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Comparison of contacting wet and dry gas seals for main pipeline pumps in NGL services

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ABSTRACT

Recent incident reports and studies of pipeline equipment indicate that pump seal performance is likely at the root of a significant increase in releases to the environment. Although these releases are small compared to a breach in a pipeline, they are of great concern to pipeline companies. While crude oil and refined fluid pipelines have been around for a long time, the pumping of natural gas liquids (NGLs) such as ethane, propane, butane and various mixtures of these liquids is relatively new and presents demanding challenges for the mechanical seal manufacturer and pump OEM's. API (American Petroleum Institute) 682, the governing mechanical seal standard for mechanical seals in hydrocarbon services, is a great foundation for the sealing of process plant equipment. However, for pipeline services API 682 is of limited use due to more demanding operating conditions as well as the different operating character of pipeline pumps.

Generally, two seal face lubrication technologies can be applied to seal NGL Pipeline Pumps with dual unpressurized seals:

A contacting wet lubricated mechanical seal (2CW-CS / Arrangement 2 Contacting Wet – Containment Seal)
A non-contacting Dry Gas Seal (2NC-CS / Arrangement 2 Non Contacting – Containment Seal)

Both sealing solutions include a high-pressure non-contacting containment seal to protect the environment.

Within this paper we discuss the general design aspects for two different sealing technologies, in particular the leakage and friction behavior in NGL services. The impact of critical operating parameters like vapor pressure and temperature margin, flush flow rates, solids handling, axial shaft shuttling is assessed. In addition, the safety, leakage containment and monitoring related aspects are described, summarized and compared with the mechanical seal recommendations.

INTRODUCTION

1. BACKGROUND INFORMATION

Main pipeline pumps transport natural gas liquids such as ethane, propane, butane and various mixtures. It is generally accepted that the mechanical seal is the most sensitive component in a pump and usually drives the need for maintenance and repairs. This is especially true in the NGL pipeline industry due to challenging operating conditions in combination with poor lubricating characteristics of typical NGL fluids. Seal chamber pressures can be as low as 50 psig (3,45 barg) and as high as 1440 psig (99,2 barg) at rpm's variable up to 5000. Shaft diameters will vary between 2,5 to 5,5 inches (63,5 to 139,7 mm). Pump design is nearly always Between Bearing Type 3[1], and many operate with suction pressures close to the vapor pressure of the NGL at ambient temperature or with high suction pressures when pumped in series. To get a better understanding of the degree of difficulty of an application with respect to seal face friction, wear and leakage, it is useful to compare three different pipeline applications handling a light crude oil, a refined fluid such as gasoline, and a light flashing fluid such as propane.

Figure 1 shows an f-G plot for mechanical seal faces in general, i.e. regardless of OEM or seal type. Whereas f is the overall coefficient of friction, G is a hydrodynamic coefficient that characterizes the lubrication regime for a set of simple flat seal faces with a specific hydraulic layout under viscosity of the fluid, seal face angular sliding velocity, pressure differential. Mechanical seals operate within three lubrication modes: (1) dry contact friction without any fluid film support, (2) boundary friction or mixed

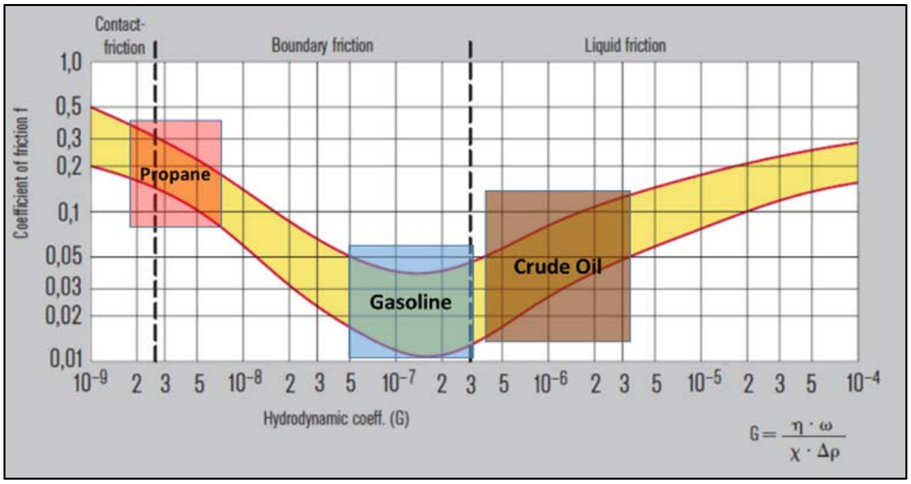

Figure 1: Lubrication diagram of mechanical seals

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[1] Between Bearing Typ3 (BB3) is a API 610 pump type

lubrication, i.e. part mechanical contact and fluid film load support and (3) liquid friction or full fluid film lubrication, i.e. no face contact.

Table 1 summarizes the operating conditions for a seal on a 4” shaft diameter turning at 3600 rpm with an individual design for fluids with high specific gravity.

Fluid	Pump operation	Suction Pressure (Psig/[bar])	Specific Gravity	Viscosity (cP)	G-number
Water	single	50/[3,4]	1	1	5.0E-07
	series	900/[62,1]	120	80	5.3E-08
Crude Oil	single	50/[3,4]	0,85	5	3.8E-06
	series	900/[62,1]			4.1E-07
Gasoline	single	50/[3,4]	0,7	0,5	3.8E-07
	series	500/[34,4]			4.1E-08
Propane	single	300/[20,7]	0,5	0,07	1.5E-08
	series	1100/[75,8]			4.7E-09

Table 1: Pipeline operating conditions

The diagram illustrates that from a frictional perspective, the seal faces in the crude oil application will tend to separate and operate on a thin fluid film due to hydrodynamic effects in the seal face gap. There will be some visible leakage with very little to no wear of the materials. A similar seal design applied in gasoline applications will operate with slight contact but wear and leakage will still be minimal. In propane application the seal would operate with strong contact friction, especially in the second or third pump when pumping in series and will wear out quickly and sensitive to face damages. Other common NGL’s such as Y-grades (variable compositions of ethane, propane, pentane and butane), ethane-propane mixtures and pure ethane will all operate in the region of the propane case example in the region of high contact, special features in the faces will be necessary to enhance face lubrication and extend the lifetime of the seal. As compared to gasoline and crude oil, NGL fluids will vaporize in the seal face gap, as a result of the pressure drop across the seal faces and the face temperature rise due to friction. This additional complication must be dealt with through specific features in the seal design and adequate seal chamber pressure and flush flow rate in the piping plan of the primary seal.

Other challenges of pipeline services involve the operation of the pumps and pipeline, i.e. variable product demand, batching of different NGL’s and refined fluids, intermittent operation, variable speeds and pressures, operation off BEP, occasional presence of solids, limited accessibility for personnel, no utilities, and single or series/parallel pump operation. All these characteristics result in a very tough demand for mechanical seals.

To achieve satisfactory operating performance of the mechanical seal both the seal layout and the operating mode need to be adjusted in order to fulfill the demanding characteristics of the NGL application.

2. DESCRIPTION OF THE SEAL DESIGN OPTIONS

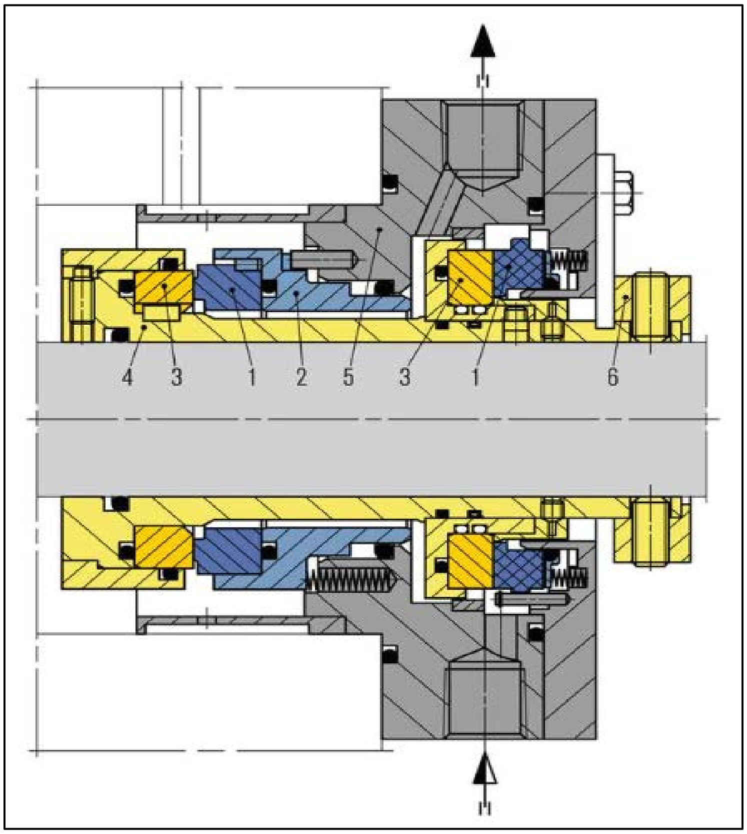
Figure 2: Wet seal design shows for comparison two sealing options with specific design for low gravity fluids. Yellow colored parts rotate and are connected to the shaft, grey colored parts are stationary and connected to the pump case or seal chamber. Dark yellow parts are the rotating seal faces or mating rings. Dark Blue colored parts are the stationary faces. Both designs are dual, unpressurized “tandem” seals (API 682 Arrangement 2) with the springs of both the primary and containment seal stationary in the seal flange, which connects to the pump case. They utilize the same piping plans to operate and monitor mechanical seal performance: plan 02, 11 or 12 for the primary seal, plan 72, 75 or 76 for containment seal. The containment system allows monitoring of the leakage rate by measuring the back pressure created by the gaseous leakage flow against a 1/8-inch orifice before it escapes to the environment.

Conventional (wet) mechanical seals with a typical face width in the range of 5-8mm use an adjusted hydraulic layout to assure proper lubrication and minimal or no mechanical contact of the two sliding faces in operation with low viscos fluids. This is needed to assure full-face separation and contact free operation. The wet mechanical seal has an advantage if different fluids from non-vaporizing to vaporizing fluids are pumped. This happens normally in multi fluid pipelines when light ends, and heavier products are pumped like ethane, propane, Y-grade and Gas fuel or Kerosene. As mentioned above the lubrication in the mechanical seal gap needs to be maintained at all times. Therefore, the wet mechanical seal is a hybrid mechanical seal optimized to handle the wide operation range without any contact friction between the seal faces.

Gas seals with a significantly enhanced face-width have a higher likelihood of reaching contact free operation even with very low viscous fluids. The gas lubricated mechanical seals rely on a thin gas film between the mechanical seal faces to assure proper lift off and no mechanical contact of the two sliding faces during operation. The gas seal faces will only touch during start up and shutdown of the pump. The gas mechanical seal has its advantage if light ends like methane, ethane, ethylene are pumped, also for CO2. Further differences in the design layout of the seal usually relate to features that are application or OEM/user specific such as the sleeve fixation to the shaft, stuffing box dimensions and other pump/seal/piping plan interactions. Both seal face designs however are standardized to cover typical shaft diameters, seal chambers, pressures and speeds across a wide spectrum of fluids, from very light such as ethane to heavier refined fluids such as gasolines and light oils.

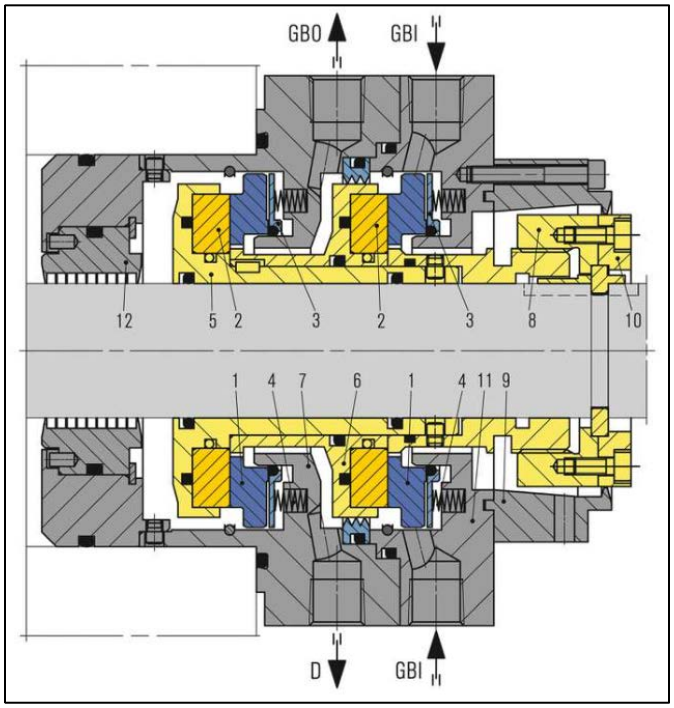
The performance and service life of a mechanical seal depends on several factors internal and external to the seal. The ability of the seal faces to withstand damage because of inherent difficult lubrication conditions, under variable operating conditions of the pipeline pump, is fundamental for a high probability of acceptable performance. This can only be achieved with materials and seal face shapes that are stiff, thermally conductive and wear resistant. External, operational factors that can be at the root of seal troubles are related to

- the vapor pressure and temperature margin of the fluid in the area of the seal faces
- the flush flow rate that is injected in the seal face area
- the cleanliness of the flush fluid
- mechanical, high frequency movements that are induced by the shaft during operation.
- the operation of the pump



1	Seal face
2	Face housing
3	Mating ring
4	Shaft sleeve
5	Housing
6	Set ring

Figure 2: Wet seal design, 2CW-CS



1	Primary seal face with diamond material, stationary
2	Primary mating ring with diamond material, rotating
3	Thrust ring
4	Spring
5	Shaft sleeve and seat retainer
6	Intermediate sleeve
7	Housing
8	"Adjustable" nut for axial misalignment
9	Split ring
10	Clamping ring
11	Cover
12	Process side labyrinth
GBI	Gas Buffer Inlet
GBO	Gas Buffer Outlet
D	Drain

Figure 3: Dry gas seal design, 2NC-CS

Experience shows that both seal design options can provide consistent performance. The differences in the seal design options are in the relationship of acquisition costs versus risk for failure. Whereas comparison of the acquisition cost is straightforward, the “risk for failure” comparison is not. In the next section, an effort is made to assess each seal’s vulnerability to seal face damages under adverse conditions of the key operational factors.

3. FRICTION, WEAR AND LEAKAGE BEHAVIOR OF THE PRIMARY SEAL

The general lubrication diagram in Figure 1, clearly illustrates why NGL’s can be hard to seal reliably with conventional flat seal faces. Although plain flat seal faces may work adequately in the lower pressure/shaft diameter range, i.e. typically below 500 psig (34,4 barg) and 4 inches (101,6 mm), they will be vulnerable to damage and excessive wear in higher pressures as for example in a second pump in series.

To enable the seal faces to work properly across a wide operating spectrum, lubrication enhancement features are necessary to reduce friction and wear at the expense of higher leakage rates. The lubrication enhancement feature can be as simple as a pre-machined convex tapered face profile (V-shape) in a wet seal to bi-directional, shallow precision manufactured grooves in a dry gas seal. Figure 4 shows different examples for typical lift off grooves for wet and dry mechanical seals used in NGL services. In all designs, the result is a strong reduction or elimination of mechanical contact between the seal faces, hence low heat generation with very little wear to the sealing faces. From a mechanical seal face design perspective, both design options are calculated for their predicted behavior with respect to power consumption, operating gap geometry, leakage and face temperature under several load cases.

Figure 4: Three-dimensional groove designs

Dynamic testing on a test fluid allows for verification of the calculated results and fine tune the seal faces as needed for effective performance across a wide operating spectrum. What is important is that transient field conditions and most fluids are nearly impossible to mimic because of HSE (Health Safety and Environment) and other concerns. In other words: vibration levels are low, axial shaft displacements are not present during the tests. Vapor pressure and temperature margin, flush flow rate and cleanliness of the fluid are all well controlled. The real world is often quite different.

The most important design requirement for seal faces to perform in NGL pumps is controlling the thermal and pressure induced deformations so that the original sealing gap profile varies little across a wide range of fluids, pressures and speeds. The magnitude and direction of these distortions is optimized through design with customized calculation software and selection of the best materials.

The face materials must be wear resistant, thermally conductive and stiff. The highest wear resistance is achieved by applying a microcrystalline diamond layer on a silicon carbide base material. This relatively new material feature adds protection against damage when the seal faces would touch for one reason or another or if particles are present in the pumped fluid. The other material that has proven to perform very well in the NGL field is a hybrid of silicon carbide and carbon in one homogenous structure (Composite SIC + Carbon). When run against silicon carbide (SIC) or tungsten carbide (TC), this hybrid exhibits high load capabilities and a good tolerance for poor lubrication conditions and solids.
Table 2 shows that this material group has several favorable properties that make it the preferred seal face material as compared to carbon for NGL services. Field experience shows that antimony carbon appears vulnerable to damage and excessive wear in the higher-pressure ranges of the NGL pipeline application field.

Properties	**Composite SIC + Carbon**	**Carbon**	**SIC**	**TC**	**Diamond**
Thermal expansion 1/K	3,0 $*10^{-6}$	6,4 $* 10^{-6}$	4,0 $* 10^{-6}$	5,0 $* 10^{-6}$	1 – 4 $* 10^{-6}$
Thermal conductivity W/mK	125	12	120	80	2000
Modulus of Elasticity kN/mm²	140	24	390	600	390

Table 2: Seal face materials overview

Vapor Pressure Margin of the NGL in the seal chamber

Figure 5 shows an ideal example of a pressure drop in the mechanical seal face gap. A real pressure drop curve is difficult to predict as several boundary conditions are present in the seal gap, but it shows theoretical the seal chamber pressure and temperature in the area of the seal faces. The vapor pressure margin of the fluid in the seal chamber must be maintained at a minimum of 50 psi (3,44 bar) for a wet seal to stay out of trouble. This value may be marginal for the larger shaft sizes, lighter fluids and higher RPM's and can be increased by adding a bushing in the throat of the seal chamber and an API piping plan if needed.

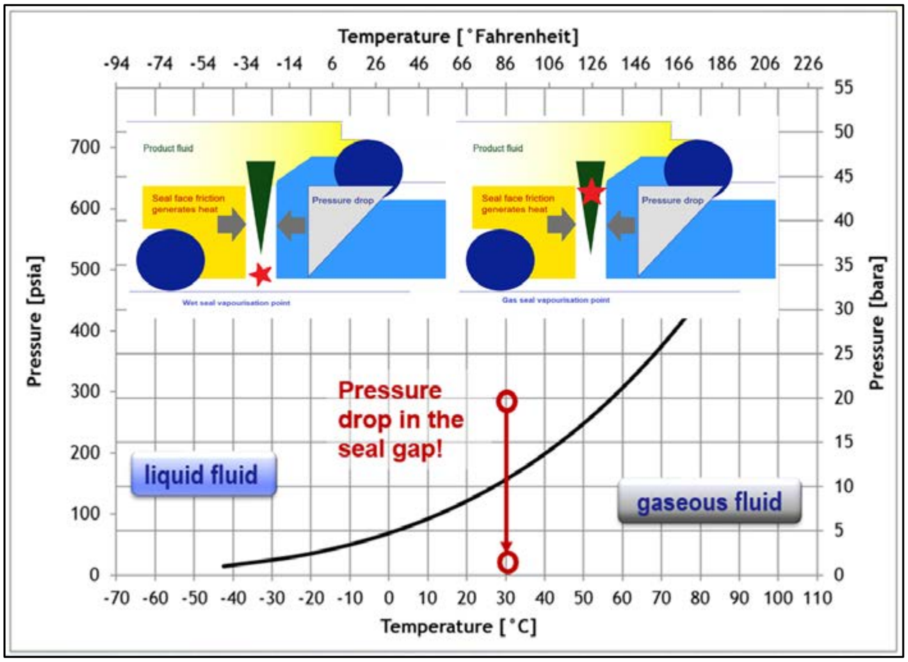


Figure 5: Ideal Sealing Gap of a mechanical seal during sealing situation

Contrary to the wet seal, rapid vaporization enhances the performance of the DGS as the seal faces are typically designed for a gaseous fluid, i.e. a low vapor pressure margin (VPM) is not critical for gas seals. Instead, they tend to be limited by high VPM which may cause the fluid to stay in the liquid phase until it exits the seal faces into the containment chamber. However, gas seal field experience and lab tests show that this condition does not result in face damages but in a higher leakage rate due to increased hydrodynamic forces in the sealing gap. Since the seal chamber pressure is close to suction pressure in a typical NGL pump, the minimum suction pressure set points should consider the VPM requirement of a wet seal but not for a gas seal.

In summary, it is safe to say that from a VPM sensitivity perspective, the gas seal is less sensitive to damage at low VPM whereas the wet seal is more reliable if the VPM is higher.

Flow rate and cleanliness of the flush fluid injected in the seal face area

Besides the VPM, the flow rate and the importance of the cleanliness of the flush fluid stream to each seal is evaluated for both sealing options. For the wet seal, the minimum flow rate is calculated based on the maximum anticipated seal face power across all possible operating modes of the pipeline pumps. For the gas seal, the minimum required flush flow rate is calculated based on a minimum velocity requirement of clean flush fluid through the throttle bushing gap on the primary side of the gas seal faces. This is intended to prevent back flow of unfiltered fluid into the seal face area. Practically, it results in flow rates of 1 to 3 GPM (3,8 to 11,4 L/min). In fact, low flow is desirable for a gas seal as the cleaned flush stream will heat up and vaporize faster. Wet seals on the other hand, can generate more heat and therefore require typical flow rates from 5 GPM (18,9 L/min) up to sometimes 20 GPM (75,7 L/min). This flush flow parameter offers another plus for the gas seal as the minimum required flush flow rates are much lower as compared to wet seals. They are not as vulnerable to complete loss of flush as a wet seal is. Two benefits for the DGS seal that may deserve consideration in the selection process: significant lower recirculation loss in the pump, i.e. a slightly higher throughput through the pump, smaller filters in the piping plan 12 and not sensitive to loss or reduction of flow, if only for a reasonable short period.

Pipeline solids handling

The solids handling capability of the wet seal is better as the average sealing gap width is smaller which makes it more difficult for particles to enter the seal gap. The closing spring force of the wet seal is higher which makes it less prone to hang up failures due to solids buildup in the spring and dynamic seal areas over time. On the topic of the solids, the wet seals will still offer a benefit. The weight of this parameter should be low with an adequate filtration system but over time fine particles will still enter the seal chamber area and it is possible it may drive to a long-term life of the seal faces and dynamic sealing element.

Displacements of the shaft

During transient operation of the pump, the seal faces may have to cope with increased levels of vibrations and axial shaft displacements. Such movements, if excessive and repetitive, can cause trouble for the seal faces and its secondary seal. A way to reduce the seals' sensitivity against shuttling is by adding diamond coating to the seal faces and a hard coating under the dynamic sealing element. O-rings can be substituted with low drag, spring energized seals - sometimes called U-cups - to further reduce the breakaway and sliding force of an O-ring. Of course, the most effective way to reduce movements is to maintain small thrust bearing clearances and operate the pump within acceptable vibration limits, although that is not always possible.

From "an ability of the seal faces to handle axial movement during operation", the wet seal appears more vulnerable as compared to the gas seal. The reason is that the fluid is already vaporizing at the beginning of the seal gap, which means that the gas seal faces are separated by a gas film which is compressible and generates a resistive opening force, if the closing force increases because of the movement. In other words, the film acts as a cushion between the two seal faces. In the wet seal on the other hand, an extra axial force may "temporary" increase the load on the face materials because the liquid is incompressible, hence hard contact could occur that lead to the onset of slight damage and higher leakage rates.

One safety aspect relates to the seal sleeve fixation to the shaft. Wet lubricated mechanical seals typically use the traditional set screw drive, but also a split ring/key design can be used. Setscrews can slip if they are not torqued properly or if an unforeseen pressure surge would take place. An excessive axial movement of the shaft sleeve would be the consequence with the seal faces being subjected to the full hydraulic force of the shaft sleeve. In such an upset scenario, the likelihood of severe damage and fracturing is high. The split ring approach eliminates this risk altogether. Figure 3: Dry gas seal design before just shows an example for both designs. Generally, all sleeve fixations are possible for both sealing solutions, whereas the preferred solution should be the split ring/key design.

4. LEAKAGE CONTAINMENT AND MONITORING RELATED ASPECTS

Monitoring of the seal typically consists of measuring the backpressure in the containment system which is indicative of the leakage behavior of the seal faces. The flush flow rate is usually monitored but not directly measured. The seal chamber pressure is typically not measured as it is close to suction pressure.

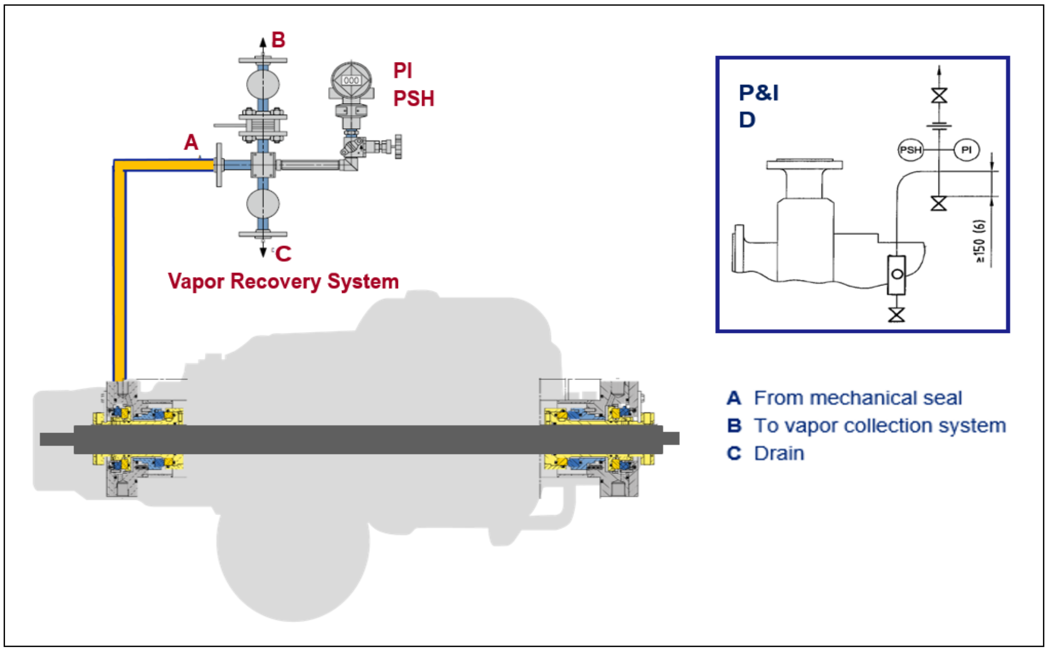


Figure 6: API Piping Plan 76

Figure 6 shows the typical containment-piping plan for flashing hydrocarbons. It is used with arrangement 2 seals (dual unpressurized) to route, dispose and monitor the mechanical seal face leakage of the primary seal. Whereas in a process plant, the gaseous leakage from the API Plan 76 flows to a flare or vapor recovery system, in a pipeline application, the leakage flows into the surrounding environment.

Table 3 shows the results of the orifice backpressure in the plan 76 for the propane case. A substantial amount of propane emissions ends up in the environment if a slight backpressure is created due to excessive leakage of the primary seal. The maximum anticipated leakage rates of the two sealing options for our propane case at max suction pressures will range up to 1 l/hr (= approx. 4,8 Gallon/day for propane) for the wet seals and 1-2 SCFM for the gas seal. The equivalent backpressure in the API Plan 76 equates to 5 - 6 psig (0,34 - 0,41 barg). In other words, for the most typical of NGL fluids, a well operating seal should show near 0 psig. At 5 to 10 times the max. calculated leakage rate, the likelihood is high that operating mechanical seals with backpressures of 1 psig or higher implies damages or excessive wear of the seal faces or an O-ring that is leaking. This means the seal can continue to operate, however, at the expense of a substantial environmental impact.

Propane Temperature = 68F (20°C)				
Back Pressure in API Plan 76 in PSIG	1	5	10	15
Gas Volumetric Flow in SCFH	47	100	136	164
Equivalent Seal face Volumetric Leakage flow in GPD	33	71	95	116
Max. Anticipated Leakage from the seal faces in GPD	6,3			
Max. Anticipated Leakage from the seal faces in litre/hour	<1			
Equivalent Back pressure in API Plan 76 in PSIG	0,1			

Table 3: Back pressure calculation

Alarm set points are set at 10 psig (0,68 barg) or higher. The reason for these relatively high set points (significantly higher than normal seal leakage) is to avoid frequent “nuisance” alarms and/or pump shutdowns. They are called “nuisance alarms” because in many cases the seal recovers soon after it started leaking excessively. These sudden releases through the faces are most likely the result of instabilities in the machine and/or seal itself. These events usually occur during starts and stops of the pump, for example when the shaft will tend to move a bit axially, the amount will depend on several factors related to the thrust bearing clearance.

Out of field installation typically leakage values for contacting wet lubricated mechanical seal are in the range between 0 - 5 psig (0 - 0,34 barg) on the API plan 76. This depends on how the pump is operated. For non-contacting Dry Gas Seal typical leakage values start at 0,5 – 1 psig (0,034 - 0,068 barg) on the API Piping Plan 76.

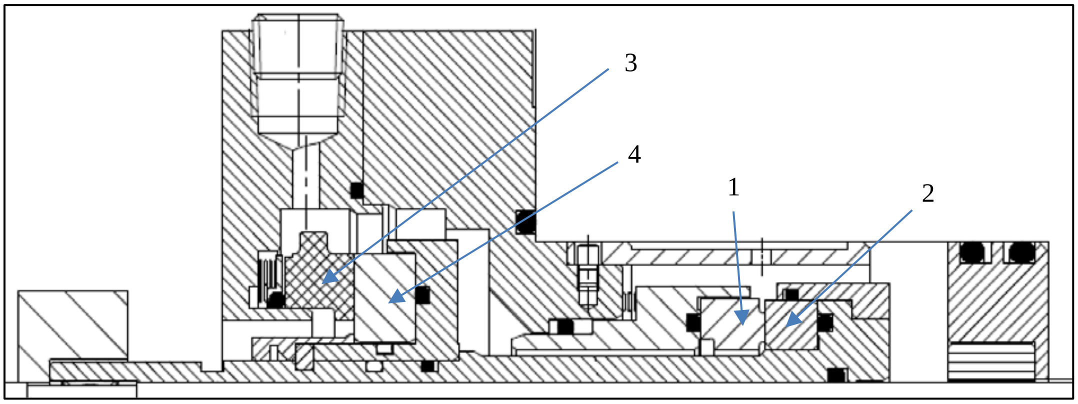
For operational safety, the containment seal needs to be specially looked at. The containment seal is the last barrier between the pump cavity and the atmosphere. In case of a inboard seal failure, the outboard seal needs to contain the product inside the pump. Therefore, the containment seal needs to be rated to the full pipeline pressure. Since seal face materials tend to be brittle, the potential for fracture is real. This aspect needs to be considered and can be dealt with through seal design features that minimize the likelihood of total loss of containment. In that case both sealing options have a special high pressure containment seal that is rated for full pipeline pressure in both dynamic and static condition.

6. FIELD REFERENCES

Both sealing solutions have been fully tested on R&D test rigs and have proven their capability and suitability to operate on NGL pipeline pumps. To demonstrate the above-described sealing solutions, different examples in NGL pipeline applications were taken. Both solutions are possible with either a contacting wet lubricated mechanical seal (2CW-CS), or a non-contacting Dry Gas Seal (2NC-CS).

Wet lubricated mechanical seals

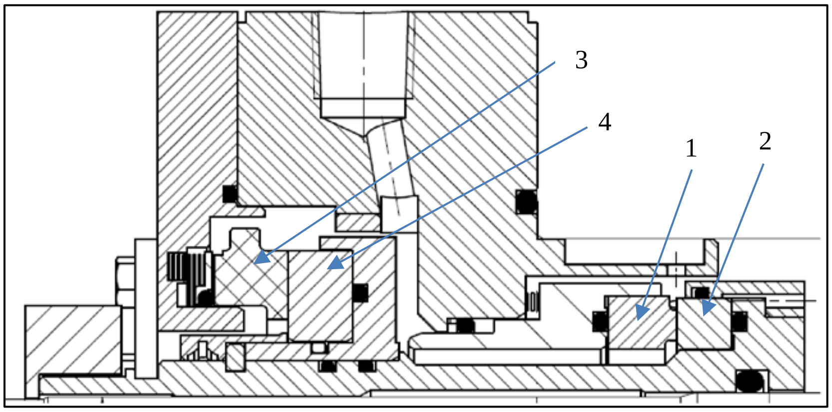
The Service is a NGL Pipeline pump with a wet mechanical seal. The Pipeline runs from Southeast Texas to Central Texas. The pump is a BB3 pump and operated with 2000 - 3570rpm and has a shaft size of 5” (127mm). The suction pressure is between 325 – 500 psig (22,4 - 34,4 barg) and the pump delivers between 1350 - 1850psig (93 – 127,5 barg) head. The NGL Mix is pumped between 60 - 130°F (15,5 – 54,4°C). The seal is designed for a dynamic sealing pressure of 1450psig (100 barg) and a static pressure of 2250 psig (153 barg). The seal chamber pressure can vary between 425 - 800 psig (29,3 – 55,1 barg). To assure the performance the vapor pressure distance had been increased with an API Plan 12 with multi point injection. The stuffing box includes a separate close clearance throttle bushing. The 2CW-CS seals have been in operation for 3 and a half years. More than 40 seals have been supplied to date.



1 Wet seal face
2 Wet mating ring
3 Containment seal face
4 Containment mating ring

Figure 7: Wet seal reference in NGL Pipeline, 2CW-CS

The Service is a NGL Y-Grade application in Texas which runs from West to East Texas. The pump is a BB3 pump and operates at 3550rpm with a Shaft size of 4.45” (113mm). The suction pressure is 450 psig (31barg) and the pump delivers between 1435 – 1682 psig (99 – 116barg) head. The Y-Grade fluid temperature is between 70 - 100°F (21 – 37,7°C). The seal is designed for a MAWP of 2220 psig (153 barg). The Seal chamber pressure has 494 psi. To seal is supported by an API Plan 12 with multi point injection and API Plan 76. The 2CW-CS seals have been in operation since 2020 in 10 pump stations.

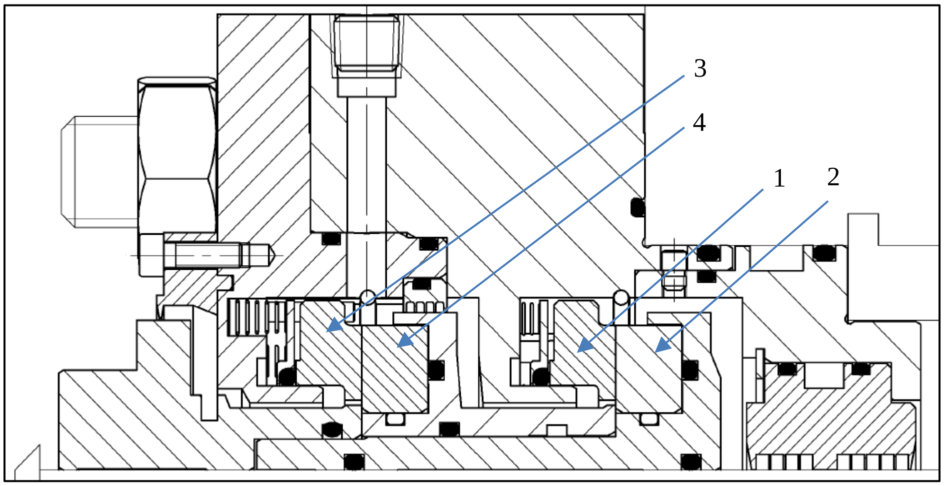


1 Wet Seal face
2 Wet mating ring
3 Containment Seal face
4 Containment mating ring

Figure 8: Y-Grade wet seal application, 2CW-CS

Dry gas mechanical seals

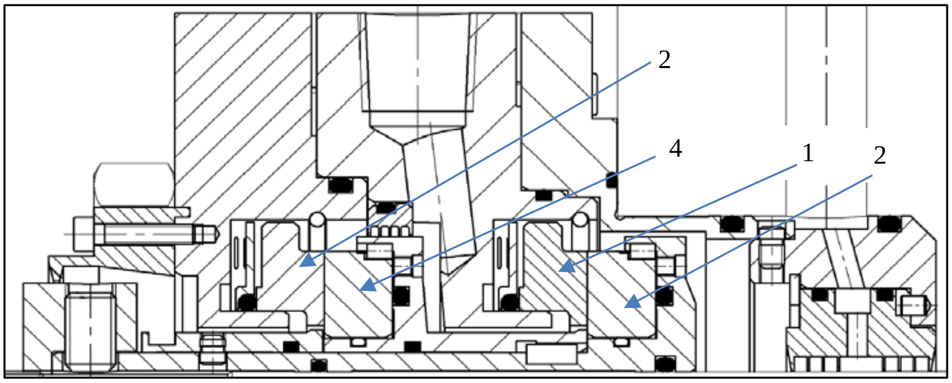
The service is a ethane pipeline pump in Louisiana USA using a dry gas seal. The pipeline pump stands in Plaquemine. The pump speed is at 3570rpm and has a shaft size of 2.766” (70mm). The primary seal pressure is between 950 – 1000 psig (65,5 - 69 barg). The ethane has an inlet temperature between 60 - 100°F (15,5 – 37,7°C). The seal is designed for a dynamic sealing pressure of 1250psig (86,18 barg). The seal faces are designed with lift off grooves. To assure performance, a labyrinth had been installed in front of the seal connected to the API Plan 12. Besides this, the seal is connected to an API Plan 76. The 2NC-CS seals have been in operation for 4 years.



1 Dry gas seal face
2 Dry gas mating ring
3 Containment seal face
4 Containment seal mating ring

Figure 9: Ethane dry gas seal installation, 2NC-CS

The service is a multi-fluid (batch) pipeline pump in East Texas USA using a dry gas seal. The pipeline pump is an axially split multistage pump. The pumped media is a batch of EP-Mix, propane, n-butane and iso-butane. The pump speed is between 2500 - 3600rpm and has a Shaft size of 3.5" (89mm). The primary seal pressure is between 350 – 650 psig (24,13 – 44,82 barg). The multi-fluid has an inlet temperature between 40 - 90°F (4,4 – 32,2°C). To assure the performance the seal faces are designed with lift off grooves. A labyrinth had been installed in front of the seal connected to the API Plan 12. Besides this, the seal is connected to an API Plan 76. The 2NC-CS seals have been in operation for 3 years.



1 Dry gas seal face
2 Dry gas mating ring
3 Containment seal face
4 Containment seal mating ring

Figure 10: Multi fluid dry gas seal, 2NC-CS

7. CONCLUSIONS OF COMPARING WET MECHANICAL SEALS AND DRY GAS SEALS IN NGL SERVICE

As a means of comparison, we have taken two summarized approaches and present them in Tables 4 and 5. In Table 4 we list the advantages and disadvantages for each design option. Then in table 5 we rank each design option relative to the operational factors that may impact the reliability of the seals. The ranking is based on actual field experience and the numbers are simplified from "good resistance" as 1, to "marginal resistance" as 4. No other weights are given to each factor.

wet mechanical seal	**dry gas seal**
advantage	**advantage**
Operates independently from process fluid, composition and temperature	Less sensitive in operation due to a stable Gas film
Simple supply system	Simple supply system
No product leakage to the environment	No product leakage to the environment
No risk of condensation or icing	Negligible power consumption, even at high speed
Resistant against solids	High reliability due to diamond seal face material
disadvantage	**disadvantage**
100% gas can't be sealed if vaporization takes place in the pump	Not all gas mixtures are suitable, especially non-vaporizing fluids exact Product composition needs to be known
Moderate friction power so cooling is required	Risk of condensation or icing
Higher Power consumption	Operating parameters for all modes need to be known such as Start-up and Slow roll condition

Table 4: Comparison between the two sealing concepts

Comments & general recommendation:

The gas seal with silicon carbide Diamond material ranked as first as it utilizes the best combination of face materials and contact-free operation. Due to enhanced seal face material, a dry gas seal does however allow for periodic contact and is designed to operate with a very thin gas film to generate heat and keep leakage at a minimum. Since the wear rate of the materials will be virtually zero, life of the gas seal is infinite. Face wear is not the only driver for the life of the seal. It is generally accepted that gas seals are sensitive to the presence of solids and therefore filtration is critically important to achieve long run times. Their insensitivity to vapor pressure margin and flush flow rate variations is a key advantage as these potential causes are often mentioned in wet seal failure investigations. The gas seal face design has a larger radial seal face width in order for the sliding area to create a better lift off. Therefore more radial space is required.

Wet seals have a finite “normal wear” life, as they have potential for slight face contact from time to time. The seal faces are more sensitive to adverse effects from its surroundings and increases the risk for the onset of damage and excessive wear. When all the critical operating and design parameters are met, a wet seal works best. When adverse conditions occur, wet seals are more vulnerable as compared to the gas seal. Also, if solids cannot be avoided, the wet seal is better choice than a gas seal. In other operational parameters, especially if only pure ethane or CO2 is pumped, the wet seal shows a higher degree of vulnerability. For multi fluid applications with vaporizing and non-vaporizing fluids, the wet seal provides significant advantages; so long as no highly vaporous fluids like ethane are included. Also, in terms of installation space requirements, the wet mechanical seal has an advantage. The wet seal design can work with a smaller seal face height, as the liquid film is stiffer. This gives the advantage for the wet seal to fit in narrow stuffing box dimensions, smaller than standard API 610 requirements.

Capability to handle adverse conditions related to: **1 = good resistance** **4 = marginal resistant**	**wet mechanical seal**		**dry gas mechanical seal**
	SIC/SIC	**Diamond**	**Diamond**
Low vapor pressure margin	3	2	1
Low flush flow rate	3	2	1
Presence of solids in the pipeline	2	1	3
Exposure to high frequency shaft movements	2	1	1
Multi fluid applications	2	1	3
Stuffing box size requirement	1	1	3
Leakage	2	2	1

Table 5: Seal type ranking

In conclusion, by comparing the two distinct sealing solutions, diamond as a seal face material provides both wet and dry gas seals with beneficial advantages to conventional face materials. This highlights both wet and dry gas seal options to cover the broad spectrum of challenging operating parameters that NGL pipeline pump applications present. Diamond gas seals are the most effective solution for NGL pumps, especially for fluids with specific gravities below 0.4. This group of fluids will tend to have the poorest lubrication related properties and be pumped at higher pressures whether in single, series, or parallel pump installations. Should a wet seal be preferred, using diamond seal faces should also be considered as an option and will ensure the seal faces are less sensitive to any damage. Diamond seal face materials provide the added advantage from a safety perspective in comparison to conventional face materials.

Finally, the decision of sealing philosophy and material selection for main pipeline pumps in NGL services needs to be performed in a close cooperation between the end-user, the pump manufacturer and the mechanical seal manufacturer.

NOMENCLATURE

2CW-CS = Arrangement 2 Contacting Wet – Containment Seal
2NC-CS = Arrangement 2 Non Contacting – Containment Seal
OEM = Original Equipment Manufacturer
API = American Petroleum Institute
DGS = Dry Gas Seal
NGL = Natural Gas Liquids
BEP = Best Efficiency Point
FEM = Finite Element Method
HSE = Health Safety and Environment
PI = Pressure Indicator
VPM = Vapor Pressure Margin
SCFH = Square feet per hour
GPM = Gallon per minute

FIGURES

TABLES

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