2019

SEALING DEVICES REDUCTION OF FUGITIVE EMISSIONS DOCUMENT

BEST AVAILABLE TECHNIQUES

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SEALING DEVICES FUGITIVE EMISSIONS REDUCTION DOCUMENT

NOTE: This document is a working version for the European IPPC Bureau (of the Commission's Joint Research Section). It focuses on the Industrial Emissions Directive (IED) 2010/75/EU and the part sealing devices play in the reduction of fugitive emissions. It is not an official publication of the European Union and does not necessarily reflect the position of the European Commission.

SECTION 1. Executive summary

The European Sealing Association (ESA) represents the majority of Sealing Product manufacturers in Europe. The ESA has over 50 members, with a combined turnover of Euros 2.6billion, and employs some 12,500 people. 50.6% are in manufacturing, 8.8% in R&D, and 25.9% in Sales and Marketing. The ESA works in very close co-operation with the Fluid Sealing Association (FSA) which represent the large majority of Sealing Product manufacturers in USA, Canada and Mexico.

This Sealing Devices Fugitive Emissions Reduction document reflects an information exchange originally carried out within the sealing industry under **Article 16(2) of Council Directive 96/61/EC**. This update revision reflects the Industrial Emissions Directive (IED) 2010/75/EU adopted on 24th November 2010 and implemented on 7th January 2013 and the **Directive 2008/1/EC** covering Integrated Pollution Prevention and Control (IPPC) which came into force on 18th February 2008.

All details can be found in the various published Industrial Emissions Directive BAT Reference Documents (BREF) which all refer to Best Available Techniques (BATs) which are an integral part of all reference BREFs. This document is available on the **BATIS** system for all BREFs (special access is required via EIPPCB)

The IED covers the following industries as specified in existing BREFs:

- Energy industries (Power stations, Oil and Gas up and down stream);
- Metal industries (Foundries and Finishing processes);
- Mineral industries; (Mining)
- Chemical industries; (Organic and Inorganic, pharmaceutical)
- Waste management;
- New industries – like intensive livestock farming.

This Executive Summary is intended to be read in conjunction with the specific sealing device chapters which are relevant for any particular source of emissions from industrial processes or applications.

For the purposes of BAT information exchange, this document has been divided into different sealing devices, and reflects the key areas where emissions are likely to occur on industrial sites which are likely to be covered by EU Industrial Emissions Directive (IED) 2010/75/EU.

IED 2010/75/EU

One of the main reasons given for the introduction of IED 2010/75/EU was the insufficient implementation of BATs, leading to limited progress in the prevention and reduction in fugitive industrial emissions, as well as limitations with regard to compliance, enforcement and environmental effectiveness.

Fugitive emissions are generally defined as those unplanned emissions from Industrial processes, as opposed to those planned via flares, chimneys, and safety relief valves.

It has not been possible to carry out a detailed information exchange on sealing technology used in every industrial process because the scope would be so large.

Consequently, this fugitive emissions reduction document contains a mixture of generic and detailed information on sealing devices used on typical industrial processes.

MAJOR CHANGES WITH THE INTRODUCTION OF THE IED 2010/75/EU CAN BE BEST SUMMARIZED AS FOLLOWS:

Better regulation:

Merging of 7 existing directives (IPPC 1996/61/EC and 2008/1/EC); Large Combustion Plants (2001/80/EC); Waste Incineration (2000/76/EC); Solvent Emissions (1999/13/EC); TiO2 x 3)

Strengthened provisions on:

- Inspections – article 23 – to be carried out every 3 years as an absolute minimum.
- Public access to information – article 24 and annex 1V
- Role of Best Available Techniques (BAT) in permitting of licenses for industrial plants:
- Definitions of BREF, BAT conclusions, and information exchange – articles 3, 13, and annex 111
- Enhanced role of BREF, BAT conclusions, developments and **Emissions limit values** – articles 14, 15, and 19
- Review of permit conditions – articles 4, 5, 12 and 14

IED scope for environmental issues:

Article 3 Definitions covers:

(2) Defines “Pollution”

(4) Defines “Emissions”

(5) Defines “Emission Limit Values” (ELV)

(10) Defines “Best Available Techniques”

(11) Defines “BAT reference documents”

(12) Defines “BAT conclusions”

(13) Defines “Emission levels”

Article 14 confirms “Permit conditions”

The IED now covers the following aspects of the environment:

- Emissions to air – annex II
- Emissions to water – annex II
- Emissions to land
- Energy and Water use
- Waste prevention and recovery
- Prevention and control of accidents – article 7
- Noise
- Vibration
- Heat
- Odour

Essential requirements include:

- Achieve a high level of protection for the environment as a whole.
- Prevent pollution and, if not feasible, reduce pollution.
- Access to information and public participation - article 24 and annex IV
- Permit is required for operating the installation – article 4

Permit conditions include:

- Emission Limit Values (ELVs) for all relevant pollutants – listed in article 15
- ELVs based on the use of Best Available Techniques (BATs)

Article 13 BAT reference documents and exchange of information

The IED directives required that permit conditions would be based on best available techniques (BATs) which are described in BAT reference documents (BREFs) which had been adopted by the commission. Each BREF document contains specified BAT requirements which were to be used as guidance for Competent Authorities when setting permit conditions.

Article 13 forum. The IED article 13 requires the commission to “organize an exchange of information between member states, the industries concerned, non-governmental organisations promoting environmental protection (like ESA) and the commission.”

The Article 13 forum is the working group for this process, which is often referred to the “Seville Process”

A Technical Working Group (TWG) is set up by the Commission to draw up and or review a BREF document. The Commission has published a timetable of BREF review work over the next few years.

TWGs consists of Technical Experts representing member states; industry; Non-governmental organisations (NGOs) promoting environmental protection; and the Commission. TWG members are nominated based on their technical, economic, environmental and regulatory expertise, as well as their ability to bring information into the BREF from an end user perspective.

It should be noted that the **ESA is a full member of the Article 13 forum TWG**, which is chaired by EU DG Environment, which acts as the sounding and steering board for BREF details and introduction. In particular this TWG is responsible for the guidance on the collection of data, the work programme for the exchange of information, and guidance in drawing up of BREFs and their quality assurance.

The role of BATs are to act as a reference for setting permit conditions (Article 14 (3)), and should contain the appropriate Emission Limit Values (ELV) (15 (3)), so that **emissions never exceed BAT emission levels**. Note BATs should be updated at least every 8 years.

IED 2010/75 requires that the Competent Authority MUST set emissions levels that did not exceed those specified in the BAT conclusions adopted as a Commission Implementing Decision, and ensure that these ELVs are not exceeded

Additional activities in IED annex. There are several amendments to the list of activities that are now within the remit of the IED directive.

Soil Monitoring and remediation is a new requirement in the IED which requires periodic monitoring of soil and groundwater.

There is a new requirement for the Competent Authority to provide for a system of environmental inspections, and that all plants must have an inspection plan.

BAT CONCLUSION AND THE IMPORTANCE OF THE SEALING DEVICES EMISSIONS REDUCTION DOCUMENT

ESA members manufacture the following products **Sealing Devices** that are essential in achieving the aim of significantly reducing fugitive emissions to atmosphere***.***

Gaskets are used to provide a static seal between two stationary components. They are used on flanges that connect piping, valves, compressors, pumps, instrumentation, and many other types of equipment, like heat exchangers. Due to the high number of flanges and equipment connections subject to the thermal and mechanical stresses associated with industrial processes, the correct use of high performance gaskets can significantly contribute to reduced fugitive emission levels. Gaskets come in several forms: Soft cut gaskets, semi metallic gaskets and metallic gaskets. The selection of the correct gasket is vital and is usually made based on chemical compatibility, temperature and pressure of the service.

Mechanical Seals which are used to seal rotating shafts as they enter the housing of pumps, centrifugal compressors and agitators. The seals prevent gases and liquids from escaping in the space where there is relative motion between the shaft and the housing. Various mechanical seal technologies are used: Single spring seals, double seals, dry gas seals or wet oil seals all with significantly different emission characteristics.

Compression Packing is most commonly made of braided fibres and is used to seal valve stems and shafts of reciprocating compressors. Valves have been identified as a major contributor to emissions, primarily due to their extremely high usage. Modern fibres and construction methods allow sealing at extremely low emission levels.

Expansion Joints for Piping are used to provide a flexible connection between pipes flange connections and other equipment. The use of expansion joints can reduce the number of piping connections, eliminate stress on a pipe that can create leaks in bolted joints, and reduce stress on rotating equipment that could affect seal or bearing wear, thereby significantly contributing to the reduction of emissions in piping systems.

Elastomeric and Polymeric Seals. Typically these are custom moulded or machined components (including "O" ring seals) manufactured from a whole host of deformable and resilient materials to seal liquids and gases in pressure containing systems. Frequently static but are also used between parts in relative motion such as hydraulic cylinders or valve stems, and continuous rotary motion such as marine and automotive drive shafts.

Summary. In short, where ever a pipe has to connect to a piece of plant equipment such as a pump, valve or compressor several sealing devices are the component that contains the gases or liquids and prevents the unplanned release of these substances.

THIS DOCUMENT FOCUSSES ON THE MAIN SOURCES OF FUGITIVE EMISSIONS TO THE ATMOSPHERE, AND THE APPROPRIATE SEALING DEVICE TO COMBAT THESE MOST EFFECTIVELY.

It cannot be overemphasized that Sealing Technology and Technician Training must both be taken extremely seriously to ensure that fugitive emissions from industrial processes are minimised. Training, in line with *EN 1591 part 4* ***is available from ESA members and many other sources.***

Training in the use of emissions measuring devices should also be considered to ensure accurate emissions measurement.

SECTION 2. General introduction to Emission Reduction using Sealing Devices

RELEVANT LEGAL OBLIGATIONS OF THE IED DIRECTIVE

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex 1, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community's industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim is to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 11 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

DEFINITION OF BAT

The term "**best available techniques**" is defined in Chapter I Article 3 of the Directive as "**the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce fugitive emissions and the impact on the environment as a whole."**

Annex III of the Directive contains a list of **"considerations to be taken into account generally or in specific cases when determining best available techniques... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention".**

This document can be considered the Sealing Industry BAT using the most modern technology available in Sealing Devices

The key legal requirements of the IED Directive

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Articles 14 and 15 when determining the conditions of the permit. These conditions must include fugitive emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures.

According to Article 15 of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimization of long-distance or trans-boundary pollution (Article 26) and must ensure a high level of protection for the environment as a whole. Member States have the obligation, according to Article 19 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

OBJECTIVE OF THIS DOCUMENT

The aim of this document is to provide reference information for industrial sectors on expected fugitive emission rates from sealing devices, to enable them to comply with the requirements of the IED Directive.

The document also aims to provide reference information for appropriate permitting authorities to take into account when determining permit conditions, and especially **Emission Limit Values**

Specifically, by understanding the major sources of fugitive emissions on Industrial process plants, and the available solutions provided by Sealing Technologies, the permitting authorities and the process operators can make the most informed decisions on how best to prevent emissions.

It should be noted that the techniques and solutions presented in each section will not necessarily be appropriate for all installations.

On the other hand, the obligation to ensure a high level of environmental protection including the minimization of long-distance or trans-boundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. Therefore, it is of the utmost importance that the information contained herein is taken into account fully by permitting authorities.

Since the best available techniques inevitably will improve over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European Sealing Association.

THE MAIN SOURCES OF INDUSTRIAL EMISSIONS

It is recognised that industry must reduce its impact on the environment if we are to continue global development for future generations (the so-called "sustainable development" option). A major contributory factor will be through the lowering of industrial emissions, which has been catalysed by a combination of public pressure, environmental legislation and the internal requirement to minimise the loss of valuable feed-stocks.

Large proportions of the emissions to atmosphere are represented by the by-products of combustion (notably the oxides of carbon, nitrogen and sulphur), along with known losses of volatile hydrocarbons and steam. In general, ***these are all emissions anticipated from the industrial process***, under the control of the plant operator.

However, a proportion of ***industrial emissions occurs through unanticipated or spurious leaks in process systems***. It is clear that sealing systems play a vital role in the environmental performance of industrial installations, and ***yet the sealing technology itself is usually given scant consideration!***

It must be emphasised that sealing technology can perform at its peak only after careful selection (appropriate for the specific application), correct installation, and operation according to the performance envelope, regular inspection and maintenance. **These areas are the key focus for this document.**

The best available techniques for sealing technology are described, together with the best practices for their selection, installation and use, in order to enable the plant operator to achieve the requirements of the IED Directive.

FUGITIVE EMISSIONS

The term "fugitive emissions" covers all losses of (usually volatile) materials from a process plant, through evaporation, flaring, spills and unanticipated or spurious leaks

To put the scale of the challenge into perspective, fugitive emissions in the USA have been estimated to be in excess of 300,000 tonnes per year, accounting for about **one third of the total organic emissions from chemical plants,** and these will inevitably be mirrored in Europe.

A typical Oil Refinery will have a minimum of 20,000 flanged joints connected with pumps, compressors, mixers, valves, level gauges, instruments, heat exchangers and vessels, all of which are a potential leak source. Although losses per piece of equipment are usually very small the total loss via fugitive routes may be very significant. For example, fugitive emissions from European refineries range from 600 to 10000 tonnes of VOC's per year. In some plants in the Netherlands, 72% of VOC emissions were attributed to leakage losses from equipment, 18% from flaring, 5% from combustion, 1% from storage and 4% from other process emissions. In these plants, leakage is the greatest challenge and therefore it is crucial that programmes are established to identify leak sources and to instigate actions to minimise them.

Many process streams in petrochemical refineries are “light” (containing at least 20% of substances with a vapour pressure greater than 0.3 kPa at 20°C) and at high pressure (1500 - 3000 kPa), conditions which encourage fugitive losses. On the other hand, in some Aromatics operations with lower operating temperatures and pressures and where the fluid vapour pressures are lower, fugitive emissions are considerably less.

Irrespective of any environmental impact which it may cause, this is a tremendous financial burden on industry because it represents a huge loss of potentially valuable materials, and cause of plant inefficiency. Yet in most instances, the true costs are not appreciated, since many of the costs associated with fugitive emissions are invisible.

The values of fugitive emissions will depend upon:

- ***Equipment design***
- ***Age and quality of the equipment***
- ***Standard of installation***
- ***Vapour pressure of the process fluid***
- ***Process temperature and pressure***
- ***Number and type of sources***
- ***Method of determination of emissions***
- ***Inspection and maintenance routine***
- ***Rate of production***

Visible costs include the cost of the lost material. Invisible costs include, the cost of labour to repair the leak; materials to repair leaks; wasted energy; plant inefficiency; environmental "clean up"; environmental fines; lost sales due to poor image; and claims for personal injury.

Other European approaches to the control of fugitive emissions

Some EU Member States have introduced other legislation to control fugitive emissions, much of which is complementary to the IED Directive and in some cases this may be necessary in the transposition of the Directive into national legislation. On the other hand, some legislation or guidelines have been introduced which go further than the IED Directive. These include the latest refinements of the TA-Luft VDI 2440 on emission reduction in mineral oil refineries. The reader is advised to refer to these items as appropriate.

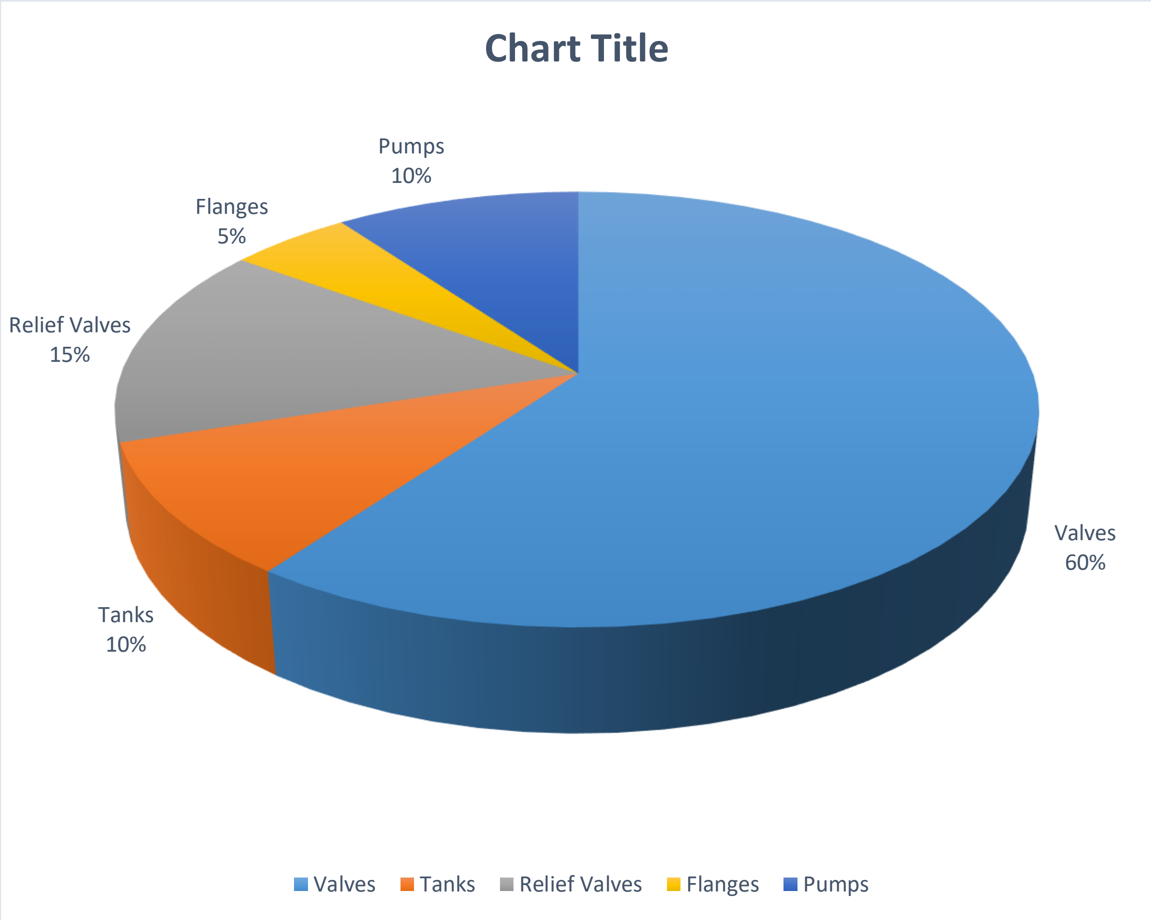
Other country approaches to the control of fugitive emissions

Other parts of the world have their own rules and regulations to reduce the impact of fugitive emissions.

North America in particular have strong rules under the EPA guidance. Canada, Mexico, and U.S. states like California, Pennsylvania, Colorado, and Wyoming have all recently issued regulations limiting the emission of Methane

SOURCES OF FUGITIVE EMISSIONS

A significant proportion of fugitive emissions can be losses from unsealed sources, including storage tanks, open-ended (non- blanked) lines, pressure-relief valves, vents, flares, blow-down systems, spills and evaporation from water treatment facilities. These are part of the industrial process, anticipated (usually) by the process operator, and will not be considered further here.



In other cases, these losses may be caused by **leaks in the sealing elements of particular items of equipment**, such as:

1. **Valves. 50%-70%**
2. **Pumps. 10%**
3. **Flanges. 5%**
4. **Compressors. 3%**
5. **Agitators / mixers. 2%**

As unsealed point sources have become well controlled in recent years, equipment leaks are often the greatest source of fugitive emissions. These equipment leaks are where the sealing industry is playing a crucial role, through the development and application of innovative sealing technology appropriate to **low or zero emission requirements**.

The primary purpose of a seal is to contain a fluid and so protect the immediate environment from contamination (and vice versa), which may vary in significance from innocuous fluid loss (such as steam, water, etc.) up to nauseous, toxic or hazardous fluid loss. In the former case, the loss of such innocuous fluid will lead primarily to lack of plant efficiency and financial loss for the operator, although some such leakages, of high pressure water or steam, may still present hazards.

It has been estimated that for every **pump** on an average plant, there will be 32 valves, 136 flanges, 1 safety valve and 1.5 open-ended lines. Hence, with so many potential sources, leaking losses are often hard to determine. They are also very dependent on the age of the equipment and how well the installation is maintained.

Some important causes of leaking losses are:

- **Ill-fitting internal or external sealing elements**
- **Installation or construction faults**
- **Wear and tear**
- **Equipment failure**
- **Pollution of the sealing element**
- **Incorrect process conditions**
- **Competency of technicians operating and maintaining the equipment**

Leaking losses are generally higher from dynamic equipment (compared with static equipment) and from older equipment.

Valves are considered to account for approximately 50-60% of fugitive emissions, due to the numbers of valves found on a typical industrial plant. Furthermore the major proportion of fugitive emissions comes from only a small fraction of the sources (e.g. less than 1% of valves in gas / vapour service can account for more than 70% of the fugitive emissions in a refinery)

Some valves are more likely to leak than others such as:

- **Valves with rising stems (gate valves, globe valves) are likely to leak to atmosphere more frequently than quarter turn type valves such as ball, butterfly and plug valves.**
- **Valves which are operated frequently, such as control valves, may wear quickly and allow emission paths to develop. However, newer, low leak control valves provide good fugitive emissions control performance.**

Flanges represent approximately 5% of fugitive emissions on a plant despite the huge numbers of flanges found on most industrial plant.

A survey by the Pressure Research council in USA found that the common causes of flange leakage are due to improper gasket installation (26%), Flange damage (25%), loose Bolts (15%), and Flange misalignment (12%). Other common failures are bolt tension relaxation issues, incorrect gasket selection for the service, including wrong gasket thickness and corroded flange faces.

Typical achievable Emission Limit Values:

Using Methane gas as an example the following leakage rates using LDAR “sniffing” equipment the following leakage could be expected:

- Valves: 50 ppmv now
- Flanges: 50 ppmv now with a target of 25 ppmv within 5 years

- Pumps: 500 ppmv now with a target of 250ppmv in 5 years. Note these values refer to pumps fitted with Single Seals, if fitted with Dual liquid or gas seals the emission rates would be much lower.
- Centrifugal Compressors: 1000 ppmv now, with a target of 500ppmv within 5 years

EPA Document Protocol for Leak Emissions Estimates EPA-453/R-95-017 Nov 19

Energy use as a source of emissions.

It must also be remembered that energy is consumed whenever heating or pumping action is applied to a process. This creates additional emissions at the power generation plant, emphasising the need for utilising efficient pumping and heating technologies.

There are freely available programmes that can estimate accurately the Life Cycle Costs of most equipment and sealing devices, taking into account the initial cost, the energy required to operate the equipment, the cost of maintenance, and the cost of replacement.

Volatile Organic Compounds (VOC's)

VOC's emissions are of significant environmental concern because some have the potential for Photochemical Ozone Creation Potential (POCP), Ozone Depletion Potential (ODP), Global Warming Potential (GWP), toxicity, carcinogenicity and local nuisance from odour. The prevention of VOC emissions is therefore one of the most important issues facing the operation of many industrial processes.

VOC is the generic term applied to those organic carbon compounds which evaporate at ambient temperature, and is defined usually as "a substance having a vapour pressure of greater than 0.3 kPa at 20°C" (this is close to the US definition for the application limits of systematic LDAR). The term covers a diverse group of substances and includes all organic compounds released to air in the gas phase, whether hydrocarbons or substituted hydrocarbons. Their properties, and hence need for control, vary greatly and so systems have been developed to categorise VOC's according to their harmfulness.

On many installations, there has been a focus on the control of point sources of VOC's and losses of fugitives as leaks (from pumps, valves, tanks etc.) have become the major source of VOC emissions from many plants. This emphasises the importance of best available techniques for sealing technology and reinforces the need for this document.

Technician training

There also needs to be a focus on the competency of the technicians tasked with fitting sealing devices. This is fast becoming a very important issue with users. An example is in Germany, where the new TA Luft regulations state that VDI 2290 is mandatory, and this means all Technicians fitting sealing devices MUST pass a competency test. There are many accredited Technician Training programmes available, including those provided by ESA and FSA members.

EN 1591-4 also sets out the appropriate training, and standards that should be achieved by technicians.

Leak Detection and Repair (LDAR) systems and programmes are also available, as is the training of technicians to use these effectively (See SECTION 8)

Importantly, the in-service performance and life of any sealing technology is very reliant upon correct installation. As an example, the major cause of flange sealing failure is due to assembly errors. Consequently:

Comprehensive training of all appropriate personnel on correct installation plays a vital role in reducing Fugitive Emissions

PROCESS DESIGN

Operators should work to written standards and procedures when modifying existing installations or designing new plant. As a minimum this should follow the requirements of any national and international technical codes for materials, equipment design and fabrication. All design decisions or modifications should be recorded in order to provide an audit trail. Environmental protection should be an inherent feature of the design standards since techniques incorporated at the design stage are both more effective and more economical. Initial process design should consider how fundamental principles may be applied to process materials, process variables and equipment in order to prevent releases. For example, consideration should be given to identify opportunities for using new, low emission sealing developments or other appropriate sealing technology options.

Other possible operational and maintenance techniques include:

- ***reverse the pressure gradient by operating the plant at below ambient pressure (this is probably most feasible at the design stage)***
- ***obviate the need for vessel opening through design modifications (e.g. cleaning sprays) or change the mode of operation (e.g. spray anti-caking reagents directly into vessels)***
- ***convey leaks from compressor seals, vent and purge lines to flares or to flameless oxidisers***
- ***enclose effluent drainage systems and tanks used for effluent storage / treatment***

MAINTENANCE

The maintenance of process plant and equipment is an essential part of good operation and will involve both pro-active (preventative) and reactive approaches.

Preventative maintenance plays a very significant role in optimising environmental performance and it is often the preferred approach. A structured programme of preventative maintenance should be established after detailed consideration of equipment failure frequencies and consequences. The maintenance programme should be supported by appropriate record keeping systems and diagnostic testing. There should be clear responsibility for the planning and execution of maintenance.

The need for reactive maintenance can be minimised by employee vigilance in relation to imminent problems (e.g. process upsets and leaks). Leak Detection and Repair programmes can also play an important role.

Equipment modifications during maintenance are a frequent occurrence on many plants and should be covered by procedures which give authorisation only after a suitable level of risk assessment. Subsequent process start-up should be dependent upon suitable post-modification checks.

MONITORING TO DETERMINE LEAKING LOSSES

Leaking losses are often hard to determine since there are many potential sources and they are very dependent on how well the installation is operated, maintained and inspected. Some important causes of leaking losses are:

- **Ill-fitting sealing elements**
- **installation**
- **construction faults**
- **wear and tear**
- **ageing**
- **equipment failure**
- **contamination of the sealing element**
- **excursions out of normal process conditions**
- **poor maintenance procedures**

Leaking losses are generally higher from dynamic equipment (compared with static equipment) and from older equipment.

A structural reduction of leaking losses is only possible when insight on the leaking losses is gained. There are various methods to determine the leaking losses. The simplest way to estimate the leaking losses is by multiplying the number of each type of equipment by an ***emission factor*** for that type of equipment. This method can be applied to obtain a general estimation of the emissions **without measurements**. Emission factors are not intended as an accurate measure of a single piece of equipment, and do not reflect the site-specific conditions of process units.

Many companies determine their leaking losses by calculations or estimations based on measurements, but it is hard to measure all possible sources in a large plant (possibly tens of thousands) and not all sources are accessible. In most cases, a representative sampling of sources will suffice to estimate or calculate the leaking losses of the plant. The number of samples depends on the kind of process fluids in the plant and the kind of equipment (the sources). However, to provide the best estimate of emissions, every potential "source" on a site must be **monitored** (usually using a "sniffing" process such as that described in EPA Method 21).

Monitoring has been identified as a common activity across Industrial processes and is the subject of a horizontal BREF note, entitled, *"Monitoring of Emissions to Air and Water from IED Installations ".* The document provides generic information on sampling and analysis and should be read in conjunction with other industry-specific BREF notes. There is also a separate section in this document on the measurement of leakages ***(See SECTION 8)***.

Monitoring is often expensive and time consuming, so the objectives should be clear when a programme is established. Process operators and regulators may use monitoring to provide information on a wide range of topics.

For this Emissions Reduction guidance note on sealing technologies, the key objectives of monitoring are:

- Process control and optimisation; monitoring is the way used to control a process by means of following-up significant physical and chemical parameters. By control of the process, it is meant the application of conditions in which the process operates safely and economically.

- Emission monitoring; fugitive emissions to air and water are characterised and quantified to provide a check on compliance with permit requirements (or other performance measures). This also provides a check of whether all significant emissions are covered by the permit and can indicate the effectiveness of abatement techniques and sealing technologies employed. For the latter, emission monitoring can give an assessment of leaking losses and will indicate equipment where attention is required. Wherever possible, data should be collected on flow rates to enable the calculation of mass discharges.
- Occupational health and safety; tests to identify the short and long term risks to personnel from work place exposure.
- Troubleshooting; intensive, short duration programmes may be used to study specific topics.
- A monitoring programme to address any of these topics will need to stipulate the frequency, location and method of both sampling and analysis. Monitoring usually involves precise quantitative analysis, but simple operator observations (either visually or by smell) can also play an important role in the detection of abnormal releases. The results of monitoring programmes should be actively utilised; records of results should be kept for trend analysis and diagnostic use.

Some estimates have been made of the costs of monitoring schemes. For example, a simple LDAR scheme, involving the annual inspection of gas and volatile liquid service components, is estimated to have a net annualised cost of over €15K per year (for a typical plant handling 20000 tpa of gaseous hydrocarbon streams and 30000 tpa of volatile liquids).

A strategy to reduce VOC emissions may include a complete inventory and quantification by a DIAL LIDAR technique (differential absorption light detection and ranging). In some cases, emissions estimates using “sniffing” methods give lower emissions than estimates based on the DIAL monitoring. In some cases, the discrepancies are very large. For example, by using the method for estimating fugitive emissions proposed by EPA "Workbook for estimating fugitive emissions from petroleum production operations 1996", the emissions from the process area at an average European refinery have been estimated to be 125 tonnes per year. Extrapolations of the DIAL measurements to a yearly emission give emissions of 500- 600 tonnes per year.

Note that most reported fugitive emissions are calculated rather than monitored (measured), but unfortunately, correlations are often dubious! Equally, not all calculation formats are comparable. For example, monitoring at well-maintained plants in the Netherlands shows that the average emissions factors are generally higher than measured (monitored) values.

Spill and leak prevention

Precautionary modifications should be made to ensure that spills and leaks do not occur, and that they are dealt with promptly when they do arise. The following techniques may be applicable:

- identify all hazardous substances used or produced in a process
- identify all the potential sources / scenarios of spillage and leakage
- assess the risks posed by spills and leaks
- review historical incidents and remedies
- implement hardware (e.g. containment, high level alarms) and software (e.g. inspection and maintenance regimes) to ameliorate the risks

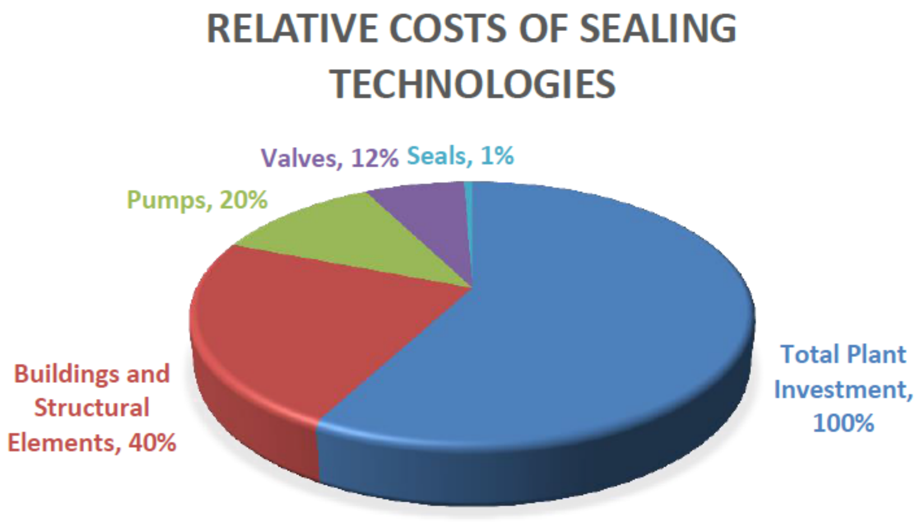
- establish incident response procedures
- provide appropriate clean-up equipment (e.g. adsorbents for mopping up spills after small leaks or maintenance works)
- establish incident reporting procedures (both internally and externally)
- establish systems for promptly investigating all incidents (and near-miss events) to identify the causes and recommend remedial actions
- ensure that agreed remedial actions are implemented promptly
- disseminate incident learning, as appropriate, within the process, site, company or industry to promote future prevention

Along with improved process design, operation, monitoring and maintenance (all identified above), one of the key techniques which may be used to minimise leaking losses is to install **high integrity performance tested equipment**. For example:

- install low-emission valve stem packing on critical valves (e.g. rising-stem gate-type control valves in continuous operation)
- use alternative low-release valves where gate valves are not essential (e.g. quarter-turn and sleeved plug valves both have two independent seals)
- fit high performance sealing systems (especially on dynamic equipment and for critical applications)
- fit blind flanges to infrequently used fittings to prevent accidental opening during plant operation
- minimise the number of flanged connections on pipelines (e.g. by using welded pipes)
- fit double isolation at any points with high risk of leakage
- use balanced bellows-type relief valves to minimise the valve leakage outside of design lift range
- use advanced technology performance tested (like API 682) mechanical seals in pumps
- use zero leakage pumps on critical applications (e.g. double seals on conventional pumps, canned pumps or magnetically driven pumps)
- use containment seals in centrifugal compressors to channel leakage through vent and purge lines to flares or to flameless oxidisers
- use end caps or plugs on open-ended lines and closed loop flush on liquid sampling points
- losses from sampling systems and analysers can be reduced by optimising the sampling volume/frequency, minimising the length of sampling lines, fitting enclosures and venting to flare systems

Relative costs of Sealing Technologies

In most cases, the cost of the actual sealing technology is infinitesimally small when compared with the investment made in the plant as a whole. Indeed, for many sealing technologies, the



cost per unit may be in the region of a few cents, completely insignificant when the total plant costs are considered. Importantly, the unit cost of the sealing technology is overwhelmed completely by the labour costs required to fit the seal, let alone the downtime of the plant. Consequently, the actual cost of the sealing device is immaterial in terms of economic considerations for BAT. However, indications of relative costs are provided as examples in specific sections in this document.

Section 3. Static Seals (Gaskets)

Where pipe work and process equipment on an industrial installation need to be inspected, maintained and / or repaired on a regular basis, connections are usually in the form of bolted flanges for easy removal and replacement. Individual flanges generally do not have very large leaking losses, but since plants utilise so many flanges, they can make a major contribution to the overall leaking losses. For example, a major German chemicals manufacturer reported that emissions from flanges represent 28% of the total fugitive emissions from their plants.

As a general rule, where a removable connection is unnecessary, flanges should be replaced with welded piping. Where welding is not feasible, the flange joint system must be appropriate for the application and should be maintained by trained personnel only.

A brief guide to gaskets and flanged connections follows, a more detailed guide on gasket selection, installation and maintenance are available online from the European Sealing Association. (**European Sealing Association (ESA) / Fluid Sealing Association of America (FSA), Gasket Handbook**

GASKETS

A gasket is used to create and retain a static seal between two stationary flanges, which may connect plant equipment, and which may contain a substance under pressure. These static seals aim to provide a barrier to block any leakage. To achieve this, the gasket must be able to flow into (and fill) any irregularities in the flange surfaces being sealed, while also resist extrusion and creep under operating conditions.

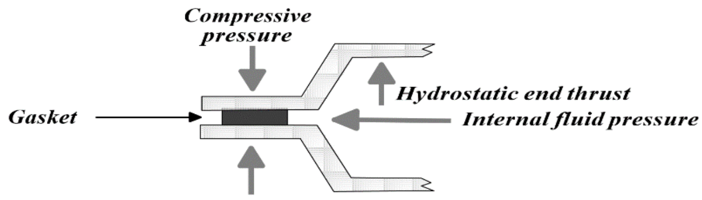
The gasket is compressed by clamping forces causing it to flow into any flange imperfections. The combination of contact pressure between the gasket and flanges, and densification of the gasket material, prevents the escape of the contained media. As such, gaskets are vital to the operation of industrial equipment and therefore are an integral design element.

On seating, a gasket must be able to act against minor alignment and flange imperfections such as; non-parallel flanges, distortion troughs / grooves, surface waviness, surface marks/scratches, corrosion and other surface imperfections.

When assembled, a flange gasket seal or ‘joint’ is usually compressed by bolts under tension. In order to ensure the maintenance of the seal throughout the lifetime of the assembly, enough pressure must remain on the gasket surface to prevent leakage. Under operating conditions, this pressure will be reduced by hydrostatic end thrust, the force produced by the internal pressure which acts to open the flanges.

The gasket is also subject to a side force due to the internal fluid pressure attempting to push it out of the connection. To maintain a seal, the effective compressive pressure on the gasket (that is, the assembly load minus the hydrostatic end thrust) must be greater than the internal pressure by a multiple which is dependent on the gasket type/material, the process involved and level of tightness required. A number of publications provide more detail of the flange/gasket interaction.

FIGURE 1- FLANGE / GASKET INTERACTION



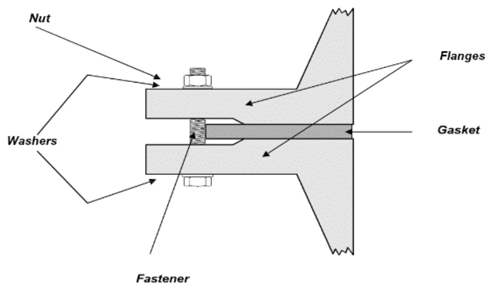
The primary function of a gasket is to create and maintain a seal between flanges, under conditions which may vary from one joint to another. To meet these varying conditions, a number of flange / fastener / gasket systems have been developed, and many factors must be considered when selecting the most appropriate assembly.

Table 1- Factors to be considered when using a bolted flange connection

Application	Flange arrangement	Gasket
Pressure of media	Configuration / type	Blow out resistance
Temperature of media	Surface finish	Creep resistance
Chemical reactivity of	Material	Stress relaxation
Corrosive nature	Available bolt load	Ability to recover / elasticity
Searching ability of media	Likelihood of corrosion /	Expected service life
Viscosity	Flange strength / stiffness	Comparative cost
pH of media (acidity)	Alignment tolerance	Chemical and physical compatibility
Concentration		Ease of handling / installation / removal
		Fire resistance
		Seal ability
		Combined pressure temperature resistance
		Specific Approvals
		Technical Regulations

The performance of the seal depends upon the interaction of all the elements of the flange joint system.

Figure 2 - Elements of the flange joint system



Only when all the elements of the system are working together will the seal be maintained. The integrity of a safe seal depends upon; selection of components for the application, preparation, cleaning, installation and assembly, correct bolt tightening and loading and regular inspection.

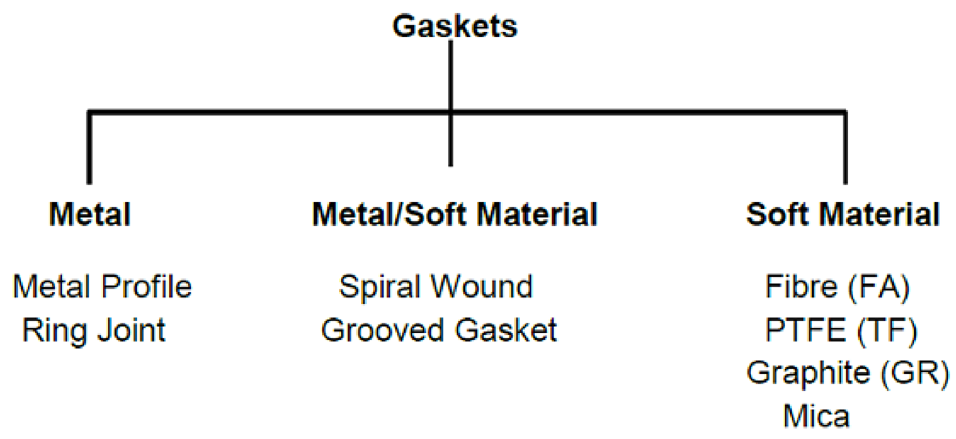
The behaviour of a flanged joint in service depends on whether or not the force created by the fasteners will clamp the joint components together with enough force to resist failure of the seal, but small enough to avoid damage to the joint components (fasteners, gasket etc). The clamping load on the joint is created on assembly, as the nuts on the fasteners are tightened. This creates tension in the fastener (often referred to as *preload*).

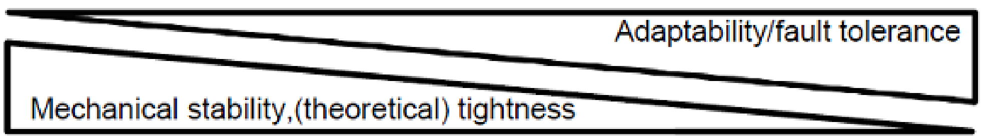
Effectively, the entire system operates as a spring, with the fasteners being stretched and the other joint components being compressed. To reduce the bolt relaxation, it is recommended to use only one washer under the turning part (bolt head or nut).

GASKET SELECTION

Primarily, gasket selection must be based upon the sealing capability (appropriate to the application), compatibility with the media (process fluid), operating temperature and pressure, variations of operating conditions (for example, during cycling) and the type of joint involved (raised face, tongue and groove, RTJ)

Gaskets can be defined into 3 main categories:





1. **Soft gaskets (non-metallic)**: Often composite sheet materials, suitable for a wide range of general and corrosive chemical applications. Generally limited to low to medium pressure applications. The limits of sealing materials are based on the calculation acc. to EN 1591-1 and the gasket characteristics acc. EN 13555. See paragraph below – assembly procedure – chart of EN 1591 calculation

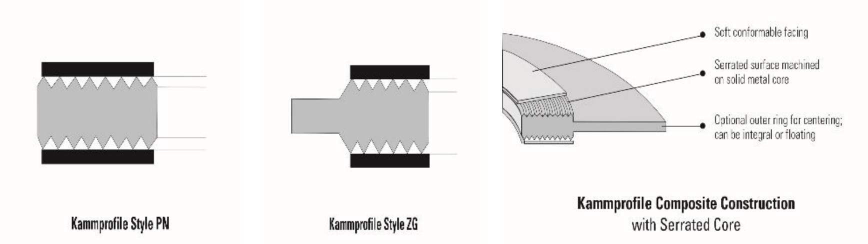
   Types include: fibre reinforced sheet, exfoliated graphite, sheet PTFE in various forms and high temperature inorganic sheet materials like Graphite and Mica.

Fibre reinforced sheet cut gasket

Graphite reinforced sheet cut gasket

2. **Semi-metallic gaskets**: Composite gaskets consisting of both metallic and non-metallic materials, the metal generally providing the strength and resilience of the gasket. Suitable for both low and high temperature and pressure applications.

   Types include: covered serrated metal cored (Kammprofile gaskets), covered metal jacketed, covered corrugated metal, metal eyelet, metal jacketed, metal reinforced soft gaskets, corrugated metallic and spiral wound gaskets.



Kammprofile gaskets and some different styles, and a detail of composite construction

Spiral Wound Gasket, (SWG) with no inner ring

Spiral Wound Gaskets (SWG), with inner ring

Typical SWG styles, with and without inner ring

3. **Metallic gaskets:** Fabricated from a single metal or a combination of metallic materials, in a

variety of shapes and sizes. Suitable for high temperature and pressure applications.

Types include: Lens rings, ring type joints (RTJ) and weld rings.

Ring Type Joints (RTJ), and various typical cross-sections of RTJs

The mechanical characteristics and sealing performance capabilities of these categories vary a lot. The gasket must be resistant to the media being sealed. For gaskets which are electrically conductive, consideration must also be given to electrochemical (or “galvanic”) corrosion. Gaskets cut from sheets, always use the thinnest material possible, but thick enough to compensate for unevenness of the flange surfaces, their parallelism, surface finish and rigidity etc. The thinner the gasket, the higher the bolt load which the gasket can withstand, the less the loss of bolt stress due to relaxation, and hence a longer possible service life.

For more information about mechanical characteristics of gasket types, please refer to EN13555 for specific performance details and recommendations for particular applications, please consult the gasket’s manufacturer.

STORAGE AND HANDLING OF GASKETS AND GASKET MATERIALS

Whilst it is clear that re-using gaskets is definitely NOT recommended, most gasket materials can be used safely after storage for many years, ageing will have an effect only on the performance of certain types of gasket materials. Primarily, materials bonded with elastomers, like fibre sheet which should not be used after 3-5 years from the date of manufacture. This is not a problem for metallic gaskets, but it may have an effect on semi-metallic gaskets (specifically, those which are combined with elastomer-bound materials).

All gaskets and gasket materials are best handled with care and attention. Bent, nicked, gouged, scratched or hammered gaskets will not seal!

Assembly procedures

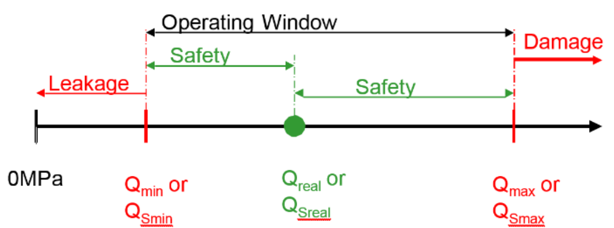


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FIGURE 3 - OPERATING WINDOW USING EN1591 TERMINOLOGY

For the seal to perform as designed, proper assembly of the joint is crucial. This process is subject to a large number of variables, including the condition of all the components, the smoothness, hardness and the lubricity of surfaces, the calibration of the tools, the accessibility of the fasteners and the environment in which the engineers must operate. Ultimately the install wants to get the joint evenly compressed and in the operating window of the joint.

EN1591 can be used to select a gasket stress, Q, in the operating window, Q maybe limited due to leakage rate considerations or material limitations; the force to create the stress then has to be applied via the fasteners. Despite the number of developments to improve the reproducibility of fastening flanged joints (such as tension control fasteners, hydraulic tensioning devices, ultrasonic fastener analysis and simultaneous torque / turn methods), torque is the most popular method to control joint tightening and the torque wrench the tool of choice.

Torque to force calculations involve overcoming the friction of the load bearing surfaces rubbing against each other. Unlubricated bolts can lose half the applied torque due to friction, requiring the installer to apply twice the amount of torque for the same amount of bolt force. The amount of force lost due to friction is calculated using the *friction factor*, μ this is the co-efficient between applied and actual clamping force created by the bolt.

Methods for calculating the applied force created by a standardised bolt under torque can be found in ASME PCC-1-2013, however the friction factor is generally a hard value to gauge. Lubrication manufacturers will sometimes quote a value that can be used in calculations, but general values can be found in Table 2.

Lubrication	Friction factor, μ
Unlubricated	0.40-0.60
Normal lubricant	0.15-0.25
Quality lubricant	0.10-0.15

Table 2 - Generic bolt friction

Installation in this document will be briefly covered but th ESA/FSA Installation Booklet available online covers installation in great detail. There is also an installation leaflet for use in the field, to act as a quick reminder for installation personnel.

Calculation: Make sure all calculations are done before installation begins, this prevents “back of the hand” calculations being made on-site which may contain errors.

Tools: Protective clothing, cleaning brush (brass is recommended), tensioners (calibrated torque wrenches as a minimum or another system with a controlled torque). High quality lubricant.

Cleaning: Ensure all surfaces to be sealed are clean of dirt/grease or remains of another gasket, clean dirt / old grease off any bolts with the brass brush or for really hard to remove pieces use a brass chisel. Take care to not damage the sealing surfaces.

Visual: Check for any serious defects, flange warping etc. Check components are OK and correct for application. Take particular care to check the bolt threads for damage.

Lubrication: All load bearing surfaces which are not sealing surfaces should be lubricated, bolt threads and heads, nut threads and heads, washer surfaces and flange contact areas. A higher quality lubricant will not only make the joint easier to open at service end, but also lowers the amount of torque force lost due to friction when torqueing up the fasteners.

Installation: The gasket should be placed centrally as possible and the flange surfaces should meet up well. The fasteners should be easily loosely installed and well lined up with appropriate holes. For large diameter gaskets multiple personnel may be required to ensure the gasket doesn’t bend or warp during handling into place.

Tightening: The sequence in which bolts or studs are tightened affects the distribution of the gasket stress. Improper bolting may move the flange out of parallel. A gasket will usually be able to compensate for a small amount of distortion of this type, but serious difficulties will be encountered if the flanges are substantially out of parallel so always torque nuts in a cross bolt tightening pattern, see Table 4 below. It is also required that the force is applied stages to ensure equal compression around the gasket. The ESA/FSA recommend a 4 pass system where initially the bolts are tightened by hand, then 33% of the required torque, 66%, 100% and a final pass at 100% a minimum of 4hrs after the first 100% pass.

Database: The flange should be tagged with a unique identification so its history can be tracked. You should record the gasket, bolt nut, washer, lubricant information alongside torques used and the dates.

Retightening: For the majority of materials in the flange system, relaxation sets in after a fairly short time. For soft gasket materials, one of the major factors is usually the creep relaxation of the gasket. Relaxation causes a loss of load on the gasket, increasing the possibility of a leak. Many engineers recommend that fasteners should be re-tightened to the original torque 24 hours after the initial assembly. Any re-torqueing is strictly done at ambient temperature, however any elastomer based materials subjected to heat should never be re-torqued.

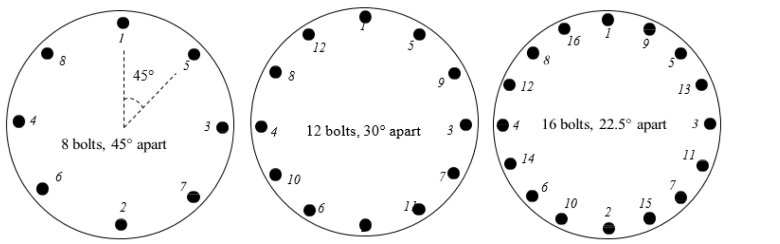


Figure 4 - Bolt tightening patterns

EXPECTED EMISSIONS

EN1591 calculations are designed so that the engineer calculating the joints bolt loading can select a target leakage rate. Gasket manufacturers generally use a leakage rate value of L0.01 mg/m/s aka. Mg/ (m*s) as a minimum required gas leakage rate. (VDI2200 TA Luft 2017 requirement) generally tested with helium, the escaped mass (mg) per second is normalized per meter of the seal length exposed to the pressurised media i.e. the internal circumference of a ring gasket. Therefor to calculate an expected emissions rate in mg/s the targeted leakage rate is multiplied by the total seal length in m. This can be used then on multiple joints of differing sizes.

SAFETY ASPECTS AND JOINT FAILURE

Joints fail, not just gaskets! Seal failure can occur when any component of the flange / fastener / gasket system is not performing correctly. The normal result is leakage from the joint, which may be virtually undetectable at first and build up over time, or may be a sudden, drastic failure. It is mainly observed when the fasteners fail to perform their clamping function, usually when they provide too little force, but occasionally when they exert too much!

A study commissioned by the Pressure Vessel Research Council (PVRC) of the USA, indicated that most flange joint failures resulting in leaks are due to improper installation (26%), flange damage (25%), gasket (22%), loose bolts (15%) and flange misalignment (12%). This list is not complete and further details are available in a number of publications 5.

Some common failures and there reasons are;

Fasteners under-tightened; incorrect initial torque, damaged fastener, self-loosening (vibrations), no lubricant used.

Fasteners over-tightened; gasket crushed, flanges bent.

Fasteners yielded; bolts don't meet design, bolts threads sheared, bolts stretched past elastic limit.

Fastener fault; double threaded, cracked or nicked threads, no washers used.

Gasket faults; wrong material for media, wrong thickness for conformability, external forces (bending moments), over heated, gasket reused, gasket greased up, retightened at temperature, embrittlement.

Flange faults; excessive surface damage or warping, not parallel, wrong material, not cleaned beforehand.

User faults; incorrect torque calculations, poor maintenance, installer(s) not trained, incorrect tools, cheap materials, poor handling

MINIMIZING THE CHANCES OF JOINT FAILURE

The selection of the correct materials for the application is fundamental. Make sure that all components of the joint are compatible with each other and with the conditions during service. Follow the gasket storage and handling recommendations as given by the manufacturer. Follow the cleaning and visual inspection recommendations, to ensure that the joint components are free from defects and fit for use. Good installation practices are essential, the use of fully trained personnel and calibrated tools ensure the joint is put together with sufficient care; else it cannot be expected to provide a safe seal.

Corrosion is one of the most common challenges in the field! It can affect the integrity of the clamping force and will reduce the life of the joint components.

Stress corrosion cracking (SCC) is the result of a combination of stress and electrochemical attack. All metallic fasteners are susceptible to SCC under certain conditions, but most of the problem can be minimised with suitable heat treatment. As with corrosion, provision of a suitable coating (aluminium, ceramics, or graphite) on the fasteners can minimise contact with the electrolyte. However, stress control is the most common way to reduce SCC, by keeping the stress level in the fasteners below a given limit (specific for the material).

Fatigue is time dependent and in general, the higher the loads, the faster fatigue will set in. The item which usually has the greatest impact on reducing fatigue of the joint is the reduction of load excursions. Therefore, identify and achieve the correct preload in the fasteners. Note the differences in maximum preload between fasteners with rolled versus machined threads. Also, periodically replace the fasteners before they fail. Ideally, replace the fasteners when reassembling the joint!

Self-loosening is usually experienced in the presence of vibration. This is often countered by preventing slip between the fastener, nut and / or joint components by mechanical lock nuts or washers, or by the use of adhesives.

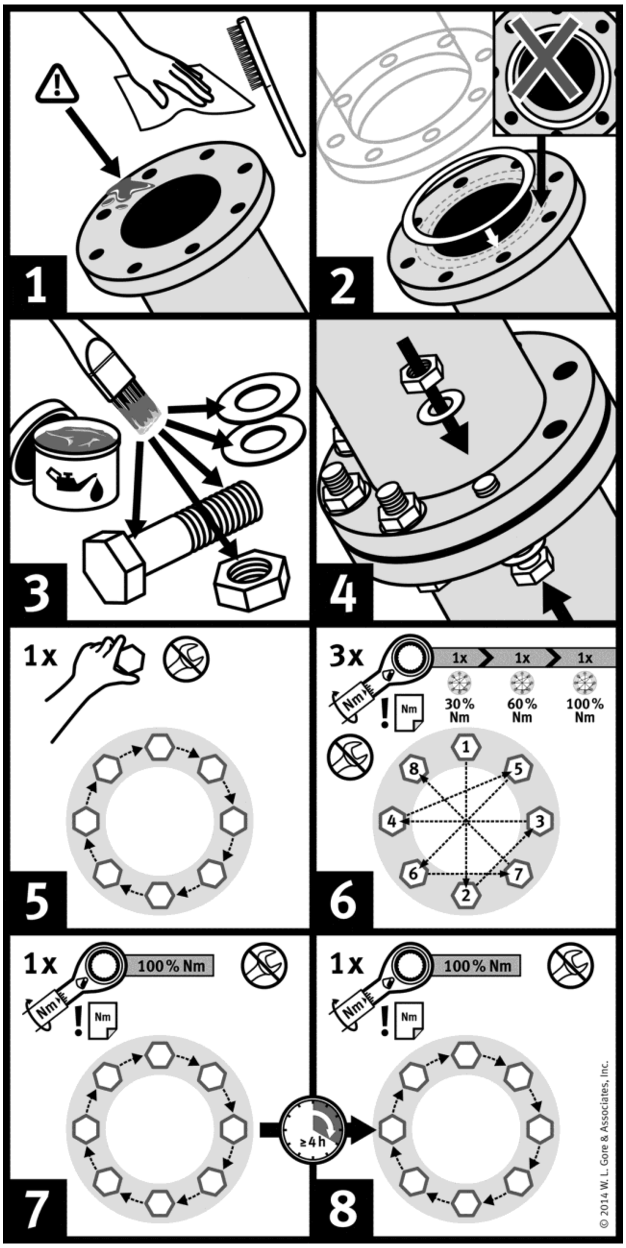


Figure 5 - Simplified Installation Instructions

SECTION 4. Mechanical Seals

DYNAMIC SEALING

Sealing technology has been continually improved, in anticipation of increasing environmental regulations, and over the past few years a new generation of mechanical seal products has been developed to provide cost-effective solutions for the control of fugitive emissions. Cost-effectiveness is an important consideration here, because the vast majority of low emission applications are covered successfully by mechanical seals.

The oil production and Refining Industries have been driven by the need for greater reliability and a lower level of VOC emissions from pumps. A group of major USA users came together within the structure of the American Petroleum Institute and produced the first standard on Mechanical seals, API 682 in the mid-90's

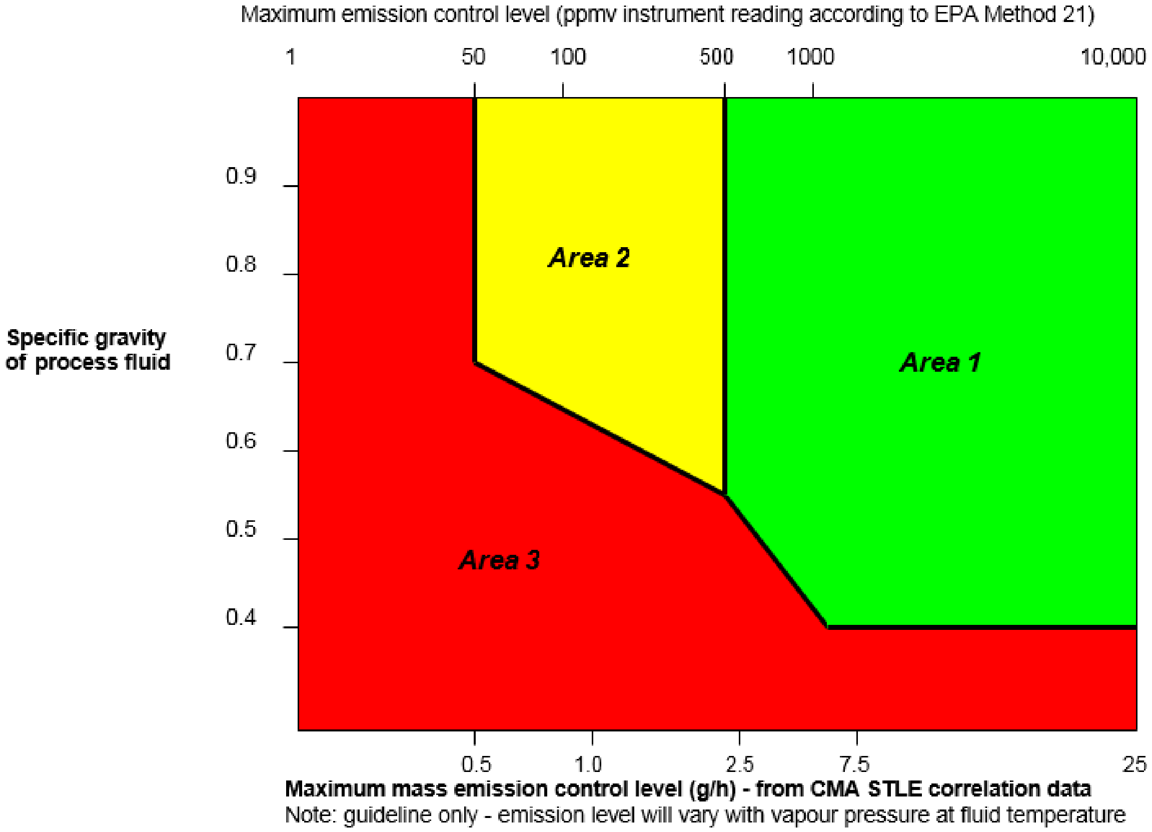
The scope of the standard requires that the sealing systems supplied, '*have a high probability of meeting the objective of at least three years of uninterrupted service while complying with emission regulations*'. It revolutionised the Industry by specifying rationalised seal designs and materials of which users had good field experience and required seal suppliers to carry out rigorous qualification tests on a variety of fluids before being able to market their products to the standard. It is the default seal selection in the renowned pump standard API 610 and has become the base standard for most global oil refiners and producers.

A second Edition of API 682 was issued which extends the original sealing philosophy to include the Chemical Industry and has added newer technologies for improved seal emission management and elimination. This new document has been developed with the International Standards Organisation and published as ISO 21049. A third Edition of API 682 mirrors this standard. The current version is API 682 fourth edition where improvements in piping plans have made seal installations more reliable.

PLEASE NOTE: The American Petroleum Institute has moved to issue its standards independently of the ISO standards organisation. For this reason, the current version was issued as API 682 fourth edition and not as ISO 21049.

Correct seal selection is dependent on the clarity and detail of the information provided to the seal vendor. Pump and mechanical seal data sheets as described in the above international standards are effective structures for ensuring the information needed is supplied.

The chart below (Adapted from STLE SP-30, revised in April 1994, with the kind permission of the Society of Tribologists and Lubrication Engineers, Illinois) can be used as a guideline for selecting the recommended sealing solution based on EPA Method 21 emission levels or mass emission rate.



Area	Leak rate maximum	Specific gravity of process fluid	Acceptable sealing solution
1	2.5 – 24.0	> 0.4	General purpose single seals, advanced technology single seals, dual unpressurised (tandem) or dual pressurised (double) seals
2	0.5 – 2.5	> 0.5 – 0.7	Advanced technology single seals, dual unpressurised (tandem) or dual pressurised (double) seals
3	< 0.5	> 0.4	Advanced technology single seals vented to a closed vent system, dual unpressurised (tandem) seals vented to a closed vent system, dual pressurised (double) seals, or sealless systems
		< 0.4	Dual pressurised (double) seals, or sealless systems

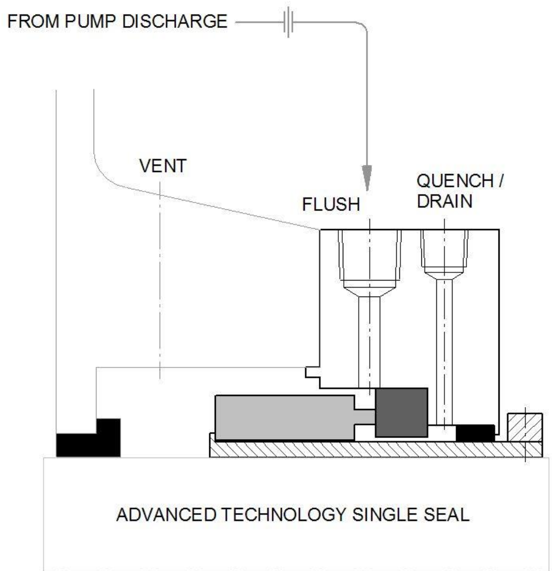
This general guideline describes typical performance of mechanical seals of less than 150 mm (6 inch) shaft size, at pressures of less than 4100 kPa, with speeds of less than 28 m/sec and temperatures between -40°C and +260°C. Readers should be aware that local emission and/or hazardous fluid legislation may dictate a particular sealing solution, and operators should consult the appropriate regulatory authorities for precise compliance details.

When initially introduced by STLE, the above *'Application Guide'* was derived from user experience in the field, incorporating the performance of mechanical seals from a wide variety of suppliers. The guide represents a reliable performance profile for mechanical seals from all manufacturers, each of whom has access to differing levels of technological sophistication. Clearly, those manufacturers with access to more advanced technology are able to provide products with generally higher performance levels.

Many of today's single mechanical seals, using modern materials and advanced technology, are reliably performing within Area 2 of the Application Chart, with emissions typically below 1 g/h under normal operating conditions in the field. For this reason, where low emission rates are essential, operators should approach mechanical seal manufacturers in order to be assured of the use of modern materials and advanced technology. Mechanical seal manufacturers should be able to demonstrate how today's mechanical seals incorporate 'design-in' capabilities to offset the combined effects of pressure distortion, thermal distortion and heat generation.

Advanced technology single seals
The simplest form of mechanical seal, still employed widely today, is a single mechanical seal installation aimed at general purpose applications and consists of a fixed ring in the casing held in tight contact with a rotating ring on the shaft to form a seal. More recently, the application of **advanced sealing technology** has enabled the development of reliable, **low emission single mechanical seals**, which can give leak rates close to those of some dual seal installations. The technologies employed include highly sophisticated finite element and other modelling techniques in the optimisation of component shapes, computational fluid dynamics, specialised material developments, improved tribological properties rubbing face surface profile adjustments and pre-set packaged assemblies to eliminate fitting errors. A further essential factor, in support of the enhanced performance and reliability of new seal technologies, is the performance testing capability of the reputable seal manufacturers.

Additionally, for applications where hazard containment is required from the single seal arrangement, it is usual to include some form of external containment device to allow collection of any abnormal levels of vapour leakage and, where required, warn operators through a pressure induced alarm system. There are many kinds of secondary containment devices, including fixed or floating bushing and lip seals (spring energised or pressure energised). The space between the mechanical seal and some types of secondary containment device can be filled with a fluid to provide an environment where degradation or crystallisation of leakage is prevented.



A single mechanical seal provides the most economical form of seal, with emission values typically below 1 g/h under normal operating conditions in the field. Single mechanical seals provide cost effective, reliable sealing for most VOC services, in line with API Standard 682 specifications provided the following conditions are satisfied:

- ***process fluid specific gravity > 0.4***
- ***vapour pressure margin in the seal chamber is sufficient for seal face lubrication process or flush fluid provides adequate lubrication and cooling of the seal faces***

For advanced technology single mechanical seals, users report leak rates of between 0.42 and 1.25 g/h on one petrochemical plant in the Netherlands and between 0.63 and 1.67 g/h on a chemical plant in Germany.

This experience and data has been consolidated into the German Technical Rule VDI 2440 -'Emission Control – Mineral Oil Refineries' which recommends that operators use 1 g/h as the mean leakage rate from single mechanical seals on process pumps.

Single seals with a mechanical containment seal (dual unpressurised seals)
The simple sophistication of a single seal (which contains the process fluid) is attractive to operators but where the process fluid is a VOC and the emissive leakage to the atmosphere requires minimising it is common to include a second mechanical seal outboard of this primary seal. This provides a far more effective containment device than bushings.

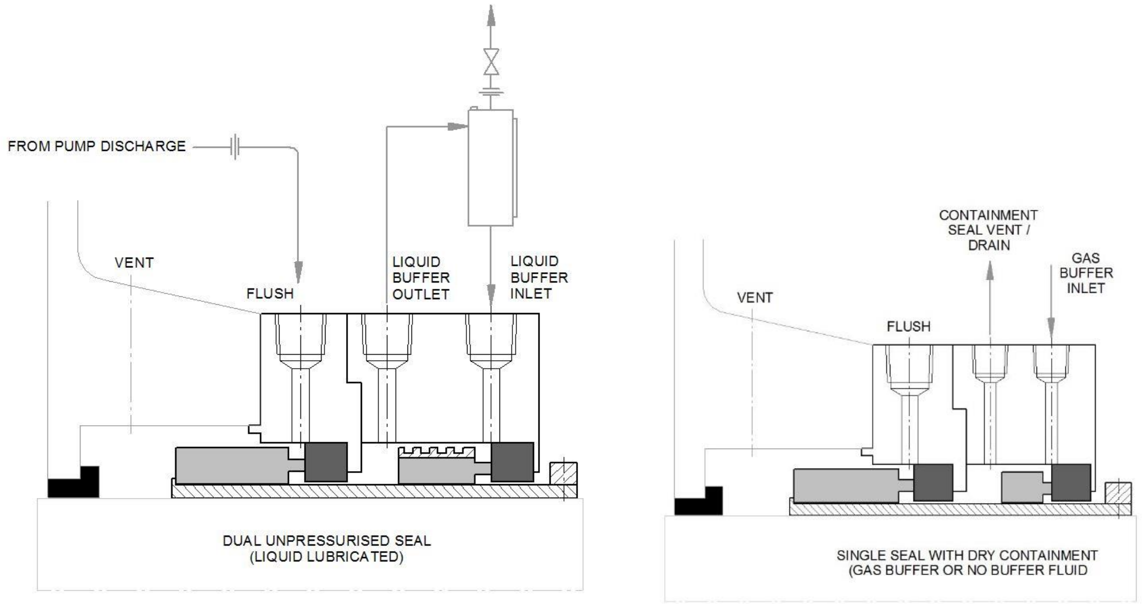
The VOC leakage entering the containment chamber between the two seals can then be effectively channeled to a plant flare or vapour recovery system. Dual Unpressurised seal arrangements will provide very low levels of process emissions to the atmosphere.

Dual unpressurised seals use two different technologies for the lubrication of the outer mechanical containment seal. The numerically highest proportion fills the containment chamber with a separate buffer liquid that is piped to and from an adjacent reservoir. Flow is induced around the circuit, both lubricating the containment seal and assisting the channeling of VOC leakage into the buffer-fluid reservoir, where it is able to separate from the carrier buffer liquid. Ordinarily there is a connection from the top of the reservoir to a plant flare or vapour recovery system together with an orifice and an alarm to warn of deterioration in the sealing performance of the primary seal. This is referred to as flush Plan 52 in ISO 21049.

Dual seal arrangements with unpressurised buffer liquid provide emission values typically below 0.01 g/h, achieving emission levels less than 10 ppm (< 1 g/day).

Engineers on a hydrocarbon plant in the USA report emissions of less than 10 ppm (< 1 g/day) from most dual unpressurised seals with buffer liquids on site after 12 months operation from start-up. The alternative and more recent technology has been created by advances in high speed gas lubrication of mechanical seals; no liquid buffer is required and the VOC gas, now at atmospheric conditions in the containment chamber, itself provides the lubrication of the containment seal. The containment chamber is directly connected to a plant flare or vapour recovery system with an orifice and a pressure alarm to warn of deterioration in the sealing performance of the primary seal.

The benefit to the operator is a lower investment and operating cost. This is referred to as flush Plan 76 in API 682 and ISO 21049.



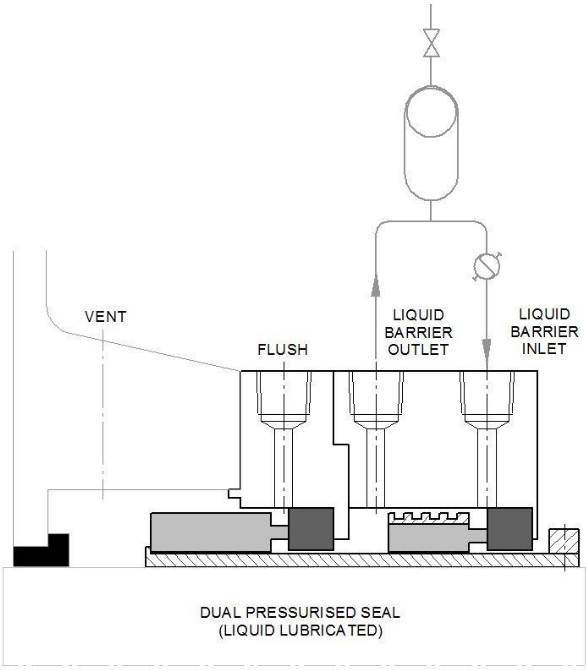
A recent assembly of data from European and USA plants studying single seals with gas lubricated mechanical containment seals concluded that 93.8% had Method 21 emission levels less than 1000 ppm and over 70% less than 50 ppm.

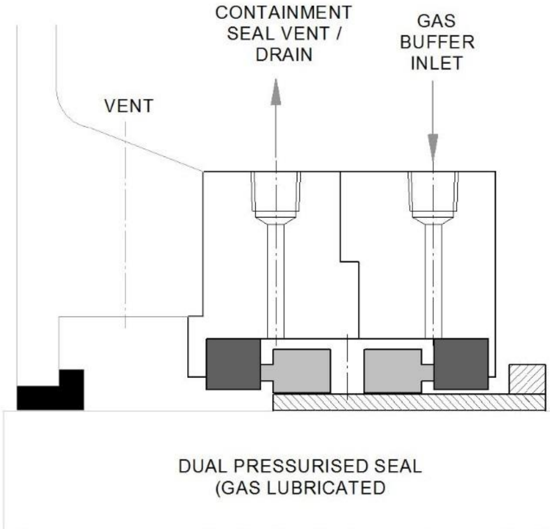
To achieve near complete elimination of emission to the atmosphere some plant operators connect a flow of Nitrogen buffer gas to purge the gas lubricated, mechanical containment seal of process VOC's and help channel them to the recovery/disposal system. This is referred to as Flush Plan 72 in API 682 and ISO 21049.

Double seals with a separate barrier system (dual pressurised seals)

This solution consists of two seals with a barrier fluid (liquid or gas) between them operated at a pressure greater than the process stream. Any leakage (outboard to atmosphere or inboard to the process stream) is of the barrier fluid, and therefore, selection of a safe barrier fluid compatible with the process stream is essential. This type of seal arrangement is useful for sealing process fluids with poor lubricating properties, on services where single seals are unreliable, or where the process fluids may change frequently (such as in pipeline services) and is selected when the process fluid is particularly hazardous.

Dual pressurised systems virtually eliminate leakage of the process fluid into the environment and typically have emission values approaching zero, usually described as ***'not measurable with existing instrument technology'***. Liquid lubricated mechanical seals typically use water or a light lubricating oil as the barrier fluid supplied from a self-contained support system and gas lubricated designs utilise a convenient plant gas source such as Nitrogen managed by a control system. This former is referred to as flush Plan 53 or 54 and the latter flush Plan 74 in API 682 and ISO 21049.The simplicity and very low energy consumption of dual pressurised gas seals has been a strong driver in the growth of this technology in recent years.





Dual non-contacting seals with a pressurised nitrogen barrier fluid are showing near zero emissions in field applications Double seals on a hydrocarbon plant in the USA are emitting between 0-5 ppm (<0.5 g/day) after 12 months operation from start-up.

The potential of a failure of the Barrier system to maintain a pressure greater than the process stream, although unlikely, is a scenario that must be considered by the operator. The system can be configured to warn the operator of the problem. In addition, modern Dual pressurised mechanical seals can be provided with componentry that will withstand a failure of the Barrier system and continue to effectively contain the process for a period of time; most International Pump Standards now require features that provide this capability. The features are also required if the seals are supplied to API 682 or ISO 21049.

In all installations of mechanical seals, users should refer to the appropriate machinery and mechanical seal manuals for specific tolerances and guidance. In addition, a number of independent publications offer good advice on best practice.

Sealless pump drive systems

This technology also provides a zero emission capability but may be restricted in application by the process properties. Users state that, to date, there is no universal sealing solution capable of handling satisfactorily all of the varying conditions of every application on a refinery, petrochemical or chemical installation. Consequently, although it is recognised that mechanical seals are the cost-effective solution in achieving emissions control, **on hazardous processes in general a combination of mechanical seal and 'sealless' systems is employed, with individual seal selection dependent upon the particular operating parameters**.

It should be recognised that sealless pumps typically have significantly lower levels of efficiency compared to conventional pumps, requiring more energy for the same service. Energy consumption is the largest element in the ‘Total Life Cost’ of the pump and must be considered in the context of potential stack (CO_2, SO_2, and NO2) emissions from power generation equipment. In the context of the integrated pollution strategy advocated by the IPPC Directive this ‘apparent’ transfer of emissions from the pump to a power plant should be considered if sealless drive systems are being considered.

Some of the key distinguishing features of these sealing options are:

Mechanical Seals	"Sealless" Systems
Low Capital investment -cost effective (especially single seals) - particularly advantageous as power ratings increase [22]	
Low repair and maintenance costs	Potentially lower repair frequency (although very dependent upon the service)
Long Working Lifetime	
	Less frequent monitoring required
Operator confidence in well-known technology	
Wide process applicability: - allows flexibility of equipment use - widely used on existing plant - preferred for batch process plant - preferred for majority of applications	Preferred for process streams where health hazard risk is very high (for example, carcinogens etc.). However, the technology may not be practicable on certain services.
Operator experience with technology parameters: - safely enabling performance optimisation - minimal training required	Lower risk of process stream contamination
Simplicity (especially single seals)	
Energy efficient: - low operating costs - no transfer of emission burden off-site	
Special seals can be run dry: - preferred for 'dirty' processes - preferred for process fluids with high viscosity or where fluid may undergo a high rate of change of vapour pressure - preferred for batch processes	

Best Available Practice for pumps

- Proper fixing of the pump unit to its base-plate or frame.
- Connecting pipe forces to be within those recommended for the pump.
- Proper design of suction pipe work to minimise hydraulic imbalance.
- Alignment of shaft and casing within recommended limits.
- Alignment of driver/pump coupling to be within recommended limits when fitted.
- Correct level of balance of rotating parts.
- Effective priming of pumps prior to start-up.
- Operation of the pump within its recommended performance range. The optimum performance is achieved at its best efficiency point.
- The level of net positive suction head available (NPSHA) should always be in excess of the pump design's net positive suction head required (NPSHR). This can vary dependent upon the operating position on the pump performance curve.
- Regular monitoring and maintenance of both rotating equipment and seal systems, combined with a repair or replacement programme
- Exchange gland packings in VOC services for mechanical seals where feasible. Note Lantern rings can be injected with neutral liquid
- Selection of appropriate mechanical sealing technology based on required maximum leakage control levels and with consideration of process fluid characteristics

LIFE-CYCLE COST (LCC)

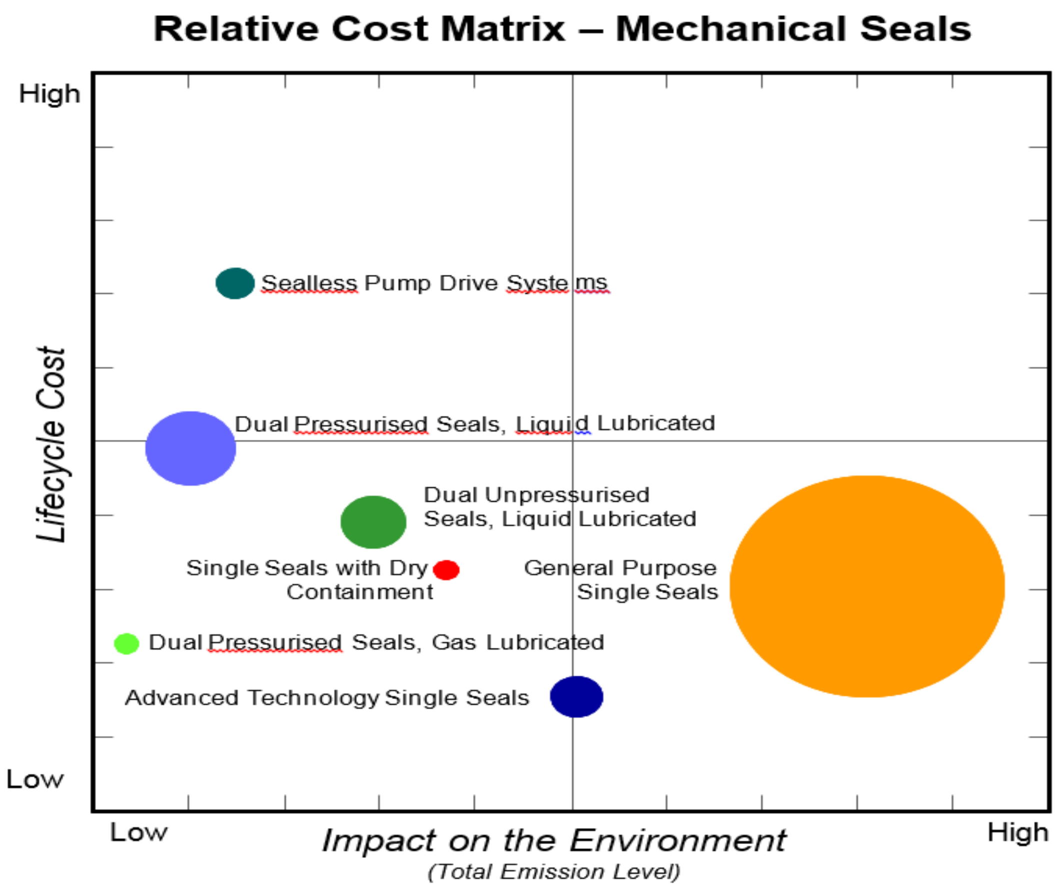
The energy demand in certain process systems can be a huge component of the total costs of operating the plant. For example, some pumping systems may account for over 25% of the total energy usage on certain industrial installations. Yet, initial procurement and installation costs are used widely as the primary criteria for equipment or system selection. In these cases, the initial purchase price of a piece of equipment may be insignificant when compared with the total lifetime operating cost. Under these circumstances, procurement and installation costs in isolation may be simple to use but will lead to poor long term decisions! This is where life-cycle cost (LCC) analysis can be a valuable management tool to help maximise capital investment and plant efficiency.

The life cycle cost of a piece of equipment is the total "lifetime" cost to purchase, install, operate, maintain and dispose of the item. LCC analysis is a useful comparative tool between a series of technology or operating alternatives and can indicate the most cost-effective solution, in order that the least long term cost of ownership can be achieved.

Components of such an LCC analysis include usually initial purchase costs, installation and commissioning costs, operating costs (including energy costs), environmental costs, maintenance costs, decommissioning and disposal costs. LCC uses net present value (NPV) concepts, which consider discount factors, cash flow and time. Consideration must be given to whenever costs occur during the life cycle of the equipment or project, while statistical equipment failure rates add further economic reality.

RELATIVE LIFE-CYCLE COST GUIDE

The following matrix is intended as a guide for the consideration of lifetime costs, including initial investment, operating and maintenance costs for different mechanical sealing configurations/technologies and sealless solutions and their impact on the environment.



The matrix is intended to be used with typical rotodynamic pumps but cannot be assumed to be universally applicable. The bubble size reflects population of seal type (hence, general purpose single seals are by far the majority of the installed pump population, whereas gas lubricated dual pressurised seals, being a more recent technology development, are the smallest).

Although often overlooked, the energy efficiency of the particular sealing technology can make the most significant contribution to the life cycle cost (LCC) overall. In addition reduced energy efficiency contributes to more emissions at the power generation plant, hence more impact on the environment in considering **total** emission level.

The general rationale behind the matrix guide is as follows;

General Purpose Single Seals:

Rotary seals, predominantly unbalanced. Initial Investment is smallest of all sealing technologies considered, but higher energy usage and shorter MTBF increase the LLC. Emission range typically 500 -1000 ppm (applying EPA Method 21).

Advanced Technology Single Seals:

Balanced stationary seals with advanced face designs. Initial investment higher than General Purpose Single Seals but with a potential for extended MTBF and therefore lower LCC. Emissions ranges 100 - 500 ppm.

Dual Seals, unpressurised:

Different containment technologies may be used, but MTBF values should be equivalent to Advanced Technology single seals. Investment costs are somewhat lower then pressurised dual seals and therefore have a lower LLC. Emission range 50 – 500 ppm depending on the containment technology applied.

Dual Seals, pressurised, liquid barrier:

Normally higher capital investment and running costs than dual unpressurised seals. Emissions approaching zero ppm.

Dual Seals, pressurized, gas barrier:

Lower capital and operational costs than liquid barrier technologies. Emissions levels comparable to sealless pump technologies at lower investment and maintenance costs.

Sealless pump technologies:

The chart position is based primarily on magnetic drive pumps. This outlined MTBF's for seals and sealless pumps as being on average comparable. Repair costs of sealless pumps are typically higher than dual mechanical seals.

A detailed and separate examination of the initial investment and operating cost, comparing the differing mechanical sealing technologies, is shown in the table below:

Relative Costs for Different Mechanical Sealing Technologies

	General purpose single seal	Advanced technology single seals	Single seal with Dry containment	Dual unpressurised seals with liquid buffers [3]	Dual pressurised seals with liquid barrier [3]	Dual pressurised seals with gas barrier [4]
Emission Level[1]	1000	500	50	10	0	0
Initial Investment	100%	125%	250%	500%	500%	435%
Operating Cost	100%	65%	100%	120%	190%	100%
Total Life Cycle Cost[2]	100%	80%	135%	205%	260%	170%

Notes:

1- ppm level measured using EPA Method 21
2 - Based on a discounted 10 year operating life
3 - Includes reservoir
4 - Includes gas seal panel

The information in the table above has been generated using the Seal Life-Cycle Cost Estimator tool, which has been developed by the ESA and FSA Mechanical Seals Divisions

This tool allows you to estimate life-cycle costs for different sealing solutions on a comparative basis to assist in decision-making when specifying capital projects or upgrading existing rotating equipment technology. The Seal Life-Cycle Cost Estimator allows comparison of a variety of sealing arrangements including single seals, dual seals, single seals with liquid lubricated and gas lubricated secondary containment, non-contacting gas seals, compression packing.

Life Cycle Costs are influenced strongly by the **reliability** of the selected sealing solution. Thermal management of the seal environment can lead to extensive losses. On some high temperature applications this can lead to power consumption of the sealing system exceeding that of the pump driver.

Users are advised to think carefully about the individual MTBR (Mean Time Between Repair) values which are most appropriate for the different sealing solutions considered and, if necessary, contact your mechanical seal, packing, or pump supplier for guidance.

Compressors

EMISSION MANAGEMENT IN COMPRESSORS

The sealing of two types of rotodynamic compressor will be discussed in this Section. The first grouping is lower velocity, positive displacement designs, operating typically at 50/60 cycle synchronous speeds. They are used with many different types of gases but are commonly used in smaller refrigeration cycle services. The same technology is applied on some process gases. The shaft bearing assemblies are at either end of the shaft and mounted in-board of the seal assembly. Equipment leakage losses occur mainly where the rotating shaft penetrates the casing. The technologies employed are similar to pumps;

Single Mechanical Seals with an energised containment seal

Single Mechanical Seals with a mechanical containment seal and leakage collection (dual unpressurised seals) Double Seals with a separate barrier fluid (dual pressurised seals)

Centrifugal Process Compressors are commonly applied on VOC process gases but typically operate at much higher velocities to achieve their performance efficiencies. The shaft bearing assemblies are at either end of the shaft and mounted out-board of the seal assembly. Equipment leakage losses occur mainly where the rotating shaft penetrates the casing at its Drive and non-drive ends. The technologies employed are;

- Labyrinth Seals
- Single Mechanical Seals
- Single Mechanical Seals with a mechanical containment seal and leakage collection (dual unpressurised seals) Tandem Mechanical Seals with a mechanical containment seal and leakage collection (Triple seals)
- Double Seals with a separate barrier fluid (dual pressurised seals)

Best Available Practice for compressors

Equipment reliability is equally important in minimising emissions from compressors and the techniques which are recommended for pumps (see above) are similarly applicable. Lower velocity Rotodynamic positive displacement compressors are typically sealed by single mechanical seals lubricated by oil which jointly flows through the inboard bearing assembly. The oil is separated and recycled. To minimise process gas leakage when the equipment is static and the barrier oil has drained back to the supply reservoir, an energised lip seal or inboard mechanical seal and by-pass gallery can be employed as a damming assembly, retaining the barrier oil locally around the mechanical seal face.

To avoid the potential oil/process chemical degradation of dynamic elastomeric components used in some types of mechanical seal there is a preference for designs which utilise a metal bellows to manage its axial and alignment flexibility requirements.

It is common practice to use an energised lip seal outboard of the primary seal to contain any oil leakage. This helps channel process contaminated oil into a suitable collection chamber. This concept is improved by the addition of a gas lubricated mechanical containment seal in the same configuration as described earlier. A nitrogen buffer gas is occasionally used with this arrangement to purge the outer containment seal and assist the collection and separation of lubricating oil and process gas.

A double seal with a separate barrier fluid, is required where no emissive process leakage is permitted.

Some centrifugal compressors with an integrated gearbox are successfully sealed using similar technologies to the positive displacement type machines. These machines have relatively low velocities at the seal faces because the sealing point is at the input shaft to the gearbox. Centrifugal compressors are traditionally sealed by labyrinth seals (fixed or floating carbon bushings) or oil lubricated mechanical seals as described above for positive displacement compressors. High leakage levels from labyrinth seals however negate their use in VOC emissive services and they should be exchanged for mechanical seal assemblies.

The high capital investment and relatively poor reliability of oil lubricated mechanical seals at the high velocities employed in centrifugal compressors encouraged the development of gas lubricated mechanical seals in the 1970's. The technology utilises macro-topographical alteration of the rubbing surface profile to encourage hydrodynamic and hydrostatic gas film forces; this enables the maintenance of a dynamic, non-contact gap a few microns thick. In most circumstances a single mechanical seal is employed to seal the process pressure and an outer containment seal, using the same technology, minimises the emissions to the atmosphere and channels the primary seal process leakage to a flare or recovery system. It is important for the reliability of the outer containment seal to exclude from it lubricating oil from the outer shaft bearing and, where practical, a gas purge (air or nitrogen) between two labyrinths or floating bushings is used to separate the mechanical seal assembly from the bearing. This purge assists with channeling process leakage through the containment seal into a flare or recovery system and minimising escape to the atmosphere.

In circumstances where the process gas is contaminated by a toxic impurity (e.g. H_2S in a sour hydrocarbon gas), an inert buffer gas such as nitrogen, if practical, can be used to purge the process side of the containment seal Where this is not practical, inert gas flush can be added.

In very high process pressure services the dual configuration is also employed utilising metal spring energized polymer rings as secondary sealing elements. Such seals have been operating at over 30000 kPa since 2001.

Other rotodynamic equipment

Other rotodynamic equipment includes agitators, reactors, de-waxing filters, dryers, mixers, rotary kiln furnaces and rotary pumps for drinking water distribution, where heavy wear and shaft misalignment are notorious. Whilst leaking valves are rightly considered to be the largest **total** source of fugitive emissions, large rotary vessels will generally suffer greater mass losses as a single point source. The emissions from one rotary vessel can often exceed the total emissions from a large number of valves, costing the operator a significant amount in lost product and wasted energy.

As expected, emission performance in these applications relies upon the sealing of the rotating shaft or cylinder against the stationary sections of the equipment. Yet, in many cases, accurate alignment of the rotating shaft may be difficult to achieve, particularly as differential thermal expansion and contraction takes place during the process cycle. In addition to thermal effects, both shaft and bearings can become worn, even though speed of rotation is often low, and the net result is that the shaft can move radially by amounts in excess of 2mm, particularly on start-up. Operating equipment under these conditions may cause excessive emissions during operation and result in excessive leakages caused by premature failure and/or rapid degradation of the sealing system. It is evident that such operation should be avoided if possible by adequate equipment (re-) design and operation within the design specification.

Mechanical seals are used widely as sealing technology for agitators and mixing equipment, providing maximum control of fugitive losses in critical applications. Both single and double mechanical seals are available which are designed specifically to handle larger radial and angular misalignments (‘mixer seals’) or mechanical seals with integrated bearings which effectively constrain radial run-out directly at the point of sealing.

In other instances however, especially on existing equipment, the investment required for more sophisticated sealing technologies cannot be justified. In these cases, compression packings may provide an economical alternative. Such a sealing system often comprises a sealing flange fixed to the rotating shaft, over which sealing carriers are clamped. According to requirement, these are fitted with two or four packing rings. The appropriate contact pressure for the packing rings is achieved by means of adjustable springs or hydraulic guidance.

Rotation of the sealing carriers is prevented by suitable torque brackets. As size increases, the entire sealing system (except for the sealing flange) may be freely suspended, so that that the system can accommodate small misalignments while retaining its sealing performance. In all of these cases, the compression packings must be selected carefully to accommodate shaft misalignment (transient and permanent), vibration and shock loadings. Readers should consult reputable sealing material manufacturers for advice on the best choice for their specific application. BAT in other rotodynamic equipment.

Losses from large rotating machines may be reduced dramatically by a combination of approaches:

- use mechanical seals designed to accommodate large radial and angular misalignments ("mixer seals")
- use mechanical seals with bearing(s) integrated into their assembly, to constrain equipment run-out
- use advanced compression packing designs from reputable manufacturers only
- re-engineer the gland arrangement where necessary to accommodate shaft misalignment, run-out and equipment wear
- use "live loading" (see below)
- close collaboration between the user and seal manufacturer can provide the most economical sealing solution

In many agitators and mixing equipment, the sealing arrangement operates in either a dry environment or in media which provide little or no lubrication to the seal faces. Therefore, the applicability of single mechanical seals is limited to very slow rotating equipment where the dry run limit of the mating faces is not exceeded, and applications where an external lubricating system can be employed (such as a liquid flush, greasing system or a quench arrangement). In cases where such alternatives are neither feasible nor allowed, double pressurised seals should be considered. In critical equipment where the lowest possible emission levels need to be warranted, only double, pressurised mechanical seals provide emissions levels approaching zero.

Whilst "live-loading" is generally considered to reduce the total requirement for maintenance and adjustment, it also serves to provide cushioning for the effects of growth and contraction during thermal cycling. This is where live-loading has far greater benefit than simply for taking up wear of the packing. It also ensures that the correct initial gland load was applied by compressing the spring stacks evenly by a known amount. Inevitably, as the packing wears and the springs open-up, then their applied force decreases and eventually some re-tightening will be required.

It is evident that the variety of equipment, operating conditions and allowable emission levels require a close collaboration between the user and seal manufacturer to determine the best sealing arrangement a given application.

Emerging techniques

Split seal technology is used increasingly on large rotodynamic equipment as an alternative sealing solution for compression packings. Although split seal seals should not be installed on equipment where emissions control is critical, advances in split seal technology provide emission containment levels exceeding those of conventional packings The higher investment required for such technology is often offset by more favorable sealing efficiency, for instance when equipment maintains a vacuum. In other instances, the application of split seal technology may offer longer MTBR and lower overall operating costs.

The sealing of high vapour pressure liquids, including cryogenic liquid gases, can be sealed reliably and with lower levels of leakage using shaped, recessed regions between the seal running faces. This new technology has enabled much improved sealing Mean Time Between Failures (MTBF) of liquefied gases with corresponding lower overall emission volumes.

RECIPROCATING SHAFTS

Process equipment with reciprocating shafts is usually equipped with gland packings to minimise emissions into the atmosphere.

Best Available Practice for reciprocating compressors

Reciprocating compressors are mainly applied in the process industry for gas transportation, and pressure increase of various gases.

Packing Cases

Packing cases create the seal between piston rod and cylinder. The cross-head guided piston rod is sealed towards the cylinder with a packing case design. The packing cases cover a broad range of operating conditions and are used widely in lubricated and oil free compressors. They consist of a series of angular plates with cup-like recesses which house the sealing elements. These angular cups and a mounting flange are combined by tie rods. The number of sealing elements in a packing case is determined by the operating conditions of the compressor.

In order to obtain enhanced running time, the use of cooled packing cases is often applied for oil-free as well as lubricated compressors, depending on operating temperatures. Cooled packing cases have internal passages for circulating coolant for heat dissipation. The coolant channel design enables cleaning during packing case reconditioning. The closed coolant passage meets API standards.

The packing case designs are tailored to cope with the full spectrum of pressure, temperature, venting, purging and lubrication requirements. Customised solutions for fugitive emissions reduction are offered from reputable manufacturers.

Packing Rings

The sealing rings are mostly segmental rings or multiple ring assemblies. Materials are either compounds or metal for lubricated service or combinations of both.

Segmental Packing Rings

The full floating segmental ring seal fully compensates for normal wear on the rings throughout their lifetime. Radial or tangential cut ring segments balance the wear at the contact face.

Multiple Packing rings

These are free floating packing rings, which follow the radial piston rod movement to assure a positive seal in the packing cups. As this ring configuration has a smaller cross section, they are suitable for restricted packing case dimensions.

Piston Rings

The clearance between the piston and the cylinder liner is sealed with piston rings. The material is mostly a non-metallic composition, which provides a unique combination of sealing and bearing properties. They satisfy the operational requirements of many reciprocating compressors in oil-free service and in applications permitting various levels of lubrication, including min-lube.

Metallic piston rings consist of one piece, multiple piece or segmental rings to meet the needs of lubricated reciprocating compressors.

The design features must be selected in accordance with the operating conditions and should be discussed with the manufacturers.

- select packing case, packing ring and piston ring design appropriate for operating conditions
- please consult the manufacturer

Rotodynamic equipment

Modern process equipment with rotating shafts (such as pumps and compressors) is equipped with gland packings, mechanical seals or “seal-less” systems to eliminate (or at least minimise) emission of the process fluid into the atmosphere.

Gland packings, mechanical seals and sealless drive systems all require fluid for lubrication; in the majority of arrangements the process fluid is used for this lubrication and a very small level of leakage is inherent in pumps and compressors.

Emissions from centrifugal pumps can be reduced by an order of magnitude by replacing packed glands with mechanical seals or seal-less drive systems.

Pumps

Emission management in pumps. The relatively low process leakage levels emitted from pumps and their relatively low numbers in a plant result in the overall leakage contribution from pumps being relatively small. As there are few pumps it is relatively simple to find and repair leaking pumps. Pump leaking losses occur mainly where the rotating shaft penetrates the casing. The technologies employed are;

- Gland Packing
- Gland Packing with a barrier flush Single Mechanical Seals
- Single Mechanical Seals with a mechanical containment seal and leakage collection (dual unpressurised seals) Double Seals with a separate barrier fluid (dual pressurised seals)

Seal-less drive systems

Gland packing leaks more than the mechanical seals in rotodynamic pumps, and in general, for this reason and reliability issues, is not used in VOC services that are emissive. It is used in some slow speed applications.

Historically, field surveys have investigated both liquid and gas phase leakage from mechanical seals, in general, these results have been excessively high by today's standards, indicating for example, that 25% of pumps equipped with mechanical seals were leaking more than 10 g/h. Continual developments by seal suppliers, pump manufacturers and end users however have resulted in significant improvements in sealing performance, such that the results of these earlier studies do not reflect the impact of new and current seal design technology or improved design, maintenance and operation of rotating machinery.

Recent field studies in the USA, using EPA Method 21 to measure the VOC fugitive emissions from a variety of manufacturing facilities, show that 83% of single mechanical seals currently in use meet the Phase III Level of 1000 ppm in the US Regulations. From this survey, pumps with excessive leakage represent **only 11% of the pump population, but 93% of the total emissions**, and for this reason it is clear that priority action must be focussed on these relatively few, but excessive leakers!

Detailed sampling in the USA has indicated that low emission single mechanical seals can operate in the field for over three years and after this time they remain in compliance with the 1000 ppm regulatory limit. Indeed, most are still emitting less than 100 ppm at the exit point of the shaft. The same study showed that **dual unpressurised** mechanical seals can operate reliably in the field for over three years and after this time **most are still emitting less than 10 ppm**.

The CMA / STLE joint survey of leak rates from pumps in a variety of services in chemical and petrochemical plants found typical leak rates of around 1 g/h for single mechanical seals with good face materials. Of all the pumps surveyed, 91.7% w e r e emitting less than 1000 ppm (using EPA Method 21) and were thus within the Phase III standards of the US Regulations.

The survey reports that a substantial proportion of the 8.3% outside of the standard may be brought into compliance through the implementation of improved maintenance programmes, upgrades of seal face materials, secondary seal materials and selection of more appropriate seal design. The study concludes with the statement that *'single mechanical seals can perform to meet the requirements set forth by the United States Environmental Protection Agency's current and proposed future standards'*. A 1991 survey in the USA of 1,112 pumps using ***single*** mechanical seals found that 94% were producing emissions of less than 1000 ppm, 92% were below 500 ppm and **84% were below 100 ppm (~0.7 g/h)**.

Double Seals with a separating barrier fluid (dual pressurised seals) eliminate process leakage to the atmosphere, as do seal-less pumps. Seal-less rotodynamic pump designs are available in two formats, ‘canned’ and magnetic drive, both of which enclose the rotor in the casing and provide the drive energy magnetically through a thin-walled region of the casing. The technology, in general, uses the process fluid for lubricating the rotor bearings, resulting in poorer reliability in some services.

Pump reliability

Single mechanical seals provide low levels of leakage but these levels increase significantly when they begin to fail. The design, installation and operation of the pump influence heavily the life potential and reliability of the seal. The following are some of the main factors which constitute best practice;

- Proper fixing of the pump unit to its base-plate or frame.
- Connecting pipe forces to be within those recommended for the pump.
- Proper design of suction pipe work to minimise hydraulic imbalance.
- Alignment of shaft and casing within recommended limits.
- Alignment of driver/pump coupling to be within recommended limits when fitted.
- Correct level of balance of rotating parts.
- Effective priming of pumps prior to start-up.
- Operation of the pump within its recommended performance range. The optimum performance is achieved at its best efficiency point.
- The level of net positive suction head available (NPSHA) should always be in excess of the pump design’s net positive suction head required (NPSHR). This can vary dependent upon the operating position on the pump performance curve.
- regular monitoring and maintenance of both rotating equipment and seal systems, combined with a repair or replacement programme

Pump Standards provide the current best practice for all these subjects. Examples are ISO 9908, ISO 5199, ISO 9905, ANSI B73.1 & 2, API 610, ISO 13709.

SECTION 5. Packings

Typical Graphite Packing **Typical PTFE Packing**

DYNAMIC SEALING

VALVES

Valves are used widely on installations for controlling (or preventing) the flow of fluids. The choice and design of valves is very specific to the application, although in general terms the most common valve types are gate, globe, plug and control valves. Valve internal parts are usually actuated externally and this necessitates an operating stem. The loss of process fluid from valves is prevented usually by the use of a packed gland seal, in a similar manner to pumps.

The integrity of the seal is crucial and may be affected by poor selection, poor installation, heat, pressure, vibration, corrosion and wear, any of which may significantly reduce performance. Valves which fail to perform as designed may have severe environmental implications, either for fugitive emissions or catastrophic failure. The risk of mechanical failure can be minimised by an appropriate regime of inspection and maintenance. However, valve failure is more frequently due to incorrect operation, which underlines the need for effective operating procedures.

Valve leakage

Valves, and especially control valves, are an important source of leaking losses, and may account for more than 60% of the fugitive emissions in a plant. Furthermore, the major proportion of fugitive emissions comes from only a small fraction of the sources (e.g. less than 1% of valves in gas / vapour service can account for more than 70% of the fugitive emissions in a refinery).

Some valves are more likely to leak than others: valves which are operated frequently, such as control valves, may wear quickly and allow emission paths to develop. However, newer, low leak control valves provide good fugitive emissions control performance. Valves with rising stems (gate valves, globe valves) are likely to leak more frequently than quarter turn type valves such as ball and plug valves.

The valve packing performs the role of the shaft seal and hence is a major influence on valve leaking losses.

Compression packings

Control of fluid loss is essential to the successful operation of mechanical equipment used in fluid handling. Various methods are utilised to control leakage at shafts, rods, or valve stems and other functional parts of equipment requiring containment of liquids or gases.

The original and still most common of these sealing devices is the compression packing, so called because of the manner in which it performs the sealing function. Made from relatively soft, pliant materials, compression packings consist of a number of rings which are inserted into the annular space (stuffing box) between the rotating or reciprocating member and the body of the pump or valve. By tightening a gland follower against the top or outboard ring, pressure is transmitted to the packing set, expanding the rings radially against the side of the stuffing box and the reciprocating or rotating member, effecting a seal.

Compression packings are used in all process industry sectors to seal all types of media. They are used in rotary, centrifugal and reciprocating pumps, mixers, agitators, dryers, valves, expansion joints, soot blowers, and many other types of mechanical equipment. In this document, the focus of attention will be on their use as valve packings.

Compression packings are relatively easy to install and maintain. With proper attention, a high degree of successful operation can be anticipated.

- Successful sealing with compression packings is a function of several important and related factors:
- careful selection of packing materials to meet the specific application requirements
- complete consideration of surface speeds, pressures, temperatures, and medium being sealed
- proper attention to good installation and break-in procedures
- high standards of equipment maintenance

These factors are discussed in other segments of this publication and are covered in detail in most of the product bulletins of the major packing manufacturers.

Also comprehensive information about compression packings can be found online from the joint European Sealing Association (ESA) / Fluid Sealing Association of America (FSA), Compression Packing Technical Manual (4th Edition).

Compression packings are made from various materials in a variety of shapes, sizes, and constructions:

Diagonal-interlock Braided Yarn Packings

This braid is designed for general service applications or as braided end rings on the top and bottom of graphite die-formed tape rings for critical or control valve applications. When used alone (straight-sets), required compression rates generally fall within a range from 25 to 30%. When used as braided end rings on the top and bottom of a set of die-formed graphite tape rings, the required compression rates are reduced to approximately 20%. These rings act as anti-extrusion rings, wiper rings, and they compensate for any surface irregularities in the bottom of the stuffing box as well as add resiliency to the set. For packings of 5 mm and under, square or plait braid is normally used.

Flexible Graphite Products

Graphite packings are available in 3 different forms, as described below:

Flexible Graphite Die-Formed Rings

Typical Die-Formed Valve Ring Set

Valve stem packing rings manufactured from flexible graphite are die-formed from flexible graphite ribbon. A predetermined length of flexible graphite tape is compressed in a properly dimensional mould to the desired density resulting in a solid ring. Traditionally, the rings are of square cross section and have a density of about 1.6 gm.cm^{-3} but square section rings can be manufactured in density ranges from 1.2 - 1.8 g.cm^{-3}. For such square section rings, especially those of high density, the clearances of the ring with respect to the dimensions of the valve stem and stuffing box are crucial for good sealing.

The recent trend in die-formed graphite rings has been to move away from such rings as described above. One alternative consists of sets which are made up of rings of different densities, with the density used depending upon the position of the ring in the set. Another alternative is to use rings which are **not** of square section. In both cases the purpose of the design modification is to allow more of the effort from the gland follower nuts to be concentrated in to radial force on to the stem and box wall to ensure a better seal, rather than being lost as friction down the set.

Whatever form is used, for ease of installation when the valve bonnet cannot be removed, split rings should be specified. These are available in a range of forms of cut construction. All the forms of cut rings are designed to assist the user in obtaining a good quality seal.

Die-formed flexible graphite rings are available in commercial grade (95-98% purity) and nuclear grade (99+% carbon purity), while low sulphur content forms are also available. The commercial grade material makes up the vast majority of usage for industrial applications. Nuclear grades are almost exclusively specified by the power generation industry for service in PWR installations. The nuclear grade rings are made under stringent control procedures during manufacturing.

Active or passive inhibitors may be applied during or after fabrication of each ring to insure against corrosion and pitting of the valve stem.

Rings of a compatible braided material are recommended as anti-extrusion and wiper rings. These latter rings should be selected from a material that will not relax or creep excessively during service and thus allow the load from the follower nuts to be lost.

A prime consideration of the installation of such sets is that the load imposed upon the sets of rings should not be so high that the valve stem cannot be operated!

Similarly, and perhaps of critical importance in an emergency, the hysteresis created by the packing set of a control valve should not be significant in terms of the positioning of the stem. To reduce this problem, various forms of modified design of die formed graphite rings are available. Low density braided materials allowing the formation of rectangular rather than square section anti-extrusion rings are also available for the same reason.

Expanded Graphite Tape

When flexible graphite die-formed tape rings are not available, one solution is to actually die-form flexible graphite tape into packing rings in the stuffing box itself. Using this method, a length of tape is wrapped around the valve stem or pump shaft until the build-up of the material is sufficient to completely fill the packing space. The wrapped tape ring is then eased down into the box and individually compressed to approximately 50% of the original tape width until the stuffing box is completely filled. A top and bottom end ring of a compatible braided material should be used to eliminate tape extrusion during the compression operation and in subsequent service.

Other Graphite Packing Forms

In addition to die-formed graphite ring packings and expanded graphite tape packings, flexible graphite packings are available in several other forms, including: braided packings, laminated rings, wire reinforce flexible graphite yarn packings, and injection moulded rings.

Installation of compression packings

The importance of packing the valve correctly cannot be over-emphasised. Many packing failures are due to incorrect installation of the packing. The first step in getting the most out of a valve packing is correct installation. The following steps have been devised to ensure effective installation of packings on valves:

Remove the old packing from the stuffing box

Make sure the stuffing box is cleaned out and all remnants of the old packings are removed. Ensure both shaft and sleeve are not damaged.

Clean stuffing box and shaft thoroughly

- ***Examine shaft or sleeve for wear and scoring***
- ***Replace shaft or sleeve if wear is excessive***

Use the correct cross section

To determine the correct packing size, measure the diameter of the shaft (inside the stuffing box area if possible) and then measure the diameter of the stuffing box (to give the OD of the ring). Subtract the ID measurement from the OD measurement and divide by two. The result is the required size.

- Use correct cross section for stuffing box and shaft size

When using coil or spiral packing, always cut the packing into separate rings

Never wind a coil of packing into a stuffing box. Rings can be cut with butt (square), skive (or diagonal) joints, depending on the method used for cutting. The best way to cut packing rings is to cut them on a mandrel with the same diameter as the shaft in the stuffing box area. If there is no shaft wear, rings can be cut on the shaft outside the stuffing box.

Hold the packing tightly on the mandrel, but do not stretch. Cut the ring and insert it into the stuffing box, making certain it fits the packing space properly. Ensure the first ring is cut carefully and tested on the stem. Each additional ring can be cut in the same manner, or the first ring can be used as a master from which the balance of the rings is cut.

If the butt cut rings are cut on a flat surface, be certain that the side of the master rings, and not the OD or ID surface, is laid on the rings to be cut. This is necessary so that the end of the rings can be reproduced.

When cutting diagonal joints, use a mitre board so that each successive ring can be cut at the correct angle.

It is necessary that the rings be cut to the correct size. Otherwise, service life is reduced. This is where die-cut rings are of great advantage, as they give you the exact size ring for the ID of the shaft and the OD of the stuffing box. There is no waste due to incorrectly cut rings.

- ***cut coil or spiral into separate rings***
- ***cut the packing rings on a mandrel***
- ***fit the first ring carefully and test on the stem***
- ***use a mitre board to cut diagonal joints***
- ***alternatively, use die-cut rings of the correct size***

Install one ring at a time

Make sure it is clean and has not picked up any dirt in handling. Seat rings firmly, Joints of successive rings should be staggered and kept at least 90 degrees apart. Each individual ring should be firmly seated with a tamping tool, or suitable split bushing fitted to the stuffing box bore. When enough rings have been individually seated so that the nose of the gland will reach them, individual tamping should be supplemented by the gland.

- *install one ring at a time*
- ***seat ring correctly***

Last ring

After the last ring is installed, take up gland bolts finger tight or very slightly snugged up. Do not jam the packing into place by excessive gland loading.

- ***after the last ring is installed, take up carefully***
- ***do not load excessively***

Slide gland forward until it makes contact with the packing

Make sure gland bolts are tightened up evenly. Tighten to the point when heavy resistance is felt. During this time, turn the valve stem back and forth to determine ease of turning. Do not torque down to the point where the stem won't turn.

- ***tighten the gland bolts evenly***
- ***Take care not to tighten too much; ensure the stem can still turn!***

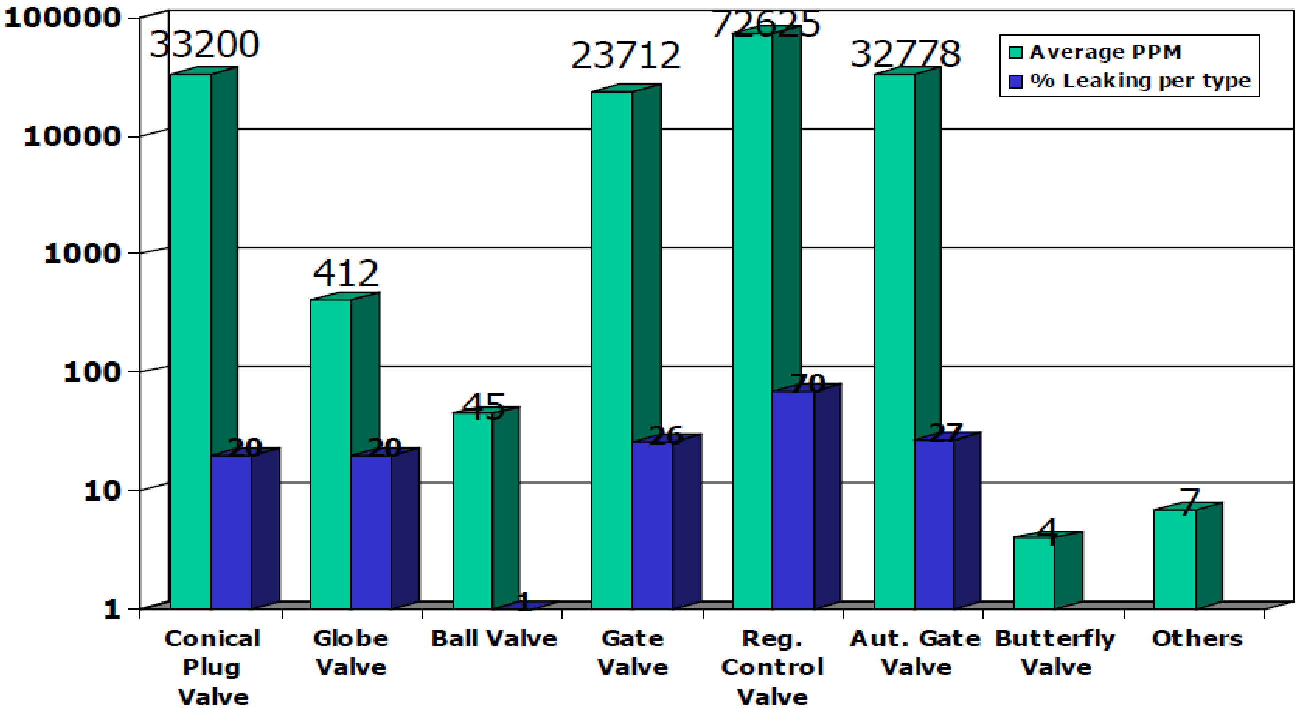
Inspect the valve after it has been on line

If leakage is observed, adjust the gland in accordance with safe maintenance procedures and manufacturer’s recommendations.

- ***inspect and adjust gland bolts if necessary***

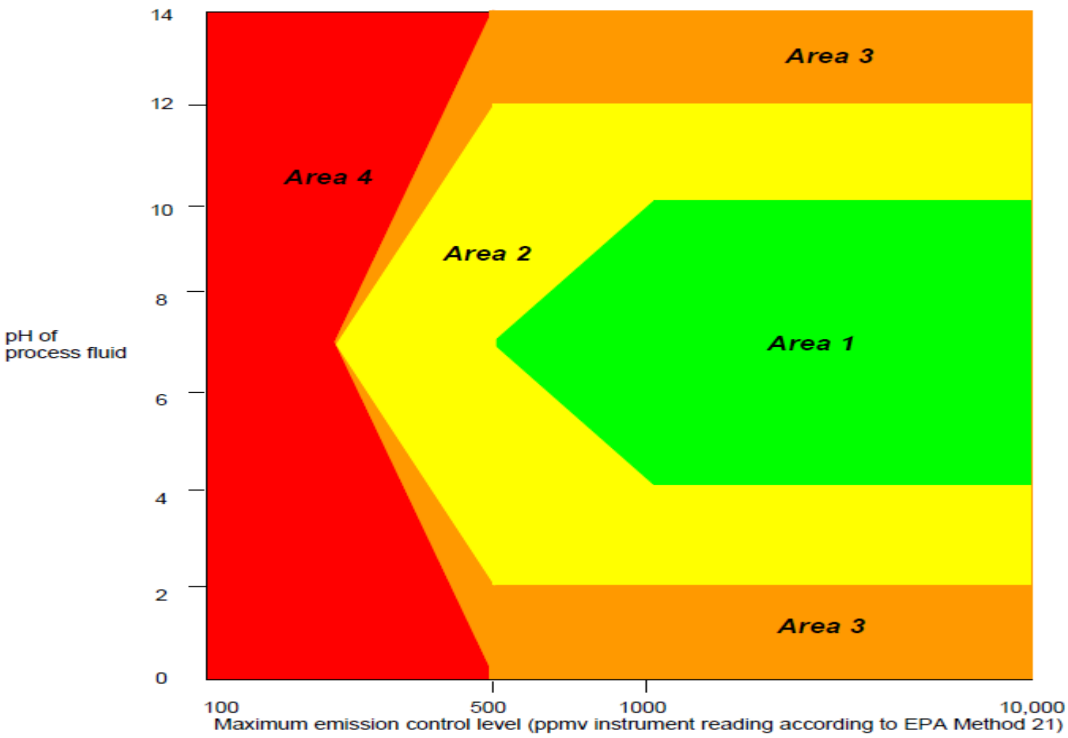
Current emission levels

Each valve type performs differently in terms of emissions, as indicated in this study by Cetim:
Application guide for BAT in valves



Although stuffing box packings are one of the oldest forms of sealing technology, new developments have been introduced continually. This has been the case particularly since the advent of low emission valves, where high integrity packings materials and constructions have been provided to meet the tighter controls.

As a simple guide:



Area	pH of process fluid	Maximum emission (ppm)	Sealing solution options
1	4 - 10	1000	Simple packings materials, often of traditional materials and constructions plus any of the options below ….
2	2 - 12	500	Advanced packings constructions, including acrylic, aramid, glass, melamine, novoloid and polyphenylene materials plus any of the options below ….
3	0 - 14	500	Braided flexible graphite (but not with oxidising media), PTFE packings materials (various constructions)
4	0 - 14	<100	Low emission / high integrity packings, generally of graphite (but not with oxidising media) or PTFE materials Seek specialist solution from the manufacturer

Note that this is a general guide only. Many of the sealing options will give improved performance under certain conditions. For specific performance details and recommendations for particular applications, **please consult the manufacturer**.

Valve live-loading

In its simplest form, live loading is the application of a spring load to the gland follower of a packed valve. Live loading may enable a seal to be maintained for a longer period. A disc spring assembly between the gland follower and its fastening studs and nuts provides an effective way to establish and maintain a controlled amount of stress in the packing set. The amount of the packing stress in a live loaded system can be controlled by the size of the disc spring used and how far it is compressed or deflected.

In a live loaded packing system, the follower will continue to push against the packing even when packing volume is lost (by friction, extrusion, consolidation, etc.) The spring load will be slightly reduced as the springs expand, but this reduction in load will be much less than the load which would be lost if the packing set were not live loaded. This remaining load allows the packing stress to remain at a level above the minimum sealing stress and may enable the packing to remain leak free for a longer service period.

The major benefit of valve live-loading is the amount of elastic energy that is stored in the spring assemblies, which is typically 10-30 times that of the bolts themselves. This ensures that packing relaxation over time is fully compensated for, so that the reliability of a packed application is significantly increased. A properly designed live-loading arrangement in combination with a low emission packing is deemed equivalent to a “bellows valve”. Live-loaded valves with low emission packing can be and often are proven to be comparable in performance to a bellows valve (TA-Luft). In addition, in the USA, live-loaded valves are deemed MACT (Maximum Achievable Control Technology) “equivalent to a bellows valve” in terms of leak tightness and reliability.

Whilst live-loading is generally considered to reduce the total requirement for maintenance and adjustment, it also serves to provide cushioning for the effects of growth and contraction during thermal cycling. This is where live-loading has far greater benefit than simply for taking up wear and relaxation of the packing. It also ensures that the correct initial gland load was applied by compressing the spring stacks evenly by a known amount. Inevitably, as the packing wears and the springs open up, then their applied force decreases and eventually some re-tightening will be required.

Live-load spring assemblies should be designed for each application, based on the packing materials and operating parameters involved. Some packings require higher preloads than others and therefore one spring assembly design will not suit all packing materials and combinations.

Valve live-loading, in combination with a low emission, fire safe packing is a best available technique for fugitive emissions control in VOC or hazardous services.

BAT for reduction in fugitive emissions from valves

As these can provide such an impact on plant emissions, valves should be a high priority for attention. Best available techniques for valves include:

- *correct selection of the packings material and construction for the process application*
- ***correct installation of the packings material into the stuffing box***
- ***regular monitoring, combined with a repair or replacement programme (LDAR)***
- ***focus on those processes most likely to cause emissions (such as gas/light liquid, high pressure and / or temperature duties)***
- ***focus on those valves most at risk (such as rising stem control valves in continual operation)***
- ***For critical valves fit high-integrity packings. Many of these are available in special constructions, using advanced technology materials, often specifically formulated for environmental performance***
- ***use live-loading, in combination with low emission, fire safe packings in VOC or hazardous services***
- ***where toxic, carcinogenic or other hazardous fluids are involved, fit diaphragm, ball or bellows valves***

Note that safety valves can be responsible for 10% of a plant's fugitive leak losses. Losses are higher where safety valves are exposed to pressure fluctuations, and when a safety valve has activated. Therefore, safety valves should be checked after an emergency situation. Leaking losses via safety valves may be reduced by the installation of rupture discs prior to the safety valve to damp small pressure fluctuations. However, these fluctuations may pollute the valve, making complete closure impossible. An additional measure is to connect safety valves to a central flare system or another type of dedicated collection system (e.g. vapour recovery/destruction unit).

RE-WORK OR NEW VALVE

In many instances it is questionable if an old and worn valve should be reworked or replaced by a new one. Experience has shown that most valves can be upgraded to fugitive emission requirements if the work is carefully done. But for smaller valve sizes there is always an economic decision which has to be made. Experience at bigger plants has led to a general rule being adopted: stainless steel valves smaller than DN 50 and carbon steel valves smaller than DN 80 for use in fugitive emission applications should be replaced by new valves. In general, replacement proved to be more economic than refurbishment.

If new valves are purchased it should be made sure that they are qualified or type tested according to the latest fugitive emission valve standards like:

ISO 15848-1:2015 – Measurement, Test and Qualification Procedures for Fugitive Emissions - Part 1: Classification system and qualification procedures for type testing of valves

This standard specifies testing procedures for evaluation of external leakage of valve stem seals (or shaft) and body joints of isolating valves and control valves intended for application in volatile air pollutants and hazardous fluids. End connection joints, vacuum application, effects of corrosion, and radiation are excluded from this part of ISO 15848. Test media can be either methane or helium. There are three leakage classes A, B and C with varying leakage levels depending on the medium. There are different cycle classes as well as temperature ratings also.

API 624 (2014) – Type Testing of Rising Stem Valves Equipped with Graphite Packing for Fugitive Emissions

The API 624 standard specifies the requirements and methane leakage criteria < 100 ppm for fugitive emission type testing of rising and rising-rotating stem valves equipped with packing previously tested in accordance with API Standard 622. The fugitive emissions testing includes 310 mechanical cycles with three thermal cycles from ambient to 260 °C at a pressure of 41.5 bar.

API 641 (2016) – Type Testing of Quarter-turn Valves for Fugitive Emissions

The standard specifies the requirements for type testing quarter-turn valves for fugitive emissions and applies to all stem seal materials. The maximum allowable methane leakage rate is 100 ppm and the number of 90° alternating rotations is 610. The pressure rating is 41.5 bar. Test temperatures are rated up to 260 °C and above.260 °C with three temperature cycles.

Existing valves should be surveyed and refurbished with appropriate low emission packing or sets. A packing or packing set should be used which is qualified according to:

TA- Luft (VDI 2440)

The German TA-Luft legislation defines emission levels for two temperature classes up to 250 °C and higher than 250 °C. The helium maximum leakage levels are 10^{-4} mbar*l*s/m for temperatures up to 250 °C and 10^{-2} mbar*l*s/m for higher temperatures. Pressure ratings and amount of cycles are based on the intended use of the valve. Testing is done according to VDI guideline 2440 where packings or packing sets can be tested in a fixture or in a valve and certification is issued by the manufacturer or independent test laboratories.

API 622 Rev. 3 (2018) – Type Testing of Process Valve Packing for Fugitive Emissions

This emission test which is performed by using a standardised test fixture. The testing can be done by independent test laboratories which will provide certification stating the measured methane emission levels of maximum 500 ppm. Test pressure is 41.5 bar with 5 temperature cycles from ambient to 260 °C and 1510 cycles, with no re-torque allowed.

RE-WORKING OF VALVES

If a valve has to be re-worked the principle component in most cases will be the spindle. Due to damage, the spindle may have to be replaced or machined slightly smaller. In the case of a smaller spindle the packing set should be able to adapt to the changed dimensions. If this is not possible new sets made from appropriate tooling have to be manufactured. It is also necessary to ensure that the permissible clearance dimensions are not exceeded after the rework. If they are appropriate metal disks should be used which can bridge the bigger clearances to reduce any possibility of extrusion. Similar measurements apply for the enlargement of the stuffing box bore due to corrosion problems. In addition bolts and nuts should be checked to make sure they are still in proper working condition.

SPRING LOADING OF GLAND BOLTS

If the valve is to be fitted with discs springs on the gland bolts, all the dimensions for the spring assembly have to be measured. In some cases longer gland bolts are needed to accommodate the disc spring solution. The protection of the springs by an additional cover bushing is also recommended to guide the spring stack and to protect the springs against contamination. This solution is very user-friendly because it is virtually impossible to over or under tighten the set. Additionally there is a visual indication when the springs need to be re-tightened due to volume loss of the packing set.

There should always be a cost evaluation to see if spring loading is necessary. It is recommended if the valve is hard to access for re-tightening or if long maintenance free periods are expected. Also if there are a high number of spindle movements or larger temperature fluctuations during operation, a spring-energised system can guarantee more sustained and consistent axial force retention and sealing performance.

INSTALLATION OF PACKING SETS

Maintenance Plan

The supply of detailed installation information and maintenance plans with all packings or sealing sets is very important to ensure low emissions. All installation forces have to be specified to achieve the best sealing performance. If torque measurement is not possible, a specific dimension diagram for the compression-related tightening should be supplied. This information will often be incorporated into customer standards. Experience shows that the maintenance information needs to be easy to understand. Diagrams are more informative than formulae or tables. If the instructions are too complicated they will not be followed and errors can occur, resulting in poor seal performance.

Training of Maintenance Personnel

In situations where there are problems or dimensional deviations the experience and skill of the maintenance personnel is crucial. In addition to the specific maintenance and installation instructions seal suppliers will provide training seminars for end users or refurbishment companies. Thorough theoretical and practical training is given which ensures that not only standard situations but also potential problems are covered. Helpful is the ESA/ FSA pocket guide on installation procedures as an 'aide memoir' to the trained operator.

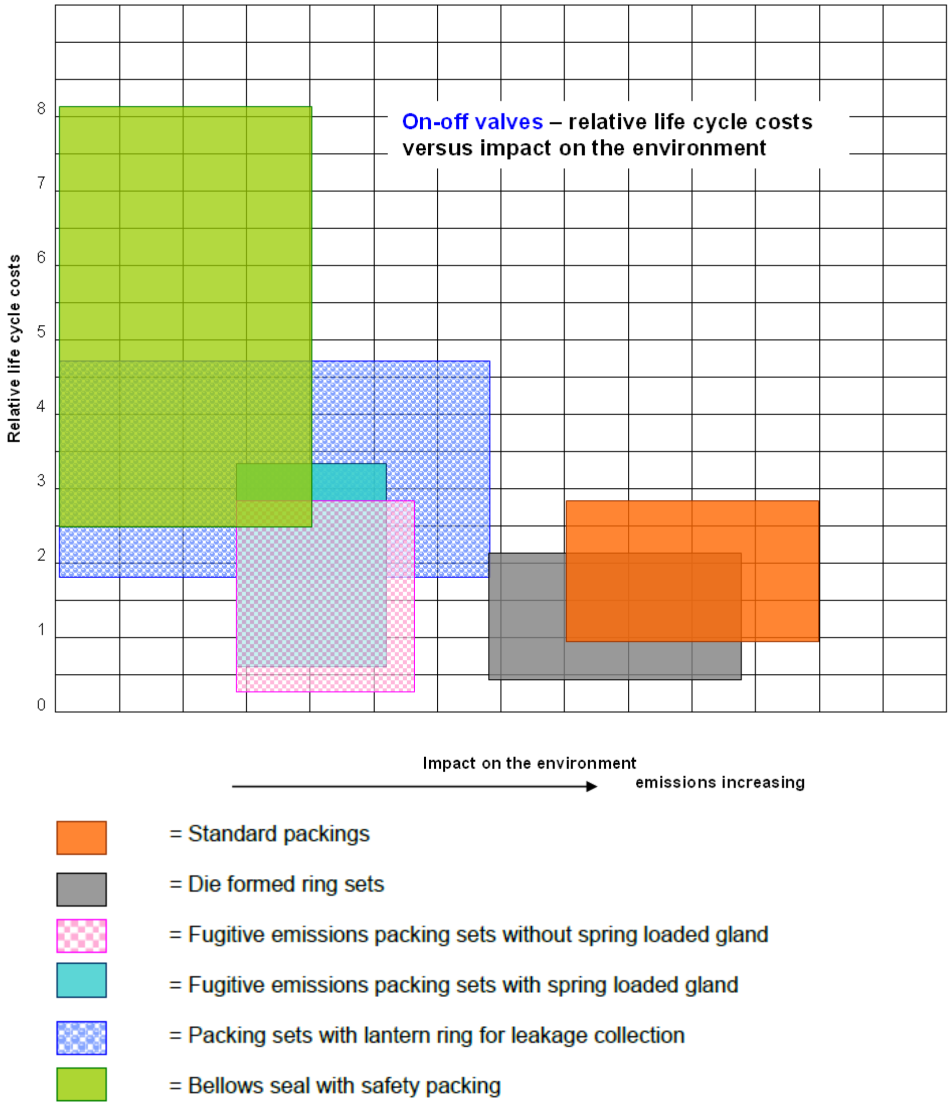
LDAR PROGRAM

To ensure that the installed new or refurbished valves are working correctly and adhere to the required leakage levels a LDAR (Leak Detection and Repair) program can be set-up. The EPA (Environmental Protection Agency) in the US, the Environment Protection Agency (EPA) has published a guide "Leak Detection and Repair – A Best Practice Guide" outlining the elements of a good leak detection program. Technical guidance in regard to quality assurance of emission monitoring systems can be found in "Technical Guidance Note (Monitoring) M20 Quality assurance of continuous emission monitoring systems - application of EN 14181 and BS EN 13284-2".

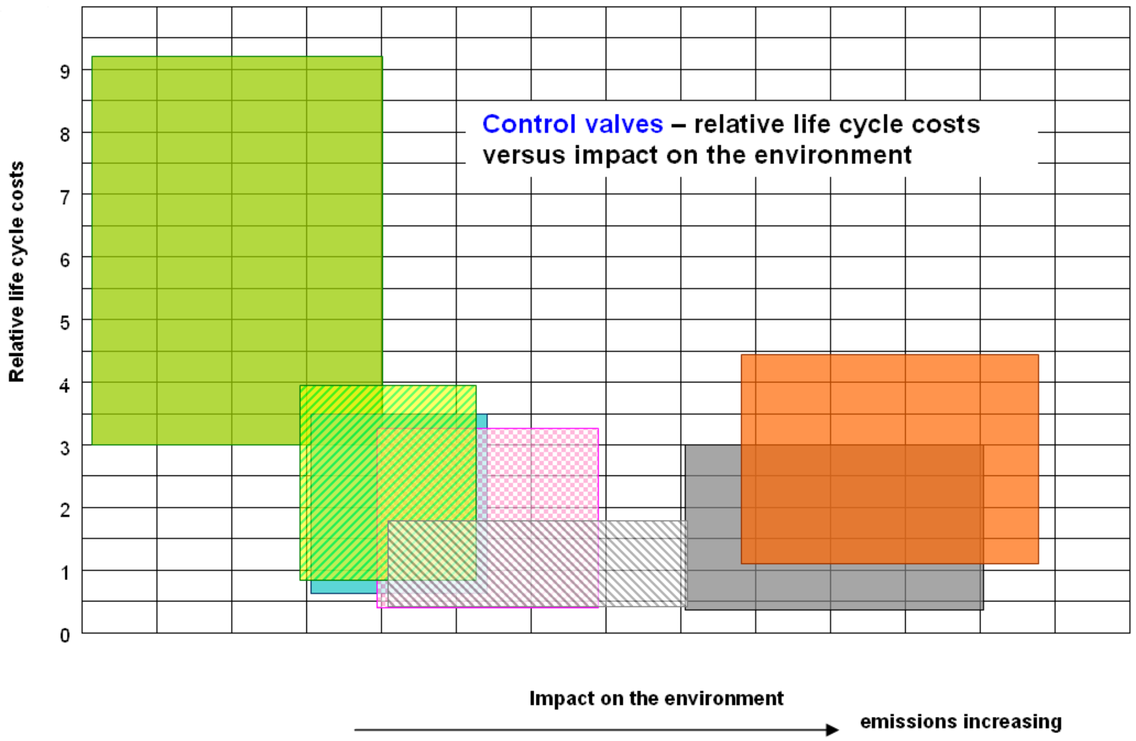
Relative costs of Best Available Practice for valves

As mentioned in the section covering generic BAT, the cost of the actual sealing technology is infinitesimally small when compared with the investment made in the plant as a whole. Indeed, for many sealing technologies, the cost per unit may be in the region of a few cents, completely insignificant when the total plant costs are considered. Importantly, the unit cost of the sealing technology is overwhelmed completely by the labour costs required to fit the seal, let alone the downtime of the plant. Consequently, the actual cost of the sealing device is immaterial in terms of economic considerations for reduction in fugitive emissions. However, for the sake of completeness, the following diagram provides an overview of the relative cost of the best available sealing technologies for valves and the environmental impact of the sealing systems.

The challenges associated with valves are dependent upon the valve type, the application and the sealing technology employed. The first matrix below represents the relative life-cycle costs versus impact on the environment for on-off valves:



The matrix is intended to be used with **typical valves** but cannot be assumed to be applicable universally. The second matrix below represents the relative life-cycle costs versus impact on the environment for **control valves**:



= Standard packings

= Die formed ring sets

= Fugitive emissions packing sets without spring loaded gland

= Fugitive emissions packing sets with spring loaded gland

= Packing sets with lantern ring for leakage collection

= Bellows seal with safety packing

The matrix is intended to be used with **typical valves** but cannot be assumed to be applicable universally.

SECTION 6. Elastomeric and Polymeric Seals

Typical Examples of Elastomeric and Polymeric Seals

Introduction

Elastomers and polymers can form integral parts of the sealing systems described elsewhere in this document (examples include the core of a compression packing or the binder in CNAF jointing) so many of the observations in this section may be relevant to other seal types.

Elastomeric and polymeric seals can be sub-divided into many different types, each with their own specific strengths (and potential weaknesses). Elastomeric and polymeric sealing materials with the widest temperature and broadest chemical resistances may not be the most cost-effective choices for a given application.

Generic chemical resistance guides are freely available and offer a good starting point for any potential application however care should be taken when using such guides, particularly when resistance to mixtures of chemicals is required.

It is of critical importance to consider the temperature requirements of a given application. The physical properties of an elastomeric or polymeric seal can vary markedly over its temperature operating range. This in itself is not necessarily a problem providing these limitations have been considered at the design stage and the seal manufacturer is aware of these requirements.

Elastomers can be particularly complex in terms of formulation and most seal manufacturers have their own proprietary formulations. These formulations are often optimised for specific applications or industry requirements. A seal material and design optimised for use in the semiconductor industry may not be the most optimum choice for a downhole oil and gas application.

Similarly formulations optimised for rotary applications may not be the best choice for a long term o' ring application.

Seal manufacturers and/or third party test houses should be consulted if in any doubt. Involving seal manufacturers and third party test houses at the earliest opportunity in a project and using their specialised expertise gives the best chance of successful sealing.

Failure mechanisms

For a more detailed description of the failure mechanisms and recommendations to alleviate the effects please refer to the ESA publication ['Successful sealing with elastomers']

Compression Set

In general, compression set occurs with one or more of the following conditions:

- Molecular alignment/rearrangement occurs due to excessive temperature, pressure and/or media permeation
- Molecular scission of the backbone chain or crosslink structure broken by the loads placed upon them or as a result of chemical attack. This scission can also be caused by elevated temperature
- Cross-links are generated within the elastomer material, which reduce the ability of the elastomer to move and recover following deformation

Recommendations for optimising performance:

- Decrease the squeeze applied to the elastomer, but still ensure it will resist the initial pressure impulses and allow for housing tolerances
- Reduce system temperature and/or pressure or protect seals from them.
- Change the material to one with higher compression set resistance under application conditions

Low Temperature Effects

In general, low temperature effects occur with one or more of the following conditions:

- Prolonged low temperature near or below the glass transition point (Tg) of the elastomer
- Low squeeze or low system pressure allows the elastomeric molecular chains to rearrange to a low energy level state
- A material with a Tg close to the operating or ambient temperature is used

Recommendations for optimising performance:

- Select appropriate material for the given process conditions
- Increase the squeeze or use seal profile that will respond to system pressure at operating temperature. If possible pressurize seal prior to reducing temperature.
- Provide localised heating to seal area
- Provide additional energisation device such as a spring
- When using lubrication ensure it is also suitable for the operating temperature

High Temperature Effects

In general, high temperature failures occur with one or more of the following conditions:

- An elastomeric compound is selected which cannot withstand the upper operating limit or excursion temperatures
- Process conditions have changed and a new material needs to be selected
- Excessive frictional or localised heat is present

Recommendations for optimising performance:

- Appropriate choice of material type and grade for application temperature
- Avoidance of excessive friction by careful consideration of design, tolerances and material grade
- Eliminate source of localised heat damage such as at the seal faces
- Remember that the presence of ozone and aggressive chemicals will accelerate thermal degradation and the avoidance of such influences can postpone degradation

Thermal Cycling

In general, thermal cycling failure effects occur with one or more of the following conditions:

- Large temperature cycles are inherent to the system and/or process
- Hardware dimensions do not accommodate the thermal expansion of elastomer at high temperature
- An improper material selection has been made

Recommendations for optimising performance:

- Isolate the sealing system from large thermal gradients
- Reduce the number of cycles between high and low temperatures
- Review the material properties to ensure the properties are appropriate at high and low temperatures

Extrusion / Nibbling / Shaving Damage

In general, these failure modes occur with one or more of the following conditions:

- Excessive clearances
- High pressure
- Material too soft
- Degradation (swelling, softening, shrinking, cracking etc.) of the material by the system fluid/circumstances
- Irregular clearance gaps caused by eccentricity
- Increase in clearance gaps due to excessive system pressure e.g. ballooning of cylinder bore
- Improper size (too large) seal installed causing groove overfill

Recommendations for optimising performance:

- Decrease clearance by reducing machining tolerances.

- Use back-up rings.
- Check seal material compatibility with system fluid/circumstances
- Increase rigidity of metal components.
- Replace current seal with a harder seal
- Break sharp edges of gland to a minimum radius 0,2mm
- Insure installation of proper size seal.
- Use alternative seal profile.

Spiral twist / rolling

In general, this failure modes occur with one or more of the following conditions:

- Over-compression of part of the elastomer
- Dynamic movement of the elastomer particularly in reciprocating applications
- Installation of elastomer over shaft
- Small O-ring cross section to diameter ratio

Recommendations for optimising performance:

- Improve surface finish of sealed assembly at dynamic interface (Cylinder Bore, Piston Rod)
- Check for out-of-round components (Cylinder Bores especially)
- Provide proper lubrication. Consider the use of internally lubricated O-rings
- Replace with a harder, more rigid O-ring
- Increase the cross section to diameter ratio
- Consider use of alternate seal shapes, for example X-rings, D-seals or T-seals

Installation and/or port damage

In general, this failure mode occurs with one or more of the following conditions:

- There are sharp corners on mating metal components such as the seal gland or threads over which the seal must pass during assembly
- Insufficient lead-in chamfer
- Blind grooves in multi-port valves
- Oversize seal on piston seal application
- Undersize seal on rod application
- Seal twisted/pinched during installation
- Seal not properly lubricated before installation
- Seal dirty upon installation
- Seal gland and/or other surfaces over which seal must pass during assembly contaminated with metal particles

Recommendations for optimising performance:

- Break all sharp edges on metal components
- Provide a 15 to 20° lead-in chamfer
- Check all components for cleanliness before installation
- Tape the threads over which the seal will pass
- Use a seal lubricant
- Check seal to ensure correct size and material

- To prevent damaging of seals during assembly, chamfers are necessary on all leading edges. All edges must be free from burrs and sharp edges bevelled.

Chemical Degradation

In general, this failure mode occurs with one or more of the following conditions:

- The energy in the system activates or maintains chemical reactions, to either make or break bonds. This is typically in the form of excessive temperature
- The sealing fluid is an easily polymerising fluid such as styrene or acrylic acid
- The density of the elastomer is low, or highly permeable to the sealed medium
- The backbone structure, plasticiser, filler and/or cross-links of the elastomer is susceptible to chemical attack by the sealed fluid.

Recommendations for optimising performance:

- Reduce the permeability of the elastomeric material when sealing highly polymerising fluids
- Verify the fluid is compatible with the elastomer backbone structure, plasticiser, filler and/or cross-links
- When possible reduce temperature in the sealing system below levels where reactions occur
- Consider the use of a barrier fluid to isolate the elastomers from the aggressive fluid

Compression fracture

In general, this failure mode occurs with one or more of the following conditions:

- The initial compression caused by the hardware induces high strain
- High temperatures are found in the system
- Initial volume fill is too low
- The surface finish of the compression surfaces is poor
- The system is exposed to rapid gas decompression (RGD)

Recommendations for optimising performance:

- Reduce the initial compression
- Reduce the temperature in the system
- Reduce the width of the groove
- Improve surface finish conditions of the hardware
- Control the pressure losses in the system to a level below which RGD occurs

Dieseling / Air entrainment

In general, this failure mode occur with one or more of the following conditions:

- Air / gas entrapment due to pressurising or improper venting
- Process fluid has a low auto-ignition temperature and/or allows air to dissolve easily

Recommendations for optimising performance:

- Minimize the presence of air in the system.
- Provide venting
- Use single-acting seals where appropriate
- Consider using a bladder to separate pressurising air and fluid

Short Stroke Failure

In general, this failure mode occur with one or more of the following conditions:

- Lubrication to the sealing surface is inadequate
- Excessive force is placed on the sealing surface

Recommendations for optimising performance:

- Ensure a minimum stroke length of 2.5 times the stack depth to provide lubrication to all contact lips
- Use shallow seals, even single element (unit) seals, as multi-lip packings can reduce seal life and cause premature failure.

Pressure trapping

In general, this failure mode occurs with one or more of the following conditions:

- Pairs of double-acting seals are used in a reciprocating application

Recommendations for optimising performance:

- Two double-acting seals should never be used in series
- If opposed seals are necessary then it is essential that at least one of them is a true single-acting seal in order that any inter-seal pressure build-up is automatically vented.

Bunching

In general, this failure mode occurs with one or more of the following conditions:

- Over compression caused by system or chemical interactions
- Rotary or swivel motion is present in the system
- High friction limits elastomers motion
- Small cross section to seal diameter ratio

Recommendations for optimising performance:

- Lubrication of the seal surfaces on assembly or the use of low friction seals such as rubber or spring energised PTFE seals
- The introduction of reinforcement into elastomeric seals can give increased stiffness which resists the bunching effect.
- The use of a larger cross section can also give increased stiffness which resists the bunching effect.

Wear and fatigue

In general, this failure mode occurs with one or more of the following conditions:

- The velocity of the lubricating fluid film is sufficient to cause wear
- The elastomer is incompatible with either the lubricant or sealing fluid
- The surface finish of the hardware is poor
- Contamination in the sealing fluid or lubricant
- Excessive temperature due to friction

Recommendations for optimising performance:

- Select the appropriate elastomer type and grade for the operating conditions
- Ensure that the seal does not operate outside its design conditions
- Ensure contacting surfaces are of the correct surface finish
- Ensure any lubrication is of the correct type for the conditions and elastomers used and that hydrodynamic films are maintained by correct control of speed and lubrication.
- Ensure all good fitting and operational practice is maintained to avoid the introduction and generation of contaminants

Volume Change

In general, this failure mode occurs with one or more of the following conditions:

- Loss of physical properties
- Seal extrusion
- Overfill of the seal housing/groove
- In extreme cases, fracture of the metal hardware

Recommendations for optimising performance:

- Select the appropriate elastomer type and grade for the operating conditions
- Ensure any swell will be accounted for in the design of the seal housing/groove

Storage and handling of elastomeric and polymeric seals

These guidelines make use of the relevant sections of:

- BS ISO 2230: 2002. Rubber Products - Guidelines for storage
- BS 4F 68: 2002 - Controlled storage for vulcanised rubbers.

Damage resulting from poor storage and handling procedures can be manifested in the following ways:

A. <u>Accelerated oxidative degradation</u>

Oxidative aging will occur slowly over time whenever a rubber is in direct contact with oxygen or ultraviolet radiation from the sun. Oxidisation will lead to chain scission, so weakening the material by lowering the molecular weight, and cracks start to grow in the regions affected.

Being stored at too high a temperature and the presence of certain metals or other contaminants can accelerate the oxidative process.

B. <u>Ozone degradation</u>

Ozone is formed when oxygen molecules absorb the sun's radiation, split into free radicals and recombine with other oxygen radicals to form a triatomic molecule of oxygen, O_3. It is a powerful oxidizing agent which attacks any unsaturated bonds within the polymer, leading to chain scission. This causes the polymer to lose its strength and, cracks will from the surface at right angles to the strain, under strains of only 1%.

The kinetics of this reaction are increased as temperature is raised above 25°C or when the rubber is in contact with catalytic metals/contaminants.

C. <u>Hydrolysis</u>

Hydrolysis is technically a chemical reaction with water but the reaction is so slow that it is only when there is an acid or alkali present to act as a catalyst that much concern is necessary. Hydrolysis is of particular importance to Fluorocarbons and Nitriles but is also relevant to other elastomer types.

D. Swelling

Any liquid or vapour introduced by humidity or contaminants, given enough time will diffuse into and be absorbed within the polymer, forcing the macromolecules apart and causing the elastomer to swell. This increase in molecular separation results in a reduction in the secondary bonding forces, making the material softer. An elastomers susceptibility to swelling depends on the similarity of the chemical structure between the solvent and rubber. The greater the similarity the more likely the elastomer will swell. Temperature will also affect swelling and a higher temperature will increase the rate at which the solvent is dissolved.

E. U.V degradation

U.V light is absorbed by rubbers removing an electron from a specific atom converting it into a positively charged ion. There is then a rearrangement of atoms at this point and either chain scission or cross linking will occur leading to either a loss of strength or hardening and cracking.

F. Low temperature embrittlement

When rubbers are stored in cold conditions the temperature of the rubber may fall below its glass transition point, Tg when it will become glassy and brittle. Its toughness is lost and any deformation incurred while in this state will be plastic and permanent. Providing the rubber is not damaged whilst cold, embrittlement is fully reversible by warming the rubber to a temperature above its Tg.

G. Chemical degradation

Chemicals can attack double bonds in the rubber molecular structure causing chain scission and new chemical bonds to be formed which harden the material. Chemicals can also cause/exacerbate swell and hydrolysis.

Factors affecting the likelihood of deterioration during storage and handling:

H. Packaging

Contact with light , U.V, oxygen, ozone or other contaminants that cause hydrolysis or chemical degradation, such as oil/grease/water vapour etc can be prevented by enclosing rubber products in individually sealed, clean, black, dry, and preservative free packages in an atmosphere of less than 65% humidity. Packaging should be completed as soon as is practical after the final vulcanisation processes so that this protection in place before any contact can occur.

Polyethylene, polyethylene coated Kraft paper and aluminium foil would make good packaging materials but PVC film or film containing plasticisers should not be used.

I. Induced stresses

Induced stresses as a result of deformation during storage will accelerate the degradation processes. Therefore components should not be stored in a deformed, twisted or highly loaded state.

Where it is not possible to store components in a free state, large rings for example, they should be coiled into three equal superimposing loops to avoid twisting and laid flat. They should not be hung on hooks.

Storage conditions

To minimise degradation, rubber products should be stored under the following conditions.

1. Protected from all sources of natural and artificial light especially that having a high ultraviolet (UV) content.
2. At a temperature below 25ºC and in area free from condensation. Should items be stored below 15ºC then special care will need to be exercised in their handling, refer to ISO 2230.
3. Well away from any sources of ionising radiation and from electrical equipment likely to generate ozone.
4. By protecting products and packaging from distortion, stresses and other damage.
5. By preventing direct contact with certain other materials, including all liquids, vapours, semi-liquids and metals, in particular copper, magnesium and iron. The only exception being when one or more are supplied as an integral part of the component.
6. By resealing protective packaging and retaining identification labels for remaining product components after removing others for use, when contained in the same packaging.
7. By using the oldest products first, i.e. those with the earliest cure date.

The above guidelines form an outline of storage requirements. Complete recommendations for the controlled storage and packaging of vulcanized rubber and rubber products can be found in ISO 2230.

STORAGE LIFE

STORAGE LIFE IS THE MAXIMUM PERIOD OF TIME THAT A PRODUCT, SUITABLY PACKAGED, MAY BE STORED BEFORE BEING REGARDED AS UNSERVICEABLE FOR THE PURPOSES FOR WHICH IT WAS MANUFACTURED. THE STORAGE LIFE OF RUBBER PRODUCTS DEPENDS UPON THE STORAGE CONDITIONS AND THE TYPE OF RUBBER INVOLVED.

In terms of general storage, vulcanised rubbers are classified into 3 groups, according to their susceptibility to deterioration.

Initial Storage Period

The initial storage period is the maximum time, from date of manufacture, that a product may be stored before being inspected or re-tested. For products stored in accordance with the above guidelines, the initial storage period from date of cure for each type of rubber is shown in the table below.

Extension Storage Period

The extension storage period is the period for which a product may be stored after the initial storage period before further inspection or re-testing is required. Rubber products still in storage at the end of their initial storage period may have their storage life extended, provided they are examined and found to be in good condition.
The examination of a representative sample from each item (product type and cure date) shall include visual inspection for the following defects: -

1. Physical damage, surface hardening, softening or tackiness
2. Permanent set or distortion
3. Surface cracking, which if present is more clearly visible if the product is gently flexed. Whilst cracking will normally be visible to the naked eye, a magnification of 10 times is recommended.

If none of the above defects are present it can be assumed that the product is still in good condition. For products found to be satisfactory, provided the above storage conditions are maintained (including repackaging of examined products), the extension storage period is as shown in the table below.

Group	Rubber	Acronym	Initial Storage (years)	Extension (years)
A	Natural	NR	5	2
A	Butadiene	BR	5	2
A	Synthetic isoprene	IR	5	2
A	Styrene butadiene	SBR	5	2
A	Polyester and polyether urethane	AU/AE	5	2
B	Acrylonitrile butadiene	NBR	7	3
B	Carboxylated and hydrogenated NBR	XNBR/HNBR	7	3
B	Polyacrylic	ACM	7	3
B	Chloroprene	CR	7	3
B	Isobutylene isoprene	IIR	7	3
B	Halogenated IIR	BIIR/CIIR	7	3
C	Chlorosulphonated polyethylene	CSM	10	5
C	Ethylene propylene/diene	EPR/EPDM	10	5
C	Fluorocarbon	FKM	10	5
C	Silicone	MQ/FMQ/PMQ /VMQ/PVMQ	10	5

Note: It is recommended that any product taken from storage should be inspected, as detailed above, prior to being put into service.

SECTION 7. Fabric (non-metallic) Expansion Joints

Introduction and Overview of Expansion Joints

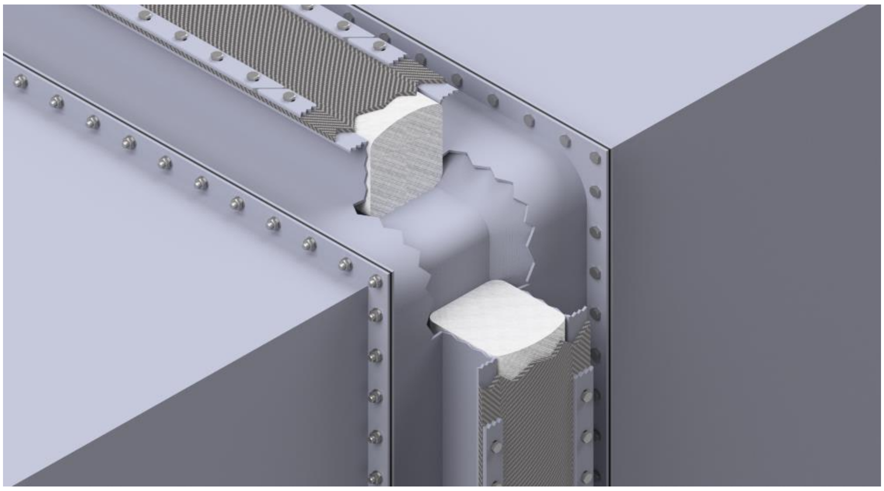
The generic description ‘Expansion Joint’ covers a wide variety of products used to absorb movement in ducts and pipelines. There are many applications for these products, and there is some overlap between the various types of expansion joint that can be used for a specific purpose. However there are general groupings which help to define the types of expansion joint, and their applications. Both metallic and non-metallic expansion joints can be used in ducts or pipelines.

The following features regarding emissions are only valid for non-metallic expansion joints including single layer, multilayer, fluoroplastic and elastomer flue duct expansion joints.

Rubber pipe joints and metal expansion joints are not covered

Fabric Expansion Joints

These guidelines describe the design and application of fabric expansion joints, manufactured from single or multiple layers of fabric and elastomers, which are used in ducts, or as seals for containing gaseous media.



Typical Fabric Expansion Joint

Fabric Expansion Joint Types

The term “Fabric Expansion Joint” is a little misleading, in that it covers a wider range of products and materials than just “fabrics”. However, it is useful as a generic title for expansion joints which are non-metallic and used in ducts at low pressures. Fabric expansion joints are used primarily to contain gaseous fluids and is a proven technology.

Fabric expansion joints are flexible connectors designed to provide stress relief in ducting systems by absorbing movement caused by thermal changes. They also act as vibration isolators, shock absorbers and, in some instances, make up for minor misalignment of adjoining ducting or equipment. Fabric expansion joints may also be known as “compensators”.

They are fabricated from a wide variety of materials, including synthetic elastomers, fabrics, insulation materials and fluoroplastics, dependent upon the design. The designs range from a single ply to complex, multi-ply constructions attached to metal frames for operation under extremes of temperature or corrosion.

By the nature of the materials it is possible to design to specific shapes and sizes, generally without the constraints of tooling or moulds, and nearly all fabric expansion joints can be manufactured:

Circular or Rectangular Belt or flanged type

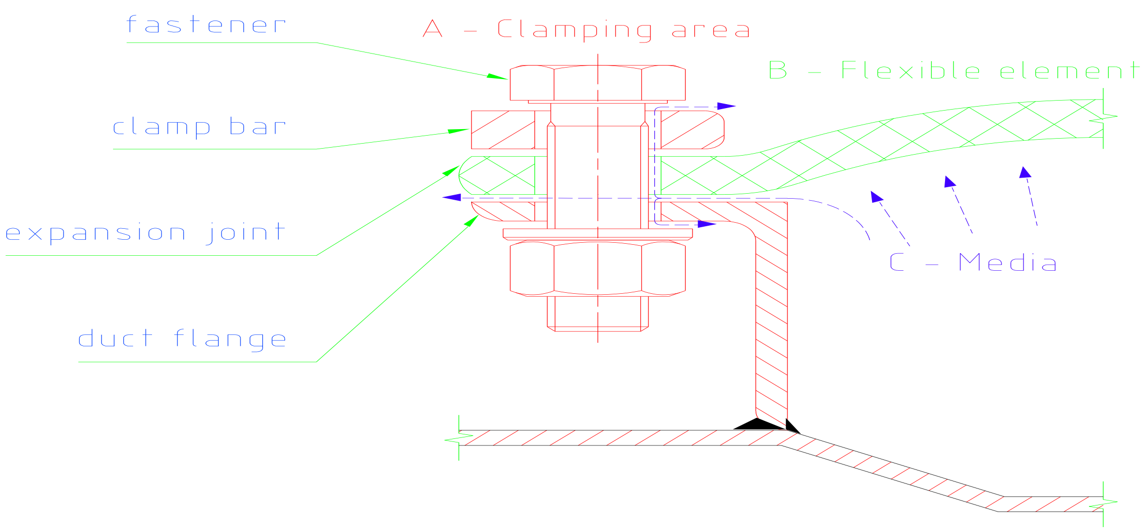
Belt type expansion joints provide the most effective joint from both a manufacture and attachment point of view. In these joints, the materials are subject to minimum stress until moved under operating conditions, and the airflow over the seal outer cover is largely uninterrupted. Frames for belt type expansion joints can be slightly more complex than for flanged expansion joints, but this is offset by the ease of repair or replacement of the flexible element.

Flanged type expansion joints offer the duct designer the simplest methods of attachment, but the nature of their construction restricts their use at higher temperatures. For multi-layer expansion joints where there are more than 3 or 4 plies of material, the fabrication of the flange restricts the available movement, and necessitates deeper flanges and a wider breach opening.

Fugitive Emission Factors

The design and selection of the Expansion Joint is critical and needs to take into account all the process variables which are in the questionnaire in the Selection section of this document. After evaluating the information supplied the manufacturer of the Expansion Joint will supply the design best suited for the application.

Typically the main emissions would arise from the **Clamping area shown as A** in the following diagram. Over time this will also include the **flexible element shown as B.**



Factors for actual emissions

A: Clamp bar, duct flange, fasteners, bolt spacing
B: Quality and quantity of sealing- and insulation layers
C: Media, pressure, temperature
D: Installation, Inspection, maintenance

The quantity of fugitive emissions will be influenced by the base design of the **clamping bar**, **duct flange, fastener** and **bolt spacing** (Factor A), **material quality**, and makeup of the **layers** (Factor B) in the expansion joint. Equally the actual **operation conditions and cycles** (Factor C). Proper **installation**, regular visual **inspections** and **maintenance** (Factor D) will increase the life and ensure maximum leak-tightness.

Expansion Joint Technology

Expansion joints provide flexibility in ductwork and are used to allow for 4 main situations:

- expansion or contraction of the duct due to temperature changes
- isolation of components to minimise the effects of vibration or noise
- movement of components during process operations
- installation or removal of large components, and erection tolerances

The benefits of fabric expansion joints include:

Large movements in a short length – this requires fewer expansion joints, reducing the overall number of units and providing additional economies.

Ability to absorb simultaneous movements easily in more than one plane – this allows the duct designer to accommodate composite movements in fewer (and simpler) expansion joints.

Very low forces required to move the expansion joint – the low spring rate enables their use to isolate stresses on large, relatively lightweight, equipment. A particular example is a gas turbine exhaust, where it is crucial to minimise the forces from the duct expansion on the turbine frame.

Corrosion resistant materials of construction – modern technology materials enable the use in aggressive chemical conditions.

Noise and vibration resistance – fabric expansion joints provide a high degree of noise isolation and vibration damping.

Ease of installation and maintenance.

Minimal replacement cost – the fabric of the expansion joint assembly can be replaced simply and economically.

Design freedom – fabric expansion joints can be tailored to suit the duct application, with taper, transition or irregular shape, so allowing the designer the maximum variety of options.

Thermal breaks – self-insulating properties of the fabric allow simple hot-to-cold transition.

For further detailed information please refer to ESA Engineering Guide publication No 011/01

Selection

Common designs are described in more detail in the ESA Engineering guide.

The manufacturer will require some detailed information in order to design the most suitable Expansion Joint for the application. Please note that there may be several alternative designs which could be used but the manufacturer will advise you on this.

A typical industry design questionnaire is the following:

RAL TI-004

These are also available from all ESA and RAL Expansion Joint manufacturers of this product.

Expected Emission Rates.

Flue Gas Tight Leakage Standard: RAL TI – 002

This is the most commonly used test standard. Typical Leak rates can only be verified in lab conditions as there are so many variables. The RAL leak rates are typically below 10l/min/meter of gas. The only practical method on site is a bubble test.

Nekal Gas Tight Leakage Standard RAL TI – 003 is a higher tightness class for toxic or critical media.

The test methodology is described in RAL TI-005

Installation

Poor Installation will lead to higher leak rates and premature failure. Correct Installation procedures can be found in ESA Fabric Expansion Joints - Installation Guide publication No 015/04 and RAL Installation document TI 010

The training of installation technicians is critical if reductions are to be minimised. Ideally an experienced person should supervise the installation process.

Note: This type of structure wears and will require regular visual inspection and will require complete replacement, the timing of replacement depends on many factors and cannot be predicted but usually a visible inspection will be acceptable.

Maintenance

Regular maintenance is required to prevent or minimize emission and leakage during operation as well as to extend the lifetime of the product. For frequency of inspections and measures refer to RAL – TI 012

SECTION 8. Methods of Measuring Emissions Accurately

MONITORING TO DETERMINE LEAKING LOSSES

Leaking losses are often hard to determine since there are many potential sources and they are very dependent on how well the installation is operated, maintained and inspected.

Some important causes of leaking losses are:

- ill-fitting sealing elements
- installation
- construction faults
- wear and tear
- corrosion
- ageing
- equipment failure
- contamination of the sealing element
- excursions out of normal process conditions
- poor maintenance procedures

Leaking losses are generally higher from dynamic equipment (compared with static equipment) and from older equipment.

Leaking losses are also very dependent on process conditions:

- pressure
- temperature
- speed of pumps and compressors
- choice of sealing solution
  - Single Mechanical Seals leak more than double seals (where barrier fluid is the leakage to atmosphere)
  - Gaskets and Packings need careful selection to have correct style selected for the particular service.
  - All seals need careful and correct fitting.

A structural reduction of leaking losses is only possible when insight on the leaking losses is gained. There are various methods to determine the leaking losses.

There are several accepted methods for measuring leakage. The most commonly followed technique used on Chemical plants, Refineries and oil and Gas upstream production facilities is the **US Environment Protection Agency** EPA Method 21.

There are several other methods available. These include:

- CWP 453/R/95 where EPA method 21
- IR OGI Alternative Work Practice (AWG), using an Infra-Red camera
- API 220
- EPA 6560-50-P 2008 where two measures Parts per Million PPM) and KG/Hr.
- Netherlands Technical Agreement (NTA) NTA 8399, which focusses on VOC emissions and takes into account Air Temperature; Wind Speed; Humidity and Cloud cover.
- DIAL LIDAR technique.

Monitoring frequency is a key issue to be agreed, as are acceptable leakage rates.

The simplest way to estimate the leaking losses is by multiplying the number of each type of equipment by an ***emission factor*** for that type of equipment. This method can be applied to obtain a general estimation of the emissions ***without measurements***. Please note that emission factors are not intended as an accurate measure of a single piece of equipment, and do not reflect the site-specific conditions of process units.

Many companies determine their leaking losses by calculations or estimations based on measurements, but it is hard to measure all possible sources in a large plant (possibly tens of thousands) and not all sources are accessible. In most cases, a representative sampling of sources will suffice to estimate or calculate the leaking losses of the plant. The number of samples depends on the kind of process fluids in the plant and the kind of equipment (the sources). However, to provide the best estimate of emissions, every potential "source" on a site must be monitored (usually using a "sniffing" process such as EPA Method 21).

Leaking losses from equipment and fittings can be significantly reduced by the use of monitoring and maintenance programmes such as **LDAR (Leak Detection and Repair**). Leaks are detected by monitoring equipment and repairs must be carried out if the leakage rate exceeds certain levels. A leak detection and repair programme consists of using a portable VOC detecting instrument to detect leaks by "sniffing" (usually, according to EPA Method 21) during regularly scheduled inspections of valves, flanges, and pump seals. Leaks are then repaired immediately or are scheduled for repair as quickly as possible. An LDAR programme could reduce fugitive emissions by 40% to 60%, depending on the frequency of inspections, the process conditions and the fluid emitted.

LDAR can be structured to meet local requirements using appropriate techniques, frequencies and priorities, but in all cases the largest losses should be tackled first. Such programmes have shown that gland leaks on valves and pumps are often responsible for the majority of leaking releases.

Monitoring has been identified as a common activity across industrial processes and is the subject of a official IED Reference document (REF) entitled "JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations ". The document provides generic information on sampling and analysis and should be read in conjunction with other industry-specific BREF notes.

Monitoring is often expensive and time consuming, so the objectives should be clear when a programme is established. Process operators and regulators may use monitoring to provide information on a wide range of topics.

For this Fugitive Emissions Reduction guidance note on sealing technologies, the key objectives of monitoring are:

- Process control and optimisation; monitoring is the way used to control a process by means of following-up significant physical and chemical parameters. By control of the process, it is meant the application of conditions in which the process operates safely and economically.
- Emission monitoring; emissions to air and water are characterised and quantified to provide a check on compliance with permit requirements (or other performance measures). This also provides a check of whether all significant emissions are covered by the permit and can indicate the effectiveness of abatement techniques and sealing technologies employed. For the latter, emission monitoring can give an assessment of leaking losses and will indicate equipment where attention is required. Wherever

possible, data should be collected on flow rates to enable the calculation of mass discharges.

- Occupational health and safety; tests to identify the short and long term risks to personnel from work place exposure.
- Troubleshooting; intensive, short duration programmes may be used to study specific topics.
- A monitoring programme to address any of these topics will need to stipulate the frequency, location and method of both sampling and analysis. Monitoring usually involves precise quantitative analysis, but simple operator observations (either visually or by smell) can also play an important role in the detection of abnormal releases. The results of monitoring programmes should be actively utilised; records of results should be kept for trend analysis and diagnostic use.

Some estimates have been made of the costs of monitoring schemes. For example, a simple LDAR scheme, involving the annual inspection of gas and volatile liquid service components, is estimated to have a net annualised cost of over €25K per year (for a typical plant handling 20000 tpa of gaseous hydrocarbon streams and 30000 tpa of volatile liquids).

DIAL LIDAR technique. A strategy to reduce VOC emissions may include a complete inventory and quantification by a DIAL LIDAR technique (differential absorption light detection and ranging). In some cases, emissions estimates using “sniffing” methods give lower emissions than estimates based on the DIAL monitoring. In some cases, the discrepancies are very large. For example, by using the method for estimating fugitive emissions proposed by EPA "Workbook for estimating fugitive emissions from petroleum production operations 1992", the emissions from the process area at an average European refinery have been estimated to be 125 tonnes per year. Extrapolations of the DIAL measurements to a yearly emission give emissions of 500- 600 tonnes per year.

Note that most reported fugitive emissions are calculated rather than monitored (measured), but unfortunately, correlations are often dubious! Equally, not all calculation formats are comparable. For example, monitoring at well-maintained plants in the Netherlands shows that the average emissions factors are generally higher than measured (monitored) values.

Leaks are then repaired immediately or are scheduled for repair as quickly as possible. An LDAR programme could reduce fugitive emissions by 40 to 60%, depending on the frequency of inspections, the process conditions and the fluid emitted.

Measuring leakage

The current onsite method of measuring PPMv values using an Organic Vapour Analyser, commonly known as a **SNIFFER** is used due to the EPA Method 21 being more practical.

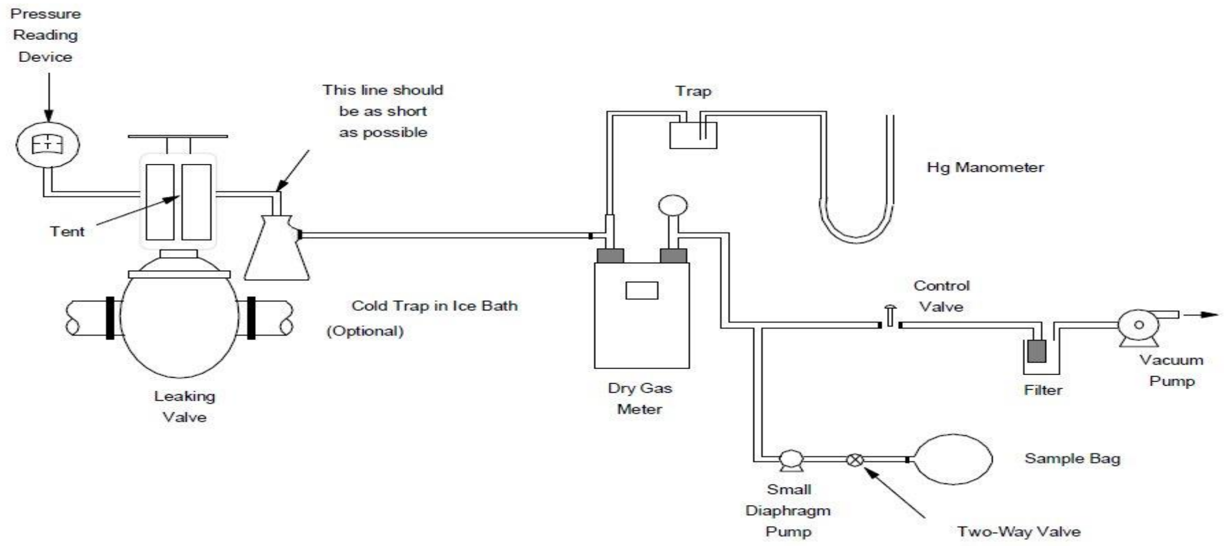
Method 21 Survey Specifics

- 8.3.1 Type 1 -- 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:

- 8.3.1.1 Valves. The most common source of leaks from valves is the seal between the stem and housing. Place the probe at the interface where the stem exits the packing gland and sample the stem circumference. Also, place the probe at the interface of the packing gland take-up flange seat and sample the periphery. In addition, survey valve housings of multipart assembly at the surface of all interfaces where a leak could occur.
- Other sub paragraphs discuss flange, screwed connections, etc

- **Bagging method**
  - the leaking component is enclosed in a “bag” or tent
  - An inert carrier gas (e.g., nitrogen) is conveyed through the bag at a known flow rate.
  - When the carrier gas attains equilibrium, a gas sample is collected from the bag, and the TOC (total organic compounds) concentration of the sample is measured.

Bagging Vacuum Method



Bagging Blow-Through Method

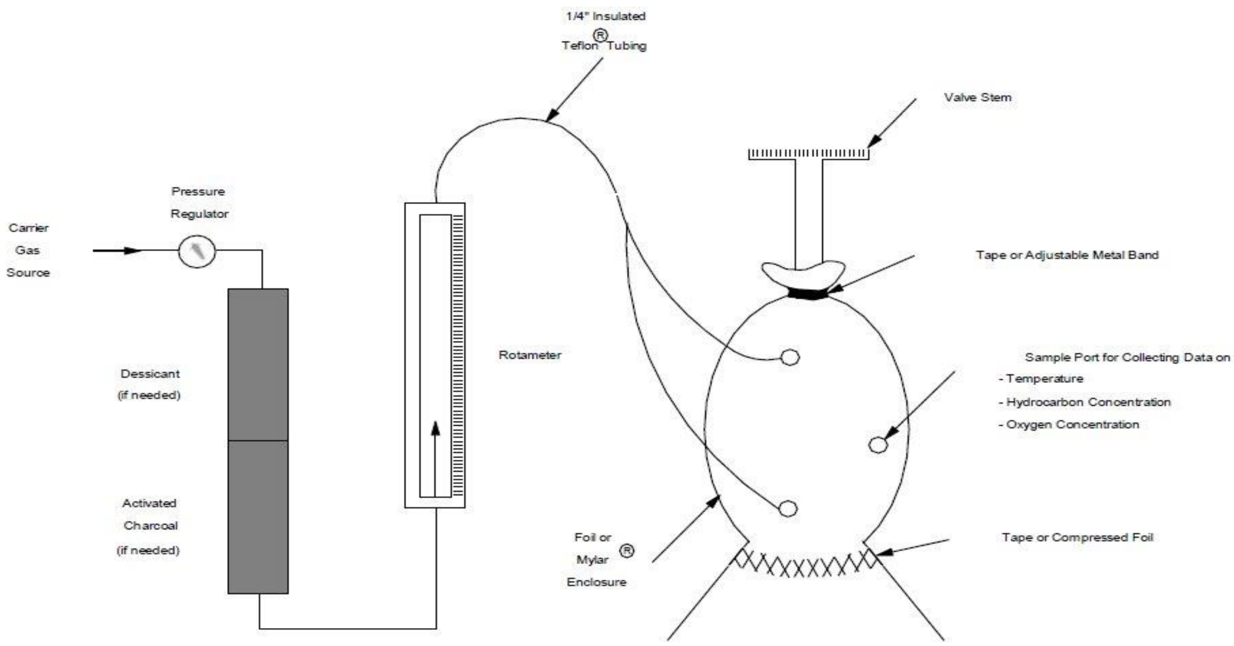


Table 2-2. Equipment Leak Rate for Petroleum and SOCMI Equipment

Equipment Type (All Services)	Default Zero Emission Rate (kg/hr/source)	Pegged Emission Rates (kg/hr/source)		Correlation Equation[b] (kg/hr/source)
		10,000 ppmv	100,000 ppmv	
Leak Rates for Petroleum Industry (Refinery, Marketing Terminals, and Oil and Gas Production)				
Valve	7.8E-06	0.064	0.14	$2.29E-06 \times SV^{0.746}$
Pump	2.4E-05	0.074	0.16	$5.03E-05 \times SV^{0.610}$
Other[c]	4.0E-06	0.073	0.11	$1.36E-05 \times SV^{0.589}$
Connector	7.5E-06	0.028	0.030	$1.53E-06 \times SV^{0.735}$
Flange	3.1E-07	0.085	0.084	$4.61E-06 \times SV^{0.703}$
Open-ended line	2.0E-06	0.030	0.079	$2.20E-06 \times SV^{0.704}$
Leak Rates for Synthetic Organic Chemical Manufacturing Industry (SOCMI)				
Gas valve	6.6E-07	0.024	0.11	$1.87E-06 \times SV^{0.873}$
Light liquid valve	4.9E-07	0.036	0.15	$6.41E-06 \times SV^{0.797}$
Light liquid pump[d]	7.5E-06	0.14	0.62	$1.90E-05 \times SV^{0.824}$
Connector	6.1E-07	0.044	0.22	$3.05E-06 \times SV^{0.885}$

Note: kg/hr./source = kilograms TOC per hour per source
a. Data reported in U.S. EPA, 1995b.
b. SV is the screening value (SV, ppmv) measured by the monitoring device.
c. The “other” equipment type was developed from instruments, loading arms, pressure relief devices, stuffing boxes, vents, compressors, dump lever arms, diaphragms, drains, hatches, meters, and polished rods. This “other” equipment type should be applied to any equipment other than connectors, flanges, open-ended lines, pumps, or valves.
d. The light liquid pump factors can also be applied to compressors, pressure relief valves, agitators, and heavy liquid pumps.

- When a screening value is zero use the default zero in Table 2-2 to estimate TOC emissions.
- When the meter is pegged (goes to the maximum) use the pegged values in Table 2-2 are used to estimate emissions.
  - Note - one value for instruments with a maximum of 10,000 and another for 100,000
- The uncertainty of the correlations for any single measurement may be as much as a factor of 3 higher or a factor of 10 lower than the actual but when summed over thousands of components, the uncertainty in the cumulative total emissions is expected to be much less.
  - Example – Monte Carlo simulations of 100 leaking components using an uncertainty of plus or minus a factor of 10, the uncertainty in the cumulative emissions is approximately plus or minus a factor of 1.4

Hi-Flow Monitor

- **High volume sample allows for direct measurement of mass**
  - **Method 21 with an OVA is a point measurement**

Table 2-3. Screening Ranges Emission Factors [a]

Equipment type	Service	Refinery Factors[b]		SOCMI Factors[c]	
		≥10,000 ppmv emission factor (kg/hr/ source)[b]	<10,000 ppmv emission factor (kg/hr/ source)[b]	≥10,000 ppmv emission factor (kg/hr/ source)[c]	<10,000 ppmv emission factor (kg/hr/ source)[c]
Valves	Gas	0.2626	0.0006	0.0782	0.000131
	Light liquid	0.0852	0.0017	0.0892	0.000165
	Heavy liquid	0.00023	0.00023	0.00023	0.00023
Pump and agitator seals	Light liquid	0.437	0.0120	0.243	0.00187
	Heavy liquid	0.3885	0.0135	0.216	0.0210
Compressor seals	All	1.608	0.0894	1.608	0.0894
Pressure relief valves	All	1.691	0.0447	1.691	0.0447
Connectors	All	0.0375	0.00006	0.113	0.000081
Open-ended lines	All	0.01195	0.00150	0.01195	0.00150

a. Data reported in U.S. EPA, 1995.
b. These factors are for non-methane organic compound emissions.
c. These factors are for total organic compound emissions.

The EPA takes the recorded methane PPMv screening value (SV) and converts it to a mass emission rate (ER) in kg/hr using a correlation chart measured in real world plants.

(see Protocol for Equipment Leak Emission Estimates)

The SV can be changed depending on the content of the leak media using a correction factor i.e. for different hydrocarbons and /or hydrocarbon mixes, but they then still use the same conversion method to get to a final kg/hr ER.

So when measuring in PPMv, the idea was always to end up finally with a mass flow rate. I.e. measuring PPMv was only to get to an indication of the mass flow rate.

The idea was that because there are measurements at lots of points when measuring a whole plant it is not necessary to be accurate, because it sorts itself out with the average over many measurements.

Now in labs it is possible to measure the mass flow rate directly and accurately, using either displacement of helium or methane. So there is no need to make many measurements. At these leakage levels mass spectrometers are not even required.

Therefore we should measure in mass flow rates and convert back to expected PPMv rates. Not measure in PPMv directly as that is, by the EPA's own admission, inaccurate unless done many times.

Also we all know the EPA also have a kg/hr level for a 0 PPM reading. It is about 5 x 10-7 kg/hr (~1.50e-4 mg/s) for "connections" this is all in the EPA document linked in the excel file.

For final limits for the test in Germany they like 0.01 mg/s Helium as a leakage allowance, using this EPA method that's a PPMv reading of around 20 PPM, our old limit of 0.1 mg/s would have been around 500 PPM.

While we want to follow EPA criteria that is used in the field (since that is mostly what end-users care about), we don't think laboratory tests need to be concerned with "screening values" and mass emission rates. While we are "sniffing" leaks, the method that we are proposing should be capturing most, if not all the gas coming out, which is not the case for field screenings.

For methane testing. Most sensors being used report in PPMv. If they are calibrated according to API 622/624/641, then the sampling rate is standardisedd as 1000 cc/min. So the PPMv reading can be easily and accurately converted to a leak rate by dividing by 1000 for a cc/min leak. So 100 PPMv equals 0.1 cc/min leak rate. If mass flow is wanted, then multiply by the density of the gas. (.66mg/cc for methane)

For helium mass spectrometers, it is common to use flow standards to calibrate. The PPMv output given by machine is calculated from an average sampling rate. Pfeiffer samples at about 40 cc/min for sniffing. So a 100 PPMv concentration at a 40 cc/min sampling rate would equal 0.004 cc/min. Conversely, a 0.1 cc/min helium leak rate equals 2500 PPMv.

Optical Gas Imaging (OGI)

Advances in Optical Gas Imaging (OGI) Technology allows improved Leak Detection and Repair (LDAR) surveys by more efficiently identifying fugitive sources. Unfortunately they are not too good at quantifying emission rates. Other methods can be used when leak identified.

- An owner of an affected source who chooses to use the alternative work practice must comply with the requirements of paragraphs (e) (1) through (e) (5).

- (1) *Instrument specifications:* The optical gas imaging instrument must comply with the requirements specified in paragraphs…
- (2) *Daily instrument check:* On a daily basis, and prior to beginning any leak monitoring work, test the optical gas imaging instrument at the mass flow rate determined in paragraph…
- (3) *Leak survey procedure:* Operate the optical gas imaging instrument to image every regulated piece of equipment selected for this work practice in accordance with the instrument manufacturer's operating parameters. All emissions imaged by the optical gas imaging instrument are considered to be leaks and are subject to repair.
- (4) *Recordkeeping:* Keep the records described in paragraphs…
- (5) *Reporting:* Submit the reports required in the applicable subpart.

Toxic Vapour Analyser

A common alternative is to use Toxic Vapour Analyser (TVA), which use photo ionisation detectors (PID). There is a further option using detectors that use the principle of Flame Ionisation (FID).

SECTION 9. Appendix

FURTHER READING

1. ***Determination of emissions of flange joints in a chemical plant***, K.Kanschik and H. Schmidt-Traub, proceedings of the 2nd European Fugitive Emissions Conference, Düsseldorf (8 - 9 September 1998), published by VDI-Verlag as VDI Berichte 1441(ISBN 3-18-091441-6), Düsseldorf 1998.

2. ***Control of Fugitive Emissions of Mechanical Seals***, E Vanhie (Durametallic Europe NV), presented at the Shaft Sealing Seminar of the I Mech E, London, February 1992.

3. ***Seal Systems for Emissions Control***, W Key (BW/IP International Inc.), presented at the 11th International Pump Users' Symposium, Houston, March 1994.

4. ***Seal Technology, a Control for Industrial Pollution***, James P Netzel (John Crane Inc.), presented at the 45th STLE Annual Meeting, Denver, May 1990.

5. ***Controlling Emissions to Atmosphere through the use of a Dry-sliding Secondary Containment Seal***, P M Flach, J E Sandgren and D P Casucci (EG & G Sealol), proceedings of the 10th International Pump Users' Symposium.

6. ***Emissions of Hydrocarbons to the Atmosphere from Seals on Pumps and Compressors***, B J Steigerwald, Joint District, Federal and State Project for the Evaluation of Refinery Emissions, Report N°· 6, NTIS N°- PB 216582, 1958.

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8. ***Assessment of Atmospheric Emissions from Petroleum Refining***, Radian Corporation, Vol. 1-4, Research Triangle Park, North Carolina, USA, Pub. N°- EPA - 600/2-80-075a-d, 1980.

9. ***CMA / STLE Pump Seal Mass Emissions Study***, T Kittleman, M Pope, W Adams, proceedings of the 11th International Pump Users' Symposium, Houston, March 1994.

10. ***National Emission Standards for Organic Hazardous Air Pollutants for Equipment Leaks***, Federal Register, Vol. 59, No. 78, Subpart H, pages 19568 - 19587, April 1994.

11. ***Effectively Managing your Pump Seal Emissions***, C J Fone (John Crane EAA), proceedings of the Pump Performance and Reliability Conference, Aberdeen, October 1993.

12. ***Mechanical Seal Practice for Improved Performance***, I Mech E, Mechanical Engineering Publications, Second edition, 1992. ISBN 0 85298 806 0.

13. ***Guidelines for Meeting Emission Regulations for Rotating Machinery with Mechanical Seals***, Society of Tribologists and Lubrication Engineers, Special Publication SP-30, September 1990.

14. ***Guidelines for Meeting Emission Regulations for Rotating Machinery with Mechanical Seals***, Society of Tribologists and Lubrication Engineers, Special Publication SP-30, revised April 1994.

15. ***Measurement of Vaporised Leakage***, Dr A Voigt (John Crane GmbH), presented at the STLE/ I Mech E Environmental Forum, Pittsburgh, May 1994.

16. ***Canned Motor and Magnetically-coupled Pump Applications, Operations, and Maintenance in a Chemical Plant***, H Vollmtiller, W Seifert (Hoechst AG, Frankfurt) and K B Fischer (Hoechst-Celanese, Houston),

proceedings of the 10th International Pump Users' Association.

17. ***The increasing pressures on Process Plant Operators and how Mechanical Seal Technology is keeping pace***, C J Fone (John Crane EAA), proceedings of the Process Pump Seminar, I Mech E, London, June 1991.

18. ***Zero Emission Solutions for Mechanical Seals on Light Hydrocarbons***, N M Wallace and JAM ten Houte de Lange (Flexibox International), proceedings of the 9th International Pump Users' Symposium, College Station, March 1992.

19. ***A User's Engineering Review of Sealless Pump Design Limitations and Features***, T Hernandez (Exxon Chemical Company), proceedings of the 8th International Pump Users' Symposium.

20. ***Shaft Sealing Systems for Centrifugal and Rotary Pumps, API Standard 682***, American Petroleum Institute, September 1992 (First and Second Edition).

21. ***Die Bestimmung der Leakage von Gleitringdichtungen***, G Knoll, H Peeken, R Schroder (Rheinisch-Westfalische Technische Hochschule Aachen), VDMA-Projekt Literaturrecherche, February 1993.

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25. ***Design and Development of Gas Lubricated Seals for Pumps***, J R Wasser (John Crane Inc.), R Sailer and G Warner (GE Plastics), proceedings of the 11th International Pump Users' Symposium, Houston, March 1994.

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31. ***API 624 - Type Testing of Rising Stem Valves Equipped with Graphite Packing for Fugitive Emissions***, First Edition, American Petroleum Institute, 2014

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36. ***Life-cycle cost and reliability for process equipment,*** H. Paul Barringer, proceedings of the 8th Annual Energy Week Conference and Exhibition (28 - 30 January 1997), organised by the American Petroleum Institute, published by the American Society of Engineers and Penn Well Publishing.

37. ***Life-cycle cost estimator*****,** software tool developed jointly by the Mechanical Seals Divisions of the Fluid Sealing Association and European Sealing Association.

38. ***Gasket Handbook – 1st Edition 2017*** Successfully sealing a bolted flange connection is dependent on all components of a well-designed system working together, effectively and safely. This handbook includes guidance to plant engineers on specifying gaskets; maintenance operators on installing and trouble-shooting bolted flange connection leaks, as well as purchasing personnel on the important functional distinctions between various gasket types.

39. ***Flange Gaskets – Glossary of Sealing Terms*** Detailed guidance on the terminology and standardisation challenges facing users of gaskets.

40. ***Gasket Installation Procedures.*** A guide to successful gasket installation. This document provides guidance to maintenance operators, engineers and fitters to ensure successful gasket installation and assembly of bolted flange connections. It is intended to complement other plant-approved installation procedures. English language version. Published in collaboration with the FSA

41. ***Expansion Joints –Fitters Guide.***This handy pocket sized guides are written for those physically installing the expansion joints. Pictorial and easy to follow the guides ensure that the products are installed to best practice to maximise the performance and lifetime of the product. Available in other languages.

42. ***Expansion Joints – Installation Guide*** This publication is focussed on the actual installation of the Expansion Joint. Available in a variety of languages the guide assumes that the joint and its components are now at the point of final installation.

43. ***Expansion Joints – Engineering Guide.*** This publication is aimed at engineers designing systems that include expansion joints. It contains details on typical designs, capabilities and design guidelines. Available in other languages.

44. ***Elastomeric & Polymeric Seals - Successful Sealing with Elastomers.*** This document offers guidance on how to prevent seal failure through appropriate material selection and design.

45. ***Compression Packing Technical Manual 4th Edition 2019.*** Provides detailed information on compression packings and their components, with guidance on their selection and installation. A substantial revision of the 3rd edition which was published in 2008. English language version.

46. ***Pump and Valve Packing Installation Procedures.*** A guide to effective pump and/or valve packing installation. This document provides guidance to maintenance operators, engineers and fitters to ensure successful packing installation in pumps and valves.