The bolted connection - seal

As was discussed in our column in the February issue of Valve World, preventive and corrective actions are needed to minimize seal failures and subsequent down times. In this article, possible causes, checks and remedial actions are discussed.

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spiral wound gasket; sealing element with outer ring only. Failure: mode inner ring buckling. Cause: incorrect size\no inner support ring

In general, seal failure shows itself as one of three relatively distinct failure modes; an immediate or sudden 'catastrophic' usually gross leak also known as a "blow out", a slow 'progressive' or chronic leak or a 'transient' leak that may occur for a time then self seal and may subsequently reoccur.
Catastrophic leaks can occur on plant start up, pressure test or during normal operation. They normally arise because of insufficient, too much or uneven load being generated in the connection during assembly. During service catastrophic leakage is normally attributable to excessive stress loss, usually caused by process pressure and/or temperature excursions, or may be the final result from a slow progressive leak that went unnoticed e.g. occurred under pipework of vessel insulation. Much can be learned from a simple used gasket inspection. The presence of a clearly damaged gasket; crushed non-metallic or buckled spiral wound gasket is fairly easy to diagnose, however simple thickness analysis can also be an indicator of excessive and/or uneven assembly stress. The following table highlights

failure analysis and corrective action

Table 1. Gasket selection and installation leaks.

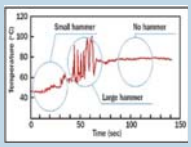
Effect	Possible Cause	Checks & Remedial Action
Leakage on system pressure test 	Insufficient compressive load	Gasket thickness and visual inspection. Check for even imprint of reverse flange finish on gasket contact faces. Review assembly practice and load (torque). **Consider higher stress gasket**
	Excessive compressive load	Gasket Inspection – thickness / condition – buckled, crushed, cracked Review assembly load (torque). **Consider lower loads or a higher load bearing gasket.**
	Uneven compressive load	Gasket thickness and visual inspection. **Review assembly procedure load (torque).**
	Gasket defective and/or damaged	Gasket inspection – radial scoring/scratches, face missing, corrosion. Welding issues ring rolled - under and over dressed welds. Pass bar attachment – high weld spots and or weld spatter. **Replace gasket.**
	Flange sealing face damage	Face sealing inspection, radial scoring/scratches, pitting, corrosion, weld spatter, appropriate surface roughness **Replace flange and or re-machine flange sealing face(s) in line with industry standards.**
	Flange faces non-parallel and/or not flat	Flange inspection. Replace / realign flanges in line with industry standards. **Consider thicker and or higher compression gasket.**
Leakage on process start up with temperature	See previous	
Leakage on process start up and/or shut down with temperature 	Gasket relaxation	Gasket inspection – excessive damage, radial extrusion/intrusion. Consider gasket with improved creep resistance style/material **Review gasket selection and/or assembly load (torque)**
	Excessive load cycling	Consider gasket with improved resilience characteristics. Consider alternative bolt material / design – longer and/or reduced shank. **Review assembly load (torque)**
Leakage during steady state operation 	Excessive load cycling	Check for process excursions/spikes (temperature and pressure). Improve process control. Consider gasket with improved resilience. Consider alternative bolt material / design. **Review assembly load (torque)**
	Unnoticed progressive leak	Gasket inspection. Consider gasket with improved creep and/or chemical/temp resistance. **Review assembly load (torque).**

Table 2. Progressive leaks.		
Effect	**Possible Cause**	**Checks & Remedial Action**
Progressive or chronic leak during steady state operation.	Insufficient assembly stress	No apparent issues on general hardware inspection. **Review flange assembly load.**
	Gasket relaxation	Gasket inspection – damage, extrusion. **Consider gasket redesign with improved creep / load bearing properties**
	Gasket chemical degradation	Gasket inspection – damage, extrusion, swelling, discoloration, corrosion, pop corning. Review chemical compatibility under application conditions. **Consider gasket with improved chemical resistance.**
	Gasket thermal degradation	Gasket inspection – damage, charring, mass loss, discolouration, facing and/or winding disappearance, metal carburisation. **Consider gasket with improved thermal resistance.**
	Bolt relaxation	Can be difficult to visually detect. Bolt inspection – permanent elongation, necking, male thread damage. **Consider bolt length (full thread engagement), review assembly procedure, review bolt material selection.**
	Bolt corrosion	Bolt inspection – general or galvanic corrosion, pitting, stress cracking (hydrogen, chloride). **Consider alternative bolt material. Consider possibility of protective coating (Xylan, Zinc passivation etc.).**
	Flange face corrosion	Flange face inspection – General pitting, galvanic. **Consider re-machining flange faces, alternative gasket style / materials.**
	Gasket incorrectly sized	Gasket inspection – Damage initiating on exposed surfaces. **Review gasket design**

some of the more common primary causes and suggests some cost effective checks and preventative action to be considered in the event of 'catastrophic' seal failure mode.

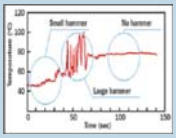
Progressive leaks

Progressive leaks can be defined as those that begin slowly and as time passes generally increase in severity. This type of leak is associated with time related progressive stress loss in the connection. Stress loss can be attributable to any one or all of the mechanical components in the connection. Alternatively the initial assembly stress may have been insufficient to accommodate the calculated relaxation in the connection over the required seal life. Consideration of the initial assembly stress in the context of relaxation and seal life is key to achieving a successful seal. Relaxation is the enemy of joint integrity. Studies have shown that it can and does occur over many months. All the components in the connection can be subject to relaxation, depending on the application conditions some more than others. Connections using lower quality non-metallic gaskets can be more prone to relaxation effects, particularly in elevated temperature service. In this type of time related failure mode the effects of corrosion and chemical degradation can also be a significant cause of load loss in the connection.

Transient leaks

Transient leaks are associated with bolted connections that are subject to changes in load during the normal operation of the plant and / or equipment. As the name implies they appear and disappear seemingly at will. Unfortunately flange design codes don't normally consider these transient load conditions. Increasing the overall load in the connection may solve the problem but only if the individual mechanical components are kept within their acceptable limits. Increasing the resilience of the connection can also prove useful in addressing these types of problems. These types of leaks are generally associated with fluctuations in temperature and / or pressure during start up, shutdown or during normal operation if batch and/or cyclic in nature. Seal integrity can also be affected by a phenomenon known as radial shear. This can occur due to differences in the thermal expansion characteristics between the mating sealing faces.

Table 3. Transient leaks.

Effect	Possible Cause	Checks & Remedial Action
 Transient leak on process start up/ shut down and/or normal cyclic operation	Thermal expansion effects	Review connection metallurgy. Review process.
	Insufficient assembly load	**Review assembly procedure** Consider increasing flange stiffness – use of collars. **Review bolt material.**
	Insufficient connection resilience	Review bolting – reduced shank (anti-fatigue), increased length (collars). **Consider spring washers.** **Review gasket style/materials with improved resilience**
 Transient leak during steady state operation	Process excursion	Check for process excursions (temperature and pressure). Improve process control. Consider gasket with improved resilience. **Consider alternative bolt material / design.** **Review assembly load (torque)**
Transient leak during environmental aberration	See previous	See previous **Shield connection from environmental extremes**
	Radial shear	Gasket inspection – gasket disintegration, radial scoring **Review gasket selection to radial shear resistant type.**

Fixed and floating tube-sheet connections can be particularly susceptible. Transient leaks may in certain circumstances be correlated with seasonal or sudden changes in the weather if the connection is exposed to the external environment. In many ways, because of their relatively complex nature transient leaks can be the most difficult to mitigate.

The European Sealing Association (ESA) has produced this article as a guide towards Best Available Techniques for sealing systems and devices. These articles are published on a regular basis, as part of their commitment to users, contractors and OEM's, to help to find the best solutions for sealing challenges and to achieve maximum, safe performance during the lifetime of the seal. The ESA is the voice of the fluid sealing industry in Europe, collaborating closely with the Fluid Sealing Association (FSA) of the USA. Together, they form the key global source of technical knowledge and guidance on sealing technology, which is the basis for these articles.
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