REDUCING LIFE-CYCLE COSTS FOR PUMPS HANDLING CRYOGENIC FLUIDS

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ABSTRACT

Advancements in the science of sealing technology have had a dramatic effect in increasing equipment reliability and reducing the cost of equipment ownership. One such area of success has been the pumping cryogenic fluids that are stored near atmospheric pressure and pumped near their normal boiling points. The most common cryogenic fluids used in industry are argon, nitrogen, and oxygen. These fluids are delivered over the road in tank trucks to industrial users and hospitals. Each truck uses a single-stage centrifugal pump driven by a hydraulic motor to move these liquids from the truck to storage tanks.

This paper reviews the development of the technology to increase equipment reliability. Reduced life-cycle cost analysis and savings are presented.

INTRODUCTION

In 1991, a major effort began to increase mean time between failure (MTBF) on pumps used on over-the-road tank trucks used to deliver cryogenic fluids such as oxygen, nitrogen, and argon. One operator with a fleet of 25 trucks would always have three trucks in their maintenance bays at any given time for the repair of leaking pumps. An analysis of seal life and repair cost for the fleet is shown in Table 1. From the table, it can be determined that the average cost of repair is only $1500 per event. However, the frequency of repair is excessive. This was driving up the cost of maintenance for the equipment. Not only was the maintenance cost excessive, there were also financial losses when deliveries could not be made. Each truck has the capability to travel at least 300 miles from the terminal. If a pump began leaking during a delivery, everything had to be shut down and the tanker had to return to the terminal, many times with a load of cryogenic fluid that could not be delivered.

Table 1. Analysis of Seal Life and Repair Cost for a Fleet of 25 Tank Trucks in 1991.

Cryogenic Fluid Sealed	Tankers in Service	Average Seal Life in Weeks	Failures Per Year	Cost Per Year
Argon	5	6	45	$ 67,500
Nitrogen	10	14	35	$ 52,500
Oxygen	10	25	20	$ 30,000
Cost of Maintenance Per Year				**$150,000**

Down time for the tanker for pump repairs, including deliveries that could not be made, had a substantial impact on the company. Seal life was measured in weeks. It was not uncommon to have some pumps run only between four to six weeks before maintenance was required. The most difficult fluid to seal was argon.

SCIENCE OF SEALING TECHNOLOGY

Outstanding performance of a seal is measured in terms of years of trouble-free service. Performance is dependent on the seal's ability to develop a fluid film between the seal faces and to dissipate the heat developed from sliding contact. Regardless of the fluid sealed, these two processes must occur and be within design limits for a given seal design for extended seal life. Each seal design has an operating envelope that will result in excellent seal performance. A typical operating envelope for a contacting seal is illustrated in Figure 1.

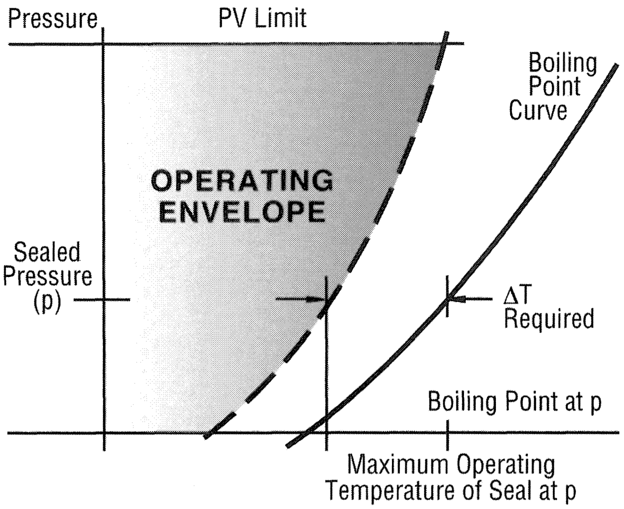

Figure 1. Operating Envelope for a Contacting Seal.

The upper limit of operation is determined by wear of the seal faces and usually defined by a pressure velocity limit for the materials used. Equally important for good performance is the removal or dissipation of heat to prevent flashing or the carbonization of the fluid sealed. The heat transfer process in a mechanical face seal is illustrated in Figure 2. The heat generated from sliding contact must pass through the seal faces into the surrounding fluid. The amount of heat generated will increase when the pump operates at low net positive suction head (NPSH). This commonly occurs at certain times during the operation of the equipment when the liquid in the tanker is at a low level and cavitation can occur.

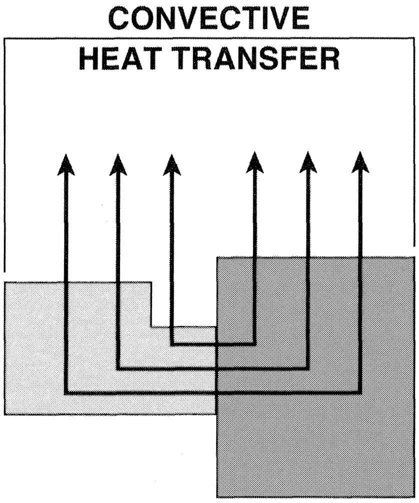

Figure 2. Heat Transfer Path Through the Mechanical Seal Faces.

State-of-the-art computer programs have allowed engineers to determine the type of seal technology that will provide for maximum reliability and service life.

OPERATING NEAR THE BOILING POINT

Traditionally, developed seal heat is removed by a seal flush. In fact, API 682 (1994) defines various piping plans that can be used to remove seal heat. However, when operating near the boiling point of the liquid being sealed, a seal flush may not be enough to remove the developed heat. When reviewing seals that had failed on cryogenic service, it became clear that at certain times during the operation of the pump, the fluid at the seal faces was flashing. This was evident due to the extreme wear and in some cases heat checking of the mating ring in the seal assembly. This type of result has also been observed on light hydrocarbon fluids, at atmosphere temperature. However, it was not believed to be possible that the same failure could occur at cryogenic temperatures below −300°F.

The common element for both classes of fluids, light hydrocarbon and cryogenic gases, was operating near the boiling point of the fluid sealed.

Further complicating the problem of developing stable operation was the cool down period required when maintenance had been carried out on the equipment. Both pump and piping had to be cooled down to the liquid gas temperature. Any rise in product temperature reduces the NPSH. This would increase the possibility of the pump cavitating, which would lead to dry running of the seal. Failures were also more common on tanker fill-ups where short delivery distances were involved and cool down periods were shortened.

The discovery of the flashing problem led to the development of a noncontacting seal for cryogenic service (Figure 3). This design illustrates a stationary seal head and a rotating mating ring. The cryogenic fluid is located at the outside diameter of the seal. A metal bellows provides for the necessary flexibility required of the seal design. A static seal is used between the floating carbon primary ring and the metal bellows. To be successful operating near a fluid's boiling point and in an environment where cavitation can occur, a seal design is required that eliminates frictional heat from the sliding surfaces in contact and can run on a gas film. In a controlled environment, the liquid at the seal faces must be allowed to change to a gas. This is accomplished in the design of the seal faces and the use of spiral groove seal technology.

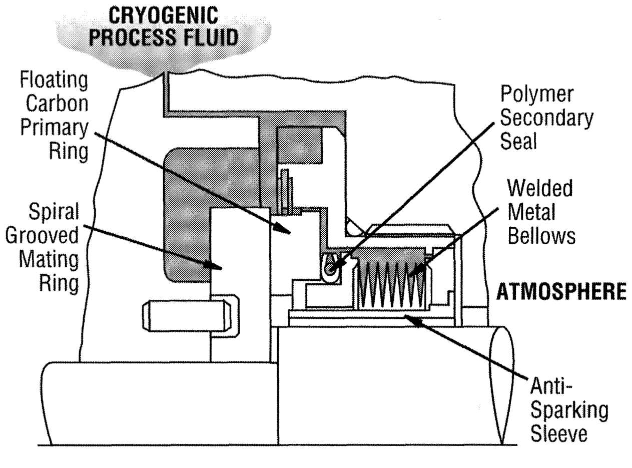

Figure 3. Noncontacting Seal for Cryogenic Fluids.

The properties of the cryogenic fluids to be sealed are given in Table 2. The temperature range from solid to a gas for argon, nitrogen, and oxygen is 6, 25, and 65°F, respectively. The smaller the temperature range of the fluid as a liquid, the more difficult the fluid is to seal with a conventional contacting seal.

To meet the extremes of low temperatures to be encountered, the design must be free of any distortion that would affect seal performance. In addition, it must be flexible to handle all equipment vibrations and motion at cryogenic temperatures.

The success of this seal can be explained by reviewing the vapor pressure curve for one of the cryogenic fluids. Here nitrogen has been selected for analysis (Figure 4). Nitrogen transported by tank truck is normally at 30 psig (2 bar) and −320°F (−190°C). When

Table 2. Properties of Cryogenic Fluids.

Cryogenic Fluid	Boiling Point @ Atmos. Pressure	Freezing Point @ Atmos. Pressure
Argon	-302.50°F -185.60°C	-308.50°F -189.20°C
Nitrogen	-320.46°F -195.81°C	-345.80°F -209.90°C
Oxygen	-297.40°F -183.00°C	-361.90°F -218.83°C

using a contacting seal, the temperature increase at the seal faces is sufficient to start the boiling process at pumping temperatures and pressure. In an uncontrolled environment such as a contacting seal, this continuous flashing damages the seal faces shortening seal life. A noncontacting gas lubricated seal liquid can turn to a gas in a controlled environment. Since there is no contact during operation, the temperature rise at the seal faces is only a few degrees. Violent flashing of the cryogenic liquid is eliminated.

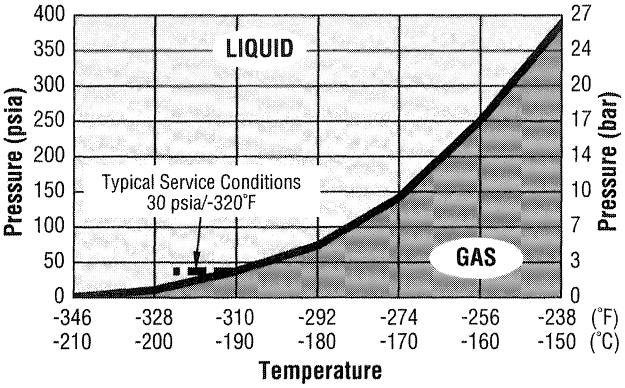

Figure 4. Vapor Pressure Curve for Nitrogen.

FIELD RESULTS

The very first noncontacting gas lubricated seal was installed in March 1993 and taken out for examination in May 1994. The entire seal was in excellent condition. The seal faces were repolished and reinstalled. This seal was operated for more than 2500 hours before being taken down again for inspection. Again, there was no visible wear or distress on the seal faces. This first installation was made on a tanker used to deliver liquid nitrogen. Prior to the use of noncontacting seal technology, the average seal life was only 14 weeks. Conservatively, this is not even 150 hours of running time on the pump.

On another application of an original installation of a noncontacting gas lubricated seal, it ran for 3000 hours in liquid nitrogen until a failure of the pump bearing. Examination of the seal revealed that no wear or contact at the seal faces had occurred. This pump was rebuilt and last reported to have completed 9000 hours in service.

Shown in Figure 5 are the seal faces that have been in service 6000 hours. This set of seal faces had been taken out of service due to a bearing failure. Surface measurements taken through 360 degrees on these seal faces indicate that the flatness of the mating and primary rings were 4.3 microinches (less than 1 light band) and 31.9 microinches (approximately 3 light bands), respectively. These are exceptional values of flatness after 6000 hours of running time in liquid nitrogen. The surface waviness traces are shown in Figures 6 and 7.

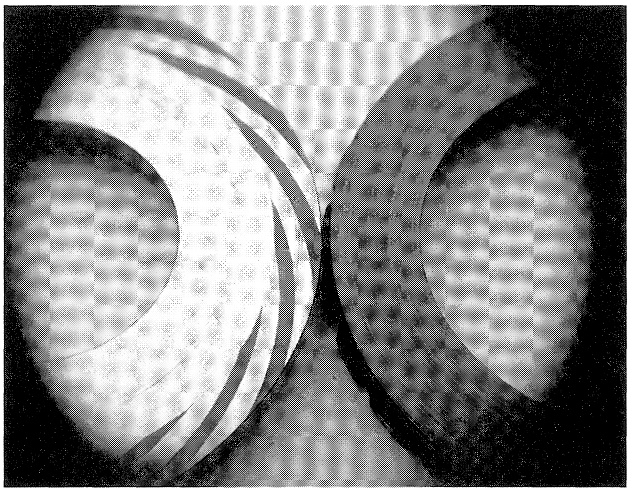

Figure 5. Seal Faces After 6000 Hours in Liquid Nitrogen.

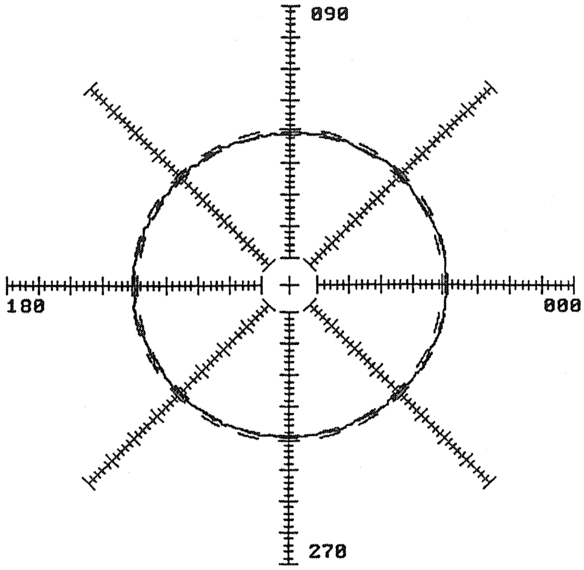

Figure 6. Mating Ring Flatness Measurement.

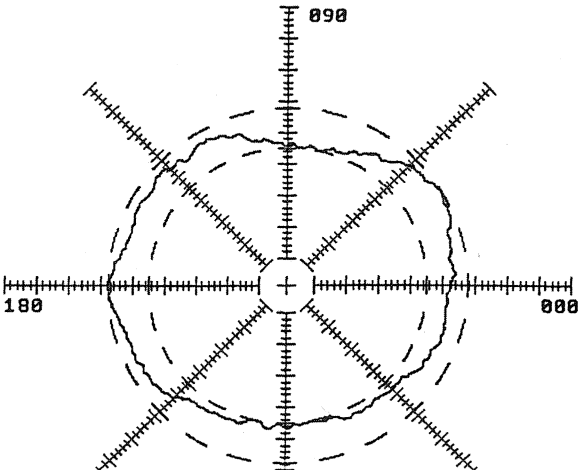

Figure 7. Primary Ring Flatness Measurement.

Profile traces were also taken of the seal faces and are shown in Figures 8 and 9. For the mating ring in Figure 8, the trace is taken from the inside diameter (ID) of the seal face to its outside diameter (OD). Each vertical division is 50 microinches. The mating ring at the sealing dam exhibits approximately 200 microinches of wear. The surface trace in Figure 9 for the carbon ring is taken from the outside diameter to the inside diameter of the seal face. Each vertical division is also 50 microinches. The surface of the carbon ring illustrates some minor scoring of the sealing surface. This type of wear on both parts is believed to have occurred after the bearing had failed. It was also reported that the wear rings in the pump had also begun to wear as well. This caused additional wear particles in the seal area. This seal represents a unit that had 12,000 starts and stops, each delivery taking 30 minutes of run time for the pumps.

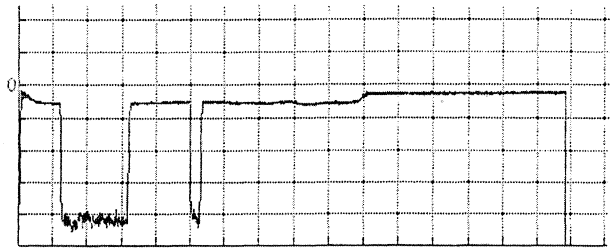

Figure 8. Profile Trace Face ID to OD. (Mating ring wear.)

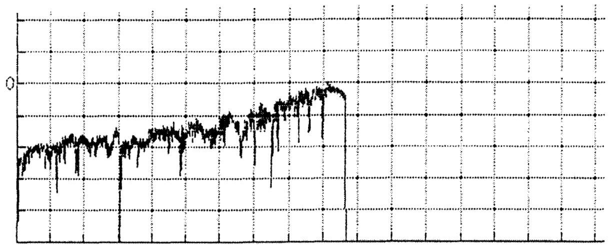

Figure 9. Profile Trace Face OD to ID. (Primary ring wear.)

This technology has also been applied to stationary pumps used at the terminal locations to load the tank trucks. Seal life on these pumps has been successful for over 20,000 hours in cryogenic service.

LIFE-CYCLE COST ANALYSIS

The cost associated with a piece of mechanical seal through its entire life are known as life-cycle costs (LCC). This is the true cost of equipment ownership. These costs are the purchase cost of the equipment, startup spares, procurement, installation, operation, maintenance, and disposal. When the frequency of failure is exceptionally high, the maintenance cost for the equipment will dominate life-cycle costs. If the cost of a new seal, which may represent a new technology as well, plus the maintenance costs can be recovered in less than 12 to 18 months, the plant or equipment operator will proceed with the improvement. In many cases, where frequency of failure is high, the payback will be less than 12 months. The payback of the cryogenic pumps covered in this paper was less than three months.

Typically, the cost of a new pump is only 7 to 10 percent of the total life-cycle costs. Normal maintenance cost can range from 10 percent to 15 percent just for a light duty pump, including four to six rebuilds during a 20-year life of the equipment. For high frequency failures as found on the cryogenic applications, the maintenance cost can be greater than 60 percent of the total life-cycle cost. Focusing in on the dominant factor of life-cycle costs will result in substantial reduction of the cost of ownership of the equipment. One fleet operator has installed approximately 200 seals in a period of three years. The result is a 50 percent savings in maintenance cost for his pump population.

The most spectacular result is that the operator can handle a 5 percent growth in transportation volume due to higher reliability of the truck pool. Investing in new tank trucks is not necessary at this time.

The reliability of the original fleet of 25 tank trucks increases to an average seal life greater than six years. The achieved savings in reduced repair cost is shown in Table 3. Some tankers are now beyond a six-year average life and approaching eight and nine years. If the average seal life becomes 10 years, then the achieved savings is even greater, as shown in Table 3.

Table 3. Achieved Savings in Repair Cost for Fleet of 25 Tank Trucks.

Cryogenic Fluid Transported	**Average Seal Life**	
	6 Years	**10 Years**
Argon	$405,000	$ 675,000
Nitrogen	$315,000	$ 525,000
Oxygen	$180,000	$ 300,000
TOTAL	**$900,000**	**$1,500,000**

Today over 1200 seals have been successfully installed on various fleets throughout the world.

SUMMARY

Substantial progress has been made within the science of sealing technology to develop solutions to improve the reliability of equipment. These solutions are having a major impact on company profits.

Eliminating the heat from sliding contact allows a seal to operate near and at the boiling point of the fluid sealed. The application of this technology to cryogenic fluids has resulted in extended equipment life by a factor of 10. Continued focus on problem areas by fleet operators and manufacturers will result in further increases in reliability and savings.

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