Methane Savings from Compressors

Lessons Learned from the
Natural Gas STAR Program

Shell Exploration & Production Company,
Chevron Corporation,
Offshore Operations Committee, and
Gulf Coast Environmental Affairs Group

Offshore Technology Transfer Workshop
New Orleans, Louisiana
May 6, 2008

epa.gov/gasstar

Compressors: Agenda

- Methane Losses from Reciprocating Compressors
  - Methane Savings through Economic Rod Packing Replacement
    - Is Rod Packing Replacement Profitable?
    - Industry Experience – Occidental
- Methane Losses from Centrifugal Compressors
  - Methane Savings through Dry Seals
    - Is Wet Seal Replacement Profitable?
    - Industry Experience – PEMEX
  - Finding More Opportunities
    - Industry Experience – TransCanada
- Discussion

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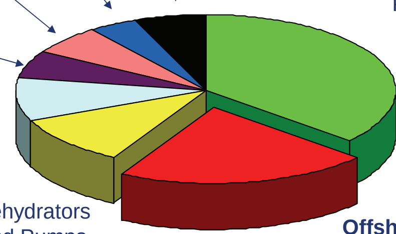
Methane Emissions from Natural Gas Production Sector (2005)

- Compressor seal fugitives make up 6% of total offshore emissions



*Bcf = billion cubic feet

EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 – 2005.* April, 2007. Available on the web at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions.html
Natural Gas STAR reductions data shown as published in the inventory.

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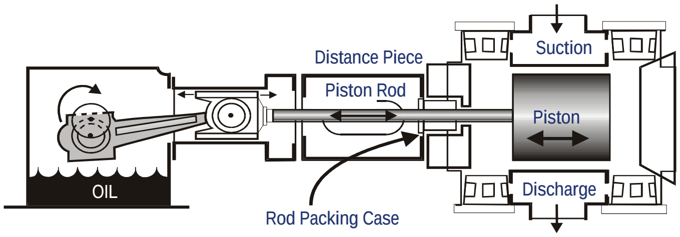
Methane Losses from Reciprocating Compressors

- Reciprocating compressor rod packing leaks some gas by design
  - Newly installed packing may leak 60 cubic feet per hour (cf/hour)
  - Worn packing has been reported to leak up to 900 cf/hour



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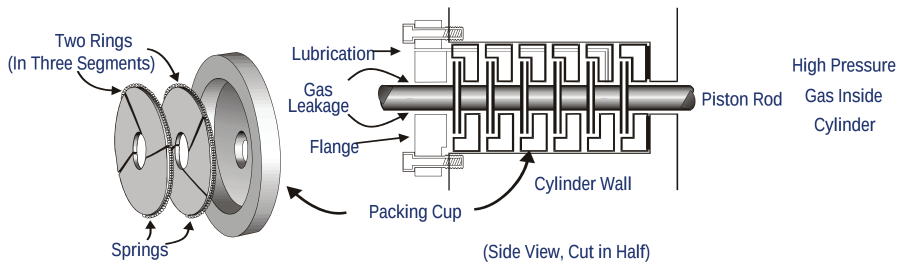
Reciprocating Compressor Rod Packing

- A series of flexible rings fit around the shaft to prevent leakage
- Leakage may still occur through nose gasket, between packing cups, around the rings, and between rings and shaft



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Impediments to Proper Sealing

Ways packing case can leak

- Nose gasket (no crush)
- Ring to rod (surface finish)
- Ring to cup (lapped surface)
- Ring to ring (dirt/lube)
- Cup to cup (out of tolerance/dirt)

What makes packing leak?

- Dirt or foreign matter (trash)
- Worn rod (.0015"/per inch dia.)
- Insufficient/too much lubrication
- Packing cup out of tolerance ($\leq$ 0.002")
- Improper break-in on startup
- Liquids (dilutes oil)
- Incorrect packing installed (backward or wrong type/style)

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Methane Losses from Rod Packing

Emission from Running Compressor	99	cf/hour-packing
Emission from Idle/Pressurized Compressor	145	cf/hour-packing
Leakage from Idle Compressor Packing Cup	79	cf/hour-packing
Leakage from Idle Compressor Distance Piece	34	cf/hour-packing

Leakage from Rod Packing on Running Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (cf/hour)	70	63	150	24

Leakage from Rod Packing on Idle/Pressurized Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (cf/hour)	70	N/A	147	22

PRCI/ GRI/ EPA. *Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations*

Steps to Determine Economic Replacement

- Measure rod packing leakage
  - When new packing installed – after wear-in period
  - Periodically afterwards (e.g. six months)
- Determine cost of packing replacement
- Calculate economic leak reduction
- Replace packing when leak reduction expected will pay back cost

Cost of Rod Packing Replacement

- Assess costs of replacements
  - A set of rings: $ 675 to $ 1,100
    (with cups and case) $ 2,100 to $ 3,400
  - Rods: $ 2,500 to $13,500
    - Special coatings such as ceramic, tungsten carbide, or chromium can increase rod costs

Source: CECO

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Calculate Economic Leak Reduction

- Determine economic replacement threshold
  - Partners can determine economic threshold for all replacements
  - This is a capital recovery economic calculation

Economic Replacement Threshold (cf/hour) = $\frac{CR * DF * 1{,}000}{(H * GP)}$

Where:

CR = **Cost of replacement ($)**

DF = **Discount factor at interest rate *i* =** $DF = \frac{i(1+i)^n}{(1+i)^n - 1}$

H = **Hours of compressor operation per year**

GP = **Gas price ($/thousand cubic feet)**

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Economic Replacement Threshold

- Example: Payback calculations for new rings and rod replacement

CR = \$1,620 for rings + \$9,450 for rod
= \$11,070
H = 8,000 hours per year
GP = \$7/*Mcf

DF @ i = 10% and n = 1 year

$$DF = \frac{0.1(1+0.1)^1}{(1+0.1)^1-1} = \frac{0.1(1.1)}{1.1-1} = \frac{0.11}{0.1} = 1.1$$

DF @ i = 10% and n = 2 years

$$DF = \frac{0.1(1+0.1)^2}{(1+0.1)^2-1} = \frac{0.1(1.21)}{1.21-1} = \frac{0.121}{0.21} = 0.576$$

One year payback

$$ER = \frac{\$11{,}070 \times 1.1 \times 1{,}000}{(8{,}000 \times \$7)}$$
$$= 217 \text{ scf per hour}$$

*Mcf = Thousand cubic feet

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Is Rod Packing Replacement Profitable?

- Replace packing when leak reduction expected will pay back cost
  - "leak reduction expected" is the difference between current leak rate and leak rate with new rings

Rings Only

Rings: \$1,620
Rod: \$0
Gas: \$7/Mcf
Operating: 8,000 hours/year

Leak Reduction Expected (cf/hour)	Payback (year)
32	1
17	2
12	3
9	4

Rod and Rings

Rings: \$1,620
Rod: \$9,450
Gas: \$7/Mcf
Operating: 8,000 hours/year

Leak Reduction Expected (cf/hour)	Payback (year)
217	1
114	2
79	3
62	4

Based on 10% interest rate
Mcf = thousand cubic feet

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Industry Experience – Occidental

- Occidental upgraded compressor rod packing at its Elk Hills facility in southern California
- Achieved reductions of 400 Mcf/day/compressor
- Saving 145 million cubic feet per year (MMcf/year)
- Payback in under 3 years

Source: Occidental

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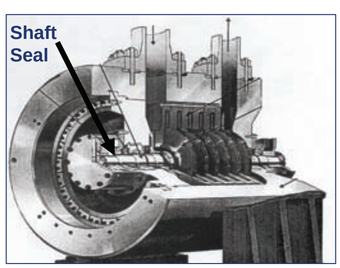
Methane Losses from Centrifugal Compressors

- Centrifugal compressor wet seals leak little gas at the seal face
  - Seal oil degassing may vent 40 to 200 cubic feet per **minute** (cf/minute) to the atmosphere
  - A Natural Gas STAR Partner reported wet seal emissions of 75 Mcf/day (52 cf/minute)



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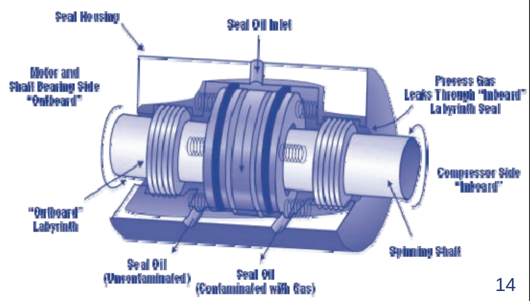
Centrifugal Compressor Wet Seals

- High pressure seal oil circulates between rings around the compressor shaft
- Oil absorbs the gas on the inboard side
- Little gas leaks through the oil seal
- Seal oil degassing vents methane to the atmosphere

Source: PEMEX



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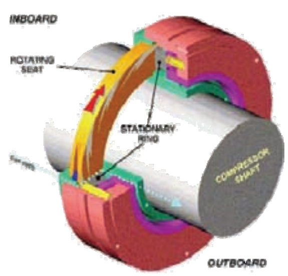
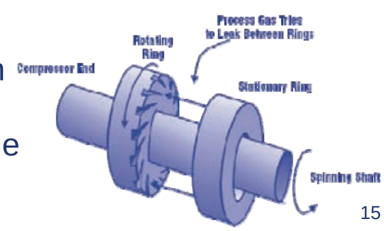
Natural Gas STAR Partners Reduce Emissions with Dry Seals

- Dry seal springs press the stationary ring in the seal housing against the rotating ring when the compressor is not rotating
- Sealing at high rotation speed pump gas between the seal rings creating a high pressure barrier to leakage
- Only a very small volume of gas escapes through the gap
- Two seals are often used in tandem
- Can operate for compressors up to 3,000 pounds per square inch gauge (psig) safely



Source: PEMEX



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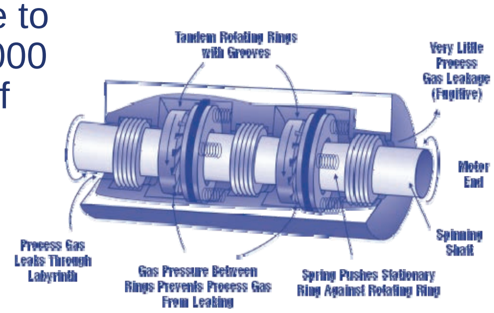
Methane Savings through Dry Seals

- Dry seals typically leak 0.5 to 3 cf/minute
  - Significantly less than the 40 to 200 cf/minute emissions from wet seals
- Gas savings translate to approximately $112,000 to $651,000 at $7/Mcf

Source: PEMEX



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Economics of Replacing Seals

- Compare costs and savings for a 6-inch shaft beam compressor

Cost Category	Dry Seal ($)	Wet Seal ($)
Implementation Costs[1]		
Seal costs (2 dry @ $13,500/shaft-inch, with testing)	$162,000	
Seal costs (2 wet @ $6,750/shaft-inch)		$81,000
Other costs (engineering, equipment installation)	$162,000	$0
Total implementation costs	$324,000	$81,000
Annual Operating and Maintenance	$14,100	$102,400
Annual Methane Emissions (@ $7/Mcf; 8,000 hours/year)		
2 dry seals at a total of 6 cf/minute	$20,160	
2 wet seals at a total of 100 cf/minute		$336,000
Total Costs Over 5-Year Period	$495,300	$2,273,000
Total Dry Seal Savings Over 5 Years		
Savings	$1,777,700	
Methane Emissions Reductions (Mcf; at 45,120 Mcf/year)	225,600	

[1] **Flowserve Corporation (updated costs and savings)**

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Is Wet Seal Replacement Profitable?

- Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hours/year
  - Net present value = $1,337,769
    - Assuming a 10% discount over 5 years
  - Internal rate of return = 129%
  - Payback period = 10 months
    - Ranges from 3 to 11 months based on wet seal leakage rates between 40 and 200 cf/minute
- Economics are better for new installations
  - Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals

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Industry Experience – PEMEX

- PEMEX had 46 compressors with wet seals at its PGPB production site
- Converted three to dry seals
  - Cost $444,000/compressor
  - Saves 20,500 Mcf/compressor/year
  - Saves $126,690/compressor/year in gas
- 3.5 year payback from gas savings alone
- Plans for future dry seal installations

Source: PEMEX

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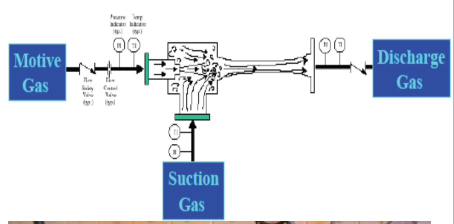
Finding More Opportunities

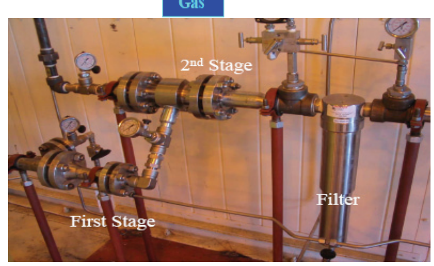
- Partners are identifying other technologies and practices to reduce emissions
  - BP-Indonesia degasses wet seal oil to low pressure fuel gas, capturing emissions as fuel
    - Reduces expensive implementation costs of replacing with dry seals
  - TransCanada has successfully conducted pilot studies on the use of an ejector to recover dry seal leakage

Source: TransCanada

Industry Experience – TransCanada

- Two-stage supersonic ejector for capturing dry-gas seal vent gases
  - First stage - expansion of the motive gas
  - Second stage - recompression to a pressure equal to the fuel gas pressure
- Installed and commissioned successfully in one of TransCanada's compressor stations in Alberta
  - 3,960 Mcf/year savings (4 cfm/seal)
  - 100% recovery of vented gas
  - Zero operating cost
  - Payback in 1-2 years





Source: TransCanada

Discussion

- Industry experience applying these technologies and practices
- Limitations on application of these technologies and practices
- Actual costs and benefits

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