Directed Inspection & Maintenance (DI&M) and Compressor Best Practices

Ministerio de Minas y Energia
Ministerio de Ambiente, Vivienda y Desarrollo Territorial
Occidental Oil & Gas Corporation and
Environmental Protection Agency, USA

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Methane to Markets

DI&M and Compressor Practices: Agenda

- Directed Inspection and Maintenance (DI&M)
  - **David Picard, Clearstone Engineering**
- DI&M with Optical Imaging
  - **Don Robinson, ICF Consulting**
- Compressor Best Practices
  - **Don Robinson, ICF Consulting**

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Directed Inspection and Maintenance (DI&M)

Agenda

- Leak Characteristics
- Leak Trends
- Key Principles
- Important Benefits
- Conclusion

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Leak Characteristics

- Contribute significantly to total VOC and GHG emissions at upstream oil and gas facilities
- Only a few percent of the components at a site actually leak
- Most of the leakage is usually from just a few big leakers.
- Big leakers often go unnoticed because they occur in difficult-to-access, low-traffic, crowded or noisy areas, or the amount of leakage is not fully appreciated
- Big leakers may also occur because of severe/demanding applications coupled with high cost or difficulty of repairs
- Leakage is mostly from components in gas/vapor service

Fugitive Equipment Leaks

Facility Type	Number of Components surveyed Per Site	Leak Frequency (%)	Emissions From All Leaking Sources		Combustion to THC Emissions
			Methane	Value	Top 10 Sources
			(tonnes/year)	($/year)	(%)
Gas Plants	56461	1.7	997	500253	35
	16050	3.5	471	320608	36
	14424	3.0	1412	558665	64
	14174	4.0	1376	553248	36
	11556	3.3	1215	621061	33
	13133	2.5	186	386538	57
	13471	1.2	299	178744	93
	3672	10.3	2334	1262874	77
	5979	0.6	29	11863	93
TOTAL	**148920**		**8320**	**4393854**	
AVERAGE	**16547**	**2.5**	**924**	**488206**	**54**
Compressor Stations	608	5.1	110	61572	90
	4626	1.1	98	49184	83
	3084	0.7	169	98802	95
	6168	1.0	194	103508	64
	1568	4.2	80	33552	80
	224	1.3	0	189	100
	1391	1.9	4	2367	88
	2115	1.8	67	27855	89
	2516	1.1	45	18901	91
TOTAL	**22300**		**767**	**395928**	
AVERAGE	**2478**	**1.5**	**85**	**43992**	**83**
Well Sites	1474	0.2	1	501	100
	1617	1.5	1	351	88
	1797	0.4	1	585	100
TOTAL	**4888**		**3**	**1437**	
AVERAGE	**407**	**0.7**	**0**	**120**	**97**

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- Value of emissions based on natural gas price of $6.78/GJ

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Residual Flaring

Facility	Residual THC Flaring Rate (10^3 m^3/day)	THC Emissions (10^3 m^3/year)	Methane Emissions (10^3 m^3/year	GHG Emission tonnes CO_2E/year	Value of Flared Gas ($/year)
Gas Plant #1	0.56	4	3	540	53,765
Gas Plant #2	NA	NA	NA	NA	NA
Gas Plant #3	5.28	39	28	5,136	227,445
Gas Plant #4	3.43	29	18	3,336	342,272
Gas Plant #5	NA	NA	NA	NA	NA
Gas Plant #6	2.83	21	14	5,590	219,000
Gas Plant #7	NA	NA	NA	NA	NA
Gas Plant #8	10.99	80	66	10,266	1,249,588
Gas Plant #9	NA	NA	NA	NA	NA
TOTAL	23.09	172	130	24,868	2,092,070
AVERAGE	2.57	19	14	2,763	232,452

Value of emissions based on natural gas price of $6.78/GJ

NA – Excessive flaring was not observed at this facility

Noteworthy Leak Trends

- Most likely sources of big leaks:
  - **Compressor seals**
  - **Open-ended lines and blowdown systems**
  - **Pressure relief valves**
  - **Pressure-vacuum safety valves**
  - **Tank hatches**
- Least likely sources of big leaks:
  - **Valve stem packing systems**
  - **Connectors**
- Components in odorized or H_2S service leak less than those in non-odorized or non-toxic service
- Components in thermal cycling, vibration or cryogenic service have increased leakage

Key Principles of DI&M

- Minimize the potential for big leakers and provide early detection and repair of these when they occur
- Focus efforts on the areas most likely to offer significant cost-effective control opportunities, with coarse or less frequent screening of other areas
- Implement repairs as soon as possible, or at the next facility turnaround if a major shutdown is required
- Consider leakage directly to the atmosphere as well as into vent, flare, drain and blowdown systems

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Important Benefits of DI&M

- Attractive payback (often <6 months)
- Reduced maintenance costs
- Reduced downtime
- Improved process efficiency
- Safer work environment
- Cleaner environment
- Resource conservation
- Lower methane emissions

Useful Tools

- Leak Detection
  - **Bubble Tests**
  - **Handheld Vapor Sensors**
  - **Ultrasonic Leak Detectors**
  - **IR Cameras**
- Leak Quantification
  - **Bagging**
  - **Hi-Flow Sampler**
  - **Tracer Tests**
  - **Velocity Probes**
  - **Total Capture and Flow Measurement**
  - **Remote Sensing (e.g., DIAL)**

Conclusions

- DI&M is a rational approach to managing fugitive emissions.
  - **Effective means of achieving significant cost-effective reductions in methane emissions.**
  - **An environmentally responsible choice.**

- A BMP for conducting DI&M at production facilities is currently being developed in Canada (CAPP, SEPAC, EC and EUB) and is expected to become a regulatory requirement (End of 2005).

- A multi-years study for US EPA/GRI/KSU will also be producing additional data for the Natural Gas STAR DI&M BMP (Fall 2005)

DI&M with Optical Imaging

Agenda

- DI&M by Leak Imaging
- Imaging Technology
- Imaging Video

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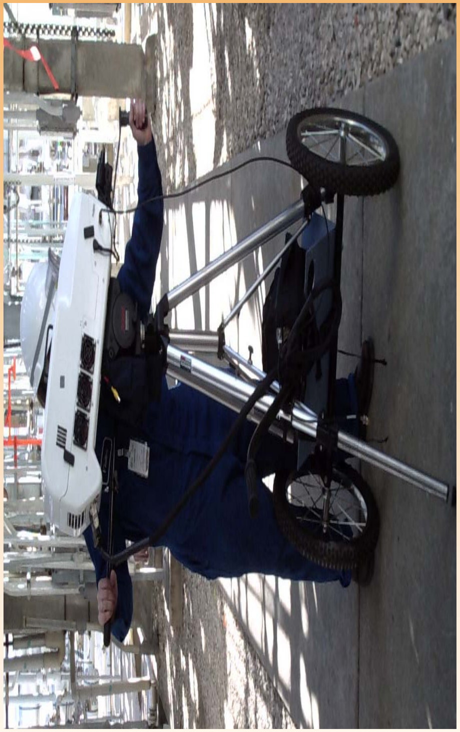
DI&M by Leak Imaging

- Real-time visual image of gas leaks
  - **Quicker identification & repair of leaks**
  - **Screen hundreds of components an hour**
  - **Screen inaccessible areas simply by viewing them**



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Technologies for Methane Detection

- Two technologies currently in development
- Backscatter Absorption Gas Imaging (BAGI)
  - Viewing area illuminated with IR laser light
  - IR camera images reflected laser light
  - Gas cloud absorbs the IR light (negative image)
- Passive IR Imaging
  - IR camera acquires image in full light spectrum
  - Optics separate IR frequency characteristic to chemical leak
  - Camera images equipment at selected IR frequency where light absorption by gas cloud provides a visual image

IR BAGI Camera

- Developed by Sandia National Laboratory
- Real-time instantaneous detection
- No quantification of detected leaks yet
- Does not differentiate chemical species
  - Tuned to optimum wavelength absorbed by chemical species

Backpack power/control

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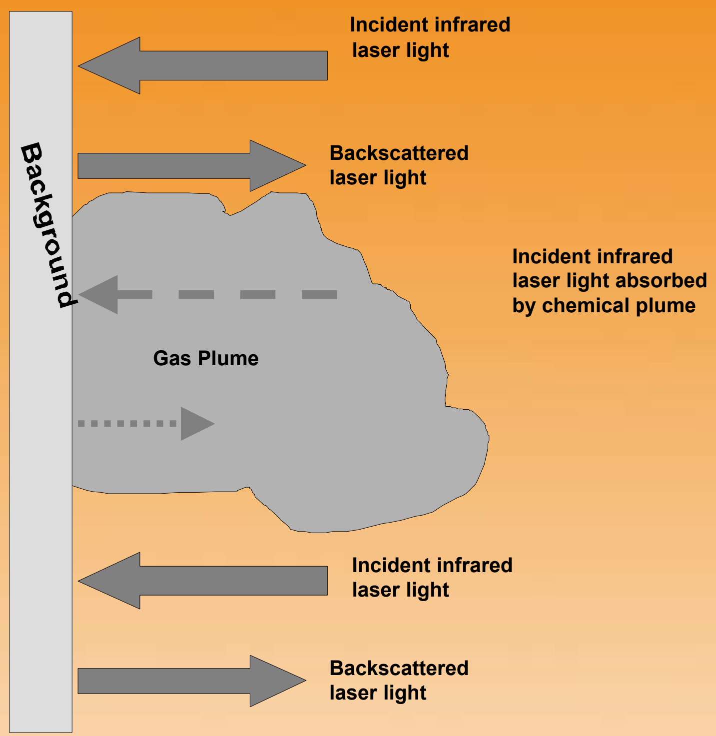
Backscatter Absorption Gas Imaging (BAGI) Process

- Incident IR laser light reflects off background & returns to camera
- IR camera creates black & white image of equipment
- Chemical plume absorbs IR light creating a negative image
- Leak plume appears as a black, smoky image in BAGI camera



Source: As Adapted from McRae, Tom, *GasVue: A Rapid Leak Location Technology for Large VOC Fugitive Emissions*. (Presentation at the CSI Petroleum Refining Sector Equipment Leaks Group, Washington, DC, Sept. 9, 1997).

Note: Although this Exhibit shows the gas in contact with the background material, it is not a requirement that the gas be in contact with the background. The gas plume need only be between the background and the infrared camera.

IR BAGI Camera, cont.

- Portable
  - Camera ~20 pounds
  - Shoulder- or tripod-mounted operation
  - Size of a shoulder-mounted TV camera
- DC or AC Power
  - Rechargeable battery back-pack ~12 pounds
- Camera viewer and tape recording toggle between IR and visible light

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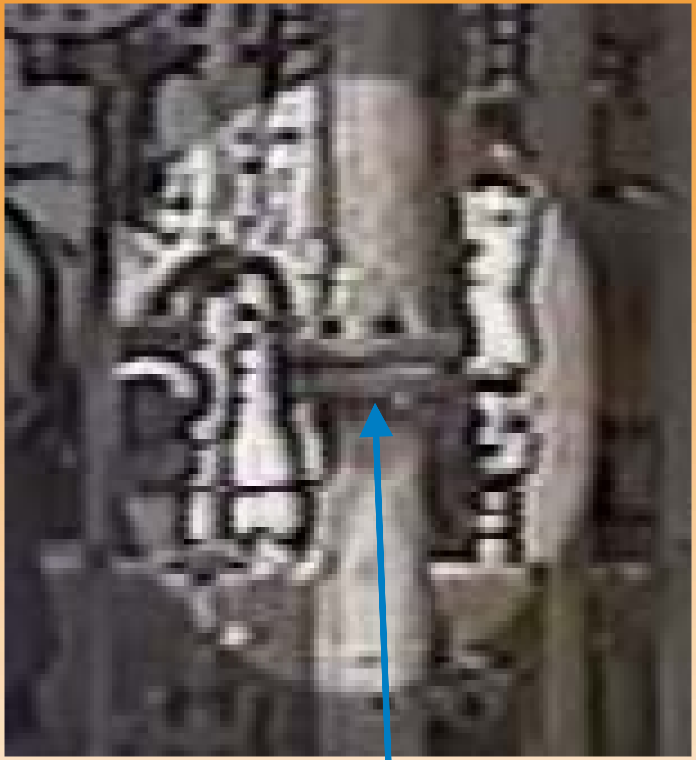
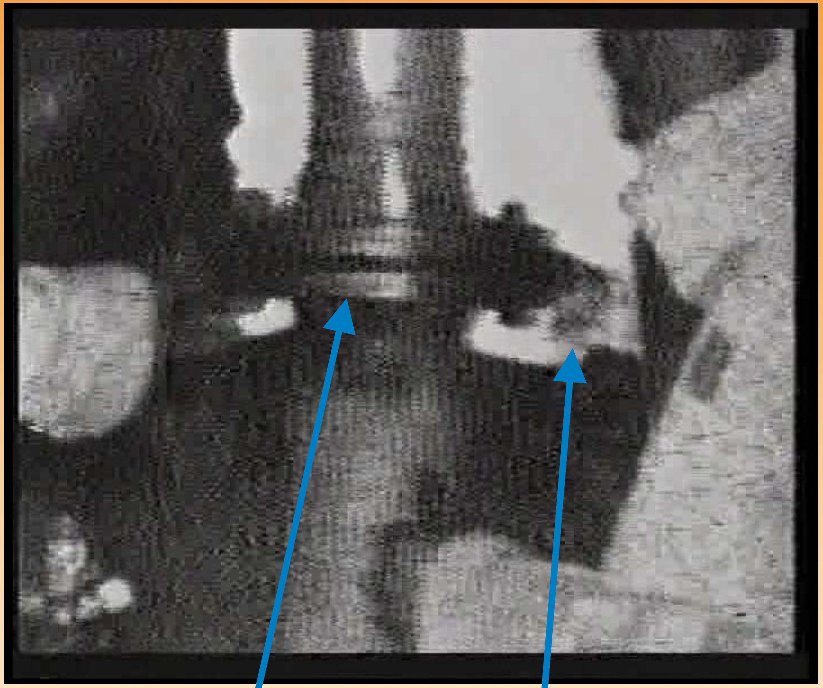
Leak Detected w/BAGI Camera

Visible light view of leaking flange



Leaking flange

Infrared view of leaking flange



Flange

Hydrocarbon plume

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LSI Hawk Camera

- Does not quantify leaks
- Battery operated
- Also operated from helicopter to survey cross country pipelines
- Images pipeline leaks from 2 miles distance

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Infrared Gas Imaging Video

- Recording of fugitive leak found by infrared camera

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Compressor Best Practices

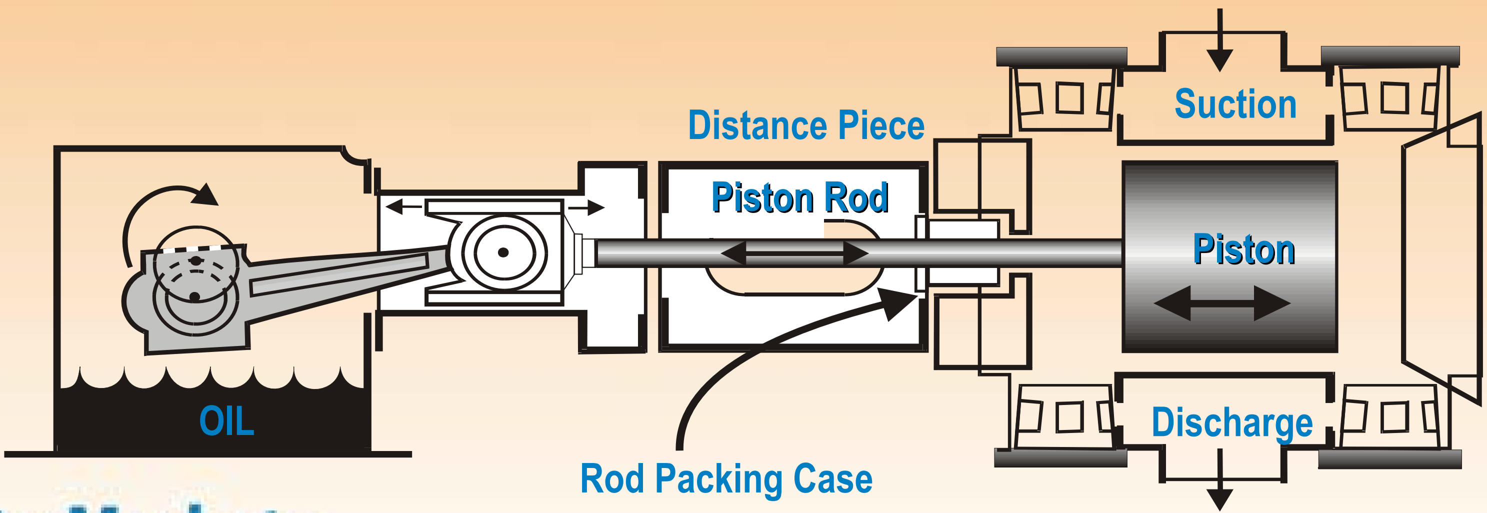
Agenda

- Reciprocating Compressor Losses
- Rod Packing Replacement
- Centrifugal Compressor Losses
- Wet and Dry Seals
- Taking Compressors Offline

Source: CECO

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/h)**
  - **Worn packing has been reported to leak up to 900 cf/h**



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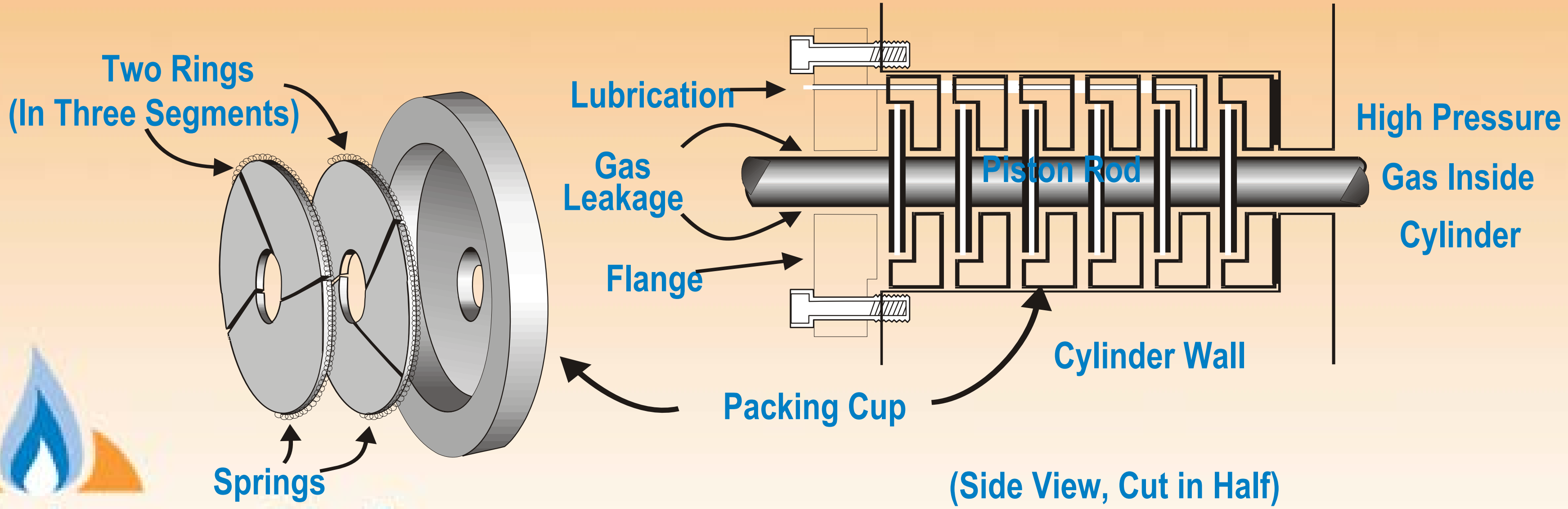
Reciprocating Compressor Rod Packing

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



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Methane Recovery Through Economic Rod Packing Replacement

- Step 1: Monitor and record baseline leakage and rod wear
  - **Establishing baseline leak rates and monitoring rod wear can help to track leakage and evaluate economics**
- Step 2: Compare current leak rate to initial leak rate to determine leak reduction expected
  - **Leak Reduction Expected (LRE) = Current Leak Rate (CL) – Initial Leak Rate (IL)**
  - **Example: The current leak rate is measured as 100 cf/h, the same component leaked 11.5 cf/h when first installed**

LRE = 100 cf/h – 11.5 cf/h
LRE = 88.5 cf/h

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Methane Recovery Through Economic Rod Packing Replacement

- Step 3: Assess costs of replacements
  - **A set of rings: $ 700 to $1100**
    (with cups and case) $2100 to $3500
  - **Rods: $2500 to $4900**
- Step 4: Determine economic replacement threshold
  - **Partners can determine economic threshold for all replacements**

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

Where:

CR = Cost of replacement ($)

DF= Discount factor (%) @ interest *i*

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

H = Hours of compressor operation per year

GP = Gas price ($/Mcf)

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Is Recovery Profitable?

- Step 5: Replace packing and rods when cost-effective
  - **Example:**

Rings Only

Rings:	$1,200
Rod:	$0
Gas:	$1.5/Mcf
Operating:	8,000 hrs/yr

Leak Reduction Expected (cfh)	Payback Period (years)
110	1
58	2
40	3
32	4
26	5

Rod and Rings

Rings:	$1,200
Rod:	$7,000
Gas:	$1.5/Mcf
Operating:	8,000 hrs/yr

Leak Reduction Expected (cfh)	Payback Period (years)
752	1
394	2
275	3
216	4
180	5

Based on 10% interest rate
Mcf = thousand cubic feet, scfh = standard cubic feet per hour

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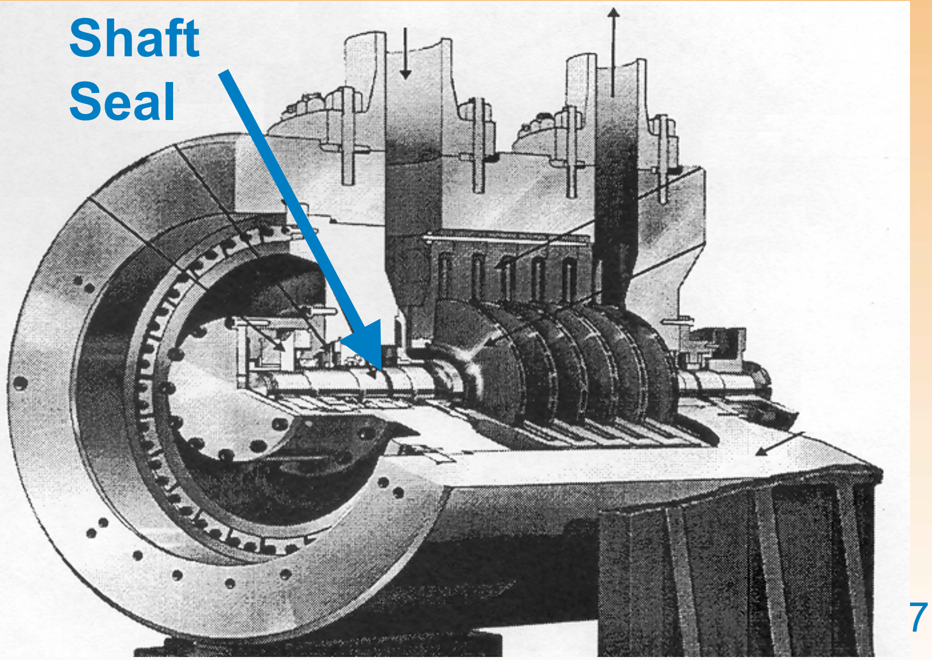
Methane Losses from Centrifugal Compressors

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



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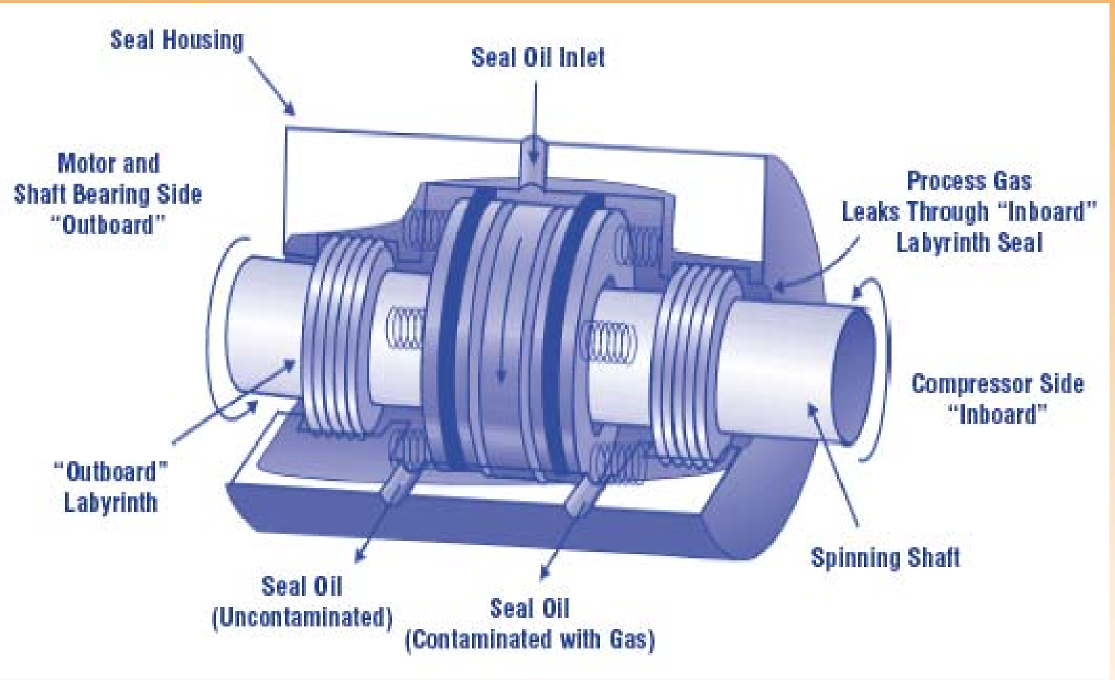
Centrifugal Compressor Wet Seals

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



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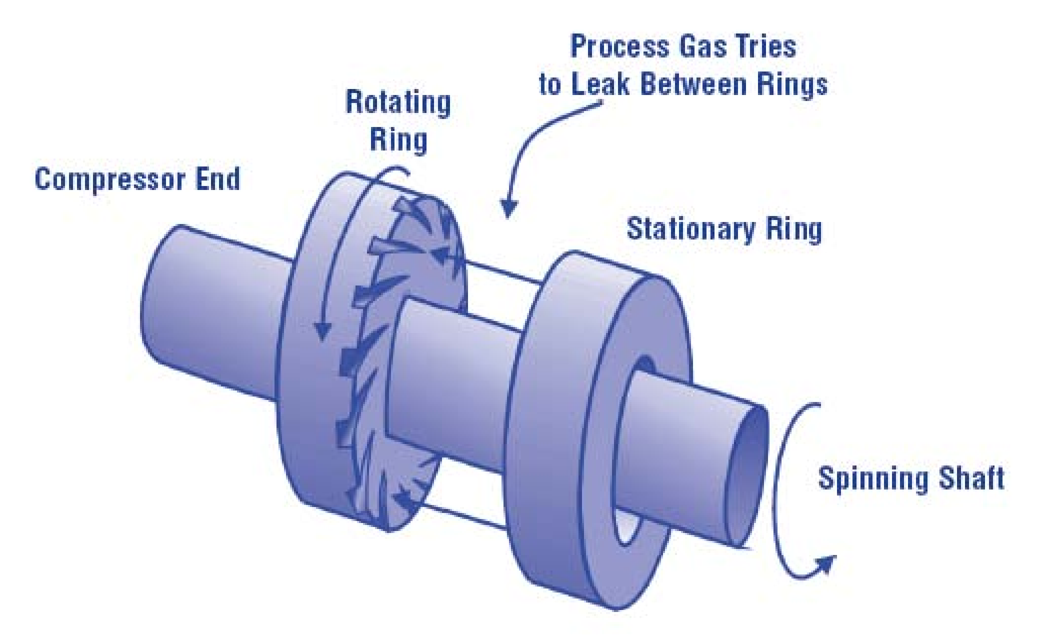
Reduce Emissions with Dry Seals

- Dry seal springs press the stationary ring in the seal housing against the rotating ring when the compressor is not rotating
- At high rotation speed, gas is pumped between the seal rings creating a high pressure barrier to leakage
- Only a very small amount of gas escapes through the gap
- 2 seals are often used in tandem



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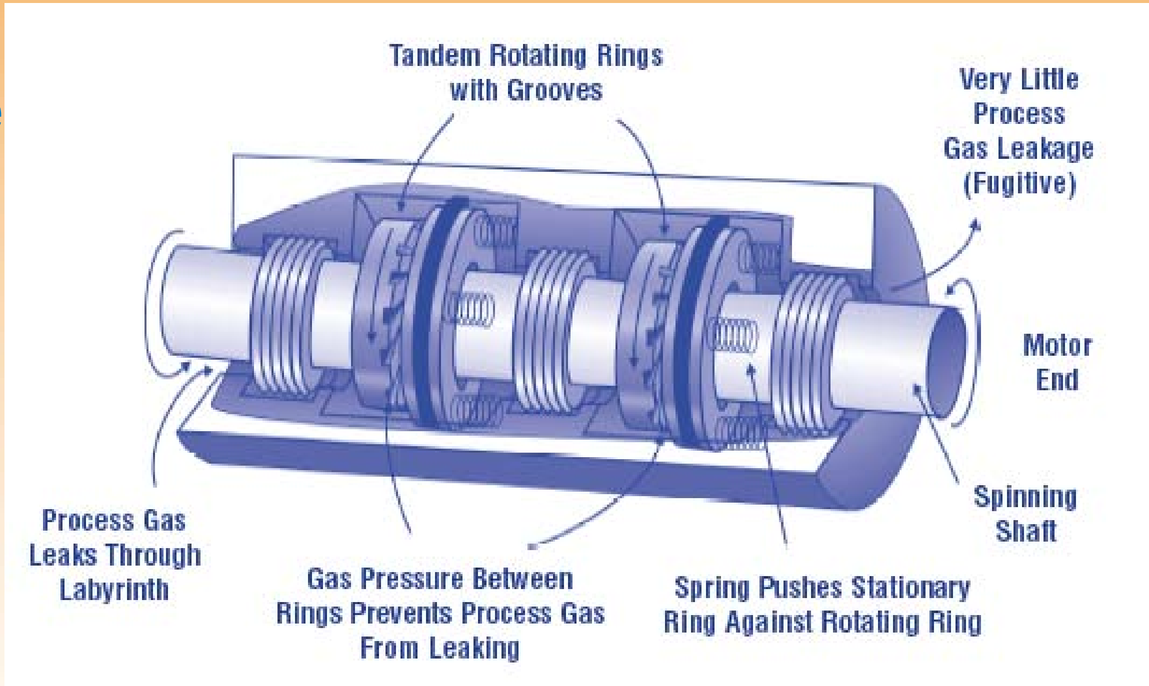
Methane Recovery with Dry Seals

- Dry seals typically leak at a rate of only 0.5 to 3 cf/m
  - **Significantly less than the 40 to 200 cf/m emissions from wet seals**
- These savings translate to approximately $24,480 to $139,680 in annual gas value



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Economics of Replacing Seals

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

Flowserve Corporation

Cost Category	Dry Seal ($)	Wet Seal ($)
Implementation Costs[1]		
Seal costs (2 dry @ $14,000/shaft-inch, w/testing)	168,000	
Seal costs (2 wet @ $7,000/shaft-inch)		84,000
Other costs[2] (engineering, equipment installation)	128,000	-
Total Implementation Costs	296,000	84,000
Annual O&M	10,500	77,500
Annual methane emissions[3] (@ $1.5/Mcf; 8,000 hrs/yr)		
2 dry seals at a total of 6 scfm	4,320	
2 wet seals at a total of 100 scfm		72,000
Total Costs Over 5-Year Period ($)	370,100	831,500
Total Dry Seal Savings Over 5 Years		
Savings ($)	461,400	
Methane Emissions Reductions (Mcf) (at 45,120 Mcf/yr)	225,600	
Notes:		
1. Flowserve Corporation		
2. Re-use existing seal oil circulation, degassing, and control equipment for wet seal		
3. Based on typical vent rates		

Is Wet Seal Replacement Profitable?

- Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hr/yr
  - **Net Present Value = $242,543**
    - **Assuming a 10% discount over 5 years**
  - **Internal Rate of Return = 41%**
  - **Payback Period = 24 months**
    - **Ranges from 16 to 35 months based on wet seal leakage rates between 40 and 200 cf/m**
- Economics are better for new installations
  - **Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals**

Taking Compressors Offline: What is the Problem?

- Natural gas compressors cycled on- and off-line to match fluctuating gas demand
  - **Peak and base load compressors**
- Standard practice is to blow down (depressurize) off-line compressors
  - **One blowdown vents 15 Mcf gas to atmosphere on average**
- Isolation valves
  - **Leak about 1.4 Mcf/hr on average through open blowdown vents**

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Methane Recovery Options

- Option 1 - Keep off-line compressors pressurized
  - **Requires no facility modifications**
  - **Eliminates methane vents**
  - **Seal leak higher by 0.30 Mcf/hr**
  - **Reduces fugitive methane losses by 0.95 Mcf/hr (68%)**

- Option 2 - Route off-line compressor gas to fuel
  - **Connect blowdown vent to fuel gas system**
  - **Off-line compressor equalizes to fuel gas pressure (100 to 150 pounds per square inch)**
  - **Eliminates methane vents**
  - **Seal leak higher by 0.125 Mcf/hr**
  - **Reduces fugitive methane losses by 1.275 Mcf/hr (91%)**

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Methane Recovery Options contd.

- Keep pressurized and install a static seal
  - **Automatic controller activates rod packing seal on shutdown and removes seal on startup**
  - **Closed blowdown valve leaks**
  - **Eliminates leaks from off-line compressor seals**
  - **Reduces fugitive methane losses by 1.25 Mcf/hr (89%)**

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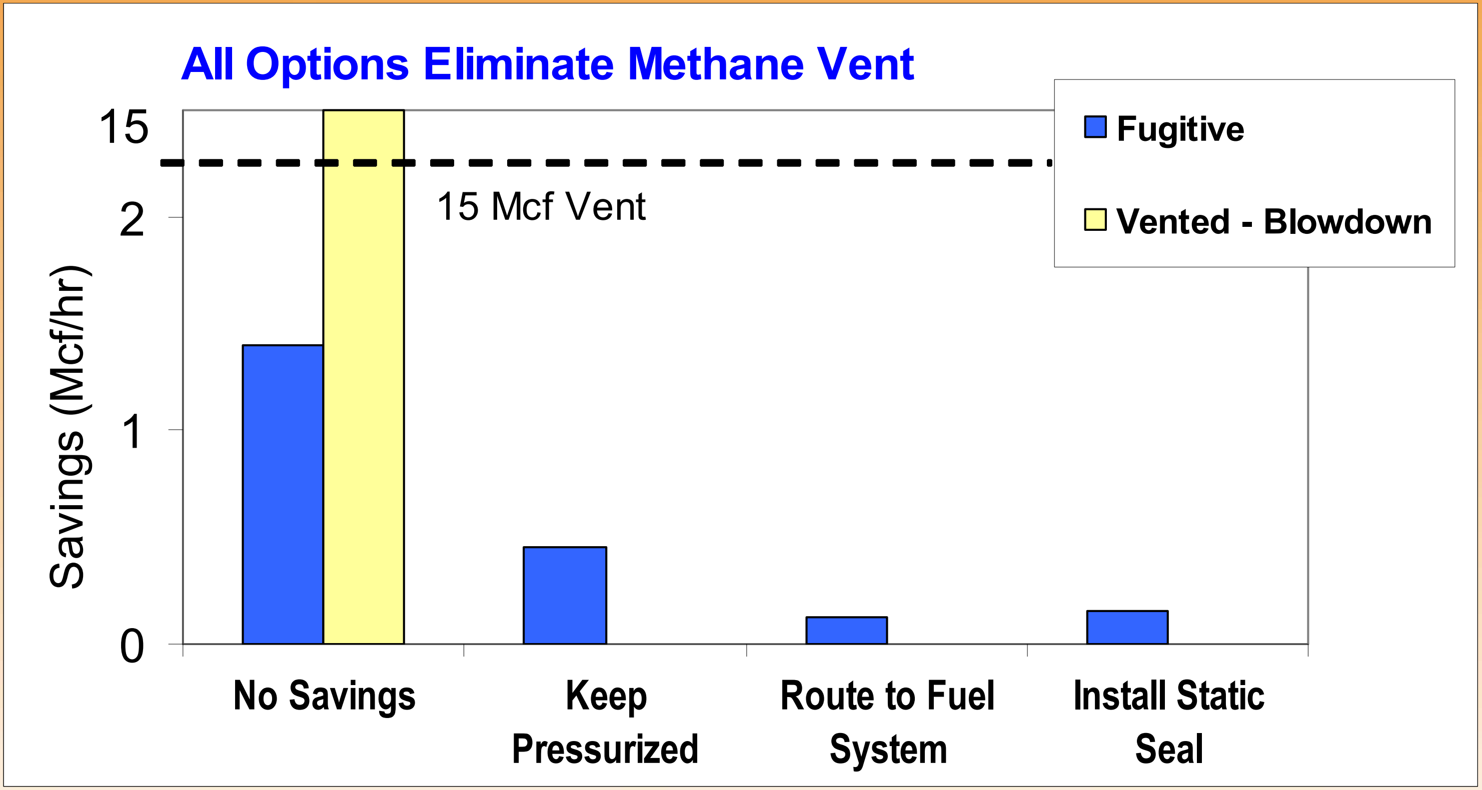
Methane Recovery Options

- Methane savings comparison



Calculate Costs

- Option 1: Do not blow down
  - No capital costs
  - No O&M costs
- Option 2: Route to fuel gas system
  - Add pipes and valves connecting blowdown vent to fuel gas system
  - Upgrade costs range from $1,250 to $2,250 per compressor
- Option 3: Do not blow down and install static seal
  - Seals cost $700 per rod
  - Seal controller costs $1,400 per compressor
  - Less cost-effective in conjunction with option 2

Is Recovery Profitable?

- Costs and Savings

Capital Costs and Savings of Reduction Options

	Option 1: Keep Pressurized	Option 2: Keep Pressurized and Tie to Fuel Gas	Option 3: Keep Pressurized and Install Static Seal
Capital Cost	None	$1,250/compressor	$3,000/compressor
Off-line Leakage Savings			
Base Load	475 Mcf/yr $713	638 Mcf/yr $957	625 Mcf/yr $938
Peak Load	3,800 Mcf/yr $5,700	5,100 Mcf/yr $7,650	5,000 Mcf/yr $7,500
Base Load assumes 500 hours offline per year; Peak Load assumes 4,000 hours offline per year. Gas cost = $1.5/Mcf. This table does not include blowdown savings.			

Economic Analysis

- Economic comparison of options

	Facilities Investment		Dollar Savings		Payback		IRR	
	Base Load	Peak Load	Base Load	Peak Load	Base Load	Peak Load	Base Load	Peak Load
Option 1	$0	$0	$713	$5,700	Immediate	Immediate	>100%	>100%
Option 2	$1,300	$1,300	$956	$7,650	<1.5 yr	<1 yr	68%	>100%
Option 3	$3,200	$3,200	$938	$7,500	<3.5 yr	<1 yr	14%	>100%

Assuming $1.5/Mcf Gas Price, 5 year life

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Discussion Questions

- To what extent are you implementing these practices/ options?
- How could these practices/ options be improved upon or altered for use in your operation(s)?
- What are the barriers (technological, economic, lack of information, regulatory, focus, manpower, etc.) that are preventing you from implementing these practices/ options?

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