European
Sealing
Association e.V.

Sealing Technology – BAT guidance notes

Guidance notes to the best available techniques for sealing technology used in equipment on industrial installations covered by the EU IPPC Directive

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Revision 1 contains amendments to section 10.4 on Conversion factors (SI units)

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The **European Sealing Association** is a pan-European organisation, established in 1992 and representing a strong majority of the fluid sealing market in Europe. Member Companies are involved in the manufacture and supply of sealing materials, crucial components in the safe containment of fluids during processing and use.

The ESA is a non-profit-making trade association, registered in Neu-Ulm (D) as VR 713.

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Contents

1. Executive summary

This Sealing Technology - BAT (Best Available Techniques) Guidance Notes document reflects an information exchange carried out within the sealing industry under Article 16(2) of Council Directive 96/61/EC. This Executive Summary is intended to be read in conjunction with BAT chapters which are relevant for any particular application.

For the purposes of BAT information exchange, this document has been divided into sectors of equipment found typically at industrial sites which are likely to be covered by Council Directive 96/61/EC. 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 BAT document contains a mixture of generic and detailed information on typical industrial processes. The remainder of the document is arranged as follows:

Preface (Chapter 2)

This Chapter provides basic details and obligations about Council Directive 96/61/EC, including the definition of BAT and how to use this document. For guidance throughout this document, bullet points are used as follows:

- ⚐ ***warning – this is where the challenges may arise***

- ☑ ***recommendation – use these approaches to achieve BAT***

General introduction (Chapter 3)

This Chapter describes the challenge of industrial emissions in general, with a focus on, and definition of, fugitive emissions. This Chapter also has particular reference to fugitive emissions of Volatile Organic Compounds (VOC's).

Generic BAT for sealing technologies (Chapter 4)

This Chapter provides an overview of generally available techniques and their application to generic processes. It includes details of good operating practices and focuses especially on **key sources of leaks**. Generic BAT for sealing technologies includes:

- ☑ ***comprehensive training of all appropriate personnel on correct installation plays a vital role***
- ☑ ***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***
- ☑ ***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***
- ☑ ***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 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***
- ☑ ***quantify VOC emission sources with the idea of identifying the main emitters in each specific case***
- ☑ ***focus on the high emitters first of all***
- ☑ ***execute an ongoing LDAR programme***
- ☑ ***route relief valves to flare and add rupture disks***
- ☑ ***route off-gases to flare system (also as part of an odour abatement programme)***
- ☑ ***install flare gas recovery***
- ☑ ***install a maintenance drain-out system to eliminate open discharges from drains***

BAT for bolted flange connections (Chapter 5)

This Chapter focuses on the sealing of pipe connections, providing advice on the variety of technologies available and the key details about how to ensure good sealing performance. BAT includes:

- ☑ ***minimise the number of flanged connections***
- ☑ ***use welded joints rather than flanged joints where possible***
- ☑ ***fit blind flanges to infrequently used fittings to prevent accidental opening***
- ☑ ***use end caps or plugs on open-ended lines***
- ☑ ***ensure gaskets are selected appropriate to the process application***
- ☑ ***ensure the gasket is installed correctly***
- ☑ ***ensure the flange joint is assembled and loaded correctly***
- ☑ ***instigate regular monitoring, combined with a repair or replacement programme***
- ☑ ***focus on those processes most likely to cause emissions (such as gas/light liquid, high pressure and / or temperature duties)***
- ☑ ***for critical applications, fit high-integrity gaskets (such as spiral wound, kammprofile or ring joints)***

BAT for rotodynamic equipment (Chapter 6)

This Chapter focuses on the sealing of rotating shafts (such as in pumps, compressors and agitators). BAT includes:

- ☑ ***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***
- ☑ ***Selection of appropriate mechanical sealing technology based on required maximum leakage control levels and with consideration of process fluid characteristics***

- ☑ ***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"***
  close collaboration between the user and seal manufacturer can provide the most economical sealing solution

BAT for reciprocating shafts (Chapter 7)

This Chapter focuses on the sealing of equipment with reciprocating shafts. BAT includes:

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

BAT for valves (Chapter 8)

This Chapter focuses on the sealing of valves, usually considered to be the greatest challenge for fugitive emissions. BAT includes:

- ☑ ***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***
- ☑ ***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***

Glossary of sealing terms (Chapter 9)

This Chapter contains an alphabetical listing of special features and technical terms which are of common usage in sealing technology terminology.

Conversion factors (Chapter 10)

This Chapter covers the International System of Units (Le Système International d'Unités, or SI units) and gives equivalent conversions into SI units (and other units where appropriate) for **non-SI units** which are used regularly in connection with sealing terminology.

Further reading (Chapter 11)

This Chapter provides a listing of appropriate ESA technical documents which form the basis for this particular publication on BAT.

References (Chapter 12)

This Chapter is a listing of references cited throughout this publication.

2. Preface

This document is a publication of the European Sealing Association. It is not an official publication of the European Communities and does not necessarily reflect the position of the European Commission. Unless otherwise stated, the terms ***"the Directive"*** and "***the IPPC Directive***" in this document refer to the Council Directive 96/61/EC on integrated pollution prevention and control.

2.1. Relevant legal obligations of the IPPC Directive

Some of the most relevant provisions of the IPPC Directive, including the definition of the term "best available techniques", are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, 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 of such an integrated approach must be 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 3 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.

2.2. Definition of BAT

The term "***best available techniques***" is defined in Article 2(11) of the Directive as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole." Article 2(11) goes on to clarify further this definition as follows:

> "***techniques***" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
>
> "***available***" techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
>
> "***best***" means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV 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". These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) 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 minimisation of long-distance or trans-boundary pollution and must ensure a high level of protection for the environment as a whole. Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

2.3. Objective of this Document

The aim of this document is to provide reference information for industrial sectors, to enable them to comply with the requirements of the IPPC Directive. The document also aims to provide reference information for appropriate permitting authorities to take into account when determining permit conditions. By providing relevant information concerning best available techniques, this document should act as a valuable tool to drive environmental performance.

2.4. Information Sources

This document represents a summary of information collected from a number of sources, including in particular the expertise of the sealing industry in Europe. All contributions are gratefully acknowledged.

2.5. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations. Consequently, the techniques and levels 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 minimisation 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.

For guidance throughout this document, bullet points are used as follows:

- ⚐ ***warning – this is where the challenges may arise***
- ☑ ***recommendation – use these approaches to achieve BAT***

Other bullet points are used as appropriate.

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

3. General introduction

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, and will not be considered in detail here.

However, a proportion of industrial emissions occurs through unanticipated or spurious leaks in process systems. From this, it is apparent 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, 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 IPPC Directive.

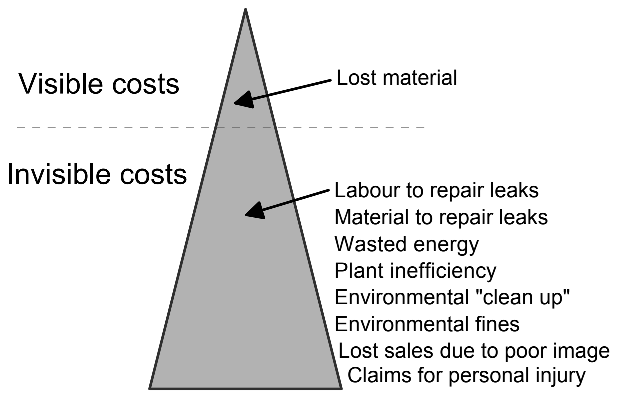
3.1. Fugitive emissions

The term "fugitive emissions" covers all losses of (usually volatile) materials from a process plant, through evaporation, flaring, spills and unanticipated or spurious leaks. It is often defined as; ***any chemical, or mixture of chemicals, in any physical form, which represents an unanticipated or spurious leak, from anywhere on an industrial site***.

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 inevitably mirrored in Europe. 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***
- ***inspection and maintenance routine***
- ***rate of production***



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.

3.2. 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 IPPC 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 IPPC Directive. These include the latest refinements of the TA-Luft (D), and VDI 2440 (D) on emission reduction in mineral oil refineries[27]. The reader is advised to refer to these items as appropriate.

3.3. 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:

- ***agitators / mixers***
- ***compressors***
- ***flanges***
- ***pumps***
- ***tank lids***
- ***valves***

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 for the operator, although such leakages may still present hazards (such as leakages of high pressure water or steam). Clearly, in the latter case it is not only financially inefficient but also environmentally dangerous; for employees, members of the public and for nature at large! Consequently, the correct selection and use of the appropriate sealing technology for the application is just part of the environmental responsibility of the plant operator.

Although losses per piece of equipment are usually very small, there are so many items of equipment on a typical Large Volume Organic Chemical (LVOC) plant or petrochemical refinery that 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.

It has been estimated that for every pump on an average plant, there will be 32 valves, 135 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:

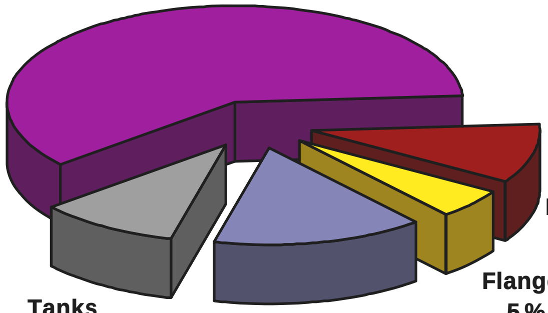
- ***ill-fitting internal or external sealing elements***
- ***installation or construction faults***
- ***wear and tear***
- ***equipment failure***
- ***pollution of the sealing element***
- ***incorrect process conditions***

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. 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 more frequently than quarter turn type valves such as ball 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.***



Although out of the main scope of this document, it must 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, as part of pollution prevention and good operating practice.

3.4. 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. These properties mean that VOC's are a major contributor to the formation of "summer smog". 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.

For example, a system developed in the UK Environment Agency identifies three classes of VOC and requires a commensurate level of prevention and control for each class. The three classes are:

- ***extremely hazardous to health*** *(such as benzene, vinyl chloride and 1,2 dichloroethane)*
- ***class A compounds****, which may cause significant harm to the environment (for example, acetaldehyde, aniline and benzyl chloride)*
- ***class B compounds****, which have lower environmental impact.*

Some VOC's may also be highly odorous, for example aldehydes, amines, mercaptans and other sulphur-containing compounds. This may necessitate additional stringency in the prevention measures (e.g. high integrity equipment to reduce fugitives) and the abatement of losses.

VOC emissions typically arise from: process vents; the storage and transfer of liquids and gases; fugitive sources and intermittent vents. Losses are greatest where the feedstock or process stream is a gas; in these cases VOC losses can exceed 2 % of total production.

On many installations, there has been a focus on the control of point sources of VOC's over recent years 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.

4. Generic BAT for sealing technologies

In a formal BREF note (also known as BAT Reference note) approved by the European Commission, usually this chapter provides a catalogue of techniques which can be used to prevent and control emissions from the specific process in question. However, this is not possible for the many sealing technologies employed across the variety of industrial processes covered by IPPC. Instead, this section provides an overview of generally available techniques and their application to generic processes. In reading this chapter, reference should also be made to relevant horizontal BREF's, especially the BREF on emission monitoring, describing the techniques which may be used across all industrial sectors.

In most cases, processes will maximise environmental protection with sealing technology by using a combination of management commitment, training, plant design, selection of the optimum sealing technology for the application, monitoring, inspection, maintenance and repair. Some of these concepts are described in detail throughout the industry-specific BREF notes, and so will be mentioned only briefly here. The chapter therefore considers techniques involving**: good operating practices, management systems, training, process design, maintenance, monitoring, determining leaking losses, key sources of leaks, spill and leak prevention, and volatile organic compounds.**

4.1. Good operating practices

The IPPC Directive definition of best available techniques strongly emphasises the presumption for preventative techniques over other methods. The prevention of pollution is just part of good operating practices, which are techniques involving management, organisation or personnel. Good operating practices can often be implemented quickly, at little cost, and bring efficiency savings with a high return on investment.

Prevention offers a ***precautionary***, rather than curative, approach to environmental protection. As such, it is compatible with the principle of "sustainable development". Many companies have already shown that the creative use of pollution prevention techniques not only minimises environmental impact, but also improves efficiency and increases profits.

The points which follow in this section on generic BAT for sealing technologies are **all** part of good operating practices.

4.2. Management systems

In order to minimise the environmental impact of any process, it is necessary to appreciate the central role of effective management systems. **The purchase of state-of-the-art hardware does not automatically guarantee the best environmental performance since it must also be installed and operated correctly**. Likewise, the limitations of older equipment can often be mitigated by diligent operation. The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of "techniques" as *"both the technology used and the way in which the installation is designed, built, maintained, operated, and decommissioned".*

An Environmental Management System (EMS) is that part of the overall management system which includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the management and operation of a process. Effective environmental management involves a commitment to continuous environmental improvement through a cyclical system of: gathering and analysing data, establishing objectives, measuring progress and revising the objectives according to results.

Management action is crucial in the motivation of personnel and this appears to be an important factor in the overall emission abatement of leaking losses. Management practices should also include a clear specification to employees of what ***good practice*** actually entails.

4.3. Training

Appropriate training should be given to all staff involved in process operation to ensure that they are competent for their duties. The training should include the environmental implications of their work and the procedures for dealing with incidents. This is crucial for the correct selection, installation and performance of sealing systems. It is equally important that sub-contractors, who may be responsible for maintenance work, or installation of sealing systems during plant shutdown, should be fully trained in the handling and installation of sealing materials. A number of relevant guidebooks on the selection, handling and installation of sealing materials are available from the European Sealing Association (see ***11. Further reading***).

Ensure environmental awareness is included in training programmes. Records should be kept of the training given to staff and these should be reviewed periodically to ensure that they reflect the needs of the job and the latest technologies.

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***

4.4. 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***

4.5. 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.

4.6. 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 faults***
- ***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 EPA Method 21).

Monitoring has been identified as a common activity across IPPC processes and is the subject of a horizontal BREF note, entitled, "***Monitoring of Emissions***". The document provides generic information on sampling and analysis, and should be read in conjunction with other industry-specifc 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 BAT 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.

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.

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[26] (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.

4.7. Key sources of leaks

The main potential sources of leaks, and possible reduction techniques, are considered below, in alphabetical order:

4.7.1. Compressors

Lower speed, **positive displacement compressors** are typically sealed by a barrier oil lubricated, mechanical seal and emissive leakage is low; containment sealing arrangements are used in many services. The larger, higher speed **centrifugal compressors** may have high leaking losses. The change to gas lubricated single seals with an outer containment seal has enabled improved reliability and the management of primary seal emissive leakage to a flare or recovery system. Various externally supplied gas purges are used with both types of machinery. Regular control and maintenance is indispensable.

4.7.2. Flanges

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. Preventative measures, among which correct selection of the gasket and regular maintenance (e.g. controlled tightening of the flange), are very important. The regular control and replacement of the gaskets is also necessary, especially for those gaskets exposed to temperature fluctuation or vibration (where gasket load may be lost). When a removable connection is not necessary, flanges can be replaced by welded piping. When welding is not possible, a conventional gasket may be replaced by one providing a higher level of sealing integrity.

4.7.3. Open-ended lines

Emissions from open-ended lines can be controlled by installing a cap, plug or second valve at the open end. If a second valve is installed, the upstream valve should always be closed first after use of the valves to prevent the trapping of fluids between the valves.

4.7.4. Pipe work

Leaking losses in pipe work can be reduced at the design stage by arranging equipment to minimise the pipe run length, eliminating underground piping (or design with cathodic protection) and using lined pipe. Once in place, pipe work leaks can be minimised by painting to prevent external corrosion and regular monitoring for corrosion and erosion. Releases when cleaning lines should be minimised by using “pigs” for cleaning, sloping pipe work to low point drain, using heat tracing and insulation to prevent freezing and flushing to product storage tank or treatment facility.

4.7.5. 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 sealing 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)
Sealless drive systems

Gland packing leaks more than the mechanical seals in rotodynamic pumps, and for this reason and reliability issues, is not used generally in services where emissions must be avoided. It is sometimes used in some slow speed equipment. Single mechanical seals can provide adequate sealing of emissive VOC process liquids but improvements can be achieved with the addition of a mechanical containment seal and even better results are obtained with a dual mechanical seal (a barrier liquid between the two mechanical seals which almost completely prevents leaking losses). Leakage losses may also be reduced by replacing conventional pumps with sealless pumps. These pumps have a completely closed construction which prevents leaking losses almost completely but they may be restricted in application by the process properties. Their lower energy efficiency compared to conventional pumps and the upstream influence on power generation may restrict the wider usage of this technology.

4.7.6. Safety valves

Safety valves can be responsible for 10 % of a plant's leaking 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).

4.7.7. Sampling points

Emissions from sampling connections can be reduced by using a closed-loop sampling system or by collecting the purged process fluid and transferring it to a control device or back to the process.

4.7.8. Tank lids

There are numerous static sealing applications, such as tank lid seals, which are used extensively in ships and lorries (primarily for the transportation of media) and they are also used in housing seals in chemical plants and refineries. In general, these static seals do not have high leakage amounts, but are likely to be a larger contributor than flanges and, as such, they do contribute to the overall emission level. As they are opened and closed from time to time, these seals should be checked for integrity of fit and wear, and replaced on a regular basis.

4.7.9. Valves

Valves, and especially control valves, are an important source of leaking losses, and may account for 75 % of the leaking losses in a plant. The chance of leakage depends on the kind of valve. Diaphragm valves, ball valves and, above all, bellows-sealed valves, offer better sealing characteristics than other types.

The stuffing box packing has a dominant influence on valve leaking losses, especially in disc valves. For processes containing hazardous fluids, conventional packings can be replaced with ***low emission packings*** made from advanced technology materials and constructions.

4.8. 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***

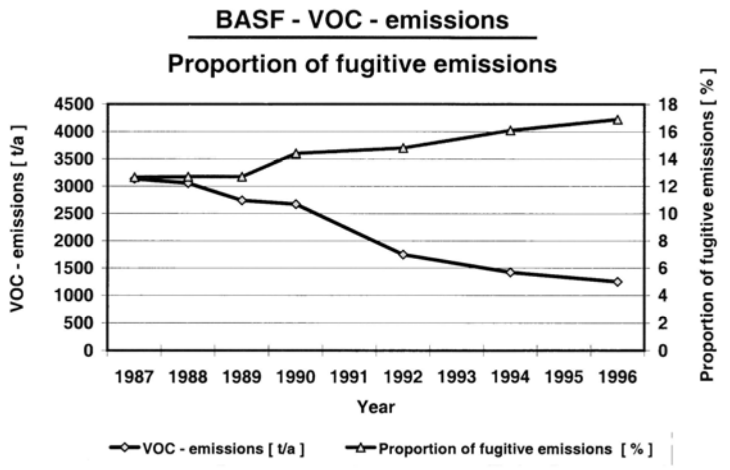
Along with improved process design, operation, monitoring and maintenance (all identified above), one of the key techniques which may be used to minimise leaking losses is to install **high integrity equipment**. For example:

- ☑ ***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 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***

4.9. Volatile Organic Compounds

As mentioned in the ***General Introduction*** section, volatile organic compounds (VOC's) are high priority species for emission reduction, as a consequence of their specific chemical and physical properties. They present a major challenge to sealing technology and, for this reason, a separate section has been included here on general minimisation techniques.

During the ESA's 2nd European Fugitive Emissions Conference in Düsseldorf in 1998, BASF reported [34] that in 1996, VOC fugitive emissions amounted to 17% of their total VOC emissions, so emphasising the priority for control.



The effectiveness and costs of VOC prevention and control will depend on the VOC species, the VOC concentration, the flow rate, and the source. Inevitably, resources are targeted initially at high flow, high concentration, process vents, but recognition should be given also to the cumulative impact of low concentration diffuse emissions.

In general, toxic VOC's should be replaced by less harmful substances as soon as possible, where this is technically and economically feasible. Where possible, it is also good practice to substitute volatile compounds with compounds that have a lower vapour pressure. Where this is not possible, the initial efforts should be to minimise losses and then to recover the calorific value of unavoidable emissions.

In many cases the VOC's in question are used as solvents in the process and the Solvents Directive provides useful guidance on the prevention and reduction of air pollution from solvent emissions.

In general, VOC's as such do not offer challenging sealing problems but every leak has to be considered in the context of the environment of the process equipment or pipeline which is being considered. The interaction between that environment and the seal may make the creation of a reliable seal far more complex than the medium alone would require.
In addition to the points noted above (***sections 4.7 and 4.8***), some general techniques to reduce VOC emissions are:

- ☑ ***quantify VOC emission sources with the idea of identifying the main emitters in each specific case***
- ☑ ***focus on the high emitters first of all***

- ☑ ***execute an ongoing LDAR programme***
- ☑ ***route relief valves to flare and add rupture disks***
- ☑ ***route off-gases to flare system (also as part of an odour abatement programme)***
- ☑ ***install flare gas recovery***
- ☑ ***install a maintenance drain-out system to eliminate open discharges from drains***

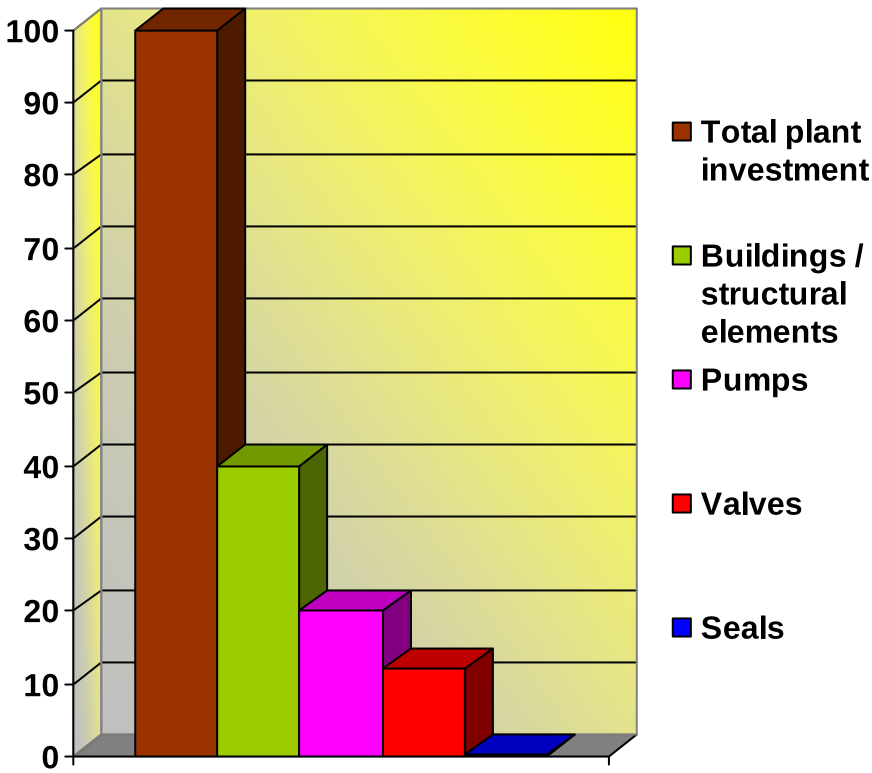
The investment cost for those techniques is negligible and the operating cost is around 0.1 M€/yr (accounting for 190 € per tonne of VOC recovered).

About 93% of the sources of fugitive emission are accessible. The achievable emission reduction depends on the current conditions of the components, with typical reduction rates of at least 50 to 75% related to average emission factors. The estimated efficiency for quarterly inspection and maintenance is 80 to 90%. Higher efficiencies may be reached, when more intensive inspection and maintenance programmes are implemented.

A good inspection and maintenance programme for valves and flanges is a very cost-effective way to reduce VOC emissions in a refinery. Savings may reach 0.19 €/kg of hydrocarbon reduced.

4.10 Relative costs of generic BAT for 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.



Source: *Valve World* and similar publications

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.

5. BAT for bolted flange connections

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 flanges, so enabling 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, BASF has reported [28] that emissions from flanges represent 28% of the total fugitive emissions from BASF 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.

5.1 Gaskets

Historically, **c**ompressed **a**sbestos **f**ibre sheet material (CAF) has been the material of choice for "soft" gasket materials. It was regarded as easy to use and very tolerant of abuse, for which it was recognised as very "forgiving". Consequently, the material was used to seal almost all common applications, and usually gave performance which was deemed satisfactory at that time. A broad experience of the material was established over many years amongst manufacturers and users alike.

More recently, with the ban on the use of asbestos fibres, a new generation of asbestos-free substitutes has been developed by the sealing industry. These provide improved levels of sealing performance, although they are usually more application specific than the earlier asbestos materials. Equally, handling of these new materials requires more care in general. Overall, these new materials can outperform their asbestos predecessors, but are usually less forgiving; users must exercise more care in selecting the right material for the job and assembling the seal.

Over time, alternative gasket styles have been developed, especially for more severe services, and these include the "hard" gasket types, primarily of metallic or semi-metallic construction. These offer users even more choice in higher performance sealing technology for the application.

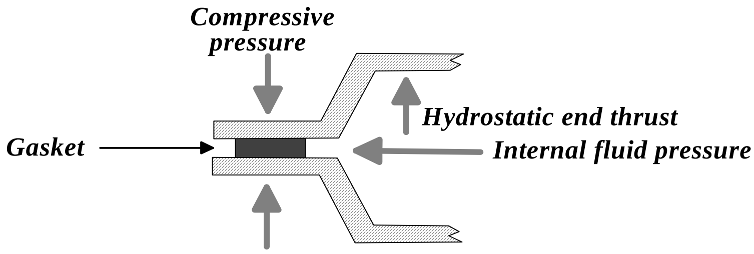
Useful guidance notes on gasket selection and installation are available in a recent publication from the ESA, ***Guidelines for safe seal usage - Flanges and Gaskets*** (ESA publication n$^{o.}$ 009/98), available in several language versions.

A gasket is used to create and retain a static seal between two stationary flanges, which may connect a series of mechanical assemblies in an operating plant, and which may contain any one of a wide range of fluids. These static seals aim to provide a complete physical barrier against the fluid contained within, and so block any potential leakage path. To achieve this, the gasket must be able to flow into (and fill) any irregularities in the mating surfaces being sealed, while at the same time be sufficiently resilient to resist extrusion and creep under operating conditions. The seal is effected by the action of force upon the gasket surface, which compresses the gasket, 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 fluid from the assembly. As such, gaskets are vital to the satisfactory operation of a broad range of industrial equipment and must be regarded as an integral design element of the whole plant.

On seating, a gasket must be capable of overcoming minor alignment and flange imperfections, such as:

- ***non-parallel flanges***
- ***distortion troughs / grooves***
- ***surface waviness***
- ***surface scorings***
- ***other surface imperfections***

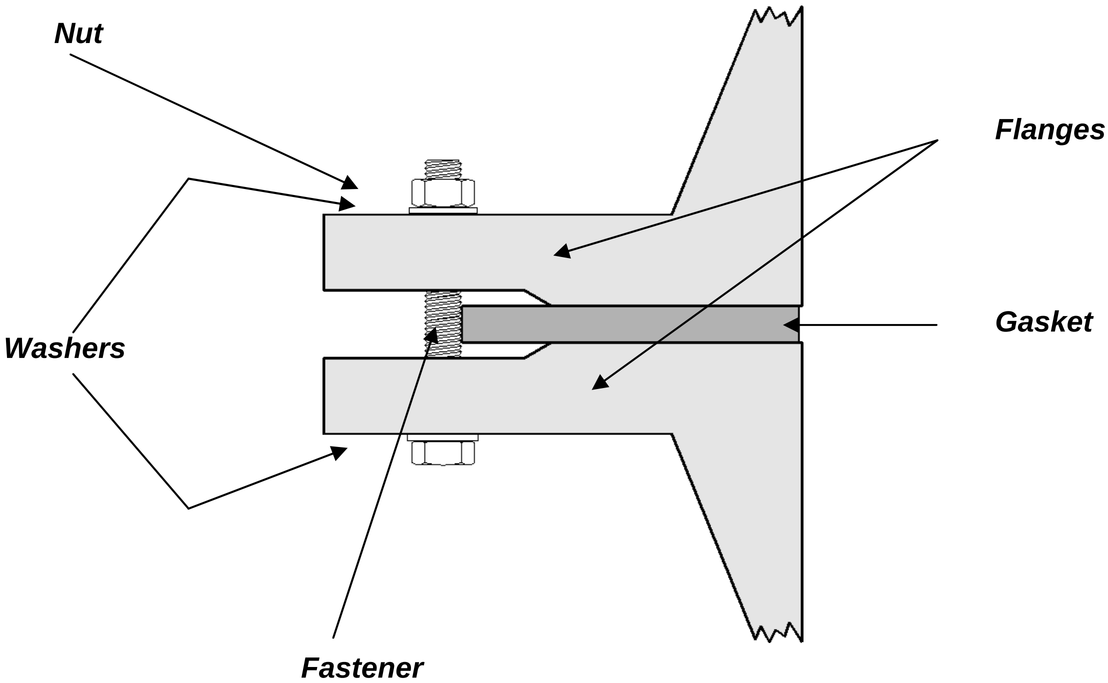
When assembled, a flange gasket seal or 'joint" is subject to compressive pressure between the faces of the flanges, usually achieved by bolts under tension. In order to ensure the maintenance of the seal throughout the lifetime of the assembly, sufficiently high pressure must remain on the gasket surface to prevent leakage. Under operating conditions, this pressure will be relieved by *hydrostatic end thrust*, the force produced by internal pressure which acts to separate the flanges. The gasket itself is also subject to a side load due to the internal fluid pressure tending to extrude it through the flange clearance space. To maintain seal integrity, 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 some multiple, dependent upon the gasket type, manufacturing process involved and level of tightness required. For soft gaskets, there must also be adequate friction between the gasket and flange faces to help prevent extrusion (blow-out) of the gasket from the joint. To allow for any relaxation of gasket compressive pressure which is normally inevitable, a factor of at least two is usually recommended between the compressive pressure on the assembly and that required to maintain a seal. A number of publications [3, 4, 5, 6] provide more detail of the flange / gasket interaction.



So, the primary function of a gasket is to create and maintain a seal between flanges, under conditions which may vary markedly from one joint to another, dependent upon the nature and type of application. 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, including:

Application	Flange arrangement	Gasket
Pressure of media	Configuration / type	Blow out resistance
Temperature of media	Surface finish	Creep resistance
Chemical reactivity of media	Material	Stress relaxation
Corrosive nature	Available bolt load	Ability to recover / elasticity
Searching ability of media	Likelihood of corrosion / erosion	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
		Sealability
		Combined pressure temperature resistance

Importantly, for all of these systems, the performance of the seal depends upon the interaction of the **various elements of the flange joint system:**



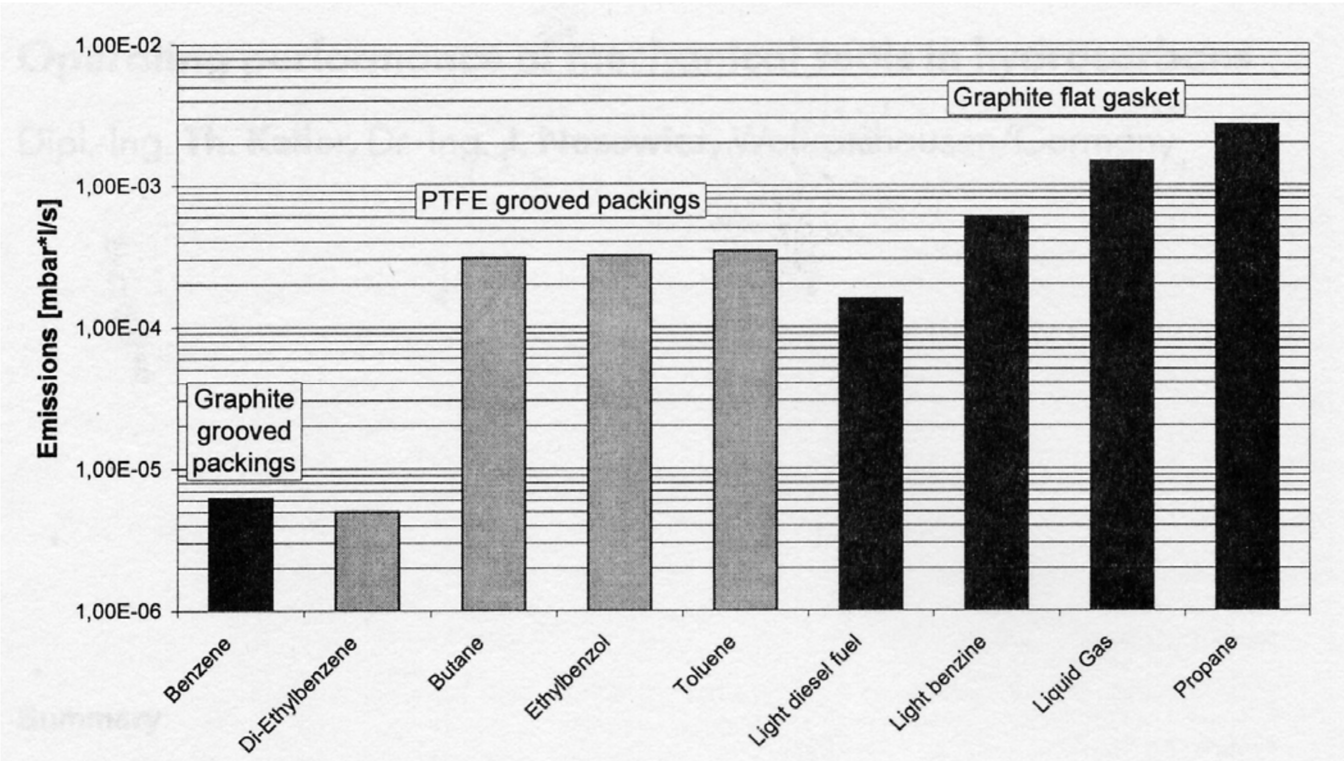
Only when all the components of the system are working together in harmony can the seal be expected to provide a good performance over a reasonable lifetime. The integrity of a safe seal depends upon:

- ☑ ***selection of correct components appropriate for the application***
- ☑ ***careful preparation, cleaning, installation and assembly***
- ☑ ***correct bolt tightening and loading***
- ☑ ***regular inspection***

The behaviour of a flanged joint in service depends on whether or not the tension created in the fasteners will clamp the joint components together with a force great enough 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*). Although there may be some plastic deformation in the threads when a fastener is tightened normally, especially on the first tightening, most of the joint components respond elastically as the nuts are tightened. Effectively, the entire system operates as a spring, with the fasteners being stretched and the other joint components being compressed.

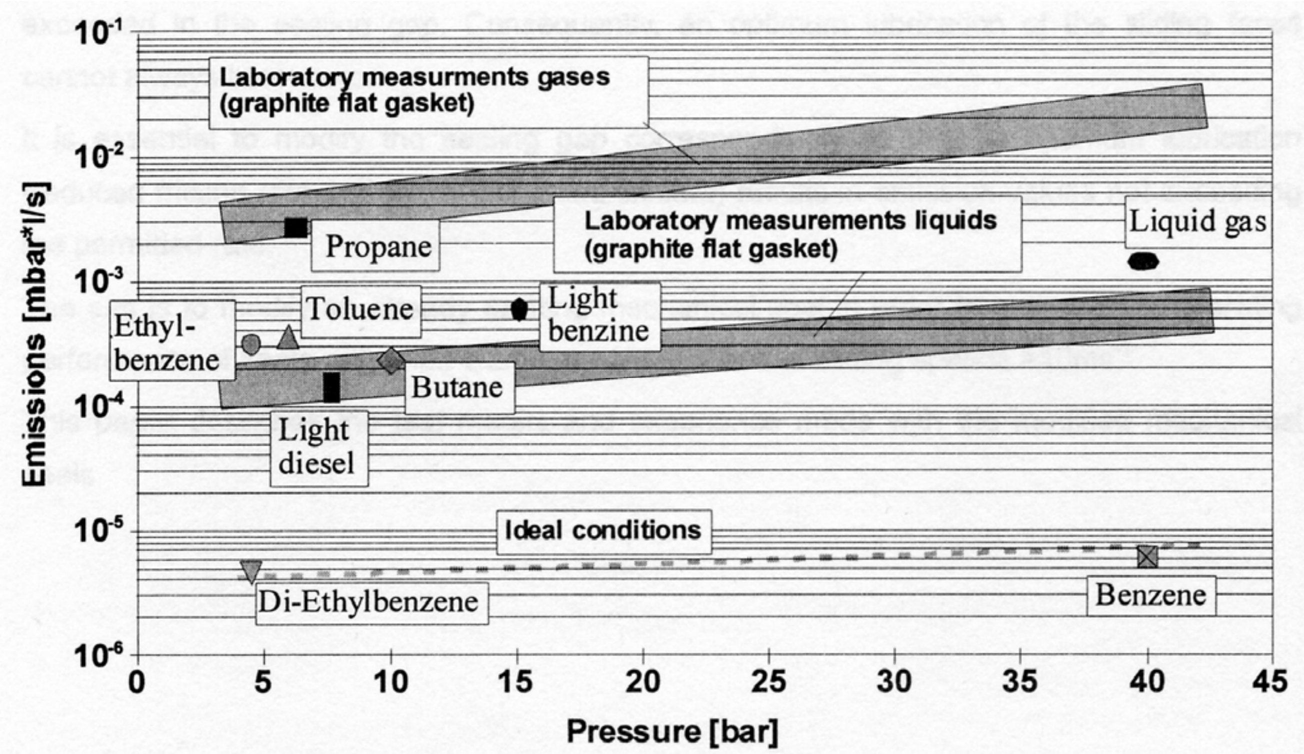
5.2. Current emission levels

Typical emission levels experienced today were reported[1] in the ESA's 2nd European Fugitive Emissions Conference, which was held in Düsseldorf in September 1998. The project was conducted by a team from the University of Dortmund.

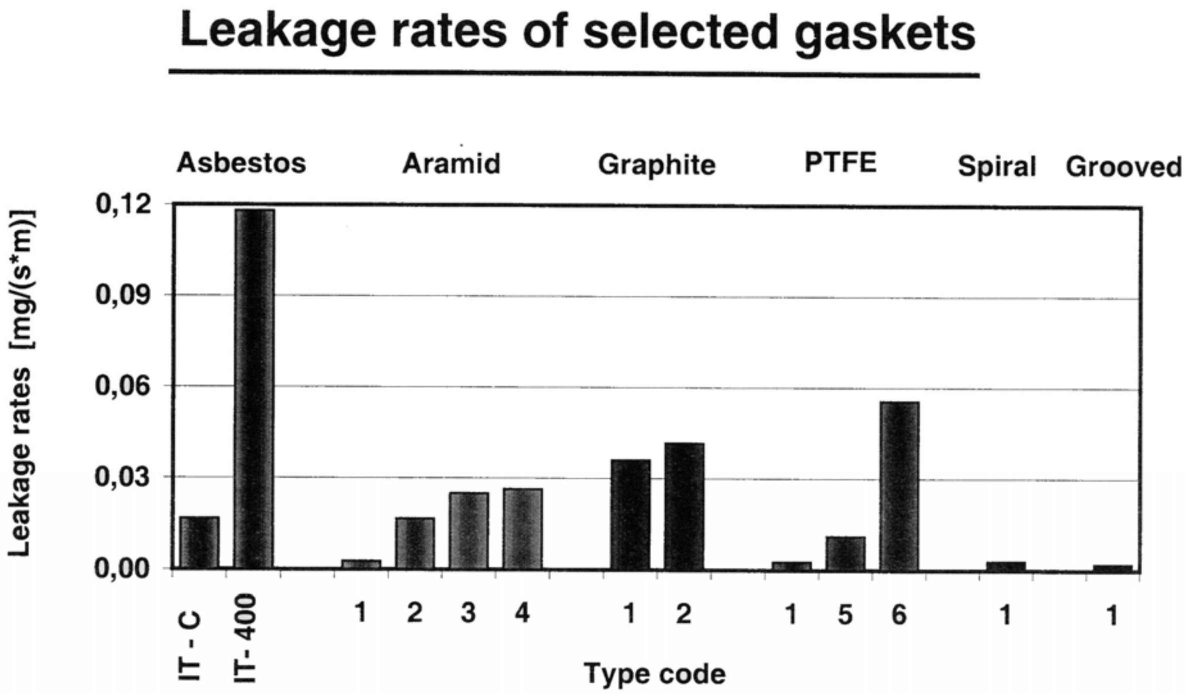


Readings were taken on flanges of various process installations at a chemical plant.

These results were compared with laboratory checks on the same type of flange gasket systems:



A similar study was conducted by BASF and the results were also reported [28] during the ESA's 2nd European Fugitive Emissions Conference. This study had run in parallel to the Brite Euram Project, which focussed on gathering data on asbestos-free gasket materials (note, in this chart IT-C and IT-400 refer to particular grades within the former DIN 3754):



For more information about leakage rates of gasket types, please refer to EN 1591, part 2 (data generated according to EN 13555). For specific performance details and recommendations for particular applications, **please consult the manufacturer**.

5.3. Gasket selection

Primarily, selection must be based upon:

- *sealing capability, appropriate to the application*
- *compatibility with the operating medium (process fluid)*
- *operating temperature and pressure*
- *variations of operating conditions (for example, during cycling)*
- *the type of joint involved*

A word of caution; despite the similarity of many materials, the properties of the seal, and performance achieved, will vary from one manufacturer to another. **Always consult the manufacturer for detailed guidance on specific products and their applicability**.

☑ ***importantly, always use a good quality gasket from a reputable supplier, because the cost of a gasket is insignificant when compared to the cost of downtime or safety considerations.***

Gaskets can be defined into 3 main categories:

- *soft (non-metallic)*
- *semi-metallic*
- *metallic*

The mechanical characteristics and sealing performance capabilities of these categories will vary extensively, depending on the type of gasket selected and the materials from which it is manufactured. Obviously, mechanical and sealing properties are important factors when considering gasket design, but the selection of a gasket is usually influenced primarily by:

- *temperature and pressure of the medium to be contained*
- *chemical nature of the medium*
- *mechanical loading affecting the gasket*
- *sealing characteristics of the gasket*

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.* *Types include: fibre reinforced sheet, exfoliated graphite, sheet PTFE in various forms and high temperature sheet materials based upon forms of mica.*
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, covered metal jacketed, covered corrugated metal, metal eyelet, metal jacketed, metal reinforced soft gaskets (including tanged graphite and wire reinforced fibre materials), corrugated metallic and spiral wound gaskets*
Metallic gaskets	*Can be 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 and weld rings*

The gasket must be resistant to deterioration from the fluids being sealed, and it must be compatible chemically and physically. For gaskets which are electrically conductive, consideration must be given to electrochemical (or “galvanic”) corrosion, which can be minimised by selecting gasket and flange metals which are close together on the electrochemical series. This type of corrosion is an electrochemical process occurring in the presence of an ion-conducting medium, which may be an aqueous solution made conductive by dissolved ions. The base element is dissolved in a redox process, in which electrons emitted by the base element (anode) are taken into solution and deposited on the noble element (cathode).

For gaskets cut from sheets, always use the thinnest material which the flange arrangement will allow, 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 the longer the service life of the gasket. Also, the lower the gasket area which will be exposed to attack from the internal pressure and aggressive media.

5.4. Storage and handling of gaskets and gasket materials

Although many gasket materials can be used safely after storage for many years, ageing will have a distinct effect on the performance of certain types of gasket materials, resulting from chemical degradation which occurs over time. Primarily, this is a concern with materials which are bonded with elastomers, which, in general, should not be used after about 4 years from the date of manufacture. Those materials with elastomeric binders will inevitably deteriorate over time, and even more quickly at higher ambient temperatures. Degradation is also catalysed by intense sunlight. Although this is of little concern with metallic gaskets, it may have an effect on semi-metallic gaskets (specifically, those which are combined with elastomer-bound materials). Since graphite and PTFE materials contain no binders, sheets and gaskets of these materials have a virtually indefinite shelf life.

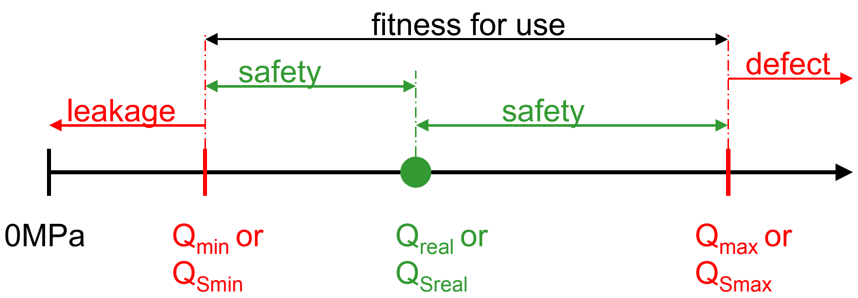
The condition of the gasket plays an important part in its performance. Some gasket materials are relatively robust (such as metallic gaskets), others are reasonably forgiving (such as PTFE), but others may be very brittle or prone to cracking. Consequently, all gaskets and gasket materials are best handled with the same care and attention. Bent, nicked, gouged, scratched or hammered gaskets will rarely seal effectively! When working in the field, carry cut gaskets carefully, ideally within some form of protective cover. Although carrying small gaskets in a pocket is a common practice, it is best avoided! If you bend the gasket it will be damaged. If it picks up debris from the inside of your pocket or elsewhere, it may scratch the surface and so create a leak path.

Never re-use a gasket, since it may have been modified dramatically under operating conditions and hence cannot guarantee the required level of sealing performance. Even if the gasket appears to be okay, it is not worth taking a risk! The cost of a new gasket is minuscule when compared with the cost of down time caused by a leak or blow-out and the considerations of safety and environmental protection.

Similarly, bolts or studs may have been damaged due to corrosion, or may have lost ductility by being tightened past yield; if you cannot be sure - do not take the chance! Consequently, never re-use gaskets or fasteners.

5.5. Assembly procedures

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, the hardness, the lubricity of surfaces, the calibration of the tools, the accessibility of the fasteners, the environment in which the engineers must operate ....



Most importantly, it is a good idea to be consistent. If your present practices follow recommended procedures (according to the ***Guidelines for safe seal usage***) and have proved robust, then don't change them! You should aim to keep the number of variables to a minimum. If possible, use the same tools in the same manner.

5.5.1. Tools required

You will require tools to both clean the flange and tension the fasteners. The tensioners will require regular calibration and may include torque wrench, hydraulic or other tensioners. Instruments to measure tension may include a micrometer, or ultrasonics.

Generally, this can be a pretty messy job! Therefore you will need appropriate clothing (protective clothing where necessary), safety helmet, safety goggles, gloves, and a security pass to the area, as appropriate.

5.5.2. Cleaning

To ensure good seal performance, all load-bearing surfaces must be clean:

- ***Fasteners / nuts / washers*** — *- clean with a wire (ideally brass) brush to remove dirt on the threads*
- ***Flange assembly*** — *- clean gasket seating surfaces with suitable implements (see below)*

On opening the flange and removing the previous gasket, the flange faces will often be contaminated with fragments of the old gasket material, which must be removed before a new gasket can be safely installed. Suitable implements for cleaning the faces of a flange may include a wire brush (use stainless steel bristles on alloy components). However, always brush in the direction of the grooves (rather than perpendicular to them), in order to minimise undue wear. Inevitably, use of a wire brush will result in wear across the faces over time. Consequently, other tools have been developed, such as the ***brass drift***. This concept is based upon the use of a softer material (brass) than the flange surface (usually steel) to avoid damage. A suitable drift can be made from a sheet of brass, ~5 mm (0.2 in) thick x 50 mm (2 in) wide, which is filed and shaped to a 45° chisel across the width. Using a hammer, lightly tap the drift into the flange grooves to remove debris.

5.5.3. Visual inspection

All load-bearing surfaces must be free from any serious defects. Even a perfect gasket will be unable to seal a badly damaged or warped flange:

- ***Fasteners / nuts / washers*** — *- examine after cleaning to assure freedom from defects, such as burrs or cracks*
- ***Flange assembly*** — *- inspect the flange surfaces for defects, such as radial scores and warping*
  - ensure the flange surfaces are sufficiently flat and parallel
- ***Gasket*** — *- check that the correct gasket is available (suitable for the service, size, thickness)*
  - examine the gasket prior to installation to ensure it is free from defects

If any defects are observed, don't take chances!

☑ ***replace defective components with a good alternative. If in doubt, seek advice***

Note that for spiral wound gaskets in particular, the flatness and parallelism of the flanges are important factors for good sealing performance:

- **flange surface flatness** should vary by less than 0.2mm over the gasket seating width
- **flange surface parallelism** should be less than 0.4mm total out of parallel across the whole flange

5.5.4. Lubrication

It is estimated that, in the absence of a suitable lubricant, up to 50% of the torque effort may be used to merely overcome friction. Effectively, this would mean that the same torque applied to non-lubricated fasteners on a joint might provide markedly different loads on each one! Therefore, lubrication is essential when torque is used as the control for setting tension in the joint.

When selecting a lubricant, the following factors should be considered:

- ***lubricity*** — *- the better the lubricant, the lower will be the effect of friction*
- ***compatibility*** — *- the lubricant must be compatible with the fastener materials (including nuts and washers), and ideally also with the process fluid. For example, copper-based lubricants may contaminate the process fluid, while chlorides, fluorides and sulphides may contribute to corrosion of the fastener materials (including nuts and washers)*
- ***temperature*** — *- ensure the recommended service temperatures of the lubricant are within the process service temperature limits*

The following procedures are recommended:

- ☑ ***lubricate fastener threads and all bearing surfaces (underside of bolt heads, nuts, washers)***
- ☑ ***use only specified or approved lubricants***
- ☑ ***apply the lubricant in a consistent manner as a thin, uniform coating (avoid "lumps" of lubricant as this may reduce the efficiency)***
- ☑ ***ensure lubricant does not contaminate either flange or gasket faces***
- ☑ ***avoid contamination of the lubricant (store in a closed container). After use, store in a "clean" area***
- ☑ ***avoid contaminating the gasket with the lubricant***

5.5.5. Gasket installation and centralisation

Prior to installation, ensure that the flange components are correctly assembled and the flange mating surfaces are parallel.

- ☑ ***carefully insert the new gasket between the flanges to prevent damage to the gasket surfaces***
- ☑ ***for large diameter spiral wound gaskets, seat the gasket in its mounting on the flange, remove securing straps, then slide the gasket from its mounting onto the flange using an appropriate number of persons to avoid damage to the gasket***
- ☑ ***ensure the gasket is central in the flange***
- ☑ ***do not use tape to secure the gasket to the flange. If it is necessary to secure the gasket to the flange, use a light dusting of spray adhesive (e.g. 3M type 77)***
- ☑ ***do not use jointing compounds or release agents, as these would reduce the friction between flange faces and gaskets, leading to extrusion of the gasket***
- ☑ ***line up the joint components (including the flanges and the gasket) and examine them to ensure that an acceptable fit has been obtained***
- ☑ ***take care when bringing the flanges together, to ensure that the gasket is not pinched or otherwise damaged***

5.5.6. Calculation of torque

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 remains the most popular method to control joint tightening. When using torque tightening methods, there are 3 main factors to take into account in order to ensure that the required forces are produced:

Factor 1	**+**	**Factor 2**	**+**	**Factor 3**
(torque applied to load the fastener)		(torque applied to overcome thread friction)		(torque applied to overcome friction at the nut)

These factors include the pre-load on the fastener spot face. Factors 1 and 2 include the dimension of the thread and Factor 3 includes the dimension of the nut. Factors 2 and 3 also include the coefficient of friction between these surfaces, which is dependent upon the type of lubricant used.

It must be emphasised that friction makes a significant contribution to the torque which must be applied, and hence the use of specified lubricants is crucial for good torque control. Values for the coefficient of friction provided by the lubricant must be known, in order to establish the fastener load accurately. Torque may be represented (in either metric or imperial units):

$$T = W\left[\frac{P}{2\pi} + \frac{R_e \mu}{\cos\theta} + R_s \mu\right]$$

- $\frac{P}{2\pi}$: Incline plane (constant)
- $\frac{R_e \mu}{\cos\theta}$: Thread friction at effective radius (variable)
- $R_s \mu$: Nut friction at spot face mean radius (variable)

where:
T = Torque
W = Force
P = Thread pitch
θ *= ½ Thread included angle*
R_e *= Effective thread radius*
R_s *= Nut spot face mean radius*
μ *= Coefficient of friction*

In simplified form, for lubricated fasteners, washers, nuts etc., the relationship between torque and fastener load may be represented as:

$T = L \times 0.2 \times db$ where: T = torque per fastener in N.m (in-lbf)
L = load per fastener in kN (lbf)
db = nominal diameter of fastener in mm
0.2 = factor of loss due to friction

Note also that the factor of 0.2 may vary considerably. It may be increased to 0.3 for non-lubricated systems, or reduced to 0.15 for lubricants with a low coefficient of friction.

The performance of the seal is largely dependent upon the correct level of tension in the fastener. Remember that for maximum effectiveness, the load on the fastener should be kept within its elastic region.

Other points to consider:

- ***the crushing strength of the gasket material***
- ***hydrostatic end thrust will increase the fastener tension under the operating internal pressure***
- ***using a fastener stress which represents less than 50% of yield may cause problems***
- ***most flanges are tightened by ordinary wrenching methods, and it is advantageous to have design stresses which can be achieved with this! (often impossible for larger diameter fasteners)***

5.5.7. Bolt / stud tightening pattern

One of the most difficult jobs facing the specifying engineer is to produce the correct assembly pressure on the gasket, low enough to avoid damaging the gasket, but high enough to prevent a leak in the seal. The gasket supplier will always be happy to assist in this task. Asbestos sheet materials are sufficiently robust usually to resist damage from overloading, but the same is not always true for asbestos-free alternatives! Consequently, when tightening up fasteners on a flange with any gasket type not incorporating a metal stop (such as a sheet gasket), never use an impact tool or scaffolding pole! It is vitally important to control accurately the amount of force applied to any particular flange arrangement, and hence:

☑ ***always use a torque wrench or other controlled-tensioning device (recently calibrated)***

The sequence in which bolts or studs are tightened has a substantial bearing upon the distribution of the assembly pressure on the gasket. 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 may be encountered if the flanges are substantially out of parallel. Consequently:

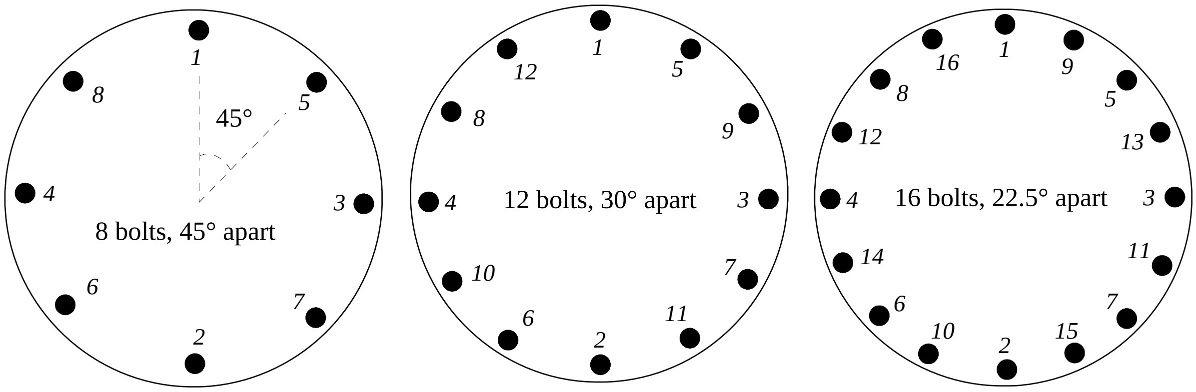
☑ ***always torque nuts in a cross bolt tightening pattern***

Always run the nuts or bolts down by hand initially. This gives an indication that the threads are satisfactory (if the nuts will not run down by hand, then there is probably some thread defect - check again and, if necessary, replace defective parts).

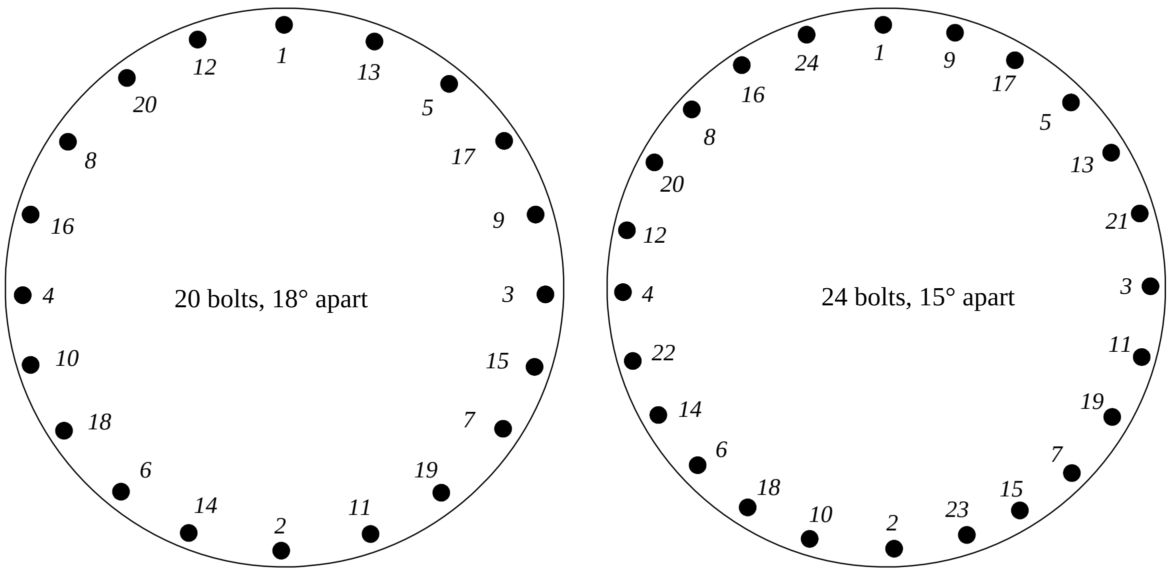
Now torque the joint using a minimum of 5 torquing passes, using a cross-bolting sequence for each pass, as shown. The following procedure is recommended:

☑ ***Pass 1 - Tighten nuts loosely by hand in the first instance, according to the cross bolt tightening pattern, then hand-tighten evenly***
☑ ***Pass 2 - Using a torque wrench, torque to a maximum of 30% of the full torque first time around, according to the cross bolt tightening pattern. Check that the flange is bearing uniformly on the gasket***
☑ ***Pass 3 - Torque to a maximum of 60% of the full torque, according to the cross bolt tightening pattern***
☑ ***Pass 4: Torque to the full torque, according to the cross bolt tightening pattern***
☑ ***Pass 5 : Final pass at full torque, in a clockwise direction on adjacent fasteners***

After the five basic torquing passes are completed, it may be beneficial to repeat pass 5 until no further rotation of the nut is observed. The final tightening must be uniform, with each bolt pulling the same load.



Cross bolt tightening pattern



Hydraulic tensioners are often used to preload fasteners. Although a number of engineers believe that these tensioners provide very good control (because the hydraulic ram exerts an accurate force on the fastener during the assembly operation), some load on the fastener is lost when the tensioner is removed as a result of elastic recovery. When the tensioner load is applied, the nut is run down against the joint (finger tight). The hydraulic pressure is then released and the tensioner removed. The nut and fastener now carry the full load, although there may be some embedment of material at the thread surfaces and at the nut bearing surfaces, which will reduce the load. Although hydraulic tensioners provide a consistent result, they require particular care, because the fasteners must be given a higher load to compensate for relaxation when the tensioner is removed. This may create hydraulic overload, which can cause fastener yielding (despite the apparent safety margin below 0.2% proof stress), especially a risk with certain fastener alloys (such as duplex stainless steels and other cupro nickel alloys), where the true elastic limit can be over 30% below the 0.2% proof stress value.

Alternatively, there are tension control fasteners available, which are pre-set to the required load.

Another way to tighten large bolts is to insert a heating rod in a hole drilled down through the centre of the bolt. As it heats up, the bolt expands length wise, and the nut can be run down against the joint (finger tight). The heater is now removed, and as the bolt cools, it shrinks, so developing tension. The method is relatively slow, but inexpensive (heaters are cheaper than high torque tools, for example). However, by itself, heating is not an accurate way to control a specified tension, and it should be combined with a measure of the residual stretch of the fasteners (such as with ultrasonics), which will then provide much more accuracy. There is some danger that heaters may alter the surface characteristics of the fastener, leaving them more susceptible to fatigue and stress corrosion cracking. If you plan to use heaters, use several at once at cross points around the joint, go for the final stretch in a single pass, measure the residual stretch after the bolts have cooled, re-heat and re-tighten those which are not correct.

5.5.8. Tagging

During a major overhaul, many thousands of flanges are required to be disassembled and then reassembled, usually involving teams of fitters who work their way through the plant. After the event, if a poorly assembled joint is discovered, it can be difficult (if not impossible!) to identify the root cause of failure. Consequently, tagging has been employed successfully on a number of industrial installations to encourage fitters to assemble the flange joints with care. It relies upon the following principles:

- *each fitter is given a unique identification (letters and / or numbers)*
- *each fitter is provided with metal or plastic tags ("dog tags") stamped with his/her unique identification number*
- *one tag is connected (by wire or cord) to each flange joint as the fitter completes the assembly*
- *tag may vary from one metal to another, one colour to another, one shape to another, at every overhaul*

Hence, as the installation comes back on stream, the plant operator will be able to identify which fitter has assembled which joint. Obviously, a fitter who is working sloppily will know that he/she can be readily identified after the event. However, on a positive note, the procedure will encourage some competition between fitters to be the best! It will identify those fitters who may need more training in one (or more) aspect of the job, and it will identify those fitters who are particularly good at their job - can they help to train others?

Equally, it may also highlight inferior quality gaskets.

With tags which vary from one overhaul to another, the operator can easily identify the date of assembly.

5.5.9. Re-tightening

For the majority of materials in the flange system (including gaskets, fasteners, nuts, washers), 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. These effects are accentuated at elevated temperatures, with the net result that the compressive load on the gasket is reduced, thus increasing the possibility of a leak. Consequently, some engineers recommend that fasteners should be re-tightened (to the rated torque) 24 hours after the initial assembly, and again after 48 and 72 hours (care: always re-tighten at ambient temperature). However, this is an area of conflicting views (!): depending on temperature and duration, soft gasket materials cure until they have become too brittle to withstand any additional force.

Certainly, care must be exercised with repeated re-torquing in order to avoid damage to the gasket. This is especially important in the case of gaskets with relatively narrow sealing areas, as the stress on the gasket is liable to be high and therefore closer to the limit which the gasket can withstand.

Elastomer-based "*it"* gasket materials (the German abbreviation for CAF) continue to cure in service, especially on start up as the operating temperature is reached. Once fully cured, gasket materials may become embrittled and liable to cracking under excessive load, and this is especially the case with elastomer-based asbestos-free materials. It is impossible to predict the time for embrittlement to start, as it will depend on the application temperature and the gasket composition. **Always consult the manufacturer for advice about re-tightening**, but as a general rule:

☑ ***do not re-torque an elastomer-based asbestos-free gasket after it has been exposed to elevated temperatures***

5.6. Safety aspects and joint failure

Joints fail, not just gaskets! Low bolting torques, over-tight bolt loads, weak bolt materials, inadequate bolt / washer / nut lubrication, poor flange design or materials, poor gasket cutting or storage, improper installation practices, may each and all contribute to seal failure, even though the gasket material itself may be correctly specified! This publication will attempt to provide solutions to all of the above challenges.

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%)***
- ***flange misalignment (12%)***

Although this list is by no means exhaustive (further details are available in a number of publications [5]), some common failure modes follow.

5.6.1. Failure due to the fastener

Fasteners which are insufficiently tight provide the most common cause of joint failure, which may result from:

- ***incorrect assembly***
- ***fastener failure***
- ***self-loosening***
- ***fatigue / relaxation over time***

On the other hand, when a **fastener is too tight** (usually as a result of an over-enthusiastic fitter or mechanic during assembly!), the joint may fail because the excessive load has:

- ***crushed the gasket***
- ***encouraged stress corrosion cracking***
- ***increased fatigue***

Fastener failure occurs when the applied load exceeds the ultimate strength of the fastener or threads, and for a variety of reasons, typically:

- ***fasteners do not meet design specifications (ruptured during assembly or at elevated temperature)***
- ***over-tightened during assembly***
- ***corrosion***
- ***stress corrosion cracking***
- ***fatigue***

5.6.2. Failure due to the gasket

This may result from a number of causes, such as:

- ***selection of incorrect gasket for the application conditions***
- ***selection of incorrect gasket thickness, particularly for soft gaskets***
- ***excursions outside normal operating envelope or bending moments on pipe work***
- ***gasket damaged in storage, handling or on installation***
- ***gasket crushed by excessive load during assembly***
- ***deterioration over time***
- ***gasket reused***
- ***re-tightening after exposure to service (elevated) temperature***

5.6.3. Failure due to the flange

Fairly unusual, but may result from:

- ***flange surfaces damaged***
- ***flanges warped***
- ***flanges not parallel***
- ***corrosion***
- ***flanges not clean on assembly***

5.6.4. Minimising the chances of joint failure

From the above list of key causes of joint failure, it is obvious that 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 which they will face during service. Allow an additional safety margin, just in case the application conditions move outside of the expected operating envelope (known as "*excursions*!").

Follow the gasket storage and handling (and cutting recommendations, where appropriate) key recommendations throughout this publication.

Follow the cleaning and visual inspection key recommendations, to ensure that the joint components are free from defects and fit for subsequent use.

The above list also emphasises the requirement for good assembly practices. Unless the joint is put together with sufficient care, it cannot be expected to provide a safe seal. Ensure that the engineers involved are thoroughly trained in assembly procedures and briefed about the challenges they will face on site. Follow the key recommendations on installation, assembly and bolt tightening.

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. It requires all four of the following conditions:

- ***an anode***
- ***a cathode***
- ***an electrolyte***
- ***an electrical connection between anode and cathode***

If any one of the conditions can be eliminated, corrosion will not occur. A solution is to keep the area dry by providing drainage holes (not always feasible) or, more commonly, by selecting fasteners manufactured from corrosion-resistant material. Most popular of all, by providing some form of protective coating on the fasteners and /or the flange.

Stress corrosion cracking (SCC) is the result of a combination of stress and electrochemical attack. Just humid air, or a dirty fingerprint, may be sufficient to initiate SCC! It is a specific form of corrosion and requires:

- ***a susceptible material***
- ***an electrolyte***
- ***an initial flaw***
- ***stress levels above a threshold***

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 requires:

- ***a susceptible material***
- ***elevated stress levels above an endurance limit***
- ***cyclic tensile stress***
- ***an initial flaw***

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 (it is advisable to keep records of how long they have lasted between failures, and then reduce the time frame somewhat to provide a reasonable safety margin). Ideally of course, always replace the fasteners when reassembling the joint!

Self-loosening is usually experienced in the presence of vibration, requiring:

- ***relative motion between fastener, nut and joint components***
- ***cyclic loads perpendicular to the fastener axis***

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.

5.7. BAT for bolted flange connections

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. Preventative measures, among which regular maintenance (e.g. controlled tightening of the flange), are very important. Regular inspection and replacement of the gaskets is also necessary, especially for those gaskets exposed to temperature fluctuations or vibrations as they age rapidly. When a removable connection is not necessary, flanges can be replaced by welded piping.

Best available techniques for bolted flange connections include:

- ☑ ***minimise the number of flanged connections***
- ☑ ***use welded joints rather than flanged joints where possible***
- ☑ ***fit blind flanges to infrequently used fittings to prevent accidental opening***
- ☑ ***use end caps or plugs on open-ended lines***
- ☑ ***ensure gaskets are selected appropriate to the process application***
- ☑ ***ensure the gasket is installed correctly***
- ☑ ***ensure the flange joint is assembled and loaded correctly***
- ☑ ***instigate regular monitoring, combined with a repair or replacement programme***
- ☑ ***focus on those processes most likely to cause emissions (such as gas/light liquid, high pressure and / or temperature duties)***
- ☑ ***for critical applications, fit high-integrity gaskets (such as spiral wound, kammprofile or ring joints)***

Alongside the introduction of asbestos-free gasket materials, there have been many developments for alternative gasket technologies. As a result, there is a vast range of gasket surface pressure and temperature limits in which the various gasket types may be used safely and readers should be aware that gasket performance may be improved or reduced under specific application conditions. For specific performance details and recommendations for particular applications, **please consult the manufacturer**. Members of the **ESA Flange Gaskets Division** may be contacted via the ESA web site at:

www.europeansealing.com/divisions/flange_gaskets.htm

For the maximum and minimum sealing surface pressures for specific types of gaskets, please refer to EN 1592, part 2 (data generated according to EN 13555).

5.8. Relative costs of BAT for bolted flange connections

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 BAT**. However, for the sake of completeness, the following table provides an overview of the relative cost of the gasket and its installation.

Gasket type	*Gasket cost index*	*Installation cost index*#
Compressed fibre sheet	1 - 10	300 - 1000
Elastomeric	1 - 5	300 - 1000
Micaceous (fibre free) sheet	4 - 60	300 - 1000
Reinforced graphite sheet	2 - 25	300 - 1000
Spiral wound	5 - 65	300 - 1000
PTFE	4 - 80	300 - 1000
Covered corrugated metal	4 - 60	300 - 1000
Kammprofile	8 - 90	300 - 1000
Note #; installation cost index includes process shut down, removal of the gasket to be replaced and installation of the new gasket. This index is very dependent upon the local labour rate involved.		

Besides these common types of gaskets, there may be special designs for specific sealing solutions, but these tend to be rare and usually well above the cost ranges mentioned here.

For some applications, only certain types of gasket options may be appropriate. The specific parameters of the application may preclude certain gasket types in order to attain the required safety margin, and this is likely to be reflected in the overall cost range.

Relative cost of gasket technology is dependent upon:

- plant type (for example, chemical, power generation, pulp and paper etc.)
- plant size (for example, power station 200MW, 500MW etc.)
- process type (for example, continual, batch etc.)

The relative cost of the actual gasket itself is dependent upon:

- raw material
- energy costs to manufacture the gasket material
- energy cost to manufacture the gasket
- resource costs (for example, running costs of buildings and equipment, labour costs etc.)

5.9. Emerging techniques

Sealing materials were previously based upon asbestos fibre and the manufacturing processes which evolved for those materials were therefore dependent upon aspects of that fibre for their successful operation. Thus, when the manufacturers of sealing materials started the development asbestos-free sealing materials, it was natural that the use of fibres other than asbestos in conjunction with those processes should be the starting point.

However, as we now know, that approach was not entirely successful as the available fibres with the characteristics required were limited in their capabilities compared with asbestos. Consequently attention turned to trying to create sealing materials by alternative processes and using alternative materials.

This approach has turned out to be very successful. Exfoliated graphite and processed PTFE sealing materials have been the outcome and these have been proved to be very successfully applied to a whole range of gaskets styles providing the user with sealing performance way beyond that of the original asbestos-based gaskets.

It is to be expected that such novel development will continue as the sealing potential of further new materials are exploited.

6. BAT for rotodynamic equipment

Modern process equipment with rotating shafts (such as pumps and compressors) is equipped with gland packings, mechanical seals or “sealless” 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 sealless drive systems.

A glossary of sealing terms used in this section is contained in section 9.2.

6.1. Pumps

6.1.1. 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)
- Sealless 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, which are discussed in section 6.3

Historically, field surveys have investigated both liquid and gas phase leakage from mechanical seals [6, 7, 8] and, 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 [2] 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 [3] 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 [9] 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% were emitting less than 1000 ppm (using EPA Method 21) and were thus within the Phase III standards of the US Regulations [10]. 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 [11] in the USA of 1112 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 sealless pumps. Sealless 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.

6.1.2. Pump reliability

Single mechanical seals provide low levels of leakage but these levels increase significantly when they 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.

6.1.3. Mechanical seals

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 emissions. Cost-effectiveness is an important consideration here, because the vast majority of low emission applications are covered successfully by mechanical seals.

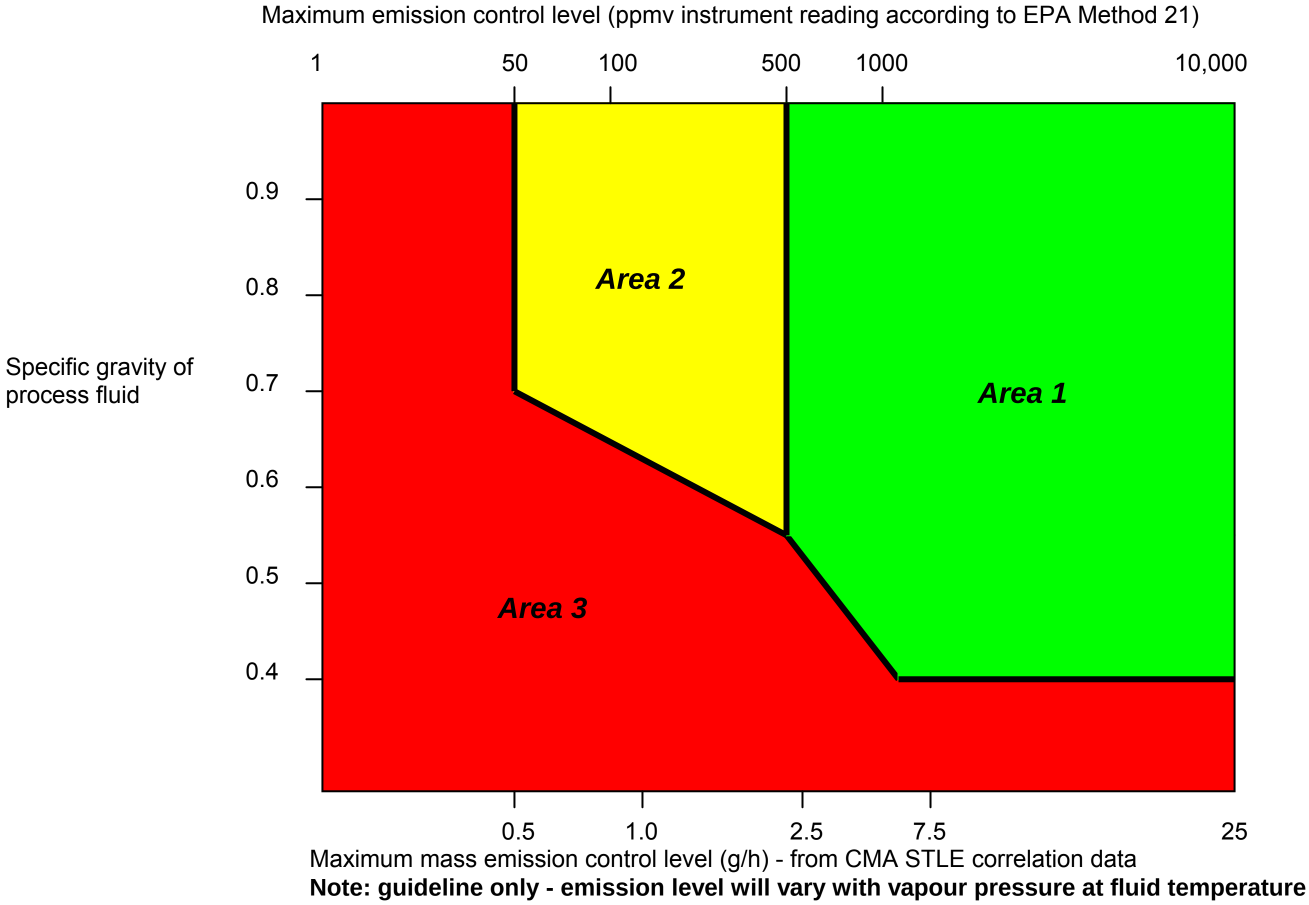
The oil production and Refining Industries have been driven by the need for greater reliability and a lower level of VOC emissions from pumps. A group of major USA users came together within the structure of the American Petroleum Institute and produced the first standard on Mechanical seals, API 682 [20] 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 has been 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 [27]. A third Edition of API 682 will mirror this standard.

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 [14], 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. A detailed explanation of the recommended sealing solutions referenced in the three segregated areas is given in Sections 6.1.3.1 to 6.1.3.4.



Area	Leak rate maximum (g/h)	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 [15]. For this reason, **where low emission rates are essential, operators should approach only respected mechanical seal**

manufacturers in order to be assured of the use of modern materials and advanced technology. These 'qualified' suppliers will ensure that today's mechanical seals incorporate 'design-in' capabilities to offset the combined effects of pressure distortion, thermal distortion and heat generation.

6.1.3.1 Advanced technology single seals

The original 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 [15]. Single mechanical seals provide cost effective, reliable sealing for most VOC services [4], in line with API Standard 682 specifications [20] and ISO 21049 [27], provided the following conditions are satisfied [3]:

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 [21] 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 guideline VDI 2440 [27] which recommends that operators use 1 g/h as the mean leakage rate from single mechanical seals on process pumps.

6.1.3.2 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 low 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 the bushings described in 6.1.3.1. The VOC leakage entering the containment chamber between the two seals can then be effectively channelled to a plant flare or vapour recovery system. Dual Unpressurised seal arrangements will provide very low levels of process emissions to the atmosphere (see Section 6.1.3).

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 channelling 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 [27].

Dual seal arrangements with unpressurised buffer liquid provide emission values typically below 0.01 g/h, achieving emission levels less than 10 ppm[17] (< 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 [22].

The alternative and more recent technology has been created by advances in high speed gas lubrication of mechanical seals (see Section 6.2); 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 ISO 21049 [27].

A recent assembly of data from European and USA plants [26] 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 ISO 21049 [27].

6.1.3.3 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 [4] 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 ISO 21049 [27].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[3, 25]. 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[22].

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[20] or ISO 21049 [27].

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[12, 13] offer good advice on best practice.

6.1.3.4 Sealless pump drive systems

This technology also provides a zero emission capability but may be restricted in application by the process properties (see Section 6.1.1). 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, NO_2) 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[16,17] - cost effective (especially single seals) - particularly advantageous as power ratings increase[22]	
Low repair and maintenance costs[16]	Potentially lower repair frequency[16] (although very dependent upon the service)
Long working lifetime[17]	
	Less frequent monitoring required[10]
Operator confidence in well-known technology[16]	
Wide process applicability: - allows flexibility of equipment use - widely used on existing plant - preferred for batch process plant - preferred for majority of applications (see Section 4 for specific suitability guidance)	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.
	Lower risk of process stream contamination
Operator experience with technology parameters: - safely enabling performance optimisation[16] - minimal training required	
Simplicity (especially single seals)	
Energy efficient: - low operating costs[16] - no transfer of emission burden off-site[18]	
Special seals can be run dry: - preferred for 'dirty' processes[19] - preferred for process fluids with high viscosity or where fluid may undergo a high rate of change of vapour pressure[19] - preferred for batch processes	

6.1.4. BAT 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***
- ☑ ***Selection of appropriate mechanical sealing technology based on required maximum leakage control levels and with consideration of process fluid characteristics (section 6.2.2)***

6.1.5. Life-cycle cost (LCC)

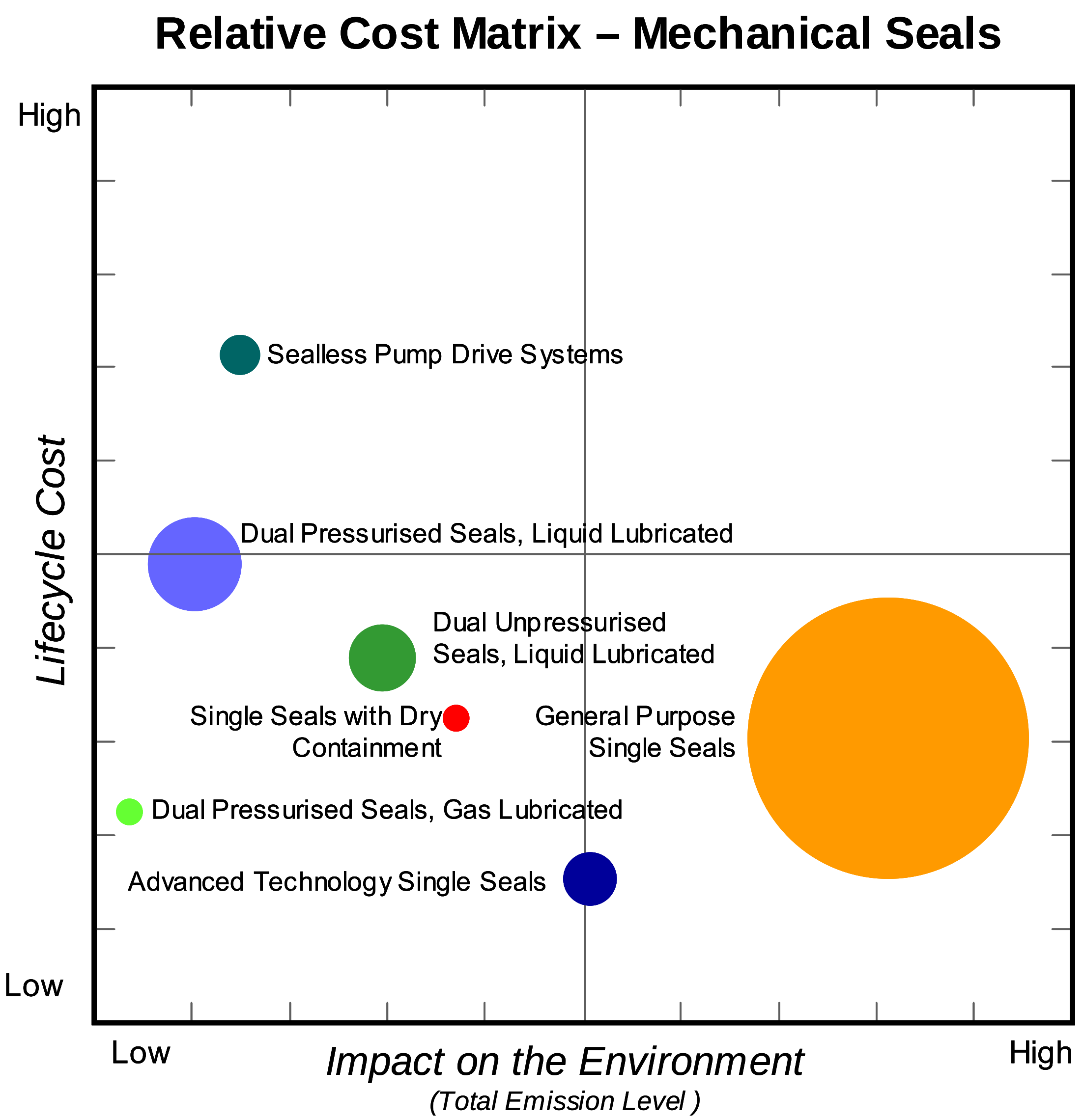
The energy demand in certain process systems can be a huge component of the total costs of operating the plant. For example, some pumping systems may account for over 25% of the total energy usage on certain industrial installations. Yet, initial procurement and installation costs are used widely as 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** [35] 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.

6.1.6. 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;

1. 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).

2. Advanced Technology Single Seals:

Balanced stationary seals with advanced face designs. Initial investment higher than for (1) but with a potential for extended MTBF and therefore lower LCC. Emissions ranges 100 - 500 ppm.

3. Dual Seals, unpressurised:

Different containment technologies may be used (6.1.3.2) 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.

4. Dual Seals, pressurised, liquid barrier:

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

5. 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.

6. Sealless pump technologies:

The chart position is based primarily on magnetic drive pumps [29]. 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 unpressurized seals with liquid buffer [3]	Dual pressurized seals with liquid barrier [3]	Dual pressurized 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** [36] 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, and sealless pumps.

Life Cycle Costs are influenced strongly by the **reliability** of the selected sealing solution. 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.

6.2. Compressors

6.2.1 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
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)

6.2.2. BAT for compressors

Equipment reliability is equally important in minimising emissions from compressors and the techniques which are recommended for pumps in Section 6.1.2 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 that described in Section 6.1.3.2. 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, as described in 6.1.3.3, 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 channelling 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 as described in Section 6.1.3.2. 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.

6.3. Other rotodynamic equipment

6.3.1. Emission management in 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.

6.3.2. 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.

6.4. 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 favourable 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.

7. BAT for reciprocating shafts

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

7.1. BAT for reciprocating compressors

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

7.1.1. 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.

7.1.2. 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.

7.1.2.1. 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.

7.1.2.2. 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.

7.1.3. 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***

8. BAT for 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. 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.

8.1. 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.

8.2. 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 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.

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

8.2.1. Diagonal-interlock Braided Yarn Packings

This braid is designed for general service application 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 5mm and under, square or plait braid is normally used.

8.2.2. Flexible Graphite Products

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

a. Flexible Graphite Die-Formed Rings

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.

b. 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.

c. 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, and injection moulded rings.

8.3 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:

8.3.1. 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***

8.3.2. 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***

8.3.3. 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***

8.3.4. Install one ring at a time

Make sure it is clean and has not picked up any dirt in handling. Seat rings firmly (except PTFE filament and graphite yarn packings, which should be snugged up very gently, then tightened gradually after the pump is operating). 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***

8.3.5. 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***

8.3.6. 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!***

8.3.7. 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***

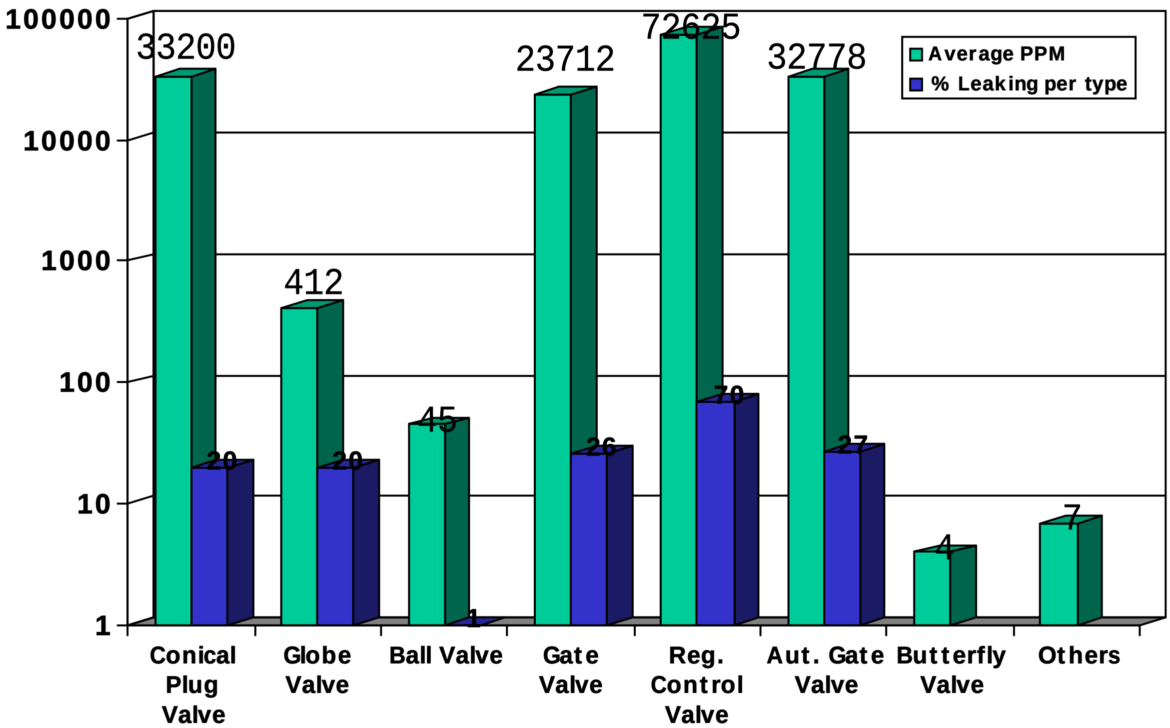
8.3.8. Live loading of the valve stem gland

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 belleville spring 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 belleville 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.

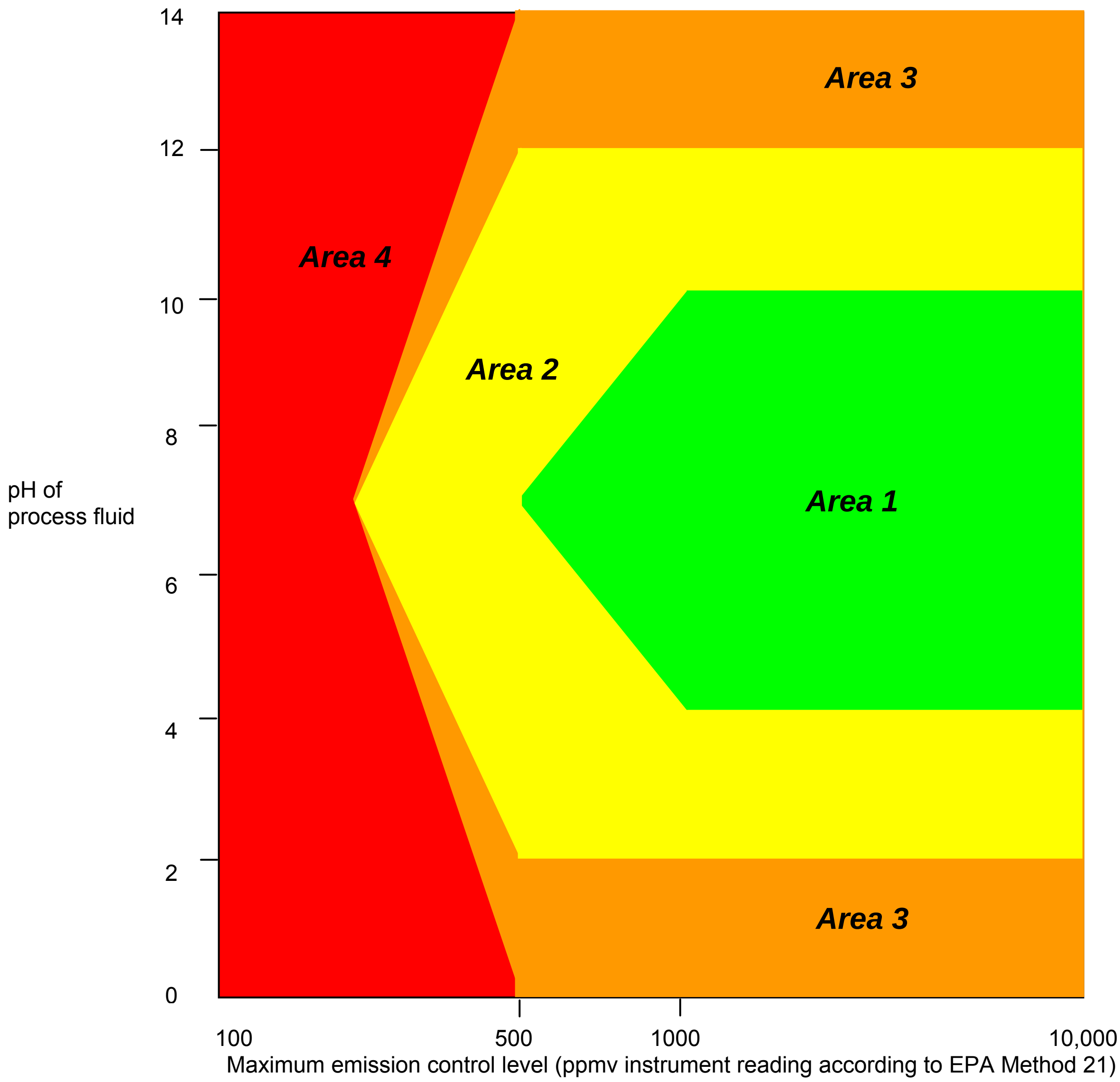
8.4. Current emission levels

Each valve type performs differently in terms of emissions, as indicated in this study by Cetim:



8.5. 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	<500	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**.

8.6. Valve live-loading

Live-loading involves the use of disc spring assemblies mounted above the gland on the gland bolts or between the packing gland and gland nose. The live-load assemblies transfer the bolt force to the packing set. 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.

Normally when valve packing is installed in the stuffing box, a high preload is required to ensure deformation of the packing rings and minimize in service consolidation of the packing. Preloads up to 40MPa are sometimes recommended to minimize further relaxation of the packing over time. Yet these high preloads will result subsequently in high stem friction. With valve live-loading, a much lower preload is required to ensure that the leak tightness requirement is achieved. The live-loading assembly will then compensate automatically for the packing relaxation over time, without excessive valve stem friction.

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.

8.7. BAT for 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:

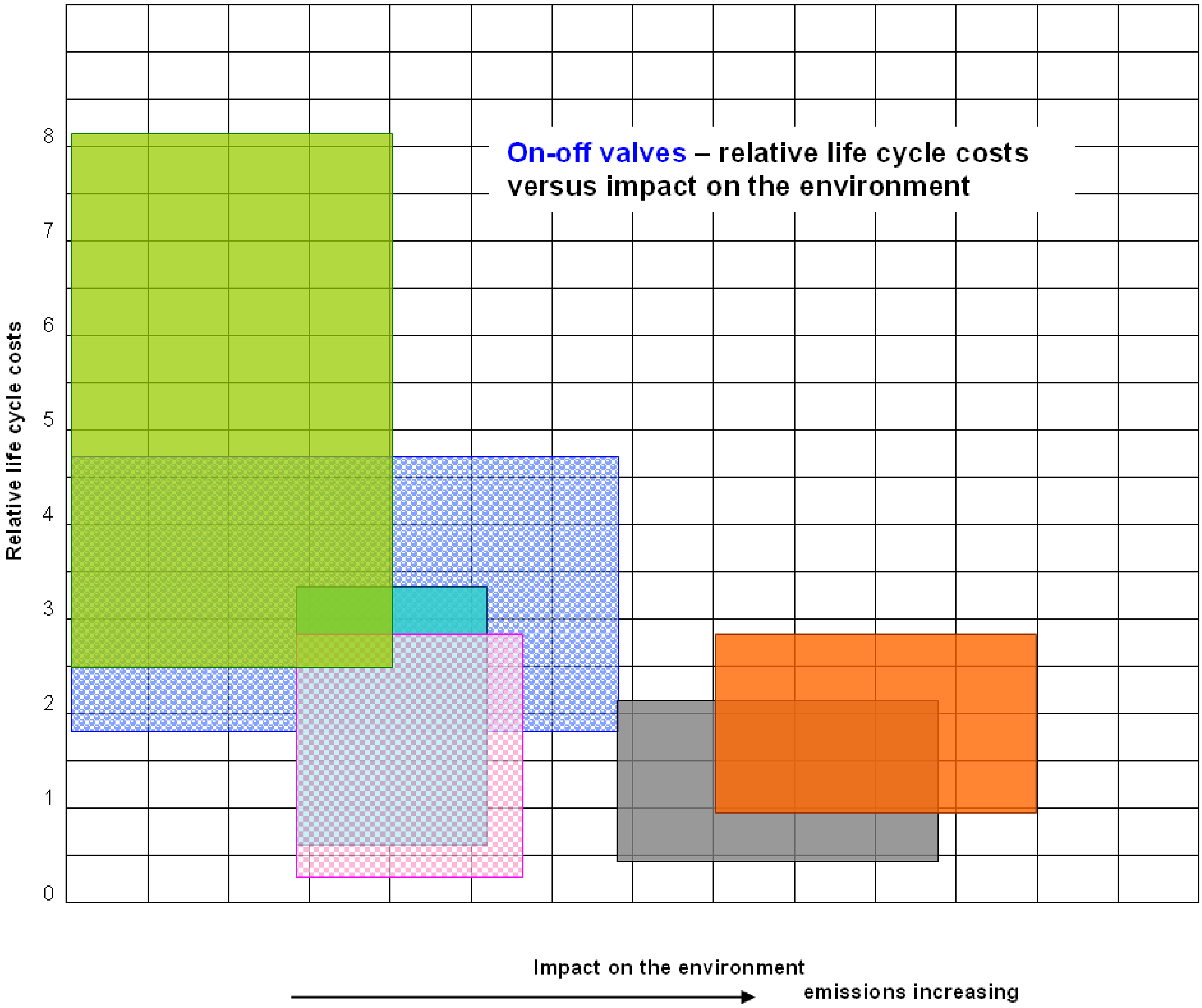
- ☑ ***correct selection of the packings material and construction for the process application***
- ☑ ***correct installation of the packings material into the stuffing box***
- ☑ ***regular monitoring, combined with a repair or replacement programme***
- ☑ ***focus on those processes most likely to 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 leaking 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).

8.8. Relative costs of BAT 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 BAT. 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**:



= Standard packings

= Die formed ring sets

= Fugitive emissions packing sets without spring loaded gland

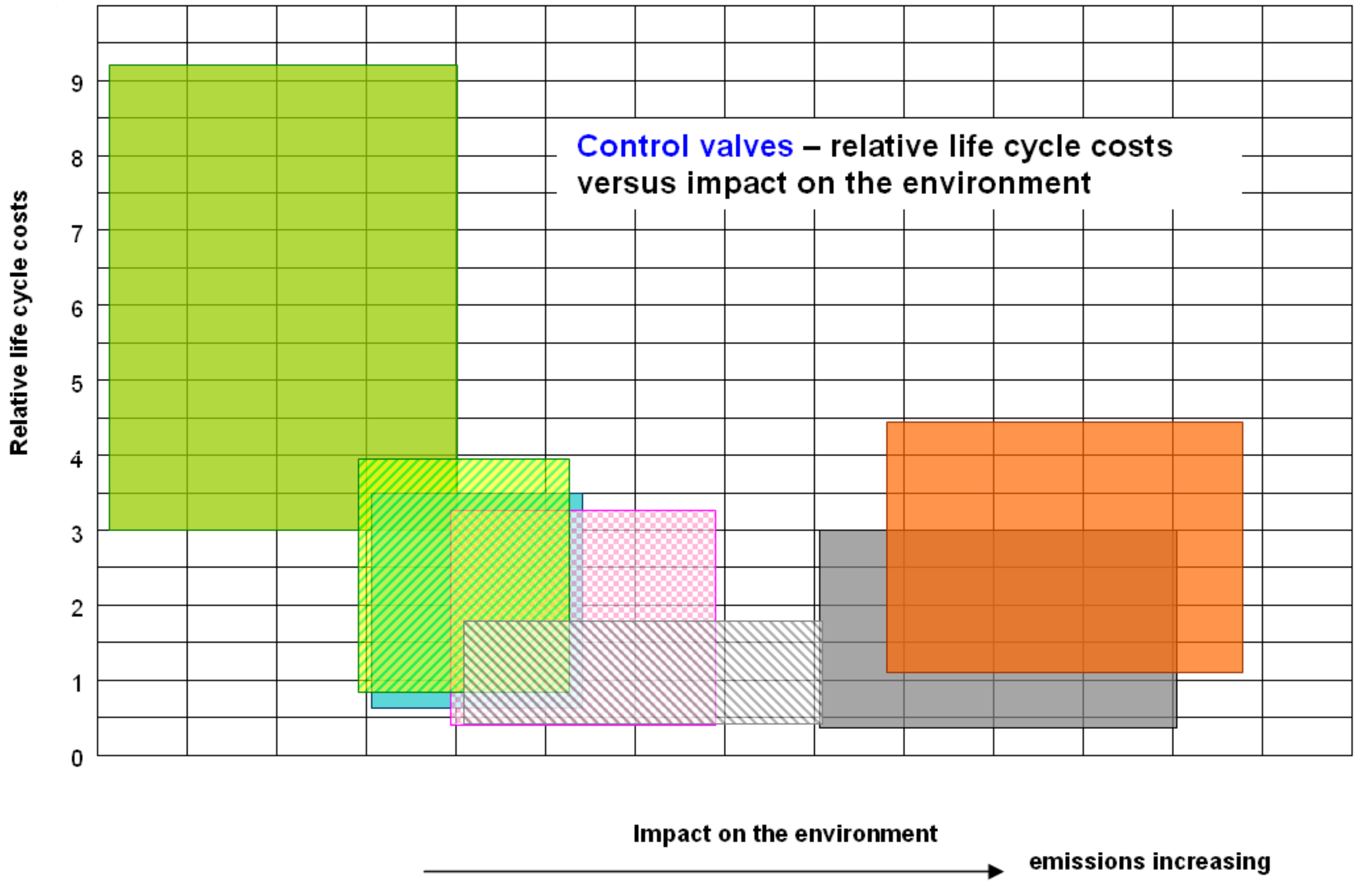
= Fugitive emissions packing sets with spring loaded gland

= 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.

The second matrix below represents the relative life-cycle costs versus impact on the environment for **control valves**:



= Standard packings

= Die formed ring sets

= PTFE V-ring sets

= Fugitive emissions packing sets without spring loaded gland

= Fugitive emissions packing sets with spring loaded gland

= Special high performance sealing systems

= Bellows seal with safety packing

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

8.9. Emerging technologies

The ***valve stem leak tightness testing methodologies*** project of the ESA (financed under the EU's Standards Measurement and Testing Protocol), may provide some interesting spin-offs. This SMT Project (SMT4-CT97-2158) was initiated to provide guidance on the various methodologies for measuring ***fugitive emissions***, and especially those fugitive emissions from ***valves***. Importantly, these methodologies were aimed at ***valve qualification and QA tests***, rather than the choice of test methods in the field.

This collaborative project started in 1997 October, to investigate valve stem seal leak-tightness testing methodologies. Part funded by the European Commission under the Standards, Measurement and Testing (SMT) programme, this 30 month, k€uro 500 project brought together independent R&D organisations (BHR Group and Cetim), a petrochemical end user (Elf Antar), a valve manufacturer (Neles Automation), a sealing material manufacturer (Chesterton) and two manufacturers of leakage detection equipment (Inficon and Alcatel). Widespread support for the work was ensured by the involvement of European sealing industry (ESA) and valve industry (AFIR) umbrella organisations.

8.9.1. Background and scope

With increased concerns over environmental issues, plus legislation in the USA and Europe have focused attention on fugitive emissions of VOC's from chemical and petrochemical plant, and over leakage from particular sources. Site surveys have indicated that the largest contribution to plant VOC leakage comes from valves, and particularly from their stem seals[30]. In an attempt both to reduce product loss, to comply with plant emission targets and to rationalise procurement, plant operators are increasingly insisting on procuring valves demonstrating acceptable leakage performance. Two important messages coming from the chemical and petrochemical end-users [31] are:

It is not enough to know that the valve, as purchased, gives acceptable leakage. The real test is: how will it perform after a representative number of mechanical and, especially, thermal cycles?
This highlights the necessity for a ***leak-tightness qualification test***.

Assuming that the valves purchased are of a design which has been qualified against such a test, the end-user who buys large quantities wants to know what proportion of these are likely to leak in service.
This highlights the necessity for a systematic ***quality assurance strategy***.

A valve stem leak-tightness test comprises three essential elements [32]:

- the test protocol (specification of test temperature, pressure, duration, mechanical and thermal cycles, etc.)
- the leak-tightness criterion (specification of what level of leakage is deemed acceptable)
- the leakage measurement method

This project focussed on ***measurement methods for valve qualification and QA tests***, and the interpretation of readings thus obtained. It must be emphasised that the project was not concerned with the choice of test methods *in the field*.

The emergence of standards on leak-tightness of industrial valves has given rise to a set of problems associated with the way in which leak-tightness is both measured and expressed. Issues surround:

- ***The specified gas;*** End users prefer a leakage target in gases representative of the duty. Valve manufacturers and test houses prefer the use of helium as a safe, detectable, inert test gas, widely used for leak testing in many other contexts.
- ***The measurement method;*** Many end users prefer a leak-tightness result expressed in terms of ppm measured by sniffing, since this is the format of Environmental Protection Agency (EPA) targets in the USA and is widely used across the world for on-site leakage detection and repair (LDAR) programmes.

Unfortunately, ppm is a not a measure of leakage rate, but rather provides an indication of leakage severity. Thus, the requirement is for means of "translating" both between ppm and leak rate and between leakage of one gas and leakage of another under similar conditions.

"Translation" between ppm and leakage is usually accomplished by means of empirical power law correlations. However, due to the wide range of data sources on which they are based, scatter in the data is very broad, rendering this approach, as it stands, unsuitable for valve qualification and QA test standards.

"Translation" between leakage rates of different gases can either adopt a similar empirical approach or, alternatively be based on predictive relationships derived from an understanding of which leakage mechanism predominates. Until now, little directly relevant work has been undertaken in this area.

The project work programmes provide relevant technical data and analysis to help resolve these issues by:

- ***investigating measurement methods and recommending means by which scatter in the relationships between ppm and leak rate can be dramatically reduced***
- ***evaluating measurements of leakage of different gases under similar conditions to identify means of predicting leakage of various gases from measurements of helium leakage***

Experimental work was concentrated on valves representative of typical volatile organic compound (VOC) duties over a range of sizes and types (but particularly 4" Class 300 gate valves) with several different packing types (but mostly graphite) over a range of leakage rate representative of this duty.

8.9.2. Key conclusions and recommendations

- ☑ ***The use of a single detector type and elimination of significant local air currents can dramatically reduce scatter in the accuracy of power law relationships between ppm and leakage rate (from 2 orders of magnitude to a factor of <3).***
- ☑ ***Sniffer probe flow rate has a major first-order effect on this relationship.***
- ☑ ***Under well-controlled circumstances, the typical near-proportionality between leakage rate and ppm suggests the basis for a predictive relationship based on an empirical "sniffing factor" (percentage of leaking gas taken up by the detector) and known probe flow rate. The first is not a constant, but can be averaged over a range of measurement circumstances, with some increase in the resulting scatter. The second is a function of the detector employed. By specifying these quantities, use of this approach removes significant sources of scatter. Further work is required for both helium and VOC detectors across a wide range of temperatures valve types and sizes, packing types, etc.***
- ☑ ***Flushing represents a suitable, reasonably accurate alternative to sniffing over the range of leakage rates for which it was evaluated and is a suitable technique for VOC leak rate measurement. Lantern ring ports may facilitate the use of this technique.***
- ☑ ***The vacuum method is suitable over a wide range of helium leakage rates. It may involve minor modifications to a valve, however, to ensure a good vacuum seal. Again, a lantern ring port may circumvent that problem.***
- ☑ ***Molecular flow appears to predominate at room temperature in many (not all) cases studied, but some data are contradictory. An assumption of laminar leakage flow could not be supported. Conclusions are not generally applicable to other valve types, sizes, packing types and test gases. Further work is required to confirm results, generalise and determine error bands.***
- ☑ ***A significant data set was obtained for high temperature helium across a range of pressures and under well-controlled conditions. This represents a useful database for future studies.***
- ☑ ***VOC ppm measurements at elevated temperature confirmed the scatter involved in this approach and contributes to a significant margin of error in any correlation from helium leak rate to VOC - typically a decade or more.***
- ☑ ***Leakage measurements of methane, ethane and propylene by flushing demonstrated the feasibility of this approach for VOC's at elevated temperature. Results enabled selective checks on the relationship between leak rates of helium and VOC's.***
- ☑ ***Whilst molecular flow appeared to be the predominant leakage mechanism in the high temperature helium tests reported here, the role of temperature on the leak rate versus pressure relationship was not as expected: more work is required.***
- ☑ ***The leakage mechanism in VOC's at elevated temperatures remains unknown: more work is required.***

The full conclusions and recommendations from the project are documented in the Publication Report [33]

9. Glossary of sealing terms

This section contains an alphabetical listing of special features and technical terms which are of common usage in sealing technology terminology.

The section is divided into sub-sections dependent upon the specific sealing technology:

9.1. Expansion joints and flange gaskets terminology

Term	Definition
Assembly pressure	Pressure generated on a gasket during assembly
Back-up ring	A ring (often metallic) around the outer periphery of a sealing material, usually to prevent extrusion
Beater addition product	Gasket material manufactured by a paper-making process
Belleville washer	Washer with a slightly conical shape, which acts as a spring when compressed axially
Binder	A substance (usually organic) used to bond the components of a gasket material into a matrix
Blank flange	Flange with no bore, used to provide a sealed closure to a flanged opening
Blind flange	See **Blank flange**
Bolt	Threaded fastener used to secure the members of a flange joint together and to apply compressive force to flange
Bolt load	Means of applying compressive pressure to make the gasket material flow into surface imperfections in the flange to create a seal
Bolt tension	Tension (tensile stress) created in a bolt by assembly preloads and/or thermal expansion, service conditions etc
Calendered sheet	See **Compressed fibre sheet**
Centring ring	An extension of a gasket for the purpose of locating it centrally on a flange
Chemical compatibility	See **Fluid resistance**
Class	An alpha-numeric designation related to a combination of mechanical and dimensional characteristics of a component of a pipe-work system. It comprises the word `CLASS', followed by a dimensionless whole number and is used to identify ranges of related components in a number of different standards (for example, EN 1759)

Term	Definition
Compressed fibre sheet	Gasket material, primarily containing fibres, rubber and fillers, manufactured on a calender under high load
Compressibility	Percentage reduction of thickness under a compressive pressure, applied at a constant rate, at room temperature
Compression set	Residual deformation of a gasket after it has been subjected to, and then released from a specified compressive pressure, over a defined time and at a given temperature
Controlled swell	Property of gasket material to swell to a defined extent when in contact with the retained fluid, to provide additional sealing pressure
Corrugated metallic gasket	Metal gasket, usually incorporating a filler material in the well of the corrugations, in which the seal is formed between the peaks of the corrugations and the mating flanges
Creep deformation	Percentage loss of thickness over a specified time under constant load, applied at a specified rate, at a specified temperature
Cure	Cross-linking reaction of elastomer with various chemicals, creating a matrix of greater stability
DN	A designation of nominal size of components in a pipe-work system, defined in EN ISO 6708
Double-jacketed gasket	A gasket design in which the gasket material is enclosed within an outer metal cover
Effective sealing width	That part of the actual width of a gasket considered to contribute to the performance of the gasket
Elasticity	Property of a body to recover its original size and shape immediately after removal of the external forces which cause it to deform
Elastomer	Generally long chain polymer molecules, which show elastic properties
Envelope gasket	A gasket design in which the gasket material is enclosed within an outer cover (typically PTFE) to minimise chemical degradation by the sealed fluid
Eyelet	Metallic cover around inner periphery of gasket material, to minimise chemical degradation by the sealed fluid. Depending on selection of geometry and metal, it may also improve sealability and blowout resistance
Flange	Basic component of a gasketed joint assembly, incorporating a substantially radially extending collar for the purpose of joining two or more items of process equipment
Flanged joint	See **Gasketed joint**

Term	Definition
Flange rotation	Deformation of a flange caused by imposed forces
Flat-face flange	A flange where the entire mating faces are flat
Fluid resistance	Measure of the ability of the material to resist chemical attack
Fugitive emission	A chemical, or mixture of chemicals, in any physical form, which represents an unanticipated leak, from anywhere on an industrial site
Full-face gasket	A gasket which covers the entire flange surface extending beyond the bolt holes
Garter ring	A metal or hard elastomer material used to apply additional pressure to self energising seals
Gasket	Deformable material (or combination of materials) intended to be clamped between flanges to prevent leakage of contained fluid
Gasketed joint	The assembly of components (e.g flanges, bolts, gaskets) required to join two or more items of process equipment and to prevent leakage
Gasket load reaction	Point at which the load on a gasket can be considered to react for moment calculation purposes
Gasket pressure	Effective compressive load per unit of gasket area
Grip length	Distance on a bolt between the inner face of a nut and the inner face of the bolt head
***Hard* and *soft* gasket materials**	Differentiation between predominantly hard, metal-based gaskets (e.g. spiral wound) and softer or fibre-reinforced materials
Hot creep during service	Percentage reduction in thickness under constant compressive pressure at elevated temperature
Hydrostatic end thrust	Relieving force caused by the pressure of the retained fluid, resulting in a reduction in gasket pressure and an increase in bolt load
Initial preload	Tension created in a single bolt as torque load is applied. It is usually modified by subsequent assembly operations and service conditions
Inside bolt circle (IBC) gasket	A gasket lying wholly within a ring of bolts
Internal pressure	Fluid pressure applied to the joint
Kammprofile gasket	Metal gasket with grooved faces, with or without resilient sealing layer on surfaces
Leakage rate	Quantity of fluid passing through the body and/or over the faces of a gasket per unit periphery of the gasket over a specified time
Lip gasket	Gasket design which is self-tightening by virtue of a protruding lip, and which may alternatively be used for attachment
Live loading	Application of a spring load to maintain seal surface pressure
Load compression characteristic	Reduction of thickness under specified load and temperature conditions
Maximum assembly pressure	Maximum allowable pressure during assembly to prevent unacceptable creep or failure of the gasket material under operating conditions
Maximum gasket pressure under operating conditions	Maximum allowable pressure under operating conditions to prevent unacceptable creep relaxation or failure of the gasket material
Minimum assembly pressure	Minimum pressure required on assembling the gasket in the flange to achieve the desired level of sealing under operating conditions
Minimum gasket pressure under operating conditions	Minimum pressure required on gasket to remain within leakage class under operating conditions
Nominal pipe size (NPS)	An alpha-numeric designation of size for components of a pipework system. For the purpose of Class-designated flanges, it comprises of the letters NPS, followed by a number which is related to the physical size of the bore or outside dimensions of the pipe component (e.g. see EN 1759)
Operational gasket pressure	Pressure retained on the gasket under operating conditions (the situation after initial tightening when the flange has been pressurised, is at operational temperature, and creep and other relaxation mechanisms have occurred)
O-ring	A seal (often referred to as a packing or moulded ring in the USA), usually elastomeric or hollow metal, of circular cross section, nipped in a groove
Permeability	A measure of the ease with which a fluid can pass through a gasket material
Pipe schedules	Tables defining pipe thickness in relation to nominal bore and process pressure, according to ISO standard
PN	Alpha-numeric designation related to mechanical and dimensional characteristics of a component of a pipework system. It comprises of the letters ``PN", followed by a number. Used to identify ranges of related components in a number of standards (e.g. EN 1092) and is defined in EN 1333

Term	Definition
Porosity	Percentage difference between the theoretical and actual density of a material (as a result of small voids or interstices within the material matrix)
Preload	Clamping force which a bolt exerts on a joint when tightened
Pressure	Load per unit area on a body
Proof load	The maximum, safe, static, tensile load which can be placed on a fastener without causing it to yield. It is an absolute value, sometimes defined as force (N), or pressure (MPa)
p/T rating	The rating of a flange manufactured from a specified material, indicating the allowable pressure (non-shock) at which it may operate at a specific temperature (e.g. see tables in EN 1092 and EN 1759)
PT value	Numerical value resulting from the multiplication of the internal pressure by the temperature of the fluid being sealed. Provides only a rough guide for limiting gasket usage
PVRC	Pressure vessel research committee (USA)
Raised-face flange	A flange which makes contact with its mating joint member only in the region where the gasket is located. The faces of the flange do not make contact with each other at the bolt circle
Recovery	Increase of thickness over the compressed thickness, once the compressive load has been removed
Reinforcement	Material (such as fabric, cord and/or metal) within the gasket matrix, which imparts increased tensile strength or other desirable properties
Residual stress	Stress remaining in a gasket after service for a given time
Ring-joint flange	A flange system in which both flanges are grooved to accept a ring-joint gasket
Ring-joint gasket	A gasket machined from metal (usually oval or octagonal in cross-section) and used in conjunction with ring-joint flanges
ROTT	Room temperature operational tightness test, as defined by the PVRC
Sealability	Ability of a gasket material to prevent flow of fluid through the body and / or over the surfaces
***Soft* gasket materials**	See ***Hard* and *Soft* gasket materials**
Spiral-wound gasket	A gasket design which is formed by winding spring-like material, usually “V”-shaped, plus a suitable filler material, into a spiral

Term	Definition
Spring constant	Equivalent to the ``stiffness" of a bolt and defined as the initial preload divided by the elongation of the bolt after application of load
Stiffness	Ability of a body to resist deformation due to the action of external forces. Reciprocal of elasticity
Strain	Change in dimensions or shape of a body due to applied force or stress
Stress	Effect of load per unit area on a body
Stress corrosion cracking	A common form of stress cracking in which an electrolyte encourages the growth of a crack in a bolt under stress
Stress relaxation	Loss of stress at a constant gasket thickness as a function of time, after application of a specified compressive load at a specified rate, at constant temperature
Stud	Fastener which is threaded at both ends
Surface roughness	Fine irregularities of the flange surface finish
Tensile strength	Breaking tensile force divided by the original cross-sectional area
Tightness class	Maximum acceptable specific leakage rate for particular applications
Tightness parameter T_p	Mathematical relationship between the measured specific leakage rate and the internal fluid pressure causing it
Tongue and groove flange	A flange system in which one flange is provided with an anular tongue and the other with a complimentary groove to accept it

9.2. Mechanical seals terminology

Term	Definition
Barrier fluid	Externally supplied fluid at a pressure above the pump seal chamber pressure, introduced into a **dual pressurised seal** to isolate the process fluid completely from the environment.
Barrier liquid	See **Barrier fluid**
Buffer	See **Buffer fluid**
Buffer fluid	Externally supplied fluid at a pressure lower than the pump seal chamber pressure, used as a lubricant and/or diluent in a **dual unpressurised seal** .
Buffer liquid	See **Buffer fluid**
Bushing	Close-clearance restrictive bush around the shaft or sleeve. It may be fixed or flexible radially when used in the casing or gland plate.
CMA	Chemical Manufacturers Association. A US-based Industry group
Containment chamber	Component forming the cavity into which the **containment seal** fits.
Containment seal	**Mechanical seal** design with one flexible element, **seal ring** and **mating ring** mounted in the **containment chamber.**
Data sheets	A template used to list data, information and specifications applicable to a particular item of plant equipment.
Double seal	See **Dual pressurised seal**
Dual mechanical seal	A **dual pressurised seal** or **dual unpressurised seal** of any kind.
Dual pressurised seal	Seal configuration having two seals per assembly which utilise an externally supplied **barrier fluid**.
Dual seal	See **Dual mechanical seal**
Dual unpressurised seal	Seal configuration having two seals per assembly with a **containment chamber** which is at a pressure lower than the **seal chamber** pressure.
Energised containment seal	Lip seal mounted in the **containment chamber** and used in the manner of a **containment seal**.
EPA Method 21	US Federal Regulation 40 CFR 60, 1990, 'Determination of Volatile Organic Compound Leaks', Reference Method 21, Appendix A
Flush	Fluid which is introduced into the **seal chamber** on the process fluid side in close proximity to the **seal faces** and used typically for cooling and lubricating the **seal faces**.

Term	Definition
Flush Plan	Configuration of pipe, instruments and controls designed to route the fluid concerned to the seals. Auxiliary piping plans vary with the application, seal type and arrangement.
General purpose mechanical seals	**Mechanical seals** which have not had the benefit of recent technological advances in design, materials and tribology.
Live-loading	Method used to compress gland packing that is independent of any manual tightening of gland plate studs. Ordinarily, it comprises of a controlled spring-force.
Mating ring	Disc or ring-shaped member, mounted either on the sleeve or in a housing such that it does not move axially relative to the sleeve or housing, which provides the mating seal face for the **seal ring**.
Mechanical containment seal	See **Containment seal**
Mechanical seal	A device which prevents the leakage of fluids along rotating shafts. Sealing is accomplished by a **seal ring**, mounted flexibly on the shaft or the equipment casing, which bears against a radial face of a fixed **mating ring**. The **seal faces** are perpendicular to the shaft axis. Axial mechanical force and fluid pressure maintain the contact between **seal faces**.
Mechanical seal data sheets	See **Data sheets**
Metal bellows	A series of metal convolutions or a stack of welded metal diaphragms used to provide secondary sealing and spring-type loading in a **mechanical seal** design.
MTBR	Mean Time Between Repairs. A statistical methodology used to measure reliability in equipment.
Non-contacting seal	**Mechanical seal** design in which the mating faces are designed intentionally to create aerodynamic or hydrodynamic separating forces in order to sustain a specific gap between the **seal ring** and the **mating ring**.
Primary seal	**Mechanical seal** which seals the process fluid in a **dual unpressurised seal**.
Rotodynamic pump	Pump which functions by adding energy to the pumped fluid through a rotating impeller. This may be an axial, mixed or radial flow pump.
Rotor	Assembly of all the rotating parts of a **rotodynamic pump**.

Term	Definition
Seal chamber	Component, either integral with or separate from the pump case (housing), which forms the region between the shaft and casing into which the **mechanical seal** is installed.
Seal face	Side or end of a **mating ring** or **seal ring** which provides the sealing surface on the ring.
Seal ring	Seal face which contacts the **mating ring**; it is mounted flexibly using springs or bellows.
Secondary containment device	Component or seal used to restrict process leakage to the environment in the event of a malfunction of the **primary seal**.
Single mechanical seal	Seal configuration having only one **mechanical seal** per assembly.
Split seal	**Mechanical seal** which has the **seal ring** and **mating ring**, and in some designs the other parts of the seal assembly, supplied in two halves such that they can be assembled on or removed from the equipment without removal of adjacent parts of it.
STLE	Society of Tribologists and Lubrication Engineers. A US-based organisation which, amongst many other subjects, addresses **mechanical seal** related issues.
Vapour pressure margin	The pressure difference between the **seal chamber** pressure and the pressure at which the process liquid changes to a vapour at the sealed temperature.
VOC	Volatile Organic Compound. A chemical compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, which vaporises at or below 21^{o}C

10. Conversion factors

The International System of Units (Le Système International d'Unités, or SI units) was first adopted by the 11th General Conference of Weights and Measures in 1960. This list is not exhaustive, and more details of the SI system can be found in publications such as ISO 31, ISO 1000, DIN 1301, BS 5555, BS 5775.

10.1. SI units

Quantity	Name of unit	Symbol	Expressed in terms of other SI units
Energy (work)	joule	J	$J = N.m = kg.m^2.s^{-2}$
Force	newton	N	$N = kg.m.s^{-2}$
Length	metre	m	
Mass	kilogram	kg	
Pressure	pascal	Pa	$Pa = N.m^{-2} = MN.mm^{-2}$
Power	watt	W	$W = kg.m^2.s^{-3}$
Temperature (thermodynamic)	kelvin	K	$K = {}^{o}C + 273.15$
Time	second	s	

10.2. Multiples of SI units

The multiples are expressed by orders of magnitude, which are given as a prefix to the SI unit:

Prefix name	Prefix symbol	Factor by which the primary unit is multiplied	
exa	E	10^{18}	1 000 000 000 000 000 000
peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto	h	10^{2}	100
deca	da	10^{1}	10
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000 001
nano	n	10^{-9}	0.000 000 001
pico	p	10^{-12}	0.000 000 000 001
femto	f	10^{-15}	0.000 000 000 000 001
atto	a	10^{-18}	0.000 000 000 000 000 001

As an example, the multiple unit MPa (megaPascal = 10^6 Pa) is often used when referring to pressure in fluid systems, such as those in the process industries.

10.3. Units of common usage in sealing terminology

The following list covers **non-SI units** which are used regularly in connection with sealing terminology, and gives equivalent conversions into SI units (and other units where appropriate). The list is in alphabetical order (for conversion factors for SI units, please refer to ***Section 10.4***):

Unit	SI equivalent	Other non-SI unit equivalents				Various other units or conversions
		bar	*kp.cm^{-2}*	*N.mm^{-2}*	*psi*	
1 at	0.1013 MPa	1.013 bar	1.033 kp.cm^{-2}	0.1013 N.mm^{-2}	14.695 psi	
1 bar	0.1 MPa			0.10 N.mm^{-2}	14.504 psi	0.987 atmospheres
°C	–273.15 K					
°F						(°C x 1.8) + 32
1 ft (foot)	0.305 m					
1 in (inch)	0.025 m					
1 in^2	645.2 mm^2					
1 kgf	9.81 N					2.2046 lbf
1 kg/cm^2	0.098 MPa	0.981 bar	1 kp.cm^{-2}	0.098 N.mm^{-2}	14.223 psi	
1 N/mm^2	1 MPa	10.0 bar	10.197 kp.cm^{-2}	1 N.mm^{-2}	145.038 psi	
1 lb (pound)	4.45 N					0.4536 kp
1 lbf. ft	1.355 N.m					
1 lbf.in	0.113 N.m					
1 mm Hg	0.133322 kPa					
1 ppm	$35.92^{-0.733}$ g.h^{-1}					#
1 psi	6.895 kPa	0.0689 bar	0.0703 kp.cm^{-2}	0.00689 N.mm^{-2}		

This follows from the standard US field measurement technique, known as EPA Reference Method 21, which was introduced by the US Environmental Protection Agency (US EPA) for the monitoring of fugitive emissions in parts per million (ppm). This approach was established to provide a ”go" / “no go" method (i.e. there is either a **leak** or **no leak**). While this is useful as a **qualitative** measure of emissions, ppm cannot be converted directly into **quantitative** units. Accordingly, the US EPA has developed a series of correlations for the prediction of mass flow rate. These resemble closely a later joint study in the USA by the Chemical Manufacturers Association (CMA) and the Society of Tribologists and Lubrication Engineers (STLE), in which bagging data were analysed to determine the following relationship:

Leakage rate (lb.h^{-1}) = $6.138 \times 10^{-5} \times (SV)^{0.733}$, where SV is the screening value in ppm

When converted into metric units (453.6 g = 1 lb):

Leakage rate (g.h^{-1}) = $0.02784 \times (SV)^{0.733}$

10.4. Conversion factors (SI units)

Quantity	SI unit	Non-SI unit	Conversions
Acceleration	$m.s^{-2}$	$ft.s^{-2}$	1 $m.s^{-2}$ = 3.281 $ft.s^{-2}$ 1 $ft.s^{-2}$ = 0.305 $m.s^{-2}$
	9.806 $m.s^{-2}$	32.174 $ft.s^{-2}$	= Standard acceleration of gravity
Area	ha (hectare)	acre	1 ha = 10, 000 m^2 = 2.471 acres = 3.86 x 10^{-3} $mile^2$ 1 acre = 0.405 ha = 4046.86 m^2
	m^2	ft^2	1 m^2 = 10.764 ft^2 1 ft^2 = 9.290 x 10^{-2} m^2
	m^2	in^2	1 m^2 = 1.550 x 10^3 in^2 1 mm^2 = 1.550 x 10^{-3} in^2 1 in^2 = 6.452 x 10^{-4} m^2 = 645.2 mm^2
	m^2	$mile^2$	1 m^2 = 3.861 x 10^{-7} $mile^2$ 1 $mile^2$ = 2.589 x 10^6 m^2 = 259 ha
	m^2	yd^2	1 m^2 = 1.196 yd^2 1 yd^2 = 0.836 m^2
Density	$kg.m^{-3}$	$lb.ft^{-3}$	1 $kg.m^{-3}$ = 6.243 x 10^{-2} $lb.ft^{-3}$ 1 $lb.ft^{-3}$ = 16.018 $kg.m^{-3}$
	$kg.m^{-3}$	$lb.gal^{-1}$	1 $lb.gal^{-1}$ = 0.099 $kg.dm^{-3}$
	$kg.m^{-3}$	$lb.in^{-3}$	1 $lb.in^{-3}$ = 27.679 $g.cm^{-3}$
Energy (work)	J	Btu	1 J = 9.478 x 10^{-4} Btu 1 Btu = 1.055 x 10^3 J
	J	ft.lbf	1 J = 0.738 ft.lbf 1 ft.lbf = 1.356 J
	J	kcal	1 J = 2.390 x 10^{-4} kcal 1 kcal = 4.19 x 10^3 J
	J	kgf.m	1 J = 0.102 kgf.m 1 kgf.m = 9.810 J
	J	kWh	1 J = 2.778 x 10^{-7} kWh 1 kWh = 3.6 x 10^6 J
Force	N	kgf	1 N = 0.102 kgf 1 kgf = 9.81 N = 2.205 lbf
	N	lbf	1 N = 0.225 lbf 1 lbf = 4.448 N
	N	tonf	1 N = 1.003 x 10^{-4} tonf 1 tonf = 9964 N
Length	m	ft	1 m = 3.281 ft 1 ft = 0.305 m
	m	in (1”)	1 m = 39.37 in 1 in = 0.025 m
	m	mile	1 m = 6.214 x 10^{-4} mile 1 mile = 1.609 x 10^3 m
	m	milli-inch (“thou”)	1 “thou” = 25.4 µm
	m	yd	1 m = 1.094 yd 1 yd = 0.914 m

Quantity	SI unit	Non-SI unit	Conversions
Mass	kg	cwt	1 kg = 1.968 x 10^{-2} cwt 1 cwt = 50.802 kg
	kg	oz	1 kg = 35.274 oz 1 oz = 28.349 g
	kg	pound (lb)	1 kg = 2.203 lb 1 lb = 0.454 kg
	kg	ton	1 kg = 9.842 x 10^{-4} ton 1 ton = 1.016 x 10^{3} kg = 1.016 tonne 1 tonne (= 1 metric tonne) = 1000 kg
Moment of force (torque)	N.m	kgf.m	1 N.m = 0.102 kgf.m 1 kgf.m = 9.807 N.m
	N.m	ozf.in	1N.m. = 141.612 ozf.in 1 ozf.in = 7061.55 µN.m
	N.m	lbf.ft	1 N.m = 0.738 lbf.ft 1 lbf.ft = 1.356 N.m
	N.m	lbf.in	1 N.m = 8.85 lbf.in 1 lbf.in = 0.113 N.m
	N.m	tonf.ft	1 kN.m = 0.329 tonf.ft 1 tonf.ft = 3.037 kN.m
Moment of inertia	kg.m^2	oz.in^2	1 kg.m^2 = 5.464 x 10^3 oz.in^2 1 oz.in^2 = 1.829 x 10^{-5} kg.m^2
	kg.m^2	lb.ft^2	1 kg.m^2 = 23.730 lb.ft^2 1 lb.ft^2 = 0.042 kg.m^2
	kg.m^2	lb.in^2	1 kg.m^2 = 3.417 x 10^3 lb.in^2 1 lb.in^2 = 2.926 x 10^{-4} kg.m^2
Power	W	ft.lbf.s^{-1}	1 W = 0.738 ft.lbf.s^{-1} 1 ft.lbf.s^{-1} = 1.356 W
	W	hp	1 W = 1.341 x 10^{-3} hp 1 hp = 7.457 x 10^2 W
	W	kgf.m.s^{-1}	1 W = 0.102 kgf.m.s^{-1} 1 kgf.m.s^{-1} = 9.81 W
Pressure	Pa	bar	10^6 Pa = 1 MPa = 10 bar = 1 N.mm^{-2} 1 bar = 0.10 MPa = 14.504 psi
	Pa	ft H_2O (feet of water)	1 kPa = 0.335 ft H_2O 1 ft H_2O = 2.989 kPa
	Pa	in Hg (inch of mercury)	1 kPa = 0.295 in Hg 1 in Hg = 3.386 kPa
	Pa	kgf.m^{-2}	1 Pa = 0.102 kgf.m^{-2} 1 kgf.m^{-2} = 9.81 Pa
	Pa	kp.cm^{-2}	1 MPa = 10.194 kp.cm^{-2} 1 kp.cm^{-2} = 0.0981 MPa = 0.981 bar = 14.223 psi
	Pa	N.mm^{-2}	1 MPa = 1 N.mm^{-2} = 1 MN.m^{-2} = 10.197 kp.cm^{-2}
	Pa	lbf. ft^{-2}	1 kPa = 20.885 lbf. ft^{-2} 1 lbf. ft^{-2} = 47.880 Pa
	Pa	psi (lbf.in^{-2})	1 Pa = 1.450 x 10^{-4} lbf.in^{-2} 1 lbf.in^{-2} = 6.895 kPa = 0.0703 kp.cm^{-2} = 0.0689 bar
	Pa	ton.in^{-2}	1 MPa = 6.477 x 10^{-2} ton.in^{-2} 1 ton.in^{-2} = 15.44 MPa = 15.44 N.mm^{-2}
	1.013 x 10^5 Pa	14.696 lbf.in^{-2}	Standard atmosphere = 1.013 bar = 1.033 kp.cm^{-2}

Quantity	SI unit	Non-SI unit	Conversions
Rate of flow (volumetric)	$m^3.s^{-1}$	$ft^3.s^{-1}$ (cusec)	1 $m^3.s^{-1}$ = 35.314 $ft^3.s^{-1}$ 1 $ft^3.s^{-1}$ = 0.028 $m^3.s^{-1}$ = 28.317 $dm^3.s^{-1}$
	$m^3.s^{-1}$	imperial $gal.h^{-1}$	1 $m^3.s^{-1}$ = 7.919 x 10^5 imp $gal.h^{-1}$ 1 imp $gal.h^{-1}$ = 1.263 x 10^{-6} $m^3.s^{-1}$ = 4.546 $dm^3.h^{-1}$
	$m^3.s^{-1}$	$in^3.min^{-1}$	1 $m^3.s^{-1}$ = 3.661 x 10^6 $in^3.min^{-1}$ 1 $in^3.min^{-1}$ = 2.731 x 10^{-7} $m^3.s^{-1}$
	$m^3.s^{-1}$	US gal. min^{-1}	1 $m^3.s^{-1}$ = 1.585 x 10^4 US gal. min^{-1} 1 US gal. min^{-1} = 6.309 x 10^{-5} $m^3.s^{-1}$
Temperature	K	^oC	K = ^oC + 273.15 ^oC = K –273.15
		^oF	^oC = (^oF –32) x 0.556 ^oF = (^oC x 1.8) + 32
Velocity	$m.s^{-1}$	$ft.s^{-1}$	1 $m.s^{-1}$ = 3.281 $ft.s^{-1}$ 1 $ft.s^{-1}$ = 0.305 $m.s^{-1}$
	$m.s^{-1}$	$km.h^{-1}$	1 $m.s^{-1}$ = 3.6 $km.h^{-1}$ 1 $km.h^{-1}$ = 0.278 $m.s^{-1}$
	$m.s^{-1}$	$mile.h^{-1}$	1 $m.s^{-1}$ = 2.237 $mile.h^{-1}$ 1 $mile.h^{-1}$ = 0.447 $m.s^{-1}$ = 1.467 $ft.s^{-1}$
Viscosity (dynamic)	Pa.s	P (poise)	1 Pa.s = 10 P 1 P = 0.1 Pa.s
	Pa.s	$lbf.s.ft^{-2}$	1 Pa.s = 2.089 x 10^{-2} $lbf.s.ft^{-2}$ 1 $lbf.s.ft^{-2}$ = 47.880 Pa.s
Viscosity (kinematic)	$m^2.s^{-1}$	$ft^2.s^{-1}$	1 $m^2.s^{-1}$ = 10.764 $ft^2.s^{-1}$ 1 $ft^2.s^{-1}$ = 9.290 x 10^{-2} $m^2.s^{-1}$
	$m^2.s^{-1}$	$in^2.s^{-1}$	1 $in^2.s^{-1}$ = 6.452 $cm^2.s^{-1}$ = 645.16 cSt
	$m^2.s^{-1}$	St (stokes)	1 $m^2.s^{-1}$ = 10^4 St 1 St = 10^{-4} $m^2.s^{-1}$
Volume (capacity)	m^3	ft^3	1 m^3 = 35.315 ft^3 1 ft^3 = 0.028 m^3
	m^3	imperial fl oz	1 fl oz = 28.413 cm^3
	m^3	imperial gal	1 m^3 = 2.199 x 10^2 imp gal 1 imp gal = 4.546 x 10^{-3} m^3
	m^3	imperial pt (pint)	1 pt = 0.568 dm^3
	m^3	in^3	1 m^3 = 6.102 x 10^4 in^3 1 in^3 = 1.639 x 10^{-5} m^3
	m^3	litre (L)	1 L = 10^{-3} m^3 = 0.220 imp gal = 0.264 US gal
	m^3	US gal	1 m^3 = 2.642 x 10^2 US gal 1 US gal = 3.785 x 10^{-3} m^3

11. Further reading

The **European Sealing Association** has produced a wide variety of technical publications, often in collaboration with colleagues throughout the world, and focused primarily on helping users to achieve and maintain good sealing performance. These documents form the basis for this particular publication on BAT and are available from the ESA, either as hard copy or electronically. As part of good operating practice, the following ESA documents should be consulted where appropriate:

☑ ***Expansion Joints - Engineering Guide - fabric expansion joints for ducting systems***, (ESA publication n°. 011/01), published 2001, January.
Available in the following language version: English (other language versions in preparation).

☑ ***Glossary of Sealing Terms, part 1, Flanges and Gaskets***, (ESA publication n°. 008/97), published November 1997.
Available in the following language versions: English, Italiano.

☑ ***Guidelines for safe seal usage - Flanges and Gaskets***, (ESA+FSA publication n°. 009/98), a joint publication of the European Sealing Association (ESA) and Fluid Sealing Association (FSA), published September 1998.
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☑ ***Guidelines for the use of Compression Packings - revised edition***, a joint publication of the FSA and ESA, published 1997.
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☑ ***Seal Forum - case studies in pump performance***, a joint publication of the ESA and FSA, published 2003.
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In addition, the following **leaflets / pamphlets** provide installation guidance for engineers in the field:

☑ ***Fabric Expansion Joints - Installation Guide***, (ESA publication n°. 015/04), a joint publication of the European Sealing Association (ESA), Gütegemeinschaft Weichstoff Kompensatoren e.V. (RAL) and Fluid Sealing Association (FSA), published 2004 January.
Available in the following language version: English (other language versions in preparation).

☑ ***Gasket Installation Procedures***, a joint publication of the FSA and ESA, published 2000.
Available in the following language versions; Deutsch, English, Español, Français, Italiano, Nederland, Portuguese, Turkish.

☑ ***Pump and Valve Packing Installation Procedures***, a joint publication of the FSA and ESA, published 2003.
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