STATIC SEALS

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

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

GASKETS

A gasket is used to create and retain a static seal between two stationary flanges, which may connect plant equipment, and which may contain a substance under pressure. These static seals aim to provide a barrier to block any leakage. To achieve this, the gasket must be able to flow into (and fill) any irregularities in the flange surfaces being sealed, while also resist extrusion and creep under operating conditions. The gasket is compressed by clamping forces causing it to flow into any flange imperfections. The combination of contact pressure between the gasket and flanges, and densification of the gasket material, prevents the escape of the contained media. As such, gaskets are vital to the operation of industrial equipment and therefore are an integral design element.

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

When assembled, a flange gasket seal or 'joint' is usually compressed by bolts under tension. In order to ensure the maintenance of the seal throughout the lifetime of the assembly, enough pressure must remain on the gasket surface to prevent leakage. Under operating conditions, this pressure will be reduced by hydrostatic end thrust, the force produced by the internal pressure which acts to open the flanges. The gasket is also subject to a side force due to the internal fluid pressure attempting to push it out of the connection. To maintain a seal, the effective compressive pressure on the gasket (that is, the assembly load minus the hydrostatic end thrust) must be greater than the internal pressure by a multiple which is dependent on the gasket type/material, the process involved and level of tightness required. A number of publications 3, 4, 5, 6 provide more detail of the flange I gasket interaction (Figure 1).

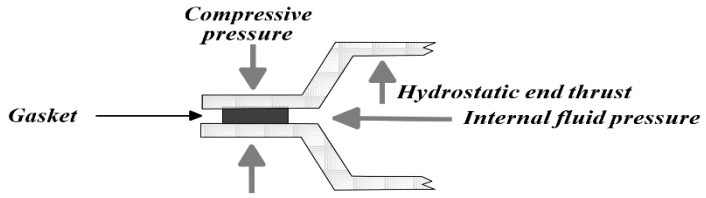


FIGURE 1- FLANGE / GASKET INTERACTION

The primary function of a gasket is to create and maintain a seal between flanges, under conditions which may vary from one joint to another. To meet these varying conditions, a number of flange / fastener / gasket systems have been developed, and many factors must be considered when selecting the most appropriate assembly (Table 1).

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

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

The performance of the seal depends upon the interaction of all the **elements of the flange joint system (**Figure 2**)**.

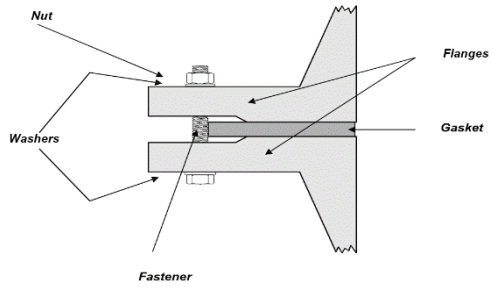


FIGURE 2 - ELEMENTS OF THE FLANGE JOINT

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

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

GASKET SELECTION

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

Gaskets can be defined into 3 main categories:

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: fiber reinforced sheet, exfoliated graphite, sheet PTFE in various forms and high temperature inorganic sheet materials.

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 fiber materials), corrugated metallic and spiral wound gaskets.

Metallic gaskets: Fabricated from a single metal or a combination of metallic materials, in a variety of shapes and sizes. Suitable for high temperature and pressure applications. Types include: Lens rings, ring type joints (RTJ) and weld rings.

The mechanical characteristics and sealing performance capabilities of these categories vary a lot. The gasket must be resistant to the media being sealed. For gaskets which are electrically conductive, consideration must also be given to electrochemical (or “galvanic”) corrosion. Gaskets cut from sheets, always use the thinnest material possible, but thick enough to compensate for unevenness of the flange surfaces, their parallelism, surface finish and rigidity etc. The thinner the gasket, the higher the bolt load which the gasket can withstand, the less the loss of bolt stress due to relaxation, and hence a longer possible service life. For more information about mechanical characteristics of gasket types, please refer to EN13555. For specific performance details and recommendations for particular applications, please consult the gasket’s manufacturer.

STORAGE AND HANDLING OF GASKETS AND GASKET MATERIALS

Most gasket materials can be used safely after storage for many years, ageing will have an effect only on the performance of certain types of gasket materials. Primarily, materials bonded with elastomers, which, in general, should not be used after about 2 years from the date of manufacture. This is not a problem for metallic gaskets, but it may have an effect on semi-metallic gaskets (specifically, those which are combined with elastomer-bound materials). All gaskets and gasket materials are best handled with care and attention. Bent, nicked, gouged, scratched or hammered gaskets will not seal!

ASSEMBLY PROCEDURES

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

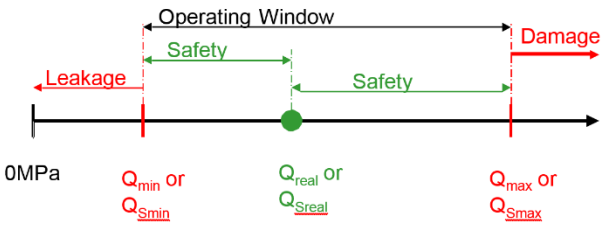


FIGURE 3 - OPERATING WINDOW USING EN1591 TERMINOLOGY (Q = INSTALLED GASKET STRESS QS= GASKET STRESS IN SERVICE)

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

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

Methods for calculating the applied force created by a standardized bolt under torque can be found in EN1591 / PCC1, however the friction factor is generally a hard value to gage. Lubrication manufactures will sometimes quote a value that can be used in calculations, but general values can be found in Table 2.

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

Table 2 - Generic bolt friction factors

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

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

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

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

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

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

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

Tightening: The sequence in which bolts or studs are tightened affects the distribution of the gasket stress. Improper bolting may move the flange out of parallel. A gasket will usually be able to compensate for a small amount of distortion of this type, but serious difficulties will be encountered if the flanges are substantially out of parallel so always torque nuts in a cross bolt tightening pattern (

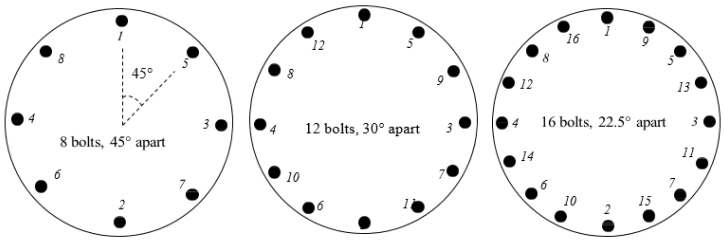


Figure 4). It is also required that the force is applied stages to ensure equal compression around the gasket. The ESA/FSA recommend a 4 pass system where initially the bolts are tightened by hand, then 33% of the required torque, 66%, 100% and a final pass at 100% a minimum of 4hrs after the first 100% pass.

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

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

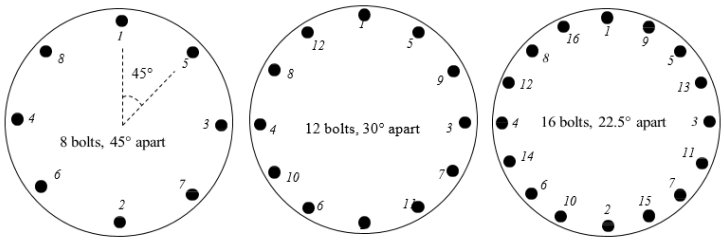


Figure 4 - Bolt tightening patterns

EXPECTED EMISSIONS

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

SAFETY ASPECTS AND JOINT FAILURE

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

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

Some common failures and there reasons are;

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

Fasteners over-tightened; gasket crushed, flanges bent.

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

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

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

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

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

MINIMIZING THE CHANCES OF JOINT FAILURE

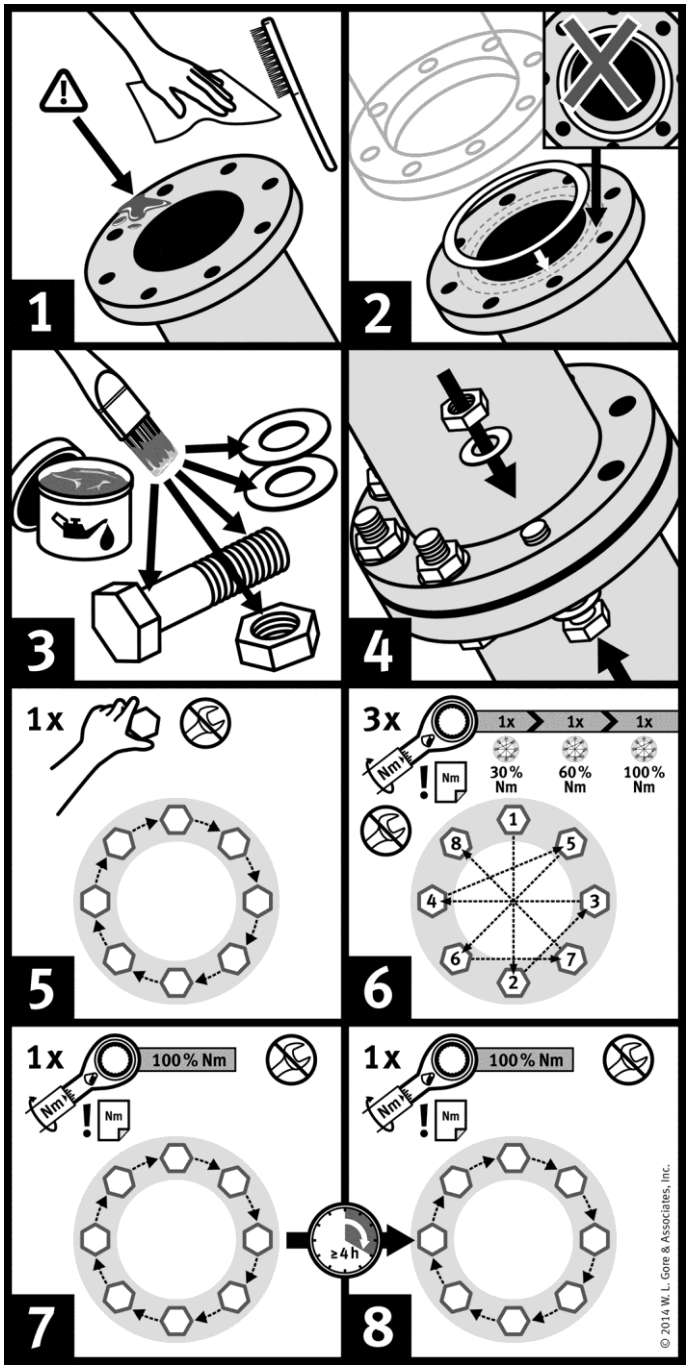
The selection of the correct materials for the application is fundamental. Make sure that all components of the joint are compatible with each other and with the conditions during service. Follow the gasket storage and handling recommendations as given by the manufacturer. Follow the cleaning and visual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

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

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

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

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