equipment
5. Secondary Packing
6. Seal Face Combinations
7. Seal Gland Plate
8. Main Body of the Seal

Product

The physical and chemical properties of the liquid being sealed will place constraints upon the type of seal arrangement, the materials of construction, and the seal design which can be used.

Now let's examine in detail some of those properties and see how they affect our choice of seal arrangement and materials of construction.

1) Pressure

The relative pressures of the material to be sealed affects the decision of whether to use a balanced or unbalanced seal design. It also affects the choice of face material because of the seal face loading.

If the service happens to be below atmospheric pressure, then special considerations are required to effectively seal the material.

Most unbalanced seal designs are applicable up to 100 psig stuffing box pressure. Above 100 psig, balanced seals should be used.

Seal manufacturers base their seal face combination designs on PV ratings. These are the multiple of the face load (P) and the sliding velocity (V) of the faces. The maximum PV rating for an unbalanced seal is about 200,000 and about 2,250,000 for a balanced seal.

2) Temperature

The temperature of the liquid being pumped is important because it affects seal face material selection as well as face wear life. This is primarily a result of changes in lubricity of the fluid with changes in temperature. It also affects the choice of the dynamic seal element because some materials such as Teflon become plastic at elevated temperatures, others harden, become brittle, and crack.

Another factor to be considered when applying a seal is what effect the heat generated by the agitation of the liquid inside the stuffing box as well as the heat generated by the seal faces will have on the material being pumped.

Corrosion rates of the seal materials may also be greatly influenced by the temperature of the pumped liquid and will be discussed later in more detail.

Common seal designs may handle fluid temperatures in the 0°F to +160°F to +200°F degree range. When temperatures are above the +200°F range special metal bellows seals may be used up to the +650°F range. Low temperature (e.g.,-100°F to 0°F) also requires special arrangements since most hydrocarbons have little lubricity in this range.

The most important consideration concerning temperature is to avoid operating close to a temperature which will allow flashing of the liquid. Mechanical seals work well on many liquids; they work poorly on most gasses.

3) Lubricity

In any mechanical seal design, there is rubbing motion between the dynamic seal faces. This rubbing motion is most often lubricated by the fluid being pumped. Therefore, the lubricity of the pumped liquid at the given operating temperature must be considered to determine if the chosen seal design and face combination will perform satisfactorily.

Most seal manufacturers limit the speed of their seals to 90 FPS with good lubrication of the faces. This is primarily due to the centrifugal forces acting on the seal which tend to restrict its axial flexibility.

4) Abrasion

When evaluating the possibility of installing a seal in a liquid which has entrained solids, the following things must be considered:

Is the seal constructed in such a way that the dynamic motion of the seal will be restricted by fouling of the seal parts?

Examples are the clogging of the convolutions of a bellows seal and the fouling of the springs on a multi-spring arrangement. We must determine if the abrasives are likely to get between the sealing faces and imbed in one or both of these faces, thus making a grinding wheel which will rapidly wear out the faces. Will the solids concentration be great enough that the stuffing box will become plugged and prevent lubricating liquid from getting to the seal faces?

Also, when considering abrasives, we must consider materials which crystallize. If this crystallizing action takes place between the sealing faces, solid deposits may be left which will abrade the seal faces. If it occurs outside the seal, it may tend to plug and foul the axial motion of the seal. If the crystallizing action occurs inside the stuffing box when the pump is idle for a period of time, damage to the seal may occur during startup.

The seal arrangement which is usually preferred when abrasives are present is a flushed single inside type with a face combination of very hard material. However, other factors such as toxicity or corrosiveness of the material may dictate that other arrangements be used.

5) Corrosion

When considering the corrosiveness of the material being pumped, we must determine what metals will be acceptable for the seal body and what spring material may be used. In addition, we must also determine what face material will be compatible with the liquid being pumped; that is, whether the binder of the carbon or tungsten carbide will be attacked, or whether the base metal of the plated seal face will be attacked. We must also determine what type of elastomer or gasket material can be used.

The corrosion rate will affect the decision of whether to use a single or multiple spring design because the single spring can tolerate a greater amount of corrosion without weakening it appreciably. Some seal arrangements such as the outside Teflon bellows seal lend themselves better to a corrosive environment than do others.

No general guidelines can be given for choosing face material combinations; however, there are a number of charts published by seal manufacturers and others which list many materials and the suggested face material for sealing them. These charts are usually developed based on past experience and generally provide an excellent guide to the selection of face combinations for various chemicals.

6) Toxicity

Toxicity is becoming an increasingly important consideration in the design of mechanical seals. Since the rubbing seal faces require liquid penetration to cool and lubricate them, it is reasonable to expect that there will be some vapor passing across the faces. This is in fact the case. A normal seal can be expected to "leak" from a few ppm to 10 cc/min. It is also generally accepted that the seal leakage rate will increase with speed.

Therefore, when a "zero" leakage seal is required due to the toxic nature of the product, consideration must be given to such designs as the double seal, including the face-to-face, back-to-back and tandem, as well as other environmental control measures such as purges, quenches, or possibly the elimination of the shaft seal altogether through the use of a canned pump.

7) Additional Product Considerations

- Is the product thermosensitive? If so, the heat generated by the seal faces may cause polymerization.
- Is the product shear sensitive; i.e., will it harden due to turbulence? The seal's configuration can have an effect on hardening.
- If the product is highly flammable, be aware of possible ignition sources. Additional safety precautions may be warranted.
- In hazardous services, plan for personnel protection in the event of seal leakage.
- Products with dissolved gas must be properly vented. In most cases, vent the stuffing box back to pump suction.
- Seals in cold services are extremely sensitive to moisture. There must be a way to "dry out the system" after repair.
- Consideration must be given to the pressure and temperature that the seal will see during normal operation, start-up, shutdown, and upset conditions.
- Vapor pressure of the product must be known in order to prevent vaporization in the stuffing box. Light hydrocarbons are especially susceptible to phase changes with very small temperature changes.

Seal Environment

Once an adequate definition of the product is made, the design of the seal environment can be selected. There are four general parameters that an environmental system may regulate or change.

1. Pressure Control
2. Temperature Control
3. Fluid Replacement
4. Atmospheric Air Elimination

The selection of the seal environment system is extremely important since it can have a large influence on seal life. The most common environmental control systems include flushing, barrier fluids, quenching, and heating/cooling systems. Each has its use in regulating the parameters mentioned above.

- Flushing is one of the most useful tools available to extend seal life. It can be provided from an outside source of cool, clean materials of good lubricating quality or it can be from the suction or discharge of the pump being sealed when bypass flushing is used.

When an external flush is used, the material must be compatible with the pumped liquid, for it will be combined with the pumped liquid after it passes through the seal chamber.

If temperature is the problem being dealt with, the flush material may be cooled through a heat exchanger before entering the seal cavity. This is frequently done with heat transfer liquids. The material will be pumped out of the stuffing box through an external cooler and returned to the stuffing box to lubricate and cool the seal.

When circulation of the material outside the stuffing box for cooling is required, a pumping ring is sometimes installed on the shaft to act as an impeller to assist in providing flow. Howver, the flow normally is expected to exit the stuffing box through a radially drilled hole in the stuffing box. If this drilled hole is provided tangential to the stuffing box, the pumping ring is much more effective and, in some cases, is unnecessary due to the pumping action of the rotating shaft and seal assembly.

If abrasives are present in the flush stream, it may be strained or filtered before entering the seal area. A flush is also advantageous when there is a possibility of running the pump dry. An external source can then provide liquid for the seal even though the pump is dry.

In order for a flush to be effective, there must be a sufficient amount of flush material available to keep the stuffing box area purged of liquid coming through the throat of the stuffing box. The amount of liquid entering the process may need to be controlled because of process reasons, expense of the material, or for other reasons. It is therefore sometimes desirable to restrict the throat area of the stuffing box with a fixed clearance bushing, a lip seal, a floating bushing, or some similar device. Many seal manufacturers provide charts which give flow rates required for various clearances, shaft sizes and pressures. They should help in determining the quantity of flush material required and the type of restriction device needed.

The normal diametral clearance at the throat of the box is .006" to .012". However, the clearance should be sized to give a flushing velocity of 10 to 15 FPS across the clearance.

- Barrier fluids are used with a double seal. This could be a back-to-back double, a face-to-face double (outside-inside), or a tandem arrangement. The barrier fluid in conjunction with the double seal is usually used for abrasive services where solids have a tendency to get into the seal cavity and plug and clog the seal parts. It is also frequently used for hazardous, flammable, or toxic liquids and vapors. This arrangement in a back-to-back arrangement may also be used for services where the pump may be run dry because the barrier liquid can provide lubrication and cooling for the seal faces.

The barrier fluid must be compatible with the process liquid because there is a small possibility of it leaking into the process. In a back-to-back arrangement, it must be at a higher pressure than the process liquid. In the case of the tandem seal, the barrier fluid should be at a lower pressure than the process liquid in the stuffing box. The double face-to-face seal can have the barrier fluid pressure higher or lower than the stuffing box pressure. The barrier fluid must be a good lubricant for the seal faces; it must be clean; and it must be capable of transferring heat away from the seal faces. Because it must keep the faces cool, the barrier fluid is most often circulated into and out of the stuffing box rather than being dead ended into the stuffing box. This circulation is accomplished by either an external pump and reservoir which forces the liquid through the seal chamber, by thermal siphoning, or by the pumping action of a pumping ring on the shaft and seal. When an external circulating pump is used, it is another piece of equipment which must be maintained, which will fail occasionally and which is expensive. When the thermo siphoning method is used, careful attention to detail is required to insure that the system will function properly. A poorly designed or installed thermo siphoning system is guaranteed not to function properly. If the circulation is provided by the shaft and seal or by a pumping ring on the shaft, the inlet and outlet holes in the stuffing box should again be drilled tangentially rather than radially to facilitate the movement of the liquid. Here again careful attention to detail will insure a system which performs as intended.

- Quenching is most commonly used for materials which crystallize. The quench is applied to the atmospheric side of the seal. It may be a solvent which is used to dissolve the materials which leaks across the seal and wash it away or it may be steam which is used to keep the material hot to prevent it from crystallizing. This type arrangement is frequently used in conjunction with metal bellows seals. Quenches are sometimes also used as a purge to prevent atmospheric moisture from contacting vapors coming across the seal faces. This is used primarily in very corrosive or toxic liquids.

A quench may be installed on a pump seal by providing a lip seal behind the mechanical seal. A few rings of auxiliary packing may be used as well as a close clearance throttle bushing. These devices may also be used as a safety device in case of a massive seal failure. They would thus limit the flow of pumped fluid and thus reduce the leakage rate.

- Sometimes heating or cooling is required to provide satisfactory life for a seal. When this is the case, a number of methods may be used. The most common method is to provide a pump with a jacketed stuffing box. When this is done, the heating or cooling medium, whichever is applicable to the particular problem being dealt with, can be applied to the area surrounding the seal chamber. Another method is the use of a seal gland ring which allows the heating or cooling medium to be circulated around the stationary seal member.

These arrangements may be used when temperature, either high or low, appears to present a problem to effective sealing. They may also be used when dealing with a material which crystallizes and requires temperature control to insure that they are liquid. They may also be applicable when there is a lubrication problem because of the material being in the wrong temperature zone.

Any one of these methods or a combination of two or more of them may be used to create an environment in which a seal of some design will be able to effectively operate.

Therefore, when confronted with the problem of designing an effective, reliable and safe seal arrangement for a particular service, one must consider the seal hardware available, the material of construction required, and the seal protection systems which may be needed based on the properties of the fluid being handled, the type of pump used and the system in which it is installed. If consideration is given to the factors involved, an adequate seal system can usually be designed.

1) Seal Environment Considerations
    - Keep the temperature of the stuffing box fluid 25°F below the boiling point at box pressure.
    - Don't use high pressure or high velocities at the face.
    - Don't flush the face if the flush has fine solids.
    - If water is the product, keep the box temperature below 160°F because of flashing.
    - Flushing a stuffing box without a good restrictive throat bushing is ineffective.
    - More manufacturers are offering floating throat or throttle bushings. They provide good control on small flush flows providing there is no grit or salt. Use of Teflon lip seals is a problem unless the sleeve is coated and a proper retention mechanism is used for the Teflon.
    - If the slurry carrier fluid can be added at the pump, use two flushes. One flush enters a special close clearance lantern ring at the throat of the box at about 2-3 gpm with velocities through the clearances at 10 to 15 ft./sec. The second flush enters at the seal face.
    - On cold pumps, use a quench and drain gland with external packing. Add methanol or antifreeze between the mating ring and packing for deicing.
    - Minimum throat bushing length is ½ inch. Bushings ¼ inch long are not effective.
    - When using a single inside seal with a close clearance throat bushing and external flush, a rotometer and a pressure gauge located between the rotometer and stuffing box is a must. The pressure gauge indicates the condition of the throat bushing.
    - For discharge flushes that have entrained gas, flush the face from the bottom of the gland and provide a line from the lantern connection back to the suction.

Assure that throttle bushings or carbon inserts have a metal lip on the gland (min. ⅛") to prevent blowout in service (Safety). Some equipment manufacturers make up for seal space limitations by an elaborate seal drawing showing a stack of spacers between the gland and the stuffing box. This method generally produces poor results especially with clamped mating rings. Use of registers and metal to metal fits are good design practices.

Seal Arrangement

Seal arrangements may be unlimited on some equipment while others offer limited choices. The basic seal arrangements are:

1. Single unbalanced either inside or outside
2. Single balanced either inside or outside
3. Double balanced seal back-to-back
4. Double unbalanced back-to-back
5. Double balanced and unbalanced back-to-back
6. Double unbalanced face-to-face
7. Double balanced face-to-face
8. Tandem seal

1) Seal Arrangement Considerations

- Double seals have been the standard in toxic and lethal product, but maintenance problems and the seal design contribute to poor reliability. The double face-to-face seal should be looked at more closely.
- Don't use a double seal in dirty service — the inside seal will hang up.
- API is a good guide as to the use of balanced and unbalanced seals. Application of a balanced seal at too low a pressure may encourage face lift off.
- The number of arrangements and auxiliary features are over a hundred. Regardless of the seal vendor, the arrangement will generally determine success.

Equipment

Too few people consider the equipment with the seal selection. In most cases, poor equipment will give poor seal performance, regardless of the seal or arrangement chosen. Also, beware that different pumps with the same shaft diameter and TDH may present different sealing problems. What areas does one look at in the equipment selection to assure reasonable seal reliability? (Note: These same considerations may be used for troubleshooting.)

1) Equipment Considerations

- Attention to how the impeller affects the stuffing box pressure should be checked against the selected seal. Many of the stuffing box pressure charts published by the equipment vendor are only true when the pump is new. Open impellers with back pump out vanes can allow pressure to build up to ½ of discharge. Normal set clearance of back pumping vanes is 0.015". They are not effective when the clearance is over 0.030".
- An unbalanced seal with a discharge flush will have face loading problems if the face material, pump TDH, and Specific Gravity are in the right combinations.
- The inboard seal of a double seal arrangement may act as a relief valve when pressure at the throat bushing exceeds the flush pressure.
- Even if the temperature is only 150°F, but the liquid is near boiling at box pressure, a stuffing box jacket or head/stuffing box jacket, or external cooler should be used.
- Balance holes in the eye of the impeller should be a part of the design even on impellers with wear rings. A rule of thumb is that the balance hole area is two times the wear ring clearance area. Conversely, if the balance hole area is 0.5 times or less the wear ring area, pressure at the throat bushing will reach about 60% of the TDH.
- Designs must have bearing systems that limit shaft end play to 0.002" to 0.003".
- Double volutes on large pumps are preferred unless more than adequate considerations were made in the shaft design.
- Shaft probe measurements have indicated that manufacturer's data on shaft deflection at the stuffing box face can be on the low side.
- Beware of mechanical seal applications to double suction pumps that were designed for packing.
- Certain designs of two stage overhung pumps have seal problems due to excessive shaft movement.
- Ease of seal repair on pumps with bearings outboard of both seals is a consideration.
- Shaft sleeves that have Teflon shaft packing and/or fixed close clearance or floating throat bushings should have a hard coating or ceramic under the bushing area. Many pump vendors resist applying a coating by dumping a $200 to $300 price adder. A few pump vendors cannot understand why a coating under Teflon is needed since, "after all, the sleeve is 316 SS." Annealed stainless steel "frets" with extreme ease because the chrome oxide from the stainless surface imbeds into the Teflon making an excellent surface grinder.
- Some manufacturers have design options on their vertical multistage pumps where the mechanical seal is *not* exposed to discharge pressure.
- Many of the features important to seal life and performance are of little consequence in the design of the equipment, so look carefully.
- The sleeve plays an important sealing function with the shaft packing. Make sure the sleeve is resistant to fretting, wear, and corrosion. Remember a coating is only as good as the base metal.
- Encourage the manufacturer to keep your sleeves in ⅛" increments for better standardization.
- Use of rubber element couplings will dampen drive shaft and coupling vibration to improve seal performance. ANSI pumps are the best area of application.
- RPM is important since surface speed of the seal is an important design parameter. Direction of rotation may be of importance in single spring seals.

Secondary Packing

More emphasis should be placed on secondary packing than it receives, especially if these members involve Teflon. Most seal designs using an "O" ring for shaft packing give similar performance. A wide variation in performance is seen between various seal vendor designs when Teflon shaft packing is used. Depending on the seal arrangement, there can be a difference in mating ring (stationary) packing performance when Teflon is used.

1) Secondary Packing Considerations

- Box and shaft dimensions force some manufacturers to use small Teflon packing members. In one case, a tandem seal under 400 psi and 280°F, had a design problem where the inside mating ring packing cold flowed and failed in several days. On very critical seals under high pressure, calculate the force on the mating ring packing (the results can be quite interesting).

- Some pump vendors force the seal manufacturer to use an anti-rotation pin on the back side of the mating ring when the manufacturer's gland is used. Radial anti-rotation pins should be a requirement. Use of a proper radius on the edges of the slot is often overlooked.
- Kalrez "O" rings have given hope to users completely trapped into Teflon packing members.
- The question of when to apply virgin versus glass-filled Teflon shaft packing may be more of a function of seal design than temperature. Depending on the pressure, the wedge may go to 350°F without glass. "V" rings are much lower depending on the seal ring material.
- "O" ring mounted stationaries are preferred for better flexibility, better sealing and less installation problems.
- Teflon "O" rings will not work as shaft packing. TFE over Silicon or Viton have performed as static seals. Depending on the design, installation of the coated "O" ring can be difficult.
- "O" rings that swell under a carbon or ceramic seal ring may break the ring before it hangs up.
- Designs using "O" rings normally have a diametrical compression of 5 to 10% and a hardness of between 70° and 90° Shore A.

Seal Face Combinations

Choices of seal face combinations have come a long way in the last eight to ten years. Stellite is being phased out in petroleum and petrochemical seal applications. Better grades of ceramic are being offered as the standard material. The cost of tungsten carbide has decreased considerably. Relapping services for tungsten are available near most industrial areas. Silicon carbide is gaining a hold on the market especially in abrasive service. The technology of manufacturing tungsten carbide in a composite or overlay arrangement is offered by all of the major seal manufacturers. The dynamics of seal faces are better understood today.

1) Seal Face Considerations
    - Silicon carbide has gained acceptance against tungsten carbide in slurry and abrasives services. Silicon carbide is being applied in tough chemical services. The solid silicon carbide rings have chemical resistance, good shock resistance, and acceptable strength properties, but the price and delivery may cause hesitation in ordering.
    - Composite seal rings such as Ceramic/316 SS will fret at the contact area from the Teflon shaft packing.
    - Composite seal ring designs using a tungsten carbide wafer ring and gasket have shown poor service.
    - Cross-sectional size of a carbon is important if it is under differential pressure. On seals with clamped carbon mating designs, location of the clamping surfaces may be important.
    - A press fit carbon should only be used as a last resort. When used, provisions should be made in the gland design where the face can be relapped after pressing.
    - Nickel binder tungsten carbide is generally more chemical resistant and has a higher thermal shock parameter than the cobalt binder tungsten carbide.
    - Don't use ceramic versus Stellite. Ceramic will groove into Stellite and the runout will cause the ceramic to shatter.
    - Hastelloy B, Hastelloy C, stainless steel and Monel have shown poor results as a seal face material.
    - Ceramic should be limited to a 250°F gradual change in temperature. Use of a low purity grade ceramic as an outside seal ring without a band is risky.
    - Generally, seal face loading is 20 to 50 psi.
    - Tungsten carbide will run cooler against carbon than ceramic against carbon because of it thermoconductivity. Tungsten carbide can be a problem with thermosensitive products because the local face temperature is hotter. Thermal expansion of tungsten carbide is much different than stainless steel; i.e., 2-4 in./in./°F versus 9-10 in./in./°F. Overlays, other than detonation embedding into base metal are, therefore, prone to thermal separation failure. Cast rings are uniform.

Seal Gland Plate

The seal gland plate is an item that is caught in between the pump vendor and seal vendor. The pump vendors can furnish good, reasonably priced alloy glands, but they are also limited because the gland is cast and must fit several seal designs. There are also some glands furnished by the pump vendor that can be easily distorted by bolting. Special glands requiring heating, quench and drain with a floating throat bushing on ANSI pumps should be furnished by the seal vendor. Gland designs on several ANSI pumps are not that impressive. Why should the pump vendors have this responsibility?

1) Seal Gland Plate Considerations
    - The gland should be registered either O.D. or I.D. pilot.
    - Specifying an extra gland feature that may be needed if a seal problem occurs is cheap insurance.
    - Gland material should be the same as the pump specification.
    - Designs using clamped inserts should be de-emphasized due to the difficulty of a craftsman applying proper bolting loadings on the clamped stationary.
    - 1/32″ or 1/16″ thick (not 1/8″) gasket for stuffing box to gland seal assures the best alignment of the stationary seal face to the shaft.

Main Seal Body

Designs differ considerably from one manufacturer to another. The term seal body makes reference to all rotating parts on a pusher seal excluding shaft packing and the seal ring. The configuration or options offered on the seal body may be the chief reason to avoid the design for that particular service.

1) Main Seal Body Considerations
    - Close clearance between stationary members and dynamic members are to be avoided in grit or dirty services. Grit will pack and lock the seal.
    - Small springs will plug with grit if it is not an open design. Chlorides will cause stress corrosion cracking and fail the seal from broken springs, if springs are not the correct material.
    - Big springs can uncoil under high speed applications.
    - Applications of metal bellows seals where corrosion rates are .003″ to .004″ per year should be viewed as a risk.
    - When a number of seals are being applied where a high alloy is required, justification may exist to consider one vendor's design because of cost.

- Don't use high velocity flushes directed at the seal body.

SEAL FAILURES AND THEIR PREVENTION

The best help that a seal user can acquire to increase seal reliability is a thorough understanding of his own problem. The information that leads to this understanding is readily available in the form of used and failed components. A systematic and detailed inspection of parts, coupled with an investigation of the pumping system, provides a wealth of information about the causes of machinery downtimes. The purpose of this section of the paper is to discuss troubleshooting seal failures, analysis of failed components, and some practical solutions to the problems identified by these analytical procedures.

Troubleshooting Seal Failures

The troubleshooting process usually begins with a report that the pump/seal system is not working as desired. The most common report about a seal problem is that it is leaking, but other reported problems include complaints that the seal is running hot or is noisy (squealing). The purpose of investigating any seal problem is to define the cause of the problem and correct it if necessary. The idea of making corrections *only* if they are necessary is an extremely important one. Too many times an unneeded correction wastes manpower and parts, adds problems such as assembly errors, or both.

With this purpose in mind, there are several important symptoms that should be noted when diagnosing seal-related problems. These include:

1. Is there leakage? If so, how much and from where?
2. Is the leakage constant or intermittent?
3. Did the problem arise abruptly or appear and gradually get worse?
4. Has the problem occurred before or is this the first time?
5. Were there any changes in the pumping system coincident with the observance of the problem?

These symptoms provide many clues to the type of problem. For example, leakage under the shaft sleeve is usually indicative of a secondary sealing problem between the shaft and the sleeve. Leakage past the throttle bushing or the gland drain indicates leakage past the seal faces, under or through the seal itself, or past the stationary face. Another clue is how the leakage rate varies. It is important to know whether the seal leaked from the moment it was subjected to pressure, or whether it leaked as soon as the pump began rotating, or whether it only leaked when the pump began to heat up or cool down. Any variation in leakage rate in conjunction with temperature or composition of the pumpage is also important in understanding why the seal won't work as it is supposed to do. An abrupt change in leakage rate can indicate the complete failure of a seal component such as a ruptured bellows or cracked face or it can indicate complete face separation. A gradually worsening situation may indicate secondary seal deterioration. Some knowledge of the past history of the seal and pump is useful in guiding the direction of the investigation. A one-time failure usually indicates an assembly or operational problem. Subsequent failures of the same type indicate design-type problems. Assembly and operational problems can be corrected by procedural changes once the error is correctly identified. Design problems require some change in the pump/seal system or its components. An obvious symptom to look for is change in the pumping system coincident to the observance of the seal problem. Cavitation, loss of pumpage, excessive temperature, pressure surges, acid/caustic carry-overs, and other severe changes in the pumping system can result in mechanical seal failures.

Generally, observance and interpretation of these symptoms is only the first step in determining the actual cause of the problem. In some cases, obvious errors in operation or installation will prove to be the cause of the reported seal problem. These errors can be easily correctable and do not require disassembly of the pump. However, most of the time a reported problem involves a seal in which one or more components is either worn or broken so that it does not function as designed; i.e. a seal which has failed. Failure analysis of the components thus becomes the second step in determining the cause of the problem.

In troubleshooting seal failures (or any other type of equipment failure), once the reported failure has been verified, a decision must be made as to whether or not the problem is bad enough to require immediate correction. In the case of seal leakage, this generally depends upon the nature of the pumpage itself and the amount of leakage. There are no generally accepted leakage rates for mechanical seals. Most often, an acceptable leakage is determined by operation and maintenance personnel directly responsible for the equipment.

Failure Analysis of Mechanical Seals

Failure analysis is simply a systematic approach to gathering information that will help to determine why a seal failed. It consists of a very close inspection of the failed part. Most of the time, a visual inspection with a low magnification lens will suffice, but extremely detailed analyses might include spectrographic analysis, metallurgical analysis, electron microscopy, etc. In general, there are several conditions that should be looked for in inspecting any part.

1. Is it the right part? Minor variations in the size of the dynamic face or in the spring(s) may cause the face to hang up on the shaft. O-rings can be easily confused unless they are color coded.
2. Any sign of wear can be an important clue. Distinctions must be made between normal and abnormal wear. All scores and scratches are important in determining what parts rubbed and can also provide information as to when and how they rubbed. Machining and lapping marks provide a reference point in determining damage to the part.
3. Cracks and chipping of the faces are usually a good indicator of the severity of the contact between parts or of rapid temperature changes.
4. Any discoloration of parts due to heat is extremely important in estimating how hot the part got during the failure and can aid in determining the source of heat. Deterioration due to heat, as occurs in an elastomer, also aids in estimating temperatures.
5. Corrosion and erosion generally indicate the unsuitability of materials for a particular service.
6. An observer should also be watching for signs of fouling or deposit buildup in the seal area.

Table 1 lists the failure characteristic and cause of failure for various seal components. The tabulation is by no means a complete list of all failure modes, but indicates the problems that can be identified by close inspection of a failed or worn component.

TABLE 1
COMMON SEAL FAILURES AND CAUSES*

Failure Characteristic	Common Causes
- *Primary Seal Faces*	
Heat checking.	Thermal shock of face due to momentary loss of lubricant between faces or rapid quenching of face.
Excessive adhesive wear (little grooving but may have galled).	Inadequate lubrication of faces. PV value too high for materials. Improper assembly (seal jammed.).
Severe abrasive wear (much grooving).	Abrasives in pumpage. Crystallization of product.
Uneven, intermittent wear over face circumference.	Face not square to mating face. Distortion due to heat or pressure.
Face hung up.	Buildup of solids between seal head and shaft or sleeve.
Chipping of outer edge.	Vibration due to unstable lubrication film.
Pitting of carbon faces.	Blisters formed by thermal cycling. Improper grade of carbon. High viscosity fluids.
Cracking.	Mishandling. Thermal shock. Shaft rubbed stationary face or rotating face rubbed stuffing box.
Corrosion.	Improper material.
Secondary Sealing Elements	
Fretting of shaft or sleeve.	Excessive shaft end play. Seal face(s) not square with shaft.
Hard, brittle.	Excessive heat.
Compression set.	Excessive heat and compression.
Soft, gummy.	Chemical attack.
Cuts, tears.	Improper assembly.
Extrusion.	Excessive pressure.
- *Driving, Pushing Elements*	
Wear.	Excessive vibration. Excessive shaft end play. Inadequate face lubrication.
Seal hang up.	Buildup of solids between seal head and shaft or sleeve.
Metal bellows cracked.	Inadequate face lubrication. Excessive pressure. Improper assembly (bellows over-compressed). Corrosion. Seal resonance. Misalignment.
Clogged, fouled springs.	Pumpage dirty. Pumpage tends to crystallize.
Corrosion.	Improper material.
- *Seal Gland*	
Rubbing of throttle bushing.	Improper assembly.

*Adapted from *Metals Handbook, Volume 10, Failure Analysis and Prevention,* Eighth Edition, American Society for Metals, 1975.

Failure Prevention

The troubleshooting and failure analysis techniques that have been discussed are methods of identifying the cause of failure. Once the cause has been determined, then steps can be taken to correct the problem. It should be obvious at this point that failure analysis and correction of the cause of failure go hand-in-hand; neither step is effective without the other. Correction of the problems require action in several different areas. First, usually there is a correction or modification to be made to a specific pump or seal. Second, there may be general modifications that can be made to a class of pumps or seals. Third, analysis of general seal failures may indicate problems with maintenance or operational techniques. Finally, the identified problems along with successful and unsuccessful solutions should be fed back to the people responsible for designing pumping systems and selecting seals.

As far as the mechanical hardware is concerned, there are four general approaches to improving seal performance. They include (1) modifications to the pump to improve the seal environment, (2) the selection of better materials, (3) changes to the seal design, and (4) minimizing the detrimental effects of the pump on the seal.

Consider the first of these approaches. Many modifications can be made to a pump to improve the environment in the seal cavity and thus improve the seal's chances for survival. For example, all of the following modifications have been made to correct specific problems.

- In most single-stage, process-type pumps, the stuffing box pressure can be controlled by the size and location of the impeller balance holes. To lower the pressure, increase the number or size of the holes or relocate the holes to a smaller radius on the impeller.
- In some double-ended pumps where one stuffing box is at a higher pressure than the other, both can be reduced to near suction pressure by connecting both seal cavities.
- The centrifuging action of a pump impeller can be used to separate abrasives from the pumpage, instead of using the pump volute as a source impeller where the pumpage is cleaner. This works only when the abrasives are heavier than the pumpage itself.
- External flushes can be added to control the temperature of the seal cavity. In some cases, these flushes may be additives that are normally injected into the pumpage for processing or corrosion-control puposes.
- Flush holes are most effective when located near the seal faces. Problems with opening the seal faces with excessive flow through the flush hole can be avoided by using a stuffing-box-to-suction flow plan (API Plan 13).
- Care should be taken to ensure that the seal cavity is as self-venting as possible. This is particularly important in vertical pumps since any vapors in the seal cavity tend to rise to the top where the seal faces are.

The second approach to improving seal reliability is by the selection of better materials. As in the other approaches, material changes are not effective unless a specific problem is identified and a material is available to fill the specific need. The following examples discuss how material changes can help to improve seal life.

- Seal face combinations can be selected on the basis of a PV (pressure-velocity) value. Another useful guideline is the thermal shock parameter. These values are generally available for most seal face combinations. A new material that rates well in both these parameters is sintered silicon carbide. It also has the advantage of being very chemically inert.

- Perfluoroelastomer (Kalrez) O-rings offer the mechanical properties of an elastomer at temperatures up to 550°F along with excellent chemical resistance.
- Fretting of the shaft or sleeve by the seal secondary element can be minimized by hard-coating the affected area. Colmonoy coatings have been widely used in the past, but plasma-sprayed tungsten carbide coatings provide a superior wear resistant surface.
- Most seal manufacturers offer several different grades of carbon-graphite faces. Significant differences exist between the grades in thermal conductivity, strength, chemical resistance, and coefficient of expansion. If a problem with a particular grade of carbon can be identified, an improved grade can usually be found.

A third method of increasing seal life concerns changes to the mechanical seal itself. In most cases, these changes involve the selection of a different type of seal, but on occasion modifications to a particular seal provide a more effective unit.

- Fouling (clogging) of the springs in a multi-spring seal can be effectively combated by the use of a metal bellows seal or a seal with a single, large spring as the pushing element.
- Improvements in seal life can be gained by eliminating the shaft sleeve and decreasing the size of the seal. This reduces the surface velocity of the seal faces and provides the additional benefit of eliminating the leakage path between the syaft and the sleeve.
- Problems with seal faces opening due to fluctuating stuffing box pressures can be overcome by increasing the hydraulic load on the seal faces. A seal with a higher balance ratio can be chosen or the existing face modified by increasing the inside diameter of the face in the seal head.

The fourth approach to changing the mechanical hardware involves minimizing the detrimental effects of the pump on the seal.

- Excessive shaft end play can cause fretting of the shaft or sleeve and wear of the seal driving components. It can be reduced by using angular contact bearings.
- Shaft deflection can also cause fretting and wear in the seal. It can be reduced by using double volute pump cases or by redesigning the shaft.

In addition to identifying design and component weaknesses, analysis of seal failures can indicate problems in maintenance or operational techniques. Once the problems are identified, training programs can be set up to inform and teach the correct procedures. Most of the general problems concerning maintenance techniques usually involve installation of the seal. Damage to secondary sealing elements, improper positioning of the seal on the shaft, and failure to keep the seal faces square with the shaft can all lead to premature failure of the seal. Operational techniques that shorten seal life are usually involved with starting a pump. The most common fault is starting a pump without properly venting it, but excessive starting and stopping of a pump can also shorten seal life. Another common operational problem is inadequate level controls or flow controls in the pumping system. The important idea is that analysis of failed components can indicate specific problem areas that can be corrected. Training programs can therefore be narrowed in scope and intensified instead of spending time on general topics that may have no bearing on the problem at hand. The result is less time wasted in non-productive training and improved seal reliability.

The last step in seal failure prevention is to ensure that the knowledge gained by analyzing seal failures is passed on to those involved in purchasing and selecting new equipment. Ideally, the problems that are encountered and the solutions that were tried would be fed back to the equipment designer/purchaser. When possible, much of this data should be incorporated into purchase standards and specifications.

CONCLUSION

The underlying theme of this paper has been to demonstrate that mechanical seal reliability *can be improved*. The person most likely to make improvements is the seal user. In order to make these improvements, the user must be actively involved on two fronts. First, he must be involved in the initial design of sealing systems for new equipment. This implies not only a concern for the particular type of seal, but also how the seal is installed in the piece of equipment and what environmental controls are needed, if any. The second area requiring action by the seal user is that of adequate follow-up. In order to anticipate problems in seal design in the specification and requisitioning stage, he must have a knowledge of what works (or doesn't) in his plant. Coordinated efforts in these two areas will greatly improve seal reliability.

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