USE OF NONCONTACTING SEALS IN VOLATILE SERVICES

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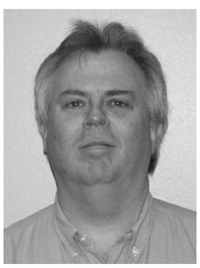

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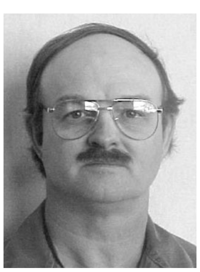

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ABSTRACT

Sealing volatile high-pressure fluids has always been a challenge unless the temperature is cold enough to produce a true liquid state around the seal. Even handling true liquids having low boiling points can result in low life expectancy due to the flashing of the fluid as it approaches atmospheric pressure and is heated by the seal faces.

As pressure levels and temperatures increase above cryogenic, there is a need for technologies other than conventional contacting seals. Fluids handled in a supercritical state are particularly difficult since they are not in a true liquid state to begin with, and lubricity of this “dense phase vapor” is extremely poor. API 682, Second Edition, (2002) recognizes the use of noncontacting dual unpressurized seals for this type of service.

This paper will present the application of a dual unpressurized seal with noncontact lift-off faces to a high-pressure volatile fluid. This application required a high-energy pump at an elevated speed to create the pressure and flow required by the process. The alternative to this pump was a reciprocating compressor, which had been used on previous process units. Compared with the pump, the

compressor option would have been significantly more expensive to purchase and would have resulted in increased maintenance over the life of the process unit.

The pump selected was a nine-stage barrel pump rotating at 6686 rpm driven by an electric motor through a gearbox. The fluid being pumped was ethylene. Suction pressure was 950 psig. The ethylene was chilled to an operating temperature of 50°F so that the pump could develop the head necessary to produce the required discharge pressure of 4450 psig.

The seals selected have now run for over two years with no failures. This includes several issues with the pump during which the pump was disassembled to correct vibration problems. At these times, the seals were removed from the pump and were not even reconditioned but were just reinstalled. Under similar conditions, a contacting seal would have been reconditioned each time the seals were removed and would have had an ultimate life expectancy of only six months.

BACKGROUND

Sealing vaporizing fluids has always presented different challenges than sealing nonvaporizing fluids. Most volatile fluids have poor lubricating characteristics, which leads to accelerated wear and shorter life. In addition to this, the vaporization characteristics cause a change in face loading due to the expansion of the fluid as it goes across the faces. Many standard seal faces would spit and pop because the expansion of the fluid would overcome the hydraulic and spring loadings and force the faces open. This could lead to rapid wear and seal face damage that often resulted in frequent repairs and costly outages.

As the vaporization characteristics were analyzed and understood, standard seal faces were modified to change the loadings to improve the stability and keep the faces from popping open. This was successful, but the change in loading caused more heat to be produced by the faces. This additional heat required more seal flush to keep the seal faces cool, which affected the overall efficiency of the pump. Fluid characteristics also affected the seal, so a seal that worked well in propane would not necessarily work well in ethane-propane (EP) mix or butane.

In the early 1990s the idea of using a gas seal similar to that used on a compressor was considered. This seal could be modified to cause the fluid to vaporize at the seal faces and behave like a noncontacting gas seal. If you are sealing a vapor, the forces trying to open the faces are much more predictable because you do not have to go through a phase change with variations in the volume that is true in liquid seals. Another advantage of using this technology is the elimination or reduction of flush to the seals since heat removal would no longer be required. Figure 1 shows a typical gas seal used as an unpressurized dual in a compressor or in a pump handling a vaporizing fluid.

INTRODUCTION

In 1999, a major chemical company was pursuing the design and construction of an additional olefins manufacturing unit for a facility in the Gulf Coast region of Texas. This unit makes an intermediate olefins product that, when further processed, is used in several specialty plastics. There were two existing units, but the demand for increased capacity suggested the need for an additional unit. During the design phase of the unit, it was suggested that a pump could be used for the main feed charge rather than a reciprocating compressor.

The primary feed to this olefins unit is ethylene. Ethylene is available from the pipeline at 1000 psi and at approximately 80°F. For this process the pressure of the ethylene must be increased to 4450 psi and injected into a reactor where the normal alpha olefin is formed in the presence of a catalyst. Older units used reciprocating compressors to create this increase in pressure, but the purchase price and maintenance cost for those compressors was high enough that the design contractor sought an alternative.

Figure 1. Isometric View of Seal.

Ethylene under the conditions available is not a true liquid. At the pressure and temperature of the pipeline, the ethylene is above its critical point and is actually a dense phase vapor. For most volatile fluids there are a temperature and a pressure limit above which the fluid behaves like a vapor. This is often referred to as the critical point for that fluid and is unique to any given fluid. For ethylene the critical point is at 742.1 psi and 49.82°F. At any pressure above 742.1 or at any temperature above 49.82°F, pure ethylene is a compressible material and acts like a vapor, not like a liquid. The lubricating characteristics and the specific heat of the fluid are more like a vapor than a liquid, so trying to seal the fluid as a liquid often results in very short life expectancy as demonstrated by several pumps boosting pressure on ethylene pipelines.

In the past when trying to seal supercritical fluids with centrifugal pumps, the only options were to accept the rapid wear of the seals or to use a high-pressure double seal. With a double seal the barrier fluid was actually being sealed—not the process fluid. This worked well but the entire pumping system was dependant on a high-pressure barrier fluid circulation system similar to a high-pressure hydraulic system. With more hardware in the system, overall reliability of the pumping system was often reduced.

For this service, a number of centrifugal pump manufacturers were consulted, and at least one of them indicated that ethylene under these conditions could be pumped with a special barrel pump (Figure 2) if the conditions were optimized. There were several issues that had to be addressed, but it was feasible to address each of them. First, due to the heat of compression and the required head, the ethylene would need to be chilled to approximately 50°F to allow the pump to generate the required pressure. Figure 3 shows the pumping system along with the two chillers. One chiller was used to cool the incoming ethylene, while the second is used to chill any feed that is recycled—either from the minimum flow system or from the process recycle that is part of the system. In addition, a shaft seal would have to be found that could seal this "dense phase vapor" at the suction pressure of 950 psi and a rotational speed of 6686 rpm. According to a representative of the selected pump company "there is only one seal that will do this job," so the option of a gas seal for vaporizing liquids was proposed for this application.

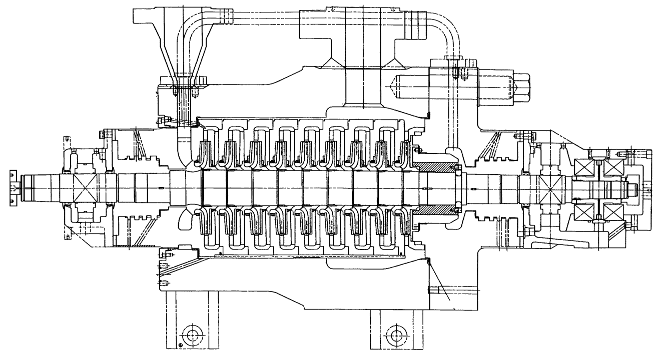

Figure 2. Nine-Stage Barrel Pump.

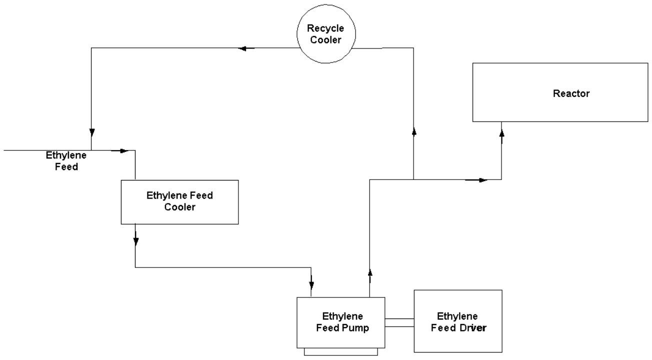

Figure 3. Process Flow Diagram of Feed Pumps.

DRY RUNNING-NONCONTACTING GAS SEALS FOR VAPORIZING LIQUIDS

Dry running-noncontacting gas seals for vaporizing liquids are based on the design principles of compressor gas seals, but the grooving on the seal faces is modified to allow the complete vaporization of the liquid, either prior to entering the gap between the seal faces or immediately after. If the liquid has a substantial amount of super-pressure (a true liquid at an elevated pressure so that it is not near the vapor pressure of the liquid), external heat may be required to make sure that the liquid vaporizes completely. Figure 4 shows the actual seal layout as applied in this service.

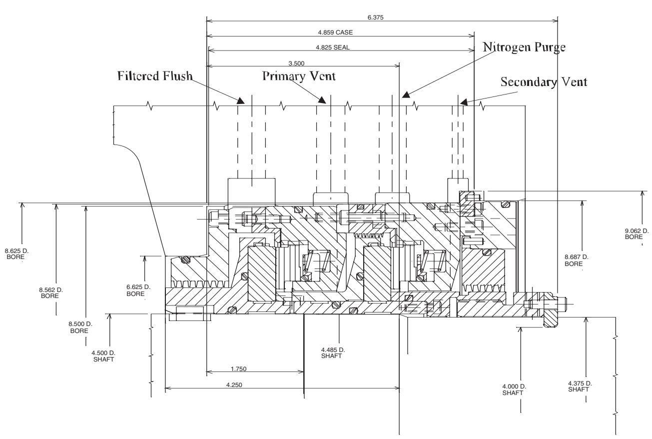

Figure 4. Gas Seal for Vaporizing Fluids.

Typical construction of the noncontacting gas seals for vaporizing liquids is very similar to that for a centrifugal compressor. The mating ring is rotating and is usually made from a premium grade of tungsten carbide. The spiral grooves are on the face of the mating rings. The primary ring is stationary and is made from a premium grade of a metal filled carbon. The springs and adaptive hardware are made to meet service fluids and conditions. In this case the gland, sleeve and other hardware are made of 410 series stainless steel and all elastomers are Viton®. Passageways for seal flush, vent to flare, nitrogen purge, and secondary vent were included in the adaptive hardware and match with the connections in the pump.

The gas seal for vaporizing liquids was designed specifically for sealing fluids above or near their saturation point for a given sealing pressure. Historically, it has been very difficult to seal these fluids since they possess properties of both liquids and gases, which can differ by several orders of magnitude. Based on the noncontacting dry gas seal for compressors, a vapor is desired to ensure long, dependable seal life. The spiral groove on the rotating face pumps the fluid down from the outside diameter of the mating ring to the root of the spiral groove. This pumping action generates an increase in pressure, which creates the small gap between the seal faces, and thus the result is no face wear.

As stated earlier, the gas seal for vaporizing liquids is to be used on fluids above or near their saturation point. To evaluate the specific application, the operating conditions are plotted on a pressure-enthalpy diagram (Figure 5). The sealing pressure and operating temperature are required. For the gas seal for vaporizing liquids to work, the seal faces must generate enough heat to overcome the sealing fluid's tendency to cool and condense as it expands to a lower pressure. The amount of heat required to achieve this is determined by plotting the starting point and desired end point on the pressure-enthalpy diagram for the specific process fluid. The difference in specific enthalpy between these end points and the leakage rate of the fluid across the seal faces determines the amount of heat required to achieve vaporization. At the inside diameter of the seal faces (typically atmospheric pressure), some minimum temperature is required to guarantee a vapor. A detailed gas analysis is helpful to evaluate potential problems. For instance, if there are any traces of water in the process, more heat may be required to prevent the water from icing on the seal faces as the process gas expands to atmospheric pressure. Since there will often be traces of water in the process and atmospheric humidity must be considered, the desired ending temperature should be sufficiently high to prevent icing (> 32°F).

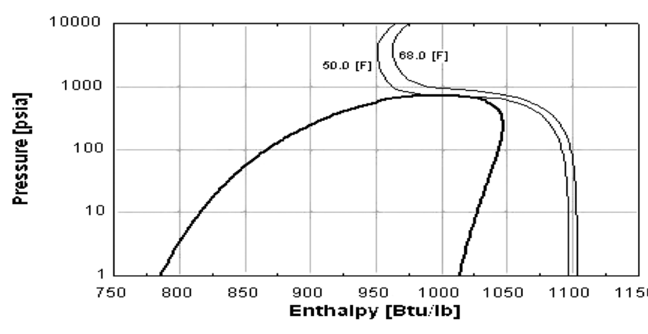

Figure 5. Ethylene Pressure—Enthalpy Diagram.

Now that the required heat has been determined, the seal faces are designed to generate sufficient heat to achieve vaporization of the process fluid. Heat is generated in two ways. First, there is a swirling effect, or windage, which takes place in the area adjacent to the rotating seat (mating ring). The amount of heat generated here is extremely difficult to calculate accurately and so is generally ignored when estimating/calculating heat generation. The second area where heat is generated is dependent on the fluid viscosity. The liquid properties of the fluid must be determined based on the seal operating conditions. As liquids enter the gap between the seal faces, the frictional heat developed by the viscous sheer of the relatively viscous liquid causes vaporization and enables the gas seal for vaporizing liquids to operate as a gas seal. The closeness of the fluid to its vapor pressure will determine where vaporization takes place. Fluids close to or at their vapor pressure are more likely to vaporize outside the seal faces, whereas those with larger vapor pressure margins to overcome will vaporize between the seal faces.

To maximize heat generation between the seal faces, the designer uses proprietary software to determine heat generation and leakage between the seal faces. The heat generated by the seal as estimated by the software is compared with the heat required from the pressure-enthalpy diagram. The seal face geometry is designed to maximize the amount of heat generated per unit leakage. There cannot be too much heat as once the fluid is vaporized, the amount of heat generated is significantly reduced due to the drop in viscosity. Once vapor conditions exist, the gas seal for vaporizing liquids behaves like the highly successful gas seal for compressors. If sufficient heat cannot be generated from the seal faces alone, the lack of heat must be supplemented with heaters.

CASE STUDY

Table 1 shows the process conditions for the ethylene service that is the subject of this paper.

Table 1. Ethylene Project Design Data.

	OLEFINS PRODUCT ETHYLENE PROJECT							
	IB CHAMBER				OB CHAMBER			
Start-up	Pressure	Temp.	h *	delta h**	Pressure	Temp.	H*	delta h**
Idle	950	70	987.5	102.5	950	70	987.5	102.5
Running - Rated Flow	950	70	987.5	102.5	950	92	1020	70
Running - Minimum Stable Flow	950	70	987.5	102.5	950	121	1055	35
Current Rating								
New - Rated Flow	950	50	950	140	950	72	987.5	102.5
New - Minimum Stable Flow	950	50	950	140	980	74	992	98
Warm - Rated Flow	950	50	950	140	950	83	1010	80
Warm - Minimum Stable Flow	950	50	950	140	980	86	1020	70
Future Rating								
New - Rated Flow	950	50	950	140	950	73	987.5	102.5
New - Minimum Stable Flow	950	50	950	140	980	75	992	98
Warm - Rated Flow	950	50	950	140	950	90	1030	60
Warm - Minimum Stable Flow	950	50	950	140	980	92	1030	60

*Enthalpy of the fluid at seal inlet conditions

** Change in Enthalpy from Seal inlet to seal outlet

After plotting all possible operating conditions, it is determined that the worse case scenario (largest Δh) is the 950 psig, 50°F starting point that results in a Δh of 140 Btu/lb. This is the amount of heat required to achieve vaporization. By observing the operating conditions on a pressure-enthalpy diagram, it is observed that the process is supercritical. That is, the fluid is above its critical point and ideal for the gas seal for vaporizing liquids. For that reason, external heat was not required as the seal was able to vaporize the fluid without a problem. The seals were designed to handle the maximum pressures and temperatures of the service along with the minimum temperature that could be seen in this service. In this application, the pump company decided to incorporate the flush, vent, and purge connections into the pump casing—like the standard design of a centrifugal compressor—rather than the more traditional design of having the connections in the gland as is common on most pump applications. Table 2 shows applications where noncontacting seals for vaporizing service have been used successfully in pumps.

The seal flush and monitoring system for this application was very similar to that which would be considered for a centrifugal compressor due to the criticality and severity of the service (Figures 6 and 7).

A typical control panel would include the following:

- *Filtered flush*—Typically the flush volume is low since it is only providing a clean environment for the seal and is not being used for cooling.

Table 2. Installation List.

Process Gas	Max Pressure	Max Speed	Max T (F)	Seal Type	Seal Size	Shaft Diameter
CO2	2100	1785	90	3VLH	6.19	4.75
CO2	2200	2160	90	2VLH	6.19	4.75
N2	338	3600	-282	1VL	1.94	1.00
N/A	600	3015	-220	2VL	3.44	2.24
Ethylene	75.5	2980	-103.7	2VL	3.94	2.62
C2 (Ethane)	12.76	1490	-54	2VL	3.94	2.56
Ethylene	7.7	2940	-74	2VL	3.44	2.17
Ethylene	67.5	2980	-35	2VL	4.44	3.15
C2 (Ethane)	1100	3560	90	2VL	4.44	3.26
Ethylene	2000	3800	150	2VL	3.69	2.64
Hydrocarbons	400	3565	125	2VL	3.88	2.88
CO2	2500	4000	120	2VLH	3.69	2.64
C2 (Ethane)	2176	3560	100	1VL	3.69	2.64
CO2	2400	3560	120	2VLH	3.69	2.51
Steam	387	3550	-243	2VL	2.44	1.38
C2 (Ethane)	700	4950	50	1VL	4.94	3.63
CO2	2220	4000	70	2VLH	4.44	3.27
C2 (Ethane)	2219	4535	88	2VL	3.94	2.75
Ethylene	1400	3550	80	2VL	3.69	2.64
CO2	225	3600	-16	1VL	2.19	1.19
CO2	2000	3600	80	2VLH	3.69	2.64
C2 (Ethane)	2146	3550	109	2VL	2.69	1.75
CO2	2200	3000	110	2VLH	3.69	2.38
C2 (Ethane)	1550	6400	17	2VL	3.94	2.75
C2 (Ethane)	270	6400	17	2VL	3.94	2.75
Ethylene	950	6625	72	2VL	5.69	4.50
Ethylene	432.3	5100	100	2VLH	3.40	2.75
Ethylene	1780.2	5100	-50	2VLH	3.94	2.75
N2	338	3600	-282.5	1VLH	1.94	1.00

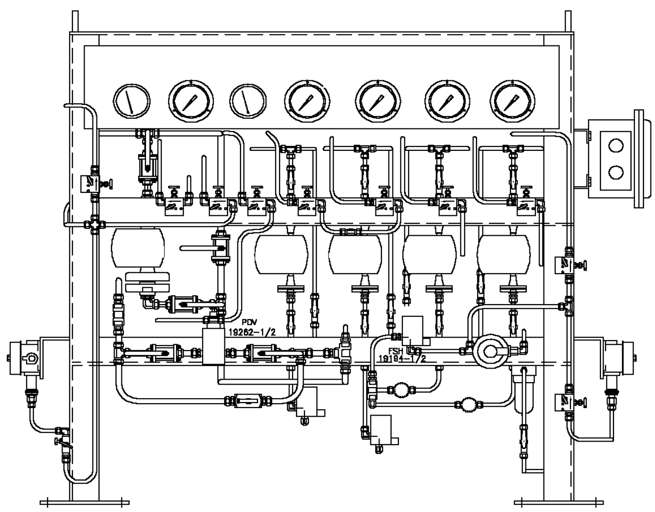

Figure 6. Seal Control Layout.

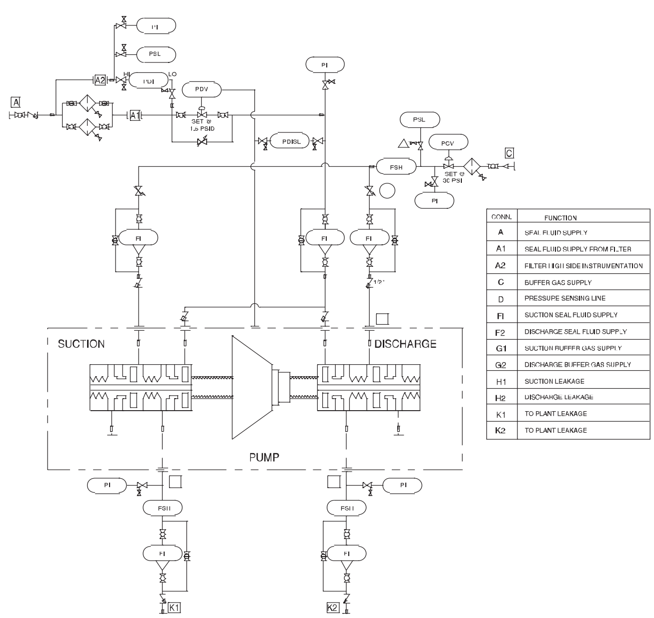

Figure 7. Control Panel P&ID.

• *Vent to flare*—As an unpressurized dual seal, the normal leakage from the process seal must be sent to a flare or vapor recovery system. This is often monitored with either a flow monitor system or a pressure sensing system upstream of an orifice.

• *Purge system*—Today most noncontacting gas seals for vaporizing liquids use a nitrogen purge to create a system that allows for zero emissions to the atmosphere. The nitrogen purge is introduced at a low volume at a pressure just high enough to sweep any vapors to the flare.

• *Secondary vent*—The secondary vent is to keep any stray vapors out of the bearings in case of a seal failure.

Figure 7 shows the process and instruments diagram (P&ID) of the flush and monitoring package that includes a sweep of nitrogen to allow the seals to run with virtually zero emissions. Figure 6 is a schematic of the actual layout of the control panel used in this application.

In order to demonstrate the seals' ability to seal the process fluid, the seals had to be tested. This testing was conducted in a test cell at the seal manufacturer's facility. The gas seals could not be used on the pump test stand since they are not compatible with water. Since testing with the process fluid (ethylene) was not an option, a test on shop air was the next best alternative. Although shop air has a similar molecular weight to that of ethylene, its viscosity is only about half that of ethylene at the operating conditions. The geometry of the seal faces was optimized for the operating conditions with ethylene (950 psig at 6625 rpm). That is, the heat generation is a function of the operating gap between the seal faces. In order to maintain a "comfortable" operating gap during the test, the test speed had to be increased to 10,000 rpm. This increased speed was required to maintain the same operating gap, which would be expected after vaporization of the ethylene during operation. The seal for vaporizing liquids is a noncontacting seal like the gas seal for compressors except it operates at a smaller gap (approximately 70 micro inches) between the seal faces, which is required due to the heat generation requirements. The test was designed to simulate a startup scenario consisting of ramping up statically to the operating pressure and then ramping up to operating pressure at full speed. Both the inboard (primary) seal and outboard (secondary) seals were tested to verify sealing performance. The pump was performance tested with water using standard contacting seals built strictly for the pump test. Since the job seals could not be used for the performance test of the pump, the decision was made to install the seals in the field during the final portion of the pump installation. The seals were installed with little incident and the pump was purged with nitrogen to prevent any contamination from entering the seal chamber prior to startup.

During the commissioning of the pumps, the feed portion of the unit was inventoried with ethylene and the pumps were to be run on full recycle. There is also a refrigeration compressor in the system that would remove the heat added to the ethylene during pumping. Prior to starting the pumps, the cases were bled to the flare to chill the pumps with the ethylene that was passing through the feed cooler.

Pump B was started first and started without incident. During the initial run of approximately two hours, some vibration was observed, but it was thought to be attributable to lower than normal flow since the pump was on full recycle.

After the initial run of Pump B, it was stopped and Pump A was started. Pump A shut down automatically on low flow. While trying to determine the cause of the low flow condition, Pump A was started three times with a one hour delay between starts to allow the motor to cool down. Then it was decided to restart Pump B to determine whether the restriction to flow was in the individual or the common piping.

When Pump B started this second time, it surged violently with the discharge pressure going from 2500 psi to 4500 psi every two to three seconds for approximately one minute before it too shut down on low flow. Still trying to determine the cause of the low flow, Pump A was started again and then Pump B was started again two more times with the same results. Each time Pump A started, it shut down immediately on low flow. When Pump B was started, it would surge for approximately one minute before it too would shut down on low flow.

Finally, it was determined that the minimum flow valve was plugged. This valve is designed to handle a very large pressure drop with as little noise as possible. The result of this design is that there are many small openings in the valve, and these openings had become plugged with debris from the newly constructed piping.

The valve was removed from service, cleaned, and returned to service. After cleaning the valve, Pump A was started without incident and showed no signs of vibration—even at the lower flow rate of the full recycle.

The number of starts and stops on the pumps during the commissioning, and certainly the surging, would have damaged any contacting seal. The fact that the seal faces were not contacting and were running on a film of gas vapors enabled the seals not only to survive this severe operation, but there was no evidence of excessive leakage at any time during the startup.

In an attempt to track down the vibration that persisted even after the flow rates were increased with the startup of the rest of the unit, Pump B was first inspected in the field, was pulled, and all wear parts replaced, then again inspected in the field. Each incident required the removal and the reinstallation of the seals. Normally, seals would be sent for reconditioning if removed after running. However, after inspecting the seals upon removal, there were no signs of wear, and the seals were reinstalled. After the pump wear parts were replaced and the pump was started again, it only ran for one minute 20 seconds before shutting down automatically on high vibration.

The seals were removed again for field inspection and it was found that the process side of the thrust end seal was coated with aluminum powder. The powder had come from the balance piston labyrinth that had contacted during the short run. The seal, however, was undamaged due to the filtered flush system that prevented the aluminum powder from getting past the process side seal's labyrinth.

The pump and casing were pulled after this failure and completely inspected. The casing was found to have an out of specification internal fit that had been the cause of the vibration. The casing was corrected, and the pump was sent back to the factory to be reassembled and put back on the test stand prior to being put back in the field. After a few adjustments, the pump passed the shop test and was reinstalled in the field—along with the seals.

The pump ran without any incident for three months when it was decided to shut the process unit down to repair some damaged process column trays. During this outage, other work was performed that caused the lube system of the pumps to be turned off. After being off for two weeks, the lube system was restarted prior to starting the ethylene pump only to have the pump shut down due to high motor amperage, as there was no oil between the bearing and the shaft. A strap wrench was applied to the coupling hub and the shaft finally rolled up onto the oil film. The shaft then turned freely but, due to the history of this pump, it was decided to pull it for another complete inspection and for installation of wear parts identical to those that had been in the original design so that it would match Pump A.

The seals were removed once again to disassemble the pump, and this time the decision was made to send the seals to the factory to have a complete inspection including replacement of all O-rings since the pump and seals had several hundred hours of run time on them. The O-rings were replaced, but the faces were still in pristine condition and were reused with no reconditioning. The condition of the seals was better than expected, after multiple starts, surging, and being removed from the pump five times.

After this last reconditioning the pump has run without incident, and has approximately 7300 hours of run time as of November 2002, with no signs of distress from the seals. The other pump, which has never been pulled, has 12,410 hours of run time as of November 2002. There have been at least two incidents where one of the pumps has shut down due to power or control problems, and the spare pump has automatically started and come up to speed with no seal leakage or process upset.

CONCLUSION

Difficult services that include vaporizing fluids can be sealed effectively and reliably if the seals are designed for the service and are built correctly. Even in services where the operation is not stable or the pump suffers from startup instabilities, the gas seal for vaporizing fluids can survive with little or no damage.

Applications where this technology should be considered include any fluid that is handled in a supercritical state, vaporizing liquids like ethylene, ethane, EP mix, and propane, as well as natural gas liquid's (NGLs) CO_2 and cryogenic gasses like nitrogen and oxygen.

The success of gas seals for vaporizing fluids has made them increasingly popular and has led to their inclusion in the second edition of the API 682 standard for mechanical seals. API 682 (2002) considers such seals to be unpressurized dual seals (Arrangement 2) and identifies them as "noncontacting inner seal with a containment seal" (2NC-CS). In contrast to this case study, API 682 (2002) is limited to pressures less than 600 psig; however, this recognition is another indication that future applications of mechanical seals in vaporizing fluids may be noncontacting designs.

REFERENCES

API Standard 682, 2002, "Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps," Second Edition, American Petroleum Institute, Washington, D.C.