



46TH TURBOMACHINERY & 33RD PUMP SYMPOSIA
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FIELD TROUBLESHOOTING COMMON MECHANICAL SEAL PIPING PLANS

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ABSTRACT

Piping plans are standardized strategies which enhance the capabilities and performance of mechanical seals. They provide a wide variety of functions including heat transfer from the seal chamber, cleaning the seal environment, capturing and disposal of seal leakage, and providing external fluids. The initial selection and operation of these plans are a critical aspect in the reliability of centrifugal pump sealing system. It however can be difficult to determine if a piping plan is functioning properly in the field. There is often limited instrumentation and many of the parameters which can be monitored are influenced by process conditions, available utilities, and ambient temperatures.

This tutorial will explain the process on how to effectively approach monitoring mechanical seal piping plans in the field. This will cover proven strategies for how to monitor specific plans. The tutorial will discuss strategies for collecting data using available instrumentation as well as hand-held data collection options. The paper will also discuss considerations on interpreting the data to evaluate the condition of the mechanical seal and piping plan.

INTRODUCTION

Mechanical seals continue to be the most commonly used method for shaft sealing in centrifugal and rotary pumps. The wide scope of available designs and arrangements make it possible to provide reliable solutions for virtually any pumping application. While a mechanical seal can be designed for a wide range of applications, it is still constrained by physics and engineering principles. Seals operate on a thin fluid film and are subjected to many of the same requirements as other tribological interfaces. Exposure to harsh environments can impact the seal components and stability of the fluid film. Heat generated by the seal components in operation must be managed to control temperatures in the sealing environment. The amount, nature, collection, and disposal of the fluid passing



through the film must be considered. These challenges have been addressed with proven solutions that are operating in countless applications the field. These solutions though extend beyond the mechanical seals themselves.

Over many years, seal manufactures and end users have developed methods for modifying the local environment around the mechanical seals. They have introduced methods of improving the fluid properties of the process fluid as well as providing external fluids to enhance the sealing environment. Strategies have been developed to control, capture, monitor, and dispose of seal leakage. In addition, redundancies can be designed in to improve safety and emissions performance. The majority of the strategies and solutions have been captured in the form of mechanical seal “piping plans”. These piping plans define the functions, design, and operation of these solutions and allow end users to effectively apply them to the new sealing challenges.

A piping plan, as any other system in the plant, must be operating correctly to achieve the desired results. This includes the initial design of the system. It also includes the proper condition and functioning of all of the components and elements in the system. Finally, it includes the availability and condition of external utilities supporting these systems. An operator must be able to ensure that a mechanical seal piping is operating correctly in the field. This, however, can be a challenge.

Piping plans are designed and operated with a focus on improving the seal performance. This is obvious since this is the purpose of providing the piping plan in the first place.

Piping plans though provide only a limited ability to monitor of the function of the piping plan itself. There are assumptions that the intended flows, pressures, and temperatures are actually present in these systems. There are limited abilities to directly monitor the condition or degradation of the performance of individual components in system. Often times, poor performance of a piping plan will lead to poor performance of the mechanical seal.

Operators need to have the ability to troubleshoot piping plans in operation in the field. This is challenging since often times the operator is faced with only visually looking at the outside of an arrangement of piping or tubing. The instrumentation on most piping is limited and directed at monitoring aspects of the seal performance. Even within these limitations, the operator can take the data that is available and develop an understanding of the performance of the piping plan. This can lead to determining causes for poor performance of the piping plan and provide insights into corrective actions to improve performance.

PIPING PLAN FUNDAMENTALS

Seal manufacturers and end users alike recognize that a mechanical seal does not operate as a single component. While its performance is obviously dependent on the design of the seal itself, the ultimate seal performance is influenced by the design and operation of the pump. It is also heavily influenced by the environment around the seal in the seal chamber of the pump. Pump OEMs will consider some aspects of the seal chamber environment in the pump design but this is normally limited to controlling the pressure. Proper seal operation requires that other aspects on the seal’s environment be addressed.

Over many decades of use, seal manufacturers and end users developed strategies for improving this environment and adding other functions to the mechanical seals. Originally these strategies were referred to as “flush plans” since they frequently focused on providing and modifying the fluid that was flushed into the seal chamber. In more modern references, the term “piping plans” is used since these plans have expanded to include strategies for addressing other areas of the seal operation. The term “sealing system” is also used which captures the piping plans and any supporting systems.

The process of defining piping plans is actively continuing even today. These plans are often defined as a result of new seal technologies being introduced into industries (e.g. gas seals). Other times they are developed to address the demands of new markets or environmental regulations. Finally, piping plans are defined to capture knowledge of systems that are being used successfully in the field.



Figure 1 Piping Plan 23 in the field



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Piping plans are defined in a number of standards but the most commonly referenced source is API 682. *API 682, Pumps – Shaft Sealing for Centrifugal and Rotary Pumps*, is a broad standard that covers aspects of the design, materials, applications, and documentation for mechanical seals and sealing systems. Annex G of the standard contains the basic definitions for these piping plans although specific requirements for the design and components can be found throughout the standard.

Piping plans can be divided into a number of specific functions that they provide. These include removing heat, cleaning the flushed fluid, cooling the flushed fluid, providing alternative fluids for sealing, capturing leakage, and modifying the atmospheric side of the seal. The numbering system for these piping plans is organized to help the user understand the function for the plan. Table 1 in Appendix A provides a quick overview of the purpose and functions of the various piping plans.

It is important to understand the functions of the piping plan when initially selecting the piping plan for an application. The piping plan must help create the environment necessary for reliable seal operation. It is required to provide the functions necessary to meet the end user's expectations and meet any regulatory requirements. This may impact areas such as permitting, LDAR (Leak Detection And Repair) processes, or maintenance activities.

It is also important to understand the function of the piping plans because any troubleshooting activities will focus will be on confirming that the plan is actually performing these functions.

APPROACHING A PIPING PLAN IN THE FIELD

Approaching an operating pump and mechanical seal in the field is both enlightening and confusing. It is enlightening because the general layout the piping plan, the tubing or piping, the instrumentation, utility lines, and valve positions can all easily be observed. There is an assumption that the piping plan was correctly installed with proper elevations and locations for all of the system components. There is an assumption that the instrumentation is correctly sized and is reading accurately. There is an assumption that the observer can review the instrumentation and detect any deviations from acceptable values. If so, the observer can easily walk by and observe the system and conclude that that everything is “working well”.



Figure 2 Examining a pump and seal in the field

At the same time, the observer has a very limited view of the actual functions of the system. Most piping plans only offer an external view of piping, tubing, the seal, and any auxiliary equipment. In most cases, the system is a collection of stainless steel components with a very limited amount of instrumentation. Is there flow actually flowing through the lines? Is the flow rate correct? Are the lines filled with debris? Is the orifice or flow control device plugged? Are the temperatures at various points in the system at the expected values? None of these questions can be answered by a casual external view of the seal and sealing system.

Many piping plans have no instrumentation for monitoring the performance of the plan. This includes the most commonly used piping plans such as a Plan 11 and Plan 13. The decision to have no instrumentation is based on literally thousands of applications that operate successfully in the field without instrumentation. In more complex plans, the standardized piping plans provide only the minimal amount of instrumentation required to monitor the system. Again, this has proven to be suitable for observing the condition of a normally operating system. In most cases however, a system with a failed component, degradation in performance, and questionable availability and condition of external utilities will not be easily monitored with the standard instrumentation. The default instrumentation is intended to provide an overview of the system performance and may not be sensitive to specific problems.



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GATHERING DATA

The challenge in troubleshooting a specific piping plan is twofold. First, there must be adequate data to describe the conditions in the system. Second, there must be a structured approach to interpreting this data to determine if a problem exists and identify potential corrective actions.

DCS and end user sources

Gathering data is often the most challenging aspect of troubleshooting piping plans. Most modern plants have extensive data collection systems which are necessary for operating the plant. The data that is monitored and recorded through these systems is directed primarily at ensuring that the plant processes are in control and producing the quantity and quality of products for production. Equipment in the plant is also monitored but often the degree of monitoring is associated with the criticality of the equipment to the process. Expensive, unspared equipment will be monitored more closely than less critical or spared equipment. Mechanical seals are often not viewed as a high priority in most plants.

Instrumentation on the piping plans

Historically, most seal piping plans were provided with local indicators and switches. There is still a large installed base using this method and it is still an option for new equipment. The local indicators provide the end user with the ability to walk up to the sealing system and quickly determine the measured parameter. Pressure gauges, temperature indicators, flow meters, and other instruments are located in a convenient location and at an appropriate height so that an operator can read them. Data collection is manual and can be recorded on paper or into an electronic data collection system. Many of the measured parameters are also monitored by switches. These will indicate that the parameter reached a high or low level depending upon the piping plan. For example, a Plan 53A reservoir would be provided with both a high level and low level switch for monitoring the barrier fluid level.

One of the most significant limitations for using local indicators and switches is the ability to continuously know what is happening in the system. Parameters which are not considered critical may not be manually monitored on a frequent basis. These may be operating abnormally for a long period of time and will only trip the alarm when an alarm limit is reached. When an alarm is tripped, the operator has no way of knowing whether the limit was reached as a gradual degradation or as a rapid, instantaneous deviation.

More modern piping plans utilize a transmitter with a local indicator for most measured parameters. These are often seen as a transmitter with a small digital readout that displays the data that is being transmitted to the plant DCS system. There are other designs of transmitters which resemble more conventional gauges (e.g. analog readout) but still transmit digital data to the DCS system. The local indicators provide the same benefits as standard instruments by giving the operator the ability to monitor the equipment locally. It adds the benefit of also providing data into the plant's data collection system.

Using a transmitter provides the end user with a far richer set of data for the operation and troubleshooting on piping plans. The end user can monitor not only for a specific alarm level but also a rate of change in the data. The user can also set multiple alarm levels for a single parameter. This may initiate different responses ranging from scheduling a maintenance activity to shutting down the equipment. A transmitter also provides a continuous set of data during the operation of the system. This is collected in the DCS system and can provide insights into the level and stability of the measured parameter during operation. This is useful for correlating changes in the parameter in relation to other measured parameters or to the operation of the plant.

Manually collected data

There are a few additional opportunities to collect data from a system in operation. If a system is in operation, the only easy areas to monitor are the exterior surfaces of the seal gland, piping and tubing, and auxiliary equipment. Fortunately, this gives the user the ability to measure temperatures throughout the system. Knowing the temperatures in different areas of the pump, piping plan, and utilities (e.g. cooling water) can provide useful insights into the operation and condition of the system.



Figure 3 Transmitter with local indicator



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One of the most common ways to measure the skin temperatures of a surface is with an (IR) infrared thermometer (often referred to as a temperature gun). IR thermometers provide some unique benefits. They operate in a non-contacting mode so that the user does not need to touch the equipment. This allows the measurement of moving, dirty, or extreme temperature surfaces. IR thermometers, while technical sound, are often misused in practice and can provide inaccurate data. The area of the measured surfaces is a function of the distance from the thermometer to the surface. It makes it easy to include a larger area (including background temperatures) into the reading. The emissivity of the surface will also impact the temperature reading. A flat or matte black surface will give a more accurate reading than a shiny reflective surface. If possible, confirm temperature readings with a contact thermometer.

SPECIFIC PIPING PLANS

Each piping plan has a different set of functions and different instrumentation. This requires that each piping plan be approached in a different manner. Fortunately, much of the same type of data is required for each plan.

In the sections below, a select number of the most popular piping plans are introduced. Each section will include a basic description of the plan, typical issues seen in the field, requirements for data collection, and monitoring points in the system. These monitoring points are either commonly available instrumentation or can be obtained manually by the operator. In addition, a group of RCA (root cause analysis) charts are included in the appendices describing a structured approach to each of the covered plans.

When troubleshooting a specific “bad actor” pump, it may be necessary to add additional monitoring points. These may include pressures (e.g. seal chamber pressure), flow rates (e.g. cooling water, barrier fluid, etc.), vibrations and/or shaft movement. More data will allow for a more complete analysis of the applications. In these situations, the seal OEM and end user will develop a specific data collection plan based on the pump design, operating conditions, failure modes of the equipment, seal design, and piping plans.

PIPING PLAN 02

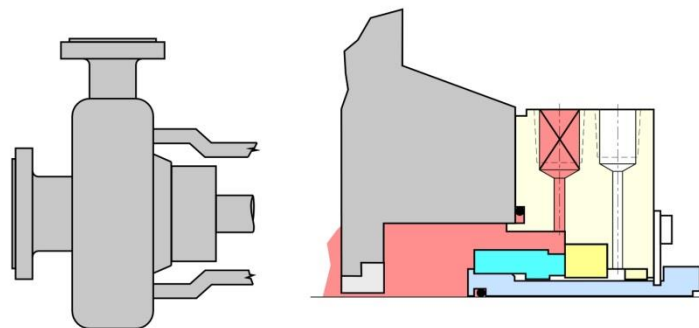


Figure 4 Piping Plan 02

Definition

Plan 02 is a mechanical seal installed in a seal chamber with no forced circulation or exchange of fluid between the seal chamber and the process fluid in the pump (dead-ended seal chamber). This plan is most commonly used in applications with very low seal generated heat or in high temperature applications.

Functions

None - While the fluid in the seal chamber certainly provides the lubrication for the seal and removes seal generated heat by convection, the piping plan itself does not specifically provide these benefits.



Common field issues

Since the piping plan is simply defined as “dead-ended seal chamber”, there is virtually nothing to go wrong with the plan itself. There are however still concerns with the environment around the seal.

Excessive temperature – There is no forced exchange of fluid between the seal chamber and the process fluid. If the seal generated heat is high, this can result in high seal chamber temperatures, poor fluid properties at the seal, and coking on the atmospheric side of the seal.

Venting – There is no direct path for captured vapors or bubbles in the seal chamber to escape. This is especially true for pump in a vertical orientation.

Debris – There is a small continuous leakage past the mechanical seal which can carry debris from the process fluid into the seal chamber. In dirty services, this may result in an accumulation of solids in the seal chamber.

Monitoring points

Temperature - at pump casing, at seal chamber, on seal gland

What to look for

Look for excessive temperature differences between the pump casing, the seal chamber, and the seal gland. A high temperature differential may require that a different piping plan should be used (e.g. Plan 03 or Plan 11) to better control the temperature rise in the seal chamber.

See Appendix B for more details on troubleshooting this piping plan.

PIPING PLAN 11

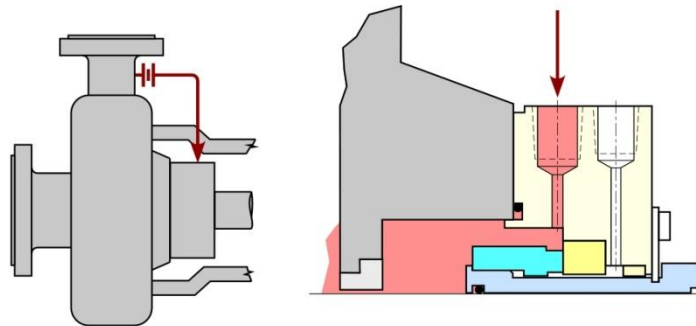


Figure 5 Piping Plan 11

Definition

A Plan 11 is a circulation of fluid from a high pressure region of the pump, through external piping or tubing, through a flow control device (e.g. orifice), into the seal gland and seal chamber, and back into the pump. This is the most commonly used piping plan in industrial pumps.

Functions

Cooling – The circulation of process fluid through the seal chamber effectively removes the seal face generated heat as well as heat created by turbulence in the seal chamber.

Common field issues

Plugged orifice – An orifice is a restriction in the Plan 11 piping which regulates the flow to the desired flow rate. The orifice can



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become plugged if there are particles in the process stream which are larger than the hole in the orifice. The orifice may also plug or become obstructed if there are a high percentage of solids or other debris in the process fluid.

Plugged lines (solidification, freezing) – Many pumps are operated at elevated temperatures to prevent the process fluid from becoming too viscous or solidifying. If the temperature in the Plan 11 piping becomes too low, the process may solidify or freeze and prevent circulation through the piping.

Inadequate or excessive flow – The Plan 11 flow rate is controlled by the differential pressure and the orifice size. If the orifice is improperly sized, it may result in excessive or insufficient flow rates. In multi-stage pumps, the Plan 11 for both ends of the pump may come from a common location. This requires that the piping design and orifice locations ensure equal flow to each seal.

Improper pressure differential – A Plan 11 requires a pressure differential between a high pressure region of the pump and the seal chamber. In most single stage pumps, the high pressure region will be the pump discharge. In multi-stage pump, the pressure in the discharge may be excessive and create problems with excessive flow or require complex flow control devices. This may require piping the Plan 11 from the pump crossover or an intermediate stage.

Monitoring points

Temperature – on piping near the pump casing and near the seal

Noise – at the orifice

What to look for

Since fluid should be continuously flowing through the Plan 11 piping, the temperature along the length of piping should be relatively constant. A significant difference in temperature along the pipe indicates that there is no (or very low) flow.

Excessive noise occurring at or slightly downstream of the orifice may indicate an excessive flow velocity is causing cavitation at the orifice.

See Appendix C for more details on troubleshooting this piping plan.

PIPING PLAN 13

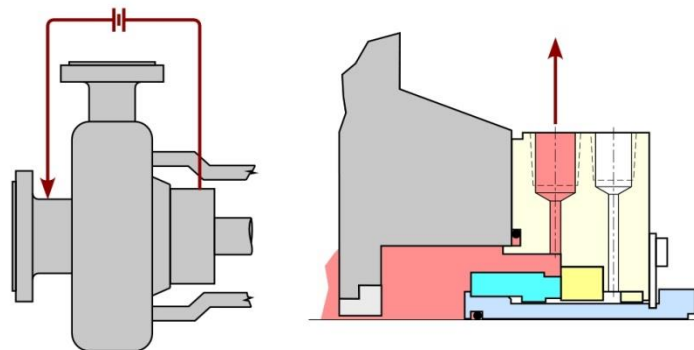


Figure 6 Piping Plan 13

Definition

A Plan 13 is a circulation of fluid from the seal chamber, through external piping or tubing, through a flow control device (e.g. orifice), and into a low pressure region of the pump. This is commonly used vertical turbine style pumps.



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Functions

Cooling – The circulation of process fluid through the seal chamber effectively removes the seal face generated heat as well as heat created by turbulence in the seal chamber.

Common field issues

Plugged orifice – An orifice is a restriction in the Plan 13 piping which regulates the flow to the desired flow rate. The orifice can become plugged if there are particles in the process stream which are larger than the hole in the orifice. The orifice may also plug or become obstructed if there are a high percentage of solids or other debris in the process fluid.

Plugged lines (solidification, freezing) – Many pumps are operated at elevated temperatures to prevent the process fluid from becoming too viscous or solidifying. If the temperature in the Plan 13 piping becomes too low, the process may solidify or freeze.

Inadequate or excessive flow – The Plan 13 flow rate is controlled by the differential pressure and the orifice size. If the orifice is improperly sized, it may result in excessive or insufficient flow rates.

Improper pressure differential – In a vertical turbine style pump, the Plan 13 flows from the high pressure seal chamber back to the pump suction or the sump. Since the seal chamber is at discharge pressure, there may be a very large pressure differential which can create problems with excessive flow or require complex flow control devices. While Plan 13's are most often used in vertical multistage pumps, they are also sometimes used in single stage pumps. In these cases, the pressure in the seal chamber may be very close to the suction pressure in the pump resulting in low flow rates.

Monitoring points

Temperature – on piping near the seal and downstream of the orifice

Noise – at the orifice

What to look for

Since fluid should be continuously flowing through the Plan 13 piping, the temperature along the length of piping should be relatively constant. A significant difference in temperature along the pipe indicates that there is no (or very low) flow.

Excessive noise occurring at or slightly downstream of the orifice may indicate an excessive flow velocity is causing cavitation at the orifice.

See Appendix D for more details on troubleshooting this piping plan.

PIPING PLAN 21

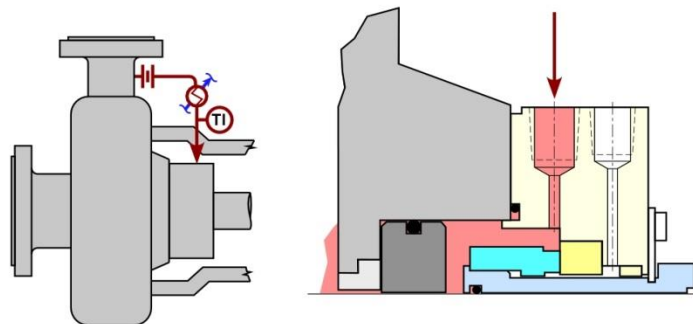


Figure 7 Piping Plan 21



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Definition

A Plan 21 is a circulation of fluid from a high pressure region of the pump, through external piping or tubing, through a flow control device (e.g. orifice), through a seal cooler, into the seal gland and seal chamber, and back into the pump.

Functions

Cooling – The circulation of process fluid through the seal cooler decreases the temperature of the process fluid before injecting it into the seal chamber. This effectively lowers the operating temperature inside the seal chamber and improves the environment for the seal. The flow through the seal chamber also effectively removes the seal face generated heat, heat created by turbulence in the seal chamber, and heat soak into the seal chamber.

Common field issues

Plugged orifice – An orifice is a restriction in the Plan 21 piping which regulates the flow to the desired flow rate. The orifice can become plugged if there are particles in the process stream which are larger than the hole in the orifice. The orifice may also plug or become obstructed if there are a high percentage of solids or other debris in the process fluid.

Plugged lines (solidification, freezing) – Many pumps are operated at elevated temperatures to prevent the process fluid from becoming too viscous or solidifying. If the temperature in the Plan 21 piping becomes too low, the process may solidify or freeze. This is especially a concern for the fluid in the seal cooler during standby conditions.

Inadequate or excessive flow – The Plan 21 flow rate is controlled by the differential pressure and the orifice size. If the orifice is improperly sized, it may result in excessive or insufficient flow rates.

Inadequate cooling water – Water cooled seal coolers require a continuous supply of cooling water at a reliable flow rate and cool temperature. In most plants, this is not monitored and there can be wide swings in flow and temperature based on other conditions in the plant. The cooling water supply can be accidentally shut off upstream of the seal cooler during operation.

Fouling of seal cooler – When cooling water is exposed to high temperatures in the tubing of the seal cooler, localized boiling can deposit solids or debris onto the surface of coils. This fouling results in a reduction of the heat transfer in the seal cooler and higher temperatures on the outlet of the cooler.

Lack of bushing in seal chamber – For a Plan 21 to be effective, the fluid in the seal chamber must be isolated from the higher temperature process fluid in the pump. This requires that an effective bushing be installed in the bottom of the seal chamber to prevent intermixing of the hot and cool fluids.

Monitoring points

Temperature – on the pump casing, on process fluid tubing inlet and outlet from seal cooler, on cooling water tubing inlet and outlet from seal cooler

What to look for

The most important function of this piping plan is to provide a cool environment in the seal chamber. Excessively high temperature readings on the outlet from the seal (and into the seal cooler) indicate that the system is not operating correctly. Properly determining the cause of this condition requires comparing the actual temperatures throughout the system for the process and cooling water against the predicted temperatures.

See Appendix E for more details on troubleshooting this piping plan.



PIPING PLAN 23

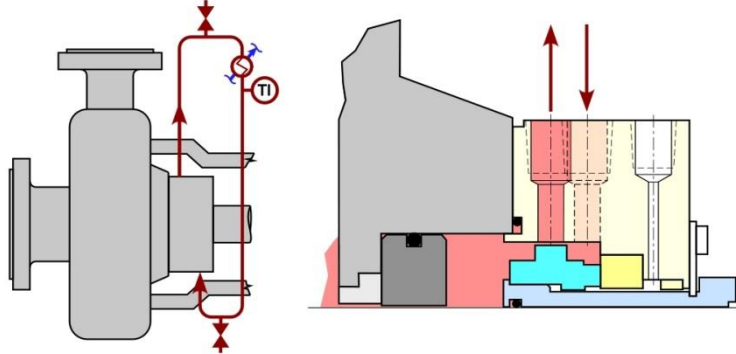


Figure 8 Piping Plan 23

Definition

A Plan 23 recirculates process fluid from the seal chamber, through external piping or tubing, through a seal cooler, and back into the seal chamber. The circulation of this fluid is provided a pumping feature on the rotating seal components.

Functions

Cooling – The circulation of process fluid through the seal cooler decreases the temperature of the process fluid in the seal chamber and throughout the piping plan. This improves the environment for the mechanical seal. Since the cooled fluid is circulated back to the seal cooler, this piping plan can provide more effective and efficient cooling than a Plan 21. The flow through the seal chamber also effectively removes the seal face generated heat, heat created by turbulence in the seal chamber, and heat soak into the seal chamber.

Common field issues

Inadequate flow – The Plan 23 circulation is provided by a pumping feature on the rotating seal components. The head generated by these pumping features is relatively low but adequate to provide circulation on a properly designed system. Inadequate flow may be caused by poor initial design, incorrect direction of rotation of the seal (CW vs CCW), excessive restrictions in the piping plan design, excessive viscosity of the cooled fluid, or low operating speeds.

Plugged lines (solidification, freezing) – Many pumps are operated at elevated temperatures to prevent the process fluid from becoming too viscous or solidifying. If the temperature in the Plan 23 piping becomes too low, the process may solidify or freeze. This is especially a concern for the fluid in the seal cooler during standby conditions.

Improper venting – If vapors are present in the piping or tubing, they will migrate to high points in the system and restrict flow. A Plan 23 requires that all air, vapor, bubbles, etc. be vented from the system during commissioning of the pump. Process fluid which produce vapors or emit gases may require periodic venting after the pump is in operation.

Inadequate cooling water – Water cooled seal coolers require a continuous supply of cooling water at a reliable flow rate and cool temperature. In most plants, this is not monitored and there can be wide swings in flow and temperature based on other conditions in the plant. The cooling water supply can be accidentally shut off upstream of the seal cooler during operation.

Lack of bushing in seal chamber – For a Plan 23 to be effective, the fluid in the seal chamber must be isolated from the higher temperature process fluid in the pump. This requires that an effective bushing be installed in the bottom of the seal chamber to prevent intermixing of the hot and cool fluids.

Incorrect installed height of seal cooler – The seal cooler is required to be installed at an elevation above the mechanical seal. This is necessary to properly vent the system and promote thermosyphoning on the fluid in the piping plan. Thermosyphoning is especially critical during standby operation. The reservoir must also be located suitably close to the seal to minimize the length of



piping or tubing in the system.

Monitoring points

Temperature – on the pump casing, on process fluid tubing inlet and outlet from seal cooler, on cooling water tubing inlet and outlet from seal cooler

What to look for

The most important function of this piping plan is to provide a cool environment in the seal chamber. Excessively high temperature readings on the outlet from the seal (and into the seal cooler) indicate that the system is not operating correctly. Properly determining the cause of this condition requires comparing the actual temperatures throughout the system for the process and cooling water against the predicted temperatures.

See Appendix F for more details on troubleshooting this piping plan.

PIPING PLAN 52

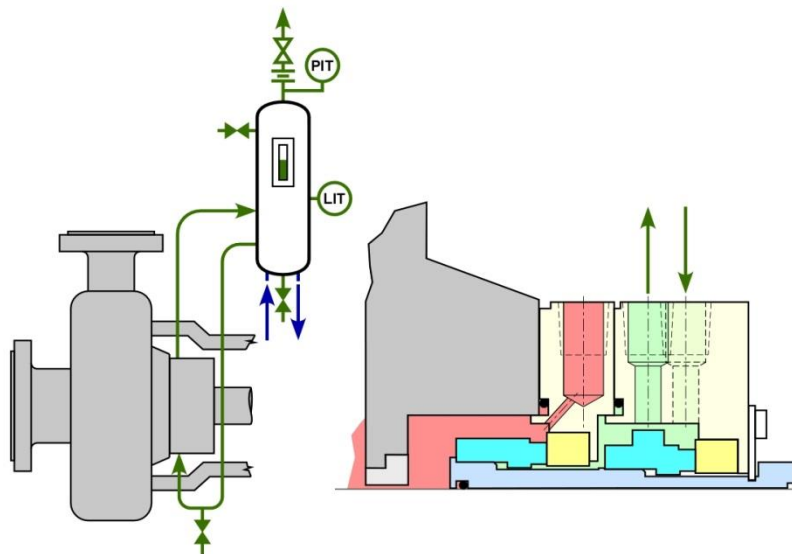


Figure 9 Piping Plan 52

Definition

A Plan 52 is used with Arrangement 2 (2CW-CW) seal. It provides a recirculation of an unpressurized external fluid (buffer fluid) from a buffer fluid cavity between the inner and outer seals, through external piping or tubing, through an unpressurized reservoir, and back to the buffer fluid cavity. Circulation is provided by a pumping feature on the rotating seal components. The pressure in the buffer fluid cavity must be less than the pressure in the seal chamber.

Functions

Provides an alternative fluid – The buffer fluid provides the environment for the outer seal. The buffer fluid provides both lubrication and cooling for the outer seal.

Capture leakage – The buffer fluid provides a means to capture leakage which migrates across the inner seal. This allows for options to dispose of the process leakage and minimizes emission to the atmosphere.

Monitor leakage – The Plan 52 system is designed to monitor both liquid or vapor phase leakage into the buffer fluid. The instrumentation can also monitor leakage past the outer seal.



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Cooling – The circulation of buffer fluid through the buffer fluid chamber effectively removes the seal face generated heat and heat created by turbulence in the buffer fluid cavity.

Common field issues

Poor buffer fluid selection – The buffer fluid used in a Plan 52 helps create the environment for the outer seal. This requires that the fluid have the proper qualities for reliable seal operation. The fluid must also tolerate contamination from the process fluid.

Poor buffer fluid maintenance – The buffer fluid will be exposed to a constant inflow of leakage past the inner seal. This can accumulate in the buffer fluid over time and change buffer fluid properties. It can also increase process emissions to atmosphere. For these reasons, the buffer must be periodically changed for reliable performance.

Inadequate buffer fluid flow – The Plan 52 circulation is provided by a pumping feature on the rotating seal components. The head generated by these pumping features is relatively low but adequate to provide circulation on a properly designed system. Inadequate flow may be caused by poor initial design, incorrect direction of rotation of the seal (CW vs CCW), excessive restrictions in the piping plan design, excessive viscosity of the buffer fluid, or low operating speeds.

Contamination from flare or disposal system – The Plan 52 reservoir is vented to a disposal system such as a flare or recovery system in the plant. Products in the disposal systems are prevented from backing up into the reservoir by a check valve in the vent line near the reservoir. Failure or sticking of this check valve can allow products from the disposal system to contaminate the buffer fluid.

Inadequate cooling water – Many reservoirs are provided with cooling coils to remove heat from the buffer fluid. This requires a continuous supply of cooling water at a reliable flow rate and cool temperature. In most plants, this is not monitored and there can be wide swings in flow and temperature based on other conditions in the plant. The cooling water supply can be accidentally shut off during operation.

Improper location of reservoir – The reservoir is required to be installed at an elevation above the mechanical seal. This is necessary to properly vent the system and promote thermosyphoning on the buffer fluid in the piping plan. The reservoir must also be located suitably close to the seal to minimize the length of piping or tubing in the system.

Monitoring points

Pressure – in the reservoir

Level – in the reservoir

Temperature – on the pump casing, on buffer fluid tubing inlet and outlet from reservoir, on cooling water tubing inlet and outlet from reservoir (if applicable)

What to look for

The normal monitoring points for a Plan 52 are the level and pressure in the reservoir. An increase in level in the reservoir commonly indicates an accumulation of liquid phase inner seal leakage into the buffer fluid. An increase in pressure in the reservoir indicates an excessive leakage of vapor phase process past the inner seal. A decrease in buffer fluid indicates leakage past the outer seal.

Temperatures also play an important role in Plan 52 systems especially in high temperature applications. Monitoring the temperatures throughout the system can identify problems with circulation or cooling. Properly determining the specific cause requires comparing the actual temperatures throughout the system for the process and cooling water against the predicted temperatures.

See Appendix G for more details on troubleshooting this piping plan.



PIPING PLAN 53A

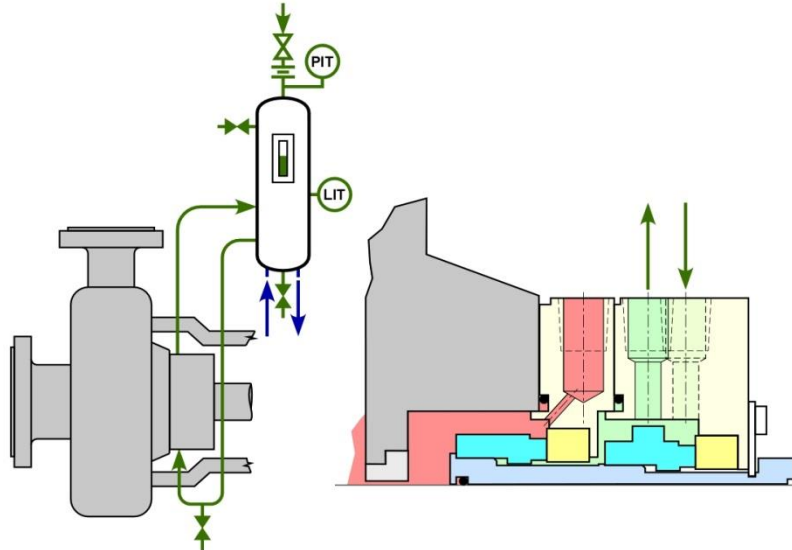


Figure 10 Piping Plan 53A

Definition

A Plan 53A is used with Arrangement 3 (3CW-XX) seal. It provides a recirculation of a pressurized external fluid (barrier fluid) from a barrier fluid cavity between the inner and outer seals, through external piping or tubing, through a pressurized reservoir, and back to the barrier fluid cavity. Circulation is provided by a pumping feature on the rotating seal components. The pressure in the barrier fluid cavity must be greater than the pressure in the seal chamber.

Functions

Provides an alternative fluid – The barrier fluid provides the environment for both the inner and outer seal. The barrier fluid provides both lubrication and cooling for both of the seals. This allows the seal to operate with a challenging process fluid (or even no fluid) in the pump.

Reduce process leakage to atmosphere – The pressurized barrier fluid prevents process fluid from entering the barrier fluid system. This, in theory, eliminates any process fluid from migrating to atmosphere.

Monitor leakage – The Plan 53A system is designed to monitor leakage from both seals by the level of the barrier fluid in the reservoir.

Cooling – The circulation of barrier fluid through the barrier fluid chamber effectively removes the seal face generated heat, heat created by turbulence in the barrier fluid cavity, and heat soak from the seal chamber.

Common field issues

Improper barrier fluid pressure – One of the biggest challenges with a Plan 53A is setting the barrier fluid pressure correctly. The barrier fluid pressure must be set high enough to ensure it is greater than the seal chamber pressure at all times (including commissioning, normal operation, upset, and shut down). This requirement is made more difficult since the seal chamber pressure may not be accurately known or may vary in operation. The pressure must also be not set too high to prevent an excessive pressure differential across the inner seal (e.g. seal pressure rating) and to prevent excessive gas absorption into the barrier fluid.

Loss of pressurization gas – Most Plan 53A systems are pressurized from a Nitrogen header in the plant. This provides the most reliable source of Nitrogen for most applications. There is still a potential that there may be a loss in pressure due to demands on the header or from an operator accidentally closing a valve on the supply line. Pressurization from a pressurized Nitrogen cylinder



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is not recommended for most applications.

Poor barrier fluid selection – The barrier fluid used in a Plan 53A helps create the environment for both the inner and outer seals. This requires that the fluid have the proper qualities for reliable seal operation.

Poor barrier fluid maintenance – The Plan 53A may operate on a fixed volume of barrier fluid for an extended time. Any degradation of the barrier fluid, especially in higher temperature applications, may impact the barrier fluid properties and affect seal reliability. For this reason, the barrier must be periodically changed for optimum performance.

Inadequate barrier fluid flow – The Plan 53A circulation is provided by a pumping feature on the rotating seal components. The head generated by these pumping features is relatively low but adequate to provide circulation on a properly designed system. Inadequate flow may be caused by poor initial design, incorrect direction of rotation of the seal (CW vs CCW), excessive restrictions in the piping plan design, excessive viscosity of the barrier fluid, or low operating speeds.

Inadequate cooling water – Many reservoirs are provided with cooling coils to remove heat from the barrier fluid. This requires a continuous supply of cooling water at a reliable flow rate and cool temperature. In most plants, this is not monitored and there can be wide swings in flow and temperature based on other conditions in the plant. The cooling water supply can be accidentally shut off during operation.

Improper location of reservoir – The reservoir is required to be installed at an elevation above the mechanical seal. This is necessary to properly vent the system and promote thermosiphoning on the barrier fluid in the piping plan. The reservoir must also be located suitably close to the seal to minimize the length of piping or tubing in the system.

Monitoring points

Pressure – in the reservoir and in the seal chamber (either measured directly or calculated)

Level – in the reservoir

Temperature – on the pump casing, on barrier fluid tubing inlet and outlet from reservoir, on cooling water tubing inlet and outlet from reservoir (if applicable)

What to look for

The normal monitoring points for a Plan 53A are the level and pressure in the reservoir. A decrease in level in the reservoir commonly indicates the total leakage from both the inner and outer seal. Since there is an expected leakage rate for the seals, there will be a normal decrease in the barrier fluid level which will require that the operator periodically add additional fluid. If the refill frequency increases or the level changes rapidly, it may indicate a seal failure. The level indication in the reservoir is for both the inner and out seal. The operator can also directly observe leakage past the outer seal at the seal gland or drain port.

A decrease in pressure in the reservoir indicates a loss of barrier fluid pressure from the Nitrogen supply. This may be due to a decrease in header pressure, closing a valve in the supply line, or a change in the pressure regulator setting. A rapid decrease in barrier fluid pressure along with a loss in barrier fluid level may indicate failure of either the inner or outer seal.

Temperatures also play an important role in Plan 53A systems especially in high temperature applications. Monitoring the temperatures throughout the system can identify problems with circulation or cooling. Properly determining the specific cause requires comparing the actual temperatures throughout the system for the process fluid and cooling water against the predicted temperatures.

See Appendix H for more details on troubleshooting this piping plan.



PIPING PLAN 72

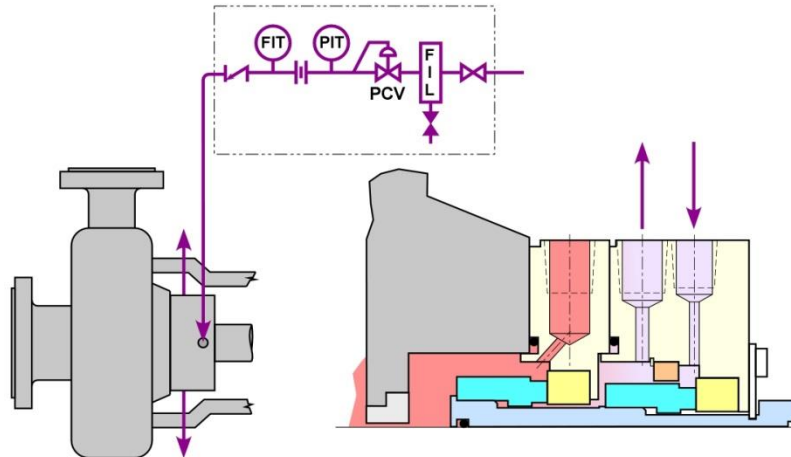


Figure 11 Piping Plan 72

Definition

A Plan 72 provides a continuous flow of buffer gas (normally Nitrogen) from an external source, through a control panel, and into the containment seal cavity of an Arrangement 2 (2CW-CS or 2NC-CS) seal. This flow is at a low pressure (less than 10 PSIG [0.7 bar]) and must be maintained at a pressure less than seal chamber pressure. Flow is generated by a differential pressure between the panel outlet and containment seal cavity. While the Plan 72 piping plan is part of a larger sealing system, the official definition focuses primarily on the design and functions of the control panel.

Functions

Providing an alternative fluid – The primary function of the Plan 72 is to maintain a clean environment in the containment seal cavity. This clean environment is created by introducing clean, dry buffer gas from an external source. This helps sweep away process leakage from the inner seal into a collection or disposal system. This also minimizes the process fluid from migrating across the outer seal into the atmosphere.

Flow control – In the standard Plan 72, flow regulation is controlled by an orifice and differential pressure. The differential pressure can be difficult to determine in advance since the downstream pressures may be unknown or variable. As an alternative, the orifice may be replaced with a needle valve which provides a more precise control of the flow rate.

Pressure regulation – The Plan 72 control panel is provided with pressure regulator to control the pressure of buffer gas supply to the containment seal cavity.

Cleaning – The buffer gas supply for a Plan 72 is cleaned through a coalescing filter on the control panel. This helps remove both solids contamination and condensation from the supply gas.

Common field issues

Improper buffer gas supply pressure – The buffer gas outlet pressure is controlled by the pressure regulator on the control panel. This pressure must be set higher than the backpressure in the disposal or collection system. Since the pressure in these systems is unknown or variable, it can be a challenge to properly set the initial buffer gas pressure.

Improper buffer gas flow rate – The buffer gas flow rate must be sufficient to prevent an accumulation of process fluid in the containment seal cavity. In effect, it must sweep any process leakage out of the cavity into the disposal or collection system. If the flow rate is too low, it may not adequately protect the containment seal and may allow process leakage to migrate to atmosphere.



If the flow rate is too high, it may upset the inner seal operation or introduce an unacceptably high volume of Nitrogen into the recovery system.

Loss of buffer gas pressure – The buffer gas pressure requirements for a Plan 72 are very low and are unlikely to be affected by changes in the supply header pressure. It is however possible that a valve in the supply line (e.g. at the inlet to the control panel) is accidentally closed.

Plugging of coalescing filter – Over time, the filter element in the coalescing filter may be plugged. This will create an excessive restriction in buffer gas supply and may result in a drop in outlet pressure from the panel. The filter element must periodically be changed to ensure proper operation.

Monitoring points

Pressure – on control panel

Flow rate – on control panel

What to look for

The most important function of a Plan 72 is to provide the correct flow of buffer gas into the containment seal cavity. If there is a positive flow into this cavity, the piping plan is working. The seal OEM can give guidance on the recommended flow rate for a specific application and seal size. If the pressure in the containment seal cavity is greater than 10 PSI, there is a potential that this condition could be damaging the containment seal (especially contacting containment seal designs).

See Appendix I for more details on troubleshooting this piping plan.

PIPING PLAN 74

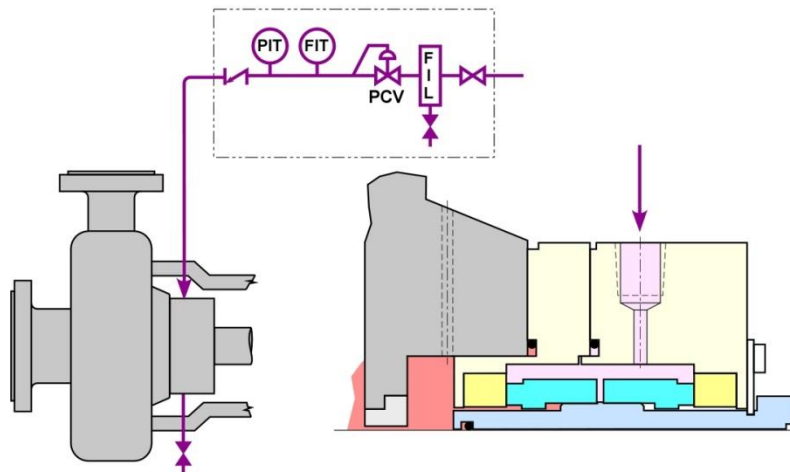


Figure 12 Piping Plan 74

Definition

A Plan 74 is used with Arrangement 3 (3NC-XX) seal. It provides a pressurized external gas (barrier gas) into a barrier gas cavity between the inner and outer seals. The flow of barrier gas is defined by the leakage rates of the seals. The pressure in the barrier fluid cavity must be greater than the pressure in the seal chamber. While the Plan 74 piping plan defines the majority of the sealing system, the official definition focuses primarily on the design and functions of the control panel.



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Functions

Providing an alternative fluid – The primary function of the Plan 74 is to provide a clean environment of the operation of the non-contacting (gas) seals. This fluid must be environmentally acceptable so that leakage to the atmosphere is not regulated. The fluid leaking into the pump process must be inert so that it does not react with the process fluid.

Pressure regulation – To prevent process leakage into the cavity between the seals, the Plan 74 barrier gas must be maintained at a pressure greater than the pressure in the seal chamber.

Cleaning – The barrier gas supply for a Plan 74 is cleaned through a coalescing filter on the control panel. This helps remove both solids contamination and condensation from the supply gas.

Common field issues

Improper barrier gas pressure – One of biggest challenges with a Plan 74 is setting the barrier pressure correctly. The barrier gas pressure must be set high enough to ensure it is greater than the seal chamber pressure at all times (including commissioning, normal operation, upset, and shut down). This requirement is made more difficult since the seal chamber pressure may not be accurately known or may vary in operation. The pressure must also be not set too high to prevent an excessive pressure differential across the inner seal and to prevent excessive barrier gas leakage into the pump.

Loss of pressurized barrier gas – Most Plan 74 systems are pressurized from a Nitrogen header in the plant. This provides the most reliable source of Nitrogen for most applications. In many cases however, the required pressure for the mechanical seals may be approaching the pressure in the supply header. There is a potential for a decrease in the supply pressure due to demands on the header for other plant operation or from an operator accidentally closing a valve on the supply line.

Plugging of coalescing filter – Over time, the filter element in the coalescing filter may be plugged. This will create an excessive restriction in barrier gas supply and may result in a drop in outlet pressure from the panel. The filter element must periodically be changed to ensure proper operation.

Monitoring points

Pressure – on control panel

Flow rate – on control panel

Temperature – on the seal gland

What to look for

The most important function of the Plan 74 system is to provide a clean gas at the correct pressure differential across the inner seal. The system is instrumented to measure the pressure near of the outlet of the control panel to provide the most accurate representation of the pressure at the seals. Excessively long piping runs, excessive amounts of fittings, or a small tubing size between the control panel and the seals may decrease the pressure at the seal especially at higher flow rates.

The barrier gas flow rate is the most important parameter to measure when determining seal performance. There is a normal variation in flow during operation especially in response to changes in operating conditions of the pump. An increase in barrier gas flow beyond the acceptable flow rate may indicate a seal failure.

See Appendix J for more details on troubleshooting this piping plan.



PIPING PLAN 75

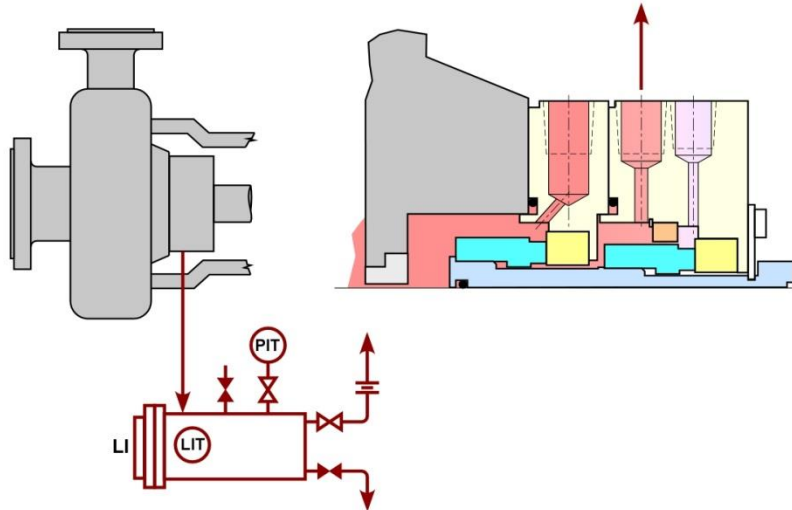


Figure 13 Piping Plan 75

Definition

A Plan 75 system collects and monitors liquid or mixed phase leakage from the containment seal cavity on an Arrangement 2 (2CW-CS or 2NC-CS) seal. The seal gland is designed to prevent the accumulation of liquid phase process in the containment seal cavity. Leakage is piped to a leakage collection reservoir which is instrumented to detect both liquid or gas phase leakage. A Plan 75 may be used by itself or in conjunction with a Plan 72 buffer gas injection.

Functions

Capture leakage – The collection reservoir provides a means to capture leakage which migrates across the inner seal into the seal containment seal cavity. This allows for options to dispose of the process leakage and minimizes emissions to the atmosphere.

Monitor leakage – The Plan 75 system is designed to monitor both liquid or vapor phase leakage from the containment seal cavity into the containment cavity reservoir. Liquid phase leakage is detected by a rapid rise in liquid level in the collection reservoir. Vapor phase leakage is detected by an increase in pressure in the reservoir.

Common field issues

High backpressure in disposal or recovery system – The Plan 75 reservoir is piped to a disposal or flare system in the plant. High vapor phase leakage from the inner seal is detected by a pressure increase in the collection reservoir. High pressures in the recovery or disposal system may also increase the pressure in the reservoir giving a false indication of vapor phase leakage.

High flow rate from Plan 72 – A Plan 75 will often use a Plan 72 to provide a sweep of buffer gas through the containment seal cavity in the seal. An excessive Plan 72 flow rate may increase the pressure in the Plan 75 reservoir and give a false indication of vapor phase leakage.

Contamination from flare or disposal system – The Plan 75 reservoir is vented to a disposal system such as a flare or recovery system in the plant. Products in the disposal systems are prevented from backing up into the reservoir by a check valve in the vent line near the reservoir. Failure or sticking of this check valve can allow liquid from the disposal system to collect in the reservoir giving a false indication of liquid phase leakage.

Plugged drain lines (solidification, freezing) – Many pumps are operated at elevated temperatures to prevent the process fluid from becoming too viscous or solidifying. If the temperature in the drain line to the Plan 75 collection reservoir becomes too low, the process may solidify or freeze. This may prevent leakage from reaching the reservoir.



Failure to drain collection reservoir – The collection reservoir is intended to collect liquid phase leakage and provide level indication through both a visual site glass and level transmitter. Over time, the level in the reservoir will increase even from normal seal leakage. To prevent the reservoir level from getting higher than the instrumentation, an operator must periodically manually open the drain valve and drain all liquid to a collection system or sump. If this is not done, the level will continue to rise and the operator will not be monitoring liquid phase leakage effectively.

Monitoring points

Level – in collection reservoir (visual site glass and transmitter)

Pressure – in collection reservoir

Icing – visual indication on vent line

What to look for

The Plan 75 system is intended to collect inner seal leakage and detect seal failures. For this to occur, the drain line from the seal gland to the reservoir must be open and unobstructed. The reservoir must also be located at a lower elevation than the seal to ensure proper draining.

The leakage is detected by both level and pressure so all instrumentation must be operating correctly. Ensure that the liquid is periodically drained from the collection reservoir and it is not operated in a liquid-full condition. Ensure that the check valve in the vent line prevents liquids from flowing into the reservoir from the disposal or collection system.

In light hydrocarbon services, a high flow rate past the orifice in the vent line may result in a refrigeration effect which causes icing on the outside of the pipe.

See Appendix K for more details on troubleshooting this piping plan.

PIPING PLAN 76

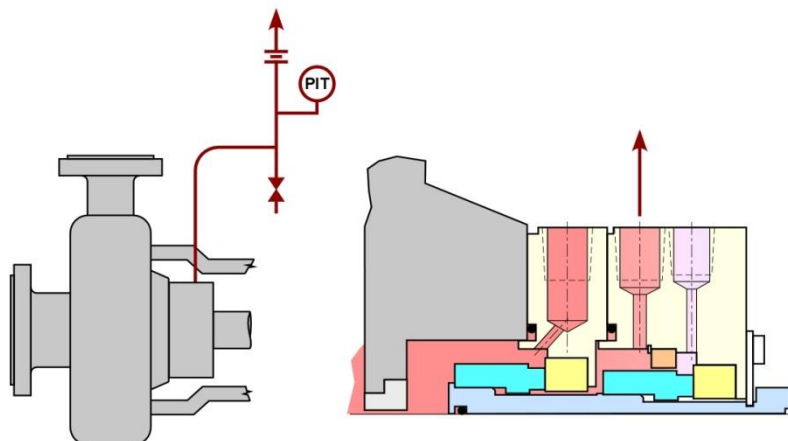


Figure 14 Piping Plan 76

Definition

A Plan 76 system collects and monitors vapor phase leakage from the containment seal cavity on an Arrangement 2 (2CW-CS or 2NC-CS) seal. This piping plan is intended to only be used on process fluids which fully vaporize under the conditions in the containment seal cavity. Leakage is piped to a leakage collection harness which is instrumented to detect vapor phase leakage. A



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Plan 76 may be used by itself or in conjunction with a Plan 72 buffer gas injection.

Functions

Capture leakage – The collection reservoir provides a means to capture leakage which migrates across the inner seal into the seal containment seal cavity. This allows for options to dispose of the vapor phase process leakage and minimizes emission to the atmosphere.

Monitor leakage – The Plan 76 system is designed to monitor vapor phase leakage from the containment seal cavity into the Plan 76 harness. Vapor phase leakage is detected by an increase in pressure in the piping plan.

Common field issues

High backpressure in disposal or recovery system – The Plan 76 system is piped to a disposal or flare system in the plant. High vapor phase leakage from the inner seal is detected by a pressure increase in the collection reservoir. High pressures in the recovery or disposal system may also increase the pressure in the reservoir giving a false indication of vapor phase leakage.

High flow rate from Plan 72 – A Plan 76 will often use a Plan 72 to provide a sweep of buffer gas through the containment seal cavity in the seal. An excessive Plan 72 flow rate may increase the pressure in the Plan 76 system and give a false indication of vapor phase leakage.

Contamination from flare or disposal system – The Plan 76 system is vented to a disposal system such as a flare or recovery system in the plant. Products in the disposal systems are prevented from backing up into the reservoir by a check valve in the vent line at the top of the Plan 76 piping harness. Failure or sticking of this check valve can allow liquid from the disposal system to collect in the reservoir giving a false indication of liquid phase leakage.

Monitoring points

Pressure – in piping harness

Icing – visual indication on vent line

What to look for

The Plan 76 system is intended to collect inner seal leakage and detect seal failures. This leakage is detected by an increase in pressure in the system. The user should ensure that the pressure indicator/transmitter is operating correctly.

Ensure that the check valve in the vent line prevents liquids from flowing into the piping harness from the disposal or collection system. This can be checked by cracking open the drain valve at the low point (dog leg) in the piping harness (following all plant safety procedures).

In light hydrocarbon services, a high flow rate past the orifice in the vent line may result in a refrigeration effect which causes icing on the outside of the pipe.

See Appendix L for more details on troubleshooting this piping plan.

CONCLUSIONS

Piping plans play a critical role in the performance of the mechanical seals in centrifugal pumps. Although piping plans are used on virtually every seal application, operators are often unaware of the performance of the piping plan and have a limited ability to troubleshoot a piping plan in operation in the field. Fortunately, there are methods that end users can use to gain better insight into the condition and performance of many piping plans. This requires an understanding of the functions performed by the piping plans, the common failure modes, and a structured approach to analyzing the available data. Engineers for the seal OEMs can help provide additional support on applying these methods and provide additional guidance on data collection strategies for a specific seal application.



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DISCLAIMER

While the information in this tutorial is believed to be correct, not all information may be suitable or applicable for a specific application. For this reason, the reader assumes the responsibility for the use of this information and should perform a thorough engineering review for their specific application and specific requirements.

ACKNOWLEDGEMENTS

The authors would like to thank the members of the Turbomachinery Machinery Laboratories and Pump Symposium Advisory Committee for their invaluable contributions in freely creating, collecting, and disseminating knowledge on pumps, seals and reliability. Special thanks to Flowserve Corporation for their support on this paper and for their continuing support of the Pump Symposium.



APPENDIX A

Overview of Functions of Piping Plans

Table 1 – Overview of functions of piping plans

	Piping Plan	Supports ¹	Circulation or Flow generated from	Fluid Source	Fluid State	Heat Removal From Operating Seal	Cooling	Cleaning	Monitor Leakage	Provide Alternative Fluid
Arrangement 1 (Single Seal) Flushes	01	Inner	ΔP in pump	Process	Liquid					
	02	Inner	NA	Process	Liquid					
	03	Inner	Seal chamber	Process	Liquid					
	11	Inner	ΔP in pump	Process	Liquid					
	12	Inner	ΔP in pump	Process	Liquid					
	13	Inner	ΔP in pump	Process	Liquid					
	14	Inner	ΔP in pump	Process	Liquid					
	21	Inner	ΔP in pump	Process	Liquid					
	22	Inner	ΔP in pump	Process	Liquid					
	23	Inner	Pumping device	Process	Liquid					
	31	Inner	ΔP in pump	Process	Liquid					
	32	Inner	External source	Process	Liquid					
	41	Inner	ΔP in pump	Process	Liquid					
Arrangement 2 or 3 (Dual Seal) Systems	51	Atmospheric	NA	Quench	Liquid					
	52	Outer	Pumping device	Buffer	Liquid					
	53A	Inner and Outer	Pumping device	Barrier	Liquid					
	53B	Inner and Outer	Pumping device	Barrier	Liquid					
	53C	Inner and Outer	Pumping device	Barrier	Liquid					
	54	Inner and Outer	External source	Barrier	Liquid					
	55	Outer	External source	Buffer	Liquid					
Atmospheric Systems	61	Atmospheric	NA	NA	NA					
	62	Atmospheric	External source	Quench	Either					
	65A	Atmospheric	NA	Process	Liquid					
	65B	Atmospheric	NA	Process	Liquid					
	66A	Atmospheric	NA	Process	Either					
	66B	Atmospheric	NA	Process	Either					
Gas Seal (Non-contacting and Containment Seal) Systems	71	Outer	NA	NA	NA					
	72	Outer	External source	Buffer	Gas					
	74	Inner and Outer	External source	Barrier	Gas					
	75	Outer	NA	Process	Gas					
	76	Outer	NA	Process	Gas					
	99	NA	NA	NA	NA					

Notes

1. Supports indicates the seal or region of the seal assembly primarily impacted by the specific piping plan,
2. Spaces in green indicate that the piping plan provides this function as a default. Spaces in yellow indicate piping plans which may provide these functions if specified.
3. Piping Plan 99 is an engineered plan and is specifically designed for the application conditions. The functions it performs are dependent on the specific design.

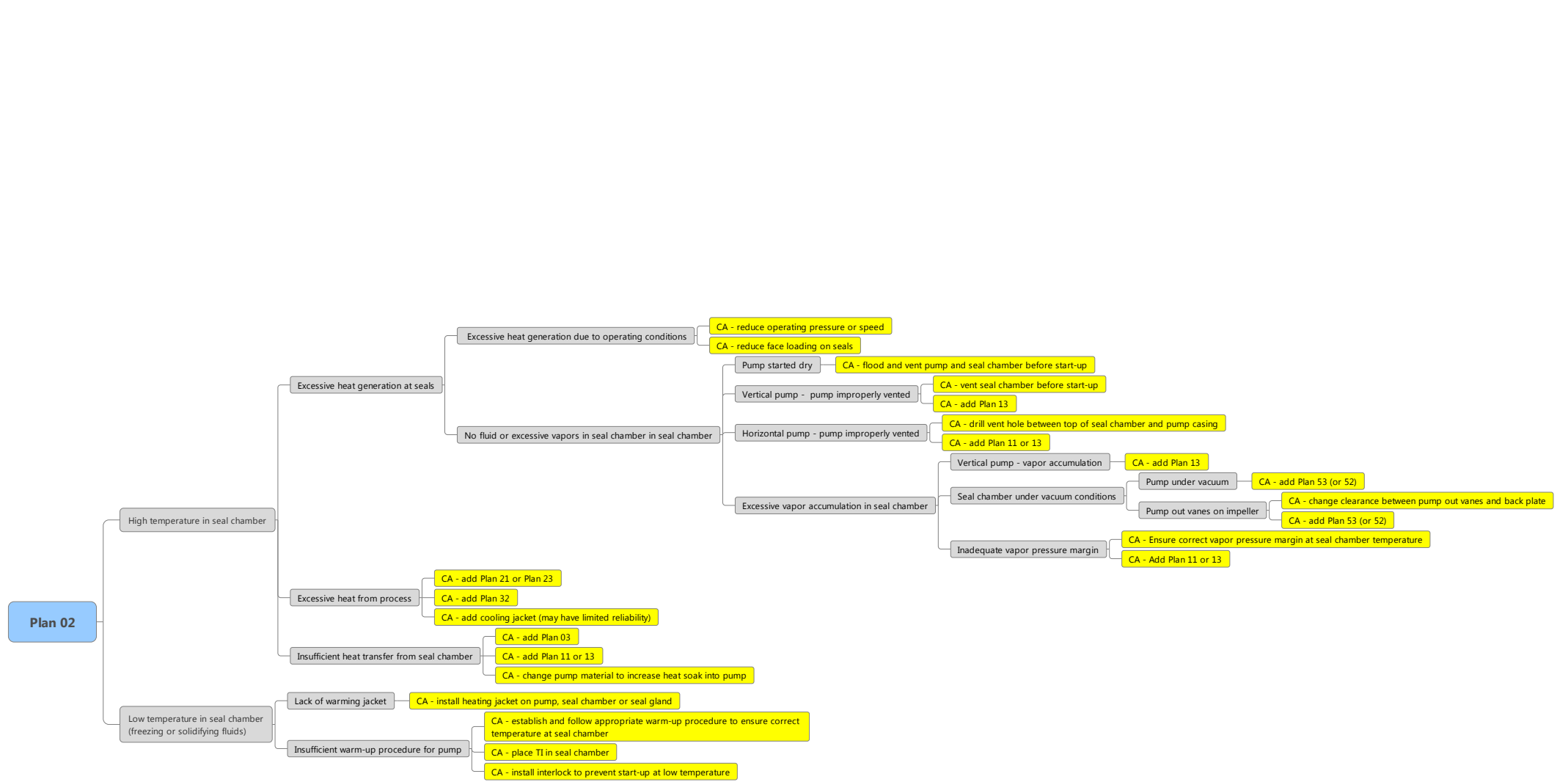


Figure 15 RCA Piping Plan 02



Figure 16 RCA Piping Plan 11

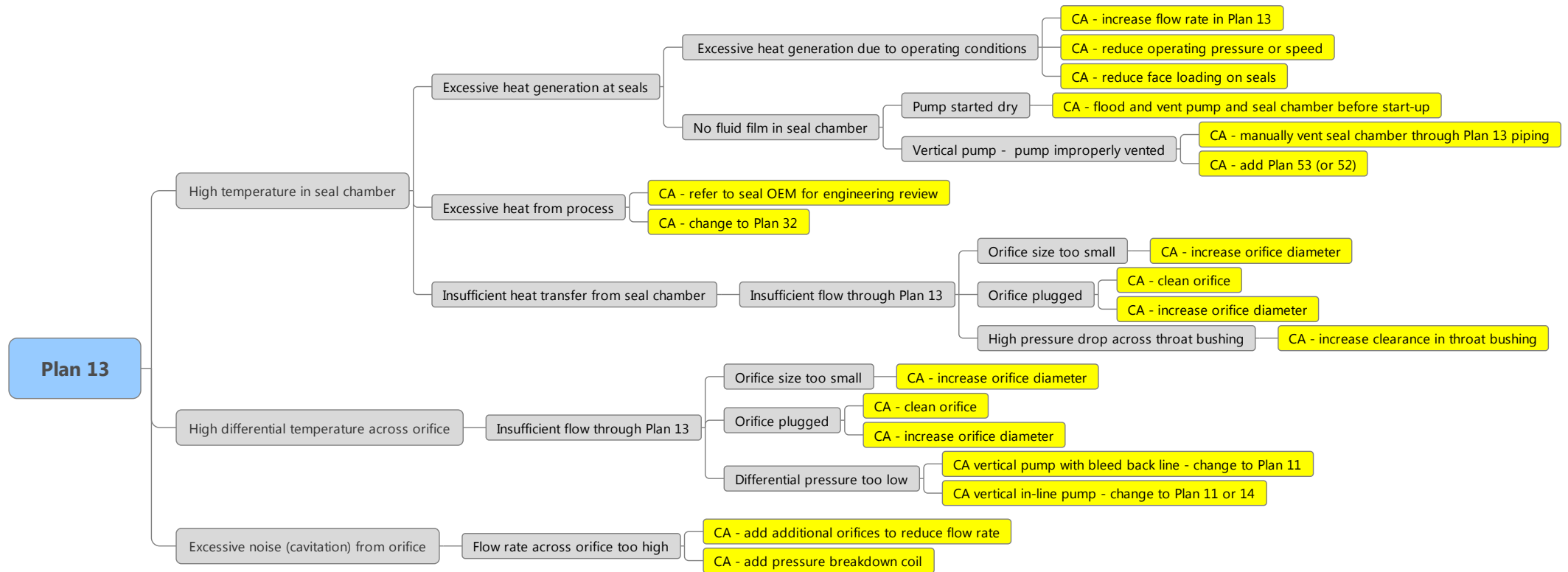


Figure 17 RCA Piping Plan 13

APPENDIX E RCA Diagram for Troubleshooting a Piping Plan 21



Figure 18 RCA Piping Plan 21

APPENDIX F RCA Diagram for Troubleshooting a Piping Plan 23



Figure 19 RCA Piping Plan 23

APPENDIX H RCA Diagram for Troubleshooting a Piping Plan 53A



Figure 21 RCA Piping Plan 53A



Figure 22 RCA Piping Plan 72

APPENDIX J RCA Diagram for Troubleshooting a Piping Plan 74



Figure 23 RCA Piping Plan 74

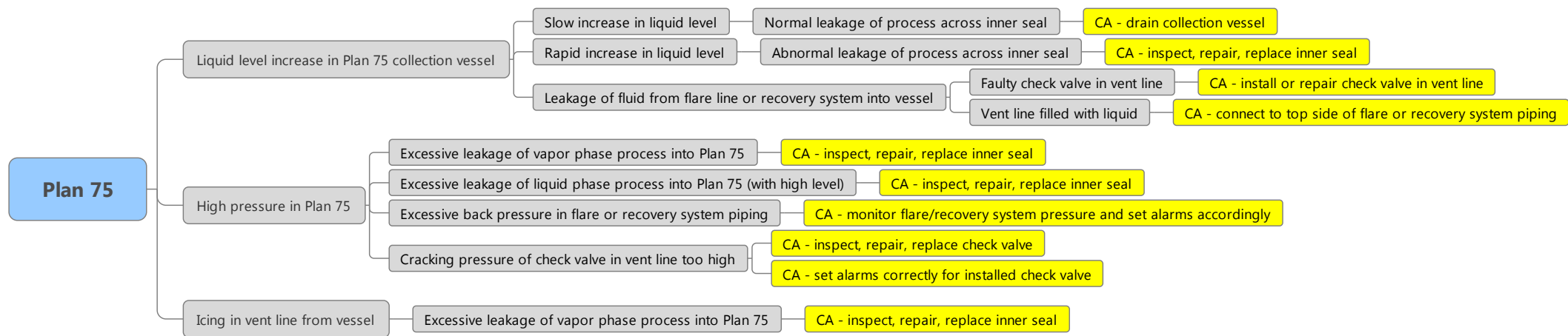


Figure 24 RCA Piping Plan 75

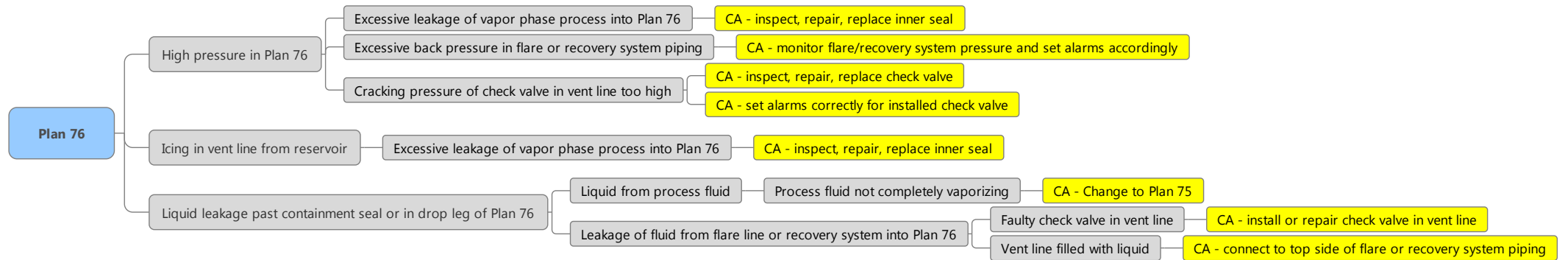


Figure 25 RCA Piping Plan 76