

Dry Gas Face Seals for Solar® Gas Compressors

Gas Compressor Engineering
Solar Turbines Incorporated

CONTENTS

SCOPE	1
DRY GAS SEAL PRINCIPLES OF OPERATION	1
SEAL FUNCTION DURING DIFFERENT OPERATING MODES	2
DRY GAS SEAL DESIGN.....	3
DRY GAS SEAL DESIGN LIMITATIONS	3
UTILITY REQUIREMENTS FOR DRY GAS SEALS	9
UTILITY REQUIREMENTS FOR SECONDARY SEALS.....	11
SEPARATION SEAL DESIGN.....	12
UTILITY REQUIREMENTS FOR SEPARATION SEALS	13
SEAL GAS SYSTEMS.....	15
APPLICATION CHECKLIST.....	17
SPECIAL TOPICS.....	19
SOLAR'S EXPERIENCE IN DRY SEALS.....	24

SCOPE

This document applies to new equipment gas compressors only. Dry seal technology has improved significantly over the years and the information presented here may not be applicable to some of the prior to 2009 dry seal systems designs. Please contact Solar for information and guidance on the use of dry seals in older units.

This version of PIL 140 includes information about the newer gas compressors and revises some of the terminology used in previous versions to match more closely the accepted usage in the Oil & Gas industry. The data in this PIL is based on the best currently available information but may not apply under all operating conditions. All current production gas compressors have dry gas seal as a standard design. Many older compressor models can be retrofitted to dry seals. Refer to PIL 213 for older compressor models.

DRY GAS SEAL PRINCIPLES OF OPERATION

Dry gas face seals consist primarily of a stationary ring that is attached to the housing and a mating ring that rotates with the compressor shaft. A spring keeps the face of the stationary ring against the rotating face of the mating ring (Figure 1) when the shaft is not turning. Face separation is achieved when the seal pressure reaches 690 kPad (100 psid) across the seal. During operation, the groove pattern in the rotating seal face (Figure 2) pumps the seal gas inward toward the un-grooved portion, or sealing dam, creating a high-pressure area behind the sealing dam. This pressure distribution separates the rotating and static seals, forming a small, controlled gap between 0.0025 and 0.0050 mm (0.0001 and 0.0002 in.) wide. This very narrow gap allows a small leakage flow to pass through. Filtered seal gas, from either an external

source or the compressor discharge, is supplied to the face seal. The extremely small gap clearances of face seals mandate clean and dry seal gas.

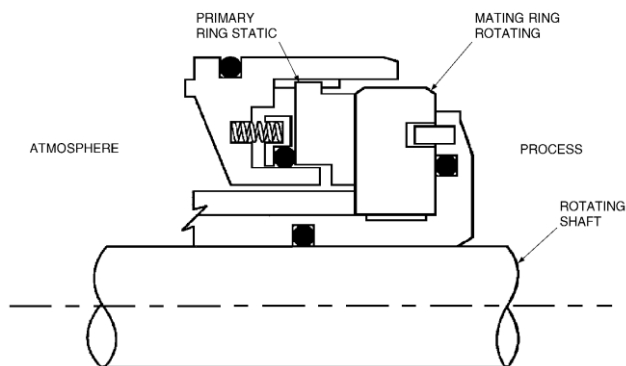


Figure 1. Gas Face Seal Assembly

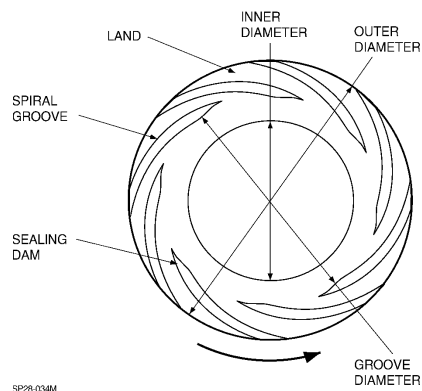


Figure 2. Cross-Sectional View of Rotating Seal Face

In the event the faces approach each other, a rapid rise in pressure instantaneously causes separation. This automatic reversal is self-correcting, and the gap width stabilizes when the hydrostatic and hydrodynamic forces equalize.

SEAL FUNCTION DURING DIFFERENT OPERATING MODES

The seal function at various operating condition modes are as follows:

No Rotation, Case is Unpressurized

The seal faces are held in contact by spring load.

No Rotation, Case Is Pressurized

The seal faces remain in contact up to a certain pressure differential. The seal faces will separate as the pressure differential overcomes the spring force between the faces. The pressure differential will vary due to variations in seal wear/ tolerances.



If an external seal gas source is used, the seal gas flow into the compressor case will cause the case pressure to rise unless the compressor loading valve or the suction valve is left open.

Rotation, Case is Unpressurized

The seal faces remain in contact up to lift-off speed, which normally occurs at 150 rpm. Separation is caused by hydrodynamic effect due to the groove configuration in the face of the rotating seal member. This is the typical condition in an unpressurized seal at start-up.

Rotation, Case Is Pressurized

The seal faces will maintain an equilibrium gap of 0.0025 to 0.0050 mm (0.0001 to 0.0002 in.) depending on the speed and pressure conditions.

DRY GAS SEAL DESIGN

The dry gas seal assembly (with primary and secondary face seals) is provided to Solar by the seal vendor as a complete and tested assembly for installation in the compressor end caps. Each seal assembly (Figure 3) has a primary and secondary face seal.

The primary face seal is exposed to high-pressure seal gas on one side and atmospheric pressure on the other. By taking the full pressure drop, this seal provides the primary sealing function. Filtered seal gas is injected between the process gas and the primary seal at a pressure slightly higher than the reference pressure. Most of the seal gas leaks into the compressor through the labyrinths on the stub-shafts into the compressor suction. This portion of the primary seal gas is not lost but is recycled. The quantity of this recycled gas is quite small (less than 0.1%) when compared to the compressor inlet flow, yet, it provides an important protective barrier for the dry seal.

An even smaller portion of the primary seal gas leaks across the face seal to the primary seal vent. This leakage is lost to vent or flare. Both leakage rates, i.e., flow through the labyrinth and through the face seal, decrease as a fraction of compressor flow with increasing compressor frame size.

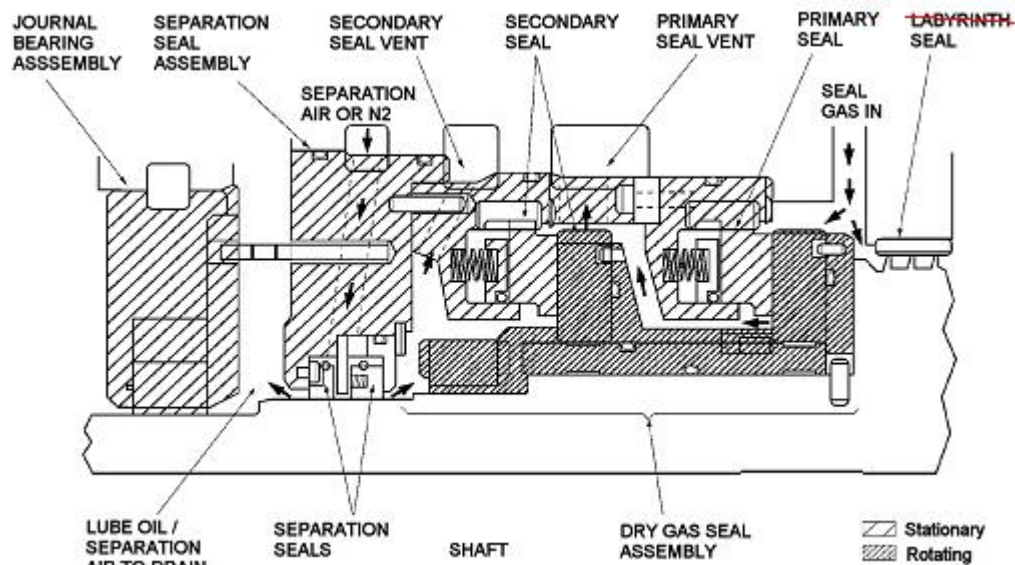


Figure 3. Tandem Seal Assembly Without Intermediate-Labyrinth Seal

The secondary face seal acts as a 100% backup to the primary face seal. It is identical to the primary seal and becomes active when the primary seal fails. To protect the secondary face seal from failure, the secondary vent pressure should never be allowed to exceed the primary vent pressure.

DRY GAS SEAL DESIGN LIMITATIONS

Dry gas seals operate under a variety of conditions however; there are component and system limitations. Table 1a provides design limits for dry gas seals.

There are alternatives for low and high-pressure seals which are compressor specific and will depend on whether optional intermediate labyrinth seals are required. **The maximum dynamic leakage rates are based on maximum pressure and maximum compressor operating speed. The leakage rates will be lower at lower operating speeds and pressure levels and at static conditions.**

Table 1b lists the package system pressure and temperature limitations at skid edge and compressor end caps for dry gas seals and available seal gas system pressure ratings at skid edge.

Note: Do not use the max dynamic leakage rates for air permitting or emissions inventory purposes. Contact Solar's Environmental Strategies department if emissions estimates are needed or see PIL 251 for emissions estimates to be used for permitting.

Terminology for dry gas seal leakage rates

This section defines some of the terminology used in relation to dry gas seal leakage rates.

Maximum dynamic primary seal leakage rates per seal (at the compressor's highest pressure and speed) under dynamic operating conditions are included in Table 1a. The seal suppliers' *maximum dynamic* leakage rates are usually twice as high as the *expected dynamic* rates.

Normal leakage rates at operating conditions depend on suction pressure and speed, and are typically less.

The *static* leakage rate (when the compressor is not running) is lower than the *dynamic* leakage.

Dry gas seal leakage rates are demonstrated at the vendor's factory. Solar's standard factory test to ES 1597, "Production Testing of Gas Compressors," verifies the mechanical operation of the seals at ambient pressure and the static leakage up to the rated suction pressure. It does not demonstrate dynamic seal leakage rates.

Table 1a. Dry Gas Seal Limits

Compressor	Compressor MAWP kPag (psig)	Maximum seal pressure kPag (psig) ^a	Max dynamic leakage per seal nm ³ /hr (scfm) ^b	Seal gas supply required per compressor nm ³ /hr (scfm) ^c
C160	10342 (1500)	10342 (1500)	19.5 (12.1)	173.6 (108.0)
C160K, C166K	27579 (4000)	10342 (1500)	7.2 (4.5)	173.6 (108.0)
C160R, C160V	15513 (2250)	20684 (3000)	18.4 (11.4)	210.6 (131.0)
C166S, C166V, C168V	24132 (3500)	20684 (3000)	24.7 (15.4)	210.6 (131.0)
C169V	24132 (3500)	20684 (3000)	24.2 (15.1)	210.6 (131.0)
C166SB ^d	31026 (4500)	20684 (3000)	24.7 (15.4)	210.6 (131.0)
C28	5171 (750)	10342 (1500)	10.1 (6.3)	173.6 (108.0)
C304, C336WA	10342 (1500)	10342 (1500)	14.0 (8.7)	482.3 (300.0)
C306	10342 (1500)	17237 (2500)	13.7 (8.5)	482.3 (300.0)
C31SL, C31LL	25855 (3750)	34474 (5000)	42.3 (26.3)	755.6 (470)
C31SH, C31LH	34474 (5000)	34474 (5000)	56.3 (35.0)	868.1 (540)
C334, C334i ^e	13789 (2000)	17237 (2500)	19.1 (11.9)	353.7 (220.0)
C336	13789 (2000)	17237 (2500)	18.6 (11.6)	353.7 (220.0)
C307i, C337, C337i ^e	8274 (1200)	17237 (2500)	11.3 (7.0)	273.3 (170.0)
C338, C336i, C338i, C336WB ^e	13789 (2000)	17237 (2500)	18.5 (11.5)	353.7 (220.0)
C334WA	10342 (1500)	17237 (2500)	14.5 (9.0)	305.4 (190.0)
C334WB	15168 (2200)	17237 (2500)	20.9 (13.0)	369.7 (230.0)
C334EL	15513 (2250)	17237 (2500)	21.5 (13.4)	373.0 (232.0)
C335EL	15513 (2250)	17237 (2500)	21.3 (13.2)	373.0 (232.0)
C336EL	15513 (2250)	17237 (2500)	20.7 (12.9)	373.0 (232.0)
C338EL	15513 (2250)	17237 (2500)	19.9 (12.4)	373.0 (232.0)
C334EH	18616 (2700)	18616 (2700)	25.4 (15.8)	409.9 (255.0)
C335EH	18616 (2700)	18616 (2700)	25.1 (15.6)	409.9 (255.0)
C404A, C405A, C406A, C407A, C408A	13789 (2000)	17237 (2500)	29.1 (18.1)	353.7 (220.0)
C404B, C405B, C406B	17237 (2500)	17237 (2500)	36.5 (22.7)	393.9 (245.0)
C407B	17237 (2500)	17237 (2500)	35.5 (22.1)	393.9 (245.0)
C408B	17237 (2500)	17237 (2500)	34.6 (21.5)	393.9 (245.0)
C401	11032 (1600)	17237 (2500)	14.6 (9.1)	313.5 (195.0)
C402	11032 (1600)	17237 (2500)	14.4 (9.0)	313.5 (195.0)
C41SL	15513 (2250)	25855 (3750)	26.3 (16.4)	377.8 (235.0)
C41ML	15513 (2250)	25855 (3750)	25.6 (15.9)	377.8 (235.0)
C41LL	15513 (2250)	25855 (3750)	25.0 (15.5)	377.8 (235.0)
C41SH, C41IH	25855 (3750)	25855 (3750)	43.4 (27.0)	482.3 (300.0)
C41MH	25855 (3750)	25855 (3750)	42.2 (26.2)	482.3 (300.0)

Compressor	Compressor MAWP kPag (psig)	Maximum seal pressure kPag (psig) ^a	Max dynamic leakage per seal nm ³ /hr (scfm) ^b	Seal gas supply required per compressor nm ³ /hr (scfm) ^c
C41PH	25855 (3750)	25855 (3750)	41.7 (25.9)	482.3 (300.0)
C41LH	25855 (3750)	25855 (3750)	41.2 (25.6)	482.3 (300.0)
C41D	25855 (3750)	25855 (3750)	42.4 (26.4)	482.3 (300.0)
C45	15513 (2250)	17237 (2500)	31.0 (19.3)	377.8 (235.0)
C505J	4137 (600)	18616 (2700)	5.5 (3.4)	305.4 (190.0)
C505U	10342 (1500)	11032 (1600)	19.3 (12.0)	482.3 (300.0)
C51SL, C51ML	15513 (2250)	20684 (3000)	24.8 (15.4)	602.9 (375.0)
C51LL	15513 (2250)	20684 (3000)	23.1 (14.4)	602.9 (375.0)
C51D, C51SH, C51MH, C51MD	20684 (3000)	20684 (3000)	33.4 (20.8)	691.3 (430.0)
C51NH, C51PD	20684 (3000)	20684 (3000)	31.7 (19.7)	691.3 (430.0)
C51LH, C51LD	20684 (3000)	20684 (3000)	31.2 (19.4)	691.3 (430.0)
C61SL	15513 (2250)	20684 (3000)	33.7 (21.0)	602.9 (375.0)
C61ML	15513 (2250)	20684 (3000)	33.0(20.5)	602.9 (375.0)
C61PL	15513 (2250)	20684 (3000)	32.5 (20.2)	602.9 (375.0)
C61LL	15513 (2250)	20684 (3000)	31.4 (19.5)	602.9 (375.0)
C601	12066 (1750)	11032 (1600)	18.9 (11.8)	530.5 (330.0)
C651	11583 (1680)	11721 (1700)	21.5 (13.4)	522.5 (325.0)
C652	11583 (1680)	11721 (1700)	21.2 (13.2)	522.5 (325.0)
C752	15513 (2250)	20684 (3000)	32.3 (20.1)	602.9 (375.0)
C753	15513 (2250)	20684 (3000)	31.3 (19.5)	602.9 (375.0)
C85	11032 (1600)	15513 (2250)	25.8 (16.0)	506.4 (315.0)

Notes:

^a Maximum seal pressure limit applies to compressor suction at dynamic conditions (operating, start-up, and shutdown), and at static conditions (settle-out or pressurized hold).

^b Maximum dynamic leakage value is for any single face at maximum continuous operating speed (MCOS) and at maximum seal pressure or MAWP whichever is lower. Normal cubic meter per hour (nm³/h) is measured at 0°C and 101.325 kPa.

^c Values are typical and provided for guidance using nominal seal clearance.

^d Maximum suction pressure is limited to 18616 kPag (2700 psig) when 31026 kPag (4500 psig) is used for MAWP.

^e The C33 & C33i compressors built before 1993 may have low-pressure seals that were limited to a maximum suction pressure of 8274 kPag (1200 psig).

Table 1b. Package Temperature and Pressure Limits

Max compressor design discharge temperature	Max seal gas supply temperature at compressor end caps	Max seal gas supply temperature at skid edge	Seal gas system pressure rating at skid edge ^a
°C (°F)	°C (°F)	°C (°F)	kPag (psig)
176.7 (350)	121.1 (250)	93.3 (200)	10342 (1500) or 19995 (2900) or 24132 (3500) or 34474 (5000)

Notes:

^a Package supply pressure should not exceed maximum seal pressure.



Higher skid edge temperature up to 121.1 °C (250 °F) may be achieved with a custom feature

Dry gas seals with optional intermediate labyrinth seal

Dry seals for certain *Solar* compressors also have an optional intermediate labyrinth seal located between the primary and secondary seals (Figure 4). The function of this intermediate labyrinth is to isolate the primary vent from secondary vent. Secondary seal gas, must be an inert gas such as nitrogen, may be injected between the secondary seal and the intermediate labyrinth. This gas also requires the same cleanliness as the primary seal gas. Some of the secondary seal gas passes through the labyrinth into the primary vent, rendering a non-combustible mixture in the primary vent. The remainder of the secondary seal gas passes through the secondary face seal into the secondary seal vent.

The flow requirements for intermediate seal gas are provided in Table 2.

If the optional intermediate labyrinth seals are used, a custom feature is required to make package/controls modifications to implement this custom feature.

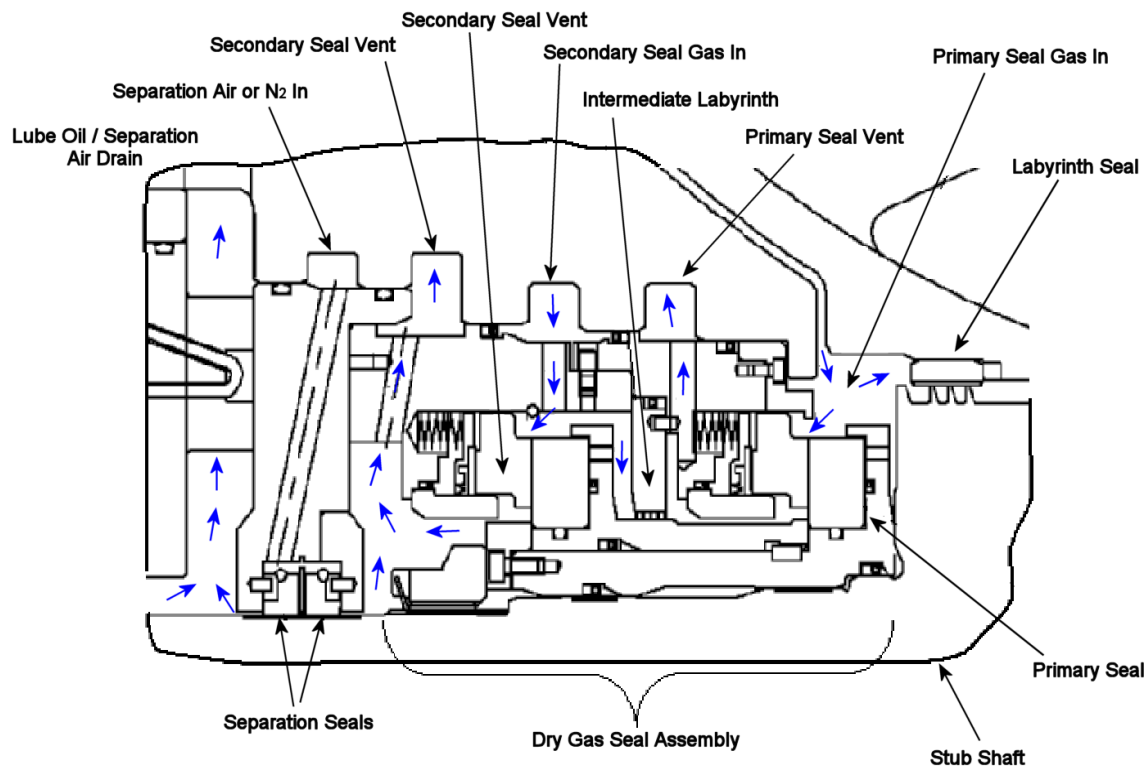


Figure 4. Tandem Seal Assembly with Intermediate-Labyrinth seal

Table 2. Secondary seal gas supply for Compressors with Intermediate Labyrinth in Dry Seals

Compressor	Secondary seal gas (N ₂) supply required per Seal nm ³ /hr (scfm) ^a
C160S/V	6.8 (4.2)
C166SB	6.8 (4.2)
C33E	6.8 (4.2)
C40M	6.8 (4.2)
C31	6.8 (4.2)
C45	6.8 (4.2)
C505J	6.8 (4.2)
C41	6.8 (4.2)
C41D	6.8 (4.2)
C51	6.8 (4.2)
C51D	6.8 (4.2)
C61	8.8 (5.5)
C65	8.8 (5.5)
C75	8.8 (5.5)
C85	8.8 (5.5)

Notes:

^a Nitrogen supply pressure is assumed to be 690 kPag (100 psig) which is regulated down to 276-345 kPag (40-50 psig). Secondary seal gas supply requirements are based on a nominal velocity of 3 m/s (10 ft/s) across the labyrinth seal



Use of this intermediate seal (when available) is entirely optional to the end-user. Supplying secondary seal gas is not mandatory for normal operation even with the intermediate labyrinth.

Use of the intermediate seal gas will increase the amount of leakage in the primary vent. Hence, package alarms and shutdown settings on the primary vent side may need to be set accordingly. Solar must be notified if the end user plans to use this feature. An intermediate lab seal system is also required which requires packages modifications to add intermediate lab seal system components

UTILITY REQUIREMENTS FOR DRY GAS SEALS

Dry gas seals require a high-pressure source of dry and clean primary seal gas. Additionally, if the dry seal is equipped with an intermediate labyrinth, the end user must procure a secondary seal gas (nitrogen).

It is the end user's responsibility to provide the required utilities (primary seal gas, separation seal gas and optionally the secondary seal gas) to the compressor skid, meeting the pressure, temperature, dryness and cleanliness requirements. The end user has comprehensive

knowledge of the process variations and the compressor application and should be proactive in making the decisions necessary for safe seal operation.

Primary seal gas

Primary seal gas can be obtained from the compressor discharge or supplied by a separate source. Either way, the seal gas must meet specific standards of supply temperature, cleanliness, dryness, and pressure to assure the efficiency and long-term operation of dry face seals. Seal gas must be provided during start-up, normal operations, shutdown and pressurized hold, and at any time there is process gas in the compressor casing.

The seal gas supply to the skid-edge connection, which flows into the on-skid seal gas system, must meet the following requirements:

1. It must be filtered process gas or nitrogen that is clean and dry. The filters shall be coalescing type and have a minimum efficiency of 99.5% on particles larger than or equal to 2 microns (beta ratio $\beta_2 \geq 200$). The gas should have no magnetically charged particles (which will agglomerate). There must be no hydrate or solids formation when expanding to atmospheric pressure. Cleanliness of the seal gas is critical to the seal's safety and life.

Note: Filters for 1-micron particle size and higher efficiency will require custom feature.

2. It must be free of liquids and leave no residue. The pressure must be 690 kPa (100 psi) or more above compressor suction pressure but below the pressure rating of the seal system. Its temperature must be such that subsequent throttling to primary / secondary vent pressure produces gas that is superheated at least 20 °C (36 °F) and is within the seal gas temperature range of 0-93.3 °C (32-200 °F). This dew-point margin shall be maintained throughout the seal and not just at the supply connections.
3. If the gas mixture contains water in a vapor form, it is important to maintain the 20 °C (36 °F) superheat relative to the hydrate line of the mixture. A typical dew point curve is shown in figure 5.



In applications where the pressure rise across the compressor exceeds 10342 kPa (1500 psi), the minimum primary seal gas pressure may need to be more than 690 kPa (100 psi) above the suction pressure.

4. The required primary seal gas supply rates per compressor are provided in Table 1a. The required seal gas supply flow rate is significantly higher than the primary seal leakage since most of the supplied seal gas flows across the compressor shaft labyrinth seals into the compressor case. The seal gas supply requirements provided are based on operational parameters that ensure effective separation of the process gas from the primary dry gas seal, particularly in maintaining a nominal velocity across the labyrinth seal inboard into the compressor.



Seal gas supply requirements are based on a nominal velocity of 5 m/s (15 ft/s) across the labyrinth seal located between the dry seal and the process gas side, at nominal operating pressures and speeds.

As mentioned earlier, the compressor discharge is a potential source for seal gas. However, using compressor discharge as the only source involves the following scenario: When the compressor is pressurized but not loaded (such as during start-up, shutdown, or pressurized hold) the compressor discharge pressure is not sufficient to flow through the regulators and filters of the standard seal gas supply system. Consequently, the dry seals are in direct contact with the process gas, which may lead to contamination. Neither Solar nor any seal supplier is responsible for contaminated dry seal failures. If this risk is unacceptable, an external seal gas source must be used. Alternatively, an optional seal system with an ancillary gas booster may be required.

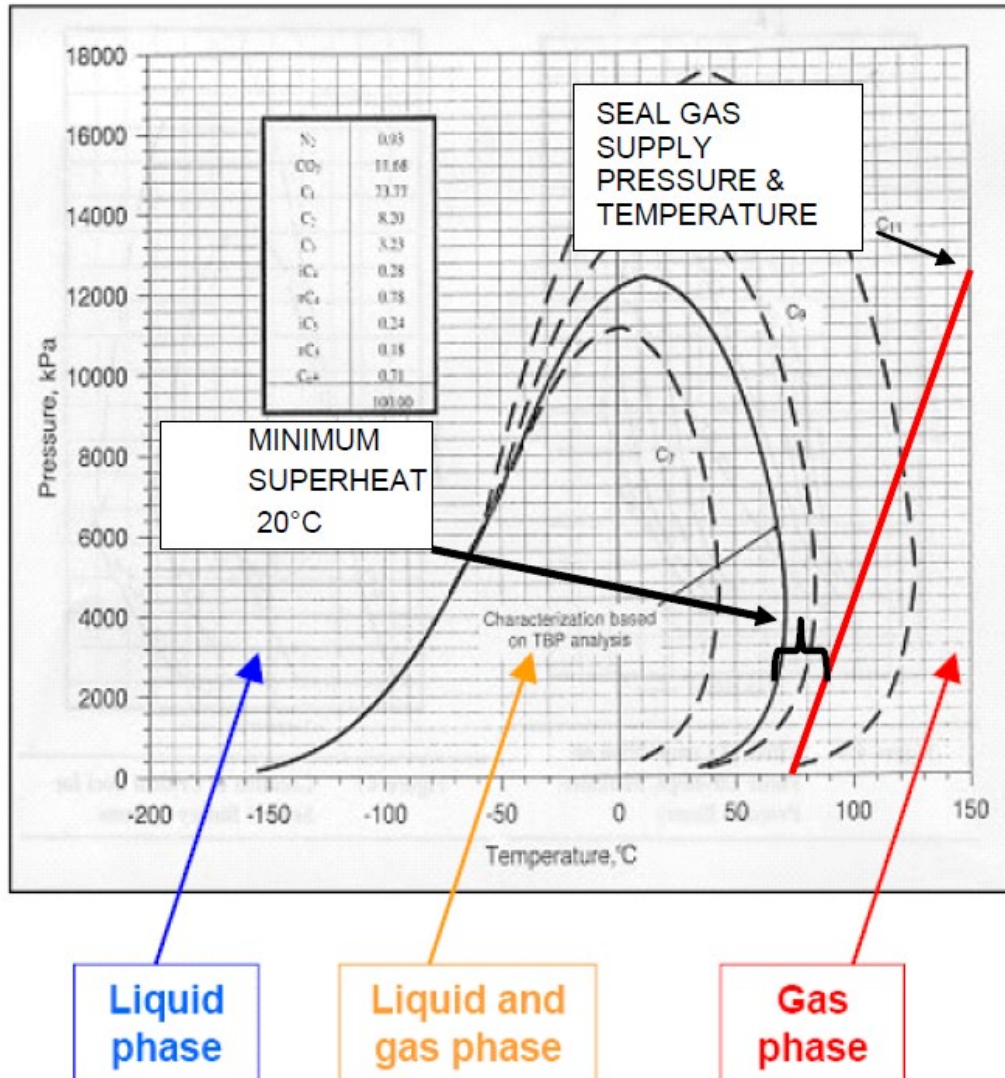


Figure 5. Typical Dew Point Curve.

UTILITY REQUIREMENTS FOR SECONDARY SEALS

When the dry seal assembly is provided with an intermediate labyrinth (see Table 2) between the primary and the secondary seal faces, an inert gas (nitrogen) may be injected into the area between the labyrinth and the secondary seal. The injected gas is referred to as secondary seal gas. Use of the secondary seal gas is not mandatory even if the dry seal has an intermediate labyrinth.

1. The secondary seal gas must meet the same temperature and cleanliness requirements as the primary seal gas.
2. The required flow-rates are provided in Table 2.
3. It must be free of liquids, and at a temperature of between 10 °C and 93 °C (50 °F and 200 °F).
4. The pressure at the secondary seal must be kept above the secondary vent pressure. The nitrogen supply pressure to the skid edge must be between 517 and 1345 kPag (75 and 195 psig).

Secondary seal gas is not mandatory for the operation of the compressor. Monitoring of the secondary seal gas flow and pressures is integral to the seal gas system. When secondary seal gas is used, the gas flow-rate through the primary vent increases as the secondary seal gas combines with the primary seal leakage. Hence, care must be taken to design primary vent systems appropriately.

Seal Vents

Seal gas leaking through the primary and secondary vents is potentially flammable and must be routed safely away from the package.

In addition, the secondary seal gas vent pressure must not exceed the primary vent pressure to prevent reverse flow across the secondary seal face.



Dry gas seals must never be subjected to reverse pressurization. Reverse pressurization of the dry gas seals will cause seal failure. The primary and secondary seal gas vent backpressure must not exceed 34 kPag (5 psig). The end-user must account for this while connecting piping from other possible sources downstream of the vent lines.

SEPARATION SEAL DESIGN

The separation seal assembly (Figure 6), which is separate from the dry gas seal assembly, is installed between the dry gas seals and the compressor lube oil drain cavity (bearings). Separation seals are the most outboard component of the complete seal system. Separation seals, also called buffer seals, barrier seals or circumferential seals by the industry, prevent bearing lube oil from migrating along the shaft to the dry gas seals. In addition, they prevent seal gas from entering the lube oil system.

Separation seals consist of two segmented, split-ring type carbon rings, statically held in close tolerance against the shaft surface. Separation gas, usually air or nitrogen (inert gas), is injected between the carbon rings at a nominal pressure of 138 kPag (20 psid) above the secondary vent pressure. Some of the separation gas then flows outboard into the bearing drain chamber and vents through the lube oil drain. The remainder flows inboard into the secondary seal vent, mixing with the leakage from the secondary face seal of the dry seal assembly.

Information on separation seal design limits is provided in Table 3. The separation seal may not be from same manufacturer as dry gas seal supplier and is selected by Solar based upon experience.

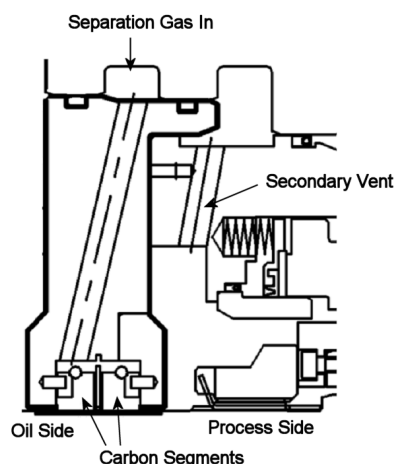


Figure 6. Typical Separation Seal Assembly

UTILITY REQUIREMENTS FOR SEPARATION SEALS

Separation seals require a reliable source of air or nitrogen for ensuring separation of the lube oil and the seal gas. Separation seal gas for separation seals must be provided at all times the lube oil pump is operational (startup, normal operations, shutdown, pressurized hold and post-lube cycle) or when the compressor is pressurized to any extent.



The primary function of separation seals is to prevent a) the lube oil from coming in contact with the secondary seals and b) the gas from the secondary vent entering the lube oil system. Separation seal gas must be provided at any time the lube oil pump is operational and the bearings are fed with lube oil.

The separation gas supply to the separation seals must meet the following requirements:

1. It must be filtered air or nitrogen that is clean and dry. The filters shall be coalescing type and have a minimum efficiency of 99.5% on particles larger than or equal to 2 microns (beta ratio $\beta_2 \geq 200$). The gas should have no magnetically charged particles (which will agglomerate). There must be no hydrate or solids formation when expanding to atmospheric pressure. Cleanliness of the seal gas is critical to the seal's safety and life.

Note: Filters for 1-micron particle size and higher efficiency will require custom feature.

2. It is recommended that the separation gas have atmospheric pressure dew point greater than -28.9°C (-20°F). This will provide lubrication to the inboard carbon rings. Industry experience has indicated that higher moisture in the air may help improve separation seal life.
3. The supply pressure must be between 517 and 1345 kPag (75 and 195 psig) at the skid-edge connection.

The supply capacity per seal is provided per Table 3.



*PCD air **cannot** be used as a sole source of separation gas due to its unavailability during startup, shutdown and pressurized hold conditions. It may be used only during normal operation provided adequate pressure is available and it is properly cooled with liquid and particles removed.*

Table 3. Separation Seal Leakage rate (see notes a through k)

Compressor	Max separation seal gas leakage per seal nm^3/h (scfm)
C160 (legacy)	5.1 (3.2)
C28	4.0 (2.5)
C160R/S/V	5.5 (3.4)
C166SB	5.5 (3.4)
C30, C33, C33i, C33E	6.8 (4.2)
C31	4.1 (2.54)

Compressor	Max separation seal gas leakage per seal nm ³ /h (scfm)
C40P	6.8 (4.2)
C40M	8.7 (5.4)
C41	8.7 (5.4)
C41D	8.7 (5.4)
C45	8.7 (5.4)
C505J	6.8 (4.2)
C505U	1.7 (1.05)
C51	9.1 (6.1)
C51D	9.1 (6.1)
C601	1.7 (1.05)
C61	12.1 (7.5)
C65	1.8 (1.1)
C75	12.1 (7.5)
C85	10.4 (6.5)

Notes:

- ^a Data provided is not supplier-specific. This ensures interchangeability of separation seals from multiple suppliers, without changing package settings.
- ^b Flow-rate values are up-to-date and reflect actual operation. In some cases, they may differ from component drawings (both Solar and vendor versions).
- ^c Separation seal gas pressure settings above secondary vent pressure will be based on the compressor frame size and the type of seal design applicable to the specific compressor model.
- ^d Each compressor has two separation seal cartridges. Hence, the maximum separation seal gas flow-rate required per compressor would be twice the maximum rates per seal cartridge.
- ^e Nominal separation seal gas flow-rates are typically half of the maximum flow-rates given above.
- ^f Maximum separation gas flow-rates (not the nominal flow-rates) must be used for sizing air or nitrogen supply to the seals.
- ^g Maximum flow-rate is the acceptable upper limit under the nominal operating differential pressures.
- ^h Normal cubic meter per hour (nm³/h) is measured at 0°C and 101.325 kPa.
- ⁱ Flow through secondary vent includes: 1) leakage flow through the secondary seals in the dry gas seal assembly, and 2) leakage flow from the gas-side carbon segments of the separation seals. A considerable proportion of the secondary seal vent flow is the leakage from the separation seals.
- ^j Packages shipped prior to 2009 have a flow-switch for monitoring secondary vent flow. This flow-switch initiates an alarm when the combined suction and discharge secondary vent flow-rates exceed a predefined limit. There is no alarm for seal gas supply high flow-rates in these packages. Refer to Figure 7.
- ^k Packages shipped starting in 2009 have flow meters to monitor the suction and discharge side secondary vent flow-rates independently (see Figure 8). In addition, flow meters measure the separation seal gas flow-rates supplied to the suction and discharge separation seals independently. In such packages, alarms are initiated under following circumstances: High secondary vent flow-rates - Secondary vent flow High Shutdown is initiated when the net inboard leakage from separation seal (secondary vent flow minus half the separation seals gas in) exceeds acceptable limits. Note that these alarms are initiated independently for the suction and discharge sides.

SEAL GAS SYSTEMS

System Description

Typically, Solar provides an on-skid dry seal system that facilitates and monitors necessary pressure and flow requirements to the dry gas seals and the separation seals. The on-skid dry seal system includes a back up filter system, piping, valves and appropriate sensors to monitor the condition of the seals with alarms and shut downs.

A typical dry gas seal system (Figure 7) is designed to:

- Provide seal gas to the face of the dry seal to prevent contamination and early failure of the seal.
- Monitor the leakage past the primary dry seal and alarm or shutdown if abnormal conditions exist.
- Provide air or nitrogen to the separation seals.
- Optionally, provide nitrogen to the intermediate labyrinth when needed.

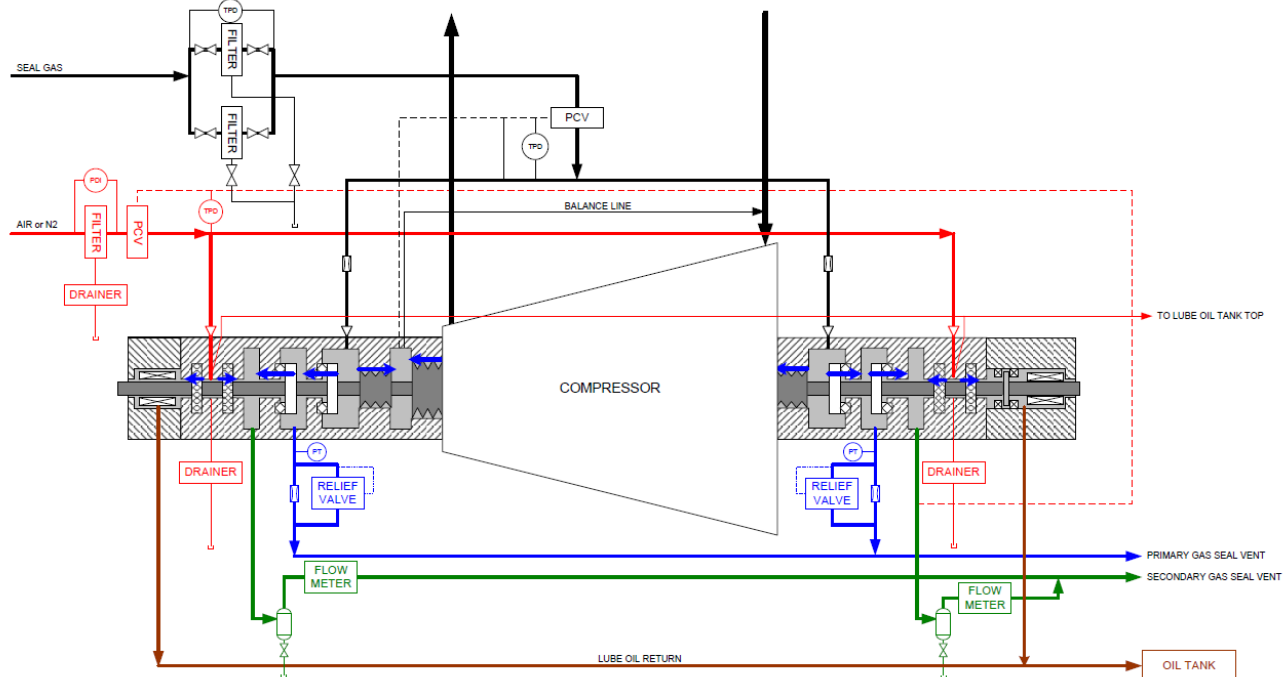


Figure 7. Typical Dry Gas Seal System (Prior to 2009)

The system consists of coalescing filters, differential pressure regulators and filter drains for seal gas and separation air or gas, drain valves, check valves, relief valves, sight glasses, pressure gauges and associated isolation valves, and a drain reservoir.

Differential pressure switches or transmitters provide low flow/high flow alarms and shutdown functions. System parameters are monitored using either electronic instrumentation or measuring gauges.

The on-skid duplex seal gas coalescing filters are intended for typical clean transmission pipeline conditions meeting utility seal gas requirements outlined in this PIL. If larger particle or liquid loads are expected, a larger off-skid filtration system with a high-pressure external seal gas supply is recommended. On-skid filters have proven adequate for majority of applications.

In cases where process gas or external seal gas are highly contaminated, consideration must be given to off-skid seal gas treatment system.

Typical seal gas supply flow is 85 to 643 nm³/h (50 to 400 scfm) per compressor body depending on the compressor model and suction pressure. The primary seal gas flow rates are metered by maintaining a constant pressure drop across a flow-limiting orifice in each seal gas supply line to each compressor seal capsule. A pressure differential, typically at 138 to 207 kPag (20 to 30 psi) above the suction pressure, must be maintained upstream of the orifice to ensure positive seal gas flow through the dry seals. This ensures that the dry seal cavity is flushed with clean, dry gas to facilitate operation in a clean environment.

Leakage past the primary dry seals is measured by monitoring the pressure drop across the primary vent flow-metering orifice. Transmitters provide high-flow alarm and shutdown functions.

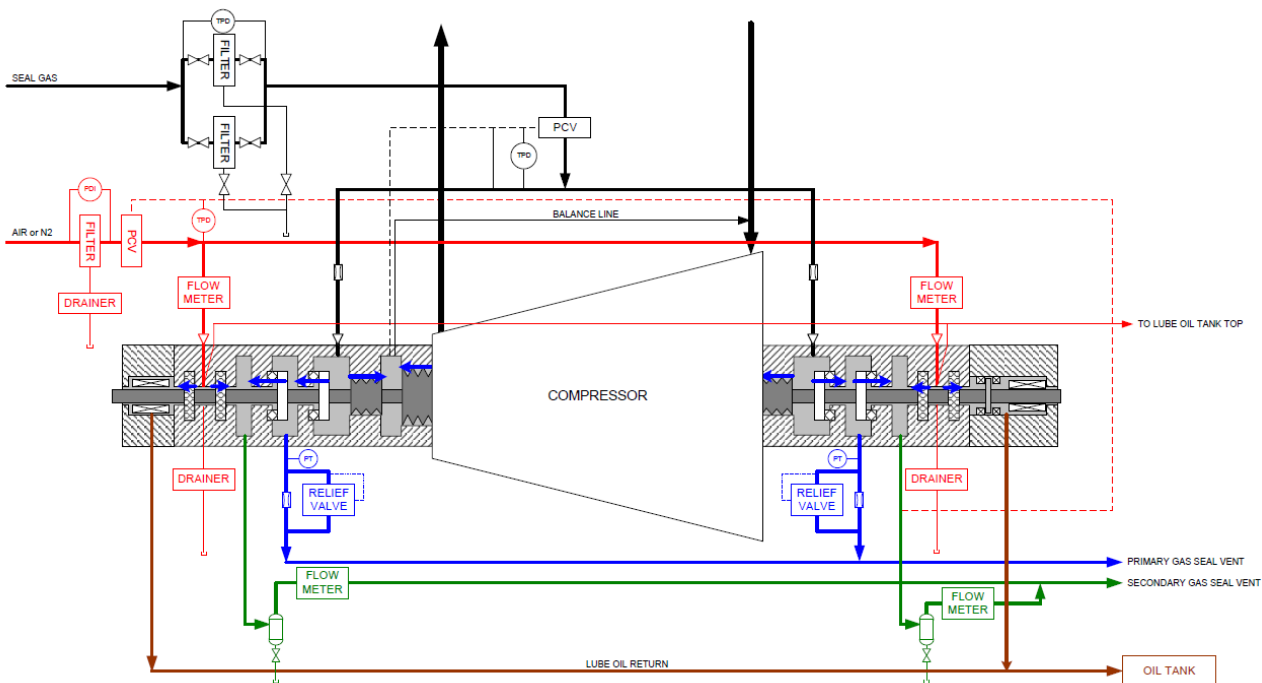


Figure 8. Typical Dry Gas Seal System (Post 2009)

When the compressor discharge is used for seal gas, but the compressor is not in operation (for example, at start-up, shutdown, or pressurized hold conditions where there is no pressure ratio across the compressor), there is no flow of seal gas through the filters. During this type of operation, the gas leakage across the dry seals is raw process gas from inside the compressor case. This is normally not a problem on clean transmission pipeline applications. It may be a problem, however, on new pipelines (until the new line cleans up) or on pipelines handling wet and/or dirty gas. Under these conditions, an external seal gas supply, meeting pressure, temperature and cleanliness requirements as mentioned earlier is required

When external seal gas is used a shut-off valve at the skid-edge connection is recommended to stop the external seal gas supply when the compressor is non-operational and vented.



Flow through the secondary vent contains a mixture of leakage from secondary face seal and a portion of separation gas from Separation seals, is monitored by a flow switch or flow meter. If air is used as separation gas, this mixture may be combustible. Instead of air, Nitrogen should be used for separation gas if a potential combustible mix must be avoided.



When the package vents are tied to station flares with static pressure, consideration must be given to possibility of gas migration (backflow) into package vents.

APPLICATION CHECKLIST

To properly evaluate applications where dry gas face seals would be a consideration and to minimize unforeseen operating problems, the information presented on the Application Checklist for Dry Gas Seals (Table 4) should be obtained. Most of the information can be obtained from the purchaser's general specification sheets. Some parameters, however, such as those under Items 5, 7, and 8 in Table 4, should be discussed with the purchaser for proper evaluation and recommendation.

Table 4. Application Checklist for Dry Gas Seals

- | | |
|---|--|
| <p>1. Application Data</p> <ul style="list-style-type: none"> • Gas Transmission • Wellhead Compression • Process Gas Compression • Gas Lift and Injection • Offshore Compression <p>2. Gas Data</p> <ul style="list-style-type: none"> • Gas analysis phase map • • Type and Amount of Contaminants <ul style="list-style-type: none"> - Corrosive Components (rust, H₂S) - Presence of Moisture/Liquids (type, volume/mass, frequency) - Presence and Description of Particulates (type, size, concentration) - <u>Presence of organic compounds (such as ketones, amines, esters, ethers, nitro hydrocarbons, alcohols)</u> <p>3. Start-up Procedure</p> <ul style="list-style-type: none"> • Time Pressurized • Suction Pressure • Pressure Downstream of Discharge Check Valve at Start <p>4. Installation Details</p> <ul style="list-style-type: none"> • Piping Arrangement • Check and Block Valve Locations • Anti-Surge Valve and Bypass Cooler Descriptions • Pipe Sizes and Trapped Volumes (attainable from layouts and schematics) • Parallel Units, If Any • Extreme Suction Pressure, Discharge Temperature • Minimum Head Operation • Vent Static Back Pressure <p>5. Shutdown Conditions</p> <ul style="list-style-type: none"> • Normal Shutdown Sequence <ul style="list-style-type: none"> - Pressure/Time Relationship • Emergency Shutdown Sequence <ul style="list-style-type: none"> - Pressure/Time Relationship • <u>Pressurized Hold Requirements</u> <ul style="list-style-type: none"> - <u>Settle out Pressure</u> - <u>Length of Time</u> | <p>6. Inlet Gas Conditioning Skid (Provided by Others)</p> <ul style="list-style-type: none"> • Equipment Description <ul style="list-style-type: none"> - Scrubber - Liquids Removal - Inlet Filtration • Equipment Effectiveness <ul style="list-style-type: none"> - Liquids Carryover - Solids Carryover <p>7. Availability of Seal Gas (Face Seals)</p> <ul style="list-style-type: none"> • Prestart • Running • Shutdown • Pressurized Hold • Type of Gas Available • Quantity Restrictions • Temperature Restrictions • Alternative Gas Source <p>8. Availability of Separation Air or N₂ (Separation Seals)</p> <ul style="list-style-type: none"> • Prestart • Running • Shutdown • Pressurized Hold • Type of Gas Available • Quantity Restrictions <p>9. Seal Gas System Requirements</p> <ul style="list-style-type: none"> • Filtration • Regulation Method • Monitoring Method <ul style="list-style-type: none"> - Flows - Pressures • Conditions of Vent (flare) Methods • Alarms and Shutdowns <p>10. Specification Requirements*</p> <ul style="list-style-type: none"> • American Petroleum Institute (API) • National Association of Corrosion Engineers (NACE) <p>* Solar's specification generally complies, with comments, to API and NACE.</p> |
|---|--|

SPECIAL TOPICS

Pressurized Hold Condition

The standard compressor package unit control system includes logic to maintain lube oil flow to the turbine, gearbox (if applicable) and compressor bearings during periods when the unit is shutdown and case pressure is maintained in the compressor (pressurized hold). This logic protects the power turbine, gearbox, and compressor bearings from damage in case of inadvertent rapid compressor blowdown. Rapid blow down of the compressor case and piping could possibly cause the compressor rotor and power turbine to spin as process gas flows through the vent system. Without lubrication, the bearings may sustain damage.

The package also requires separation seal gas, usually air or nitrogen from the end user's source, during all periods of compressor pressurization and lube oil pump operation.



If the control logic is modified to shut down the lube oil pump during a pressurized hold condition, separation gas is still necessary to prevent process gas from migrating into the bearing cavity. Pressurized holds without separation gas can lead to explosive mixtures in the lube system.

The condition of pressurized hold is meant to be a temporary condition and should not exceed a few hours without a thorough review of the valve set-up and control system logic by Solar's representatives. This is due to the concerns discussed above as well as the effectiveness of such a condition. Leakage rate for the dry gas seals in a static condition (non-rotating) may defeat the purpose of a pressurized hold for holds of very long duration.

For a pressurized hold of extended duration, contact Solar to address site-specific aspects of valves, controls, contamination of dry seals and possible impact on warranty.

Any deviation from Solar's standard control system logic to shut down the lube oil pump and/or separation gas during a pressurized hold condition after the post lube cycle is discouraged.

Explosive Decompression

Dry gas seals contain O-rings or similar gland seals in their internal assembly and hence may be subject to the limitations of depressurization rates due to explosive decompression.

Explosive decompression is the term used to describe the action that causes O-ring surfaces to blister and separate from the O-ring body. O-rings exposed to gas at high pressures absorb a small amount of gas into the O-ring material. Under those circumstances, when the gas pressure is rapidly reduced, the surface of the O-ring is separated (or scarred) from the O-ring body (see Figure 9). To prevent explosive decompression, damage the rate of decompression and the O-ring material must be considered.

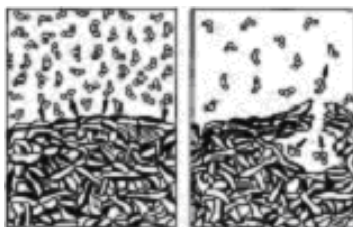


Figure 9. Explosive Decompression



The Purchaser must inform Solar if the process gas contains components that are known to chemically react with O-rings (Table 4, Item 2).

O-ring Materials

FPM A fluorinated hydrocarbon elastomer (Viton). This material can absorb certain organic compounds, such as ketones, amines, esters, ethers, nitro hydrocarbons and some alcohols. These compounds can react chemically with the FPM O-ring and cause it to swell, which can result in extrusion damage and seal malfunction. If these compounds are present, alternate O-ring materials should be used to avoid such damage.

FEPM A fluoroethylene/propylene copolymer (Aflas). This material has a better resistance to organic compounds.

PTFE Polytetrafluoroethylene (Teflon). Provides non-elastomeric pressure actuated seal designs. The performance of PTFE is not affected by the organic compounds.

Depressurization Rate

The maximum depressurization rate for the dry gas seal depends on compressor suction pressure (P1) or “settle-out” pressure, and compressor discharge temperature (T2). The recommended depressurization rate (Table 5) prevents damage to gland seal (such as O-rings), within the dry seal, due to explosive decompression. Consult Solar for material used in dry gas seal/seal systems/end cap for specific sales orders projects



The dry seals may not be the limiting factor for the depressurization rate for all gas compressors; some models may require a lower rate due to a) O-rings between the end-caps and the casing or b) package dry seal system per Table 6.

Package dry gas seal system limitations

Package dry gas seal system has components and fittings that use Viton in component or fitting o-ring material. Fittings may be used when components have SAE type threaded connections. The recommended depressurization rate for package dry gas seal system is shown in Table 6.

Industry experience suggests that gas composition affects the occurrence of explosive decompression. If the gas composition indicates significant amounts of carbon dioxide, nitrogen and/or methanol, it is suggested that the depressurization rate of seals having index “FPM” be de-rated from the value shown in Tables 5 and 6.

Table 5. Compressor Depressurization Rate for explosive decompression ^b

Suction pressure or settle-out pressure		Compressor discharge temperature (T2)		Maximum depressurization rate ^b					
				FPM ^a		FEPM ^a		PTFE ^a	
kPag	psig	°C	°F	kPa/min	psi/min	kPa/min	psi/min	kPa/min	psi/min
< 8274	<1200	38	100	4137	600	8274	1200	Pressure energized seals do not suffer from explosive decompression, therefore no limit is set here.	
		93	200	2000	290	4000	580		
		149	300	2000	290	4000	580		
		176	350	2000	290	4000	580		
8274 to 10342	1200 to 1500	38	100	2000	290	4000	580		
		93	200	2000	290	4000	580		
		149	300	2000	290	4000	580		
		176	350	813	118	1627	236		
10342 to 12411	1500 to 1800	38	100	2000	290	4000	580		
		93	200	2000	290	4000	580		
		149	300	813	118	1627	236		
		176	350	813	118	1627	236		
>12411	>1800	38	100	813	118	1627	236		
		93	200	813	118	1627	236		
		149	300	813	118	1627	236		
		176	350	414	60	827	120		

Table 6. Package Dry Seal System Depressurization Rate for Explosive Decompression

Suction pressure or settle-out pressure		Seal gas supply temperature		Maximum depressurization rate	
				FPM ^a	
kPag	psig	°C	°F	kPa/min	psi/min
< 8274	<1200	38	100	4137	600
		93	200	2000	290
8274 to 10342	1200 to 1500	38	100	2000	290
		93	200	2000	290
10342 to 12411	1500 to 1800	38	100	2000	290
		93	200	2000	290
>12411	>1800	38	100	813	118
		93	200	813	118

Notes for Tables 5 and 6:

^a See Section "SPECIAL TOPICS" for description of O-ring material.

^b Maximum depressurization rates for venting the compressor may be dependent not only on the dry gas seals and the dry seal system, but also on the types of other seals, e.g. O-rings between the casing and end-caps, within the compressor. End users must check with Solar.

Monitoring the Health of Secondary Seals

Tandem dry gas seals are built with a secondary seal or backup seal. In case of unexpected failure of the primary sealing face, the secondary seal functions to contain the process gas while the compressor can be safely shutdown and depressurized. This scenario requires that the secondary seals be healthy at all times of normal operation. However, the health of the secondary seals cannot be determined strictly from monitoring the secondary vent flow alone. Solar has a customized package system to monitor the health of the secondary seals. If this option is purchased, specific instructions may be available to the end-users to perform periodical monitoring of the integrity of the secondary seals. Briefly, the procedure involves:

- Closing the primary vent while the compressor is pressurized,
- Continuing to supply seal gas that will build up pressure between the primary and secondary seals, and
- Ensuring pressure rise in the primary vent within a few minutes, which will confirm the health of secondary seals.

It is essential to note that Solar compressors will shutdown upon primary dry seal failure, as indicated by higher primary vent flow. Solar does not allow running compressors with secondary seals alone.

System Flushing Procedure

For guidance on the procedure for flushing dry gas seal systems, please contact Solar's local field office.

Comparison with Oil Seal System

Conventional oil seal systems have some inherent operational issues, such as leakage of sealing oil into the compressed gas and the contamination of oil with gas. The mechanical dry gas faces do not require oil for sealing.

There is a perception that when process gas is used for dry gas face seals, the seals completely contain the process gas. This is not true. All commercially available seals allow *some* gas to be vented. The amount is small, typically 3.4 to 34 Nm³/h (2 to 20 scfm) per seal, but still requires disposal. Many older compressor models can be retrofitted to dry seals. Refer to PIL 213 for older compressor models

The advantages of dry gas seals on packaging can be summarized as follows:

- A simple static system
- Fewer functional components
- Elimination of oil contamination
- Reduced package weight and space
- No parasitic loads for seal oil pump
- Anticipated increase in reliability

The package items to be eliminated are:

- Engine-driven seal oil pump
- Auxiliary seal oil pump & motor
- Backup seal oil pump & motor
- Seal oil filter

- Traps, degassing tanks, and vent fan
- Package manifolds
- Overhead run-down tank

The package items to be added are:

- Separation air or nitrogen supply
- Clean seal gas supply (filters and regulators)

Dry Seal Advantages

- The dry gas seal system does not require external power source
- Gas/Oil Interface. One of the main reasons for the interest in compressors with dry seals is that there is no process gas/lube oil interface. For transmission service, a dry seal system eliminates the addition of oil to the gas in the pipeline. For wellhead or field gas service, it eliminates sour gas carryover into lube oil tanks, oil degradation, and lube oil tank explosive mixture levels.
- Pressurized Hold. Pressurized holds of longer time are possible. As environmental limits become stricter, it will be increasingly advantageous to leave the compressor pressurized instead of blowing to vent at every shutdown.
- Degassing. Degassing flues/tank connections on wet seal units have a 127 mm (5 in.) of water column limit, while dry seal vent connections have a 34.5 kPag (5 psig) limit. This makes it much easier to capture and run leakage gas into a flare system.
- Seal Gas Quantity. The seal gas flow to the dry seal cavities is easier to limit and is less than buffer gas flows on wet seal compressors. The parasitic power requirement to compress seal gas is less with a dry gas seal system.

Dry Seal Disadvantages

- The dry seal cavities must have clean, dry gas to avoid contaminating the seals.

NACE Compliance

The main components in dry seals are National Association of Corrosion Engineers (NACE) MR0175 compliant, and a NACE-compliant seal gas system is available. The seals can use sour gas as long as it is clean and dry. Depending on how sour the process gas is, many wet seal compressor applications require a large supply of sweet external buffer gas for a sour gas application.

Heavy Seal Gas

A heavy seal gas typically has hydrocarbons with other than Methane (CH₄). The dry seals can use heavy gas as long as it is clean, dry and does not form hydrates which may require seal gas heating. Dry seal applications require that the particulates and liquids be removed. The amount of gas that needs to be treated if dry seals are used is less than that for a wet seal compressor.

Emergency Shutdown

Many applications, especially those on offshore installations, require that all gas, as well as AC and DC power sources, be secured in the event of an emergency shutdown. Compressors with wet seals require that the auxiliary or backup seal oil pump run until the compressor case is depressurized. End users with this application must accept that they will have an active gas line to a pneumatic motor or AC or DC power to an electric motor. Compressors with dry seals can be shut down without these backup pumps, so

the end user could shut down all gas, as well as AC and DC power, to the package in an emergency and the compressor seals would still prevent a release of gas into the area.

Emissions

It may be possible to achieve close to zero hydrocarbon emissions from a dry seal compressor, if nitrogen is used for the seal gas. The dry seal leakage from the seals would be nitrogen and not natural gas. The case can also be purged and pressurized by nitrogen through the dry seal cavities, which would eliminate gas loss during the compressor purge cycle. Once the compressor cases were purged and pressurized, the only gas loss would occur during compressor depressurization, which could be minimized by maintaining the compressor in a pressurized hold condition. Use of intermediate labyrinth seals will avoid hydrocarbon emissions in the secondary vent.

Monitoring

The systems that support the self-acting dry gas face seals and the separation seals include safe guards with pre-engineered settings based upon the compressor model and applications.

SOLAR'S EXPERIENCE IN DRY SEALS

As of May 2018, Solar Turbines has shipped over 3100 compressors with dry gas seals since their introduction in 1986.

Solar Turbines Incorporated
9330 Sky Park Court
San Diego, CA 92123-5398

This information is intended as a general overview and is not intended to be, and should not be used as, a substitute for obtaining advice in any specific situation. This document is accurate as of the publication date and any discussion of a particular issue may become outdated.

Cat and Caterpillar are registered trademarks of Caterpillar Inc. *Solar*, *Saturn*, *Centaur*, *Taurus*, *Mercury*, *Mars*, *Titan*, *SoLoNOx*, *Turbotronic*, *InSight System*, and *InSight Connect*, are trademarks of Solar Turbines Incorporated. All other trademarks are the intellectual property of their respective companies.

© 2021 Solar Turbines Incorporated. All rights reserved. Specifications are subject to change without notice.