ASIA TURBOMACHINERY & PUMP SYMPOSIUM
12-15 MARCH 2018
SUNTEC SINGAPORE

Applying Upstream Pumping Sealing Technology for high corrosive fluid – Improve Reliability & Operating Cost

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ABSTRACT

This is a mechanical seal upgrade case study about applying advanced upstream pumping technology instead of conventional tandem seal arrangements with external flushing in high corrosive fluid pump seal applications in order to improve equipment reliability and minimize the operating cost.

INTRODUCTION

This real case occurred in an Acetyls plant in China. This plant produces acetic acid and acetate.

The equipment is a centrifugal pump transporting an organic fluid with undefined properties. This process fluid is very special for the plant as it is highly corrosive and furthermore contamination is not allowed. The process fluid has relatively high temperature, high pressure and poor lubrication characteristic.

EQUIPMENT & APPLICATION DUTY

Pump type: Overhung centrifugal pump
Suction pressure: 2.81 - 2.82 MPa g (407 - 409 psi g)
Discharge pressure: 3.35 - 3.48 MPa g (486 - 505 psi g)
Shaft speed: 1500 RPM
Process fluid: Organic fluid
Process temperature: 50 - 189 °C (122 - 372 °F)
Viscosity: 0.636 - 0.188 cP
Vapor pressure: 2.35 - 2.80 MPa g (341 - 406 psi g)
Specific Gravity: 0.823 - 1.013
Special requirement: process contamination is not allowed. Only pure acetic acid or very limited quantity of demineralized water are accepted to be mixed.

ORIGINAL SEAL SOLUTION & ISSUE

The original mechanical sealing arrangement was a tandem unpressurized seal with API 682 plan 32/52 system as shown in Figure 1. Plan 32 external flushing was pure acetic acid. The reason for using an unpressurized tandem seal was to prevent the barrier fluid contaminating the process fluid. Plan 32 was selected for the inboard seal flushing was due to the high process pressure and low margin above vapor pressure of the process fluid pressure. To ensure the inboard seal had good lubrication, external flushing was specified.

From a technical and application aspect, this seal solution has been used before on many other similar plant and it is a default solution from EPC side as well. But there are a few issues with this seal solution including:

- High initial cost for the seal and system

Pure acetic acid is a very corrosive fluid and requires all the wetted material to be Zirconium or Alloy-C. All the

O-rings were required to be FFKM (perfluoroelastomer) material. In addition, as it is an unpressurized flushing plan, the inboard seal leakage will continuously mix with the buffer fluid, so the API Plan 52 system piping material needs to be anti-corrosive.

- High operating cost

The process fluid requires the API plan 32 to be pure acetic acid. The flowrate required is 23 liters per minute (6 US gallons per minute) continuously, and the flushing pressure shall be 2 bar (30 psi) above the seal chamber pressure. Pure acetic acid is the final product of the plant, so having the final product flush back to the mid-process in the plant adds cost and also reduces the process efficiency. Especially when the market for acetic acid is growing, this seal solution becomes less cost-effective.

- Reliability

As the process fluid is tending to vaporize, so external flushing pure acetic acid was introduced to the seal chamber in order to keep the inboard seal cool and lubricated. But if the acetic acid source pressure or flow is unstable, the inboard seal will see high temperature process fluid and may experience vaporization and dry running. The chamber pressure may be up to 30 bar g (435 psi g), which is a fairly high pressure in chemical plant, so it is not easy to find and maintain a constant source of plan 32 fluid at high pressure. This reduces seal reliability, and it often fails within one year.

- Environmental & health issue

Acetic acid is a weak acid but is may react violently when in contact with other substances (International Program on Chemical Safety, 2010). For this seal solution, acetic acid used for external flushing will leak out through inboard seal faces and into the plan 52 buffer fluid. Eventually some acetic acid will leak through the outboard seal faces to atmosphere. Under certain conditions, the leakage may become concentrated in liquid form, or vaporized. Concentrated acetic acid is corrosive to skin and may cause permanent eye damage and irritation to the mucous membranes (Centers for Disease Control and Prevention, 1992). These burns or blisters may not appear until hours after exposure.

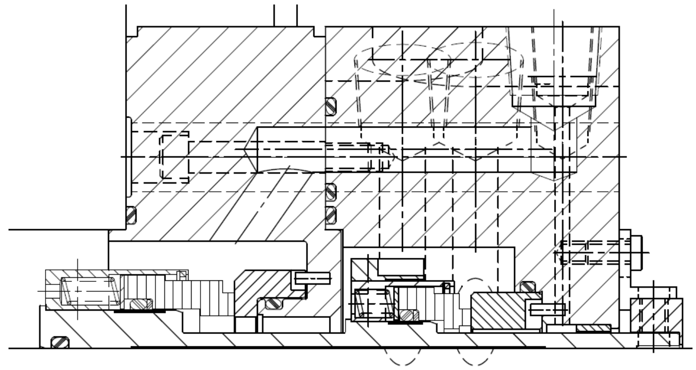

Figure 1. Original Tandem Seal (courtesy of John Crane)

SEAL UPGRADE SOLUTION

The upgraded seal is a high-integrity Upstream Pumping seal cartridge using our proven active lift technology within the inboard seal; this uses a low pressure liquid source (buffer fluid) circulated on the inside diameter of the seal face.

- Upstream pumping technology introduction

A conventional mechanical seal has lapped faces to within 2 light bands flatness. It operates by utilizing the process fluid as the interface film between the seal faces. The hydrodynamic action of the seal allows a gap of usually < 1 micron to form between the seal faces. This inter face film lubricates, cools and minimizes mechanical contact. The interface fluid should therefore be stable and clean to allow a good interface film to form and provide a long and reliable seal life. This principle ensures that any leakage that may occur is from the high pressure (product) side to the low pressure (atmospheric) side.

Active lift technology uses grooves on one of the seal faces to generate pressure between the seal rings so that they physically separate and operate in non-contacting mode. The most well-known use of this is for dry gas seals, where a barrier gas at a higher pressure than the sealed pressure is used to separate the faces.

Upstream pumping also uses active lift technology and is so called because the conventional seal face lubrication principle is reversed and a chosen unpressurised liquid is pumped from the low pressure side to the high pressure process fluid. This fluid must be clean and lubricating, and is typically water or a light oil, but even clean filtered seawater may be employed as this barrier liquid. Because liquid is more dense than gas, the pressure generated by the grooves is several orders of magnitude greater than that in gas seals; typically tens or even hundreds of bar.

Upstream pumping is a unique, patented (US4290611 A) John Crane seal technology. By utilizing specially optimized spiral grooves on the seal face in a liquid environment a pumping effect takes place between the sealing face. This has the effect of raising the pressure of the liquid between the seal faces to above that of the process. The seal acts like a pressurized dual seal without the need to pressurize the barrier fluid.

The USP face design generates a positive pressure across the seal face from inside diameter to outside diameter, i.e. from the buffer fluid into the process fluid in the seal chamber. The low pressure buffer fluid is sealed by a containment seal operating at the preset buffer fluid pressure but capable of containing the primary sealed pressure in the event of an inboard seal failure, fully designed as a bespoke engineered cartridge design as shown in Figure 4.

- Inboard Seal- Active lift technology

Seals using active lift technology are designed to provide reliable service for refineries, chemical/petrochemical processing, water treatment, mining, pulp and paper, and other industries where chemicals, low lubricity liquids, caustics, sour water, abrasives, slurries, and toxic products are pumped.

By utilizing specially optimized spiral grooves on the seal face in a liquid environment, a pumping effect takes place between the sealing faces (Figure 2). This has the effect of raising the pressure of the liquid between the seal faces to above that of the process. The seal acts like a pressurized dual seal without the need to pressurize the buffer fluid. (Figure 3)

The advantage of using an upstream pumping seal is that it no longer requires the use of a continuous plan 32 external flush. Also, the buffer fluid can be demineralized water at ambient temperature, which is easy to source from the plant and EHS-friendly.

Upstream pumping seals can generate greater than 40 bar pressure differential across the seal faces, and the upstream pumping rate will typically be less than 1 liter per hour (0.005 gallons per minute).

For this particular application, process fluid temperature is up to 189 °C (372 °F), so extra cooling for the buffer water is required in order to avoid vaporization across the grooved faces. The spiral grooves are optimized for liquid phase, if it runs on a gas then the seal faces will contact and fail. The cooling requirement is considered in the system design.

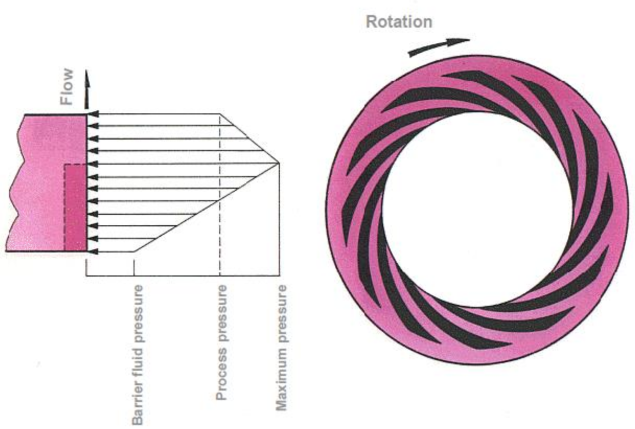

Figure 2: Mating Ring with Spiral Groove and its Pressure Profile (courtesy of John Crane)

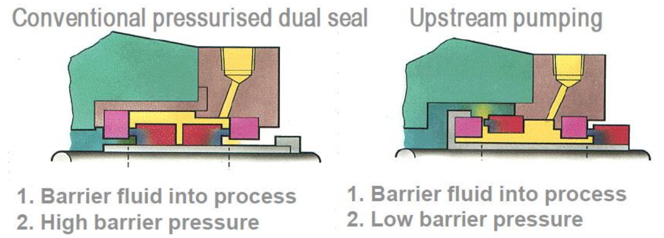

Figure 3: Leakage Direction for Pressurized Dual and Upstream Pumping Seals (courtesy of John Crane)

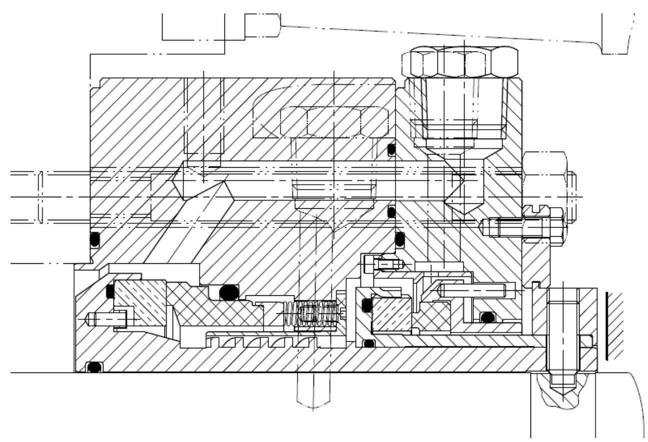

Figure 4: Upstream Pumping Seal (courtesy of John Crane)

- Outboard Seal- Containment function

The main function is to contain the buffer fluid in normal operation and in standby. And additionally to prevent major leakage of pumped product should the primary seal fail; the outboard seal is a back-up safety seal. It will run on the process liquid at seal chamber pressure long enough to allow a controlled shut down of the pump.

- Seal system- Special Plan52M

The system is used to provide a pressurized buffer fluid, at a lower pressure than the stuffing box to the space between the inboard and outboard seal of a 588USP cartridge.

As shown in Figure 5, this System uses a hydraulic accumulator to absorb any thermal expansion by the fluids in the seal loop and seal chamber. It also maintains a pressurized buffer fluid to serve as a reservoir to replenish seal leakage for a period of time if the make-up system is off line. The stored buffer fluid is piped to the local seal chamber circulation and cooling loops, where a pumping device is attached to the rotating element of the inboard seal. This pumping device circulates buffer fluid around the sealant system and the heat generated in the seal chamber by both the inboard and outboard seals is removed by this fluid circulation. It also ensures cooled liquid is available to be drawn into the spiral grooves, and removes any vapor or air present in the seal. Additional cooling is required for this application and a water cooler has been included in the scope to be installed into the seal chamber pipework.

The system is connected with site available demineralized water source, and the customer will ensure the water supply is continuous all the time. For upstream pumping technology, a stable, continuous liquid consumption source is critical. Generally all the sites have low temperature water utility.

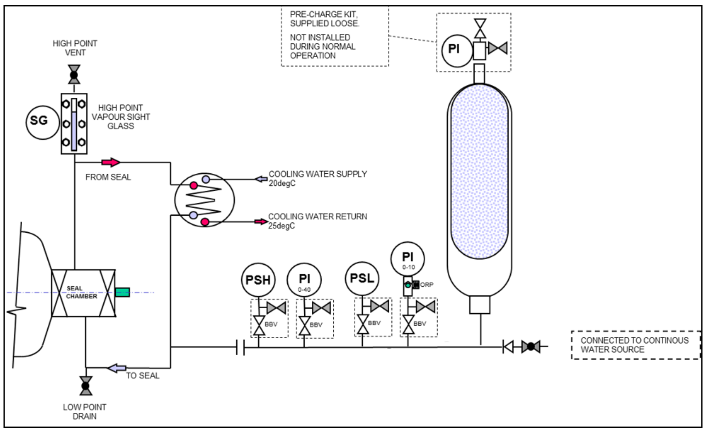

Figure 5: Seal System for Upstream Seal (courtesy of John Crane)

Note: SG: Sight Glass; PSH- pressure switch High; PI-pressure indicator; PSL-pressure switch Low; F-flush port

Another key consideration on system design is sufficient cooling in order to bring the water circulation balance temperature down below 60 °C (140 °F). The reason for this is that the lubrication property of water becomes poor when the temperature is higher, which will impact outboard contacting seal. The other reason is to minimize the risk of scale forming in the water and depositing on the shallow spiral grooves of the inboard seal face, which could reduce pumping efficiency and cause the seal faces to contact and failure.

Most upstream pumping applications have the buffer fluid at atmospheric pressure or perhaps at a few meters head. But in this application case, because of the heat soak from the high process temperature, if the cooling system failed there was a risk that the buffer fluid could get hot enough to vaporize, which would lead to a reduced seal life. Therefore, the buffer fluid system is pressurized to a few bar, to ensure it stays liquid.

ADVANTAGE OF UPSTREAM PUMPING SOLUTION

Comparing the original and upgrade seal solution, there are several advantages as follows:

- Firstly upstream pumping solution has been demonstrated to be more reliable and have longer MTBF (Mean-Time-Between-Failure) than single or even conventional dual seals on similar duties. The upgraded seal has run for at least 3 years in contrast to 1 year for the original seal. Upstream pumping uses non-contacting seal active lift technology; the stiff liquid film between sealing faces generates less heat than a normal contacting seal, and it is more tolerant of transient conditions that may occur in the equipment and process operation. Upstream pumping seal uses a low pressure water barrier (compared to a dual pressurized seal), this reduces the load on and heat generation of the outboard contacting seal, and ensures it runs well lubricated and under low stress, which extends the running life of the overall cartridge seal.
- Secondly the upgraded solution has reduced the EHS (Environment, Health, and Safety) risk. Upstream pumping seal performs like a dual pressurized seal, so it's "ZERO" emission solution. In addition, the acetic acid external flush was eliminated and water buffer is used, so the only leakage from the seal when running normally is water, not product.
- Thirdly the initial cost and operating cost of the upgraded seal solution is lower than original one. In principle, the outboard seal can use normal stainless steel material as it is not wetted, whereas on the original seal all the metal parts had to be high grade anti-corrosion material. For this particular case, the special grade material was still used because of customer requirement. Also, the upstream pumping seal doesn't need a continuous acetic acid flush, saving more cost.
- Finally, more generally Upstream Pumping seals are a cost-effective alternative to both dual unpressurized and dual pressurized seals. While the initial cost of the seal and support system is broadly similar (it may be less in some circumstances), the payback is in the increased reliability and up-time of equipment, and reduction in routine maintenance time and effort that USP seals can offer.

CONCLUSIONS

Upstream pumping technology offers several advantages compared to conventional seal arrangements, especially for certain special applications. It offers increased reliability and reduced environmental impact. Its attractiveness is increased as it requires only a simple auxiliary system (fundamentally just a water supply) even though it offers it's a more reliable seal performance.

Except for this case, upstream pumping products are also designed to provide reliable service in refineries, chemical/petrochemical processing, water treatment, mining, pulp & paper, and other industries where chemicals, low lubricity liquids, caustics, sour water, slurries and toxic products are pumped.

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