CONTROLLING EMISSIONS TO ATMOSPHERE THROUGH THE USE OF A DRY-SLIDING SECONDARY CONTAINMENT SEAL

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ABSTRACT

Increasing concern over the emission of hazardous compounds to the atmosphere has led to stricter regulations regarding the acceptable amount of leakage from pumps. This is forcing the users and manufacturers of pumps and seals to review their options for meeting these regulations.

The options pump users and manufacturers have for meeting federal and local emission regulations is discussed herein. Included among these options is a new concept which involves utilizing a dry sliding secondary seal to contain primary seal emissions and act as a reserve safety seal during primary seal failure. Discussion will include a description of the design of the containment seal that was developed, along with laboratory and field test results for this seal.

INTRODUCTION

Many pump users would like to continue to use single mechanical seals in their equipment if they can consistently and reliably meet the regulations. The advantages of single seals are their simplicity and low life cycle cost.

A discussion is included of emission data for single mechanical seals obtained from monitoring at refineries and chemical plants. The data show that single seals can effectively seal to low emission levels. The data also show, however, there can be a significant amount of variability in the emission readings from a pump over time. A seal having emission levels consistently below 500 ppm can occasionally have spikes that approach or exceed 1,000 ppm during periods of unstable operating conditions. The seal is generally capable of recovering from these upset conditions.

Standard dual mechanical seals can be used to contain the increased emissions that may come from the inner seal during upset conditions. These arrangements, however, have several disadvantages associated with the requirement for a liquid barrier fluid system.

A dry-sliding secondary containment seal can also be used to contain any increased emissions from the inner seal during operational upsets. Instead of being released to atmosphere, the emissions are routed to a vapor recovery system.

The primary advantage of the dry-sliding secondary containment seal over other dual seal arrangements is that it eliminates the need for a liquid barrier fluid, leading to a much simpler system at a significantly lower initial cost. Furthermore, the operational and maintenance costs associated with this system are much lower due to its maintenance free nature.

Recognizing the need for a reliable dry-sliding secondary containment seal, a program to develop this type of seal was begun in 1985.

EMISSION REGULATIONS

Federal and local agencies are implementing regulations to limit the amount of leakage allowed from rotating equipment. Users must review and become knowledgeable of these regulations, then review their options for meeting them.

Federal Regulations

An Environmental Protection Agency (EPA) Negotiating Committee has reached an agreement in principle on a regulation for equipment leaks at organic chemical manufacturing facilities [1]. This regulation applies to pumps which are in volatile hazardous air pollutant (VHAP) service for 300 hrs or more per year. The regulation does not apply to refineries; however, it will apply to a limited number of applications not in the synthetic organic chemical manufacturing industry. A separate rule for refineries is expected to be released within one year.

Local Regulations

The most stringent emission regulation currently being enforced is Rule 1173 [3], enacted by the South Coast Air Quality Management District (SCAQMD) in the Los Angeles basin. This rule limits the emission of volatile organic compounds (VOCs) to the atmosphere. A VOC is defined as a volatile chemical compound which contains the element carbon. Compounds excluded from this definition include methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate, and some chlorofluorocarbons.

USERS' OPTIONS FOR MEETING PUMP EMISSION REGULATIONS

Users of mechanical seals are, of course, looking for the most cost-effective and reliable method of meeting these new regulations. The most common options considered are sealless pumps, single mechanical seals, standard dual seals with a liquid barrier system, and dry-sliding secondary containment seals.

Sealless Pumps

The sealless pump is one of the options industry is looking at to meet the new emission regulations. Its main advantages are low emissions to atmosphere and the fact that a barrier fluid system is not required. One important thing to remember, however, when choosing between a mechanical seal and a sealless pump is that the most common causes of seal failure (i.e., loss of suction pressure, insufficient vapor suppression, operational upsets, and improper maintenance procedures) will also cause sealless pumps to fail [4]. Therefore, if a problem mechanical seal is replaced with a sealless pump without making any other changes, the user will merely be trading a seal problem for a pump problem. Other disadvantages of sealless pumps include the high initial cost, high repair costs, increased power consumption, product lubrication of the bearings and a more limited range of applications than mechanical seals.

Single Mechanical Seals

The standard single mechanical seal (Figure 1) is the simplest and, from a hardware standpoint, the most cost-effective method of meeting the new emission regulations. Data gathered from refinery and chemical plants bear out this point. The data show that standard single seals generally meet the new emission limits in virtually all applications for which they are typically recommended. Over 90 percent of the emission readings taken were below 1,000 ppm. There was no special attempt to correct any operational, maintenance, pump or seal design problems before these readings were taken. The data collected are consistent with the data gathered by other organizations [5].

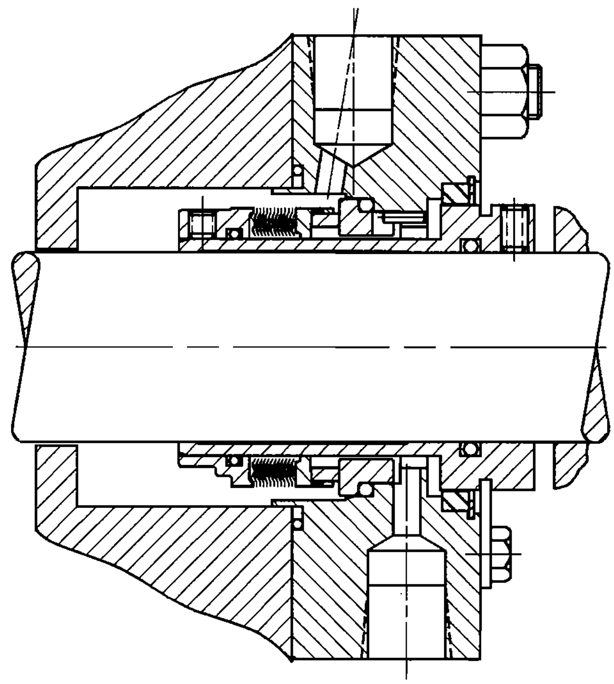

Figure 1. Standard Single Mechanical Seal.

It has also been found, however, that the emissions from a single seal can vary significantly over time. The data in one survey consisted of five to six readings taken on approximately a weekly basis for 31 single seals in a light ends unit at a refinery. The data showed that it is very common for a seal to operate reliably at emission levels well below 1,000 ppm (even below 200 ppm), then increase to levels approaching or exceeding 1,000 ppm. This increased emission level can usually be attributed to a change in operating conditions or a process upset. The data also show that the seal is typically able to recover from the operational difficulties and return to the low emission levels previously seen. Samples of the data gathered on two pumps, are shown in Figure 2. The trend shown was seen to some extent on all of the seals tested.

While the emission trends were the same for both bellows and pusher seals, the maximum values were generally higher on the pusher seals. This is attributed to the fact that bellows seals have no dynamic secondary seal and are, therefore, able to eliminate drag and maintain superior face tracking. Both the pusher and bellows seals consistently recovered from the operational upset and subsequent increased emission levels. The data show mechanical seals are much more forgiving than many people realize. They appear to be able to survive and recover from several excursions in the operating conditions.

The disadvantages of single mechanical seals are their susceptibility to improper operating conditions or process upsets and their lack of a back-up seal. Although the seal is frequently able to survive the operational difficulties, the emission level to the atmosphere during this period will increase. Another disadvantage

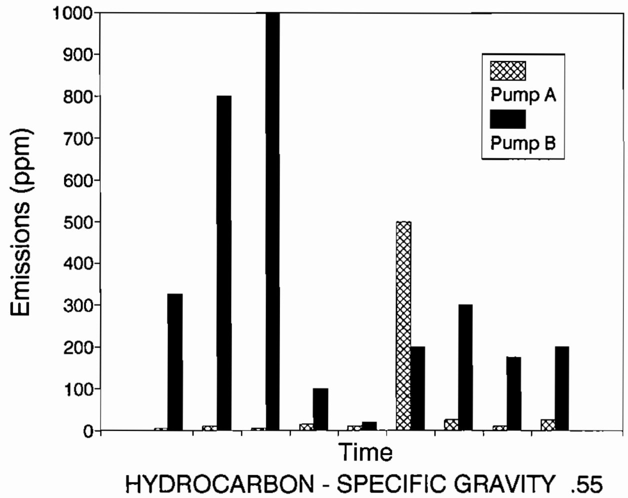

Figure 2. Emissions Data Vs Time for One Pump.

of single seals is the requirement of monthly leak detection and repair programs, proposed in the new EPA regulation.

Dual Mechanical Seals with a Nonpressurized Barrier Fluid

In a standard dual seal arrangement with a nonpressurized barrier fluid system (Figure 3), the inner seal is lubricated by the product while the outer seal is lubricated by the barrier fluid. Any emissions of the product past the inner seal in this arrangement will migrate to the barrier fluid.

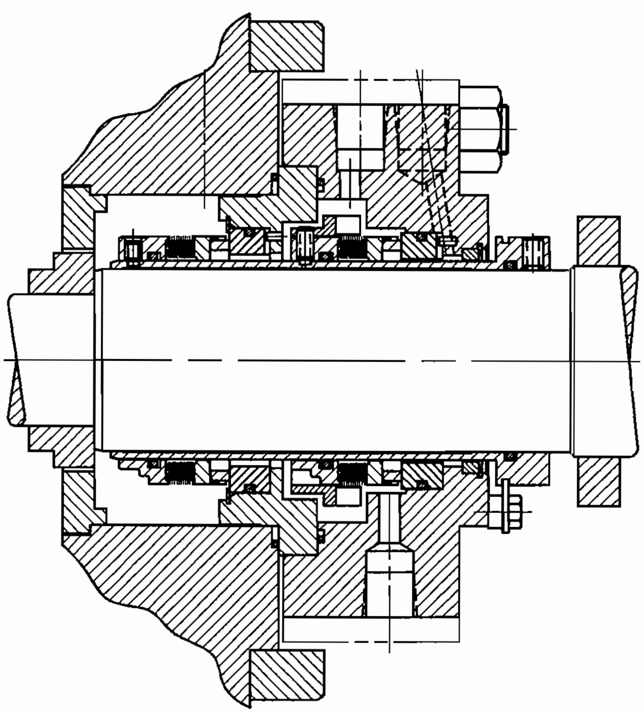

Figure 3. Standard Dual Seal Arrangement.

If the product is immiscible with and has a higher vapor pressure than the barrier fluid, emissions from the inner seal can safely be vented to the flare or any other vapor recovery system. In this case, zero emissions to the atmosphere can be achieved by using a low-leakage inner seal. If the product is miscible with the barrier fluid or has a lower vapor pressure, the barrier fluid may have to be changed on a regular basis to prevent contamination and ensure zero emissions of the product to the atmosphere.

The advantages of this system are its low leakage characteristics, the presence of a back-up seal, and the fact that the seal is not subject to the monthly leak detection and repair program if the barrier system meets certain requirements. The outer seal can be designed such that, if the pump is operating properly, the emission regulations can be met until the pump can be shut down, even if there is a significant problem with the inner seal.

The main disadvantage of this system is the presence of a liquid barrier system. Barrier systems have a high initial cost, plus a significant installation, operational and maintenance cost. Furthermore, these systems are not always more reliable than single mechanical seals. Some users get excellent reliability from dual seal arrangements, because they are giving the seal a more controlled environment in which to operate. Others get poor reliability from their standard dual seals due to improper maintenance and operation of the barrier fluid system. It can also be difficult to find a barrier fluid which is compatible with the product being pumped. Another disadvantage is the axial space requirement for dual seals. It is difficult to fit dual seals into an API stuffing box and almost impossible to fit them into an ANSI pump stuffing box.

Dual Mechanical Seals with a Pressurized Barrier Fluid

In a standard dual seal arrangement with a pressurized barrier fluid system, both seals are lubricated by the barrier fluid. Therefore, the small amount of barrier fluid that passes across the inner seal for lubrication will enter the product.

This system virtually ensures zero emissions to atmosphere. The barrier fluid can eventually become contaminated due to mixing at the inner seal faces; however, this occurs so slowly that it is generally not a concern. The outer seal acts as a backup seal and, if the pump is operating properly, it can meet the emission regulations until the pump can be shut down, even if there is a significant problem with the inner seal. This seal arrangement is also exempt from the monthly leak detection and repair program assuming the barrier fluid system meets certain requirements.

This system has essentially the same disadvantages as the dual seal arrangement with a non-pressurized barrier fluid system. One would expect even better reliability from these seals because the environment at the inner seal faces is more tightly controlled; however, the barrier system is also more complex which can lead to higher operational and maintenance costs. Also, because a small amount of barrier fluid enters the product, it is even more important to find a compatible barrier fluid.

Secondary Containment Seals

Theory and Design

Until recently, dual seal systems for pumps required a liquid barrier fluid between the two seals to lubricate the outer seal faces. Advances in sealing technology have led to the development of a dry-sliding secondary containment seal which can be used as the outer seal in a dual seal arrangement (Figure 4). This seal is a full contact face seal capable of operating without liquid lubrication. The shorter axial space requirement allows this seal to be installed in stuffing boxes where longer dual seal arrangements could not be installed.

A properly designed secondary containment seal provides the emission controlling capability of standard dual seals without the need for a liquid barrier fluid. A large percentage of standard dual seal failures can be attributed to problems with maintaining and operating the barrier fluid system. Therefore, by using a secondary containment seal, it is possible to eliminate complex and costly barrier systems, and their associated problems. Furthermore, since

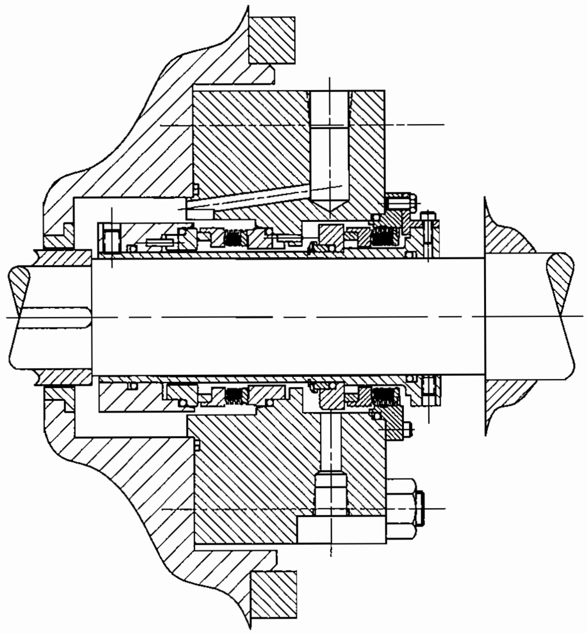

Figure 4. Dry-Sliding Secondary Containment Seal.

the emissions from the inner seal can be captured and routed to an approved control device, the secondary containment seal meets the EPA requirements for exemption from the monthly leak detection and repair program.

The primary purpose of the secondary containment seal is to reduce or eliminate emissions to atmosphere. In order to ensure emissions are reduced, the barrier area must be vented to the flare or another vapor recovery system. Otherwise, the pressure will build up in the barrier area, and the emissions across the inner and outer seals will eventually equalize.

The piping arrangement shown in Figure 5 allows for automatic venting of the barrier area at 1.0 to 2.0 psi over the vapor recovery system pressure. By preventing the pressure in the barrier area from building, virtually all emissions across the inner seal will be vented to the vapor recovery system rather than to atmosphere. To minimize undetected primary seal leakage, an orifice of 0.063 in is installed in the vent line. The pressure alarm is set to go off when the differential pressure across this orifice is 3.0 to 4.0 psi.

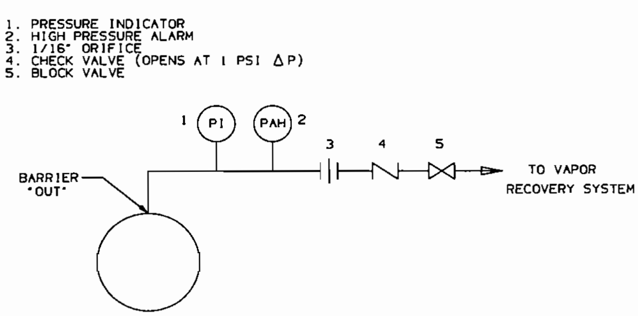

Figure 5. Recommended Barrier Fluid Piping for a Secondary Containment Seal.

The design and testing of this seal design was initiated in 1984. Since it is a full face contact seal operating without lubrication, one of the primary design challenges was to minimize the wear rate on the faces. This was accomplished by tightly controlling the seal face contact pressure (unit loading) and using the proper seal face materials.

A welded metal bellows seal with a low spring rate is the optimum seal for controlling seal face unit loading [6]. As shown in Figure 6, the bellows eliminates the need for the dynamic elastomer associated with pusher seals. When there is axial movement of the shaft or face wear, this dynamic elastomer must move back and forth along the sleeve or shaft for face contact to be maintained. Particularly in low pressure applications, the spring force on a pusher seal must be sufficient to overcome the drag or hysteresis caused by the dynamic elastomer to ensure face contact. The bellows seal also allows the faces to track better in the presence of misalignment. This results in lower leakage rates from the seal. Because tight control of the seal face unit loading is so critical, it is important for the bellows to have a low spring rate. This will ensure proper loading throughout installation, operational misalignment and shaft movement.

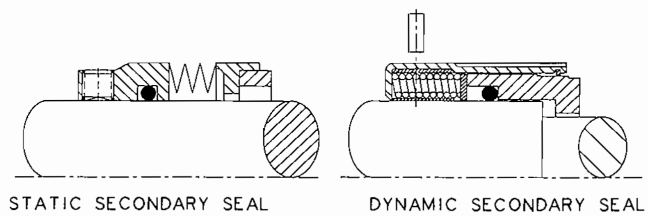

Figure 6. Pusher Seals Vs Bellows Seals.

The optimum wear pair selected for this dry sliding application was determined by an extensive seal face material test program. The particular combination of carbon-graphite-resin and silicon carbide being used, has a significantly lower wear rate and coefficient of friction than all of the other seal face combinations tested.

Historically, operating seals without lubrication has increased the chance of seal failure. For pusher seals, this failure is typically due to face damage or hangup of the seal on its drive mechanism. For bellows seals, the failure is generally due to face damage or a torsional fatigue fracture of the bellows, often brought on by non uniform sliding, such as slip stick phenomena. The face damage can be minimized by proper seal face unit loading and the use of superior face materials. A damping device [7] is used to eliminate the chance of bellows fracture.

Laboratory and Field Testing

This dry-sliding secondary containment seal has been through extensive laboratory and field testing. The initial lab testing was in accordance with stringent specifications written by a major oil company in Europe. This test required the seal to operate dry for 1,000 hrs at three psi air pressure, 10 hrs at 30 psi and two hrs at 300 psi.

The main variables measured during this testing were seal face temperature, seal face wear and the leakage rate from the seal. The face temperature was found to peak at levels between 190°F and 212°F during the first 60 minutes of operation before falling off to a steady-state reading of between 160°F and 190°F. A typical graph of face temperature versus time is shown in Figure 7. The initially higher temperature is attributed to the time required for the carbon to wear into the silicon carbide and transfer a film of carbon that acts as a lubricant.

A typical graph of carbon nose protrusion versus time is shown in Figure 8. The wear of the silicon carbide is generally negligible. As expected, the carbon seal face wear rate was also higher at the beginning of the test before dropping to lower levels. There is not sufficient longterm laboratory test data to accurately predict the life of the seal. The data gathered indicate the seal should run for more than one year and the field testing described below shows the

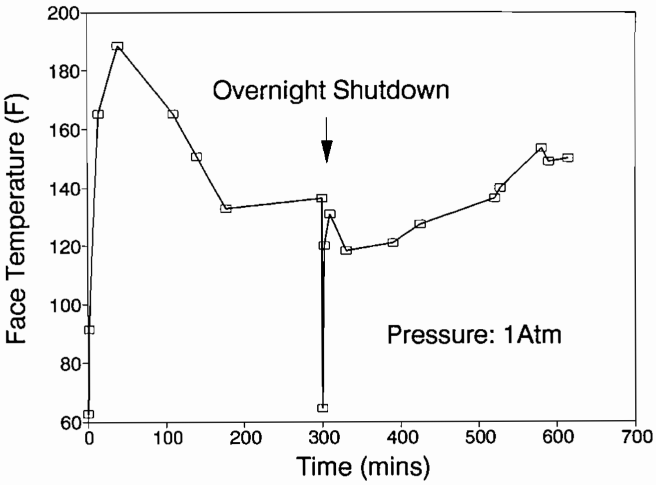

Figure 7. Seal Face Temperature Vs Time.

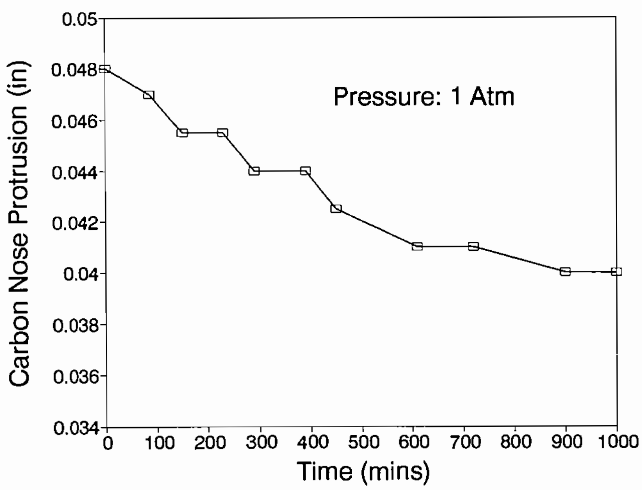

Figure 8. Seal Face Wear Rate Vs Time.

life of the seal will be significantly longer. Additional longterm runs are currently underway.

The specification for this initial testing required the seal leakage rate to be less than 0.1 standard cubic feet per minute (scfm). The gas leakage was found to be much lower than this. In fact, the instrumentation used could not measure the leakage, which means it was less than 0.002 scfm.

Further testing was performed to obtain more accurate measurements of leakage. Preliminary testing showed the expected leakage rates to be in the range of 10^{-4} to 10^{-5} (scfm). Since standard flow meters are incapable of precisely measuring flowrates of these magnitudes, an alternate method was used to determine leakage rates. By simultaneously measuring pressure and temperature in the test chamber, the ideal gas law can be used to calculate the mass of the gas in the chamber. The change of mass over time can then be converted into a leakage rate expressed over time. The test fixture utilized is shown in Figure 9.

The mass contained in the test chamber at any given time can be found by using Equation (1). In this formula, P is the pressure in the test chamber, V is the volume of the chamber, M is the molecular weight of the gas, R is the Universal Gas Constant, T is the temperature of the gas in the chamber and m is the mass of the gas in the chamber.

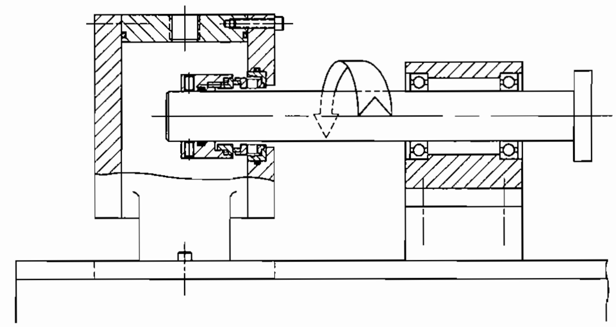

Figure 9. Secondary Containment Seal Test Chamber.

$$m = \frac{PVM}{RT} \tag{1}$$

The leakage rate can then be computed by subtracting the mass at a given point during the test from the mass at the beginning of the test as shown in Equation (2). In this formula, Q is the seal leakage rate and t is the duration of the test.

$$Q = \frac{MV\,(P_1 - P_2)}{tR\,(T_1 - T_2)} \tag{2}$$

The testing was performed in two steps. First, while the seal was running, the test chamber was charged with air to a level of 8.0 psig. The pressure was held at this level for a period of 15 hrs. After 15 hrs, the air supply was shut off with a valve. In order to ensure no leakage took place through the shut off valve into the test chamber, the air supply was physically disconnected. The gas pressure was allowed to decline for a period of nine hours, after which the whole process was repeated.

Since the leakage rate is a function of the pressure drop across the seal faces, the leakage at the beginning of the test when the seal chamber pressure is close to 8.0 psi will vary significantly from the leakage rate at the end of the test when the pressure is between 1.0 and 2.0 psi. To smooth out the effect of different pressure levels in the reporting of the leakage rates, it was assumed that the leakage is a function of pressure as shown in Equation (3). In this formula, k is a factor used to allow leakage to be reported independently from the pressure. This factor was found to be quite constant over the nine hour test periods and was used in all reporting of results.

$$Q = K\ \sqrt{P} \tag{3}$$

The seal ran for a total of 3,300 hrs at an average pressure of 6.0 psi. The leakage during the test was very consistent as shown in Figure 10. A k value of 3.0×10^{-5} represents a leakage rate of 6.7 $\times 10^{-5}$ scfm at 5.0 psig. Inspection of the seal after the test revealed a quite uniform wear pattern. Both the carbon seal face and the silicon carbide mating ring were slightly phonographed, but it was not significant enough to affect the leakage or wear rates.

After the test, the seal faces were relapped and the seal was operated for a period of 10 hrs at a pressure level of 30 psi. The leakage rate during this test was found to be 1.5×10^{-4} scfm. Due to the short duration of the test, the wear was not measurable, but it was again quite uniform.

The test was organized in such a manner that any error in the leakage reading would tend to increase the reported values. For example, it is possible for there to be a small leak through the valve connector to the air supply. By physically removing the connection between the valve and the air supply, any leakage through the valve would be from the test chamber to the atmosphere which would

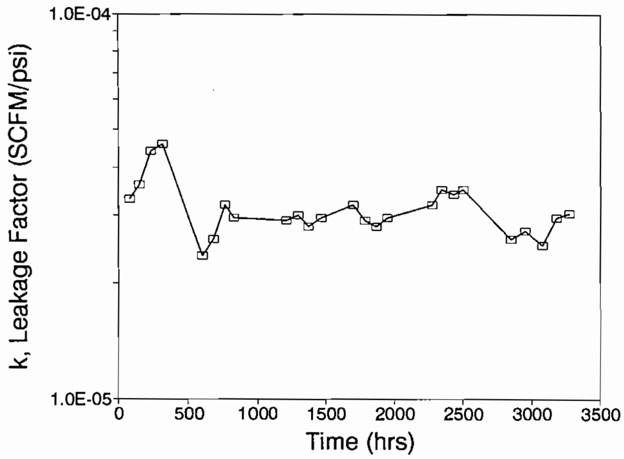

Figure 10. Seal Leakage Vs Time.

mean the measured leakage from the seal is higher than the actual leakage. The measured leakage is, consequently, a conservative estimate of the true leakage rate.

Thus, laboratory testing has shown that the seal is capable of operating without lubrication at low pressures for extended periods of time at leakage rates of between 5×10^{-5} and 10^{-4} scfm. The seal is also capable of running for up to 100 hrs at 30 psi and for two hrs at 150 psi. Further testing is currently underway to determine actual seal life.

In addition to the laboratory testing starting in 1988, 12 prototype seals were installed in field applications on propane and butane service. The operating conditions for some of these applications are shown in Table 1.

Table 1. Operating Conditions for Various Secondary Containment Seal Applications

PRODUCT	SPECIFIC GRAVITY	BOX TEMPERATURE	BOX PRESSURE	INSTALLATION DATE
GASOLINE	.75	90°F	45 PSIG	9/14/1990
GASOLINE	.43	325°F	230 PSIG	11/15/1990
HYDRO-CARBON	.67	109°F	206 PSIG	2/1/1991
PROPYLENE	.56	25°F	280 PSIG	6/1/1990
PROPANE/ BUTANE/ HCl TRACE	.52	100°F	202 PSIG	7/1/1989

After successful laboratory and field testing of the prototype seals, approximately 65 additional seals have been installed in chemical and refinery services. Another 85 seals are in the process of being installed. The longest current successful run is 26 months with approximately 20 seals in operation for 12 to 18 months, and still running.

Secondary containment seals are particularly effective in applications where operational upsets can cause a single seal to momentarily exceed the allowable emission levels. For example, one of these seals is installed in a gasoline application in a refinery on the West Coast. While on the surface this would appear to be an easy application, the pump sometimes sees low suction pressures which causes severe cavitation. The emissions from a single seal during this cavitation exceeded the SCAQMD limits.

After this seal was in operation for about one month, a process upset caused the inner seal to leak excessively. The seal was piped as described earlier and the leakage caused the alarm to go off. The rotating equipment group at the refinery used an organic vapor analyzer to measure the emissions from the secondary containment seal. There were no detectable emissions from the seal. The liquid was drained from the barrier area and the alarm was reset. The seal has continued to operate successfully for 12 months since that event, surviving more operational upsets in the process.

A similar secondary containment seal has also survived inner seal failures resulting in pressures of up to 300 psi on the outer seal. In a propylene application in another refinery on the West Coast, the inner seal failed resulting in a pressure of 300 psi on the secondary containment seal. The rotating equipment group used an organic vapor analyzer and found there were no detectable emissions from the outer seal. Furthermore, they allowed the seal to operate for two days in this condition. They monitored for emissions on a regular basis during this time period and no detectable emissions were measured. While this event shows the secondary containment seal is capable of operating for two days at 300 psi after an inner seal failure, this is not a recommended procedure. The outer seal is running dead-ended so the heat generated by the seal is not being carried away by a flush. The pump should typically be shut down as soon as possible after it has been verified that the alarm was caused by a failure of the inner seal.

CONCLUSION

Performance characteristic of the secondary containment seal provides a simple but effective method of reducing or eliminating emissions to atmosphere. It has the emission controlling and safety capabilities of a standard dual mechanical seal without the complex, expensive, and sometimes unreliable barrier fluid systems. Physically its significantly shorter length allows it to be installed in most API and ANSI pump stuffing boxes. It also eliminates the need for the continuous attention associated with standard dual seals to ensure the fluid level and pressure of the barrier system are maintained.

A dry sliding secondary containment seal has proven itself in the laboratory and in the field to be a viable option for seal users who are looking for ways to reduce emissions to atmosphere.

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