MECHANICAL SEAL RELIABILITY IMPROVED WITH API PIPING PLAN 23

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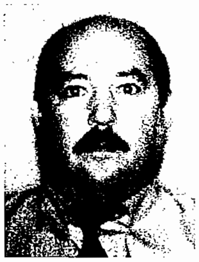

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ABSTRACT

A reliable mechanical seal is a happy seal. A happy seal is one that runs in an environment that is cool, clean, and maintains a satisfactory vapor pressure margin. However, this is not always the case. Not all pumped fluids are cool, clean, and have satisfactory vapor pressure margins. It has been found that on a large number of pumps handling hostile services, installing an API Seal Flush Plan 23 is the answer. Presently, the authors have over 400 Plan 23 arrangements in services that range from hot water to light ends and heavy aromatics. The average service life for these successful installations is more than six years.

INTRODUCTION

In a Plan 23 arrangement, the seal chamber fluid is isolated from the pump stream by a throat bushing. An internal circulating device (pumping ring) circulates the seal chamber fluid through a cooler and back to the seal chamber in a closed loop configuration. Since the same fluid is being constantly cooled over and over again, very low seal chamber temperatures result, and the heat load on the cooler is minimal. Cooler fouling is significantly reduced, due to the lower temperature of the fluid passing through it.

The API 682 Standard "Shaft Sealing Systems for Centrifugal and Rotary Pumps," recommends a Plan 23 flush arrangement for sealing low specific gravity hydrocarbons above 140°F and for hot water services. These services are, in general, clean products, free from abrasives or other contaminants. While a Plan 23 system can be utilized for services with abrasives and contaminants, present special design considerations are required for the system. These considerations are beyond the scope of this article and will not be covered herein. API recognized that Plan 23 is more energy efficient than alternative seal cooling arrangements. Plan 23 also allows the use of elastomers for pump services where they could not normally be employed, since the seal operates at a much lower temperature than the pump. The seal is kept cool, even when the pump is not in operation, by means of a thermosyphon. This allows for the selection of spring pusher seals even in hot services and eliminates the need to use metal bellows seals in higher pressures typical of hot light hydrocarbon services. Lowering the seal chamber temperature has the further advantage of providing increased vapor suppression margin, improving the lubricity of the pump product at the seal faces, and minimizing coking. Low emission readings are typical for the reduced temperatures at which a properly installed API Piping Plan 23 operates.

For years, the authors have been reluctant to employ Plan 23 arrangements because of previous poor experience and service life. However, examinations of many of these installations reveal that improper piping arrangements were the real culprit. It is essential that a Plan 23 system be properly designed and installed. Proper pump startup procedures must be used. In order for a Plan 23 system to function properly the following areas must be addressed:

- Pipe size
- Cooler elevation
- Orientation of inlet and outlet connections
- Internal circulating device
- Pipe restrictions (elbows, fittings, etc.)
- Venting of cooler

Basic guidelines for successful piping, including seal chamber porting and venting, are presented. Piping practices are based on simple theoretical modelling supported by field measurements. Furthermore, examples are discussed showing greatly increased MTBF.

VAPOR SUPPRESSION MARGIN

API 682 recommends a vapor suppression margin in the sealing chamber of at least 50 psi. The vapor suppression margin is the seal chamber pressure, minus the pumpage vapor pressure. Normally, the pumpage vapor pressure is taken at the pump impeller eye temperature. However, for Plan 23, the vapor pressure can be taken at the expected operating temperature in the sealing chamber.

In general, there are two methods to achieve a desirable vapor suppression margin in the seal chamber:

- Cooling the sealing chamber
- Pressurizing the sealing chamber

The preferred method is to cool the seal chamber. However, one of the limiting factors is that the pumpage must be hotter than the cooling medium or adequate cooling simply cannot occur. For normal cooling water temperatures, API 682 recommends a Plan 23 system whenever the pumping temperature exceeds 140°F.

Cooling Methods

There are two general methods of cooling the seal chamber, API Piping Plan 23 and Piping Plan 21. API Plan 21 (Figure 1) uses a flush plan that routes a product flush, usually from pump discharge, through a cooler to the seal cavity.

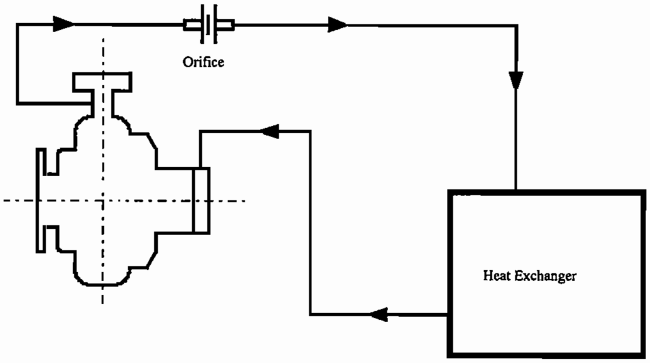

Figure 1. API Piping Plan 21. Line from Discharge through Orifice and Cooler to Seal Gland.

API Piping Plan 23 (Figure 2) also utilizes a cooler. However, instead of using a product flush from a higher pressure point in the pump case or piping, the circulation is achieved by means of an internal circulation device (pumping ring) that is a part of the mechanical seal assembly. The internal circulation device circulates fluid from the seal chamber through the cooler and back to the seal faces.

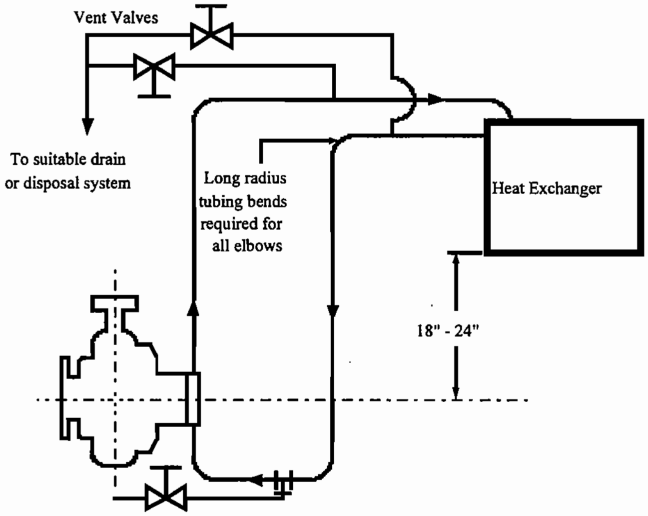

Figure 2. API Piping Plan 23. Line from Seal to Cooler and back to Seal Gland.

Plan 23 is the preferred method of cooling the "flush" to the seal chamber for several reasons. Compared to Plan 21, there is less fouling and scaling that occurs in the cooler with Plan 23. The reason for this phenomenon is that Plan 21 takes a stream from the pumpage and cools the entire stream from full pumping temperature to the desired temperature required in the seal cavity. This can place a significant heat load on the cooler and result in a high temperature rise in the cooling water. As the cooling water temperature is increased, fouling and scaling become more of a problem. On the other hand, a Plan 23 system is cooling a small volume of fluid from the seal chamber over and over again. As a result, the cooling water temperature rise is very small. Even for pumps handling very hot products, it is unusual for the cooling water temperature rise for Plan 23 to exceed 10°F (APPENDIX). If cooling water flow rates are very low, the scaling and /or fouling problem can be accelerated when using Plan 21.

A Plan 21 system must include a control orifice to regulate the flow of the flush fluid to the seal chamber. If the orifice becomes plugged or obstructed, the cooling flush can be lost resulting in a seal failure. On the other hand, if the orifice is eroded out to a larger size, the cooling flush flow may increase to the point that it exceeds the capacity of the cooler, resulting in a much higher flush temperature than originally planned. During operation, Plan 23 relies entirely on the internal circulating device to provide circulation. No orifices or other control devices are required in the flush line. When the pump is not in operation, the Plan 23 system provides cooling by means of a thermosyphon.

It should also be noted that because of this thermosyphon effect, the mechanical seal will remain cool, whether or not the pump is running. This allows the seal selection to include elastomers that would not be compatible with the full product pumping temperature. The use of expensive elastomers or even metal bellows seals can be avoided by using a Plan 23 system. The Plan 21 arrangement provides no cooling to the seal when the pump is not running, unless the flush source can be taken from the common discharge header for a pump set, i.e., a pump and a spare.

Pressurization Method

Pressurizing the seal chamber is the less desirable method for two reasons:

- Higher face loading
- Throat bushing wear

At higher pressures, increasing the seal chamber pressure results in higher hydraulic face loading. This leads to high heat generation at the seal faces, which can cause increased wear and higher emission rates. Unless a pump modification can be affected to increase the seal chamber pressure by using a naturally occurring pressure in the pump, increasing the seal chamber pressure necessarily involves the use of a throat bushing in the bottom of the seal chamber. As throat bushing wear occurs, the vapor suppression margin will be reduced.

PIPING GUIDELINES

In order to successfully utilize a Plan 23 arrangement, some basic guidelines must be followed. If these guidelines are ignored, the Plan 23 will not function properly. Briefly the guidelines are as follows:

- The internal circulating device outlet must be at top dead center in the seal chamber to promote thermosyphoning and provide for venting of the seal cavity. The actual tap location can be below top dead center, as long as the drill through intersects the seal chamber at top dead center, and the tapped hole has positive pitch to the outside of the seal gland (Figures 3 and 4).

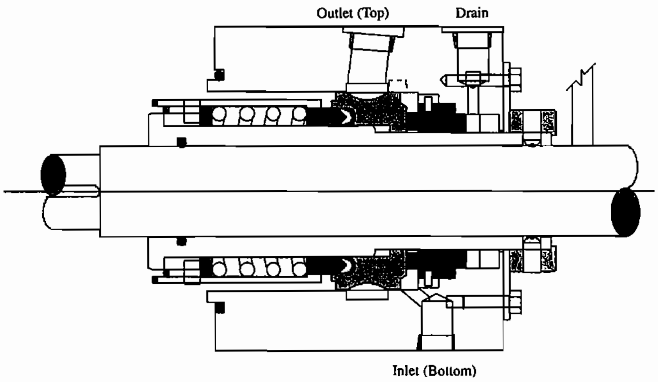

Figure 3. Preferred Tap Locations. Side View.

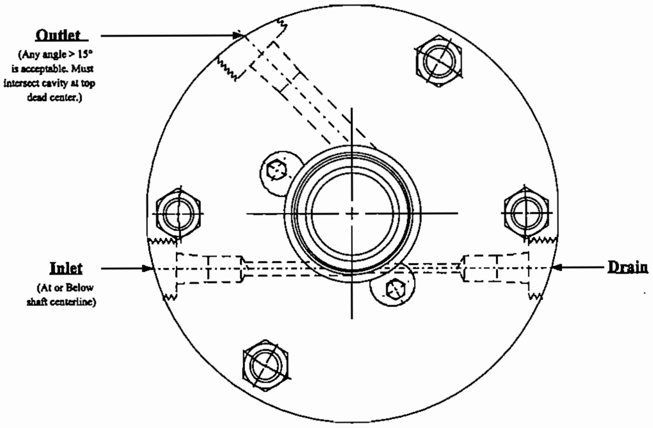

Figure 4. Alternate Tap Locations. Front View.

- The drill through into the seal gland must be full size (the drill diameter for the tapped connection) or as large as possible to minimize friction and flow losses. A 0.375 in drill through should be the minimum for most cases.

- The cooler must be elevated 18 to 24 in above the centerline of the seal chamber to promote thermosyphoning.

- All efforts must be made to reduce flow friction losses in the piping system. Connections between the seal gland and the cooler must be 0.750 in OD tubing. No small bore fittings or valves can be used. Long radius tubing bends must be made. The use of close radius fittings, etc., is not acceptable. The tubing runs should be as short as practical and the number of bends minimized to the extent possible. The cooler should be mounted as close to the seal chamber as practical, to minimize piping runs. If the cooler must be mounted farther than four horizontal feet from the seal chamber, the piping system must be reviewed to avoid excessive friction losses.

- Vent valve(s) must be installed at the high point of the circulation line(s).

- The cooler must be mounted so that it can be properly vented. The authors have had successful experience with horizontal and with vertical mountings of coolers. However, the preference is vertical mounting because of the relative ease of venting. Whether the cooler is mounted vertically or horizontally, it must be properly vented and the procedures described later under FIELD CHECKING THE SYSTEM must be followed.

- The inlet to the seal gland (return for the cooler) must be no higher than the shaft.

- A throat bushing must be installed at the bottom of the seal cavity to help isolate the seal chamber from the pump flow. Since there is essentially no flow across the bushing, close clearances are not required. Diametrical clearances of 0.025 in to 0.030 in are adequate. However, it is helpful to make the bushing longer than standard if axial space is available.

Comment

Seal chamber water jacket cooling was utilized on the pumps listed in the APPENDIX, whenever the pumping temperature exceeded the limits of the elastomer. However, no appreciable difference was noted in the performance of the Plan 23 installations with water jacket cooling *vs* those without water jacket cooling.

It is important that the cooling water system be designed properly and follows sound practices as described in API 610. The water supply should be run in series to the various pump components and not parallel.

THERMOSYPHON FLOW

A brief study of the basic principles involved in thermosyphon flow will help illustrate the need for the above guidelines.

Thermosyphon flow is generated in a closed loop system by the force of gravity acting on the line that is colder and, therefore, denser. The colder, denser fluid is pulled down by gravity displacing the hotter lighter fluid. The force of gravity is the only force active in thermosyphon flow. When the pump is not in operation, the only flow generated in this system is produced by the thermosyphon effect. An equation for the differential pressure is as follows:

$$\Delta P = (R_c - R_h)gH \tag{1}$$

The differential pressure in the system is expressed as ΔP. The density of the fluid in the cold return line is R_c. The density of the fluid in the hot riser line is R_h. The force of gravity is g and H is the height of the cooler (heat sink) above the seal cavity (heat source).

Please note that four fundamental assumptions have been made in this very limited model. These assumptions are:

- The temperature in the seal chamber is constant. It is not considered that the heat removal is ongoing, but that a final state where the temperature does not vary has been attained. Also ignored is the heat soak into the seal chamber from the pump case. It is basically assumed that the cooling being done is equal to the heat soak.

- The fluid density in the riser and return line is constant from top to bottom. In fact, it will vary slightly. However, this assumption also has little effect on the simple model.

- Any radiation or convection cooling that might be obtained from the piping system has been ignored. This amount of cooling is very small compared to the cooling being done in the cooler itself and, therefore, will have little effect on calculations.

- The friction losses in the piping system itself have been neglected. This assumption does have considerable bearing on the calculations made. According to a recent study [1], the effect of friction losses will reduce the calculated flowrates by a factor of 10 or more. If the theoretical flow rate of two gpm is calculated, the actual flow rate will be 0.2 gpm, or approximately three pints/min if the flow reduction factor is taken to be 10. The flow reduction factor can vary greatly depending on a number of related variables such as temperature difference, pipe diameter, fluid viscosity, surface roughness of the piping, and piping length.

Since ΔP is the only force in the system, it also represents the total kinetic energy in the thermosyphon system. Another expression for the kinetic energy in the system is $\frac{1}{2}R_aV^2$ (R_a is the average fluid density in the system). Since the thermosyphon is the only agent providing energy in the system, then these two equations can be made equal as follows: $\frac{1}{2}R_aV^2 = \Delta P - (R_c - R_h) \times g \times H$. Solving this equation for the velocity yields the following: $V = [\{2(R_c - R_h) \times g \times H\}/R_a]^{0.5}$. The flow in the system expressed as Q would be the fluid velocity time the inside area of the line, expressed as $Q = V \times A$. The inside area is $\frac{1}{4}\Pi\,(ID)^2$. Therefore, the flow could be calculated as follows:

$$Q = \tfrac{1}{4}\Pi\, V\, (ID)^2 \qquad (2)$$

For purposes of calculations, four basic models have been used. First, use heights of two feet and three feet to demonstrate the effect elevation has on thermosyphons. Secondly, calculations for 0.750 in OD tubing with a wall of 0.065 in (or an ID of approximately 0.625 in) and for 0.500 in OD tubing with a wall of 0.049 in (or an ID of approximately 0.400 in) have been made. All calculations done have been based on water at a seal chamber inlet temperature of 110°F.

Pipe Size

The theoretical flow rates for the thermosyphon model are shown in Figure 5. It is obvious that the larger diameter tubing has a beneficial effect on thermosyphon flow.

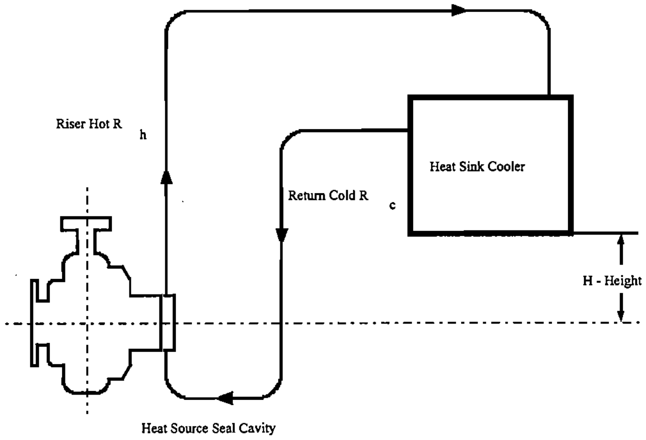

Figure 5. Thermosyphon Flow.

Cooler Elevation

It should also be noted that although the calculated flow increases slightly by elevating the cooler another 12 in, this effect is limited. Field experience indicates that 18 to 24 in of elevation is satisfactory for thermosyphon operation, although higher elevations are acceptable. In general, it is not recommended that the cooler be mounted higher than 36 in above the shaft or seal chamber centerline. There is concern about the pipe friction losses associated with the additional tubing length required for higher elevation installations.

Orientation of Connections

One major factor in applying API Plan 23 and obtaining proper thermosyphon flow during pump standby is the location and orientation of the inlet and outlet connections. It is essential that the internal circulating device outlet be located at top dead center in the seal chamber. For one thing, a tap must be located at this position so that the seal chamber can be completely vented during pump initialization. But the internal circulating device outlet must be located at this position, so that the internal circulating device and the thermosyphon will operate in the same direction. It is possible that at high differential temperatures, the thermosyphon could overpower the internal circulating device on small diameter or slow turning internal circulating devices. In fact, field experience has demonstrated this phenomenon on a number of occasions. In effect, the thermal circulation will be flowing in the opposite direction of the internal circulating device or not flowing at all.

The return line connection should be as low as possible, but no higher than the shaft centerline for horizontal pumps, establishing a clear flow path for both the thermosyphon and the internal circulating device in the same direction. For vertical pumps, the return line should be located below the internal circulating device outlet and kept as low as possible on the seal gland.

Internal Circulating Device

Success with Plan 23 installations has been achieved by specifying only proven internal circulating device designs. Designs that rely on a close clearance fit to the seal chamber bore are not permitted.

Piping Restrictions

The table in the APPENDIX lists a number of pumps at a large refinery with Type A (pusher) seals equipped with internal circulation devices installed in various services. The inlet and outlet temperatures are shown for the seal circulation lines and cooling water. It is also noted whether the pump is running or in standby service or slow rolling on a turbine. Of the 17 pumps in standby or slow rolling service that are listed, the average differential temperature between the seal circulation inlet and outlet is 38°F. Comparing this value to Figure 6 reveals that only 0.25 to 0.40 in of head is being theoretically generated by the thermosyphon effect. Therefore, it is obvious that every effort must be made to reduce any friction losses in the piping. One close radius elbow might be enough to cause the thermosyphon to become stalled. Full size drill throughs on the seal gland are essential. No valves, orifices, or restrictions of any kind can be permitted in the seal circulation piping. If a thermowell is installed to monitor the system temperature, it should never be placed directly in the flow.

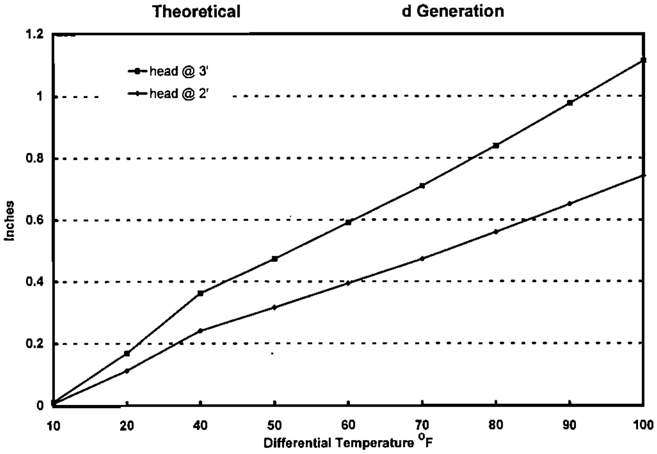

Figure 6. Theoretical Thermosyphon Head Generation.

Cooler Venting

There is one final issue that needs to be addressed for a successful Plan 23 installation. The circulation lines and the seal chamber must be vented out prior to operation in order for internal circulating device and thermosyphon circulation to occur. This venting must occur prior to startup and should occur as soon as practical after the pump has been filled with product. Venting the seal chamber during pump operation will draw hot fluid into the seal chamber. Since many Plan 23 arrangements are now being applied to hot light hydrocarbon seals, the vent piping must be arranged so that the hot fluid can be safely vented. It is common practice to pipe the vent line to a flare or other suitable enclosed recovery system. If it is only water, the vent line can be run to the sewer, but it should be insulated to prevent a possible burn. And the venting arrangement must be designed so that only a minimum of fluid is vented off to purge the system of vapors. The piping arrangement shown in Figure 2 is the optimum arrangement for circulation and also for venting.

One vent valve at the highest point in the line has been successfully employed. By having two vent valves, the risk that all the fluid and vapors being vented will simply pass through the short line and go to the disposal system is reduced. Each line can be individually vented. The system shown in Figure 2 has been proven satisfactory in many installations.

FIELD CHECKING THE SYSTEM

Once the system has been totally filled and vented, one final check must be made to ensure that the system is functioning properly. The inlet and outlet temperatures on the tubing at the seal gland must be measured. The inlet temperature should range from 30°F to 40°F hotter than the cooling medium and the outlet temperature should range another 20°F to 30°F hotter than the inlet temperature.

The skin temperature of the tubing should be taken using an electronic thermometer with a thermocouple or an infrared temperature indicator. Alternatively, a clip on type thermometer could be installed on the inlet tubing as near to the gland connection as practical. The installation of an immersion type temperature indicator with a thermowell is not recommended. However, if this type of temperature indicator must be employed for some reason, it is absolutely imperative to make sure that the thermowell does not block the inlet line in anyway. The thermowell must be installed in a greatly increased tubing or pipe cross section so that the overall flow path is equal to, or greater than, the tubing ID at the thermowell. In fact, the thermowell should be installed in a recessed area, so that it does not intrude into the liquid flow path whatsoever, since the temperatures encountered in a Plan 23 system are very stable.

The system can be checked periodically after it has been put in service in the same manner. Monitoring of the operating temperatures of the Plan 23 system on a quarterly basis is recommended.

FIELD EXAMPLES

A brief analysis of two examples from the APPENDIX will help to illustrate how API Piping Plan 23 can be used to solve seal applications.

Example A

The two pump sets noted as items 1, 2, 3, and 4 are very similar overhung process pumps in boiler recirculation service. Both sets of pumps handle boiler feedwater at 495°F to 515°F with a pump suction pressure of 650 psig. The pumps have a special construction feature because of the high suction pressure. There are no back wear rings or balance holes. Therefore, the seal chamber was very close to pump discharge pressure. The only methods of flushing the seal chamber at discharge pressure are API Plan 13 or Plan 23. There was little knowledge of Plan 23 at the time, and since cooling is required to prevent face flashing and damage to even perfluorelastomers, the user was attempting to operate a Piping Plan 21 with very little success. Normal seal life was only three to six months.

Since API Piping Plan 23 provides its own circulation, the pressure in the seal chamber is relatively unimportant. A Type A seal rated for the suction pressure with an internal circulating device was installed in both pump sets in early 1986. All of the installations operated continuously for over five years. When the pumps were initially filled and vented, the thermosyphon immediately cooled down the seal chamber.

Example B

The pump noted as Item 9 (APPENDIX) is for an overhung process pump in xylene service at 409°F. The suction pressure is 23.3 psig and the product vapor pressure at pumping temperature is 34.7 psia, resulting in an inadequate vapor suppression margin at the impeller eye of only 3.3 psi. While there were occasional problems with the elastomers due to the temperature, the most prevalent reason for a seal repair was exceeding the allowable emission limits. With a Piping Plan 11, recirculation from the pump discharge to the seal, the seal life was very short and the emission levels were consistently in excess of the allowable limits for this facility.

With a Piping Plan 21 arrangement, the seal would operate as required for some time period, usually six months to one year. Then the cooler would become fouled and excess emissions would result, requiring cooler maintenance and/or seal replacement.

A Type A seal with internal circulating device was installed in early 1987. The seal already has several years of operation without replacement. Emission readings have consistently been in the range of 20 to 40 ppm, even though the seal is not emission optimized.

Low emission readings are typical of API Piping Plan 23 installations for hot light hydrocarbons. The low readings result from the method of measurement. Emission measurements are made by the use of a volatile organic compound analyzer. The instrument measures concentrations in air by drawing in a small sample volume. It can only measure vapors. Many of these hot light hydrocarbons will have no appreciable vapors present [2] when cooled down to the levels typical of a Plan 23 installation.

CONCLUSIONS

When the preceding guidelines and practices are followed to the letter, a Plan 23 arrangement will perform reliably and economically. Plan 23 has been one of the important elements in mechanical seal standardization program, which has aided in achieving an average service life of over six years [3]. Field data clearly demonstrate successful application for the Type A (pusher) and Type C (metal bellows) seal. A major refinery company currently has over 400 successful installations in services ranging from hot water to light ends and heavy aromatics. A recent survey of 70 of these pumps at one refinery shows that for an average pumping temperature of 426°F, the seal chamber inlet temperature averages were only 122°F. Pumps on standby or slow roll, which rely solely on the thermosyphon cooling effect, show an average inlet temperature of only 100°F, clearly indicating that thermosyphon cooling really does work. When properly installed and maintained API 682 Mechanical Seals with Flush Plan 23 will perform safely, reliably, and meet or exceed all current emission regulations. After all, a happy seal is a seal with an API Plan 23 flush arrangement.

APPENDIX

The following is a table of several installations at a major refinery. The status of the pump, whether it was in operation, slow rolling, or on standby, is shown. The specific gravity and the product are also shown. The pumping temperature is listed as well. The temperatures shown for the seal circulation lines in (Seal C/I) and out (Seal C/O) as well as the cooling water supply (CWI) and return (CWO) were taken with an electronic thermometer on the outside of the tubing for the seal circulation lines or pipe for the cooling water. Thus, they are skin temperature readings and are obviously slightly lower than the actual temperature. However, the temperature differentials are of primary interest for this evaluation.

Item No.	Status	Specific Gravity	Product	P.T. °F	Seal C/I	Seal C/O	CWI °F	CWO °F
1	ACT	.80	BFW	495	133	144	87	90
2	ACT	.80	BFW	495	123	131	85	88
3	ACT	.80	BFW	495	105	120	90	100
4	S/B	.80	BFW	495	98	130	90	93
5	ACT	.78	BFW	550	148	169	84	100
6	ACT	.78	BFW	550	114	144	84	94
7	S/R	.78	BFW	550	101	165	85	92
8	S/R	.78	BFW	550	110	168	84	93
9	ACT	.70	HVY AROM	409	118	148	89	103
10	ACT	.79	BFW	495	191	204	89	104
11	S/R	.79	BFW	495	144	184	90	98
12	ACT	.88	BFW	366	100	127	83	86
13	S/B	.88	BFW	366	87	165	84	83
14	ACT	.88	BFW	366	99	140	83	87
15	S/B	.88	BFW	366	87	108	83	83
16	ACT	.88	BFW	366	97	120	84	88
17	S/B	.88	BFW	366	89	173	83	85
18	ACT	.88	ISO FEED	275	109	117	86	87
19	ACT	.88	ISO FEED	275	110	114	86	89
20	ACT	.78	BFW	496	109	147	87	101
21	S/B	.78	BFW	496	104	165	89	91
22	ACT	.78	BFW	496	109	119	87	104
23	ACT	.88	BFW	371	97	102	91	95
24	ACT	.73	LT. AROM	336	101	131	87	91
25	S/B	.73	LT. AROM	336	93	142	86	89
26	ACT	.78	BFW	496	173	224	90	99
27	S/B	.49	DESUL REB	570	95	156	97	98
28	ACT	.49	DESUL REB	570	107	120	95	111
29	ACT	.49	DESUL BTMS	570	81	121	74	83
30	ACT	.67	REACT FEED	520	107	109	84	90
31	ACT	.67	REACT FEED	520	106	125	92	100
32	S/B	.67	REACT FEED	520	99	112	91	102
33	S/B	.67	REACT FEED	520	96	112	92	97
34	ACT	.67	REACT FEED	520	163	203	88	102
35	ACT	.67	REACT FEED	520	123	140	89	96
36	ACT	.57	BTMS RECIRC	670	117	136	95	103
37	S/B	.57	BTMS RECIRC	670	93	135	89	94
38	ACT	.65	HC	540	101	116	89	96
39	S/B	.65	HC	540	97	103	85	86
40	ACT	.62	HC	490	92	105	87	89
41	ACT	.65	MID DIST	382	87	100	81	85
42	S/B	.68	COKE DRM	400	74	74	76	77
43	ACT	.68	COKE DRM	400	98	117	76	85
44	ACT	.85	GAS OIL	460	108	112	77	102
45	S/B	.85	GAS OIL	460	71	71	69	73
46	ACT	.65	ATM RECIRC	415	91	98	85	94
47	ACT	.71	MID DIST	436	119	173	73	78
48	ACT		HC	460	77	112	72	77
49	ACT	.57	JET SPLITR	680	77	81	75	89
50	S/B	.57	JET SPLITR	680	72	88	73	77

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