The Pros and Cons of Dry Gas Seals Installation in an Existing Synthesis Gas Compressor

Six years ago, in 2000, the Petrobras' Ammonia and Urea plants located in the Petrochemical Complex of Camaçari, Brazil, were revamped in order to increase the capacities to 1500 metric ton/day, in both plants. Several technological upgrades were carried out, as an effort to modernize the process and the equipments. One of these upgrades was the replacement of the synthesis gas compressor shaft seals, from floating ring oil seals to dry gas seals.

The synthesis gas train has two compressor cases, driven by two steam turbines with a total output of 30,400 HP (22,670 kW). The low pressure compressor case suction pressure is 370 psia (25.5 kgf/cm^{2}a) and the discharge pressure is 927 psia (65.2 kgf/cm^{2}a). The high pressure compressor case suction and discharge pressure are 884 psia (62.2 kgf/cm^{2}a) and 2,218 psia (156 kgf/cm^{2}a), respectively. The seals chambers had to be machined to fit the new dry gas seals and the sealing gas panels connections ports. In the low pressure case the seals modification has been a success, we are operating for six years with the seals installed in 2000, without failures. But, unfortunately, it has not been the case with high pressure compressor. In five years of operation, from 2000 to 2005, the HP case seals have failed seven times, presenting an unacceptable failure rate (1.4 failures per year).

The purpose of this paper is to describe the problem and the solution adopted, as well as to discuss the reliability aspects involved in a major change in the shaft sealing system of an existing compressor.

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Introduction

Technological updates have proven to be a major factor in companies competitiveness, either increasing productivity and efficiency of the processes or making the work safer and environmentally friendly. But, we should be careful when making decisions that lead to technological changes, for newer technology does not necessarily mean better solutions to problems or improvement in a machine performance.

Every technology has its own limitations and application range, which we have to take in consideration when designing a new machine or just carrying out a modification in an existing one. It's not different with the dry gas seal technology that, even not being new in concept, is relatively new in applications. Bringing several welcome improvements in centrifugal compressor shaft sealing, dry gas seals have quickly become the type of seal most used by the centrifugal compressors manufacturer. This paper discusses the reliability aspects involved in a major change in the shaft sealing system of an existing compressor, briefly reviews the dry gas seal concept and compares its advantages and limitations with the traditional types of shaft seals, presenting the available bibliography, as well as our own experience with the conversion of a syn gas compressors shaft seals, from floating ring oil seals to dry gas seals.

Dry Gas Seals

The dry gas seal concept is not a new one, but its application in centrifugal compressor shaft sealing has boomed just in last decade or so. Over 80% of centrifugal compressors manufactured nowadays use dry gas seals (Stahley, 2001). It works like a mechanical seal, with a rotating ring running against a stationary ring, but without any liquid lubricating the "contacting" faces. The stationary ring (or primary ring) is pushed toward the rotating ring (or mating ring) by springs. Spiral grooves in the rotating ring (**Figure 2**) generate fluid-dynamic forces that lift the stationary ring off, forming a narrow gap between the rings. So, when running, the seal faces have no contact. The gap varies from 3 to 10 microns depending on the seal type (Godse, 2000) and is determined by the equilibrium between the force due the gas pressure, springs force and pressure force developed by the mating ring grooves.

Dry gas seals are available in several configurations: single, double-opposed and tandem (API 617). The tandem type is the most used in process gas service, mainly in high pressure and/or hazardous gas applications.

Figure 1 shows a typical tandem dry gas seal assembly, where the spiral grooves can be seen on the mating rings.

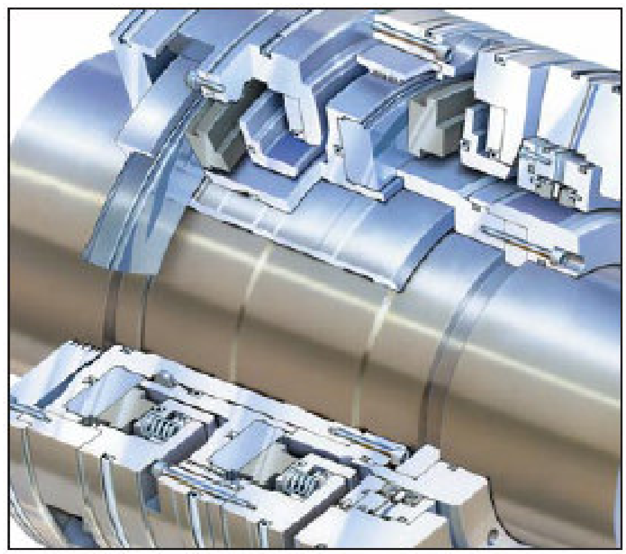

Figure 1: Typical Tandem Gas Seal Assembly

- Courtesy of John Crane -

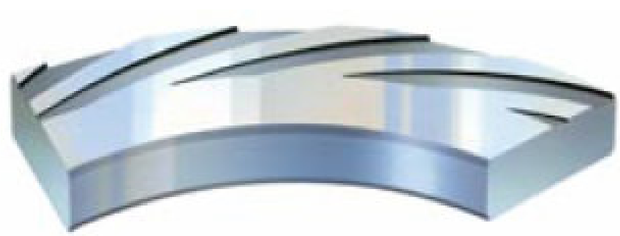

Figure 2: Standard Unidirectional Groove Design

- Courtesy of John Crane -

Due to the very narrow gap between the mating and the primary rings the gas in the seal chamber shall be clean and dry, for solid particle larger than 3 microns (Stahley, 2003) can wear the rings faces out, and liquid particles in the gas make the creation of pressure force between the rings difficult, causing the mating and primary rings running contact, leading to the seal failure due to rings faces premature wear and high temperature. That's why the dry gas seal needs a filtered gas injection in the chamber between the seal and the process gas. The seal gas may come from the compressor discharge or from others sources of clean and dry gas, and is injected with a pressure about 10 psi above the process gas pressure. Needless to say that the seal gas conditioning system is as important as the seal itself.

It is necessary, also, to avoid allowing the bearing lubrication oil to reach the seal faces. It's the function of the barrier seal installed in the bearing side end of gas seal cartridge.

Figure 3 shows a cross-sectional view of typical tandem gas seal, detailing all seal components and seal gas / barrier gas inlet ports, and gas leakage ports.

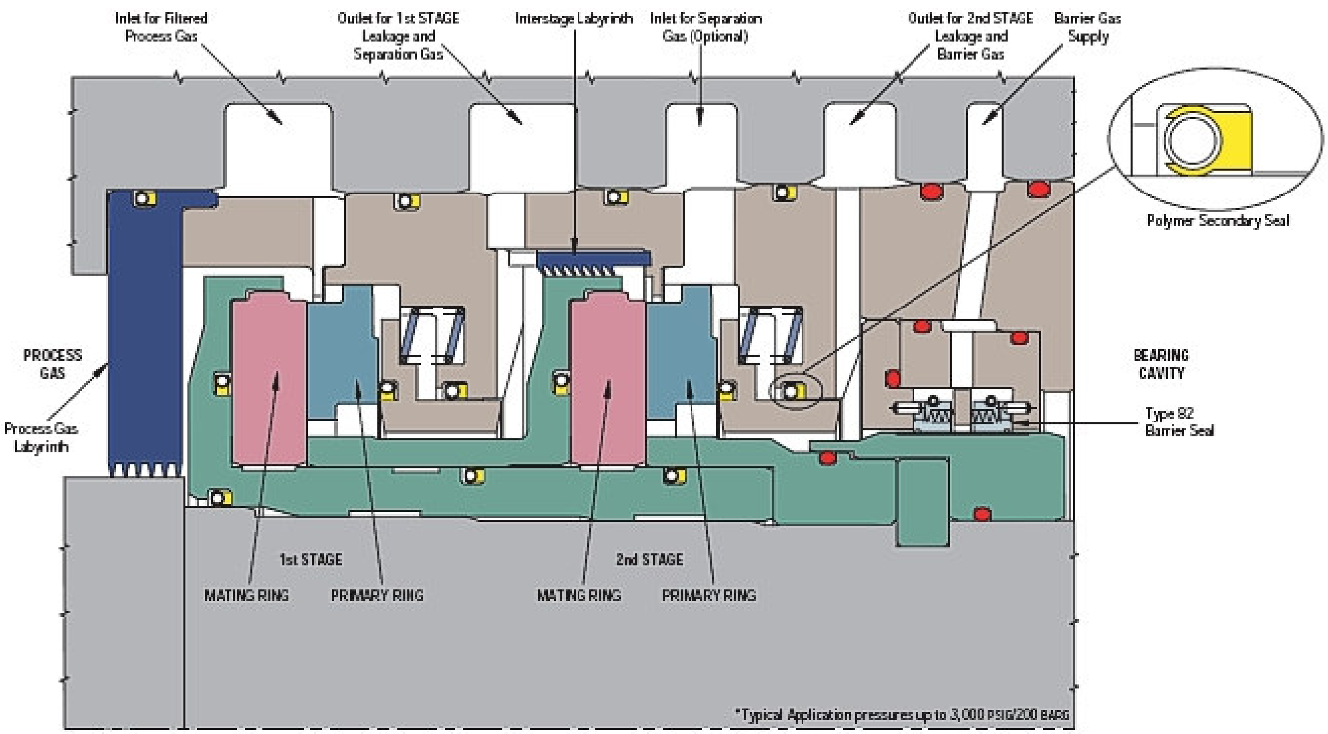

Figure 3: Cross-sectional view of a Typical Tandem Gas Seal

- Courtesy of John Crane -

Shaft Seal Types Comparison

Table 1 shows a comparative economic evaluation of oil seals (**Wet Seals**) and dry gas seals (Bloch, 1998).

Table 1

	Wet Seals	Dry Gas Seals
Seal oil support system costs	Pumps, reservoirs, filters, Traps, coolers, consoles.	None
Seal oil consumption	1-100 gallons/day	No seal oil
Maintenance costs	A major expenditure over equipment life	Negligible
Energy Costs	Seal power loss: 10-30 HP Unit driven pumps: 20-100 HP	1-2 HP
Process gas leakage	25 SCFM & Higher	< 2 SCFM
Oil contamination	Of Pipeline: High clean up costs Of Process: Catalyst Poisoning	None
Toxic and corrosive applications	Buffer gas consumption (eg N_2): 40-70 SCFM	2-4 SCFM
Unscheduled shutdowns	High downtime costs	Very reliable
Aborted startups	Frequent	Rare

The table, presented by Heinz Bloch (1998), deserves some comments:

- It was considered that the dry gas seal system has been design within state of the art, presenting, therefore, a very high reliability and low maintenance costs.
- The costs related with the oil support system (Maintenance costs and energy costs) are a major factor in wet seals disadvantage, comparing with dry gas seals.
- The costs related with oil contaminations are, also, an important factor in favor of dry gas seals.

A key difference between the wet seals and dry gas seals is the support systems. While the gas being compressed is not a major issue in wet seals design, the knowledge of the gas composition, cleanness and presence of liquid, at the entire operating range and all possible process variations that can change the gas specification, are some of the most important design requirements for a reliable dry gas seal operation.

J. Delrahim (2005), from John Crane Inc., affirms that "*Analyzing dry gas compressor seals received from the field for refurbishment validates that most seal failures result from lack of clean and dry buffer gas*". He wrote, also, "*…Common control system designs for gas seals consist of filtration, regulation and monitoring. However, although these control systems typically offer elaborate monitoring and regulation features, the filtration issue is often overlooked. In most cases, users and contractors initially choose standard filtration on virtually every application, regardless of gas composition and/or presence of liquid or condensation occurring in certain gas mixtures…*".

In that sense, R. Aimone (2007), says that "*In reviewing dry gas seal failures experienced in 2006 and previous years, our conclusion is that in a majority of cases, the root cause is that the seal and system configuration were not designed to handle all the actual site operating conditions, including startup, shut-down and upsets that should and could have been anticipated*"

Figures 4, 5 and 6 show a typical differential pressure control support system for tandem dry gas seals (API 614). The standard duplex filters used in this kind of system are not supposed to remove all solid particles and/or liquid of a dirty and/or wet seal gas. For that purpose a properly designed gas conditioning system shall be used, in order to consistently supply pressured, clean and dry gas to seals, either in steady-state operating range or on startups and shutdown transients.

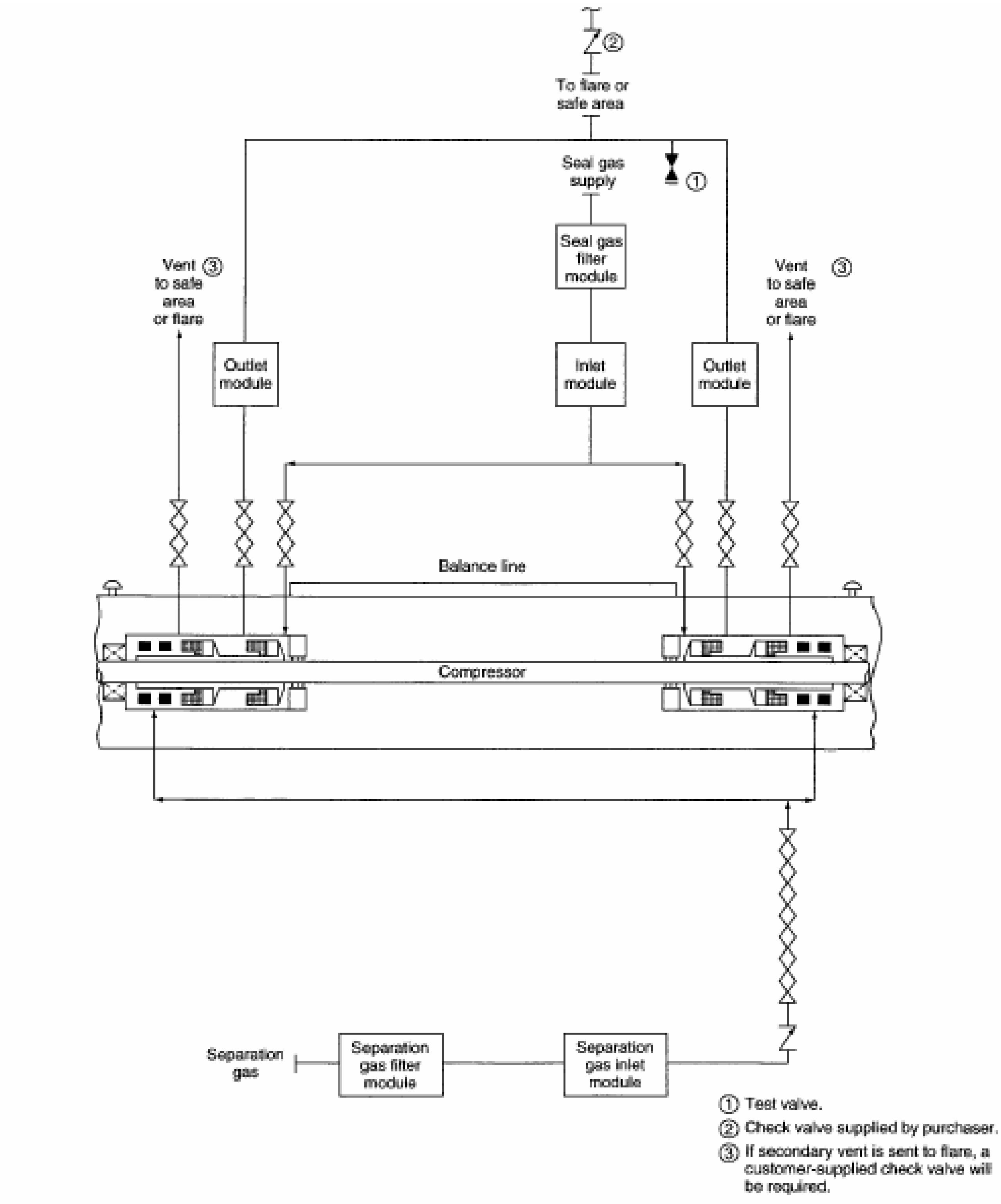

Figure 4: Tandem Dry Gas Seals Support System Schematic
- Courtesy of American Petroleum Institute -

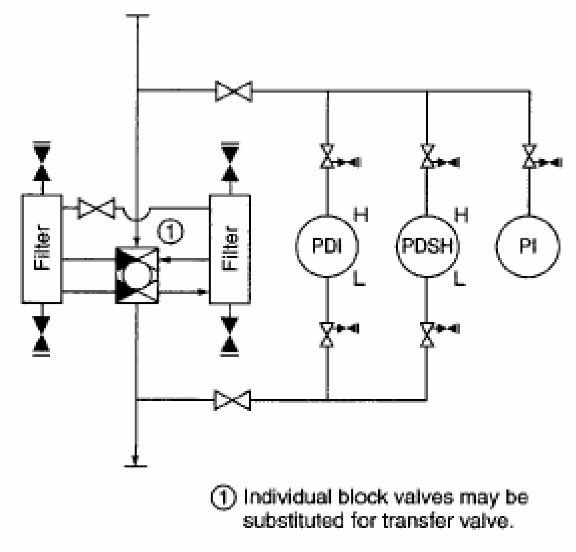

Figure 5: Seal Gas Filter Module
- Courtesy of American Petroleum Institute -

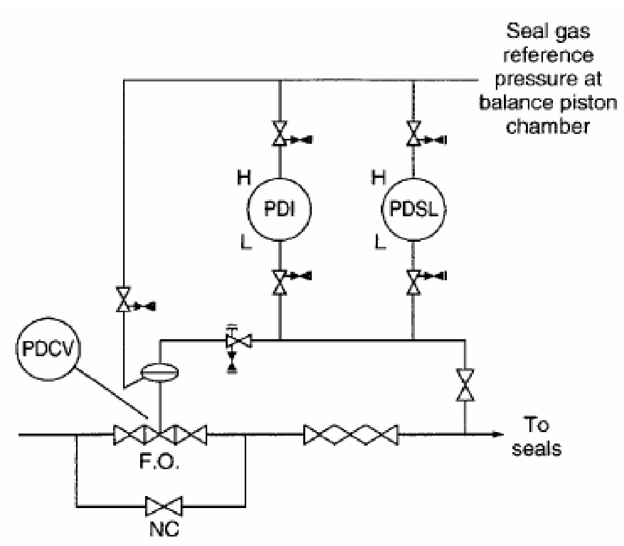

Figure 6: Differential Pressure Control
- Courtesy of American Petroleum Institute -

Why Change? (The Pros)

This is a question everyone should ask before deciding to change the original design of a system or a machine component that has been operating. An important step in a successful conversion from wet seals to dry gas seal is to know all the aspects of the new technology.

The benefits that well-engineered dry gas seals systems can present are:

- **Reliability improvement**. The mean dry gas seals failure rate is around 0.175 failures/year, meaning that we could expect one failure every six years or so (Bloch, 2005). The larger quantity of accessories in the support system is the cause of the highest percentage of downtime for a compressor using wet seals (Natural Gas STAR Partners, 2003).
- **Reduction of unscheduled downtime**, as a result of reliability improvement.
- **Elimination of oil leakage into the compressor**, avoiding the problems and costs related to process contamination.
- **Elimination of lubrication and control oil contamination with process gas**. The sour seal oil reclamation, through degassing tanks into the main oil reservoir, often leads to undesirable oil system contamination.
- **Elimination of the seal oil consumption costs**, including the costs to disposal or reclamation of the sour seal oil.
- **Reduction of operating costs**. The power loss in dry gas seals is much less; as well the energy to operate the seal oil pumps is eliminated.
- **Reduction of maintenance costs**. The wet seal system has many more components that need maintenance effort (e.g., pumps, motors and/or turbines, coolers, control valves, relief valves, etc).
- **Reduction of gas emission**. The wet seals gas leakage, from the traps vent as well as from the sour oil degassing process, is something between 40 to 200 scfm, while dry gas seals leak at a rate of 0.5 to 3 scfm (Natural Gas STAR Partners, 2003).

Why Change? (The Cons)

Unfortunately, every technology has its own limitations.

Listed below are the disadvantage dry gas seals systems can present, taken into account the replacement of existing wet seals:

- **Necessity of compressor heads machining.** In order to provide gas ports and accommodate the dry gas seals, it's often necessary to machine compressor heads (Stahley, 2003).
- **Changes in compressor rotor dynamics.** The wet seals act as dampers and, so, influence the rotor dynamics characteristics of the compressor, as critical speeds, amplification factor and logarithmic decrement. Therefore, it's necessary to carry out a complete rotor dynamic analysis (**RDA**) before replacing the oil seals by dry gas seal. If the results of RDA are unsatisfactory additional damping equipment may be required (Stahley, 2003).
- **Highly susceptible to failures due to presence of dirt and/or liquid in the gas**. The wet seals have much less problems with dirty and/or wet gas, while the dry gas seals reliability depends strongly on a system that assures a steady flow of clean and dry gas into the seals chambers.
- **Reliability can be reduced by transient conditions.** During startups, shutdown or idle in low speeds, the dry gas seals lose the capacity of develop the pressure force that keep the narrow gap between the rings faces, being susceptible, so, to premature failures of the rings in plants that have frequents shutdowns.
- **Higher prices.** A dry gas seal cartridge is much more expensive than a floating ring oil seal assembly. A tandem dry gas seal assembly costs between US$ 50,000.00 and US$ 60,000.00, while a floating ring oil seal assembly costs between US$ 20,000.00 and US$ 30,000.00
- **Higher assembly complexity**. The dry gas seal's support system is less complex than the wet seal's, but the dry gas seal assembly itself is much more complex. The maintenance team only replaces the gas seal cartridges, and sends the used cartridge to refurbishment and static and dynamic test on a test rig in the manufacturer facility. In developing, or underdeveloped, countries this means that seals have to be repaired abroad, and more spares seal cartridges have to be kept in storage than in a country where facilities with test rig are available.
- **Susceptible to failures due to reverse rotation**. The nonsymmetrical spiral grooves are not able to create the pressure force to lift off the primary ring if the compressor runs in reverse rotation. So, if reverse rotation occurs, the seals faces can fail. If reverse rotation is a probable occurrence, bi-directional dry gas seals, which use a symmetrical groove profile, should be considered. Additionally, the unidirectional dry gas seals are different for each compressor end, thus requiring at least two spare seal assemblies for each compressor.
- **Necessity of barrier gas.** It's necessary to avoid that the bearing lubrication oil reaches the seal faces. To doing so, a barrier seal is incorporated in the outboard end of the dry gas seal assembly, and barrier gas is injected into the barrier seal chamber (**Figure 3**). For safety reasons in most cases nitrogen is used as barrier gas. Therefore, a reliable nitrogen source may be necessary.

Case History: A Syn Gas Compressor Seals conversion

Six years ago, in 2000, the Petrobras' Ammonia and Urea plants located in the Petrochemical Complex of Camaçari, Brazil, were revamped in order to increase the capacities to 1500 metric ton/day, in both plants. Several technological upgrades were carried out, as an effort to modernize the process and the equipments. One of these upgrades was the replacement of the synthesis gas compressor shaft seals, from floating ring oil seals to dry gas seals.

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Over the years, the plant had experienced several process contamination events of oil from the floating ring oil seals system. Adding to this were the costs of sour seal oil disposal. For these reasons the syn gas compressor seals were upgraded to dry gas seals. A proposal was requested from the compressor OEM based only on the synthesis gas composition in normal conditions. The proposed design was installed: two sets of unidirectional tandem dry gas seals with standard seal gas support system (panels), for each compressor cases (**Figure 4**).

Each seal gas panel consisted of a standard filtration module (**Figure 5**), a standard differential pressure control module (**Figure 6**) and a vent leakage monitoring module. The sources of seal gas supply to the panels were the compressor cases discharges.

The compressor cases heads seals chambers had to be machined to fit the new dry gas seals and the seal gas panels connections ports.

In the low pressure case the seals modification has been a success. The plant has operated for more than six years with the seals installed in 2000, without any failure. The low pressure case seal's performance has proven that the existing wet seal conversion to dry gas seal can be very successful.

But, unfortunately, this has not been the case with high pressure compressor case. In five years of operation, from 2000 to 2005, the HP case seals have failed seven times, presenting an unacceptable failure rate of 1.4 failures per year.

What has been gone wrong with the HP case seals conversion? Why was the seals reliability so much different between the two cases? First, consideration was not given to the ammonia synthesis reactor catalyst reduction in startup after plant turnaround. During the reduction there was liquid water in the gas flow to the recycle suction. So, the unexpected water was the cause of the first HP case dry gas seals failure, immediately after the seals were installed.

Less than a year after the first failure, the HP case seals failed again. This time a black powder was found in the seal's chambers, clearly indicating that the gas was not as clean as thought. Investigation determined the dirt was coming from the ammonia synthesis reactor catalyst. The filtration module of the seal gas panel was not designed to cope with this kind of dirty gas. To minimize this problem, the HP case source of seal gas supply was changed to a point downstream of the synthesis reactor preheater (121-C), where the gas is cleaner and dry. But during transients in startups and shutdown the seal gas supply point had to be changed back to compressor discharge, upstream of the discharge cooler, causing saturation of the filters. During transients there was not enough differential pressure between the seal gas and the process gas into the compressor case. This allowed the dirty process gas to enter the seal's chambers causing wearing of the seals (**Figures 7 and 8**).

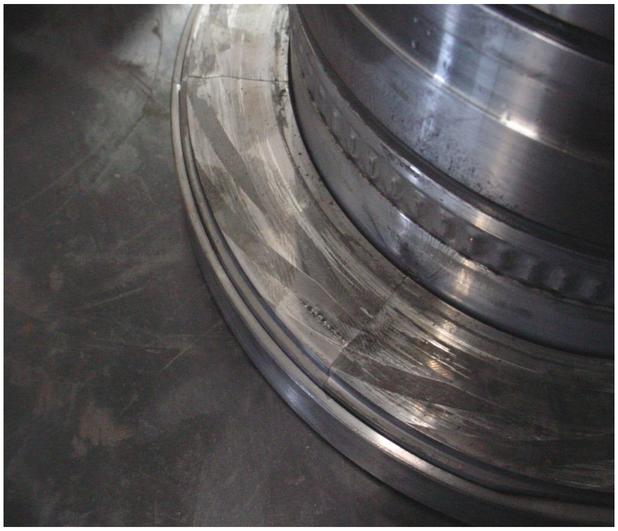

Figure 7: Damaged Mating Ring

Figure 8: Scratches on the Mating Ring

The reliability improvements used to justify the wet seals replacement, were jeopardized by a seal support system, whose design had not taken into account the actual seal gas conditions.

After review of the failures, the compressor OEM carried out a thorough engineering review of the seal gas supply sources and the existing seal gas support system. Based on the seal composition and operating conditions, a simulation of the seal gas pressure and temperature drops expected across the various components within the gas seal system, has been done. **Figure 9** shows the seal gas phase diagram for the two source of seal gas supply.

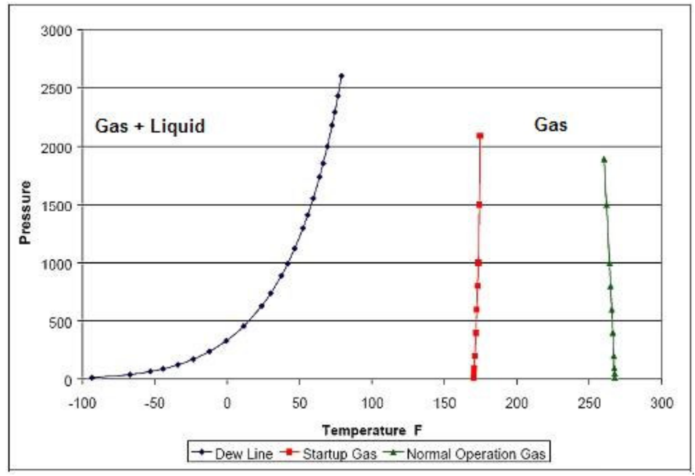

Figure 9: Seal Gas Phase Diagram

Based on the review, the compressor OEM proposed the installation of a seal gas conditioning system, upstream of the HP case seal gas panel. As shown on the seal gas phase diagram, both source of seal gas supply have sufficient margin from the dew point of the gas, and therefore no pre-heater was required in the seal gas conditioning system (**Figure 10**).

The conditioning system consisted of:

- One duplex wet gas pre-filter separator, with automatic drains
- One air driven pressure boost system (To keep proper seal gas differential pressure during startups and shutdowns)
- One relief valve
- 316 stainless steel tubing and fittings

All of the system components were mounted on a single stainless steel fabricated panel.

The seal gas conditioning system was installed two years ago and, since then, the compressors seals have operated free of failures.

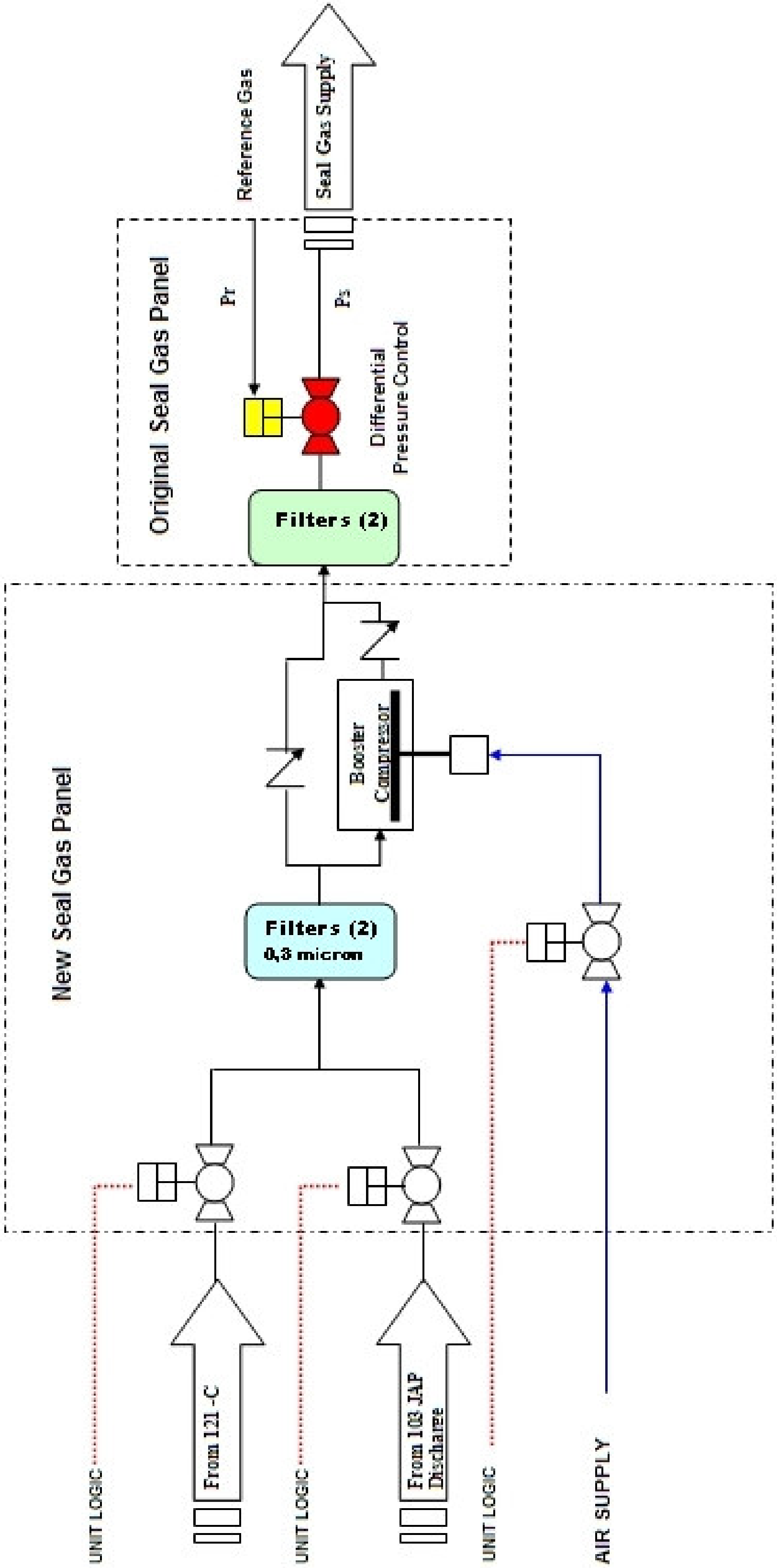

Figure 10: Seal gas conditioning system

Conclusion

Dry gas seal technology development has brought very welcome solutions for the following problems experienced with centrifugal compressors that use wet seals:

- Process contamination and catalyst poisoning with oil,
- Unscheduled shutdowns caused by loss of control of seal oil system and/or seal oil pumps/driven failures,
- Lub/control oil contamination with process gas.

All of these issues are hoped to now be history. It's hard to think today of purchasing a new centrifugal compressor with other shaft sealing system than dry gas seals.

But, the replacement of existing wet seals by dry gas seals is not a straightforward solution for compressor seals related problems. Before making the final decision be sure that:

- It's the best or the only solution available.
- A comprehensive feasibility study has been done, considering the seals chamber dimensions and ports, compressor rotor dynamics, compressor operating conditions and variations, seal gas and barrier gas supply source, reverse rotation and surge occurrence rates, the slow roll or idle operations at low speed and so on.
- The design does not overlook a seal gas conditioning system that is able to assure a steady flow of clean and dry gas to the seals at the proper pressure in the entire range of operating conditions and on startups/shutdowns. Heinz Bloch (2005) wrote: *"…Consider gas seals only in conjunction with a clean gas supply…"*.
- The maintenance facilities and spare parts availability have been assured.
- The maintenance and operating teams training is an important task of the project.

In doing this you will have an acceptable risk for the seals replacement project and can take all the high reliability advantages of a well-engineered dry gas seals system.

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