SG.17.1.4

# TECHNICAL GUIDANCE DOCUMENT NUMBER 4: RECIPROCATING COMPRESSORS ROD SEAL/PACKING VENTS

## Introduction

This document provides technical guidance to Partners of the CCAC Oil and Gas Methane Partnership (OGMP). It is one in a series describing a core source of methane emissions from oil and natural gas production operations. The guidance documents introduce suggested methodologies for quantifying methane emissions from specific sources and describe 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 result in a stoppage of 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.

Reciprocating compressors are found in a variety of oil and gas operations, both onshore and offshore. While the equipment may be similar, the way in which the emissions are quantified and mitigated may vary across activities and in particular from onshore to offshore. As such, operational conditions, as well as logistical, safety and cost considerations, must be evaluated on a case-by-case basis.

## Description of Source

Reciprocating compressors in the oil and gas industry commonly emit natural gas (where methane is the main component) during normal operation and during standby under pressure. These emissions can be vented from the rod packing and blowdowns or as fugitives from the various compressor components. Figure 4.1 presents a typical compressor rod packing system. Flanges, valves, and fittings are all common sources for fugitive emissions from compressors, and are addressed in Technical Guidance Document (TGD) Number 2 "Fugitive Equipment and Process Leaks." Experience indicates that fugitive leaks from these compressor types are minimal. Piston rod packing systems, however, typically emit the highest volume of gas for compressors in good repair and it is these emissions to which this TGD pertains.
While reciprocating compressors can be found on offshore installations (e.g., in the North Sea basin), compressors directly driven from turbines are far more common.

By design, rod packing systems emit small amounts of gas either into the distance piece or through a vent line connected to the packing case, or both. The piston rod packing itself is used to create a seal around the piston rod tight enough to prevent large amounts of high-pressure gas leakage from the cylinder, but not so tight as to bind the piston rod. A set of two or three flexible, segmented rings in a packing cup is

[1] For reporting purposes as described in the CCAC Oil and Gas Methane Partnership Framework, Section 3.

pressed against the rod to inhibit leakage down the shaft. These rings oscillate back and forth with the rod reciprocal movement, sealing against the cup faces to prevent leakage around the rings, but some gas slips around the rings with each stroke. A packing case has several cups, depending on the pressure in the cylinder. The machined face on each cup inhibits leakage between cups, and a nose gasket and flange gasket prevent leakage around the case. The rings are available in a variety of materials including bronze and carbon-impregnated Teflon.

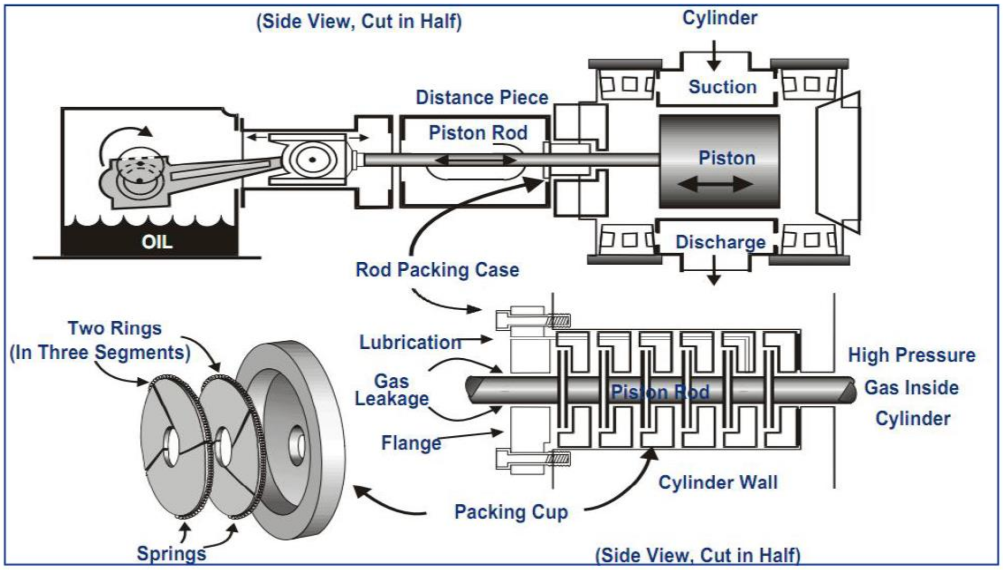


Figure 4.1: Typical Rod Packing System[2]

All packing systems leak under normal conditions, the amount of which depends on cylinder pressure, fitting and alignment of the packing parts, and amount of wear on the rings and rod shaft. A new packing system on small to medium size production compressors, properly aligned and fitted, may lose approximately 11 to 12 standard cubic feet per hour (scfh) (0.5 standard cubic meters per hour (scm/h).[3] As the system ages, however, leak rates will increase from wear on the packing rings and piston rod. Lubricating oil injected into the packing helps seal the rings and cups, reduces wear caused by operation, and lowers heat build-up that accelerates ring wear. But over the thousands of hours of typical compressor operation, rings wear and leakage increases. Average leakage of large, high-pressure reciprocating compressors ranges from 24 to 150 scfh (1 to 6 scm/h).[4] One company has reported emissions of 900 scfh (30 scm/h) from one compressor rod packing.[5] Factors other than normal wear can also contribute to emissions, such as faulty installation and damaged components (cups, rings, gaskets). Reciprocating compressors normally have multiple cylinders, and each cylinder piston rod has a packing case. Reciprocating compressor maintenance practices may vary and rod packing vents may be configured

[2] Turkmenistan Symposium on Gas Systems Management - Methane Mitigation, Ashgabat, Turkmenistan, April 26, 2010: "Methane Emissions Reduction Opportunities at Natural Gas Compressor Stations," presented by EPA
[3] EPA. Lessons Learned: *Reducing Methane Emissions from Compressor Rod Packing Systems.* 2006. https://www.epa.gov/sites/production/files/2016-06/documents/ll_rodpack.pdf. The value will vary according to which sector a compressor is used in and other operating factors.
[4] http://www.epa.gov/gasstar/documents/workshops/2008-tech-transfer/june-charlotte-compressors.pdf, slide 7 from PRCI/ GRI/ EPA. *Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations.*
[5] Ibid.

in a variety of ways; for purposes including mitigation evaluation and annual reporting, Partners should identify the configuration and maintenance practices for each compressor within their OGMP operations/assets. Some common configurations include those listed in Table 4.1.

**Table 4.1: Configurations for Reciprocating Compressors**

<table>
<tr><th>Configuration</th><th>Mitigated or Unmitigated</th></tr>
<tr><td>“Distance piece” or packing case vents (point where rod packing leakage exits the compressor) are vented to the atmosphere and rings are replaced only on a schedule that exceeds every 26,000 hours or three years.</td><td>Unmitigated</td></tr>
<tr><td>“Distance piece” or packing case vents (point where rod packing leakage exits the compressor) are vented to the atmosphere and rings are replaced at least every 26,000 hours or no less frequently than every three years.</td><td>Mitigated</td></tr>
<tr><td>Whenever maintenance occurs[6], Partner identifies and stops excessive leakage. If leakage identification is planned for, and repair, if required, occurs between main engine overhauls, the source will be considered mitigated.</td><td rowspan="3">Mitigated (if confirmed to be functioning with low[A] or no emissions)<br><br>**(OPTION A)**</td></tr>
<tr><td>Rod packing is vented to the atmosphere and Partner conducts periodic (annual) emissions measurement around each rod seal for excessive seal/packing leakage, and replaces rings/rods on seals/packing found to be excessively leaking.</td></tr>
<tr><td>Each rod “distance piece” or packing case is equipped with a leak indicating device and rings/packing cups/gaskets are replaced when the rod packing exhibits excessive leaking.</td></tr>
<tr><td>Reciprocating compressor “distance piece” or rod packing vents (point where rod packing leakage exits the compressor) are routed to recovery (e.g., vapor recovery unit, or VRU) or flare.[7]</td><td>Mitigated (if confirmed to be functioning with low[A] or no emissions)<br>**(OPTION B)**</td></tr>
</table>

[A] Expected emissions levels if mitigation option is in place and functioning properly (e.g., flare is not extinguished, etc.).

Leakage volumes/rates that are deemed to be significantly higher than what is typical for the design and operation of the compressor will be considered as “excessive.” The concept of “excessive” will therefore vary somewhat based upon the individual compressor type and operating conditions.

For the purposes of the OGMP, Partners should quantify and evaluate for mitigation any of the configurations above that are identified as “unmitigated” for methane emissions, as described in the sections below. Even for “mitigated” configurations, Partners should evaluate the compressor and corresponding emission reduction solution regularly to ensure that it is functioning properly and minimizing methane emission levels. Possible malfunctions include improper sealing of rod packing, unexpected rod or ring wear, or an extinguished receiving flare.

[6] Maintenance frequencies may differ (e.g., 4,000, 8,000, and 16,000 hours), depending of geographic location and types of maintenance.

[7] “Flare” in this document refers to vertical combustion devices using an open or enclosed flame.

Operational circumstances, including the possibility of stopping production (where redundancy is lacking), may result in a situation where Partners need to weigh identified leakages against stopped production and emissions from the associated flaring. As a result of this assessment, the Partner may not mitigate the leakages until the next maintenance stop, which could be some months away. This is often the case for offshore operations, where production stops must be planned well in advance. As such, Partners should view the combination of a fixed maintenance plan and gas recovery/routing to flare as the optimal mitigation option, where feasible from a cost/benefit standpoint.

## Quantification Methodology

To ensure consistent quantification of annual, volumetric, reciprocating compressor rod seal/packing vent methane emissions and comparable evaluation of mitigation options, the CCAC OGMP recommends that Partners use one of the following two quantification methodologies for compressors operating more than 26,000 hours (three years) between rod packing replacement. The quantification methodologies are direct measurement and emission factor calculation. In principle, because leakages from rod packings increase over the life of the packing, direct measurement is the most accurate method for quantifying methane emissions. This method is however complex, if the packing vent does not have an in-line flow meter or a measurement port for insertion of a measurement device such as an anemometer.[8] With direct measurement, Partners can be more certain of emission changes over the life of the packing, as well as the economic costs and benefits relate to the timing of rod packing replacement (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 more accurate by the Partner; in this case, the Partner should document and explain the alternative methodology in the Annual Report.

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. This flow rate can then be extrapolated over the entire year. An annual volume of methane emissions is calculated by multiplying the measured whole gas emission flow rate during operation by the operating hours of the compressor plus the measured whole gas emission flow during shutdown while pressurized by the hours of standby-pressurized, and that sum multiplied by the methane content of the whole gas. Other quantification methodologies are provided for situations in which direct measurement is not feasible.

- Direct Measurement[9]
  Prior to measurement, the Partner should determine where the gas stream resulting from rod packing is routed. This determination will help ensure that the measurement point(s) are accurately identified. Typically, the emissions from a reciprocating compressor's rod packing are routed through the vent pipe connected to the packing case flange. However, gas can also leak along the rod or around the nose gasket at the end of the packing case (or both), thus bypassing the packing cup vent and entering

[8] Partners should conduct measurements with appropriately calibrated instruments, as per the instrument manufacturer instructions. Measurements should also be conducted in operating and shutdown under pressure conditions, as such conditions can affect emissions levels. Appendix A to the Technical Guidance Documents includes guidance on instrument use. Partners seeking to generate Emission Factors for their operation of compressors beyond 26,000 hours (three years) between packing replacement should use direct measurement, based on a statistically sound number of measurements, as well as gas analyses to understand the content of methane and other valuable hydrocarbons.

[9] Greenhouse Gas Reporting Program, Subpart W – Petroleum and Natural Gas Systems, Section 98.233 Calculating GHG Emissions, 40 CFR 98.233(p) *Reciprocating Compressor Venting*. https://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol21/pdf/CFR-2011-title40-vol21-sec98-233.pdf.

the distance piece. Rod packing, being a dynamic seal, normally leaks more gas through the packing case when the compressor is shut down and maintained at pressure than while operating. Leakages under these conditions can be measured using the same method as for leakages during normal operations. Compressors housed in buildings normally have vents that are routed to the outside of the building, often through the roof, and all cylinder packing vents are often manifolded together to a single roof vent for each machine. Therefore, it may not always be clear which vent corresponds to which compressor packing. Consequently, Partners should always confirm a reciprocating compressor's vents by tracing piping from the source to the end point to avoid confusion. Where possible, Partners should review piping and instrumentation diagram (P&ID) drawings to confirm assumptions.

Viewing the vent and the compressor overall with an infrared (IR) leak imaging camera will identify emission points that should be measured. Main release points related to compressor venting are the compressor distance piece vent and the packing vent. Partners should also review compressors where the gas is routed to a combustion or utilization point other than the atmospheric vent (e.g., compressor suction, VRUs, low-pressure fuel gas, a flare) to identify any unexpected emissions. Recommended measurement tools include the following:

- Vane anemometer.
- Hotwire anemometer.
- Turbine meter.
- Calibrated bag.
- High-volume sampler.
- Acoustic detection device (for through-valve leaks).
- Orifice meter (vent flow measurement device).

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

- <u>Emission Factor Approach</u>:
  If they do not select the direct measurement approach, Partners should use an emission factor approach to quantify average hourly (and yearly) emissions rates for compressors operating more than 26,000 hours (three years) between rod packing replacement. Partners should apply an emission factor that represents emissions of methane volume per year per compressor cylinder for rod packing, adjusted for the actual operating factor (including standby under pressure) of the compressor(s). Partners are encouraged to use emission factors that best represent the typical conditions and practices at their facilities.

  Table 4.2 presents default average hourly methane emission factors. The recommended methane emission factor varies by industry sector.[10,11] The emission factor is a composite of the methane

[10] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[11] Clearstone Engineering Ltd. *Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites*. (Draft): 2006. https://www.epa.gov/natural-gas-star-program/cost-effective-directed-inspection-and-maintenance-control-opportunities.

emission factor per cylinder and the average number of cylinders for compressors in the sector. The number of average cylinders varies and is as follows: production (4)[12], gathering and boosting (3.3)[13], processing (2.5)[14], transmission (3.3)[15], and storage (4.5).[16]

**Emission Factors**

**Table 4.2: Default Emission Factors for Reciprocating Compressor Rod Packing [A,B,C]**

| Industry Sector | Methane Emission Factor | |
|---|---|---|
| | Methane Emission Factor (scm/hour-compressor) | Methane Emission Factor (scf/hour-compressor) |
| Production (Well Pads)[17] | 0.031 | 1.08 |
| Gathering & Boosting[18] | 2.4 | 85.5 |
| Processing[19] | 4.03 | 142.5 |
| Transmission[20] | 5.3 | 188.1 |
| Storage[21] | 6.5 | 229.5 |

[A] These compressor-based operating emission factors assume an average number of cylinders per compressor as follows: Production (4), Gathering and Boosting (3.3), Processing (2.5), Transmission (3.3), and Storage (4.5).
[B] Methane content by sector: Production (79 percent); Processing (87 percent); Transmission, Storage, and Distribution (94 percent). (Source: EPA. Natural Gas STAR Lessons Learned. https://www.epa.gov/sites/production/files/2016-06/documents/ll_rodpack.pdf.)
[C] A factor of 150% should be applied to default operating emission factors for standby under pressure factors. https://www.epa.gov/sites/production/files/2016-06/documents/ll_compressorsoffline.pdf .

**Mitigation Option A – Rod packing is vented to the atmosphere and Partner conducts periodic (annual) checks to each rod seal for excessive seal/packing leakage and replace rings/rods on seals/packing found to be excessively leaking.**

Time-based, rod packing replacement periods are required by regulations in some jurisdictions. The maximum replacement frequency accepted as a best practice mitigation in Table 4.1 is the typical number

[12] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Table 4-8. pg 39. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[13] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Appendix B. pg B-7. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[14] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Appendix B. pg B-11. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[15] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Appendix B. pg B-16. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[16] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Appendix B. pg B-21. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[17] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks*. Table 4-8, "Compressor Seal." Pg 39. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[18] Clearstone Engineering Ltd. *Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites*. (Draft): 2006. https://www.epa.gov/sites/production/files/2016-08/documents/clearstone_ii_03_2006.pdf.
[19] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Table 4-14, "Compressor Seal." Pg 48. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[20] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks.* Table 4-17, "Compressor Seal." Pg 52. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.
[21] EPA/GRI. *Methane Emissions from the Natural Gas Industry: Volume 8 – Equipment Leaks*. Table 4-24, "Compressor Seal." Pg 66. 1996. https://www.epa.gov/sites/production/files/2016-08/documents/8_equipmentleaks.pdf.

of engine hours at which an engine overhaul is required. Any time-based rod packing replacement shorter than this period, 26,000 operating hours (three years), is considered mitigated. Operating a rod packing beyond this period would require the rod packing emissions measurement and economic analysis described as Option A, in order to consider this source as mitigated. Rather than changing rod packing elements on a time- or operating hours-based schedule short of 26,000 hours, periodic inspection and measurement of the rod packing system enables Partners to identify when it is economical to replace the rings only, rings and cups, and piston rods, based on cost and the value of gas saved by replacement. Using an *expected leak reduction* value, a Partner can determine cost savings associated with maintenance/replacement of excessively leaking packing systems/compressor components. To determine the *expected leak reduction* value, Partners should find the difference between the current leak rate and the initial leak rate measured at the last rod packing replacement[22] (expected leak reduction = current leak rate – initial leak rate after the last rod packing replacement). Calculated leak reduction values may indicate the overall function of the rod packing systems as well as other components. For example, a high emissions measurement from the compressor packing casing vent may indicate maintenance requirements for packing system components only, and/or the piston rod, which is considered separate from the packing system. To establish the initial leak rate, Partners should measure rod packing emissions after one to two months of operation with new rings and with new rods installed (the time necessary to wear in new rings), creating a baseline value for comparing later leakage rates. Once the expected leak reduction value is determined, Partners can apply a gas value to calculate cost savings. Partners should consider replacing the piston rods and rings when the costs savings value is equal to or exceeds the equipment replacement cost.

It is important to note that this mitigation option is most appropriate for compressors which are spared, and thereby not deemed as critical (i.e., they can easily be stopped without affecting production). For unspared compressors that cannot easily be stopped for extended periods (to conduct maintenance), Partners should evaluate routing leaked gas to recovery or flares until the next scheduled shutdown.

*Operational Considerations*

Depending on how routine maintenance schedules are set, implementing this technology may involve more frequent or less frequent replacement of packing components. Replaced equipment may include packing rings, cups, gaskets, and piston rods within the compressor. A measurement-/inspection-based approach to reciprocating compressor leakage mitigation as opposed to a routine time-based schedule ensures that maintenance is performed as needed to prevent potential costly gas loss, unnecessary repairs, and safety hazards associated with excessive leakages. Though compressor packing/packing components as well as rods may typically be replaced according to a regular schedule, this method may not take into account factors such as measured emission levels, improper installation/repairs performed as part of the previously scheduled maintenance periods (which may be duplicated and result in higher than expected emissions), and changes in process conditions between maintenance periods (which may also affect emission levels as well as choice of replacement materials).

*Methane Emission Reduction Estimates*

Many factors affect the potential emission reductions, including the leakage rate of newly installed packing, ring material, amount of wear on the rings, operating hours per year, condition of the piston rod surface, amount of lubrication, and the fit and alignment of the packing system following new packing installation. Partners will determine the amount of methane emission reductions from replacing rod

[22] Ibid. 3, slide 8.

packing by the difference between measurements of leak rates prior to packing replacement and measurements of emissions from newly installed packing.

*Economic Considerations*

The economics of this mitigation technology include equipment replacement costs and gas savings by leak reduction. Replacing/maintaining reciprocating compressor equipment is considered economical based on results of a cost-benefit analysis of the value of gas saved (based on leak measurement) and expected costs associated with equipment maintenance/replacement. When determining the associated costs related to equipment maintenance/replacement, Partners should include the costs associated with production stops, if such stops are required to carry out the maintenance/replacement.

The equipment replacement costs vary among different reciprocating compressor components. For packing rings, the number of compressor cylinders, number of cups per cylinder, and the ring material determine the cost of replacement. Piston rods might also need replacing, depending on condition. Worn (pitted, corroded, out-of-round) rods will also shorten the life of rings. According to Partner experience, a typical Teflon 8- to 10-cup ring set ranges from about $1,350 to $1,700. For piston rods, the replacement cost is determined by the dimension and type of rod. Partners estimate the cost of rods to range from $2,400 to $4,700. Certain coatings such as tungsten carbide or chromium can increase the costs but extend the life of rods and rings as well. The labor cost to install a compressor rod is estimated as approximately equal to the cost of the compressor rod. The payback period of this opportunity will vary depending on the expected leak reduction value.

Once the expected leak reduction and cost of replacements have been determined, Partners can determine an "economic replacement threshold" that will indicate when replacing packing rings (and rods, if necessary) is cost-effective. A simple method is to apply discounted cash flow principles to calculate the economic replacement threshold. Partners can calculate this value for packing rings and rods using the equation below:

$$Economic\ Replacement\ Threshold\ \left(scfh\ or\ \frac{scm}{hour}\right) = \frac{CR \times DF \times 1{,}000}{H \times GP}$$

Where:

CR = cost of replacement ($).
DF = discount factor (%).
H = hours of compressor operation per year.
GP = gas price ($/thousand scm or scf).

The discount factor term is used for capital recovery for equal annual revenues and is calculated using the following equation:

$$DF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where:

*I* = discount rate or Partner hurdle rate (expressed as a decimal).
n = the payback period selected.

Assuming a packing ring replacement cost of $1,620 equipment, plus an equal cost for labor, the calculated leak reduction that will be economic for payback periods (n) of 1, 2, 3, 4 and 5 years (expressed in months) at a discount rate of 10% (i = 0.1) is shown in Table 4.3. For this example, the $1,620 ring replacement cost plus $1,620 labor can be paid back in one year with an expected leak reduction of 4.2 scmh (148 scfh). If a Partner's internal criterion for project investment is a payback of two years, the economic replacement threshold should be approximately 2.2 scmh (78 scfh). In other words, when the leak reduction expected (calculated based upon measurements) is equal to or greater than the economic replacement threshold of 2.2 scmh, Partners should replace the rings because the value of gas saved exceeds the cost to reduce the leakage.

**Table 4.3: Typical Economic Replacement Threshold for Packing Rings**

| Leak Reduction Expected (scmh) | Leak Reduction Expected (scfh) | Payback Period (months) |
|---|---|---|
| 4.2 | 148 | 12 |
| 2.2 | 78 | 24 |
| 1.5 | 54 | 36 |
| 1.2 | 43 | 48 |
| 1.0 | 36 | 60 |

Note: Assumes a gas value of $250/thousand scm ($3.00/Mscf) with 8,000 operating hours/year.

For additional information, see the Natural Gas STAR technical Document *Reducing Methane Emissions from Compressor Rod Packing Systems* (https://www.epa.gov/sites/production/files/2016-06/documents/ll_rodpack.pdf).

**Mitigation Option B – Route reciprocating compressor "distance piece" or packing case vents (point where rod packing leakage exits the compressor) to useful outlet or flare.**

Partners can reduce venting emissions by routing gas to useful outlets, including a fuel gas system, a VRU, or a compressor inlet. Alternatively, Partners can reduce methane emissions by flaring reciprocating compressor vent gas.

*Operational Considerations*

Recovering or flaring gas that leaks from rod packing may substantially reduce emissions. For facilities/operations that already have installed useful outlet(s) (e.g., VRU, fuel gas system) or flare(s), implementing this mitigation option would involve installing additional piping and valves to connect these systems to the compressor vents. In the case of a single on-site VRU, a facility may already have multiple gas lines manifolded to it, and Partners can add another line to the manifold from the reciprocating compressor. Before installing the additional line, Partners must consider process conditions such as incoming gas composition and volume from the compressor to ensure the VRU can accommodate the new gas stream. In evaluating potential inlet vent gas volume to the VRU, the Partner must ensure the VRU has sufficient capacity to accept the maximum anticipated volume from the compressor vent(s).

*Methane Emission Reduction Estimate*

Partners can expect to reduce methane emissions by up to 95 percent from reciprocating compressor venting when routing rod packing emission to a VRU (the operating factor of a VRU) and by up to 99 percent when implementing a flare connection (assuming 99 percent flare efficiency).

*Economic Considerations*

Assuming a facility has an existing useful outlet such as a VRU, the cost of piping and installation costs would be the main associated expenses for this opportunity. The incremental operating and maintenance (O&M) cost would be negligible and mainly consist of routine inspection and maintenance as well as additional electricity costs associated with additional throughput to the VRU. With a low capital cost and high methane reduction value, if technically viable, implementing this technology could quickly benefit most Partners.

Routing gas that leaks from rod packing to a flare will not result in a direct economic benefit to the Partner implementing this option. OGMP suggests that, when assessing this option, Partners consider the indirect benefits associated with this option (e.g., safety benefits, reputational risk mitigation).