Brief description of the source

Compressors are widely used to increase gas pressure for the purpose of pipeline transportation or as a process requirement. Centrifugal compressors rely on the centrifugal force created by rotating axis to accelerate gas and increase the pressure. They can be found throughout the entire natural gas value chain.

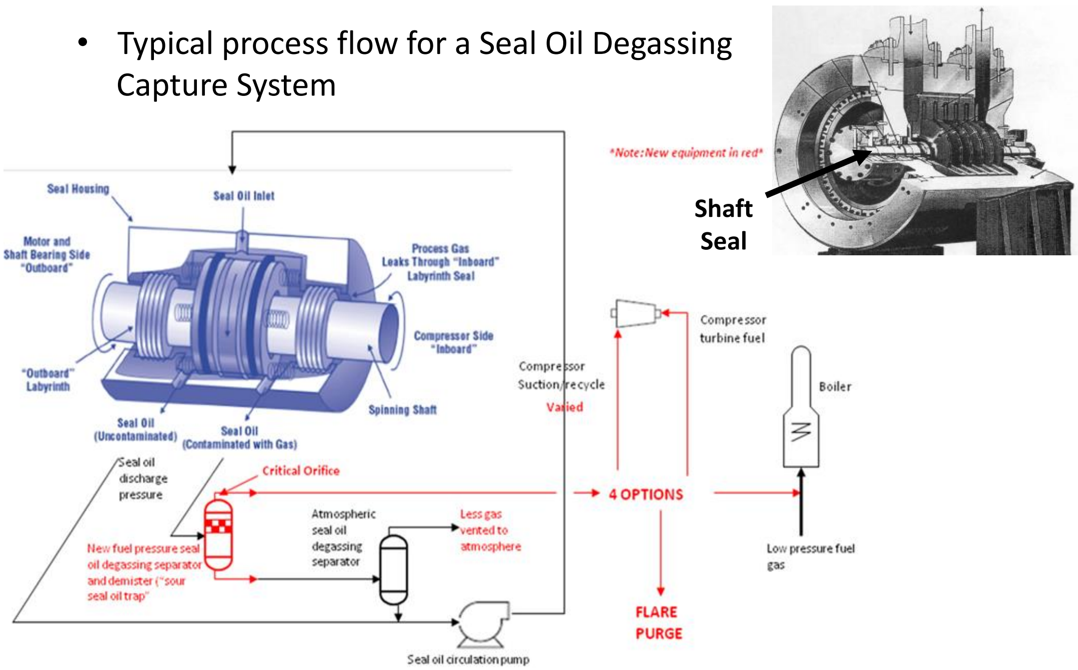
Centrifugal compressors have seals on the rotating shafts that prevent the high-pressure natural gas from escaping the compressor casing. These seals can be high-pressure oil ("wet") seals or mechanical gas ("dry") seals, which act as barriers against escaping gas. These two types of compressor seals can have a variety of configurations. The aim of the following section is to provide the general principles regarding wet and dry gas seals compressors but not all possible configurations are be covered.

Wet seal[1]

Wet seal centrifugal compressors circulate seal oil under high pressure between rings around the compressor shaft, forming a barrier against the compressed gas to prevent its escape to the atmosphere. 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 side of the seal where the oil is in contact with the high-pressure gas. The oil is then evacuated from the seal with the entrained gas. The oil is recirculated but, to maintain viscosity and lubricity, it is necessary to purge the contaminated seal oil of the entrained gas. The large majority of entrained gas is not in solution with the oil and can be disengaged by routing the oil to an atmospheric vented tank, or, in some cases to a succession of two or more vessels, each at a lower pressure than the previous one to supply high pressure gas to compressor turbine fuel, low pressure gas to low pressure fuel, back to the compressor suction, or to a flare. Gravity then drains the seal oil to an atmospheric pressure sump from which it is pumped back into the system and recirculated. A small amount of methane gas is vented to the atmosphere from the sump vent.

[1] Descriptions adapted from CCAC OGMP, *Technical guidance document number 3: Centrifugal compressors with "wet" (Oil) Seals,* 2017

Figure 1 - Illustration of typical process flow for a seal oil degassing capture system



Reference: Natural Gas Star, *Wet Seal Degassing Recovery System for Centrifugal Compressors,* 2014

Dry seal

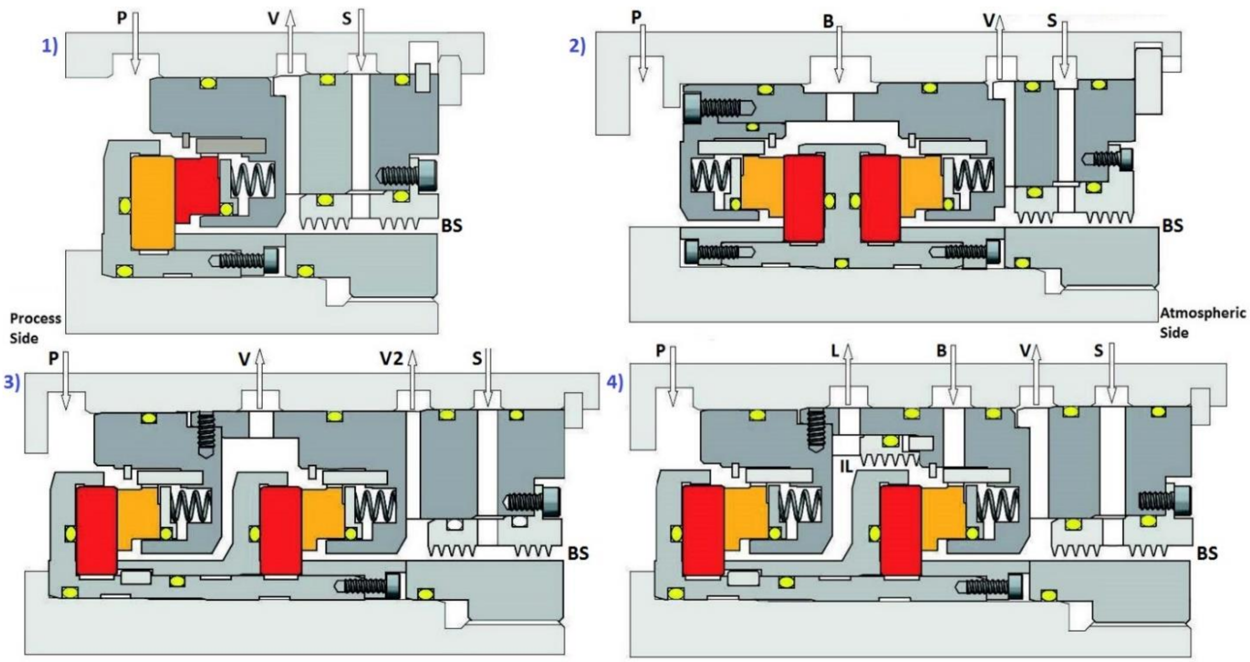
Dry seals operate mechanically under the opposing force created by hydrodynamic grooves and a stationary ring. Hydrodynamic grooves are etched into the surface of the rotating ring(s) affixed to the compressor shaft. Centrifugal compressor dry gas seals can be configured in several ways as shown in the figure below:

1) Single Seal (mainly non-hazardous process gas)
2) Double Seal (two opposed seals)
3) Tandem Seal (two single seals in series, typical for midstream applications); and
4) Tandem Seal w/intermediate labyrinth

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 the grooves in the rotating ring. The opposing force of high-pressure gas pumped between the rotating rings and springs pushing the stationary rings against it creates a very thin gap between the rings through which little gas can leak. O-rings seal the stationary rings in the seal case.

Dry seals may also be installed in a "double seal" configuration with a nitrogen purge between the two dry seals, which can reduce methane emissions to a bare minimum or no emissions of compressed gas (typically not applicable for mid-stream centrifugal compressors). Any gas that is emitted through the seal is typically released where the shaft exits the compressor case (typically, not occurring for midstream) or a vent between tandem dry seals (typical for midstream compressors). "Overhung" compressors have one seal on the turbine or motor driver (i.e. inboard) end; “beam” compressors have two seals at each end (i.e. inboard and outboard). Multi-stage compressors may also have seals between stages.

Figure 2 - Dry gas seal types



Reference: Fluid Science Dynamics, *NGT-Tandem Mass Spectometry,* https://www.fsd.co.id/product/category/NGT-Tandem-Mass-Spectrometry-16

Legend:

P = Process Gas injected into Seal/Primary Seal

B = Buffer gas (air, N2) injected in between double seal or between tandem seal with intermediate labyrinth at slightly higher pressure than the primary vent

S = Separation gas (air, N2) injected between outboard and seal/secondary seal through a labyrinth or carbon rings

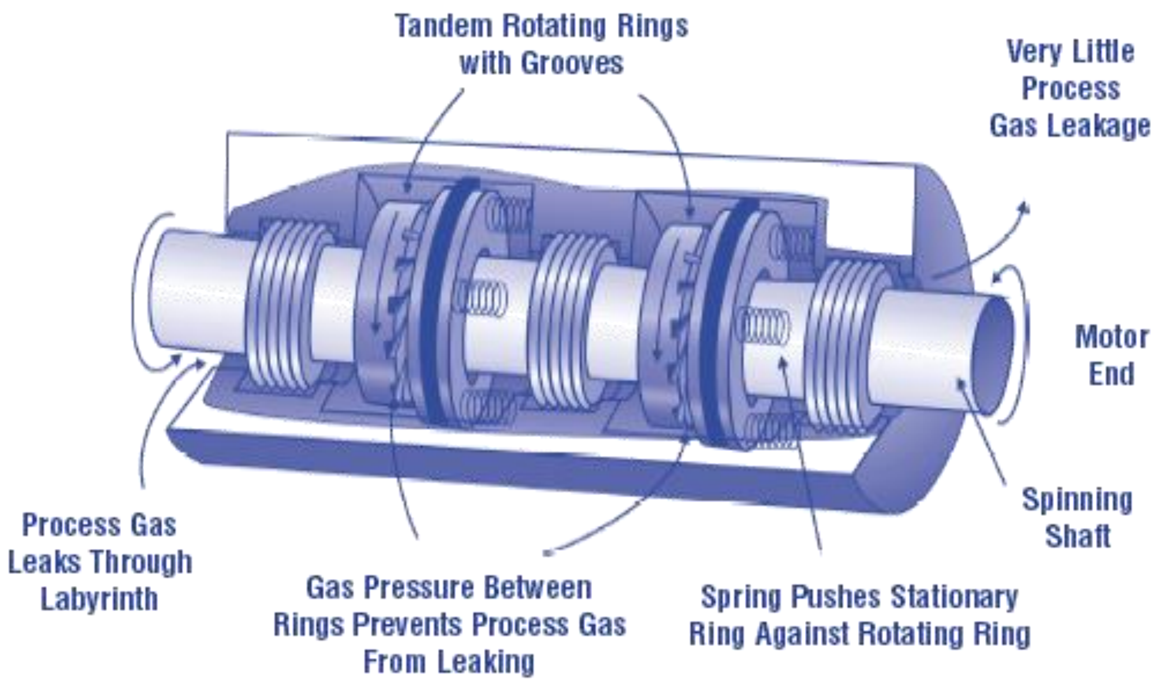
V = Vent for inboard process gas leakage from Seal/Primary Seal plus some buffer or separation gas

V2 = Secondary Vent for separation gas and some buffer typically open to atmosphere; process gas leakage if primary seal fails

IL = Intermediate Labyrinth seal between primary and secondary tandem seals; secondary seal/buffer gas is supplied between the intermediate labyrinth and the secondary seal to prevent primary seal leakage from reaching the secondary seal

BS = Barrier Seal separates the gas seal from the compressor shaft bearings and keeps the lube oil from migrating along the shaft from the bearings and into the seal

Figure 3 - Illustration of centrifugal compressor tandem dry seal



Reference: Adapted from Natural Gas Star, *Replacing Wet Seals with Dry Seals in Centrifugal Compressors,* 2006

System boundaries

This document outlines quantification methodologies and reporting for methane that is vented to the atmosphere from centrifugal compressors. Methane emissions from centrifugal compressors that are captured and reintegrated into the process, i.e. not vented, are not to be reported. Methane emissions captured and routed to flare or thermal oxidation should be reported under Flaring (see *Flaring TGD*) and fugitive methane emissions from components of the centrifugal compressors under Fugitive Emissions (see *Fugitive Emissions TGD).*

[Materiality statement]

Level 3 Quantification Methodologies

Emission factors

Accepted source-level emission factors or those prescribed by local regulation are considered as providing Level 3 estimates, provided they are specific for the source type and based on the operating time of the compressor. Practitioners are encouraged to use emission factors that best represent conditions and practices at their facilities and adjust the factors, where warranted, to more accurately estimate emissions given differences between the reference system on which the emission factor is based, and their systems.

Activity data collection (percent of time online, off-line pressurized and off-line depressurized) should be conducted based on the data required by the selected emission factors.

The following tables present some examples of emission factors which can be used to estimate methane emissions from basic wet and dry seal compressors.

	Source[2]	**Whole gas[3] Emission factor (high range) – Centrifugal compressors**	
		scm/hour/compressor	scf/hour/compressor
Natural Gas Industry Methane Emission Factor Improvement Study – Final report, 2011	Centrifugal compressor with dry seals	5.5	192.7
	Centrifugal compressor with wet seals	364	12,850

The emission factor should be applied to the number of operating hours and consider methane content of the compressed gas. When a dry seal compressor is on stand-by pressurized, an emission factor equivalent to 10% of emissions while in operation should be considered. As these are whole gas emission factors, it is necessary to multiply them with the methane content. If the methane content of the vent is unavailable, the average or typical methane content of the facility can be used.

Manufacturer documentation

If available, methane emission factors presented in manufacturer documentation can be used to estimate methane emissions from centrifugal compressors, provided they are specific for the source type and based on the operating time of the compressor.

Level 4 Quantification Methodologies

Direct measurement and Measurement-based Emission factors

Measurements (including continuous and periodic monitoring) or emission factors developed based on representative measured emissions are considered Level 4 emissions quantification. Measurements must be taken that represent the total flow of each gas stream that is vented to atmosphere from the centrifugal compressor. For wet seal compressors where the methane content varies, the methane content should be measured for each compressor vent or a conservative assumption can be considered.

[2] Harrison. M. R. et al., *Natural Gas Industry Methane Emission Factor Improvement Study – Final report,* 2011, Table 1-4 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjF-NWsmZXzAhUPmYsKHSCLCI4QFnoECAQQAQ&url=https%3A%2F%2Fdept.ceer.utexas.edu%2Fceer%2FGHG%2Ffiles%2FFReports%2FXA_83376101_Final_Report.pdf&usg=AOvVaw1IAnXuR_L4h4R5hkip-TI9

[3] Emission factors were based on whole gas with a methane content of 93.4%

Level 4 emission factors should be based on measurements conducted on a representative sample. Type of seal (wet or dry), system configurations (e.g. size, capacity, etc.), operating conditions (e.g., suction pressure, operating and standby-pressurized hours) should be considered in determining 'like' systems that carry a common emission factor. Each system that is not 'like' will require determination of a separate emission factor for that system based on the appropriate measurement studies. For guidelines on the methodology to develop a statistically representative sample, please refer to the [*General guidance TGD*].

Emission factors expressed in terms of whole gas or methane emissions per compressor seal, per hour in operation, and per hour standby-pressurized will allow for easy adjustment of activity data (i.e. number of compressors, hours).

Accepted equipment and techniques for determining gas flow are to be employed. Following are typical equipment that work well on centrifugal compressors, but the list is not exhaustive[4]:

- Vane anemometer.
- Hotwire anemometer.
- Turbine meter.
- ePV electronic packing vent monitor
- Hi-volume sampler
- Orifice meters

Engineering calculations

In the case of centrifugal compressors with dry seals, the leak rate is very dependent on the design, pressure, revolutions per minute, and to some extent temperature. As such, detailed engineering calculations taking relevant operational information, relevant manufacturer performance data (including seal test performance data) and dependencies into account may also be used to quantify emissions at level 4 in those cases where input and/or output measurement is not available, or where such measurement does not adequately reflect temporal variations, provided Partners can justify that the selected quantification approach presents a sufficient level of certainty or validation through measurements, in line with level 4.

[4] More details on various detection and measurement equipment can be found at CCAC, *Conduction Emissions Surveys, Including Emission Detection and Quantification Equipment – Appendix A of the OGMP Technical Guidance Document,* 2017