SG17.1. 3

TECHNICAL GUIDANCE DOCUMENT NUMBER 3: CENTRIFUGAL COMPRESSORS WITH "WET" (OIL) SEALS

Introduction

This is a technical guidance document for Partners to the CCAC Oil and Gas Methane Partnership (OGMP). This document is one in a series that describes a core source of methane emissions. The document introduces suggested source-specific methodologies for quantifying methane emissions and describes established mitigation options that Partners should reference when determining if the source is "mitigated".[1] The OGMP recognizes that the equipment and processes described in these documents are found in a variety of oil and gas operations, including onshore, offshore, and remote operations, and the way in which the emissions are quantified and mitigated may vary across locations and operational environments. As such, operational conditions, as well as logistical, safety, and cost considerations, must be evaluated on a case-by-case basis. The OGMP assumes that methane emission mitigation actions that require shut-downs of non-redundant equipment/processes (e.g., that would stop operations) would be carried out during regularly scheduled maintenance activities, unless the Partner deems the corrective action to be worthy of an early/additional shut-down.

Description of Source

Centrifugal compressors have seals on the rotating shafts that prevent the high-pressure natural gas from escaping the compressor casing. These seals can be high-pressure oil ("wet") seals or mechanical gas ("dry") seals, which act as barriers against escaping gas. The wet seal centrifugal compressors circulate oil under high pressure between rings around the compressor shaft, forming a barrier against the compressed gas to prevent its escape to the atmosphere. Figure 3.1[2] presents a typical wet seal setup, where the seal oil enters through the inlet (top) and provides a barrier by forming two thin films under higher pressure between the center rotating ring and the two stationary rings.

[1] For reporting purposes as described in the CCAC Oil and Gas Methane Partnership Framework, Section 3.
[2] EPA. *Wet Seal Degassing Recovery System for Centrifugal Compressors.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/capturemethanefromcentrifugalcompressionsealoildegassing.pdf.

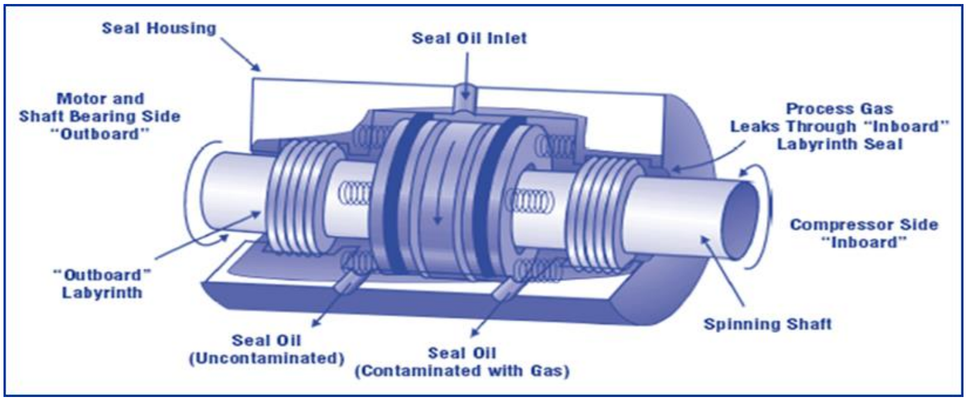

Figure 3.1: Typical Wet Seal Setup[3]

Some rings are attached to the rotating shaft, while rings on each side are stationary in the seal housing, pressed against a thin film of oil flowing between the rings to both lubricate and act as a leak barrier. Very little gas escapes through the oil barrier to the atmosphere, but a significant amount of gas can be entrained by the oil on the "inboard" (compressor) side of the seal at the oil interface with high-pressure gas, thus contaminating the seal oil. The large majority of gas entrained with seal oil as it exits the seal is not in solution with the oil; it can be easily disengaged in a small pressure vessel or atmospheric tank.

For wet seal compressors, contaminated seal oil must be purged of the entrained gas to maintain viscosity and lubricity before it is recirculated. This is done by routing the seal oil to a tank to disengage gas, and then gravity drain the "dead" seal oil to a seal oil sump from which the seal oil is pumped back to the seals. Both of these seal oil tanks are typically vented to the atmosphere in uncontrolled wet seal compressors. Wet oil seal compressor degassing systems may be configured in a variety of ways. For purposes including mitigation evaluation and annual reporting, Partners should identify the configuration of each compressor within their OGMP operations/assets. Table 3.1 describes some common configurations of wet oil seal compressor degassing systems.

For the purposes of the OGMP, Partners will quantify and evaluate for mitigation any of the configurations presented in Table 3.1 that are identified as "unmitigated" for methane emissions, as described in the sections below. Even for "mitigated" configurations, Partners should evaluate the system regularly to ensure that it is functioning properly and minimizing methane emission levels as can be observed by inspecting flare ignition and/or atmospheric vents from the seal oil sump or the seal face of a dry seal using an IR leak imaging camera. Possible equipment failures resulting from improperly functioning systems include an intermediate degassing system malfunction, dry seal malfunction or an extinguished flare.

[3] Global Methane Initiative All-Partnership Meeting, Oil and Gas Subcommittee – Technical and Policy Sessions, Krakow, Poland, October 14, 2011: "Routing Centrifugal Compressor Seal Oil De-gassing Emissions to Fuel Gas as an Alternative to Installing Dry Seals," presented by BP

Table 3.1: Configurations for Wet Oil Seal Compressor Degassing Systems

Configuration	Mitigated or Unmitigated
Seal oil is degassed at atmospheric pressure and the gas is routed to an open vent stack. Exhibit A	Unmitigated
Seal oil is degassed at intermediate pressure and intermediate pressure gas is routed to an open vent stack; seal oil is degassed again at atmospheric pressure, venting the small portion of gas remaining in the oil to the atmosphere. Exhibit A	Unmitigated
Seal oil is degassed at intermediate pressure and intermediate pressure gas is routed to productive use (e.g., compressor suction, fuel gas) or routed to flare[4]; seal oil is degassed again at atmospheric pressure, venting the small portion of gas remaining in the oil to the atmosphere. Exhibit B	Mitigated (if confirmed to be functioning with low[A] or no emissions) **(OPTION A)**
Seal oil is degassed at atmospheric pressure and the gas is recovered and used (e.g., routed to a vapor recovery unit (VRU) or other destination and not vented) or flared. Exhibit B	Mitigated (if confirmed to be functioning with low[A] or no emissions) **(OPTION B)**
Wet oil seal is replaced by a mechanical dry seal. Exhibit C	Mitigated (if confirmed to be functioning with low[A] or no emissions) **(OPTION C)**

[A] Expected emissions levels considering mitigation option is in place and functioning properly (e.g., intermediate degassing system is not malfunctioning, dry seal is not malfunctioning, flare is not extinguished, etc.).

Quantification Methodology

To ensure consistent quantification of annual, volumetric, wet seal centrifugal compressor degassing methane emissions and comparable evaluation of mitigation options, the CCAC OGMP recommends that Partners use one of the following two quantification methodologies: direct measurement or emission factor calculation. In principle, direct measurement is the most accurate method for quantifying methane emissions.[5] With direct measurement, Partners can be more certain of emissions levels and economic costs and benefits (i.e., value of gas saved). As such, measurement is highly encouraged whenever possible. Individual Partners may choose an alternative quantification methodology if judged to be similar or more accurate by the Partner; in this case, the Partner should document and explain the alternative methodology in the Annual Report.

- Direct Measurement[6]:

[4] "Flare" in this document refers to vertical combustion devices using an open or enclosed flame.

[5] Partners should conduct measurements with appropriately calibrated instruments and per the instrument manufacturer instructions. Measurements should also be conducted in different operating conditions, to the extent that those can affect emissions levels. Appendix A to the Technical Guidance Documents includes guidance on instrument use. Partners seeking to generate Emission Factors for their operations should use direct measurement based on a statistically sound number of measurements and gas analyses to understand the content of methane and other valuable hydrocarbons.

[6] Greenhouse Gas Reporting Program, Subpart W – Petroleum and Natural Gas Systems, Section 98.233 Calculating GHG Emissions, 40CFR98.233(o). http://www.ecfr.gov/cgi-bin/text-idx?SID=5f683140b2cb15cf1e9732111939df98&mc=true&node=se40.21.98_1233&rgn=div8.

Direct measurements provide a flow rate for whole gas that is then converted to methane emissions using the methane content of the gas being compressed, and then extrapolated over the entire year. An annual volume of methane emissions is calculated by multiplying the measured methane emission flow rate by the operating hours of the compressor. Partners should express the vapor volumes at relevant temperature and pressure conditions to avoid potential miscalculations and reporting inconsistencies.

Prior to measurement, it is important to determine where the gas stream resulting from seal oil degassing is routed to help ensure that the measurement point(s) are accurately identified. Typically, emissions from centrifugal compressor degassing systems are routed through a single vent stack. However, each compressor and facility setup is unique, and a compressor can potentially have multiple degassing vent stacks. Similarly, a centrifugal compressor might have a vent for its lubricating oil, which could potentially be confused with the seal oil vent. This can be determined using seal oil and lubricating oil design drawings and tracing the pipelines in the facility from the seals and degassing tank vent to the atmosphere. Observing the two vents with an IR leak imaging camera will readily show substantially more vent emissions from seal oil than lube oil vents. Compressors housed in buildings normally have vents that are routed outside the compressor building through the roof or side walls, so it may not always be clear which vent corresponds with respective wet seals. Consequently, to avoid confusion, Partners should confirm the wet seal compressor vents by tracing piping from the source to the end point and observing the vents with an IR leak imaging camera.

Surveying the vents and the compressor with an infrared (IR) leak imaging camera (designed to visually identify hydrocarbon emissions) will identify emission points that should be measured. Examining compressors where the gas is routed to a source other than the vent is also beneficial to identify any unexpected emissions. Possible routes for degassed methane from wet seals include compressor suction, VRUs, fuel gas (high or low pressure), flare, and atmosphere. However, leak detection should be performed on any other piping or equipment connected to the wet seal compressor. Recommended measurement tools include the following:

- Vane anemometer.
- Hotwire anemometer.
- Turbine meter.
- Hi-flow sampler.

For more details regarding each measurement tool, including applicability and measurement methods, please refer to Appendix A.

- <u>Emission Factor Approach:</u>
  If direct measurement is not possible, Partners should instead use an emission factor method. Using this method, Partners apply an emission factor that represents emissions of methane volume per year per compressor, adjusted for the actual operating factor of the compressors (i.e., the percentage of time in a year that a compressor is in operating mode). Partners are encouraged to use emission factors that best represent conditions and practices at their facilities. Table 3.2 presents default methane emission factors for centrifugal compressors with wet oil seals in gas processing plants.

Table 3.2: Default Emission Factors for Centrifugal Compressors with Wet Seals[7]

Source	Methane Emission Factor[A]			
	(scm/minute/ compressor)	(scm/hour/ compressor)	(scf/minute/ compressor)	(scf/hour/ compressor)
Centrifugal compressor with wet seal ("Unmitigated")	1.01	60.6	35.7	2,140

[A]Values provided are at Standard Conditions (20°C, 101.325 kPa). Partners should assume their own operating factors (i.e., the percentage of time in a year that a compressor is in operating mode) to estimate an annual emission factor.
Note: Emission factors are based upon data from compressors operated outside of the United States and for natural gas processing stage.
scm: Standard cubic meters of CH_4.
scf: Standard cubic feet of CH_4.

Mitigation Option A - The gas released from the seal oil by an intermediate pressure seal oil/gas separation system is routed to a pressurized inlet such as compressor suction, fuel gas, or flare.

Degassing the seal oil at intermediate - rather than atmospheric - pressure reduces emissions and allows pressurized gas to be captured and directed to beneficial use. In this option, seal oil contaminated with gas is degassed in a small disengagement vessel for each seal at compressor or fuel pressure. Seal oil exits a compressor at pressures ranging from less than 30 psig (2 kg/cm^2) suction pressure to over 1,000 psig (70 kg/cm^2) discharge pressure. Operating the disengagement vessel at these pressures (or an intermediate pressure above fuel gas pressures, ranging from about 50 to 250 psig (3.5 to 17.5 kg/cm^2)) allows nearly all of the gas entrained in the seal oil to be recovered. The seal oil then flows to the final existing degassing drum where a minimal volume of remaining dissolved methane is degassed and vented to the atmosphere. The regenerated seal oil is then recirculated to the compressor.

The gas collected from the intermediate pressure disengagement vessel will have a pressure of 50 to 250 psig (3.5 to 17.5 kg/cm^2), which is maintained using 1) a critical flow restriction orifice in conjunction with a liquid level control valve or 2) pressure and level control valves. This gas can then be directed to beneficial use (for sale and/or use as fuel gas, compressor suction, etc.), and/or be routed to the flare.

Operational Considerations
Sites must have several operating conditions in place to implement the seal oil recovery option and make use of the gas separated from the seal oil. Onsite equipment such as a fuel gas system or a compressor with the appropriate capacity and suction pressure to receive separated gas is needed to accept and use this new gas stream. Even though the recovered gas is separated from the seal oil, the stream(s) will entrain small amounts of seal oil, possibly requiring a gas demister/filter or knock-out vessel to remove this entrained oil to meet an acceptable fuel gas specification. This technology can be largely installed with the compressor(s) online, with the final seal oil piping connections made during a compressor shutdown. Equipment includes the installation of:

[7] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. Annex 3. April 2016. https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-annex-3-additional-source-or-sink-categories-part-a.pdf section 3.5, table A-136.

- One small seal oil/gas disengagement vessel for each compressor seal.
- A gas demister/knock-out vessel (can be used for multiple compressors).
- Piping to route the recovered gas to chosen use (compressor suction, fuel gas, flare, etc.).
- Pressure and level control instrumentation.

Methane Emission Reduction Estimate

Partners can reduce their emissions by an estimated 95 percent if degassing emissions are recovered at intermediate pressure and routed for other uses.[8] Therefore, the estimated methane emissions for a “mitigated” centrifugal compressor with degassing recovery will be 5 percent of the unmitigated volume of emissions.

Economic Considerations[9,10]

The analysis for installing a wet seal degassing recovery system should consider the capital and operational costs along with the natural gas savings. The economics for recovering wet seal degassing losses may be compelling.

Assuming two seals per centrifugal compressor and two stages of demisting (for routing to a high-quality gas line), equipment and installation costs for this technology are estimated to be approximately $33,000 per wet seal compressor.[11] This capital investment *per compressor* includes the cost of a seal oil/gas disengagement vessel for each compressor seal, two gas demister vessels, new piping, the appropriate pressure and flow controls, and the labor to design and install the equipment. Operating and maintenance (O&M) costs are expected to be minimal.

Since multiple compressors at a compressor station can be piped to a single gas demister and filtering system, the economics become more compelling for multiple compressors at a single facility. In a facility with four centrifugal compressors, the total installation and equipment cost is approximately $90,000. This includes the cost of eight seal oil/gas disengagement vessels (two per compressor), two gas demister vessels (to ensure all remaining seal oil mist is removed), relevant piping, pressure and level control instrumentation, and labor to design and install the equipment. Table 3.3 presents a cost breakdown for both the single compressor and facility scenarios.

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[8] EPA. 40 CFR Part 60, Subpart OOOO: Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews. Final Rule. August 16, 2012. Federal Register page 49523. http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf.

[9] Fluid Sealing Association Lifecycle Cost Calculator, http://FSAKnowledgeBase.org/CompressorLCC.php.

[10] EPA. *Wet Seal Degassing Recovery System for Centrifugal Compressors*. June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/capturemethanefromcentrifugalcompressionsealoildegassing.pdf .

[11] Many of the example cited in this section are based on Partner experience in the United States. Individual circumstances, in the United States or not, can vary.

Table 3.3: Wet Seal Degassing Recovery System Installation and Equipment Costs, Two Scenarios[12]

Equipment	One Centrifugal Compressor, Capital Cost ($2011)	Centrifugal Compressor (x4) Station, Capital Cost ($2011)
Seal Oil Gas Disengagement Vessels[A]	$19,000	$76,000
Seal Oil Gas Demister – Low-Quality Gas	$9,000	$9,000
Seal Oil Gas Demister – High-Quality Gas	$5,000	$5,000
Total	**$33,000**	**$90,000**

[A] Assumed two seals per centrifugal compressor and four centrifugal compressors at the station. An individual seal oil/gas disengagement vessel costs $9,500 per seal.

The capital cost for each seal oil gas disengagement vessel includes the purchase cost of the vessel, installation, piping, instrumentation, and other indirect costs. The data in Table 3.3 assume that the size of the seal oil gas disengagement vessels is 1-foot (30 cm) diameter, 3-foot (91 cm) height with a 1,125 psig (79 kg/cm^2) design pressure and carbon steel construction. The total cost of each seal oil gas disengagement vessel is $9,500; assuming two seals per compressor, the total cost for disengagement vessels per compressor is $19,000.

A seal oil gas demister/knock-out vessel can be designed to receive recovered gas from multiple centrifugal compressors with wet seals. Therefore, the design characteristics of this vessel will vary depending on the number of centrifugal compressors connected to the vessel for a given facility. Table 3.3 assumes, for a single centrifugal compressor, that the seal oil gas demister is vertical and has a 1-foot (30 cm) diameter and 4-foot (122 cm) height with a design pressure of 720 psig (50 kg/cm^2). The resulting cost for a seal oil single-stage demister/filter system is $9,000 and is applicable to both a single centrifugal compressor and a compressor station with four centrifugal compressors, with minor cost differences due to extra piping, instrumentation, structural support, etc.

If the recovered gas is used as high-pressure turbine fuel, the recovery system may include a second high-efficiency seal oil gas demister/knock-out vessel to ensure any trace amounts of seal oil do not foul the turbine fuel injectors. This economic analysis assumes the seal oil gas demister for turbine fuel quality gas will be vertical, made of carbon steel, and have a 1-foot (30 cm) diameter and 3-foot (91 cm) height with a design pressure of 300 psig (21 kg/cm^2). The resulting cost for the second high-efficiency seal oil gas demister is $5,000 for both a single centrifugal compressor and a compressor station with four centrifugal compressors, with minor cost differences due to extra piping, instrumentation, structural support, etc.

The cost savings from implementing this technology comes from the value of the gas recovered from the seal oil. This gas can be sent either to the fuel gas or sales gas lines. If sent to fuel gas, the recovered gas will offset the facility's use of site fuel gas. If sent to sales, the recovered gas can be sent back through a compressor first and/or sent directly to the sales line. Based on the emission factors presented in Table 3.2, the average methane emissions from "unmitigated" centrifugal compressor wet seal degassing is 1.35 scm/minute (47.7 scf/minute) per compressor. Assuming 8,000 hours of operation per year, the total annual methane emissions is 648 thousand scm (Mscm) (22.9 million scf, MMscf) per compressor. This analysis assumes 95 percent of the potential degassing methane emissions are captured and 5 percent is

[12] EPA. *Wet Seal Degassing Recovery System for Centrifugal Compressors*. June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/capturemethanefromcentrifugalcompressionsealoildegassing.pdf.

vented. Therefore, 615.6 Mscm (21.7 MMscf) of methane is recovered per centrifugal compressor and displaces the same volume in fuel gas and/or sales gas. Assuming a gas price of $3 per Mscf and that the recovered gas is close to pipeline quality, revenue from degassing recovery is estimated to be $65,400 per year per centrifugal compressor. A station with four centrifugal compressors connected to a wet seal degassing recovery system could potentially earn revenues of $261,600 per year.

Mitigation Option B – The gas is separated from the seal oil at atmospheric pressure and is routed to a VRU for beneficial use or for flaring.

Partners can reduce their centrifugal compressor wet seal methane emissions by routing seal oil atmospheric degassing vents to a nearby VRU, for posterior beneficial use or flaring. VRUs compress atmospheric pressure gas so that it can either be directed to productive use or be routed to flaring, which normally provides a better environmental solution than direct venting of seal gas.

Operational Considerations
To implement this project successfully, Partners need to ensure primarily that the VRU (existing or new) has enough capacity to handle the additional recovered gas from the centrifugal compressor(s), which can be significant. Because VRUs are typically associated with hydrocarbon liquid storage tank emissions, which fluctuate as tanks fill and empty, a good rule of thumb is to have the VRU's capacity equal to double the average daily volume of gas recovered.[13] For example, to handle 30 Mscf (0.85 Mscm) per day of gas, a VRU should have a capacity of at least 60 Mscf (1.7 Mscm) per day.

This project can typically be implemented with the compressor(s) online, with the final seal oil degassing vent piping connections made during compressor shutdown. Assuming a VRU is already present and connected to a fixed-roof atmospheric pressure hydrocarbon liquid storage tank, equipment includes piping installed to route the recovered gas to the tank vapor space or VRU suction manifold. [14]

If a Partner decides to install a new VRU to capture vented emissions, the CCAC OGMP recommends that the Partner considers all potential emissions sources that can be routed to the VRU and set operational parameters accordingly. The CCAC OGMP Technical Guidance Document Number 6 (Hydrocarbon Liquid Storage Tanks) provides more details about installing a new VRU. Partners should also consider the overall greenhouse gas (GHG) emission load associated with the additional electricity requirements to run the VRU against the base case (i.e., emissions from wet oil seal being directly vented to atmosphere).

Methane Emission Reduction Estimate
It is estimated that Partners can reduce emissions by 95 percent if degassing emissions are recovered at atmospheric pressure and routed to a nearby VRU.[15] Therefore, the estimated methane emissions for a "mitigated" centrifugal compressor with degassing recovery will be 5 percent of the unmitigated volume of emissions.

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[13] EPA. Lessons Learned: *Installing Vapor Recovery Units on Storage Tanks.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/ll_final_vap.pdf.
[14] Note that a VRU draws low-pressure gas from a tank vapor space, into which gas lines of various pressures can be injected, using the large tank vapor volume to dampen out the flows. In cases where the pressure difference among gas lines is large, pressure regulators may be required.
[15] EPA. Lessons Learned: *Installing Vapor Recovery Units on Storage Tanks.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/ll_final_vap.pdf.

Economic Considerations

This mitigation option's economics may be compelling, especially if the seal oil degassing vent lines are routed to an existing VRU which has sufficient capacity to handle an increase in throughput. Partners should note that increasing the VRU's throughput increases its annual electricity costs. However, normally there are no significant capital costs to route gas to an existing VRU because the cost of additional piping is minimal.

For a VRU with 100 Mscf (2.8 Mscm) per day of capacity, the value of the gas recovered annually would be approximately $52,000.[16] Compared to the incremental electricity costs (for how much energy is required to pump gas to a 100-psig (7 kg/cm^2) sales line) and provided there's sufficient capacity in the existing VRU and that there is beneficial use for the gas (for sale and/or use as fuel gas), the value of the gas recovered offsets the additional costs and the project payback is immediate. The economics may shift if the recovered gas has no beneficial use and is recovered to be sent to flare. Nonetheless, under these circumstances, there is still a significant environmental benefit, which should not be ignored.

The *Hydrocarbon Liquid Storage Tanks* technical guidance document contains more details about the economics of installing a new VRU.

Mitigation Option C - Convert centrifugal compressor wet seals to dry seals.

Installing mechanical dry seals on existing wet seal compressors is another alternative to reducing methane emissions. The mechanical dry seal system does not use any circulating seal oil, and thereby is less expensive to purchase, operate, and maintain for new compressors.

Dry seals operate mechanically under the opposing force created by hydrodynamic grooves and static pressure. Hydrodynamic grooves are etched into the surface of the rotating ring(s) affixed to the compressor shaft. Often dry seals come with two or three pairs of rings (tandem) in the seal housing. When the compressor is not rotating, the stationary ring(s) in the seal housing are pressed against the rotating ring(s) by springs. When the compressor shaft rotates at high speed, compressed gas has only one pathway to leak down the shaft, and that is between the rotating and stationary rings. This gas is pumped between the rings by grooves in the rotating ring. The opposing force of high-pressure gas pumped between the rings and springs pushing the rings together creates a very thin gap between the rings through which little gas can leak. While the compressor is operating, the rings are not in contact with each other, and therefore, do not wear or need lubrication. O-rings seal the stationary rings in the seal case.

Operational Considerations

Dry seals are applicable for centrifugal compressors operating up to 3,000 psig (210 kg/cm^2) pressure and 400 degrees Fahrenheit (204 degrees Centigrade).[17] In addition, dry seals typically include a purge gas system, especially when compressing highly corrosive or toxic gas such as hydrogen sulfide.

[16] Ibid. (Assuming 95 percent of total gas recovered at $3 per Mcf x 1/2 design capacity x 365 days.)

[17] EPA. Lessons Learned: *Replacing Wet Seals with Dry Seals In Centrifugal Compressors.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/ll_wetseals.pdf.

Dry seals are mechanically simpler than seal oil lubricating systems because there is no need for oil circulation and treatment equipment. Given that dry seals have fewer ancillary components, they generally consume less power and have higher overall reliability and less downtime.

Implementing this technology requires a lengthy and often expensive compressor shutdown to open the compressor case, lift the rotor, remove the existing wet seal rings, and install the dry seal rings on the compressor shaft at both ends. The seal oil system, including piping, instrumentation, flash tanks, and pumps, can be removed from the compressor site as well. Dry seal conversions might not be possible on some compressors because of housing design or operational requirements, in which case the entire wet seal compressor will have to be replaced by a dry seal compressor. About 90 percent of all new compressors come with dry seals. Therefore, when purchasing a new compressor, partners should ensure that it includes a dry seal.

Methane Emission Reduction Estimate
Partners will determine the amount of methane emissions reduction achieved through conversion to dry seals as the difference between measured emissions from the wet seal configuration and the dry seal configuration.

Partners should measure the emissions before installing the dry seals and again a month after installation. Alternatively, Partners can use the default emission factors for dry seal centrifugal compressors, which are presented in Table 3.4, as a proxy. If dry seals use natural gas as the seal barrier fluid, then the amount of barrier fluid needs to be added to the seal leakage figures.

Table 3.4: Default Emission Factor for Centrifugal Compressors with Dry Seals[18]

Source	Methane Emission Factor[A]			
	(scm/minute/ compressor)	(scm/hour/ compressor)	(scf/minute/ compressor)	(scf/hour/ compressor)
Centrifugal compressor with dry seal (“Mitigated”)	0.17	10.2	6.0	360

[A] Partners should assume their own operating factors for estimating an annual emission factor. Values provided are at Standard Conditions (20°C, 101.325 kPa).
Note: Emission factors are based upon a U.S. onshore context.

Economic Considerations
The cost for a dry seal system will depend on compressor operating pressure, shaft size, rotation speed, and other installation-specific factors. Tandem dry seals cost \$10,800 to \$13,500 per inch (\$4,250 to \$5,300 per centimeter) of shaft diameter.[19] These costs will double for the more common beam-type compressors with a seal on each end of the shaft. Other costs for dry seal systems include installation, engineering, and ancillary equipment. Dry seals require a filtration unit, gas console, controls, and

[18] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. Annex 3. April 2016. https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-annex-3-additional-source-or-sink-categories-part-a.pdf, mention the table…..
[19] EPA. Lessons Learned: *Replacing Wet Seals with Dry Seals In Centrifugal Compressors.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/ll_wetseals.pdf.

monitoring instruments. Depending on location, type of equipment, number of controls, and availability of components, costs can range from $40,500 to $135,000 for the ancillary equipment.[20]

OGMP estimates that costs for implementing dry seals is approximately $324,000 per compressor (including $162,000 in costs for two dry seals per compressor[21] and $162,000 in other costs for engineering and equipment installation), based on replacing fully functioning wet seals.[22]

Wet seal systems may periodically need to be replaced for operational reasons. If this is the case, cost-effectiveness calculations should consider only the *incremental* cost of installing dry seals compared to simply replacing the wet seals. The costs of replacing wet seals typically range between $6,750 and $8,100 per inch ($2,660 and $3,190 per centimeter) of shaft diameter. Additional costs of ancillary equipment for wet seals could be up to $270,000, which would include the seal oil circulation pumps, oil heaters, fan coolers, degassing unit, and controls.[23] These ancillary facility costs are the same for both the single and dual seal compressor types. If wet seals were due to be replaced anyway, Partners may find that the cost of replacing wet seals with dry seals is not significantly more, and may select this option based on the additional operational and emission reduction benefits.

Savings from implementing this technology include reduced O&M costs and reduced natural gas losses (in relation to the case where the wet seal gas was routed to flare or vent, and not recovered for beneficial use). Annual O&M costs can be as high as $140,000 for wet seals.[24] However, since dry seals do not require as much equipment (e.g., oil pumps, heaters), power, and downtime, annual O&M costs for dry seals typically range from $8,400 to $14,000.[25] Therefore, Partners can save as much as $131,600 in O&M costs by not having to purchase replacement seal oil periodically and electricity to power seal oil pumps and cooling fans. Furthermore, Partners may save on compressor and pipeline maintenance as seal oil can clog and foul internal compressor parts and pipelines. These operational benefits of converting to dry seals are estimated to save approximately 20,000 Mscf (567 Mscm) of gas per year.[26] At an assumed gas price of $3 per Mscf, that is equivalent to $60,000 in additional revenue.

For further information and detailed economic analysis, set up a free account with the Fluid Sealing Association to access the Lifecycle Cost Calculator.[27]

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[20] Ibid.
[21] EPA. Lessons Learned: *Replacing Wet Seals with Dry Seals In Centrifugal Compressors.* June 2016. https://www.epa.gov/sites/production/files/2016-06/documents/ll_wetseals.pdf (note: $13,000 per shaft-inch).
[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Note: Based on the difference between typical vent rates of wet and dry seals (i.e., 47.7 scfm versus 6 scfm) on a two-seal compressor operating 8,000 hours/year.
[27] Fluid Sealing Association Lifecycle Cost Calculator, http://FSAKnowledgeBase.org/CompressorLCC.php

Exhibit A – Wet (Oil) Seal Centrifugal that Vents Seal Oil Degassing Tank to Atmosphere[28]

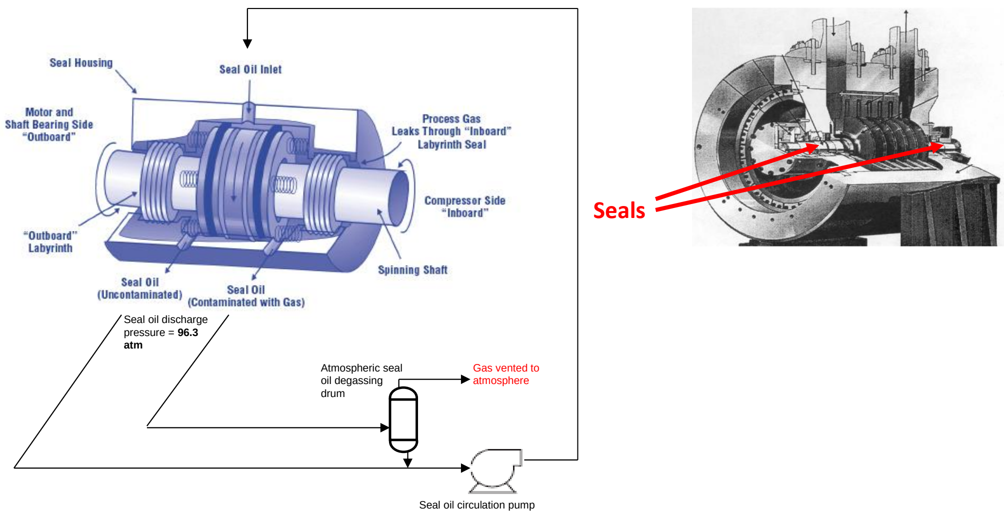
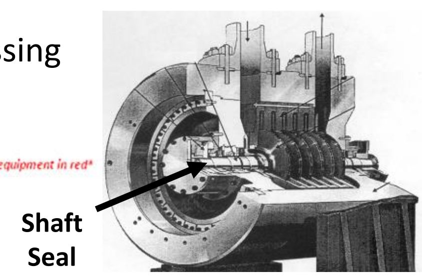
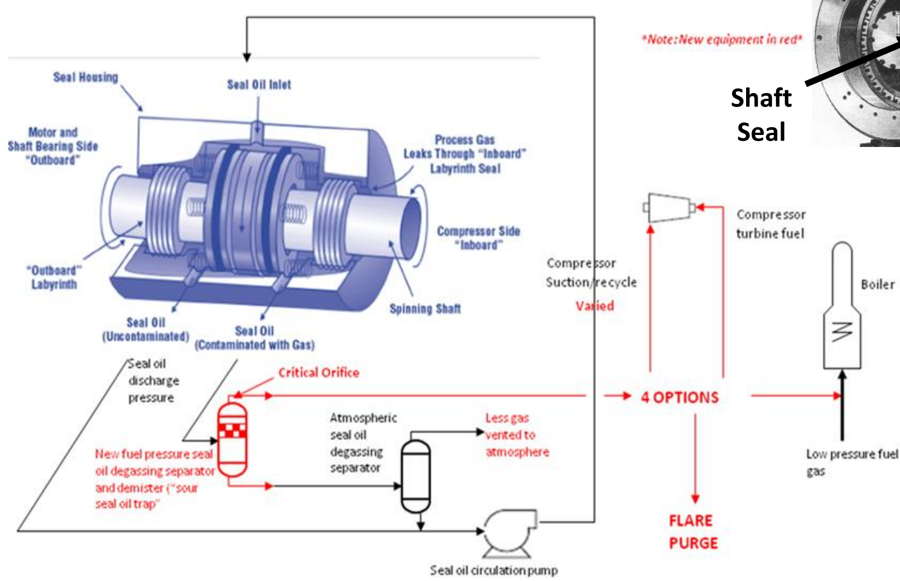


Exhibit B – Wet (Oil) Seal Centrifugal that Captures/Recycles Seal Oil Degassing Tank Vent[29]

- Typical process flow for a Seal Oil Degassing Capture System





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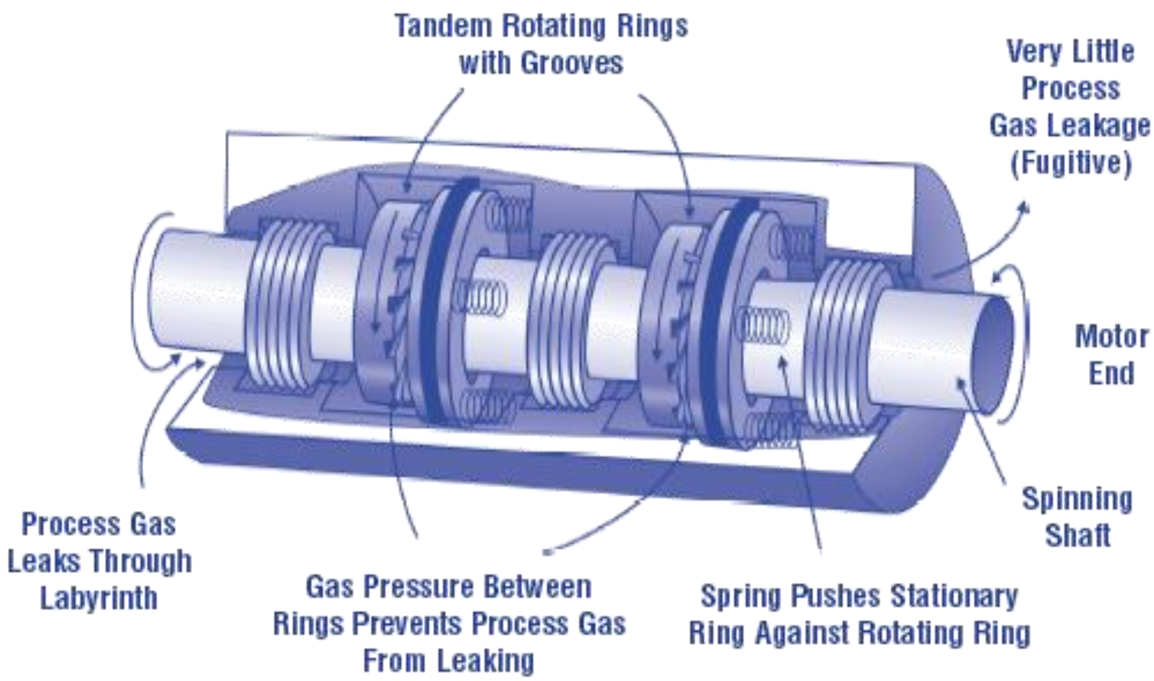
28 International Conference: Methane Emissions Control in the Russian Oil and Gas Sector Achieving Global, National and Local Benefits, Moscow, Russia, October 10, 2012: "Routing Centrifugal Compressor Seal Oil De-gassing Emissions to Fuel Gas as an Alternative to Installing Dry Seals," presented by EPA

29 Global Methane Initiative All-Partnership Meeting, Oil and Gas Subcommittee – Technical and Policy Sessions, Krakow, Poland, October 14, 2011: "Routing Centrifugal Compressor Seal Oil De-gassing Emissions to Fuel Gas as an Alternative to Installing Dry Seals," presented by BP

Exhibit C – Wet (Oil) Seal Centrifugal Compressor with Wet Seal Replaced With Mechanical (Dry) Seal[30]



[30] Global Methane Initiative All-Partnership Meeting, Oil and Gas Subcommittee – Technical and Policy Sessions, Krakow, Poland, October 14, 2011: "Routing Centrifugal Compressor Seal Oil De-gassing Emissions to Fuel Gas as an Alternative to Installing Dry Seals," presented by BP