CANADIAN ASSOCIATION
OF PETROLEUM PRODUCERS

BEST MANAGEMENT PRACTICE

Management of Fugitive Emissions at Upstream Oil and Gas Facilities

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2007-0003

The Canadian Association of Petroleum Producers (CAPP) represents 150 companies that explore for, develop and produce natural gas, natural gas liquids, crude oil, oil sands, and elemental sulphur throughout Canada. CAPP member companies produce more than 95 per cent of Canada's natural gas and crude oil. CAPP also has 130 associate members that provide a wide range of services that support the upstream crude oil and natural gas industry. Together, these members and associate members are an important part of a $100-billion-a-year national industry that affects the livelihoods of more than half a million Canadians.

Review by January 2009

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2100, 350 – 7th Ave. S.W.
Calgary, Alberta
Canada T2P 3N9
Tel (403) 267-1100
Fax (403) 261-4622

403, 235 Water Street
St. John's, Newfoundland
Canada A1C 1B6
Tel (709) 724-4200
Fax (709) 724-4225

Email: communication@capp.ca Website: www.capp.ca

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List of Acronyms

AENV	-	Alberta Environment
API	-	American Petroleum Institute
ASME	-	American Society of Mechanical Engineers
BMP	-	Best Management Practice
CAC	-	Criteria Air Contaminant
CAPP	-	Canadian Association of Petroleum Producers
CASA	-	Clean Air Strategic Alliance
CCME	-	Canadian Council of Ministers of the Environment
DI&M	-	Direct Inspection and Maintenance (DI&M)
EUB	-	Alberta Energy and Utilities Board
EC	-	Environment Canada
GHG	-	Greenhouse Gases
MTBF	-	Mean Time Between Failure
NACE	-	National Association of Corrosion Engineers
NFPA	-	National Fire Protection Association
NMHC	-	Non-Methane Hydrocarbon
NPT	-	National Pipe Thread
PTAC	-	Petroleum Technology Alliance of Canada
PTFE	-	Polytetrafluoroethylene
SEPAC	-	Small Explorers and Producers Association of Canada
THC	-	Total Hydrocarbons
TOC	-	Total Organic Compounds
TNMOC	-	Total Non-methane Organic Compounds
UOG	-	Upstream Oil and Gas
U.S. EPA	-	U.S. Environmental Protection Agency
VOC	-	Volatile Organic Compound

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Forward

The issue of fugitive emissions management has and continues to be important to the upstream oil and gas (UOG) industry. The genesis of this fugitive emissions Best Management Practice (BMP) can be traced back to earlier undertakings of the Air Research Planning Committee (ARPC) of the Petroleum Technology Alliance of Canada (PTAC).

The Canadian Association of Petroleum Producers (CAPP), the Small Explorers and Producers Association of Canada (SEPAC), Environment Canada (EC) and the Alberta Energy and Utilities Board (EUB) have coordinated efforts to develop this BMP which also satisfies recommendations No. 43 and 44 of the Clean Air Strategic Alliance (CASA) Flaring and Venting Project Team (FVPT):

43) CAPP and SEPAC develop a best management practices document by December 31, 2005 to assist the upstream oil and gas industry in managing fugitive emissions and targeting sources that are most likely to have larger volume emissions and which would be more cost effective to address. CAPP and SEPAC will incorporate improvement to emission factors into the best management practices document as they become available.

44) Once a best management practices document has been developed by CAPP and SEPAC, the EUB should require licensees to develop and implement leak detection and repair programs to minimize fugitive emissions from upstream petroleum industry facilities.

The aim of this BMP is to assist the UOG industry in meeting the requirements under section 8.7 of the EUB Directive 060 (*Upstream Petroleum Industry Flaring, Incinerating, and Venting)* and in cost effectively managing the most likely sources of significant fugitive emissions.

The emissions of primary concern are methane (CH_4) and non-methane volatile organic hydrocarbons (NMVOC).

This BMP:

- identifies the typical key sources of fugitive emissions at UOG facilities,
- presents strategies for achieving cost-effective reductions in these emissions (e.g., through improved designs, Directed Inspection and Maintenance (DI&M) practices, improved operating practices, and the application of new and retrofit technologies), and
- summarizes key considerations and constraints.

While this BMP is specific to fugitive equipment leaks, it considers leakage directly to the atmosphere and unintentional gas carry-through to storage tanks. The BMP also considers emerging technologies that have the potential to improve the efficiency and effectiveness of leak detection. The overall aim is to provide practical guidance to operators for developing focused approaches to manage and reduce fugitive emissions at individual oil and gas facilities, while giving consideration to each facility’s specific circumstances.

1 Applicability

This BMP provides guidance for the management of fugitive emissions at UOG facilities from leaks (i.e., the loss of process fluid to the environment past a seal, threaded or mechanical connection, cover, valve seat, flaw or minor damage point) on equipment components in hydrocarbon service.

A component is considered to be in hydrocarbon service when the process fluid being handled contains greater than 10 percent hydrocarbons on a mass basis. Fugitive emissions from equipment leaks are unintentional losses and may arise due to normal wear and tear, improper or incomplete assembly of components, inadequate material specification, manufacturing defects, damage during installation or use, corrosion, fouling and environmental effects. Components also tend to have greater average emissions when subjected to frequent thermal cycling, vibrations or cryogenic service.

Only a small percentage of the equipment components have any measurable leakage, and of those only a small percentage contributes to most of the emissions. Thus, the control of fugitive emissions is a matter of minimizing the potential for big leaks and providing early detection and repair.

The UOG industry is characterized by many small widely dispersed facilities rather than a few large facilities so it is appropriate to apply a directed approach that targets the sources most practicable to control, components most likely to result in big leaks. At each target facility, efforts should be focused on the areas most likely to offer significant, cost-effective control opportunities (e.g., on specific component types and service applications).

This BMP is designed to apply to components in sweet gas service which are expected to represent the greatest opportunity for emission reductions.1 Existing mechanisms to address odour, health and safety concerns in sour facilities are deemed to meet or exceed the purpose of this BMP.2 Furthermore, this BMP is designed to apply primarily to fugitive equipment leaks from components in natural gas or hydrocarbon vapour service. This reflects the greater difficulty in containing a gas than a liquid (i.e., due to the greater mobility or fluidity of gases), and the general reduced visual indications of gas leaks.

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[1] For the purpose of this BMP, sweet gas is defined as natural gas with an H2S concentration of less than 10 mol/kmol in accordance with the approach adopted in the EUB Directive 060.

[2] Odour emissions are addressed under section 14 of the EUB Directive 064, which states that *"in accordance with the OGC Act, part 1(4)(f), the EUB has jurisdiction to control pollution above, at, or below the surface in the drilling wells and in operations for the production of oil and gas. In this regard, migration of H2S emissions off lease is considered pollution and may be defined as a major unsatisfactory inspection*". Appendix 1, 3 and 11 of Directive 064 also provide additional information regarding off-site regulatory requirements for H2S odour management.

2 Implementation And Schedule For Review

Efficient management of fugitive emissions is best achieved through the application of DI&M techniques. DI&M focuses inspection and correction efforts on the areas most likely to offer significant cost-effective control opportunities, with coarse or less frequent screening of other areas for additional opportunities. The Decision Tree reproduced under Figure 1 has been developed to provide a process to effectively manage fugitive emissions.

When phasing-in their DI&M program, companies may consider factors such as size and age of facility or type of facility, percentage of components per year, percentage of facilities, business units, geographic area, shutdown schedule, and economic classification of repairs. The implementation of a DI&M program at existing UOG facilities should be completed by December 31, 2009.

While this BMP provides for a phasing-in period, CAPP members will be requested to provide interim reports on the status of implementation of a DI&M program within their companies by March 31, 2008 and March 31, 2009. These status reports will indicate any problem areas or improvements and allow for updating and additions to the BMP as necessary.

When implementing this BMP, companies should keep in mind that the EUB Directive 060 imposes a mandatory requirement to implement a program to detect and repair leaks and that such a program must meet or exceed CAPP BMP.

In view of the above, the use of the world “should” in this BMP does not imply that action is not necessary within the context of the EUB Directive 060; i.e., alternative methodologies to those described in the BMP can be used as long as the expected results are achieved or exceeded. “No action” is not an option.

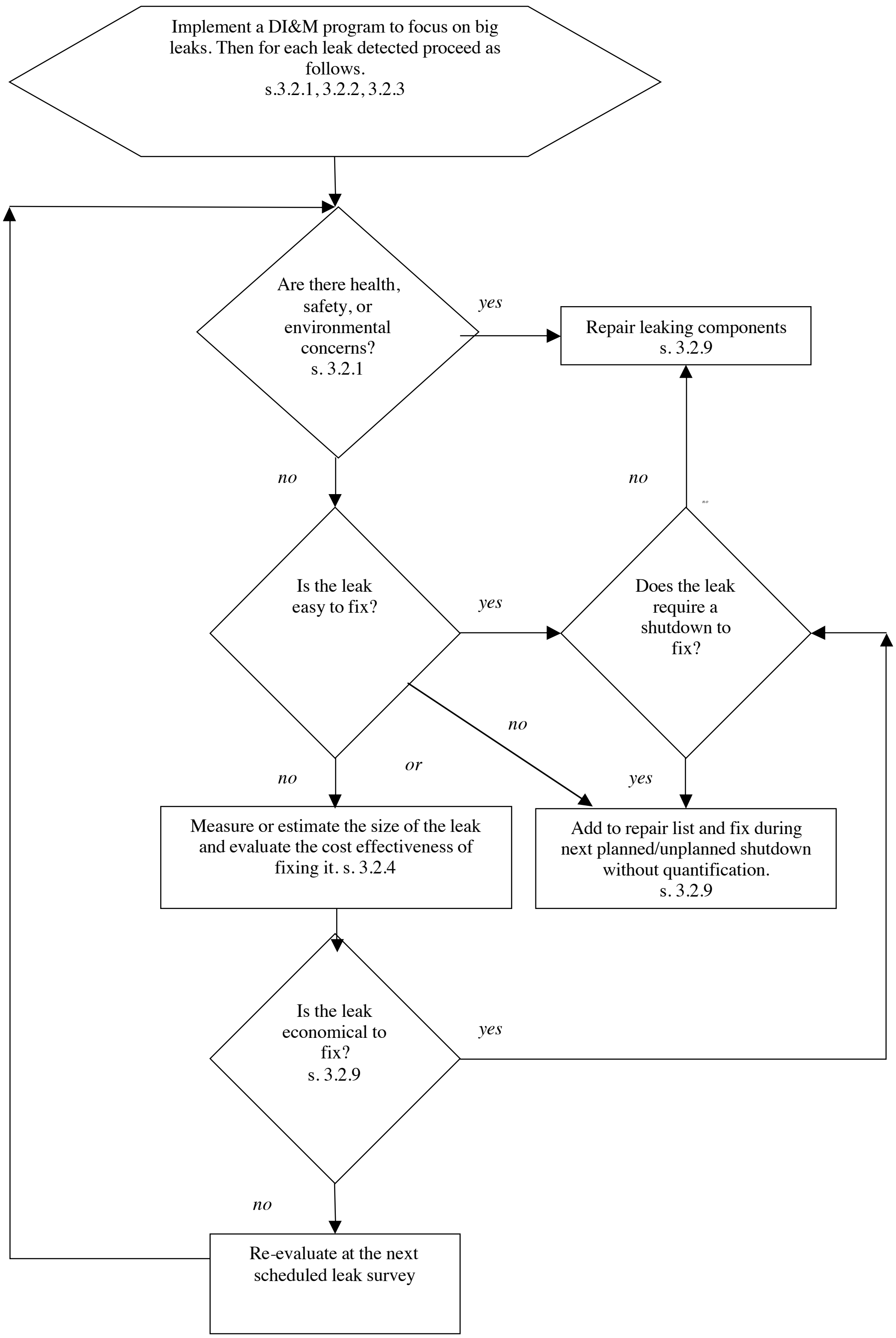
2.1 Schedule for review

Concurrent with the introduction of this BMP is a field investigation program to verify the effectiveness of the methodologies proposed in this document. The field work should provide further knowledge on key detection, monitoring and control technologies and practices, as well as additional data to review and modify as needed the recommended monitoring frequency and default repair lives for different types of equipment. This field investigation work will be conducted in cooperation with EC and EUB and will extend over a two-year period until the fourth quarter of 2008. Interim and final reports will be presented as a basis for the continued improvement of this BMP.

A review of the document is expected to take place within 24 months from the date of implementation to incorporate any adjustments that CAPP and its members deem necessary as result of the expertise gained during the first year of implementation and the ongoing field investigation work.

Thereafter, this BMP will be regularly reviewed and revised as necessary.

Figure 1 - DI&M Decision Tree:



3 Basic Control Strategy

The key elements for effective long-term control of fugitive emissions are the application of best available technology and standards, implementation of management systems, and corporate commitment. The application of control technologies and design standards, alone, do not preclude the potential for fugitive emissions. Reliable fugitive emissions control requires:

- the development of monitoring programs, operating procedures and performance objectives for controlling fugitive emissions, and
- Management's commitment to the implementation and maintenance of a DI&M program.

3.1 Technology and Standards

The first step in controlling fugitive equipment leaks should always be to minimize potential for leaks by applying proper design and material-selection standards, to follow the manufacturer's specifications for the installation, use and maintenance of components and to implement practicable control technologies (e.g., reduction, recovery and treatment systems).

3.2 Management Systems

A management system is needed to establish objective performance targets and to implement ongoing monitoring and predictive maintenance programs to ensure that leaks are detected and remain well controlled. The following sections describe the basic elements of a DI&M program.

3.2.1 Directed Inspection & Maintenance (DI&M) Program

The first step is to determine which types of components will be targeted (i.e., subjected to regular screening for leaks). The objective is to minimize the potential for leaks in the most practicable manner possible. This is done by focusing efforts on the types of components and service applications most likely to offer significant cost-effective control opportunities (see Section 3.2.5). Non-target components are subjected to coarse or less frequent screening.

Typically, a facility will phase the DI&M program over a certain number of years by progressively adding to the list of target components until all key potential contributors are being targeted. Once a leak is detected, regardless of whether it is a target or non-target component, the Decision Tree reproduced under Figure 1 should be followed to determine if a leak need to be repaired. Once a leak is determined to need fixing, this should be done within a reasonable period of time (see Section 3.2.9), or at the next facility turnaround if a major shutdown is required.

A facility may choose to simply repair or fix the leak. If it is not a simple repair or fix, an operator may choose to program the repair at the next shut down without quantification or, alternatively, the leak should be measured or estimated to determine if it is economical to repair. Where an operator believes that it may not be economical to repair, this should be documented based on reliable quantification of the amount of leakage and the repair costs (see Sections 3.2.4

and 3.2.8). If a leak poses a health, safety, or environmental concern, then it needs to be repaired regardless of whether it is economical to fix.

3.2.2 Leak Definition

Fugitive emissions control is becoming more common as a condition of a facility's operating approval. Accordingly, it is useful to consider a definition that corresponds to those typically applied in other industries. Firstly, a leak could be defined as a screening concentration of 10,000 ppm or more[3] for the purposes of deciding whether to measure the emission rate and evaluate the practicability of making repairs. Below this threshold the emissions generally become too small to quantify. Moreover, usually only the top 5 to 10 percent of leaking components account for 80 to 90 percent of the emissions at a facility. Consequently, there is limited value in dedicating resources to measure or estimate emissions from components that do not achieve the screening value identified. However facilities may still choose to repair these below 10 000 ppm emissions without measurement.

There are several new emerging technologies that have the potential to improve efficiency and effectiveness of leak detection programs and replace US EPA Method 21. These technologies include: differential lasers to measure atmospheric concentrations of component gases, computer analysis of ambient air sample trends to estimate leak source location and volumes and infrared optical technology to visually inspect the components. Many of these and other technologies are being developed and can be used to identify leaking components.

3.2.3 Leak Detection

Leak screening should be done on accessible components using a portable organic vapour analyzer in accordance with US EPA Method 21 or using such alternative methods that provide an equivalent result (see Section 3.2.2 for the leak definition). In some cases, US EPA Method 21 has been considered too slow and labour intensive and more suited for large facilities. For these reasons, this BMP provides the opportunity to use other methods.

There are several new emerging technologies that have the potential to improve efficiency and effectiveness of leak detection programs and replace US EPA Method 21. These technologies include: differential lasers to measure atmospheric concentrations of component gases, computer analysis of ambient air sample trends to estimate leak source location and volumes and infrared optical technology to visually inspect the components. Many of these and other technologies are being developed and can be used to identify leaking components.

Using alternatives to US EPA Method 21 may also allow operators to evaluate components that may have not been accessible otherwise.

[3] This is the current leak definition applied by the CCME (1993) guidelines for the measurement and control of fugitive volatile organic compound (VOC) emissions from equipment leaks at petroleum refineries and organic chemical plants based on US EPA Method 21.

3.2.4 Leak Quantification

The quantification by measurement or estimation of leak rates to evaluate the feasibility of repairing or replacing a component should be sufficiently accurate for this purpose (e.g., within ±25 percent or enough to clearly establish a positive net financial benefit). Depending on the type of component and information available, potentially valid quantification methods may include, but are not limited to, process modelling, material balances, flow capture and metering systems, duct sampling techniques, tracer tests and some types of remote sensing methods.

Table 1 provides a list of potential methods to detect, and measure or estimate leaks.

Table 1. Leak Detection and Measurement Methods[1].

Qualitative Methods[2]	**Quantitative Methods[3]**
Bubble Tests	Portable Organic Vapour Analyzers[4]
Optical emissions detection (Leak imaging)	Quantitative remote sensing techniques
Ultrasonic Leak Detectors	Engineered estimates

1 This is not necessarily a complete list of valid methods.

2 A leak detection method is deemed to be qualitative where it provides a leak detection capability consistent with, or better than, the leak definition given in Section 3.2.2 but is not able to provide a quantitative output that can be related to the leak definition. If a qualitative method can be enhanced to consistently provide quantitative output that can be related to the leak definition then it may be reclassified as a quantitative method.

3 A leak detection method is deemed to be quantitative where it provides a minimum leak detection capability consistent with, or better than, the leak definition given in Section 3.2.2 and provides quantitative output that can be related to the leak definition.

4 Operators note that the sensors may be damaged by vapours at high concentrations or give a false reading depending on the calibration gas.

Table 2 provides an indication of cost effectiveness for some of the screening and measurement techniques based on an EPA's Lessons Learned Study.

Table 2 Summary of Screening and Measurement Techniques

Instrument/Technique	Effectiveness	Approximate Capital Cost
Soap Solution	**	$
Electronic Gas Detectors	*	$$
Acoustic Detection / Ultrasound Detection	**	$$$
Toxic vapour analyzer / Flame ionization Detector	*	$$$
Bagging	*	$$$
High Volume Sampler	***	$$$
Rotameter	**	$$
Leak Imaging	***	$$$

* Least effective at screening/measurement

*** Most effective at screening/measurement

$ Smallest capital cost

$$$ Largest capital cost

Source: EPA's Lessons Learned Study & Presentation to Energy Management, Workshop, Methane to Markets, *Directed Inspection and Maintenance*, Roger Fernandez, EPA, January 16, 2007.

3.2.5 Target Components

All equipment components on process-, fuel- and waste-gas systems are potential sources of fugitive emissions. The types of components may include flanged and threaded connections (i.e., connectors), valves, pressure-relief devices, open-ended lines, blowdown vents (i.e., during passive periods), instrument fittings, regulator and actuator diaphragms, compressor seals, engine and compressor crankcase vents, sump and drain tank vents and covers. The amount of emissions from a leaking component is generally independent of the size of the component. Furthermore, as previously mentioned, <u>usually only the top 5 to 10 percent of leaking components account for 80 to 90 percent of the emissions</u>.

For equipments in gas service, the most cost-effective types of components to target tend to be, in the order of decreasing cost-effectiveness: compressor seals, open-ended lines, pressure relief valves, regulators, and control valves. The least cost-effective components to target tend to be connectors and block valves. The priority and feasibility of repairing a given component will depend on the leak rate, value of the process fluid being lost, cost of repairs, life expectancy of the repair, and the value of various potential indirect factors such as avoiding safety, health, and environment impacts, avoiding damage to the component, improved process reliability and better performance.

Storage tanks at production and processing facilities are potentially a significant source of emissions due to working or evaporation losses; particularly where intentional boiling or flashing losses occur. Other less recognized, and often unaccounted for, contributions to atmospheric emissions from storage tanks may include the following:

- Leakage of process gas or volatile product past the seats of drain or blowdown valves into the product header leading to the tanks.
- Inefficient separation of gas and liquid phases upstream of the tanks allowing some gas carry-through (by entrainment) to the tanks. This usually occurs where liquid volume (e.g., produced water) has increased significantly over time resulting in a facility's inlet separators being undersized for current conditions.
- Piping changes which result in the unintentional placement of high vapour pressure product in tanks not equipped with appropriate vapour controls.
- Displacement of large volumes of gas to storage tanks during pigging operations.

Malfunctioning or improperly set blanket gas regulators and vapour control valves can result in excessive blanket gas consumption and, in turn, increased flows to the end control device (e.g., vent, flare or vapour recovery compressor). The blanket gas is both a carrier of product vapours and a potential pollutant itself (i.e., natural gas is usually used as the blanket medium for blanketed tanks at gas processing plants).

Leakage from components in oil or light hydrocarbon liquid service is usually easy to visually detect and often is well controlled by normal maintenance programs. However due to their low average leak rates, less substantive improvements in fugitive emissions reductions are expected for these components.

3.2.6 Monitoring Frequency

The equipment components most likely to leak should be screened most frequently. Studies indicate that components subject to vibration, high use, or temperature cycles are the most leak-prone. Operators should develop a DI&M survey schedule that achieves maximum cost-effective fugitive emissions reductions yet also suits the unique characteristics and operations of their facility. Operators may choose to determine the frequency of follow-up surveys based on different factors such as anticipated life of repairs made during their previous survey, company maintenance cycle, and availability of resources. If subsequent surveys show numerous large or recurring leaks, the operator may chose to increase the frequency of follow-up surveys. These follow-up surveys may focus on components repaired during previous surveys, or on the classes of components identified as most likely to leak. Over time, operators can continue to fine-tune the scope and frequency of surveys as leak patterns emerge.[4] Where the repair frequency is high, permanent leak detection system may be a more practical solution and should be considered.

Examples of leak monitoring frequencies for leak-prone components are provided under Appendix 1. Operators should design a frequency monitoring program best suited for its operations while ensuring maximum cost-effective fugitive emissions reductions.

3.2.7 Inaccessible Components

Inaccessible sources or components can be defined as equipment that is more than 2 metres above a permanently available support surface or is cover protected or insulated (CCME 1993). This equipment is excluded from a DI&M program under this BMP. However, if these components are leaking and become accessible during facility shut-downs or turn-around, they should then be repaired.

3.2.8 Tagging Components

All leaking components should be flagged using a tag or an alternative method for identification purposes as well as to ensure that the component is repaired and that it will be given appropriate follow-up attention under the company's DI&M program. This should assist in identifying the proper monitoring frequency for that specific component.

An example of a leaker tag is provided under Appendix II while Appendix III provides an example of leak survey forms. Companies should determine the best format for flagging/identifying leaks as well as for leak surveys in accordance with the unique characteristics and operations of their facilities.

3.2.9 Leak Repairs

Decisions to repair or replace leaking components should be made on a case-by-case basis in consideration of health, safety, environmental, and economical concerns. Where feasible, repairs or replacements should be done within 45 days from the time a leak is detected. Where a major shutdown is required to facilitate this work, or there are marginal economics for repairing the component, the repair or replacement may be delayed until the next planned shutdown, provided this does not pose any safety, health, or environmental concerns.

A leaking component need not be repaired if the component is shown to be uneconomical to repair and does not pose a safety, health, or environmental concern. In such cases, the components should remain tagged/identified and be re-screened at the next scheduled leak survey.

The economics of repairing a leak or replacing the components should be based on the market value of the process fluid being lost, the repair, the replacement cost, and the life expectancy of the applied solution. All leak repairs that have a simple payback period of less than 1 year based on the following equation should

[4] Lessons Learned from Natural Gas Star Partners, Directed Inspection and Maintenance at gas processing plants and booster stations, EPA, October 2003.

be deemed economical to repair and should be repaired as soon as possible but no later than 45 days:

$$PBP = \frac{Cost\ of\ Control}{Annual\ Leak\ Rate \times Gas\ Price}$$

Where,

PBP	=	payback period (years).
Cost of Control	=	direct repair or replacement costs + gas vented during repair + cost of lost production due to shutdown
Annual Leak Rate	=	amount of gas/vapour emitted directly to the atmosphere or that leaked into a vent or flare system which does not have vent or flare gas recovery.
Gas Price	=	current market price of the gas based on criteria specified by the EUB Directive 060[5] or, for the midstream industry, the processing fee or margin received.

Components that have a payback period greater than 1 year should be re-evaluated with the "Cost of Control" equal to direct repair or replacement cost only. If this analysis shows the repair or replacement is economic to do during a major shut down, it should then be scheduled for repair at the next shut down. Where the payback period is greater than the anticipated life expectancy of the repair or replacement, the component may be deemed uneconomic to repair or replace and supporting details of this cost evaluation shall be kept on file. Table 3 is provided as an indication of possible mean default life expectancies of component repairs that an operator may choose to use in the absence of official data on the life expectancy of the affected component.

Table 3. Default mean life of repairs for economic analysis of repair costs.

Source	Category	Mean Repair Life (years)
Compressors - Reciprocating	Seals	1
	Valve Covers	1
	Variable Volume Pocket	1
	Governor	1
	Cylinder Head	1
Compressors – Centrifugal	Seals	1
Connectors	All	5

[5] The commodity price forecasts used in evaluations of conventional gas conservation projects (gas gathered, processed, and sold to market) will be the most recently published by Dobson Resource Management.

Table 3. Default mean life of repairs for economic analysis of repair costs.		
Source	**Category**	**Mean Repair Life (years)**
Open-Ended Lines	All	2
Pressure Relief Valves	All	2
Pumps	Seals	1
Regulators	All	5
Tank Fittings	Hatches	1
	Pressure Vacuum Valves	2
Valves	Quarter-Turn	4
	Rising Stem	2
Vents	All	1

Sample calculations for payback periods are presented in Appendix IV.

3.2.10 Personnel Training

Proper personnel training should be part of the DI&M program. This training is needed to ensure that the program achieves the best results.

3.2.11 Primary Calibrations and Field checks

All instruments used to detect and measure leaks should be factory serviced or serviced by a factory authorized technician and should be calibrated regularly as per the specification of the manufacturer or whenever problems arise.

4 Inspection, Monitoring & Record-Keeping

Operators should have a record program to support the company's DI&M system. Proper record keeping should assist in ensuring that leaking components are identified and repaired and that appropriate follow-up actions are implemented. This information will also assist in identifying the proper monitoring frequency for that component to achieve maximum cost-effective fugitive emissions reductions while suiting the unique characteristics and operations of the facility.

Although it remains for each company to define its record keeping system, consideration should be given to the recording of the following information:

- Records of repairs made on leaking components, including leak repair frequency.
- The economic analysis performed on all leaking equipment components that have not been fixed on the basis that this is uneconomic to do and do not pose any safety, health, or environmental concerns.

Record keeping in support of a company's DI&M program may be audited by the EUB to assess compliance with section 8.7 of the EUB Directive 060.

5 Corporate Commitment

Corporate commitment should entail full management support including adequate funding and resource allocation.

Components that are initially tight may leak, and leaks, once fixed, may reoccur. Consequently, the reduction of fugitive emissions requires a dedicated ongoing commitment.

6 Appendices

The information provided in the following appendices is included as guidance only. Operators may elect to implement other approaches to develop their DI&M program.

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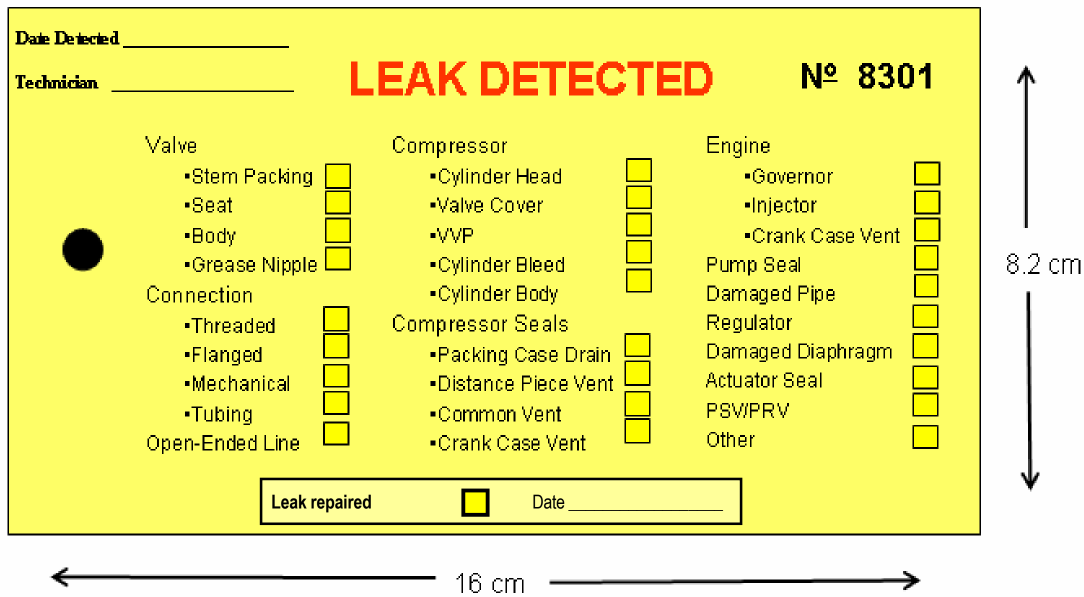
Appendix 1 Table 4. Examples Of Leak Monitoring Frequencies For Leak-Prone Equipment Components

Table 4. Examples of leak monitoring frequencies for leak-prone equipment components, presented by component category and type

Source Category	Type of Component	Service (sweet gas, light liquid)	Frequency
Process Equipment	Control Valves	Gas/Vapour/LPG	Annually
	Block Valves – Rising Stem	Gas/Vapour/LPG	Annually
	Block Valves – Quarter Turn	Gas/Vapour/LPG	Once every 5 years
	Compressor Seals[1]	All	Quarterly
	Pump Seals[1]	All	Quarterly
	Pressure Relief Valves	All	Annually
	Open-ended Lines	All	Annually
	Emergency Vent[1,2]	All	Annually
	Blowdown Systems [1,2]	All	Quarterly
Vapour Collection Systems	Tank Hatches[1]	All	Quarterly
	Pressure-Vacuum Safety Valves[1]	All	Quarterly

1 Alternatively, institute a predictive maintenance program to monitor seals performance
2 Emergency vents and blowdown systems should be screened during periods when relief or blowdown events are not occurring to determine the amount of leakage into these systems.

Appendix 2 Sample Leaker Tag



Appendix 3 Appendix III – Leak Survey Forms

LEAK RATE MEASUREMENTS									Page ___ of ___	
Site Name:									Date	
Operating Company:									Technicians:	
Location:										
Survey Contractor:										
Process Unit		Component Information								
Name/Identification Code	Type	Leaker Tag No.	Process Tag No.	Type	Process Stream		Size	Measurement Method	THC Leak Rate (m^3/h)	
					Type	Odourized				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				
						Y/N				

Direct Measure Datasheet

Location:
Date:

	Source Data			Measurement Data						
Tag No.	Type of Component	Size	Process Unit	Meter Type	Initial Volume	Final Volume	Time	Temp (C)	Pressure (kPa)	Comments

CV – Control Valve	BFV – Butterfly Valve	GOV – Govenor	C - Coupling	SW/PG – Sweet Process Gas	C – Condensate
NV – Needle Valve	MW – Manway	PIG – Pig Trap Cover	F – Flange	SR/PG – Sour Process Gas	MP – Multipahse
BV – Ball Valve	PRV – Pressure Relief Valve	FC – Filter Cover	T – Threaded Fitting	FG – Fuel Gas	O – Oil
GBV – Globe Valve	O – Open-Ended Line	VC – Valve Cap	TB – Tube Fitting	S – Sales Gas	CO – Crude Oil
GTV – Gate Valve	PR – Pressure Regulator		PS – Pump Seal	P – Propane	AG – Acid Gas
PV – Plug Valve	R - Regulator		CS – Compressor Seal	C2 - Ethane	

GAS SENSOR CALIBRATION RECORD		Page ___ of ___	
Site Name:		**Date**	
Operating Company:		**Technicians:**	
Location:			
Industry Sector:			
Facility Type:			

Device	Manufacturer	Serial No.	Date of Last Calibration		Field Calibration Checks						
					Day	Time	Zero Check	Span Check			Units of Measure
			Factory	Office			Reading	Actual	Reading	%Error	

FLOW METER CALIBRATION RECORD		Page ___ of ___	
Site Name:		**Date**	
Operating Company:		**Technicians:**	
Location:			
Industry Sector:			
Facility Type:			

Device	Manufacturer	Serial No.	Date of Last Calibration		Field Calibration Checks						
					Day	Time	Zero Check	Span Check			Units of Measure
			Factory	Laboratory			Reading	Refere nce	Reading	%Error	

Appendix 4 Economic Analysis

Table 5 presents example calculations for determining the simple payback period of individual leak repairs using the equation presented in Section 3.2.8. As indicated in the table, the simple payback period is calculated as the estimated repair costs (column C) divided by the product of the leak rate (column A) and the net gas value (column B). For the examples given, the net gas price is taken to be $4.0/GJ or $0.1496/m^3, which, in this case, is the market value of the gas (i.e., determined from the Chenery-Dobson Resource Management Ltd. Survey of Hydrocarbon Price Forecasts Utilized by Canadian Petroleum Consultants and Canadian Banks). The effect of discount rates and inflation rates are neglected for simplification purposes.

Table 5. Sample calculations of the simple payback period for individual leak repairs.

Tag ID	Process Unit / Location	Component Type	Nominal Size (Inches)	Stream Type	Hydrocarbon Leak Rate (m^3/hr)	Hydrocarbon Leak Rate (10^3 m^3/y) (A)	Net Value of Lost Gas ($/$10^3$ m^3) (B)	Estimated Repair Cost ($) (C)	Default Repair Life (y)	Payback Period (y) (C/A/B)
1982	Desiccant Dehydrator	Open Ended Line	0.5	Regen. Gas	0.0046	0.0402	149.60	60	2	10.0
1985	Desiccant Dehydrator	Regulator	0.5	Dry Gas	0.0050	0.0437	149.60	175	5	26.8
1986	Desiccant Dehydrator	Plug Valve	12	Dry Gas	0.8326	7.2934	149.60	480	4	0.4
1987	Desiccant Dehydrator	Gate Valve	0.75	Dry Gas	0.0045	0.0393	149.60	60	4	10.2
1988	Desiccant Dehydrator	Open Ended Line	0.5	Dry Gas	0.0812	0.7111	149.60	60	2	0.6
1990	Desiccant Dehydrator	Flange	8	Wet Gas	0.0010	0.0088	149.60	100	2	76.0
1991	Desiccant Dehydrator	Gate Valve	8	Wet Gas	0.0046	0.0407	149.60	353	2	58.0
1992	Desiccant Dehydrator	Flange	8	Wet Gas	0.0026	0.0228	149.60	100	2	29.3
1993	Desiccant Dehydrator	Ball Valve	0.5	Wet Gas	0.0028	0.0241	149.60	60	4	16.6
1995	Desiccant Dehydrator	Gate Valve (Control Valve)	8	Wet Gas	0.0090	0.0785	149.60	353	2	30.1
1996	Desiccant Dehydrator	Gate Valve (Control Valve)	8	Wet Gas	0.0015	0.0129	149.60	353	2	182.9
1997	Desiccant Dehydrator	Flange	8	Wet Gas	0.0036	0.0313	149.60	100	2	21.4
1998	Desiccant Dehydrator	3-Way Control Valve	8	Wet Gas	0.0021	0.0187	149.60	350	4	125.1
4087	Desiccant Dehydrator	Threaded Connection	1	Wet Gas	0.0062	0.0544	149.60	30	2	3.7

Appendix 5 Emissions Inventory From Method 21 Data

The leak screening data compiled using US EPA Method 21 (i.e., measurements of the vapour concentration at the leakage point on each component) may be used to estimate total fugitive emissions from the site for the purposes of developing an emissions inventory. These data should not to be used for quantifying the emissions from a single component for the purposes of conducting an evaluation of the economics of repairing or replacing the component since they do not provide sufficient accuracy for this purpose. The use of Method 21 data to calculate the emission rate from a single component may easily be in error by 2 to 3 orders of magnitude, while economic justification for not repairing a component should be based on a leak rate measurement accurate to ±25 percent. For component quantification purposes see section 3.2.4.

Emissions may be estimated from US EPA Method 21 data by applying one of the following methods, presented in the order of increasing sophistication and accuracy:

- leak/no-leak emission factors,
- three-stratum emission factors,
- published leak-rate correlations, and
- unit-specific leak-rate correlations.

There is relatively little difference in the effort required to apply each approach once the screening data have been compiled. Consequently, it may be preferable to use the correlation approach since it gives the most reliable results. Simple spreadsheet or database application may be developed for this purpose.

5.1 Leak/No-leak Emission Factors.

To apply this approach, the screening values must be classified as either leaking (i.e., has a maximum screening value of 10 000 ppm or more) or non-leaking (i.e., has a maximum screening value of less than 10 000 ppm), and categorized by type of component and type of service. The amount of emissions is then estimated for each source category using the equation:

$$ER = \sum_i \sum_j N_{i,j} \bullet \left[\frac{EF_L \bullet n_L + EF_N \bullet n_N}{n_L + n_N} \right]_{i,j} \bullet X_j$$

where,

ER = total methane leak rate (kg/h) of pollutant k for the target source population,

EF_L = appropriate leaking emission factor for the source/service category of interest (see Table 6),

EF_N = appropriate non-leaking emission factor for the components of type i in service j (see Table 6),

n_L = number of components screened and determined to be leaking (i.e., give a screening value of 10 000 ppm or more) for the source category of interest,

n_N = number of components screened and determined not to be leaking (i.e., give a screening value of less than 10 000 ppm, including those sources with a screening value of zero) for the source category of interest,

$N_{i,j}$ = total number of components of type i in service j (i.e., all components screened plus those not screened),

X_j = mass fraction of methane in the process stream

It is assumed, in using the leak/no-leak method, that components within each screening range leak, on average, at the same as rate as for the rest of the UOG. However, the experience in other industries is this not is not necessarily true (Schaich and Stine, 1989). For example, significant differences have been noted in the relative number of sources with zero screening values. A zero screening value indicates that the true screening value of the source is below the lower detectable limit of the vapour analyzer used to screen for leaks.

Table 6. Leak/No-leak emission factors for estimating fugitive equipment leaks at UOG facilities.

Source		Number of Sources	Percent of Sources	Emissions (kg/h/src)	95% Confidence Limits	
					Lower	Upper
Connector[1]	No Leak[9]	44512	98.79	0.0000338	0.0000271	0.0000406
	Leak[10]	556	1.21	0.01856	0.01465	0.02247
Block Valve[2]	No Leak	5907	96.02	0.0006132	0.0	0.001342
	Leak	245	3.98	0.03895	0.02728	0.05062
Control Valve[3]	No Leak	233	85.35	0.01006	0.007532	0.01259
	Leak	40	14.65	0.07581	0.0	0.1706
PRV	No Leak	63	33.87	0.0006471	0.0	0.001537
	Leak	123	66.13	0.3814	0.0	0.8673
Regulator	No Leak	108	83.72	0.0000398	0.0000175	0.0000474
	Leak	21	16.28	0.01977	0.004751	0.03439
Orifice Meter[4]	No Leak	83	79.81	0.001925	0.0006846	0.003165
	Leak	21	20.19	0.0088	0.004936	0.01286
Other Flow Meter[5]	No Leak	259	97.37	0.0000037	0.0000016	0.0000059
	Leak	7	2.63	0.0002064	0.0	0.0006932
Station or Pressurized	No Leak	27	26.47	0.0006213	0.0	0.001641
Compressor Blowdown System[6]	Leak	75	73.53	1.274	0.4989	2.049

Table 6. Leak/No-leak emission factors for estimating fugitive equipment leaks at UOG facilities.						
Source		**Number of Sources**	**Percent of Sources**	**Emissions (kg/h/src)**	**95% Confidence Limits**	
					Lower	**Upper**
Compressor Blowdown System - Depressurized Reciprocating	No Leak	4	26.67	0.000	0.0	0.0
	Leak	11	73.33	3.200	1.245	5.155
Compressor Blowdown System - Depressurized Centrifugal	No Leak	7	38.89	0.000	0.0	0.0
	Leak	11	61.11	1.200	0.0	2.422
Open-Ended Line	No Leak	179	27.88	0.0001127	0.0000249	0.0002006
	Leak	463	72.12	0.1158	0.05458	0.177
Instrument Controller[7]	No Leak	----	0.00	----	----	----
	Leak	17	100.00	0.4681	0.09325	0.8429
Compressor Seal – Reciprocating[8]	No Leak	5	13.89	0.00056	0.0	0.002115
	Leak	31	86.11	0.7682	0.4865	1.049
Compressor Seal - Centrifugal[8]	No Leak	1	4.77	0.0000075	----	----
	Leak	20	95.23	0.8546	0.2469	1.462

Source: Ross and Picard (1996), Table 6, page 19.

---- No data available.
1 Includes flanges, threaded connections and mechanical couplings.
2 Accounts for emissions from the stem packing and the valve body, and it applies to all types of block valves (e.g., butterfly, ball, globe, gate, needle, orbit and plug valves). Leakage past the valve seat is accounted for by the Open-Ended Line emission category. Leakage from the end connections is accounted for by the connector category (i.e., one connector for each end).
3 Accounts for leakage from the stem packing and the valve body. Emissions from the controller and actuator are accounted for by the Instrument Controller and Open-Ended Line categories respectively. This factor applies to all valves with automatic actuators (including fuel gas injection valves on the drivers of reciprocating compressors).
4 Accounts for emissions from the orifice changer. Emissions from sources on pressure tap lines etc. are not included in the factor (i.e., these emissions must be calculated separately).
5 Accounts for emissions from other types of gas flow meters (e.g., diaphragm, ultrasonic, roots, turbine and vortex meters).
6 Accounts for leakage past a valve seat through an open vent line to the atmosphere. These vents are typically six inches or greater in diameter and are used to blowdown major process units or sections of pipeline. Small diameter open-ended lines such as those used to blowdown chart recorders, meter runs etc. are accounted for by the Open-Ended Line category.
7 The Instrument Controller category accounts for emission from pneumatic control devices that use natural gas as the supply medium.
8 The Compressor Seal categories account for emissions from individual compressor seals (i.e., for a four cylinder reciprocating compressor unit there are four seals so the compressor seal emissions for the unit would be four times the factor in the table).
9 Non-leaking components with screening values of less than 10 000 ppm.
10 Leaking components with screening values of 10 000 ppm or greater.

5.2 Three-stratum Emission Factors

Use of the three-stratum factors offers a further increase in rigour and reliability from use of the leak/no-leak factors. The sources are categorized based on three ranges of screening values: 0 to 1 000 ppm, 1 001 to 10 000 ppm and over 10 000 ppm. The amount of emissions is estimated for each source category using the equation:

$$ER = \sum_i \sum_j N_{i,j} \bullet \left[\frac{n_1 \bullet EF_1 + n_2 \bullet EF_2 + n_3 \bullet EF_3}{n_1 + n_2 + n_3} \right]$$

where,

EF_1, EF_2, EF_3 = THC emission factors for sources with screening values in the range of 0 to 1 000 ppm, 1 001 to 10 000 ppm, and over 10 000 ppm, respectively (see Table 7).

n_1, n_2, n_3 = Total number of sources surveyed that had screening values in the range of 0 to 1 000 ppm, 1 001 to 10 000 ppm, and over 10 000 ppm, respectively.

The basic assumptions inherent in use of the three-stratum emission factor method are the same as those presented for the leak/no-leak method.

5.3 Published Leak-Rate Correlations

Leak-rate correlations provide a method for estimating the leak rates corresponding to individual screening values. The use of this approach is a considerable refinement over the available emission-factor methods in which constants are applied over discrete ranges of screening values.

The correlations are given by a two-constant relation of the form given below:

$$Log\,(ER) = B_0 + B_1\,Log(SV) \qquad (5)$$

where:

B_0, B_1 = Model parameters as given in Table 8.
ER = Leak rate in (kg/h/source).
SV = Maximum screening value above background measured using a detector calibrated to methane (ppm).

Table 7. Three-stratum emission factors for estimating fugitive equipment leaks at UOG facilities.						
Source		Number of Sources	Percent of Sources	Emissions (kg/h/src)	95% Confidence Limits	
					Lower	Upper
Connector[1]	<1000	44207	98.1	0.0000032	0.000003	0.0000033
	1000-10000	305	0.7	0.004480	0.003623	0.005337
	>10000	556	1.2	0.01856	0.01465	0.02247
Block Valve[2]	<1000	5803	94.3	0.0005027	0.0	0.001242
	1000-10000	104	1.7	0.006782	0.003705	0.009858
	>10000	245	4.0	0.03895	0.02728	0.05062
Control Valve[3]	<1000	167	61.2	0.000027	0.0000197	0.0000344
	1000-10000	66	24.2	0.03544	0.03020	0.04068
	>10000	40	14.6	0.07581	0.0	0.1706
PRV	<1000	60	32.3	0.0002125	0.0000619	0.003632
	1000-10000	3	1.6	0.009339	0.0	0.04927
	>10000	123	66.1	0.3814	0.0	0.8673
Regulator	<1000	10	26.3	0.0000127	0.0000099	0.0000155
	1000-10000	7	18.4	0.0004301	0.0001985	0.0006618
	>10000	21	55.3	0.01977	0.004751	0.03439
Orifice Meter[4]	<1000	67	64.4	0.000032	0.0000198	0.0000442
	1000-10000	16	15.4	0.009850	0.004703	0.01500
	>10000	21	20.2	0.0088	0.004936	0.01286
Other Flow Meter[5]	<1000	258	97.0	0.000003	0.0000014	0.0000045
	1000-10000	1	0.4	0.0002000	----	----
	>10000	7	2.6	0.0002064	0.0	0.0006932
Station or Pressurized Compressor Blowdown System[6]	<1000	25	24.5	0.000023	0.000001	0.000045
	1000-10000	2	2.0	0.008100	----	----
	>10000	75	73.5	1.274	0.4989	2.049
Compressor Blowdown System - Depressurized Reciprocating	<1000	4	26.67	0.0	0.0	0.0
	1000-10000	----	----	----	----	----
	>10000	11	73.33	3.200	1.245	5.155
Compressor Blowdown System - Depressurized Centrifugal	<1000	7	38.89	0.0	0.0	0.0
	1000-10000	----	----	----	----	----
	>10000	11	61.11	1.200	0.0	2.422
Open-Ended Line	<1000	173	27.0	0.0000288	0.0000161	0.0000415
	1000-10000	6	0.9	0.002533	0.0001628	0.004904
	>10000	463	72.1	0.1158	0.05458	0.1770
Instrument Controller[7]	<1000	----	----	----	----	----
	1000-10000	----	----	----	----	----
	>10000	17	100.0	0.4681	0.09325	0.8429

Table 7. Three-stratum emission factors for estimating fugitive equipment leaks at UOG facilities.							
Source		Number of Sources	Percent of Sources	Emissions (kg/h/src)	95% Confidence Limits	
					Lower	Upper
Compressor Seal - Reciprocating[8]	<1000	5	13.9	0.00056	0.0	0.002115
	1000-10000	----	----	----	----	----
	>10000	31	86.1	0.7682	0.4865	1.049
Compressor Seal - Centrifugal[8]	<1000	1	4.8	0.0000075	----	----
	1000-10000	----	----	----	----	----
	>10000	20	95.2	0.8546	0.2469	1.462

Source: Ross and Picard (1996), Table 7, page 23.

---- No data available.
1 Includes flanges, threaded connections and mechanical couplings.
2 Accounts for emissions from the stem packing and the valve body, and it applies to all types of block valves (e.g., butterfly, ball, globe, gate, needle, orbit and plug valves). Leakage past the valve seat is accounted for by the Open-Ended Line emission category. Leakage from the end connections is accounted for by the connector category (i.e., one connector for each end).
3 Accounts for leakage from the stem packing and valve body. Emissions from the controller and actuator are accounted for by the Instrument Controller and Open-Ended Line categories respectively. This factor applies to all valves with automatic actuators (including fuel gas injection valves on the drivers of reciprocating compressors).
4 Accounts for emissions from the orifice changer. Emissions from sources on pressure tap lines etc. are not included in the factor (i.e., these emissions must be calculated separately).
5 Accounts for emissions from other types of gas flow meters (e.g., diaphragm, ultrasonic, roots, turbine and vortex meters).
6 Accounts for leakage past a valve seat through an open vent line to the atmosphere. These vents are typically six inches or greater in diameter and are used to blowdown major process units or sections of pipeline. Small diameter open-ended lines such as those used to blowdown chart recorders, meter runs etc. are accounted for by the Open-Ended Line category.
7 The Instrument Controller Category accounts for emission from pneumatic control devices that use natural gas as the supply medium.
8 The Compressor Seal categories account for emissions from individual compressor seals (i.e., for a four cylinder reciprocating compressor unit there are four seals so the compressor seal emissions for the unit would be four times the factor in the table).

Table 8. Correlation parameters for estimating leak rates from equipment components at UOG facilities.				
Source	B_0	B_1	Number of Sources	Correlation (R^2)
Connectors[1]	-5.9147	0.75	305	0.71
Valves[1]	-6.0399	0.83	369	0.67
Open-Ended Lines[2]	-6.9586	1.28	64	0.44
Pressure Relief Devices[2]	-5.1479	0.91	29	0.46
Pressure Regulators[2]	-6.4821	0.91	35	0.58

1 The correlation for this source is based on screening and bagging data collected by Ross and Picard (1996), by Environment Canada (Williams, 1996), and data collected for U.S. EPA (1995).

2 The correlation for this source is based on screening and bagging data collected by Ross and Picard (1996) and Environment Canada (Williams, 1996).

The values of the correlation constants for application to the Canadian UOG industry are summarized in Table 8.

The basic approach involves processing each individual screening value as follows and then aggregating the results to determine total emissions:

- **On-scale Screening Values** - Components that have screening values within the detection range of the screening instrument and more than 1 ppm above background are assessed using equation (5). Do not average screening values and then enter the result into the correlation to estimate emissions.
- **Zero Screening Values** - Components with screening values of 1 ppm or less above background are assigned a default emission rate in accordance with Table 9. If the instrument has a minimum detection limit greater than 1 ppm, the default zero values in Table 8 do not apply. In this situation, all zero screening values should set to one-half the instrument's minimum detection limit and then processed using equation (5).
- **Off-scale or Pegged Values** - Components with off-scale or pegged values are either assigned the appropriate average emission rate for a leaking equipment component (i.e., see Table 6 or 7), or are bagged to determine the actual mass emission rate.

The level of uncertainty in the total emissions estimated by this approach is a function of the number of components considered and the portion that are pegged sources. For a single component, the uncertainty may be as high as a factor of 100. The uncertainty tends to decrease almost exponentially with the number of components. A facility would need to have at least 3000 components before the uncertainty would be below 50 percent for a 90 percent confidence level. Even more components would be required if there are pegged sources. However, very few facilities will have even 3000 components. The best overall accuracy for a facility that, generally, can be expected from use of the correlation method, including use of pegged emission factors, is about ±300 percent (telephone communication with Mr. R.A. Lott at Gas Research Institute, June 19, 1999).

Table 9. Default zero emission rates[1].	
Source Type	**Default-Zero Emission Rate[2] (kg/h/source)**
Gas valve	$6.6 (10^{-7})$
Light liquid valve	$4.9 (10^{-7})$
Light liquid pump[3]	$7.5 (10^{-6})$
Connector	$6.1 (10^{-7})$

1 Source: U.S. EPA. 1995. Protocol for Equipment Leak Emission Estimates. Research Triangle Park, NC. Report No. EPA-453/R-95-017. Table 2-11. p. 2-33.
2 Total hydrocarbon emissions.
3 The light liquid pump default zero value can be applied to compressors seals, pressure relief valves, pressure regulators, agitators and heavy liquid pumps.

5.4 Unit-Specific Leak-Rate Correlations

Some companies may wish to develop unit-specific leak-rate correlations to achieve better accuracy for their particular operations. The benefit in doing this is often questionable since, in theory, the relationship between a properly corrected screening value and the emission rate for a given component type and service is the same across all industries. Nonetheless, where there is some doubt, various nonparametric statistical methods may be applied to determine the validity of the available correlations. This involves comparing a set of predicted emission rates to actual measured values for a given source type and service category. The sign or a suitable rank-sum test may be applied to determine if the two data sets are statistically different (see almost any statistical analysis text). To apply the sign test, try using a sample size of four. If all four measured values are consistently greater than or consistently less than the predicted values, then the selected correlation probably does not provide reasonable emission estimates for the given application.

To develop a leak-rate correlation it is necessary to compile a reasonable number of data points to cover the desired screening range for each target source/service category. Each data point must comprise an actual measured mass emission rate and corresponding screening value. U.S. EPA (1995) suggests using a minimum of six random data points for each of the following ranges that the correlation will span: 1 to 100 ppm, 101 to 1 000 ppm, 1 001 to 10 000 ppm, 10 001 to 100 000 ppm and 100 001 to 1 000 000 ppm. The collected data are fit to equation (5) using a least-squares regression analysis. For further details on developing a unit-specific leak-rate correlations, refer U.S. EPA's (1995) protocol for equipment leak emission estimates.

Furthermore, use of a portable organic vapour analyzer is much slower than other leak detection techniques; especially if screening data are being recorded for each component when an analyzer is used, and other methods can eliminate this need. For example, use of bubble tests with no data recording, just tagging of leaking components, is at least 3 to 4 times faster than application of US EPA Method 21 using an organic vapour analyzer.

Appendix 6 Component-Specific Control Options

This appendix presents **potential options** for eliminating or controlling chronic leaks for each of the following common types of equipment components, respectively:

- Reciprocating compressors
- Centrifugal compressors
- Valve stem packing systems
- Sewers and drains
- Pump seals
- Flanged and threaded connections
- Pressure relief devices
- Open-ended valves and lines
- Sampling points

6.1 Reciprocating Compressors

Packings are used on reciprocating compressors to control leakage around the piston rod on each cylinder. A schematic diagram of a conventional packing system is presented in Figure 2. Typically, the distance piece is either left open with the vent piping connected directly to the packing case, or the distance piece is closed and the vents may be connected to both the packing case and the distance piece. The packing and distance piece vents are commonly routed outside the building to the atmosphere if the process gas is sweet, but should be connected to an emission controlling vent system if the gas is sour. The latter approach provides continuous treatment of any emissions and allows for more convenient scheduling of any required maintenance to the packing system.

6.1.1 Vent Monitoring Systems

It is good practice to install instrumentation on the vent lines to indicate excessive vent rates and the need for maintenance. A sensitive rotameter, an orifice and pressure differential indicator providing flow indication, or a temperature element may be used depending on the application.

6.1.2 Emission-Controlling Vent Systems

Where emission-controlling vent systems are employed they should be designed to minimize the potential for either the flow of process gas through the distance piece into the compressor crank case, or air ingress to the vent system through the nose of the packing case or through the air breather on the crank case and past the wiper packing leading to the distance piece (depending on the location of the vent connections). Both conditions pose a potential explosion hazard. Additionally, the leakage of process gas into the crank case could possibly result in contamination of the lubricating oil or corrosion problems (especially if the process gas contains hydrogen sulphide).

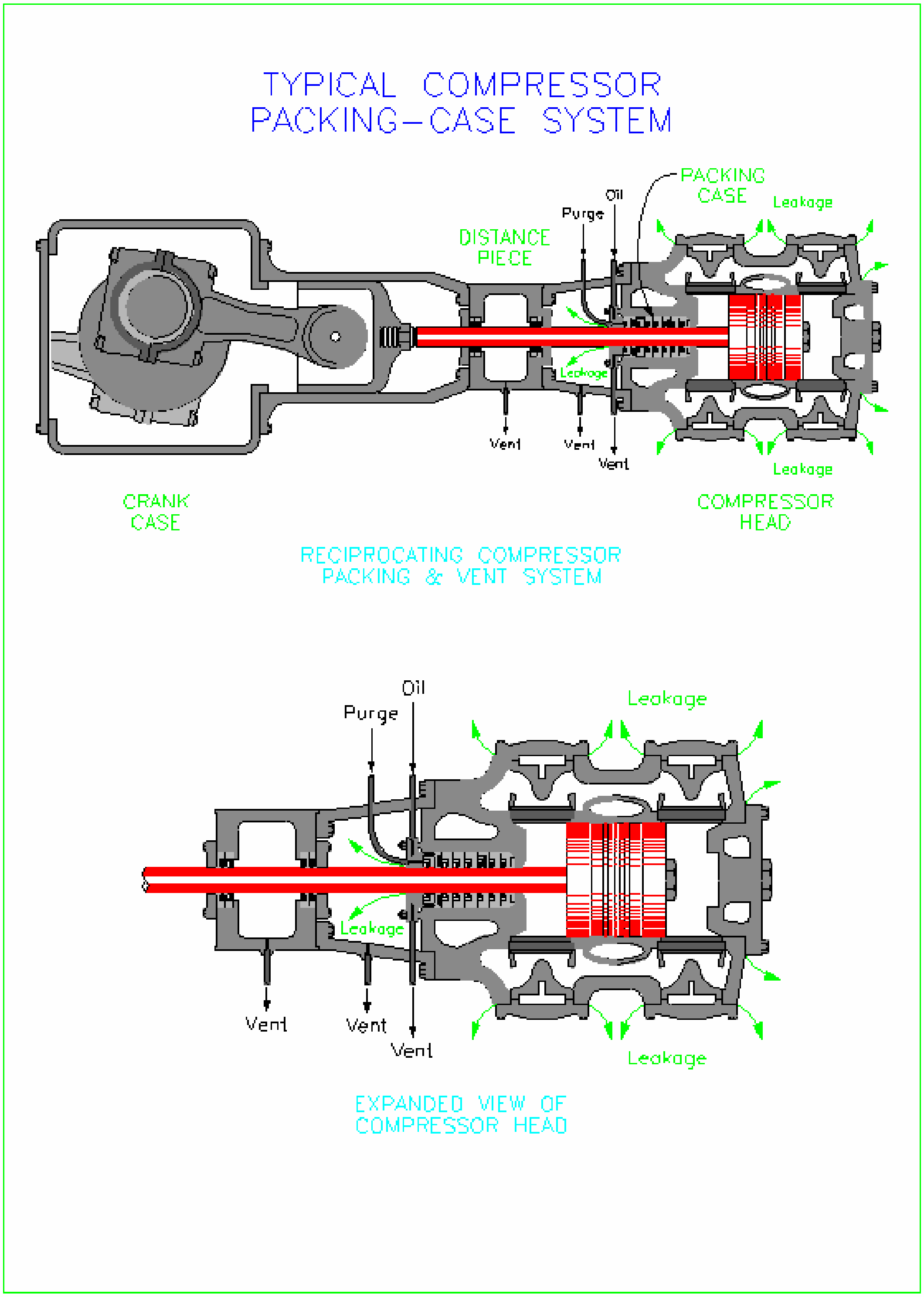


Figure 2. Schematic diagram of a piston-rod packing-case system on a reciprocating compressor.

There are three basic types of emission controlling vent systems that may be considered: low pressure vapour recovery units (e.g., for compressor fuel), incinerators, or flares. Vent gas capture may be achieved by using a small rotary vane or liquid ring vacuum pump or an ejector installed to maintain a vacuum on the vents and compress the vent gas for appropriate disposition. The gas can sometimes be used in the fuel gas system if it is compressed dry or it can be routed to a low pressure flare. The pump is usually run on a continuous basis and at a constant speed. If there is no vent gas flow, the pump produces maximum vacuum on the vent lines. To reduce the risk of pulling air into the vent gas capture system and creating an explosive atmosphere in these situations, a sweet natural gas purge controlled using a vacuum regulator may be used to limit the maximum vacuum produced.

If there is not a continuous low pressure flare system on site and recovery of the vent gas is not practical, a small natural draft incinerator unit or shrouded ground-level flare may be most suitable. A vacuum pump is not usually needed with these devices if piping distances are not too great since the natural draft of the selected combustion unit will provide a slight vacuum. The incinerator or flare may be equipped with an electronic ignition system to maintain the pilot. The pilot consumes a small amount of fuel gas. A solar panel and battery may be used to power the ignition system if there is no electricity available on site.

With compressors using lubricated packings it is important to consider that the vented and drained fluids from the packing and distance piece will contain some oil. Small pressure vessels (drain pots) should be fitted on the vent and drain lines to capture these liquids. Appropriate design and operational practices must be followed to prevent gas release when these liquids are drained. If a closed process drain system is available which has a receiver vented to flare, this can be used. If a closed drain system is not available and it is a sweet application, the liquids may be injected into the flare header if the flare system is designed to accept non-volatile liquids. Fuel gas or an inert supply gas can be used to blow liquids up to the flare header and the oil eventually accumulates in the knock-out drum. Injecting sour lubricating oil into the flare system is not recommended, especially high viscosity "tallow" based oils used for cylinder/packing lubrication, as this oil will eventually plug up the system.

6.1.3 High Performance Packing Systems

The effective life of packing systems can be increased by using more refined designs with tighter tolerances, smoother finishes, o-rings between packing cups and lapped cup surfaces. These changes should, however, be coupled with improved rod surfaces and alignment and increased packing case maintenance to be effective.

6.1.4 Barrier Fluid Systems

A barrier fluid system is an add-on control that is used in combination with an emission controlling vent system. Its purpose is to prevent leakage beyond the vent connections on the packing case or distance piece. This reduces or eliminates the need to maintain a constant vacuum on the vent system, and possibly the need to compress the vent gas. A barrier fluid system serves no useful purpose if the vents discharge directly to the atmosphere.

Barrier fluid systems should include a means for monitoring barrier fluid and vent flow, pressure, and temperature which can aid in predicting packing failures. If a higher than normal flow of barrier fluid is required to maintain barrier pressure or if high vent flow occurs, or there is a loss of pressure then a need for packing maintenance is indicated.

The barrier is created by introducing a pressurized chamber between the vent connection and the nose of the packing mechanism or distance piece, and passing a continuous supply of an inert fluid (typically nitrogen, if it is available, or oil from the cylinder lubricator) through this void. The chamber is formed and sealed using side loaded packing rings. The pressure of the purge fluid is set so that any leakage that may occur will be from the barrier chamber (i.e., into the vent system and out the nose of the packing, partition or wiper case), rather than into it. Consequently, only inert purge fluid is leaked and not process gas.

A barrier fluid system may be easily retrofit to any reciprocating compressor; although, some machining work will be required if there are no purge connections. API Specification 618 requires that a purge connection and side loaded seal rings be provided at the following: (1) primary cylinder packing, (2) the wiper packing, and (3) at the partition packing where a two compartment housing (distance piece) is used between the cylinder and the crank case.

6.1.5 Purge Gas Systems

In sour applications, it is good practice to purge sweet natural gas through the packing case, intermediate section, and wiper section to prevent sour gas from entering the crank case. To do this a vacuum pump is installed on the "cylinder" distance piece, and purge gas is admitted to the "frame" side distance piece.

6.1.6 Unit Shutdown Practices

Leakage into unit blowdown systems can be a significant source of fugitive emissions from compressors. The amount of leakage is greatest when the compressor has been depressurized promoting leakage past the seats of the upstream and downstream unit isolation valves into the unit blowdown system. When the unit is left pressurized, leakage is only promoted past the seat of the unit blowdown valve. Thus, it is generally good practice to leave compressors pressurized when they are not running if this can be tolerated. If the compressor is in sour service, a short shutdown leaving the compressor pressurized is acceptable provided that the packing is not leaking excessively, and the vent is tied into a low pressure sour vent system. For longer shutdowns, the compressor should be blown down.

In sweet applications, the compressor can remain pressurized, but this should be reviewed on a case-by-case basis to ensure that the correct packing arrangement is installed.

6.1.7 Static Packing Systems

If compressors are left pressurized when shut down, emissions from the compressor seals may be eliminated during those periods by installing a static packing system to effect a seal around the piston rod after the compressor is stopped. This helps contain the gas in the compressor cylinders and eliminates the need to maintain barrier gas flow when the compressor is stopped. Leakage from cylinder gaskets and unloader glands can still occur. The emissions during operation are unaffected except that space taken up by the static packing may dictate that a less sophisticated running packing be used.

A static packing system replaces some cups in the packing case (it is usually necessary to lap the case). It comprises a conformable seal made of relatively soft rubber or teflon. The seal is brought into contact with the compressor rod by pressurized gas when the compressor is stopped. The amount of pressure required to actuate the seal is normally about half of the pressure in the cylinder; although, this may be higher. When the actuating pressure is lowered, the seal is released and the compressor may be restarted.

Static packing systems are not applicable to all compressors, (usually because of space and design limitations).

6.1.8 Valve Cap Leakage

Leakage past the valve caps, as depicted in Figure 2, is really only a problem with improperly specified O-Rings (i.e., due to explosive de-compression), or where lead or aluminum seals are used in lieu of O-Rings (such as EI, or IR compressors).

6.2 Centrifugal Compressors

Centrifugal compressors generally require shaft end seals between the compressor and bearing housings. Face contact oil lubricated mechanical seals or oil ring shaft seals are commonly used in hydrocarbon services. Dry gas shaft seals are frequently applied in many process and natural gas services and are the preferred choice for centrifugal compressors due to their lower leakage potential.

There are several options for reducing atmospheric emissions from the seals on centrifugal compressors: emission controlling vent systems (degassing drum vent control) for mechanical contact and oil film seals, dry gas seals and pressurized motor drive compressors.

6.2.1 Emission-Controlling Vent Systems Used with Conventional Seals

Face contact seals use two sealing rings held in close contact by a spring mechanism balanced with fluid pressures from the process gas and seal oil. An oil ring seal uses a journal type ring which is sealed with pressurized and circulating oil. Both oil lubricated face contact and oil film seals, often arranged in the double configuration, use oil at a pressure higher than the process gas pressure. They provide a positive seal from gas leakage along the shaft to the atmosphere; however, other emissions are associated with the system.

Some oil leaks inward through the seal and is collected in drain traps before being returned to the reservoir. Gas from the traps should be routed to an emission controlling vent system or back to the compressor suction. Any installations which vent the traps directly to atmosphere will have very high emissions and losses of process gas. The vent on lube oil degassing drums should therefore be tied in to an emission-controlling vent gas system provided this does not impose excessive backpressure on the degassing drum and lube oil reservoir.

6.2.2 Dry Gas Seals

Dry gas seals generally offer substantially reduced emissions compared to wet seal systems depending on the vent gas controls provided. Additionally, when properly applied, gas seals often yield both capital and operating cost savings over conventional oil lubricated seals. The capital savings are due to the simplification of the oil system by deletion of the seal oil part of the system. Operational savings can be realized in services where clean seal gas is available due to the longer running life of the essentially non-contacting seals.

Dry gas seals operate without oil. The seal has two precision machined sealing plates, usually one of silicon carbide or tungsten carbide and one of carbon. The seals are separated by clean, filtered seal gas which is used to create a pressure dam effect involving radial or spiral groves in one seal face. Due to very close running clearances, leakage rates are very low. Per seal face set leakage rates of about 0.5 kg/h can be expected, depending on the seal size and pressure differential.

The pressure differential across the seal must be maintained or the hydrodynamic forces will not separate the faces. High vent back-pressure can therefore cause seal failure. To prevent loss of this pressure differential in applications involving single seals and low operating pressures, the outer seal vent is commonly routed to atmosphere at a safe location. The outer seal chamber is typically purged with nitrogen to prevent local discharge to atmosphere.

A tandem gas seal arrangement is available. The tandem arrangement provides protection in the event the inboard seal fails, and it is becoming the minimum standard for high pressure applications with flammable gases. The inter-seal vent can be routed to an appropriate emissions controlling vent system. Emissions are still typical at the outer seal vent.

6.3 Valves

There are two main locations on a typical valve where leakage may occur: (1) from the valve body and around the valve stem, and (2) past the valve seat. The latter potential source of emissions is only an environmental concern if the line downstream of the valve is open to the atmosphere, and if so, it is classified as an open-ended line.

A conventional process valve uses a packing gland to prevent the leakage of process fluid around the stem. The valve is equipped with a hand wheel or handle for manual operation, or an actuator for automatic control. The stem, itself, may be operated through either a sliding/rising or rotary motion depending on the type of valve.

The effectiveness of the packing gland is determined by the tightness of the packing material around the stem and the pressure of the process fluid. Over time the gland gradually looses some of the packing material due to extrusion and wear and must be tightened to maintain a proper seal. At some point, complete repacking of the gland is required.

Over-tightening a packing gland can prevent or make manual operation of a valve difficult. For control valves, it can cause slow stem movement, poor process control, bad seating and possibly stalled conditions. It can also damage the packing and reduce its life.

Rotary or quarter-turn valves where stems turn 90^o (e.g., plug, ball or butterfly valves) tend to be easier to seal than sliding-stem valves (e.g., gate or globe valves). This is because quarter-turn valves have less packing-to-shaft travel distance for each stroke of the valve, and therefore, less packing wear (Brestel et al., 1992). Additionally, quarter-turn valves have less of a tendency to draw dust and other abrasives into the packing gland during their operation. Wear on the stem packing is approximately 10 percent of sliding-stem valves. Leak frequencies and average leak rates for quarter turn valve are less than half of that for rising stem valves and only a quarter of that for gate valves in particular. Accordingly, where practicable to use, quarter-turn valves should be the preferred choice for manual and automated on/off applications in gas, LNG or LPG service.

For demanding service applications (e.g., vibration or thermal cycling) where leak frequencies of less than 2 percent are not being achieved and the use of rotary or quarter-turn valves is not practicable, consideration should be given to using high performance packing materials and stem seal designs and such as live-loaded packings, bellows seals and dual packing with bleed or environmental monitoring ports.

Overall, graphite packing systems are reported to provide the best leak control. One graphite packing set at the outboard end is normally sufficient, with the intervening packing box volume filled with spacer rings (Lipton, 1992). Where preformed graphite rings are installed, braided end rings are necessary.

Polymeric packing may be quite acceptable in many undemanding service applications with temperatures below 200oC. Braided non-asbestos materials are reported to be less effective than the previous braided asbestos packing and are limited to applications with process temperatures below 150oC (Aikin, 1992). The problems are with the blocking agents and fibre size. The fibre sizes of the new materials are larger than that of asbestos, so voids between the fibres are larger. These voids are filled with various blocking agents, such as polytetrafluoroethylene (PTFE), which tend to extrude or burn off at high temperatures. In addition, the large fibres fracture at relatively low packing stresses (i.e., 27.6 MPa), and with relatively low numbers of stem stroking cycles. Consequently, they are subject to inherently high consolidation and therefore should be live-loaded and used with anti-extrusion rings.

An important consideration in changing to alternate packing materials is the potential for an increase in the force needed to stroke the valve. It may be necessary to install larger handles or handwheels on manual valves, and more powerful actuators on the control valves. Additionally, the packing follower (or gland) bolts may not be capable of generating enough stress to compress the packing (Wright, 1993). The coefficient of friction of many asbestos replacement materials prevents normal packing in multiple ring packing boxes from stressing the lower rings to the level required for sealing (Wright, 1993).

The valve must be in good mechanical condition to ensure optimum packing performance and low emissions. The stem should be straight and unmarked (especially for control valves). The packing box should also be unmarked and any unused bleed-off holes should be plugged.

Extended packing housings may be required to accommodate some alternate packing materials.

Packing removal (for inspection and repacking) with a metal pick is laborious and frequently results in marring of the stem and packing box wall. Specially designed water picks are commercially available which are much faster and easier to use, and which do not mar the stem or wall services (Lipton, 1992).

Maintenance of static packing by adjusting gland bolts is required to assure emission control.

6.4 Sewers and Drains

The potential for oil to enter the process sewer system or any open drainage or storage systems should be minimized. Closed recovery system for drainage of equipment should be considered to reduce quantities of hydrocarbons being released into the open process sewers. This in turn will reduce emissions from sewer vents and from connected API separator and waste water treatment ponds.

6.5 Pumps

Excessive seal leakage is a direct symptom of the misapplication of a seal and improper operation of the seal or its associated rotating or reciprocating equipment. Few seals leak abnormally, and these can be readily identified and corrected. A strong correlation exists between the level of seal leakage and the mean time between failure (MTBF) of its associated equipment.

Mechanical seals should be the minimum standard for use on centrifugal pumps used in light hydrocarbon liquid service except where leakage from the pumps may pose an occupational health hazard (i.e., where the liquid contains large concentrations of benzene) or the pumped fluid has a specific gravity less than 0.4 (because single and tandem seals may be inadequately lubricated by such fluids). The available options for reducing emissions from the base case of single mechanical seals are, in the general order of increasing cost and performance capabilities:

- Bellows Seals,
- Throttle Bushing with Vent Diversion,

- Tandem Mechanical Seals,
- Double Mechanical Seals,
- Sealless Pumps,
- Gas Seals for Volatile Services, and
- Blow-cases Instead of Pumps.

Double seals are the best choice for maximum containment of the process fluid unless a vapour control system or sealless pumps are used. A double mechanical seal can be expected to reduce leakage to almost zero when operating properly. There are no direct or indirect increases in emissions associated with the use of this technology except leakage of the barrier fluid which is usually not a VOC or harmful substance. Some leakage of the barrier fluid into the product must be tolerated. Double seals may generate slightly more heat than tandem and single seals and additional cooling medium flow or auxiliary coolers may be required.

Sealless pumps are generally limited to single stage applications. Canned motor and magnetic drive pumps are available in sizes up to approximately 500 kW, and 50 kW, respectively.

Gas seals are not applicable to most pump services. Only very clean, volatile services such as propane are suitable.

A principal reason for using blow-cases is that they do not require electrical power; however they may offer potential for reduction of emissions in liquid moving applications. The only seals required are valve packings. There may be a potential for the application of blow-cases to other services where sealing is a chronic problem. Where blow cases are used the motive gas should be discharged to an emissions controlling vent system. A common application is on gas gathering systems for injecting low pressure condensate from a compressor suction drum into the pipeline at discharge pressure. Compressed natural gas is used as the motive gas. The expanded gas may be displaced back to the compressor suction at the end of the cycle.

If change out of a mechanical seal is called for, upgrading of the existing seal chamber with an enlarged-bore retrofit seal chamber, as specified in the ANSI B-73 standard and API Standard 610, should be considered. Introduced in the mid-1980's, enlarged bore seal chambers with increased radial clearance between the mechanical seal and seal chamber wall, provide better circulation of liquid to and from seal faces. Improved lubrication and heat removal (cooling) of seal faces extend seal life and lower maintenance costs. Extensive field and laboratory evaluations have shown that, on average, seal life is doubled when a properly designed and applied seal is operated in an enlarged-bore seal chamber (Battilana, 1989).

Reciprocating pumps have similar sealing problems to reciprocating compressors. The performance of the packing systems may be greatly enhanced by installing a barrier fluid system similar to that described for reciprocating compressors.

6.6 Threaded and Flanged Connections

A properly installed and maintained mechanical coupling or threaded or flanged connection can provide essentially leak free service for extended periods of time. However, there are many factors that can cause leakage problems to arise. Some of the common causes are summarized in Table 10. For instance, it is not uncommon for some connections to be inadvertently left un-tightened following a facility turnaround or specific inspection and maintenance activity (especially on fuel gas piping). Most of the listed issues can be addressed by conducting leak checks immediately following any changes or adjustments to a connection.

The application of proper mechanical design standards and material specifications are necessary to ensure adequate performance of connectors under load conditions (see ANSI Standards B16.5 and B31.3 for flanges).

6.7 Pressure Relief Devices

When relief or safety valves reseat after having been activated they often leak because the original tight seat is not regained either due to damage of the seating surface or a build-up of foreign material on the seat plug. As a result, they are often responsible for fugitive emissions. Another problem develops if the operating pressure is too close to the set pressure, causing the valve to "simmer" or "pop" at the set pressure.

Table 10. Common causes of leakage from flanged and threaded connections.

Flanged Connections	Threaded Connections
Thermal stress and cycles.	Thermal stress and cycles.
Incorrect or re-used gasket material.	Dirty, roughly cut or damaged threads.
Missing gaskets.	Crossed threads.
Misalignment of piping or flange faces.	Poor quality or no thread sealant used.
Dirty or damaged flange faces.	Misaligned piping.
Inadequate or non-uniform bolt stresses.	Inadequate tightening of the connection.
Improper tightening sequence.	External abuse.
External abuse.	

It is good practice, where a relief or safety valve may require servicing between scheduled facility turnarounds, to install a block valve upstream of a relief system to facilitate early replacement or repair of the components. This use of an upstream block valve is allowed under most Boiler and Pressure Vessel Acts, provided the valve is normally car-sealed open.

In demanding service applications consideration may also be given to specifying the use of resilient valve seats (elastomeric o-rings), as they have superior re-sealing characteristics, or installing a rupture disk immediately upstream of the relief valve. A pressure gauge or suitable telltale indicator is needed between the disk and the relief valve to indicate when the disk has failed (ASME, 2004). The rupture disk will shield the relief valve from corrosive process fluids during normal operation. If an overpressure condition occurs, replacement of the disk may be delayed until the next scheduled shutdown period. In the interim, protection against over-pressuring is provided by the relief valve. The rupture disk should have a set pressure that is slightly higher than that of the relief valve to help avoid simmering problems.

Relief valves should be connected to an emission controlling vent system where the process fluid is toxic (i.e., at sour facilities). Where relief valves are connected to a common vent system leakage is difficult to detect and, as a result, may lead to a significant level of waste and cause unnecessary emissions. Leakae into flare systems is considered to have a flaring efficiency of only 60 percent because the flare system is sized normally for emergency relief, and performs less efficiently at low flows (U.S. EPA, 1980).

6.8 Open-ended Valves and Lines

An open-ended valve is any valve that may release process fluids directly to the atmosphere in the event of leakage past the valve seat. The leakage may result from improper seating due to an obstruction or sludge accumulation, or because of a damaged or worn seat. An open-ended line is any segment of pipe that may be attached to such a valve and that opens to the atmosphere at the other end.

Few open-ended valves and lines are designed into process systems; however, actual numbers can be quite significant at some sites due to poor operating practices and various process modifications that may occur over time.

Some common examples of instances where this type of source may occur are as follows: scrubber blowdowns, truck loading and unloading connections on storage tanks, instrument block valves where the instrument has been removed for repair or other reasons, manual methanol injection points on pipelines, drains, and purge or sampling points.

Fugitive emissions from these sources should be controlled by installing a stopper (for example, a cap, plug or blind flange) on open-ended valves, and a stopper or a second block valve on open-ended lines. If the open end of a line is easily accessible and in close proximity to the block valve, a stopper is usually the best solution. Otherwise, a second block valve should be installed. Where a stopper is used it should be chained so it is not lost or misplaced when temporarily removed for use of the valve or line. A swivel connection may be needed to allow easy removal and replacement of the stopper.

6.9 Sampling Points

Sampling systems are generally only relevant at gas transmission facilities, gas processing plants, and possibly some oil batteries. Routine sampling is not common at most other oil and gas field facilities. The potential for emissions from sampling activities is greatest where the sample (gas or liquid) is taken from a pressurized source. The collection of liquid samples by dipping a tank is generally not a source of emissions if this is done carefully so there is no spillage.

Closed loop sampling is the primary method for controlling emissions from pressurized sampling points. This method returns purge fluid back to the process stream. Where this is not practicable, the purge material can be directed to the flare system.

Appendix 7 US EPA Method 21

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EMISSION MEASUREMENT TECHNICAL INFORMATION CENTRE
NSPS TEST METHOD

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(EMTIC M-21, 2/9/93)

Method 21 - Determination of Volatile Organic Compound Leaks

1. APPLICABILITY AND PRINCIPLE

1.1 Applicability. This method applies to the determination of volatile organic compound (VOC) leaks from process equipment. These sources include, but are not limited to, valves, flanges and other connections, pumps and compressors, pressure relief devices, process drains, open-ended valves, pump and compressor seal system degassing vents, accumulator vessel vents, agitator seals, and access door seals.

1.2 Principle. A portable instrument is used to detect VOC leaks from individual sources. The instrument detector type is not specified, but it must meet the specifications and performance criteria contained in Section 3. A leak definition concentration based on a reference compound is specified in each applicable regulation. This procedure is intended to locate and classify leaks only, and is not to be used as a direct measure of mass emission rate from individual sources.

2. DEFINITIONS

2.1 Leak Definition Concentration. The local VOC concentration at the surface of a leak source that indicates that a VOC emission (leak) is present. The leak definition is an instrument meter reading based on a reference compound.

2.2 Reference Compound. The VOC species selected as an instrument calibration basis for specification of the leak definition concentration. (For example, if a leak definition concentration is 10,000 ppm as methane, then any source emission that results in a local concentration that yields a meter reading of 10,000 on an instrument meter calibrated with methane would be classified as a leak. In this example, the leak definition is 10,000 ppm, and the reference compound is methane.)

2.3 Calibration Gas. The VOC compound used to adjust the instrument meter reading to a known value. The calibration gas is usually the reference compound at a known concentration approximately equal to the leak definition concentration.

2.4 No Detectable Emission. The total VOC concentration at the surface of a leak source that indicates that a VOC emission (leak) is not present. Since background VOC concentrations may exist, and to account for instrument drift and imperfect reproducibility, a difference between the source surface concentration and the local ambient concentration is determined. A difference based on the meter readings of less than a concentration corresponding to the minimum readability specification indicates that a VOC emission (leak) is not present. (For example, if the leak definition in a regulation is 10,000 ppm, then the allowable increase is surface concentration versus local ambient concentration would be 500 ppm based on the instrument meter readings.)

2.5 Response Factor. The ratio of the known concentration of a VOC compound to the observed meter reading when measured using an instrument calibrated with the reference compound specified in the applicable regulation.

2.6 Calibration Precision. The degree of agreement between measurements of the same known value, expressed as the relative percentage of the average difference between the meter readings and the known concentration to the known concentration.

2.7 Response Time. The time interval from a step change in VOC concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter.

3. APPARATUS

3.1 Monitoring Instrument.

3.1.1 Specifications

a. The VOC instrument detector shall respond to the compounds being processed. Detector types which may meet this requirement include, but are not limited to, catalytic oxidation, flame ionization, infrared absorption, and photoionization.

b. The instrument shall be capable of measuring the leak definition concentration specified in the regulation.

c. The scale of the instrument meter shall be readable to + or - 5 percent of the specified leak definition concentration.

d. The instrument shall be equipped with a pump so that a continuous sample is provided to the detector. The nominal sample flow rate shall be 0.1 to 3.0 liters per minute.

e. The instrument shall be intrinsically safe for operation in explosive atmospheres as defined by the applicable U.S.A. standards (e.g., National Electrical Code by the National Fire Prevention Association).

f. The instrument shall be equipped with a probe or probe extension for sampling not to exceed 1/4 in. in outside diameter,
with a single end opening for admission of sample.

3.1.2 Performance Criteria.

a. The instrument response factors for the individual compounds to be measured must be less than 10.

b. The instrument response time must be equal to or less than 30 seconds. The response time must be determined for the instrument configuration to be used during testing.

c. The calibration precision must be equal to or less than 10 percent of the calibration gas value.

d. The evaluation procedure for each parameter is given in Section 4.4.

3.1.3 Performance Evaluation Requirements.

a. A response factor must be determined for each compound that is to be measured, either by testing or from reference sources. The response factor tests are required before placing the analyzer into service, but do not have to be repeated at subsequent intervals.

b. The calibration precision test must be completed prior to placing the analyzer into service, and at subsequent 3-month intervals or at the next use whichever is later.

c. The response time test is required before placing the instrument into service. If a modification to the sample pumping system or flow configuration is made that would change the response time, a new test is required before further use.

3.2 Calibration Gases.

The monitoring instrument is calibrated in terms of parts per million by volume (ppm) of the reference compound specified in the applicable regulation. The calibration gases required for monitoring and instrument performance evaluation are a zero gas (air, less than 10 ppm VOC) and a calibration gas in air mixture approximately equal to the leak definition specified in the regulation. If cylinder calibration gas mixtures are used, they must be analyzed and certified by the manufacturer to be within + or - 2 percent accuracy, and a shelf life must be specified. Cylinder standards must be either reanalyzed or replaced at the end of the specified shelf life. Alternatively, calibration gases may be prepared by the user according to any accepted gaseous preparation procedure that will yield a mixture accurate to within + or - 2 percent. Prepared standards must be replaced each day of use unless it can be demonstrated that degradation does not occur during storage.

Calibrations may be performed using a compound other than the reference compound if a conversion factor is determined for that alternative compound so that the resulting meter readings during source surveys can be converted to reference compound results.

4. PROCEDURES

4.1 Pretest Preparations. Perform the instrument evaluation procedure given in Section 4.4 if the evaluation requirement of Section 3.1.3 have not been met.

4.2 Calibration Procedures. Assemble and start up the VOC analyzer according to the manufacturer's instructions. After the appropriate warmup period and zero internal calibration procedure, introduce the calibration gas into the instrument sample probe. Adjust the instrument meter readout to correspond to the calibration gas value. (<u>Note</u>: If the meter readout cannot be adjusted to the proper value, a malfunction of the analyzer is indicated and corrective actions are necessary before use.)

4.3 Individual Source Surveys.

4.3.1 Type I - Leak Definition Based on Concentration. Place the probe inlet at the surface of the component interface where leakage could occur. Move the probe along the interface periphery while observing the instrument readout. If an increased meter reading is observed, slowly sample the interface where leakage is indicated until the maximum meter reading is obtained. Leave the probe inlet at this maximum reading location for approximately two times the instrument response time. If the maximum observed meter reading is greater than the leak definition in the applicable regulation, record and report the results as specified in the regulation reporting requirements. Examples of the application of this general technique to specific equipment types are:

a. Valves - Leaks usually occur at the seal between the stem and the housing. Place the probe at the interface where the stem exits the packing and sample the stem circumference and the flange periphery. Survey valves of multipart assemblies where a leak could occur.

b. Flanges and Other Connections - Place the probe at the outer edge of the flange-gasket interface and sample the circumference of the flange.

c. Pump or Compressor Seals - If applicable, determine the type of shaft seal. Perform a survey of the local area ambient VOC concentration and determine if detectable emissions exist as described above.

d. Pressure Relief Devices - For those devices equipped with an enclosed extension, or horn, place the probe inlet at approximately the centre of the exhaust area to the atmosphere.

e. Process Drains - For open drains, place the probe inlet as near as possible to the centre of the area open to the atmosphere. For covered drains, locate probe at the surface of the cover and traverse the periphery.

f. Open-ended Lines or Valves - Place the probe inlet at approximately the centre of the opening of the atmosphere.

g. Seal System Degassing Vents, Accumulator Vessel Vents, Pressure Relief Devices - If applicable, observe whether the applicable ducting or piping exists. Also, determine if any sources exist in the ducting or piping where emissions could occur before the control device. If the required ducting or piping exists and there are no sources where the emissions could be vented to the atmosphere before the control device, then it is presumed that no detectable emissions are present. If there are sources in the ducting or piping where emissions could be vented or sources where leaks could occur, the sampling surveys described in this section shall be used to determine if detectable emissions exist.

h. Access door seals - Place the probe inlet at the surface of the door seal interface and traverse the periphery.

4.3.2 Type II - "No Detectable Emission". Determine the ambient concentration around the source by moving the probe randomly upwind and downwind around one to two meters from the source. In case of interferences, this determination may be made closer to the source down to no closer than 25 centimetres. Then move the probe to the surface of the source and measure as in 4.3.1. The difference in these concentrations determines whether there are no detectable emissions. When the regulation also requires that no detectable emissions exist, visual observations and sampling surveys are required. Examples of this technique are: (a) Pump or Compressor Seals - Survey the local area ambient VOC concentration and determine if detectable emissions exist. (b) Seal System Degassing Vents, Accumulator Vessel Vents, Pressure Relief Devices - Determine if any VOC sources exist upstream of the device. If such ducting exists and emissions cannot be vented to the atmosphere upstream of the control device, then it is presumed that no detectable emissions are present. If venting is possible sample to determine if detectable emissions are present.

4.3.3 Alternative Screening Procedure.

4.3.3.1 A screening procedure based on the formation of bubbles in a soap solution that is sprayed on a potential leak source may be used for those sources that do not have continuously moving parts, that do not have surface temperatures greater than the boiling point or less than the freezing point of the soap solution, that do not have open areas to the atmosphere that the soap solution cannot bridge, or that do not exhibit evidence of liquid leakage. Sources that have these conditions present must be surveyed using the instrument technique of Section 4.3.1 or 4.3.2.

4.3.3.2 Spray a soap solution over all potential leak sources. The soap Solution may be a commercially available leak detection solution or may be prepared using concentrated detergent and water.

A pressure sprayer or squeeze bottle may be used to dispense the solution. Observe the potential leak sites to determine if any bubbles are formed. If no bubbles are observed, the source is presumed to have no detectable emissions or leaks as applicable. If any bubbles are observed, the instrument techniques of Section 4.3.1 or 4.3.2 shall be used to determine if a leak exists, or if the source has detectable emissions, as applicable.

4.4 Instrument Evaluation Procedures. At the beginning of the instrument performance evaluation test, assemble and start up the instrument according to the manufacturer's instructions for recommended warmup period and preliminary adjustments.

4.4.1 Response Factor.

4.4.1.1 Calibrate the instrument with the reference compound as specified in the applicable regulation. For each organic species that is to be measured during individual source surveys, obtain or prepare a known standard in air at a concentration of approximately 80 percent of the applicable leak definition unless limited by volatility or explosivity. In these cases, prepare a standard at 90 percent of the standard saturation concentration, or 70 percent of the lower explosive limit, respectively. Introduce this mixture to the analyzer and record the observed meter reading. Introduce zero air until a stable reading is obtained. Make a total of three measurements by alternating between the known mixture and zero air. Calculate the response factor for each repetition and the average response factor.

4.4.1.2 Alternatively, if response factors have been published for the compounds of interest for the instrument or detector type, the response factor determination is not required, and existing results may be referenced. Examples of published response factors for flame ionization and catalytic oxidation detectors are included in the Bibliography.

4.4.2 Calibration Precision. Make a total of three measurements by alternately using zero gas and the specified calibration gas. Record the meter readings. Calculate the average algebraic difference between the meter readings and the known value. Divide this average difference by the known calibration value and multiply by 100 to express the resulting calibration precision as a percentage.

4.4.3 Response Time. Introduce zero gas into the instrument sample probe. When the meter reading has stabilized, switch quickly to the specified calibration gas. Measure the time from switching to when 90 percent of the final stable reading is attained. Perform this test sequence three times and record the results. Calculate the average response time.

5. BIBLIOGRAPHY

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