Seal Design Considerations for Kalrez® and Utilizing the Kalrez® Application Guide

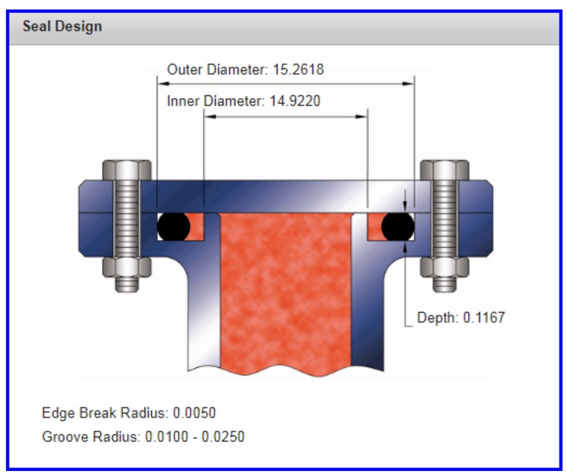
There are many factors that must be considered when designing a seal. The components of the seal comprise the gland and elastomer. Every elastomer has different properties, and these affect how it will perform in a gland. When designing a seal, the first step is the selection of an elastomer for the application. When sealing aggressive chemicals and/or at high temperatures, Kalrez® perfluoroelastomer parts are often the elastomer of choice.

The sealing performance of an elastomer is a function of its chemical stability, temperature range/stability, inherent mechanical properties and the seal design itself. Kalrez® perfluoroelastomer parts provide industry leading performance regarding chemical resistance and high temperature stability. The gland must be designed by considering the elastomer's properties and the application conditions. Failure to consider these factors may result in premature failure of the elastomeric component.

The following sections discuss seal design and how the Kalrez® Application Guide (KAG) can facilitate these designs when using Kalrez® o-rings. The KAG provides the user with general data on gland design and provides default values for typical design parameters. Experienced designers may elect to change these default values for specific applications. This document provides specific information on the use of the KAG for Kalrez® o-ring gland design.

Gland Design

A standard gland design must consider the elastomer properties of the selected material. These include: temperature range, thermal expansion, chemical swell, and more. Each of these factors is discussed in more detail in the following sections. Gland designs should be reviewed whenever a different elastomer type is used because each material has unique properties. Usually, standard gland designs will handle most elastomers. However, the design must be checked when switching elastomers, especially when the reason is due to higher application temperatures. Note that special designs may also be required for low temperature or vacuum sealing applications.



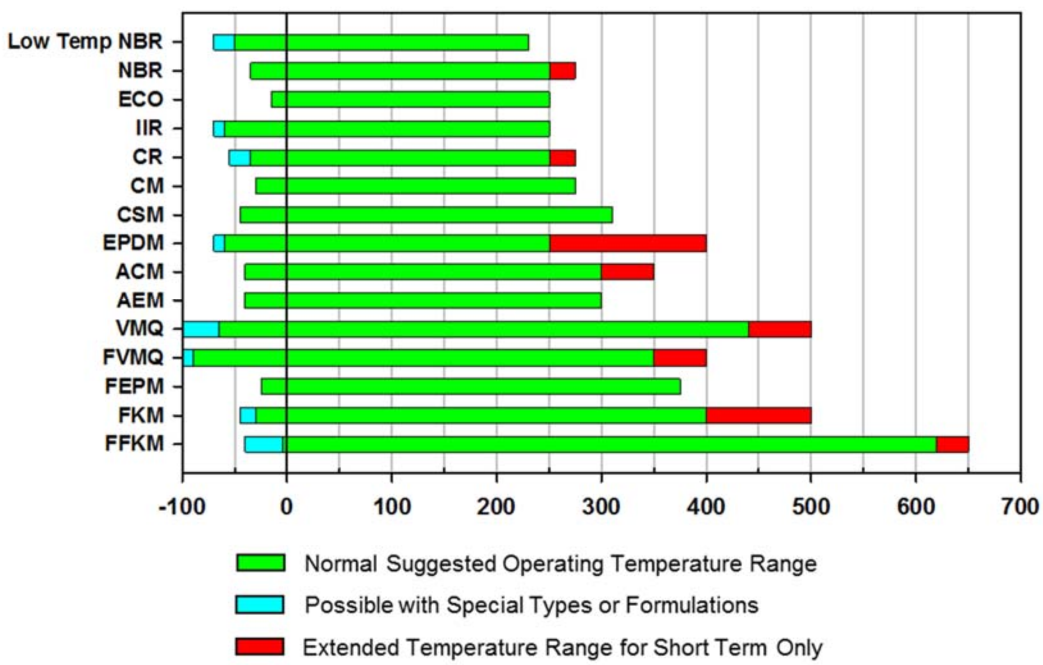
Proper design can greatly enhance the mean time between repair (MTBR) for elastomer seals. The elastomer is typically the weakest mechanical member of a seal, and as such, it will be the first part to fail if the design does not adequately deal with the material's limitations.

Kalrez® o-rings are manufactured to conform to the dimensions and tolerances of industry standards, such as AS-568, "Aerospace Size Standard for O-rings." Seal designs in the KAG can be selected for general static, dynamic and vacuum applications using industry standard o-ring dimensions. The KAG makes it easy to simply type in the o-ring size, or by selecting AS, metric, or JIS standard sizes.

Temperature and Thermal Expansion

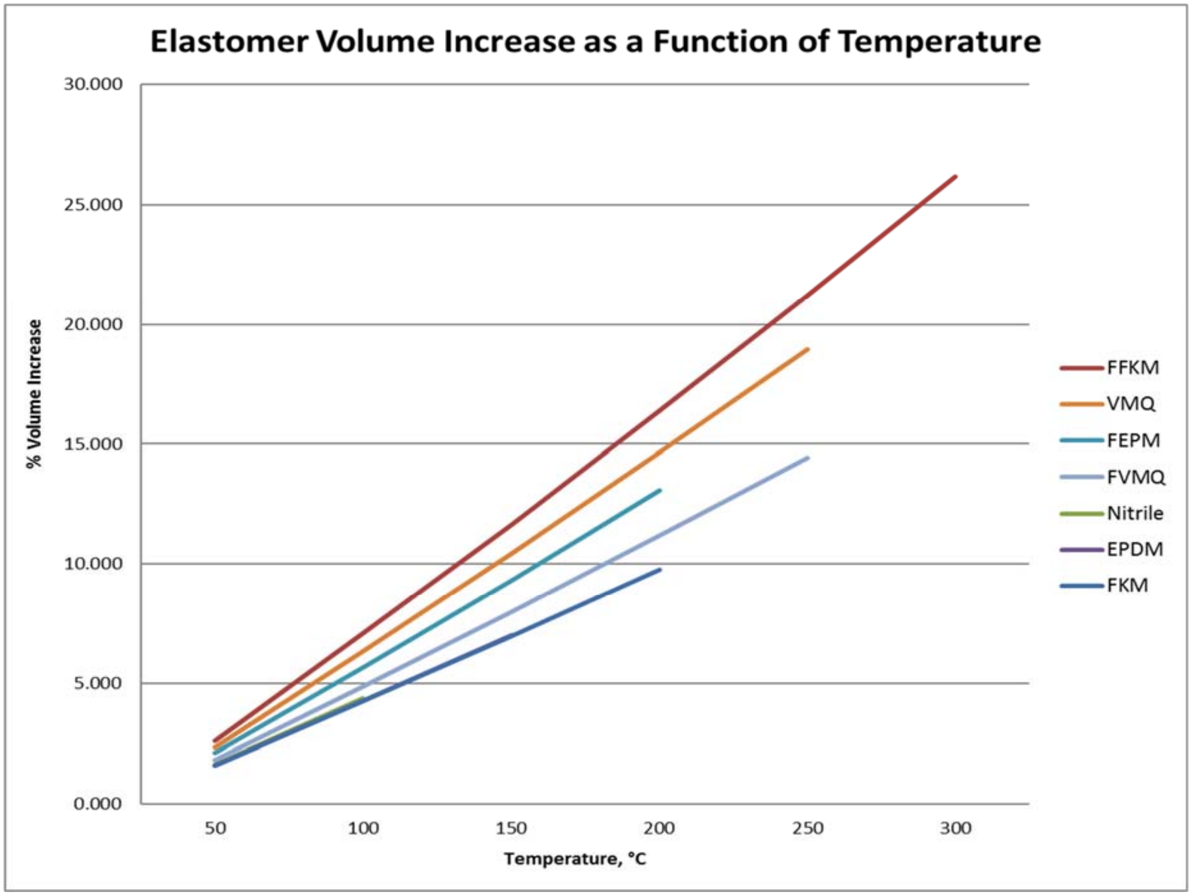
Application temperature and thermal expansion are two important aspects for elastomers. Elastomers can be used over a wide range of temperatures, however, selecting the correct one for an application can be difficult. The following chart shows the typical temperature range for different elastomers; this information is typically provided in datasheets. The chart also shows the extended lower temperature range for special elastomer formulations and the extended upper temperature for short exposure times. However, it is important to note that these measurements were made in dry air. If an elastomer is exposed to chemicals, the effective use temperature range will decrease. In the following chart, FFKM is the ASTM designation for perfluoroelastomers, such as Kalrez®.

Temperature Range for Common Elastomers (Dry Air)



Elastomers experience thermal expansion as the temperature increases above room temperature. This coefficient of thermal expansion (CTE) is unique for each elastomer. In addition to thermal expansion, thermal contraction takes place as the elastomer temperature is lowered. Although a value for the linear CTE of an elastomer is often reported in literature, this is often not exact since the CTE is not necessarily linear over the elastomer's temperature range. This fact should be considered in seal design. Finally, the CTE value can vary greatly within an elastomer family depending on the polymer type and filler content.

The linear coefficient of thermal expansion (CTE) for Kalrez® parts is generally greater than for non-perfluoroelastomers. It can be in the range of 50% greater than a fluoroelastomer of similar hardness. This greater CTE much be considered when designing seals for higher temperature applications. For example, when a lower performing seal (typically lower CTE) is being replaced by Kalrez® due to higher process temperatures, the gland design (available groove volume) must be verified “as acceptable’ to avoid seal extrusion and premature seal failure. As an example, the following graph shows the relative CTE values for several elastomer types.



The KAG is an excellent resource for analyzing seal designs that utilize Kalrez® o-rings. The KAG utilizes the specific CTE value for each Kalrez® product when designing a gland. The KAG can design grooves for specific o-ring sizes, or it can evaluate a current groove and o-ring combination to determine if there may be issues with groove overfill. If problems are identified, design changes will be suggested to enable the o-ring to perform properly. When groove overfill occurs, the result is extrusion, or circumferential splitting of the seal if it cannot extrude. In either case, the groove volume will need to be increased. Gland dimensions that are problematic are highlighted in the KAG, in “Red.” This indicates the values are out of the normal (expected) range, but does not necessarily indicate the part will fail. The KAG will automatically handle these calculations and help predict if there may be gland design issues. Specific information on the CTE value for Kalrez® products can be found in the Product Datasheet sections.

Stretch

Stretch is measured as a percentage increase in the inner diameter (ID) of an o-ring. Stretch results in a reduction and possible flattening of the o-ring cross section. There are two “types” or “phases” of stretch: installation stretch (as the seal is being placed in the groove) and assembled stretch (once the seal is seated). Because installation stretch is temporary, an o-ring can generally undergo this stretch to a relatively high degree, often 100% or more if the installation is particularly tricky or of an intricate design. Installation stretch is always an important consideration.

Care should be taken to avoid overstretching (and breaking) Kalrez® o-rings during installation. Many Kalrez® products have an elongation to break value in the range of 125-170%. It is suggested not to stretch an o-ring more than 50% of its elongation to break value to avoid breaking the o-ring. As an example, if the o-ring elongation to break value is 120%, then avoid stretching the o-ring more than 60% during installation. For small o-rings, it is best to keep the installation stretch under 25%, of the elongation to break. This is due to the difficulty in evenly stretching small o-rings. A high localized elongation can result in o-ring breakage. Special tools may be required to allow for even stretching of an o-ring during installation. For example, use of a cone device can assist with evenly stretching an o-ring.

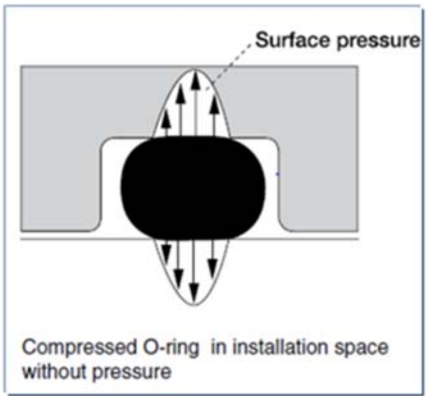
Assembled stretch, on the other hand, is permanent and must therefore be minimized to maximize the o-ring service life. Although it should be kept to a minimum, assembled stretch does not need to be eliminated altogether. A small degree of assembled stretch often ensures the o-ring will fit snugly in the groove. Assembled stretch occurs when the ID of the o-ring is slightly smaller than the groove diameter. This difference in diameters ensures the o-ring will be subjected to some degree of stretch during both installation and use.

When sealing on its inner diameter, an assembled stretch of 1-3% is suggested. Too little stretch and the o-ring may not sit properly in the groove. Too much stretch, for example, greater than 5%, and the o-ring may suffer premature failure due to high internal stresses. If an o-ring is sealing on its outer diameter, then the o-ring OD should be approximately equal to the gland OD. This is a general consideration to minimize stresses on the o-ring. However, if a sealing application has a relatively small pressure gradient, for example, an atmosphere or less (e.g. a vacuum application), then a stretch of 1% is suggested, regardless of whether the o-ring is sealing on its ID or OD. When designing grooves for o-rings, the Kalrez® Application Guide will automatically provide a suggested o-ring stretch for the application selected. Further, the KAG corrects compression values due to flattening of the o-ring cross section that can occur due to stretch in certain grooves.

Lastly, if the o-ring is sealing against a rotating shaft, there should be 0% stretch on the o-ring. O-ring compression should be achieved by the gland outer diameter compressing the o-ring against the shaft. If the o-ring is stretched in this type of application, it will heat up during operation, causing it to contract and grab the shaft more tightly. This results in more heat buildup, contraction, grabbing the shaft more tightly, etc. The result is rapid heat buildup and o-ring failure. This phenomenon is known as the Gough-Joule effect.

Compression

Compression is the amount of squeeze that is placed on an o-ring after installation and equipment assembly. It is expressed as a percentage of the original o-ring cross section and is the o-ring cross sectional diameter (CSD) compression between mating surfaces. There are two types of squeeze for static o-ring seals: radial and axial. Radial compression occurs on the o-ring's OD and ID surfaces. Axial compression occurs on the top and bottom surfaces of an o-ring. An example of axial compression is a face (flange) seal.



Assembled compression

*% compression = (O-ring CSD – gland height)/O-ring CSD * 100*

For example, if the o-ring CSD = 0.139" and the gland height = 0.115", then:

*(0.139 – 0.115)/0.139 * 100 = 17.3% compression*

Installed compression may be different than the actual compression of the o-ring during process operation, which includes thermal expansion and/or chemical swell. The term, "relative compression" might be the best term to explain this o-ring compression during actual operation. Insufficient o-ring compression may result in process leakage, while over compression may result in premature o-ring failure. Excessive compression will most likely result in the o-ring splitting or cracking, and then failing.

Compression of Kalrez® o-rings must consider the application temperature. In general, a compression of 14%-18% is suggested for static seals with Kalrez® o-rings. Excessive compression, 30% or greater, can result in parts splitting or cracking. This "high relative compression" can occur when parts are exposed to elevated temperatures, even if the "installed compression" is acceptable. The KAG will automatically take these factors into account during seal design.

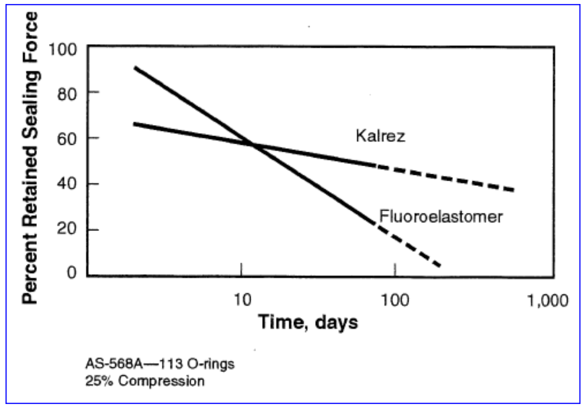
When temperatures are below 0°C, or in vacuum applications, additional compression may be needed to assist in proper o-ring sealing. In these cases, a compression of 18%-22% is suggested. This may be problematic if the application cycles between very low and very high temperatures. In those cases, an engineering balance must be reached, or specific groove design modifications may be necessary.

O-ring Compression Set

Compression set most often causes issues in applications that undergo broad thermal cycling. When a perfluoroelastomer seal is used continuously at high temperatures, it will eventually assume an equilibrium position (shape) as it seals. When the temperature is reduced, the seal may "remember" its equilibrium position. As the physical volume of the seal gets smaller (thermal contraction), combined with the established equilibrium position, leakage may occur. Should this occur, the seal should be allowed to recover, dimensionally, by raising its temperature before applying fluid pressure to it. This will allow the seal to recover and once again provide the necessary sealing force. Or the seal may need to be replaced.

Unlike some other elastomers, somewhat higher compression set values for perfluoroelastomers are primarily caused by stress relaxation, as opposed to thermal or chemical degradation. Hence, Kalrez® o-rings remain soft even after long term exposure to high temperatures. Newer grades of Kalrez® perfluoroelastomer parts have low compression set values and offer better resistance to temperature cycling.

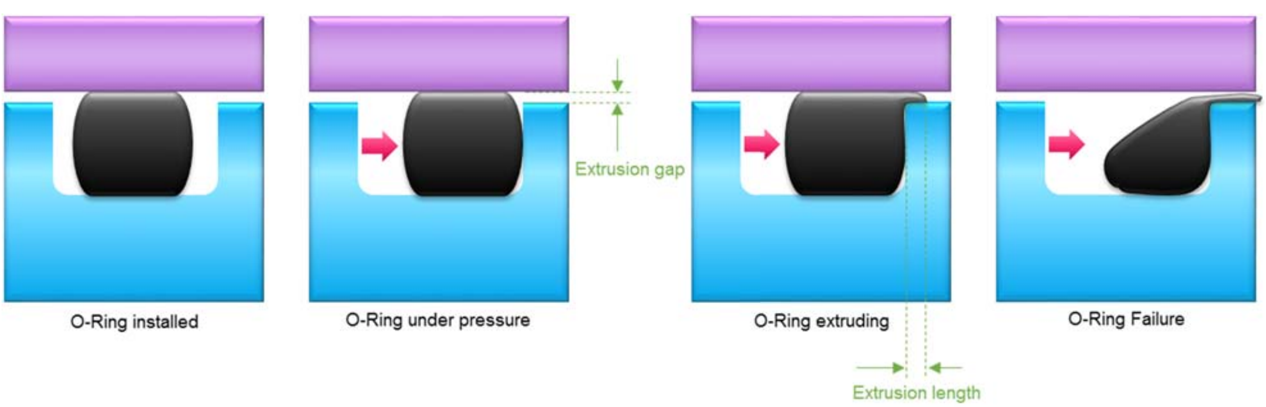
Another method for measuring long term sealing performance, similar to compression set, is stress relaxation testing. This is often referred to as the "Lucas Test." Basically, this test measures the amount of sealing force an elastomer is exerting to maintain a seal. Values are typically reported as: percent retained sealing force. The graph compares the retained sealing force of Kalrez® vs. a fluoroelastomer, aged in air at 204°C. This test shows the exceptional stability of Kalrez® with time, whereas the fluoroelastomer rapidly loses its ability to maintain a seal.



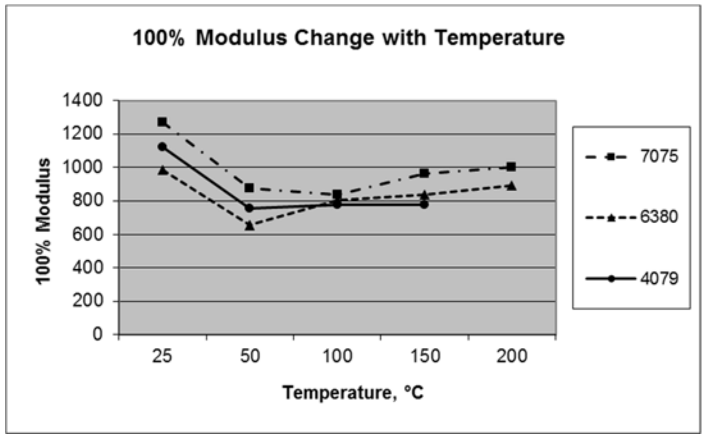
Pressure and Extrusion

Extrusion of an elastomer is a function of the operating temperature, the mechanical properties of the elastomer at that temperature, the mating surface's clearance gap, and the operating pressure. Because the elastomer is often the weakest component of a seal assembly, failure by extrusion is an indication that the seal design does not adequately address the mechanical properties of the elastomer. Under the effect of pressure, elastomer seals deform and tend to extrude into a seal gap. A slight degree of extrusion will help to maintain an effective seal. However, if the extrusion is excessive, the seal will eventually fail. An increase in the temperature, pressure or clearance gap will increase the severity of the extrusion. For high pressure applications, the KAG automatically considers the application temperature and pressure before suggesting a product, given the application constraints.

O-ring Extrusion Due to High Pressure



Kalrez® parts are often used at very high temperatures because they may be the only elastomers that are stable at those temperatures. At high temperatures, Kalrez® parts will soften and there will be some loss in mechanical properties. This decrease in properties can aggravate extrusion issues. The following graph shows the decrease in modulus for several Kalrez® products, with an increase in temperature. This graph shows that extrusion may occur at higher temperatures and not at lower temperatures. The Kalrez® Application Guide considers the application temperature, whether high or low, before suggesting products for an application. Products that do not meet the temperature criteria, or the temperature and pressure conditions are filtered out of the suggested product list. Effective use of the KAG for product selection can minimize the chance for extrusion or part failure during operation.



To help prevent extrusion it is suggested that:

- Clearance gaps be kept to the minimum achievable, consistent with an economical machining process, typically 0.002”-0.005” (0.051mm – 0.127mm). These are the standard conditions used in the KAG when considering application temperature and pressure
- Anti-extrusion (backup) rings are used for high pressure applications to reduce the sealing clearance gap. Contoured anti-extrusion rings can reduce the strain of deformation on the elastomers, providing improved service life. The width of the o-ring grooves should be increased to accommodate the volume of the anti-extrusion rings. Backup rings may be made from many different materials, for example, reinforced PTFE. The KAG can automatically increase the gland volume when anti-extrusion rings are added into the seal design.

Another issue that can occur with high pressure applications is Rapid Gas Decompression (RGD). This problem can arise when sealing fluids, such as carbon dioxide (CO_2), are under high pressure (e.g. 2000 psi). During an application, the process fluid equilibrates, with time, inside the o-ring. If there is a sudden loss of system pressure, the gas inside the elastomeric part expands rapidly and can literally blow the o-ring apart. In less severe cases, the o-ring may blister or develop small splits. The KAG can assist with the selection of products such as Kalrez® 0090 to eliminate or minimize problems associated with RGD.

Low pressure applications can also cause sealing difficulties. Gas permeation may be the problem for these applications, rather than actual leakage. In these services, more compression is often applied to the o-ring to:

- Maximize the distance a gas must traverse to go through the ring
- Decrease o-ring surface area exposure to the fluid

- Force the o-ring to better seal against irregularities in the metal surface

Finally, vacuum grease can be used on the o-ring to help reduce gas permeation.

Chemical Resistance

The chemical resistance of an elastomer is not directly related to seal design, but it can affect the elastomer performance. Elastomer selection should be such that chemical swell is minimized. Even moderate chemical swell can result in softening of the elastomer and possible extrusion from the seal gland. Although gland size can be increased to account for some elastomer swell, it is best to choose an elastomer product that is resistant to the chemical environment.

Kalrez® perfluoroelastomer parts can provide the ultimate in chemical resistance. This means minimal swell due to chemical exposure and therefore, a reduced chance of extrusion. The KAG can assist with the proper Kalrez® elastomer selection for the process environment. After product selection, the Seal Design section of the KAG allows the user to input the chemical swell of a Kalrez® product, if that value is known. Unfortunately, exposure testing in the actual chemical environment is often the only way to obtain an accurate value for chemical swell.

Surface Roughness

The roughness of the sealing surfaces in contact with the elastomer can be important, especially when sealing gases. For most applications, a 32 µinch gland sealing surface finish is satisfactory. When sealing gases, or for vacuum applications, a 16 µinch gland sealing surface, or better, is often suggested for best results. The gland surface finish for use with Kalrez® parts is the same as for standard elastomers.

Lubrication

The use of a lubricant during o-ring installation can minimize the chance of o-ring damage due to abrasion or cutting. In general, a light lubricant film applied to the Kalrez® o-ring is all that is required. The lubricant can be anything from a high performance fluorinated oil to something as simple as water. Since Kalrez® parts are often used in harsh environments, selection of a lubricant that will not break down under such conditions may be required. As an example, fluorinated oil or powdered graphite may be used. Note that immersion of perfluoroelastomers in fluorinated oils can cause significant swell. However, applying a thin film of fluorinated oil to a Kalrez® o-ring, for installation purposes, will not affect o-ring performance.

When selecting a lubricant, care must be taken that:

- The lubricant does not affect the o-ring, causing it to swell or degrade
- The lubricant does not contaminate the process