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What's inside the 'Box' When Considering API Piping Plan 54?

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ABSTRACT

API Piping Plan 54 utilizes an external source to provide a clean pressurized barrier fluid to a dual pressurized mechanical seal designed to allow minimal leakage across the primary sealing interface into the process stream. The measured leakage rate is typically a volumetric (mL/hr or fl. oz/hr) or mass rate (g/hr or lb/hr) and requires end-user approval with regards to process dilution. While given coverage in API Standard 682, there is little description or guidance given when compared to more traditional piping plans and rightfully so considering the multiple variations that could carry the description allotted to this piping plan. Graphically, API Plan 54 is denoted in the standard by a piping diagram where the barrier fluid comes from a blank space or "box" external to the mechanical seal or seals, pressurized from an external source. In reality, a Piping Plan 54 designation could cover anything from a process pump supplying conditioned barrier fluid under pressure, to a once through water system in a chemical plant, all the way up to a stand-alone lubrication system designed to API 614 specifications (*Lubrication, Shaft-Sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services*). The common determinant in arriving at this support system choice is the requirement for conditioned barrier fluid to adequately maintain the mechanical seal design integrity.

INTRODUCTION

What could typically drive support system selection towards Plan 54?

A Plan 54 support system designation may be selected as it has specific advantages over Plan 53A, B, and C. The primary difference is that the circulation rate required to cool and lubricate the mechanical seal is largely dependent on the size, internal circulation device, and piping with a 53 series piping plan. Flow to the mechanical seal is not dependent on an internal circulation device, shaft speed, or thermal siphon when supplied externally through Plan 54, which means actual desired barrier fluid circulation rate, can be achieved. The following represent some main factors to consider when selecting a pressurized external lubrication system as a means of seal support:

Circulation rate for heat removal

The minimum circulation rate required by the mechanical seal can be impacted by the limitations of the internal circulation device and as a function of the piping system's resistance. A slow shaft speed, seal size greater than 3.5" (89 mm) and total seal generated heat in excess of 30,000 BTU/Hr (8,800 Watts) per seal could be some instances where external means to provide the necessary circulation rate for cooling and lubrication may be required. One primary concern is that the heat dissipation capability, especially with a Plan 53A system, can be limited by the physical limitations of the cooling coils inside the reservoir. In addition, the larger the seal size, the more prevalent churning becomes, which therefore increases the total heat load. Higher temperatures (> 500 °F or 260 °C) will also increase total heat load on the seal due to the increased influence of heat soak. Recommended estimates for calculating heat soak in mechanical seals are detailed by Buck and Chen in proceedings from the 26th International Pump Users Symposium. (3)

Pressure

Plan 54 is not limited by available nitrogen pressure both in level of achievable barrier pressure and nitrogen entrainment in the barrier fluid as in a Plan 53A. This means that a Plan 54 support system can be used at much higher pressure applications than a Plan 53A (API 682 expresses concern with gas absorption potential at pressures 150 PSIG (10 BARG) or greater; many users have documented field experience with synthetic barrier oils suggest gas absorption at pressures up to 300 PSIG (21 BARG) will not pose an issue provided the barrier temperature is < 250 °F (121 °C). Additionally, because the barrier pressure is set externally by mechanical means, the pressure applied to the seal will remain as desired unlike in a Plan 53B where the pressure will vary over time.

Volume

Barrier fluid capacity in the lubrication system reservoir is not limited as it is with a Plan 53A/B or C. The flexibility of increased reservoir capacity not only allows maintenance and replenishment intervals to be greatly extended, it also potentially allows one Plan 54 'system' to be designed to adequately supply clean flush media to mechanical seals on multiple pieces of process equipment.

Available Space

Plan 53A/B/C require proximity to the seal to promote optimum circulation rate, based on shaft rotation. This becomes especially critical in high heat load applications, particularly in higher temperature services. A Plan 53A system, for example, could be considered in a high temperature application, but may require the use of a custom reservoir (10-20 Gallon or 38-76 L capacity). It may not be feasible to install a reservoir of this size within proximity to the seal, in which case Plan 54 becomes advantageous. In the aforementioned example, a sizeable reservoir made of either 6-8" (152 – 203 mm) pipe can require a vessel that resides 10-15' (3 – 5 m) above grade. The requirement of a ladder to access the refill port for normal preventative maintenance now becomes a potential safety issue. Some facilities are in the midst of enforcing strict fall prevention policies that potentially require scaffolding (engineering design) /fall hazard analysis review (administrative policy) to correct issues where fall distance exceeds 6 feet (2 m). While API 682 4th Edition does require seal auxiliary system fill and vent access at grade, there are many applications that may fall outside of the scope of this standard where access for these tasks would still need to be addressed from a safety standpoint.

Another common concern for end-user operations groups is the ability to access equipment for both operational and maintenance tasks. The ability to access critical isolation/shut-off valves, safety equipment and utility stations with minimal obstruction is generally preferred by the end-user. In addition, maintenance costs and equipment down-time can be reduced by improving ease of accessibility for maintenance work and reducing the scope of repair work.

Process Fluid Constraints

The nature of the process liquid can also drive the end-user into the market of a dual pressurized system. Certain process fluids fall under the designation of being a VOC (Volatile Organic Compound) that requires zero-emissions to the atmosphere and full containment in the event of a seal failure. With the appropriate instrumentation and alarm scheme, a Plan 54 console offers the ability to contain process fluid while implementing a controlled shutdown of failed equipment. The pressurized arrangement also meets emissions control requirements by site LDAR (Leak Detection And Repair) programs. Specialty chemical processing where the process liquid has a marginal temperature operating range before being subjected to polymerization is another ideal candidate for Plan 54 selection. Process fluid polymerization often results in damaged seal face components or potential seal hang-up; these occurrences can be avoided with a conditioned barrier fluid.

Flashing hydrocarbon services with poor lubricating properties are also targeted equipment for an external lubrication system (Ethane/EP Mix Pipeline service, for example). These applications typically meet the Plan 54 criteria (high speed, high pressure, larger equipment sizes, etc.) and introduce the limitations of the process fluid having poor lubricity qualities. Issues with vapor pressure margin and flashing index can be addressed with implementation of external pressurized support system that allows for the utilization of a conditioned lubricating film across the mechanical seal faces.

The constraints represent a few examples where implementation of a pressurized external lubrication system can maximize reliability in an otherwise harsh operating environment.

Summary of some typical criteria driving selection towards Plan 54:

- Pump temperature > 500°F (260 °C), ≤ 800°F (427 °C) in general.
- Barrier pressure requirement ≥ 200 PSIG (14 BARG).
- Process Fluid Constraints – hazardous, zero-emissions, poor lubricity, etc.
- Barrier pressurization requirement 100% of the time (any doubt with a gas pressurization system, i.e. Plan 53A/B, should move selection towards Plan 54).
- Unavailable space for proper Plan 53 A/B/C installation – proximity near mechanical seal per industry accepted installation guidelines.
- Circulation rate required by the seal beyond pumping ring circulation rate (based on seal size and estimated system resistance with Plan 53A/B/C).

System Component Overview

There are many variables that impact the design of a pressurized external lubrication system and often none will be more demanding than the end user's own preferences and standards on system requirements and limitations. Certain end users, particularly in the oil and gas industry, have very stringent requirements that can quickly add to the complexity and cost of a lubrication system. There are some general best practices that can be adapted to any pressurized external lubrication system that will transcend all industries and aid in increasing the reliability and usability of the support system. Several best practices will be discussed as they pertain to each system component, along with various troubleshooting and maintenance guidelines that will be useful references once a system is installed.

Reservoir

Function:

The system reservoir in its simplest description houses the barrier fluid supply. However, external lubrication system, there is more flexibility afforded the designer and user than with a more traditional reservoir used in Plan 53 arrangements. When considering a pressurized external lubrication system, the variable that should be considered first is the physical size of the reservoir, i.e. how much barrier fluid will the reservoir hold. The size of the reservoir will typically dictate the orientation and configuration of the remaining components of the system, which makes determination of its capacity a good starting point in system design.

Design/Operation:

Reservoir capacity is dictated by the amount of retention time that should be provided to the barrier fluid. Enough retention time is required to allow any entrained deposits in the barrier fluid to settle out as well as allowing any additional heat to dissipate from it. A good rule for minimum required retention time is 5 minutes; however, the longer that can be provided, the better (API 614 for example, recommends a retention time of 8 minutes for highly engineered support systems). Reservoir size will be determined by a simple calculation:

Required Circulation Rate x Retention Time = Reservoir Capacity

Therefore a 2.0 GPM (7.6 L/min) circulation rate will net a reservoir capacity of 10 gallons (38 L). The inclusion of additional seals to the system will naturally increase the reservoir size. The reservoir capacity will be based on the total required circulation rate by the entire number of seals dependent on the system, which can make for a very large reservoir when all is said and done. See Figure 1 for a typical system reservoir diagram.

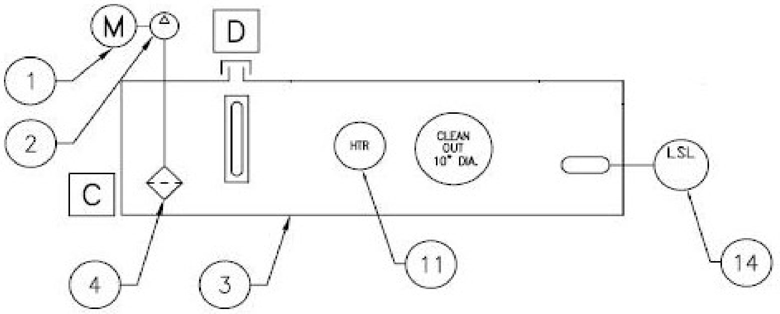

Figure 1: Typical Reservoir Configuration Diagram

Integral to the reservoir design is consideration for mounting of the primary barrier fluid supply pump, which will pull suction from the reservoir. The preferred method of installation for the supply pump is to mount externally from the reservoir; not submerged. The main driver behind an externally mounted pump is for ease of maintenance and troubleshooting. Mounting the pump (item # 2) externally may require additional steps in the system commissioning process to verify that the suction line is free of vapor pockets, but these items can be easily addressed through proper procedural steps. The inlet of the primary barrier fluid supply pump will include a suction strainer (item # 4 in the diagram), which is an item that should be replaced on a recommended preventative maintenance interval.

In addition to retention time, it is good practice to include the following items into the reservoir design if possible:

- Sloped bottom – slope bottom of the reservoir towards the low point drain.
- Low point drain – valved; (Point C in the diagram)
- Clean out cover – allows accessibility to the reservoir during shutdown and outage periods for ease in cleaning (labeled in the diagram – sufficient diameter required for access).
- Reflex level gauge – measures liquid level based on the difference in the refractive indices of liquid and vapor (located below Point D in the diagram).
- Desiccant breather – keeps contaminants out of the barrier fluid that could normally be introduced through a conventional reservoir fill / vent cap (located at Point D in the diagram).
- Reservoir material – stainless steel construction preferred (item # 3).

Along with the above items, there may be specific applications that mandate the use of additional controls for the barrier fluid, such as a heater. The use of a heater is determined based on barrier fluid properties, site ambient temperatures, and system operation. While still in the design stage, it is worthwhile to consider the addition of a future access port for a heater should one be required in the future. In Figure 1, item # 11 denotes the heater location for this system.

Depending on the size and complexity of the pressurized lubrication system, the reservoir may be component mounted on a common skid with other items or serve as the mounting base (for smaller units). When a common skid is used to house the reservoir and system components, the skid design should take into consideration accessibility of each component to allow items to be easily accessible for maintenance and troubleshooting. Inadvertent triggering a critical device or personnel exposure to an un-insulated piece of hot tubing can be just some of the undesirable effects realized with poor skid design and component placement. This is especially important of larger systems that support multiple seals as typically the controls for monitoring and maintaining the mechanical seals in the circuit become very critical. Many end users already have site specific standards in place regarding circulating oil system skid requirements. Some typical items to consider in larger pressurized lubrication system configurations should include:

- Decking design consideration – suitable for egress and accessibility.
- Drainage ports – allow any barrier fluid accumulation external from the reservoir to drain freely.
- Lifting lugs – provides a proper lifting point for the system; this should prevent the use of non-load carrying items (tubing, instrument tie-in points) being used as lifting points.

Troubleshooting / Maintenance:

Within the first few hours of operation, any foreign material in the system plumbing will be flushed to the reservoir. This makes the placement of the system filtration elements a critical component of the design, which will be discussed later. It is a good practice to drain the reservoir and change out the suction strainer, and then re-fill the reservoir with clean fluid. Depending on the cost associated with the barrier fluid being used for service, a less costly alternative fluid may be used for this flushing and commissioning stage.

On a yearly basis, it is a good practice to replace the suction strainer inside the reservoir along with the breather filter element, with a drain and flush incorporated on a bi-yearly basis. These items should be incorporated into the facilities re-occurring PM schedule so that they are not missed. Keeping up with the preventative maintenance of the system avoids potential seal issues that may be related to barrier fluid circulation rate and quality of the barrier fluid itself.

Filtration

Function:

Pressurized external lubrication systems have a distinct advantage over other conventional wet seal lubrication systems in that the barrier fluid being supplied will typically be free of debris and deposits accumulated through normal seal wear due to system filtration. Filtration should be included on any seal lubrication system as a standard component, and the filtration element(s) should be mounted on the return leg from the seal on the barrier fluid circuit to provide a first pass for eliminating contaminants that may be picked up inside the mechanical seal. It would be beneficial to specifically place the filtration element upstream of the heat exchanger, as the filter can help protect the exchanger externals from fouling should an upset condition occur. Placement upstream of the heat exchanger may require rating the filter to a higher design temperature, making a thorough review of the process conditions a necessity if placement in this location is to be considered. In specialized cases, such as in large lubricators which may support multiple mechanical seals, in would be beneficial to consider lubrication upstream and downstream of the individual usage points for each seal.

Design/Operation:

When considering system filtration, inevitably the decision to use either simplex (one filter) or duplex (two filters) will need to be made. Unless compensated for in the design by the inclusion of a bypass line, simplex filtration will require that the lubrication system be shut down for the filter to be changed. Duplex filtration is preferred as it adds a second filter in parallel to the filter in use. The second filter is a standby filter and by its inclusion it allows online filter replacement as one filter can be serviced while the other is online. The use of the additional filter requires that provisions be made for venting, draining, and isolation of each element so that maintenance can be performed. A filter element sized for 10-micron filtration (max) should be sufficient for most mechanical seal applications. A typical duplex filter arrangement is shown in Figure 2.

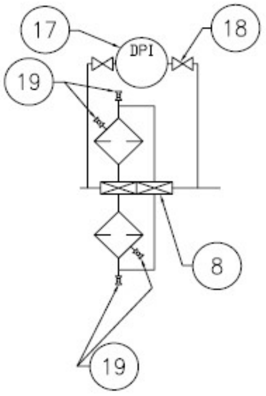

Figure 2: Duplex Filter Diagram

The diagram outlines a basic duplex arrangement in which the filtration elements share a common distribution block (item # 8) and have provisions included for venting and draining through the use of valves (item # 19). Whether duplex or simplex filtration is in use, it is a good practice to monitor the health of the filter by some means. At minimum, a differential pressure gauge (item # 17) should be mounted across the filter arrangement to provide the user with a means of determining the filter's effectiveness. More complex monitoring can be adopted for this function in the form of differential pressure transmitters. The transmitter allows alarm signals to be tied to the filter differential pressure to provide advanced notification of potential problems with plugging or fouling. Pressure differential set points for filter replacement should be determined based on conversations with the end user. The complexity of the alarm scheme associated with this variable will be dictated by the criticality of the process equipment being sealed, among other factors. The pressure drop across a new and clean filter element should not exceed 3 PSI (0.2 BAR).

Filter changeover is accomplished by a transfer valve between the two filters. It is important to exercise the transfer valve slowly when changing over between filter elements. Rapid switching of the valve could have multiple impacts, such as allowing air to be the discharged into the fluid line or creating an instantaneous high differential pressure across the filter element that may cause collapse.

Due to the potential issues, such as element collapse, that can be created if the changeover process is not handled correctly, it is a recommended practice when considering a duplex filter arrangement to include a means of equalizing the pressure on both filter elements. This can be as simple as including a piece of tubing and needle valve on the distribution block where the filters are mounted. An alternative method would be to utilize a restriction orifice in the equalization line along with a block valve for isolation purposes. The orifice method has distinct advantages, as it provides repeatability in the desired result – the needle valve is susceptible to unnecessary adjustment and can be closed inadvertently. Depending on the filter configuration, the equalization line can be added to the element housings as well. Figures 3 and 4 respectively, show both the equalization line mounted to the transfer valve nozzles as well as to the filter element housings: item # 6 is the restriction orifice referenced. Under normal operation, the line remains open to equalize pressure on both filter elements. During filter element replacement, the line would be isolated to allow the desired element to be changed.

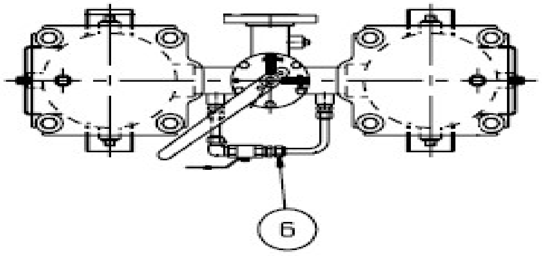

Figure 3: Equalization Line with Orifice

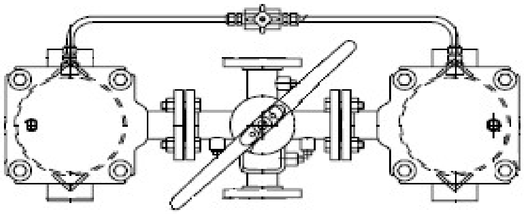

Figure 4: Equalization Line with Needle Valve

Position of the transfer valve as it relates to which element is in use can be a source of confusion for some equipment operators. During initial startup of the system, the transfer valve should be centered so that barrier fluid flow will be equal through both elements. After the barrier fluid reaches normal operating temperature, the valve handle can be moved to the desired operating position to direct flow through one element only. This process will be repeated during the filter element changeover or replacement process. During normal operation, the direction of barrier fluid flow through a specific element will be indicated by a notch or arrow mark at the top of the valve – it is not necessarily based on which element the handle is "pointing" to, which is a common misconception. In Figure 5, if the transfer valve handle is pulled to the left, the black notches will line up with the element on the right, indicating that it is the element in service.

Figure 5: Transfer Valve Orientation Notch

Troubleshooting / Maintenance:

The filtration portion of a seal lubrication system is one component that will require more regular replacement than others. For this reason, accessibility to the filter element needs to be considered during the design process. Filter elements should be mounted to facilitate easy removal and replacement. While this is a relatively simple concept, it can often be overlooked past the design stage especially if there are alterations to the system configuration.

Venting is a key aspect, especially critical to duplex filtration assemblies. As previously mentioned, having sufficient manual vent valves in place is highly recommended to allow not only venting of the system during startup but to also allow trapped air to be bled from the system periodically as air may accumulate at the top of the assembly during normal operation. The manual vent is also critical to the changeover process between elements when used in conjunction with the transfer valve. The frequency of venting of the assembly beyond each startup will vary between systems.

Maintenance on the filtration portion of the system is relatively simple as changing of the filtration element becomes the pacing item. As a general guideline, filter elements should be changed when the pressure drop approaches the predetermined value above a “new” element, or every 12 months, whichever occurs first. This frequency may be extended or increased based on the system’s performance; however, any time the barrier fluid is changed it would be a good practice to change the filtration element as well.

Cooling

Function:

As previously stated, the reservoir should be sized for adequate retention time for heat dissipation of the load carried by the mechanical seal assemblies. When specifying cooling requirements, we must first define the acceptable criteria for allowable temperature rise, which is typically 30ºF for lubricating oils used on most pressurized external lubrication systems. One of the greater concerns is the impact of temperature on the utilized barrier fluid and the possibility of thermal breakdown that leads to more frequent PM tasks and unplanned equipment outages. An added cooling mechanism to the design of an external lubrication system ensures a stable barrier fluid and optimal sealing environment. Pressurized external lubrication systems will typically use one of three cooling mechanisms, options to include an internal cooling coil, water-cooled shell & tube exchanger or an air-cooled exchanger design.

Internal Cooling Coil:

One arrangement for cooling design is to install an internal cooling coil within the reservoir assembly. The biggest advantage is the simplicity of the design, ease of installation and minimal cost. Cooling water travels through the cooling coil at a specified flow rate to minimize the temperature rise within the system. Because the coil is internal, the overall length and available surface area can be limited by available space within the reservoir. This arrangement is typically a single coil arrangement supplied on low heat load applications and within systems supporting single point process equipment.

Water Cooled (WC) Shell & Tube Design:

This arrangement generally will add more flexibility with regards to overall design. The most common WC arrangement incorporates a shell and tube design with injection of one media through the shell inlet connection and flow directed through internal baffle plates to the outlet connection. The alternate media then counter-flows through a series of tubing runs (bundle) that vary in shape and number of passes. The main components of the exchanger that promote heat transfer include tubing surface area, tube positioning to promote turbulent flow and material of construction with excellent thermal conductivity characteristics. Due to being installed on the system skid, the overall capacity of the exchanger can be sized as large as required to meet cooling demand of the application. This also allows for a more rugged design with regards to internal tubing/baffle design, tubing support, shell construction and mounting brackets. In addition, the externally mounted shell & tube design allows for improved access to the coil/bundle elements via flanged end-connections when preventative maintenance is required. Figure 6 depicts a typical design for a pressurized external lubrication system with a water-cooled arrangement.

Figure 6: Water Cooled Heat Exchanger System

Air Cooled (AC) Exchanger:

This design is typically utilized when cooling water is not readily available, typically at a remote site or potentially in a tank farm area. In some cases, the end-user does not have a suitable cooling water system and impurities can lead to premature fouling, which would also promote the use of an AC exchanger. The primary facility requirements for utilization of an air-cooled exchanger include a reliable power source and ambient conditions where the temperature is lower than desired outlet temperature of the circulation loop, with a 30°F minimum temperature differential considered to be a good guideline. Primary components of the AC exchanger include the following:

- Tube bundle to channel oil through the exchanger
- Motor-driven fan to provide cooled air for heat dissipation
- Plenum chamber to direct airflow
- Control device to regulate process outlet temperature. Design can vary between manual louvers, pneumatic/electrically operated louvers, variable frequency fan drives, etc.

While the AC design has advantages in eliminating the requirement of cooling water, it does have additional concerns not associated with the water-cooled designs. Periodic lubrication of the motor bearings is required to limit vibration of fan component and is an additional operational task that needs to be addressed prior to commissioning. In addition, the AC design is more susceptible to changing ambient conditions, which can impact the control scheme of the support system. Consideration must be given to pour point limitation of circulating fluid to prevent freezing and high viscosity situations that can be detrimental to seal performance. Figure 7 depicts a typical design for a pressurized external lubrication system with an AC arrangement.

Figure 7: Air Cooled Heat Exchanger System

Regardless of the exchanger type selected for the system, there are certain considerations which apply to each arrangement:

- Cooling systems are typically installed on the primary return line from seal assemblies back to the reservoir.
- Cooling coil / shell materials should be compatible with main process fluid.
- Redundant exchangers should be considered on all critical equipment and where systems are in support of multiple pieces of process equipment.
- Ability to vent, flush and drain exchanger components should be implemented as a "best practice" regardless of design orientation.
- Single or multiple pass designs to be defined based on facility requirements (i.e. lean cooling water supply available, noise limitations associated with higher speed motors, etc.)
- System should be designed to allow for periodic backflushing or bundle replacement.
- At a minimum, bulk reservoir temperature should be monitored at the skid with a gauge/thermometer.
- A temperature transmitter is recommended for reservoir with DCS feedback to promote changeover to redundant cooling element or equipment shut down for maintenance.
- Cooling water loop should include visible flow indicator on CW return line to ensure positive flow.
- Freeze protection on water-cooled exchangers should be considered in the form of heat tracing as required by site location.

Safety Package

Function:

In reviewing the selection criteria towards progressing with an external lubrication system, the end-user is driven by influences such as severe duty parameters (high speed, high pressure, lubrication deficiencies, etc.) and process constraints that prohibit exposure to the atmosphere. The system can be designed with an added layer of protection, so that during a manufacturing unit upset or unplanned outage, the mechanical seal can still operate with positive system pressure and provide full containment of the process liquid.

Design/Operation:

The addition of an accumulator on the primary seal supply line serves as a safety blanket of pressure should there be an upset condition within the operating facility, main process pump or pressurized external lubrication system. Examples of unplanned outages that could lead to reverse pressure situations and potential seal failure are as follows:

- Power failure to system.
- Failed external lubrication system pump or motor components.
- Designed interlock to shut down the external lubrication system (low level trip).

Regardless of the mechanism that creates a scenario where the pump or motor are no longer operational, the primary goal of the safety package is to prevent a reverse pressure situation that could lead to potential process release, compromised mechanical seal assemblies, and cross-contamination of the support system. It should be noted that as the safety package is activated, the system is only providing pressure to the mechanical seal system and the unit is no longer circulating or cooling the barrier fluid. It is also critical to keep in mind that there is a finite volume of liquid in the closed loop which is dictated by accumulator size and tubing or pipe size and length.

The safety package loop contains the following critical components (see Figure 8):

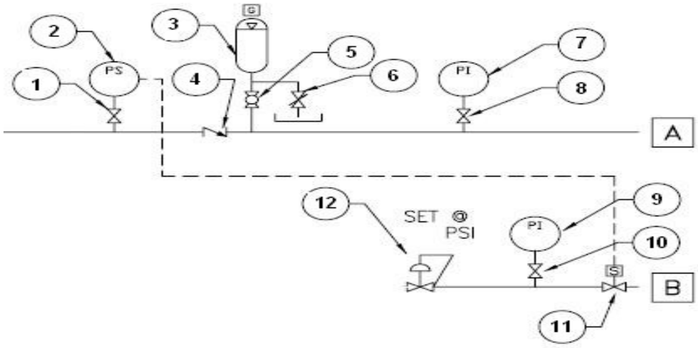

Figure 8: Safety Package P&ID

- Pressure switch (item 2)
- Accumulator w/ bladder (item 3)
- Check valve (item 4)
- Isolation valve (item 5)
- Solenoid/Actuating valve (item 11)

As the system pressure in the supply line from the lubricator tank decreases, the charged accumulator (item 3) begins to reverse flow liquid through the supply line, which activates the check valve (item 4) to seal and activates the front end of the closed loop system. Simultaneously, the pressure switch (item 2) communicates a signal to the solenoid valve (item 10) on the outlet connection to close, which prevents migration of the barrier fluid back to the supply tank. The mechanical seal assemblies are still operating with positive pressure (no circulation) and will seal the finite volume of liquid as a function of their working condition. If the sealing interfaces have been damaged or there is an alternate component leak path, the volume of liquid in the accumulator will decrease and the pressure in the system will decay rapidly. Design of all associated valves should incorporate "bubble-tight" components to prevent slow bleed-down of system pressure when activated.

Alarm/Monitoring:

Continued operation of the main process pump while operating with the safety package engaged is not recommended. Most pressurized external lubrication systems are equipped with the appropriate pressure and flow alarms or transmitters that communicate the system integrity with the end user's Distributed Control System (DCS); however, there are scenarios such as installations in remote locations where it is not feasible to monitor the unit from the process control room. In any case, communication with operations is required to optimize equipment reliability and limit process exposure to the atmosphere.

As previously discussed, the safety package when energized does not provide cooling to the barrier fluid as the system loop is closed. Operation of the main process pump with the safety package engaged will lead to increased heat loads at the sealing interface, probable face damage associated with thermal rotations and increased seal leakage. The recommended control scheme it to operate with an interlock between the PELS and the main process pump. As the safety package is activated, the pressure switch should communicate a signal to the main process pump to shut down. This system can be designed to shut down the unit on "low-low Pressure" ($P_{\text{low-low})}$ to prevent nuisance equipment trips.

Troubleshooting / Maintenance:

The recommended preventative maintenance schedule for the accumulator component is rather simple and can be executed while the unit is operational. A charging kit mounts to the top of the accumulator and will register a pressure value of the accumulator system. The system should be re-charged if the pressure setting registers at less than 10% of the original charge pressure.

A periodic test of the gas charge pressure should be conducted on a quarterly basis. The PM frequency can be adjusted based on equipment/service criticality.

A second preventative maintenance task includes integrity testing of components on the closed loop system. Components to be checked include the main pressure sensing switch, solenoid valve and check valve. In addition, all tubing and piping connections and fittings should be inspected once the unit is de-commissioned as they often serve as leak points and “false” seal leaks. During normal operation, valve positioning should be confirmed on item 5 (NO) and item 6 (NC). This ensures that the accumulator is liquid full, while charged with pressure.

Control

Function:

Paramount to reliable pressurized external lubrication systems operation is the ability to determine the quality and condition of the barrier fluid that is being circulated. Monitoring and controlling the barrier fluid temperature and pressure are two variables that have the most immediate impact on the mechanical seal performance. Degradation in pressure is obviously undesirable as a loss of containment of the process fluid is the potential result, which can lead to un-necessary personnel exposure, environmental impacts, and equipment damage. Failure to maintain a desirable barrier fluid temperature can have equally detrimental effects to mechanical seal performance as repeated exposure to temperatures inside the mechanical seal chamber will break down the fluid and impact lubricity over time. Adequately monitoring the temperature of the barrier fluid allows the end user to proactively address concerns as opposed to reacting to upsets. As a rule, the complexity of the external lubrication system control scheme should be in line with the importance of the equipment to the overall process and the associated hazards of the pumpage.

Design/Operation:

Barrier pressure for the system is set downstream of the mechanical seal by a pressure regulating or pressure control valve (PCV) of some kind. Two general methodologies adopted for pressure control rely on either a pressure tracking philosophy or a pre-determined pressure set point above seal chamber pressure. A pressure tracking valve will maintain a set pressure differential above a referenced pressure source, in this instance seal chamber or suction pressure. The advantage of pressure tracking is that there is repeatability in the desired differential pressure amount for the barrier fluid to be maintained at; the drawback is that if the process fluid is dirty or thermally sensitive, then there is a likelihood that the pressure reference line may plug. Additionally, high temperature services require additional consideration with a pressure reference line as there will now be another exposed line in the circuit that personnel would potentially encounter. Pressure referencing is possible in dirty, thermally sensitive, or hot services but would require the use of specialized instruments which may or may not be feasible depending on the scope and complexity of the installation.

Constant backpressure downstream of the mechanical seal in an external lubrication system is a reliable alternative and can be used in both single and multiple seal system arrangements. Typically, the back pressure set point is maintained the greater of either 10% or 30 PSIG (2.0 BARG) above the estimated maximum seal chamber pressure. This pressure set point determination is made because a system operating at 1000 PSI (69 BAR) will likely have larger pressure spikes than a 100 PSI (6.9 BAR) application. For this reason, arbitrarily applying a blanket designation of 30 PSIG (2.0 BAR) as a ΔP requirement for all systems, including high pressure applications, is not recommended. During operation, the back-pressure valve maintains upstream pressure (at the seal faces) by varying flow across the valve in response to pressure fluctuations. Provided accurate operating conditions are obtained ahead of time, an external lubrication system can be reliably designed with a constant backpressure control scheme.

Pressure tracking control devices have been utilized successfully, generally on higher pressure units. In context, higher pressure would be in the range of 1,000 PSIG (69 BARG) or where there are extreme changes in the process pressure during operation. Some typical examples where Plan 54 configurations have employed these devices successfully have been in batch applications, such as mixers or agitators in chemical processing where heat or reaction may increase or decrease the process pressure. In this instance an effective Plan 54 configuration can use a pressure tracking control scheme to maintain sufficient delta-P (barrier pressure to process) across the operating range, allowing for flexibility in the operation of the system. More recently, some midstream pipeline operators have utilized pressure tracking barrier control devices on Plan 54 lubrication systems for pumps seeing multiple product applications with varying suction pressures, 200 – 1000 PSIG (14 – 1000 BARG). Pressure tracking control devices can be categorized into two types – digital or mechanical valves. The digital valves do provide an added measure of precision and react more responsively to changes in pressure. Mechanical valves can be used, but respond slower and as such may not be suited to handle rapid spikes in pressure. Planning and consideration into the process control and operating parameters should be well understood between all parties when considering tracking pressure control devices in these lubrication systems. Figure 9 depicts examples of digital and mechanical pressure tracking control devices and approaches.

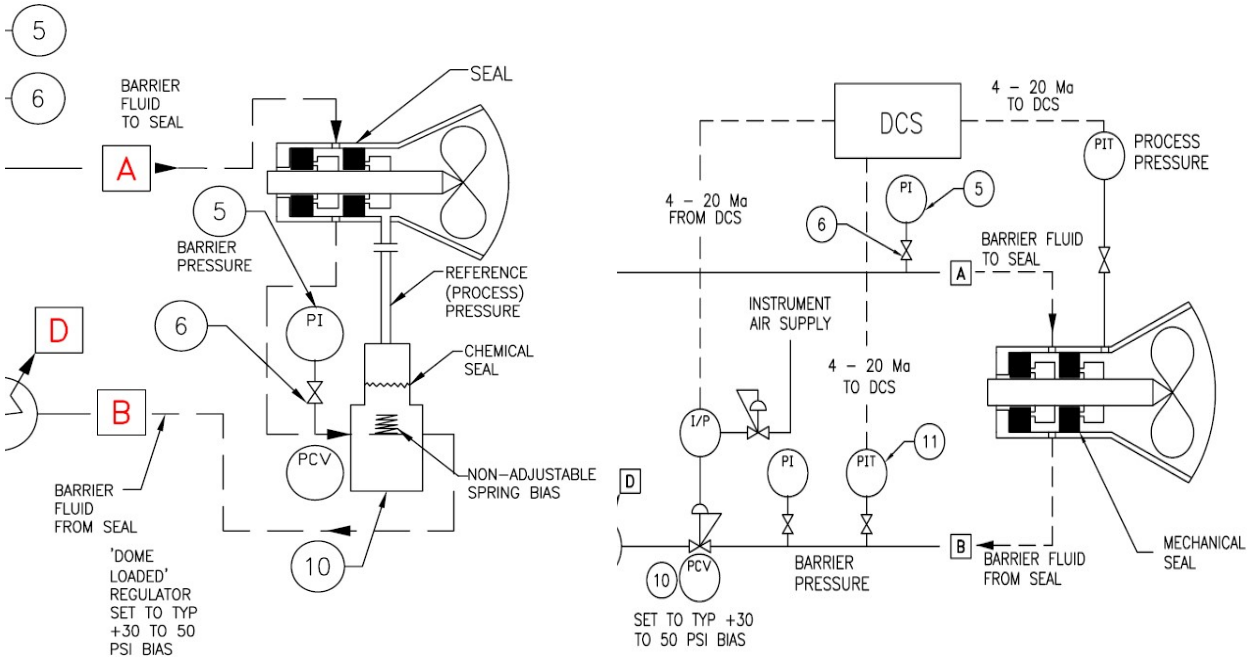

Figure 9: Digital and Mechanical Pressure Tracking

Naturally, as more seals are added to the system, pressure set point determination becomes more critical along with considerations regarding the installation and accessibility of the valve itself. In an instance where a PCV may require replacement on a multiple user system, a minimum bypass line with a globe valve should be installed to maintain back-pressure while servicing the PCV as shutting down a lubrication system supplying multiple pieces of equipment is obviously not a desirable option.

Another critical aspect of the control system is the implementation of a pump protection valve (PPV) on each individual motor component. The primary function of the PPV is to allow for re-circulation back to the main reservoir should the supply line become obstructed or a downstream component is inadvertently blocked in. Typical set-point for the pump protection valve is approximately 150 PSIG (10 BARG) above normal operating pressure. If the PPV's require setting in the field, it's imperative that an isolation valve be installed on the supply line to create a dead-headed environment to properly adjust the PPV to the proper pressure setting. Figure 10 depicts some common pump protection and bypass valve designs.

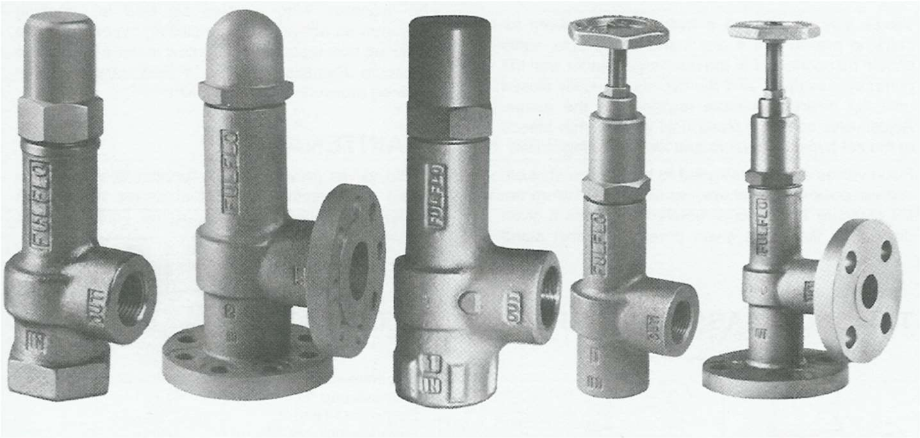

Figure 10: Pump Protection Valve Examples

It is crucial to communicate the importance of not adjusting the PPV once the system is operational. Adjustment to the PPV can lead to scenarios where the pressure is set too low and barrier fluid is re-circulated to the reservoir at much lower pressures than originally designed. This can result in inadequate forward flow to supported mechanical seal assemblies and potential premature failure. It's recommended that local signage, operator training and administrative engineering (documented operating procedures) be implemented to prevent improper adjustment. Pressurized external lubrication system shutdown is required to readjust the PPV to the original setting.

Some systems also implement the use of a separate spill-back line. This feature is utilized when multiple pumps are supported by one system and one machine is isolated for maintenance. The normal flow is then re-directed back to the reservoir to prevent potential over-pressure in the supply line. While it's acceptable to feed more fluid to the online seal assemblies, the system line isn't always sized accordingly on the front end of engineering and manufacturing. The system can be designed to accommodate these high flow or high-pressure scenarios, but there is a higher cost associated with more material and higher pressure rated instrumentation.

Monitoring of barrier fluid temperature is a necessity in pressurized external lubrication system arrangements as it provides an indication of the heat exchanger effectiveness in addition to being useful as a troubleshooting aide when monitoring other system parameters such as flow and filtration quality. In the simplest arrangements, a temperature indicator is placed in the fluid stream to provide a local indication. Multiple indicators can be used in supply and return locations; if limited to one indicator, the most beneficial location to monitor would be downstream of the heat exchanger on the barrier fluid return line but upstream of the filtration element. Oriented in this fashion, the temperature indicator can provide not only an indication of the heat exchanger performance but would yield insight into the condition of the filtration element as a reduction in barrier fluid flow through a fouled element would yield an increase in upstream temperature.

In many installations, maintaining a minimum temperature on the barrier fluid is required as dramatic cooling of certain fluids may yield an undesirable increase in viscosity. In such instances, a thermostatic control valve (TCV) may be installed to balance the bulk barrier fluid temperature and prevent un-necessary cooling. TCV's are used in a wide variety of industrial applications, and in the context of an external lubrication system, one would be used to sense temperature from two differing streams (one hot, one cool) and mix the two streams in the correct proportion so as to produce the desired outlet temperature exiting the valve. Consideration needs to be given to the desired minimum temperature of the barrier fluid. Most commonly, the barrier fluid temperature will be maintained in the 120 – 130 °F (49 – 54 °C) range with a return temperature from the seal in the 150 – 160 °F (66 – 71 °C) range. Higher minimum barrier temperature requirements would require transitioning away from an "open" reservoir system and to an engineered closed system design. A common TCV piping diagram is shown in Figure 11, along with typical representation from an installed system in Figure 12.

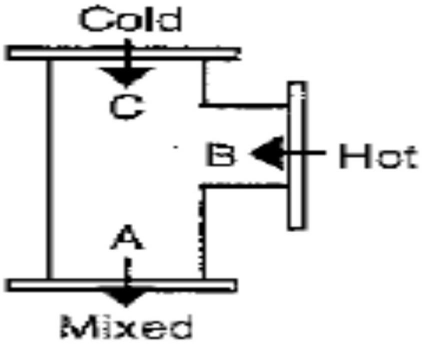

Figure 11: Simplified Temperature Control Valve (TCV) Diagram

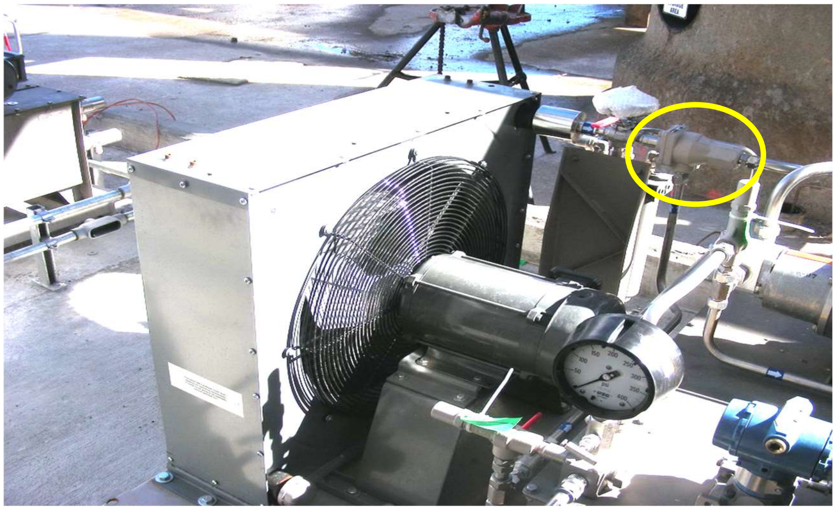

Figure 12: TCV Installation with Air-Cooled Heat Exchanger

Alarm / Monitoring:

Alarm logic for any external lubrication system should be determined during the system design process and previously mentioned the scale should mimic the importance of the equipment being sealed. As pressurized external lubrication systems can be designed to provide barrier fluid to multiple users, the alarm philosophies will reflect as such.

Single seal system:

- Barrier fluid pressure – low pressure alarm based on decreasing pressure
- Barrier fluid pressure – low-low alarm to activate solenoid switch on safety package
- Barrier fluid level – low reservoir level (loss of barrier fluid across inner seal)
- Barrier fluid level – low-low reservoir level with automatic lubricator shutoff and interlock to shut down main process pump
- Barrier fluid level – high reservoir level (reverse flow of product through seal)
- Filter ΔP Alarm – gauge at minimum, but alarm tied to high filter DP for complex systems.
- Consider temperature monitoring – high temperature alarm to facilitate troubleshooting by the site operations, maintenance, or reliability group.
- When feasible – transmitters are more desirable than switches for monitoring and trending capabilities.

Multiple seal system:

- Barrier fluid pressure – low pressure alarm; based off highest seal chamber in the circuit (dominant pressure driver). Consider also the seal furthest away from the system to account for pressure losses in the piping.
- Barrier fluid level – low / high level at the system.
- Filter ΔP Alarm / Monitoring – same as single seal system.
- Consider temperature monitoring. - high temperature alarm to facilitate troubleshooting by the site operations, maintenance, or reliability group. This is especially critical on lubricators supplying multiple pieces of equipment to prevent cascading failures.
- Consider trending barrier fluid flow – total flow output; increase in flow trend would suggest one user in the circuit is using more barrier fluid. In a multiple seal system, the end user needs to accept some usage of barrier fluid; it's dramatic spikes in usage that are the primary concern.
- Local monitoring at each seal in the circuit – barrier fluid flow in and out of each seal.
- Capability to isolate each seal in the circuit with local pressure gauge; block in the seal and monitor gauge for a loss of pressure.
- Monitor pressure around the circuit – provide indication of seal failure or loss of pressure due to a leaking fitting, busted pipe, closed valve, etc.

Troubleshooting / Maintenance:

Items to consider:

- Proper springs are installed for pressure range in control valve.
- Proper springs are installed for the pump protection valve.
- System pump suction strainer – should be replaced once a year. Pump performance issues will result from plugged strainer, which will yield insufficient barrier fluid supply quality.
- Filter elements – see filtration section; ΔP measurement is essential along with filter replacement regularly so that barrier pressure is not compromised.
- Use temperature indicator mounted strategically to determine heat exchanger effectiveness and downstream filter performance. A plugged filter will reduce flow which will yield an increase in temperature at the TI.
- Local Pressure Indicator with sensing point at each seal – use to determine barrier pressure at the seal if the system is mounted a distance away. Used in multiple seal systems with isolation valves on the inlet and outlet lines so that the seal can be isolated, and integrity checked (drop in pressure indicates a failed seal).

Process Supplied Barrier Systems

Stand-alone lubrication systems are most associated with Plan 54 designations, but many facilities support both individual and large populations of mechanical seals with externally pressurized barrier fluid through other means. In these instances, the barrier fluid is pressurized by dedicated process pumps with distribution to multiple pumps and seals within an operating unit. A more common example is a support system arrangement utilizing a combination of an API Plan 32 injection consisting of Isobutane with a pressurized barrier fluid of alkylate in the API Plan 54 loop for HF Alkylation Process pumps. The Isobutane injection is supplied to the cavity between the inner seal faces and the process fluid to keep HF acid material away from the seal components. The alkylate barrier fluid was taken from the Iso-stripper tower at a pressure of 150 PSIG (10 BARG), which was suction pressure for two dedicated flush pumps. The pumps increased the alkylate pressure to 350 PSIG (24 BARG) where it was then filtered and supplied to a distribution header that fed multiple pumps in the unit, with the outlet from each mechanical seal routed to a return header back to the suction source of the flush pumps. Figure 13 is an example of the localized barrier fluid piping at each seal in this configuration, which is a common for design certain legacy HF Alkylation unit licensors, especially in high acid containing pumps.

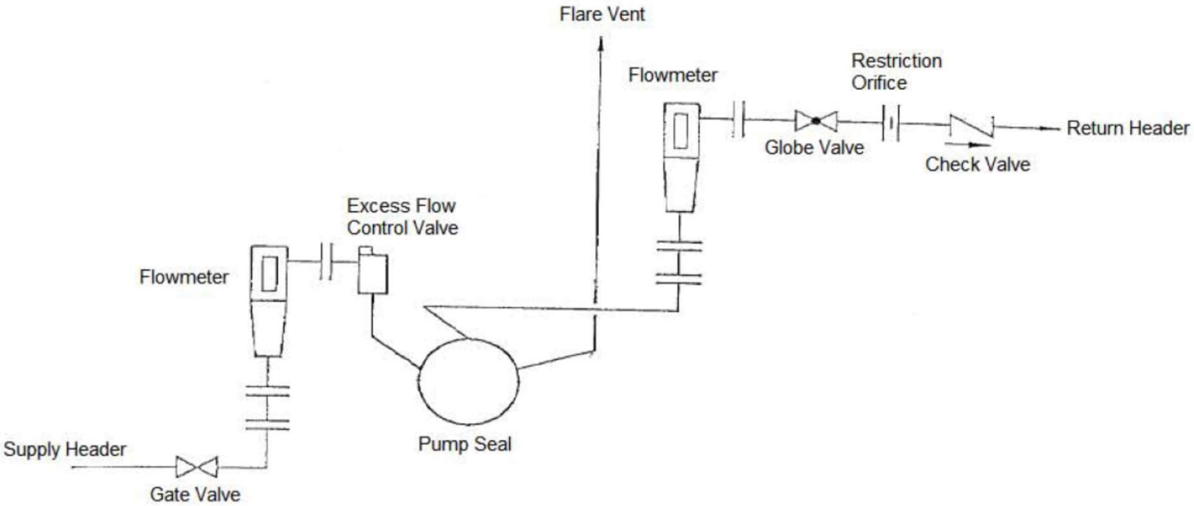

Figure 13: API Plan 54 Process Piping Example

Flow rate is controlled with the globe valve downstream of each seal, with the local flow meters register flush flow in and out of each seal; a significant difference in flow rates would be a first sign indicator of potential inner seal leakage. The excess flow valve was designed with the intent to close off Alkylate barrier fluid flow in the case of a catastrophic seal failure while the inclusion of the restriction orifice was designed to limit excess flow of alkylate and maintain back pressure on the seal. In the instance of a unit-wide barrier fluid system such as this, the user must accept barrier fluid leakage into the process stream and focus on monitoring flow rates on a macro-scale initially, then isolate troubleshooting to localized areas to determine which seals may be leaking more than predicted or acceptable. In such an arrangement, it is also useful to monitor header pressure in several locations around the piping loop to make sure system integrity is maintained and no loss of containment goes un-noticed.

A similar configuration has been utilized successfully by a major oil refinery on the Gulf Coast, US in their Delayed Coking Unit. As in the previous example, the Plan 54 system in this case utilized a light gas oil barrier fluid, pumped around the Coker through a dedicated header, delivered to multiple dual mechanical seals, and returned to the source tank. Dedicated flush pumps provided the necessary motive force to the gas oil and flow rate was controlled at each seal through control panel, one allocated at each pump. An example of a recommended barrier fluid monitoring and control panel is shown in Figure 14 below.

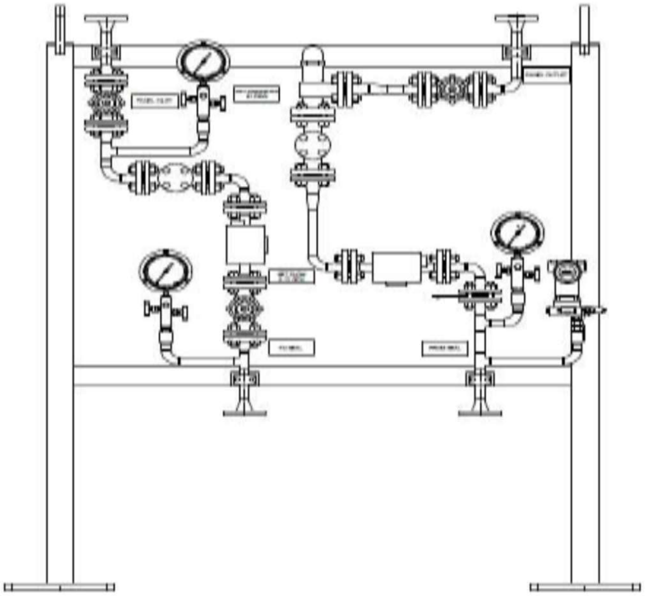

Figure 14: Process Plan 54 Control Panel Example

A suggested check list when considering a piping arrangement such as this one would be as follows:

- Monitor total barrier flow rate from supply pump discharge – trend to DCS for increases in flow (flow meter and transmitter).
- Pressure indication, both local gauges and transmitters, should be included on both the inlet lines to the mechanical seal and return lines from the mechanical seal. These are useful for both flow trending and alarm purposes.
- Utilize local vortex meters and flow transmitters at each mechanical seal – trend inlet and outlet flow to DCS; 2 GPM decrease across the seal as an indicator of a first sign of trouble. Vortex meters are advantageous against fouling or plugging.
- Monitor barrier fluid header pressure at several points – provide indication of loss of pressure, i.e. busted pipe, leaking seal, etc.
- Consider low pressure alarm on the barrier fluid header – low alarm set point would be dictated by the downstream pump and subsequent seal arrangement with the highest-pressure requirement.
- As the barrier fluid is usually finished product supplied from the process unit, considerations into alternative 'back-up' fluids should be given. These alternative fluids would be utilized coming out of unit startup (such as a turn-around), until the finished product is available to supply to the mechanical seals.

Cost Considerations

Key considerations in any mechanical seal and support system installation focus on safety, reliability, and operating costs. When an individual initially hears "Plan 54" the instant reaction may be to envision a large control skid with instrumentation upon instrumentation, and the associated upfront costs coupled with those redundant systems. While external lubrication system cost can be significant if unchecked, it is important to understand the total cost of ownership in relation to the systems that will be replaced. One common application where Plan 54 is often applied is in hot atmospheric or vacuum tower bottoms service in a refinery.

API Plan 32 is commonly used in services containing solids or contaminants where the process stream is difficult to condition in a way that will provide adequate cooling and lubrication to the mechanical seal. API Plan 32 is also used when a process stream includes components which may either result in abrasive wear or will impede free movement of critical seal components. When using API Plan 32, the flush stream is brought in from an external source, and the inherent requirements of the plan require that this source is clean and in the most basic sense would be a better lubricant for the mechanical seal as opposed to the existing process fluid. Proper design of a Plan 32 flush system involves application of hardware and logic that will provide the seal with an environment conducive to long term service, while not compromising the operation and profitability of the process stream.

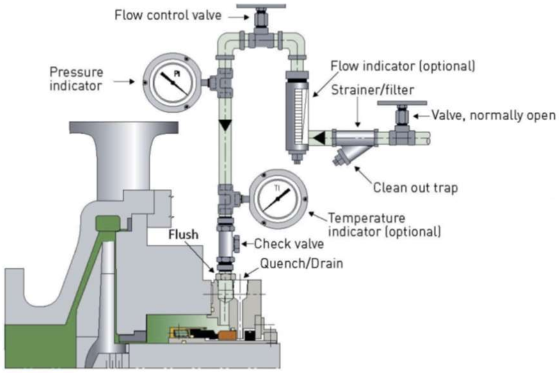

Figure 15: API Plan 32 diagram

The flush rate is critical to any seal but takes on another dimension when API Plan 32 is involved. When an outside flush source is used, concerns regarding product dilution, and/or economics almost always will surface. Product degradation or dilution will occur when utilizing this piping plan, and depending on the overall system design, introduction of an external fluid to the process stream can result in increased energy and reprocessing costs. To illustrate this point, consider a real-life application example where a Plan 32 was utilized, and processing costs evaluated:

- Service: Vacuum Tower Bottoms, 700 °F processing temperature
- Pump Type: Two stage, between bearings API 610 pump
- Mechanical Seals: Single High Temperature Metal Bellows Cartridge Seals
- API Plan 32 Fluid: Heavy Vacuum Gas Oil (HVGO) @ 350 °F
- Seal Cooling Flow Requirements: 3.5 GPM per seal, 7.0 GPM per pump (two seals)

Operability and marginal seal life prompted plant reliability engineers to evaluate the Plan 32 flush system, determine its cost effectiveness, and propose potential economical solutions if deficiencies were identified. Consultation with the plant process engineering group yielded a processing cost associated with downgrading the finished HVGO flush fluid into a lower-cost product stream, which was the Vacuum Tower Bottoms. The cost of utilizing the HVGO netted a $12.12 loss per Barrel per Day (BPD). While this initially does not sound drastic, calculating the cost over time yielded some staggering values:

- Cost of $ / barrel: $12.12
- Flow / Usage per pump: 7.0 GPM (equates to 240 BPD)
- Cost of Flush usage per day: $3,000
- Cost of Flush usage per year: $1.1 million

This was one isolated pump – consider that entire process units may utilize a similar flush system and the costs associated can be quite considerable. In the above example, the savings associated with minimizing the flush fluid usage were utilized to justify implementation of a dual pressurized mechanical seal and Plan 54 lubrication system, which yielded not only reliability improvements but provided an additional measure of safety associated with going to a dual pressurized seal design. The costs referenced above were real values provided by the specific plant, but Plan 32 usage costs may be higher depending on the process chemistry, size and type of equipment, and what types of controls are being utilized for the existing Plan 32 support system.

Often, a complete stand-alone lubrication system may not be suitable or feasible for one reason or another. That does not mean cost savings and reliability gains cannot be realized in other ways. Many times, the existing Plan 32 flush fluid for the single mechanical seal can be converted to a suitable barrier fluid and utilized as a once-through Plan 54 support system as described previously. When this solution is pursued, the cost savings and reliability improvements are still favorable over many alternative piping plan configurations, primarily as the seal consumption into the process stream becomes considerably less as the flow across two contacting seal faces is significantly less than the flow across a clearance bushing on a shaft or sleeve. The Hydraulic Institute in cooperation with the Fluid Sealing Association provides excellent comparison examples of various sealing system energy costs in *Mechanical Seals for Pumps: Application Guidelines*. These examples cover capital cost, maintenance cost, energy cost, and total cost of ownership using logic that can be applied using individual plant costs for more specific estimates. (4)

Suggested System Considerations for Mechanical Seal Reliability

When considering application of a Plan 54 support system it can be very easy to overthink the design and lose sight of potential functionality and impacts to the overall reliability of the installation. Bearing that in mind, summarization of some key points may be useful to the reader as a potential quick reference when considering these types of seal support systems in the future.

Essential items for skid design:

- Duplex filters – as described duplex filtration is preferred as it adds a second filter in parallel to the filter in use. The second filter is a standby filter and by its inclusion it allows online filter replacement as one filter can be serviced while the other is online.
- Supply and Return pressure gauges – ideal for reference of supply and back-pressure to the mechanical seal in the loop.
- Flow meters on the inlet and outlet of the seal – useful measure of seal consumption. These can be local meters or more elaborate flow transmitters.
- Minimum number of valves in the system as they can cause misdirected or no flow to the seal.
- Individual returns for every pump, on large multi-pump skids, so individual return pressures can be adjusted as needed.
- System pump protection valve should be independent from the supply and back pressure valves.
- Minimum system instrumentation should include a supply pressure transmitter and level transmitter.
- It is advantageous to use one smaller external lubrication skid per process pump so potential collateral damage is minimized (one system taking down an entire process unit).
- Use inline orifices to control the flow to each seal, as a single leaking seal on a between bearing pump can bias flow of all the barrier fluid from the lubrication system which will then lead to multiple seal failures.

Modifying old pumps:

- Consider installing back pullout retrofit kits for overhung pumps older than API 8th edition, this modification provides API 682 seal chambers and a solid plate cover while also improving bearings. Many 7th edition pumps and retrofit kits can accept modern dual seals, they however do not have current API 682 seal chambers and may have smaller bearings. As most of these pumps do have solid plate covers the seal chambers can usually be bored out if required. Keep in mind that modification costs will likely be realized through system and energy savings in short order.
- On old between bearing pump designs consider new solid plate covers. It may also be a good time to upgrade the style of bearings or address historic weak points in the design like oversized thrust bearings.
- On between bearing pumps it may also be beneficial to go from a single cover volute case to a dual cover volute case. This will eliminate un-used features like cast in water jackets and possibly restricting the ability to re-bore seal chambers to accept new dual seals.
- On between bearing pumps consider adding balance lines between the seal chambers to minimize the seal chamber pressures that the seals and skid are sealing against.

Seal design specific highlights:

- Stationary metal bellows and rotating seat pusher seals, both OD pressurized, are typically advantageous due to the enhanced cooling flow paths for the barrier fluid that can be built into the seal cartridge.
- Inner process seals must be reverse pressure capable to ensure that seal reliability is not compromised due to process upsets (process greater than barrier pressure).
- On hot process pumps, allowances for thermal growth must be considered and in extreme cases this may require different seals for each end of a between bearing pump
- Expeller devices installed/machined onto sleeves of highly viscous seal applications or applications with high number of solids have proven to be advantageous in preventing fluid from setting up in the seal chamber.
- In Plan 54 systems supplied by a process stream, an API 682 plan 62 steam quench may be required on the outer seal in the cartridge if the barrier fluid has the potential to coke (such as gas oil).

SUMMARY

As previously noted, there are many variables to address when a pressurized external lubrication system is to be considered for an application. Through careful consideration and adherence to the recommended practices addressed in this document, a reliable support system can be provided for some challenging dual pressurized seal installations.

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LIST OF FIGURES

Figures 1 -9; 11 – 15 courtesy of John Crane
Figure 10 courtesy of Fulflo Valve Company

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