Elastomer Seals – your flexible friend

Seals are ubiquitous and essential elements of any operating plant, and pumps are no exception. Pump engineers have a wide range of sealing options reflecting the diversity of pump applications. Depending upon the liquids being pumped, the seal may be PTFE, metallic - composed entirely of compressed graphite or woven glass filament, textile or paper like materials, or combinations of engineering ceramics such as silicon carbide. However, the most common type of pump seal is the flexible elastomer (rubber) seals the most common type of which is the `O` Ring.

Elastomers have one unique property that sets them apart from all other types of pump sealing material – their elasticity. In simple terms this means that when deformed, they will retract to their original shape when the force is removed. It is this ability for the elastomer to return to its original, undeformed shape that gives sealing force. When an elastomeric seal is compressed between two surfaces it will exert a force on those elements creating an effective and long lasting seal. This elastic nature of the elastomer also means that it will deform under application pressures and take up the shape and contours of the mating faces enhancing the sealing properties, unlike PTFE and other rigid sealing materials. This means that the elastomer seal makes use of the application/system pressure to effect a better seal.

The role of an `O` ring in a pump is mainly to prevent pressure leaks and protecting the pump or compressor bearings and motor from damage through ingress of contaminants. Designing equipment that delivers the expected performance relies heavily on the seal – its material and design.

Seal Types

There are two basic types of pump seal: static and dynamic. A static seal is used in flanges or on an end casing to prevent liquids or gases escaping. A dynamic seal, as the name suggests, is installed at any point were there is a small or significant movement in either axial, radial or reciprocating planes. This type of seal is more likely to fail from damage through abrasion, heat ageing due to friction and mis-alignment from worn bearings.

Elastomer dynamic and static seals used in pumps typically fall into the following categories:

> **rotary shaft seals** where the seal lip is in contact with the rotating shaft such as a crankshaft of a compressor. These are a composite seal made up of a steel reinforcing ring encased by a suitable elastomer with a spring energiser for the seal lip. The outside diameter of the seal is an interference fit in the housing and the energiser spring is designed to give the correct seal lip pressure whilst still compensating for any wear of the seal or shaft.
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> **mechanical seals** are a composite seal comprising static o-rings plus a dynamic seal. Mechanical seals can be split into two groups, self-aligning and non-self aligning. The self aligning mechanical seal is initially more expensive, but is proven to give the best long term performance. In both types, the condition of the shaft bearings is critical although the self-aligning mechanical seal will withstand greater play in the bearings as well as shaft flexing. Contamination of the rotating ceramic seal faces must be avoided at all times.

Flange or end-cap seals are used on the access points to pumps to prevent leakage. Typically these are static seals such as O-rings although shaped profile seals are increasingly being used to aid speed and accuracy of seal installation into the housing groove. The static seal can also be a composite of ferrous and non ferrous metals and fabric reinforcement.

The way in which a seal performs is an important factor in pump efficiency. Accidentally installing the wrong type of seal can damage the pump and lead to premature seal failure. However, where the seal is compatible with the process and correctly installed seal failure can be an early indication of mechanical problems in the pump. If the pump's bearings are damaged the rotating shaft will tend to 'flex' and increase wear on the seal, leading to earlier seal failure. Failing to spot these early signs can be expensive, as one oil company discovered when its production platform's gas compressor failed and, with no spare seals on board, had to halt production for a day, costing over £250,000 in lost production.

Operating environment and seal materials

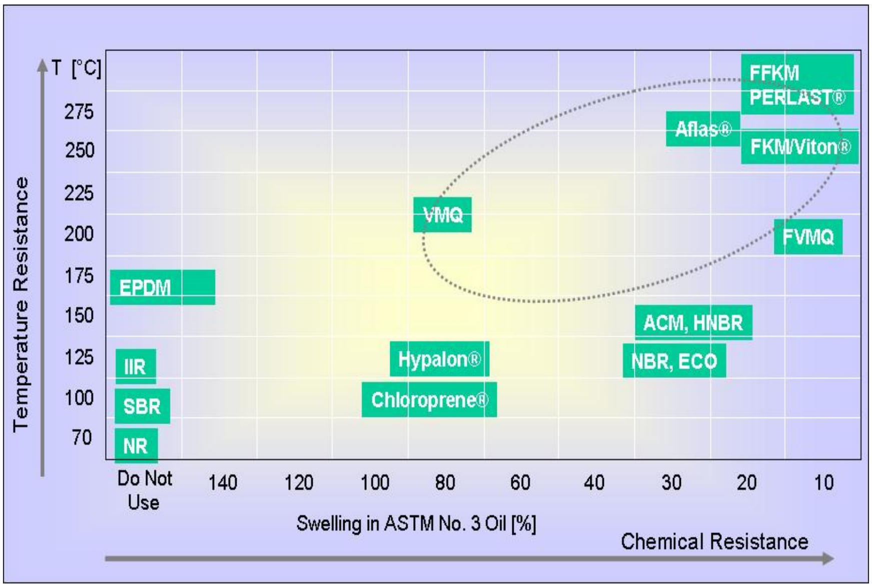


Table: Elastomer type versus temperature and chemical resistance

The chemical structure of the base polymer defines the essential thermal and chemical resistance capabilities of the elastomer. The addition of vulcanising agents, fillers and trace ingredients (plasticisers and stabilisers, for example) can enhance certain mechanical properties, and detract from others, but it allows for more precise tailoring of the elastomer compound to the specific application. Colour coding is sometimes used to ensure engineers select the right replacement seal during pump maintenance. However it should be borne in mind that replacing carbon black filler with pigment can have an adverse effect on the elastomer's mechanical properties.

In most cases pump seals are not exposed to particularly hazardous conditions. For example, in pneumatic pumps the seals are subjected to a mix of air, water, fine oil mist and moderate heat, all well within the capability of mid range performance elastomers. In the case of hydraulic pump seals the operating environment again is not particularly aggressive and consists of moderate heat, oil and in some cases mild acidity but operating pressures are significantly higher.

In consequence seals are usually made of either low cost NBR (nitrile) or the higher performing fluoroelastomer (FKM). For ultimate performance and chemical/heat resistance a perfluoroelastomer (FFKM) should be specified.

There are some important exceptions. In the case of pump applications such as laboratory test rigs or gas compressors, special elastomers are required. In such cases extremely high pressures, in excess of 300 Bar, are experienced and de-pressurisation rates are spectacularly quick i.e. from 300 Bar to atmospheric within 1 second. This puts tremendous forces on the seal as it can become saturated, through permeation, by the pressurised media. This phenomenon is called Explosive Decompression.

For seals that may encounter explosive de-compression forces, be it in positive or negative pressures, it is advisable to reduce the cross-section of the seal. Explosive decompression damage can occur when seals are subjected to high pressures for a long period. During this time, gas or liquid molecules are gradually forced into the elastomer. Whilst the seal is kept at this pressure, it will perform according to its design characteristics with no problems. If the pressure is suddenly released, however, the trapped molecules rapidly expand and permeate quickly to the surface of the seal leading to damage or the destruction of the seal. The smaller the media molecules, the greater the effect. In addition, sudden depressurisation can create very low temps -100 to -120^{o}C so here you'd expect to specify the phenyl silicone mechanical seals.

Special compounds are available which use carefully selected reinforcing fillers that combat explosive decompression damage.

Adverse Effect of Heat

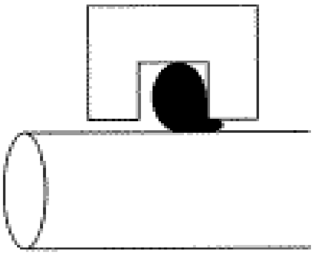
Pump users want maximum operating efficiency from their investment. Running the rotary pump or compressor longer, under greater working demands, creates increased thermal stresses on both the pump and seals. Although pumps should be designed with sufficient cooling in mind, the heat-soak during shutdown can damage the seal or at least reduce the seal life. It should be noted that the temperature of the process is not necessarily what the seal will actually have to withstand. It could be lower or higher depending upon the location of the seal and the effectiveness of the cooling system. As a general rule, elastomer temperature resistance varies from +110^{o}C for Nitrile (NBR) through to + 330^{o}C for perfluoroelastomers (FFKM), with other elastomers offering temperature resistance in between these values.

Recent Elastomer Developments

Recent developments in elastomer seals for pumps have tended to focus on extreme pumping environments where the inflexibility of traditional rigid sealing elements is reducing plant productivity.

The o-ring seal gives the designer and operator an affordable seal that is, in most cases, simple to install and gives acceptable life between maintenance checks. High pressure pumping applications, however, may present unique challenges for elastomeric seals in both design and elastomer compound type. Elastomers are essentially high viscosity liquids, and as such will flow under extreme pressure conditions. In applications where the possibility exists for the seal material to extrude into the clearance gap, the use of a back –up rings may

be recommended. These are flat or contoured rigid rings that are inserted on the low pressure side of the seal gland to prevent extrusion. If these are to be used then additional gland width is required. As with the elastomer itself, chemical, thermal compatibility and ease of installation needs careful consideration



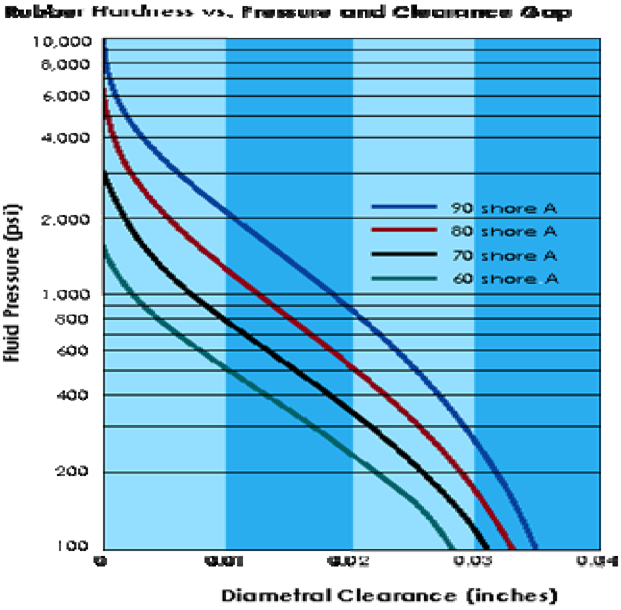
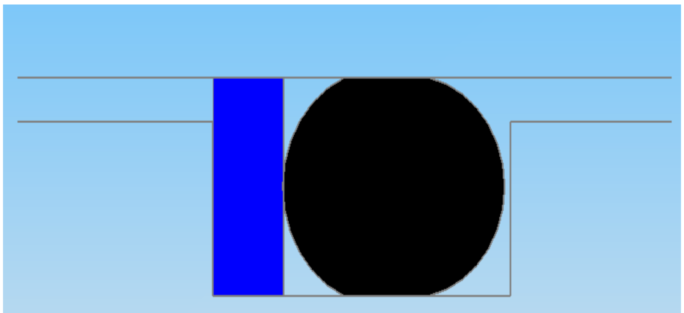
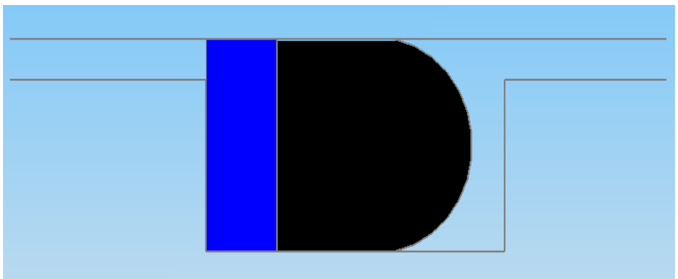


Illustration of how a back up ring would prevent extrusion

Back up rings would normally be manufactured from PTFE or PEEK for very high pressure applications





Low pressure applications are equally challenging because the performance of a vacuum chamber can be greatly influenced by the materials of construction and most importantly by the seals used.

All materials will permeate gas under extreme vacuum conditions (under ultra high vacuum of 10^{-9} Torr, hydrogen molecules can permeate through the steel walls of the chamber) Elastomeric seals will not be suitable for vacuum lower than approx 10^{-7} Torr, because of their inherent gas permeability. Some elastomer types are better than others but at some point all types will permeate gas. Low molecular weight elements within the elastomer, stemming from the polymer itself or process aids compounded into the elastomer or unreacted residues from the vulcanising reaction can create a phenomena known as outgassing, which influences the stability of the vacuum over time or the time it takes for the vacuum to be achieved. Similarly any entrapped air or gas from extrusion and moulding processes can outgas with the same effects

New sealing materials are now becoming available offering exceptionally low permeability to meet the needs of vacuum process and environmental emissions regulations. For example, the first of a new type of nanotechnology-engineered fluoroelastomer uses “fully fluorinated nano-fillers” bound within the structure of the elastomer, delivering increased chemical resistance and exceptionally low levels of permeability. The polymer’s high fluorine content significantly reduces the gas permeability of the elastomer compared with standard fluoroelastomers and perfluoroelastomers, leading to reduced swelling from exposure to solvents. Moreover, the absence of metallic or carbon-based fillers produces an exceptionally pure, translucent elastomer that is less prone to attack by chemicals

One of the main attractions of elastomers for pump engineers is the ease with which elastomers can be customised. The ‘workhorse’ sealing material AFLAS (Tetrafluoroethylene/Propylene (TFE/P) elastomer) is resistant to explosive decompression under conditions specified by National Association of Corrosion Engineers NACE TMO192-98 "Evaluating Elastomeric Materials in Carbon Dioxide Decompression Environments." Yet until recently it was let down by its temperature resistance. By customising the polymer formulation AFLAS seals can be made resistant to temperatures up to 250^{o}C and for short periods 290^{o}C, while still retaining the excellent steam and chemical / sour gas resistance that are characteristic of the elastomer.

Moreover, the AFLAS elastomer can also be combined with other materials such as metal substrates or reinforcing fabrics for high-pressure applications. The modified AFLAS has successfully operated up to 30,000psi in conjunction with a PEEK (polyetheretherketone) anti-extrusion ring, as described earlier.

At the other end of the operating spectrum, new grades of perfluoroelastomer are now available with improved compression set performance.

Perfluoroelastomers are commonly used in chemical processes characterised by high temperatures and aggressive solvents. Until now the elastomers have suffered from poor acid resistance leading to excessive compression set and increased seal maintenance downtime. This elastomer is specially compounded to provide increased acid resistance by eliminating fillers that are prone to acid attack, and optimising the cure system.

Typically perfluoroelastomers can be used in applications with temperatures ranging from -15^{0}C to +315^{0}C. In addition to excellent chemical and temperature resistance and very good mechanical properties, the acid resistant perfluoroelastomer has low permeability. As a result it is less prone to swelling, leading to extended in-service performance in pumps and viable alternative to PTFE seals where greater elasticity is needed for the mechanical seal.

For pump engineers the good news is that sealing options continue to expand as new materials become available. All that remains is for them to take the initiative and work more closely with seal developers and manufacturers to ‘fine tune’ the performance of the seal, offering their customers even more efficient pumps.