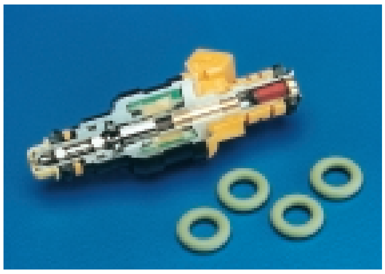
Viton® fluoroelastomer

# Viton® – Excelling in Modern Automotive Fuel Systems



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The following ASTM/DIN abbreviations are used throughout this publication:

| Abbreviation | Generic Name | Trade Name |
|---|---|---|
| ACM | Ethylacrylate copolymer | – |
| BR | Butadiene rubber | – |
| CO | Epichlorhydrin rubber | – |
| CR | Polychloroprene rubber | – |
| CSM | Chlorosulphonated polyethylene | Hypalon® |
| EAM | Ethylene/acrylate copolymer | – |
| ECO | Epichlorhydrin ethyleneoxide copolymer rubber | – |
| FEP | Fluorinated ethylene propylene | Teflon® |
| FFKM | Perfluoroelastomer | Kalrez® |
| FVMQ | Fluorosilicone rubber | – |
| FPM / FKM | Fluoroelastomer | Viton® |
| HNBR | Hydrogenated NBR | – |
| MVQ | Silicone rubber | – |
| NBR | Acrylonitrile-butadiene rubber | – |
| SBR | Styrene butadiene rubber | – |

# 1. Introduction

**Only specialty elastomers such as Viton® fluoroelastomers can function in the increasingly hostile automotive fuel system environments driven by tough new legislation.**

Modern automotive fuel systems have a tough job to do. In addition to fuel storage, metering and fuel delivery to the engine, these systems must comply with ever more stringent regulations defining the composition of fuels and emission levels. These factors combine to create hostile working conditions for fuel system components.

Fuel compositions are changing rapidly to facilitate vehicle manufacturers in their quest to meet emission limits of these new regulations. Traditional anti-knock agents such as tetramethyl- and tetraethyl-lead are being replaced by oxygenated (alcohol or ether) additives. These upgrades maintain fuel octane ratings while reducing hydrocarbon and carbon monoxide pollutants. The result of these changes is the emergence of a wide range of potential fuel compositions.

Many of the newer fuel additives alter the swelling characteristics of elastomers in fuel and contribute to property deterioration. To simplify the problem of determining the performance suitability of elastomers, a range of "test fuels" has been adopted as a basis for comparison of elastomer performance. In some cases, these fuels have been designed to test for "worst case" scenarios. Test data included in this publication assist with the selection of elastomers for use in contact with these fuels and demonstrate the outstanding performance of Viton.

Actual part performance is simulated in these test fuels, to the end of performance prediction in actual use. Elastomeric engine compartment components such as seals, hoses, diaphragms and gaskets, all face new standards of performance, driven by the factors cited above and augmented by high energy costs and escalating costs of warranty and recall. As one result, specifiers are selecting Viton for an ever broader variety of applications.

## Factors Affecting Applications

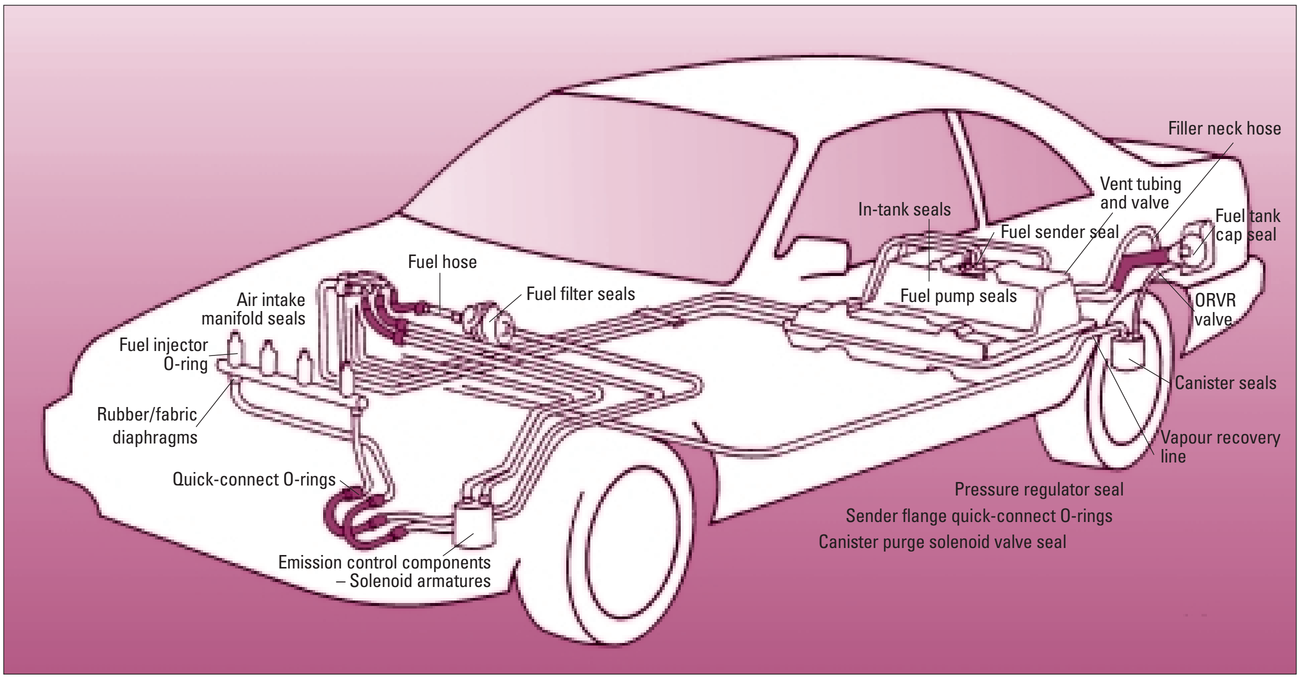
- World-wide emission regulations
- Hotter engine compartment temperatures
- Variations in fuel mixtures
- Longer warranties
- Extended service periods
- Sealing of and against plastic parts
- Designed assembly and service connections
- Vibration/noise isolation
- Crash worthiness

Fluoroelastomers in general, and Viton in particular, have become elastomers of choice for many fuel system sealing and hose components.

## Advantages of Viton

- Low permeation to fuels and gases
- –40°C to +225°C service temperature range
- Resistant to all fuels/fuel mixtures
- Resistant to 'sour' fuel
- Resistant to oils
- High strength to resist damage
- Long-term sealing performance

*Fig. 1. Viton in fuel systems*



# 2. Applications of Viton® in Fuel Systems

Evolved over 40 years, today's high performance Viton fluorolelastomers meet the toughest automotive industry requirements in most fuel system sealing and hose applications, including components for fuel storage, fuel delivery and fuel/air mixing.

Several types of Viton have been developed specifically for modern automotive fuel systems. Fig. 1 shows key applications, and the Selection Guide for Viton found in the Appendix (page 18) identifies the most suitable type per application.

## 2.a Fuel Storage Components

### 'In Tank' Fuel Pump Couplers

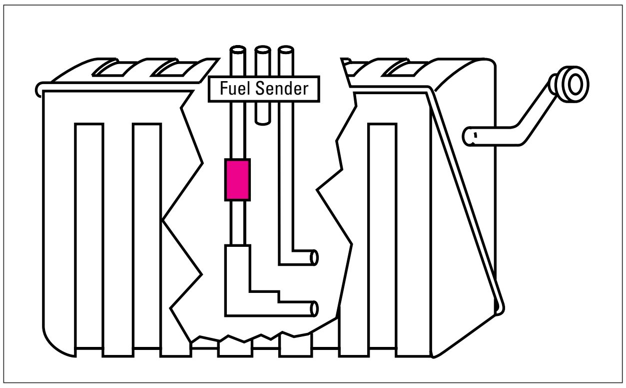



***Fig. 2. Viton fuel pump coupler***

Tubing and hose of Viton inside the fuel tank connect vapour and/or liquid lines to the fuel sender module. Components of Viton are easy to couple, and the polymer's inherent damping characteristics help minimize undesirable vibration – a fundamental cause of component fatigue, fracture and malfunction. The major performance requirement of elastomers for in-tank fuel couplings is resistance to volume swell and chemical attack by the fuels. Parts made of Viton meet these requirements and remain functional, even though they remain immersed in fuel for the life of the vehicle.

### Filler Neck Hose

***Fig. 3. Filler neck hose***

The filler neck hose is a common source of fuel emissions owing to its large surface area and the constant presence of fuel and fuel vapour. This hose must be flexible and capable of absorbing shock and must deform without rupture, major considerations for assuring vehicle crash worthiness. Designers increasingly specify multi-layer constructions using Viton as the inner fuel permeation barrier. It is chosen because it adheres well to other layer materials, meets permeation regulations and functions for the lifetime of the vehicle.

### Fuel Tank Cap Seal

***Fig. 4. Tank cap seal***

Recent low fuel emission legislation has led to redesigns of fuel tank cap seals and to fluoroelastomers replacing acrylonitrile-butadiene copolymers (NBR).

Viton GBLT is an important candidate in meeting legislation in cars with OBD II and in-tank pressure sensors, since it offers low permeation and excellent flexibility at temperatures as low as –40°C.

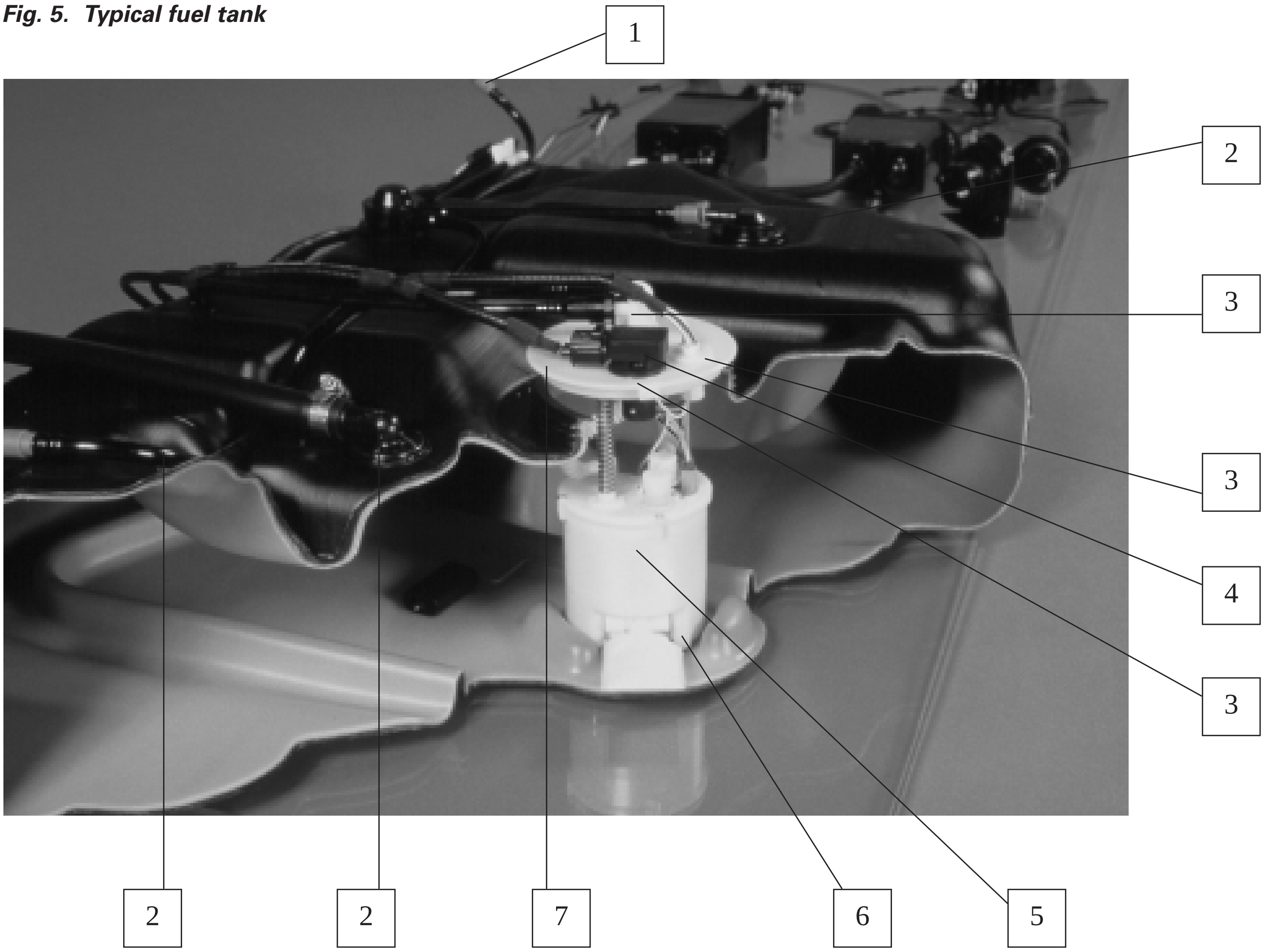
### ORVR – Onboard Refueling Vapour Recovery

ORVR is an automobile-based control system for emissions occurring during refuelling. The phase-in schedule in the US for the ORVR system requires 40% of 1998 passenger cars to be so equipped, and the system will be standard on all cars and light trucks by 2003. ORVR may require larger charcoal canisters and new vapour-vent lines, all of which represent potential and additional sources of hydrocarbon emissions.

A typical ORVR system includes the following components:

- A narrow filler pipe allows formation of a continuous seal with the nozzle while fuel is dispensed in order to prevent vapour escaping from the fuel tank.
- Vapour from the tank headspace is forced through a vent connected to a canister containing activated carbon.

*Fig. 5. Typical fuel tank*




**Fuel Tank Cut Away Description**

Description of applications of Viton®

1. Quick connect coupling containing O-ring seal
2. Rollover valve seal
3. Quick connect O-ring
4. On-board-diagnostics (OBD II) pressure sensor diaphragm
5. Fuel pump O-rings
6. Fuel sender vibration isolators
7. Sender unit seal

- The carbon bed captures and temporarily retains the hydrocarbon vapour.
- A purge system meters these vapours to the engine as fuel. This depletion process from the carbon is completed within 48 km of urban driving.

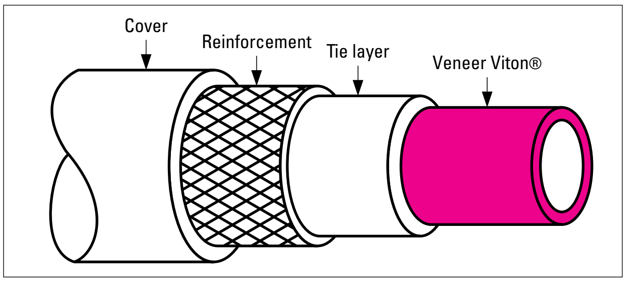
Even with these additional vapour recovery components, the 2,0 g hydrocarbon evaporative limits specified by the Environmental Protection Agency (EPA) and California Air Resources Board (CARB) methods must be met. Both new vehicles and those attaining 160 000 kilometres (100 000 miles) of service must meet the limit.

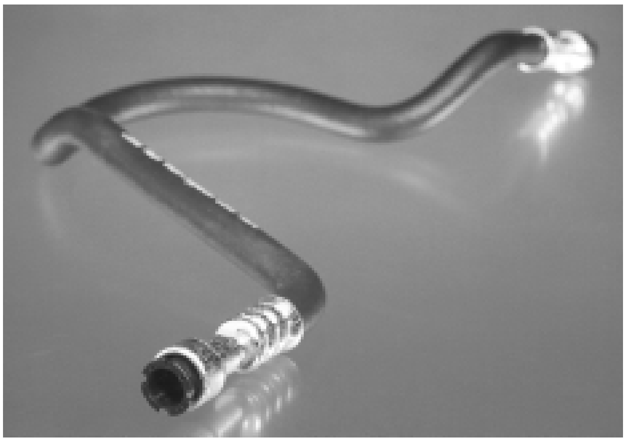
Other fuel storage components are illustrated in the fuel tank cutaway in Fig. 5.

## 2.b Fuel Delivery Components

### Fuel Line Hose and Tubing

Fuel line hose must resist permeation by conventional, as well as alcohol and ether-containing fuels. These hoses are typically constructed with 4 or



*Figs.6, 6a. Fuel line hose*

5 layers with the innermost a veneer of fluoroelastomer. This cost-efficient design allows the highly fuel resistant layer to act as a primary barrier to permeation. (See Figs. 6, 6a).

Viton® is frequently selected as the barrier layer because of its outstanding resistance to conventional, oxygenated and "sour" fuels. The fluoroelastomer is flexible, can be shaped to form, is easy to install and couple, provides long-term sealing at couplings, and damps noise and vibration.

An example of a high performance fuel hose construction is the patented F200 barrier hose shown in Fig. 7. The inner fuel contact veneer is Viton, and the barrier layer is Teflon® FEP. Reinforcement in this construction is provided by Kevlar®, and the cover stock may be Vamac® or Hypalon®. This marriage of materials of construction provides unequalled resistance to permeation from within and abuse from the exterior.

The superior permeation resistance of F200 fuel hose compared to any other elastomeric fuel hose construction becomes even more marked at elevated temperatures.

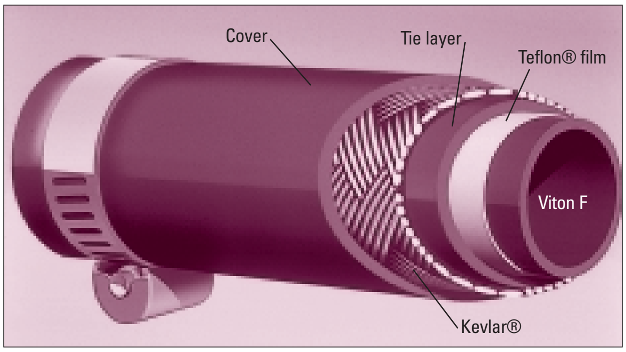



***Fig. 7. Construction of F200 barrier hose***

## Fuel Pump Seals, Check Valves and Rollover Valves (gasoline and diesel)

The fuel resistant seals found in fuel pump check valves and roll-over valves are designed to close off fuel flow if the vehicle rolls over. The major performance requirement of these seals is resistance to swell and attack by fuels, and Viton is the material choice for these seals.

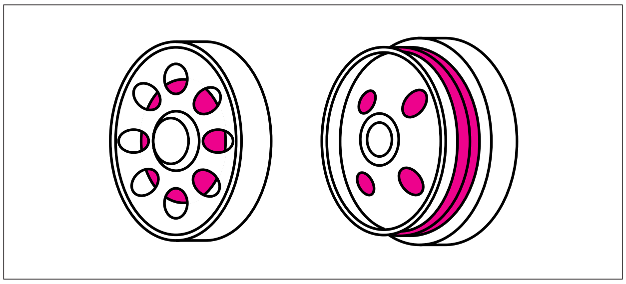


***Fig. 8. Fuel pump check valves***

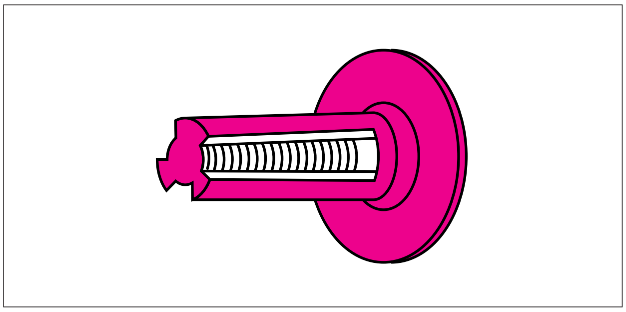


***Fig. 9. Rollover fuel valve***

## Diaphragms

The fuel pressure regulator diaphragm is an integral component which ensures accurate metering of fuel to the engine. It must be resistant to swell by automotive fuels and attack by sour gas and oxygenated fuels. In addition to an excellent flex life, it must also function at temperatures as low as –40°C.

Diaphragms made from Viton perform reliably and remain flexible from –40°C to +140°C. The flex life easily exceeds 1 million cycles – beyond the normal life of the vehicle.

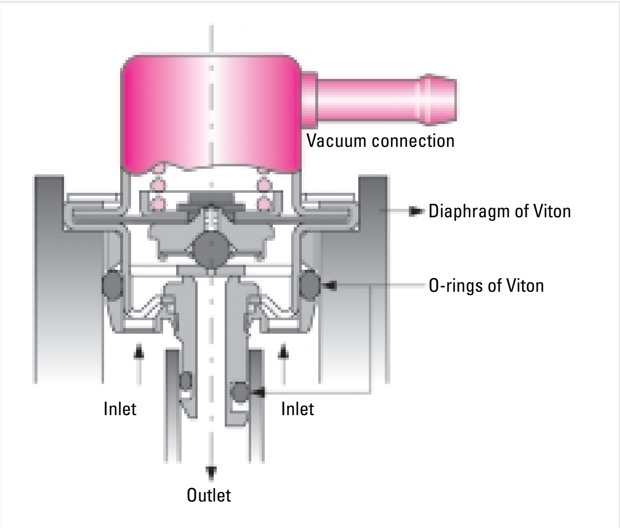



***Fig. 10. Fuel pressure regulator diaphragm***

## Quick-Connect O-rings

Quick-connect O-rings are used to seal against leakage at connections in plastic fuel lines. As the name "quick connect" implies, these couplings may be easily connected or disconnected. To maintain the integrity of the seal after reinstallation of the line, an O-ring with high tear strength, compression set resistance and sealing force retention is needed.

Viton outperforms competitive elastomers in these three critical properties and provides static sealing at –40°C when properly formulated.

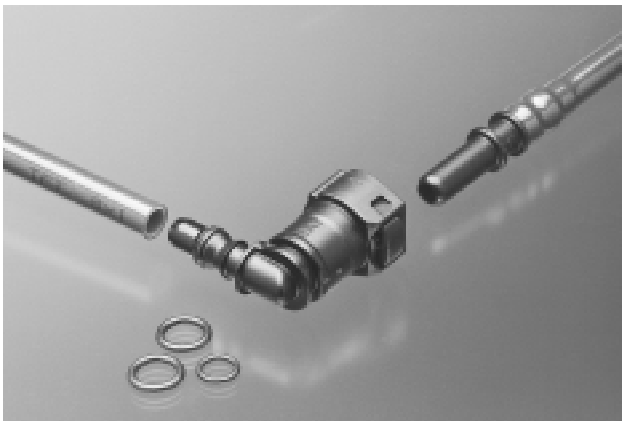


*Fig. 11. Quick-connects with Viton® O-rings*

### Fuel Injector O-rings (gasoline, diesel, and alcohol blends)

These O-rings must meet many of the same requirements as the “quick-connect” O-rings, but with the important addition of heat resistance. Sealing performance must not be adversely affected during or after excursions to extreme elevated temperatures (as may be experienced in a “heat soak” or a “coolant dump”). O-rings of Viton perform reliably from –40°C to +150°C.

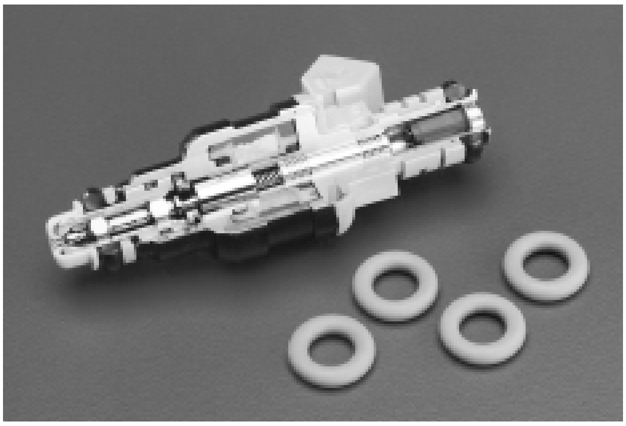


*Fig. 12. Fuel injector O-rings*

## 2.c Emission Control Components

### Emission Control Seals

Modern emission control systems consist of devices for both measuring and controlling the fuel system, and include vapour recovery canisters, catalytic converters, and exhaust gas and oxygen sensors. These components rely on seals that must be resistant to the vapours they contact at the extremes of their design temperatures.

Viton is suited to many of these applications because of its excellent balance of heat and fuel resistance properties.

*Fig. 13. Lambda probe seal*

### Air Intake Manifold Gaskets

Fuel is mixed with air in the air intake manifold. These manifolds are increasingly made of glass reinforced polyamide for performance improvements and weight savings. Plastic manifolds are difficult to seal effectively to metal blocks using traditional gaskets because of the difference in thermal expansion coefficients between the two. For sealing the two surfaces, heat- and fuel-vapour-resistant elastomeric seals have become the norm. The low modulus of the elastomer seal enables it to conform to the sealing faces and to take up creep.

Viton meets the performance requirements of this seal because of its long-term functionality in hot fuel vapour and its excellent compression set resistance.

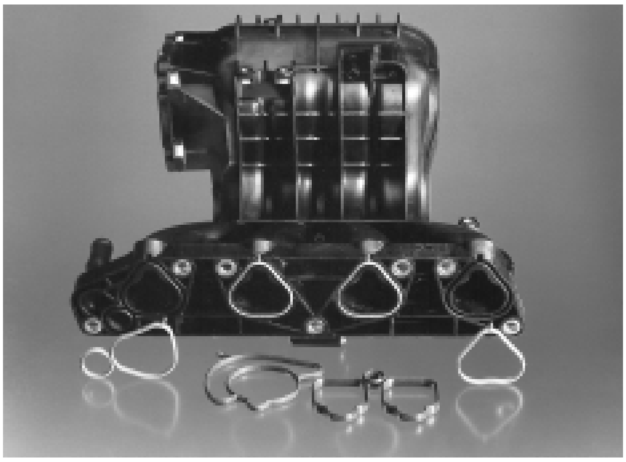


*Fig.14. Air intake manifold gasket*

### Solenoid Armatures

These rubber/metal parts are used in on-board vapour recovery and evaporative vapour canisters. Viton is specified for this application because of its durability and outstanding dimensional stability, low compression set, and resistance to fuels and fuel alcohol/ether blends. The metal bonding capability of Viton is also essential to these parts.

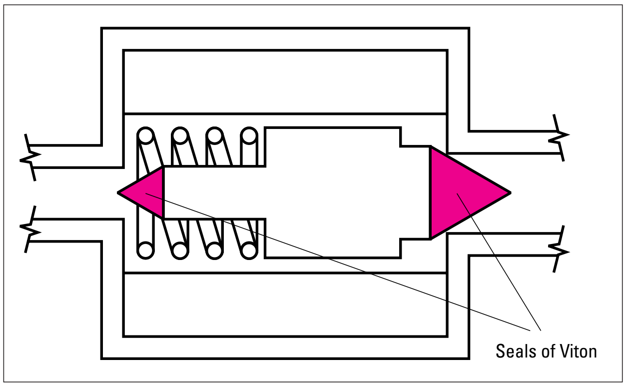



***Fig. 15. Solenoid armature***

The results of these various part requirements and the performance of fluoroelastomers in a variety of fuel related applications have led to the wide specification of Viton® by the automotive industry. In addition to fuel related applications, Viton is used to seal crankshafts and camshafts, cylinder heads, water pumps, gearboxes and many other components. These applications together bring the use of fluoroelastomers to well above 1 kg per vehicle (see Fig. 16).

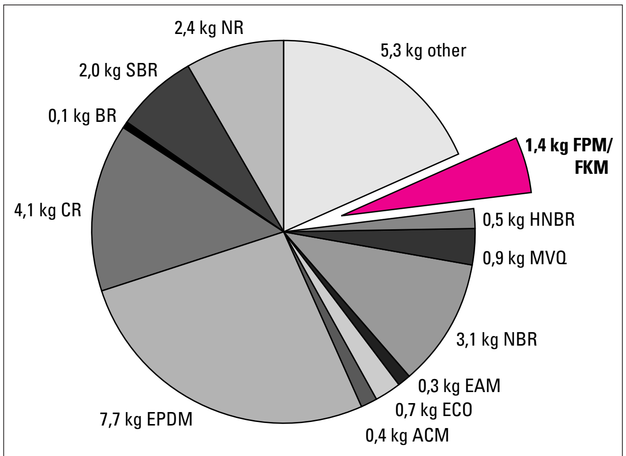



***Fig. 16. Elastomers (without tires) in Mercedes E-Class***

# 3. Emission Regulations

The aim of recent regulations is to limit emissions of various oxides of nitrogen ($NO_x$), carbon monoxide (CO), hydrocarbons (HC) and particulates. In automobiles, these are exhaust gas components, but they are also found throughout the fuel system, including in hoses, lines, connector systems and in the fuel tank.

The USA has traditionally led in vehicle emission regulations, through the work of the EPA and the CARB in particular, using data generated through the Air Quality Improvement Research Programme (AQIRP). Largely as a result of the Clean Air Act of 1990, there is also increasing emphasis on evaporative emissions as measured by the Sealed Housing for Evaporative Determination (SHED) test method. This test determines whether or not the total emission of all components exceed the permitted hydrocarbon level in 24 hours.

Near-term California and USA regulations and goals stipulate that:

- Hydrocarbon emissions levels of 1998 must be reduced 55% by the year 2000.
- Zero emissions must be achieved by 2% of vehicles in 1998, and by 10% in 2003.

Diagnostic systems which monitor specific emissions sources are being introduced. Provisions in the EPA's OBD II (Onboard Diagnostics Revision II) require continuous electronic observation of numerous sources of emissions on the vehicle. Results from this monitoring are indicated to the driver and are stored for evaluation at normal vehicle service intervals. This source-oriented data collection is expected to lead to a more accurate understanding of emissions over the life of the vehicle. These systems will be mandatory for European gasoline passenger cars from the year 2000 and for diesels from 2003.

Recently, the European Programme on Emissions, Fuels and Engine technologies (EPEFE), was set up to establish European legislation and the basis for future fuel composition and emission limits. One outcome of this programme are the EURO-2000 regulations. These regulations are similar to the enhanced evaporative emission regulations introduced in the USA. Fuel permeation is an important component of the overall evaporative emissions in both cases.

In the European Union, compliance to EURO-2000 emission standards for passenger cars and light duty trucks becomes mandatory on January 1, 2000. Motor fuel specifications decided by parliamentary conciliation in 1998 have made the emission regulations easier for vehicle manufacturers to meet by limiting sulphur in fuels in both gasoline and diesel.

US Federal regulations generally require declining emission levels and phase-in standards which become more demanding each year. For example, from 2001 onwards, a 0,075 g/mile non-methane organic gases (NMOG) fleet average must be met, while in California, the NMOG limit descends from 0,070 g/mile in 2001 to 0,062 in 2003.

The new European emission limits are shown in the following table:

**Limit in g/km for passenger cars <2500 kg**

| Year | | CO | NC | $NO_x$ | Particulate |
|---|---|---|---|---|---|
| 2000 | G | 2,30 | 0,20 | 0,15 | – |
| | D | 0,64 | – | 0,50 | 0,05 |
| 2005 | G | 1,00 | 0,10 | 0,08 | – |
| | D | 0,50 | – | 0,25 | 0,025 |

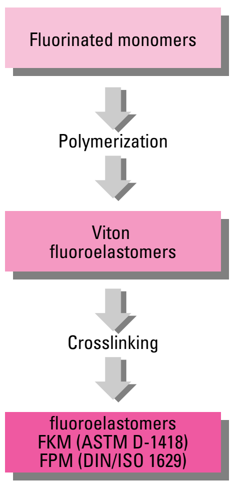
Adoption of the EURO-2000 regulations in Europe is expected to stimulate other countries to adopt enhanced regulations. It is foreseen that South America, Japan and Asia-Pacific will all eventually follow the USA and Europe.

# 4. Viton® in the Automotive Industry

## 4.a What is Viton?

The name Viton represents three major families and many specialty fluoroelastomers from DuPont Dow Elastomers. These families offer the highest continuous heat resistance of any conventionally processed rubber, combined with an outstanding resistance to swell and permeation when exposed to a range of chemicals including automotive fuels and additives. Specific types of Viton have been developed to satisfy service requirements in many demanding applications.

Viton offers superior processing and outstanding end-use performance. These characteristics result in long service-life and low lifetime-cost components.




Synthetic, noncrystalline fluoropolymers, which show elastic properties after crosslinking

*Fig. 17. Fluoroelastomers derivation*

## 4.b Classification of Elastomers based on SAE J-200/ASTM D 2000

The globally accepted standards of SAE and ASTM define a specification system based on elastomer performance. In these two standards, elastomers are classified according to their heat and oil resistance. Viton is HK classified. 'H' designates that its heat resistance after thermal ageing 70 hours at 250°C is within the following parameters:

- max. tensile strength change ±30%;
- elongation at break decreases less than 50%;
- max. hardness change ±15 points.

**Definition of types and classes**

| Type | Heat-test temperature (°C) | Swell-test temperature (°C) | Class | Volume-swell max. (%) |
|---|---|---|---|---|
| A | 70 | 70 | A | – |
| B | 100 | 100 | B | 140 |
| C | 125 | 125 | C | 120 |
| D | 150 | 150 | D | 100 |
| E | 175 | 150 | E | 80 |
| F | 200 | 150 | F | 60 |
| G | 225 | 150 | G | 40 |
| **H** | **250** | **150** | H | 30 |
| J | 275 | 150 | J | 20 |
| | | | **K** | **10** |

*Fig. 18. Classification based on SAE J-200/ASTM D 2000*

'K' represents the class of oil resistance (maximum swell 10%) achieved by Viton after 70 hours in test oil No. 3 according to ASTM D 471.

Only Kalrez® perfluoroelastomer parts and Zalak® high performance seals have higher temperature resistance and lower swell in hydrocarbons than Viton.

## 4.c Overview of the Properties of Viton

Viton fluoroelastomers offer outstanding resistance to heat, swell, permeation and degradation when in contact with aggressive automotive fuels, fuel additives, oils, lubricants and most mineral acids. They also have exceptional tensile strength, tear and compression set resistance. These characteristics, provided across a wide operating temperature range, are the reasons the fluoroelastomer is specified by automotive engineers for fuel system seals, O-rings and hoses. Parts made of Viton fluoroelastomer function in environments that destroy those made from many other plastic and rubber materials.

# 5. Types and Properties of Viton

The three major families of Viton fluoropolymers, 'A', 'B' and 'F' consist of many types, characterized by the monomers from which they are built.
To achieve a required end use performance, proper type selection is necessary.

| Viton | A | B | F | GLT | GBLT | GFLT |
|---|---|---|---|---|---|---|
| Fluorine content | 66% | 68% | 70% | 64% | 65% | 66% |
| Fuel resistance | ++ | +++ | ++++ | + | ++ | ++++ |
| Heat | +++ | +++ | | +++ | +++ | +++ |
| Low temperatures | + | o | – | ++++ | +++ | ++ |
| Compression set | +++ | +++ | + | + | + | + |

– = poor o = fair + = good
++ = better +++ = excellent ++++ = outstanding

*Fig. 19. Types of Viton and characteristics*

| Letter | Meaning | Comment |
|---|---|---|
| A | low fluorine content | good compression set |
| B | medium fluorine content | improved fuel resistance |
| F | high fluorine content | resistance against oxygenates permeation |
| G | prepared for peroxide curing system | additional base resistance |
| LT | excellent low temperature (LT) properties | special monomer incorporated |

***Fig. 20. Viton® nomenclature***

The Figs. 19 and 20 show the impact of fluorine content and other polymer design parameters on fuel resistance, compression set and high and low temperature performance.

The Viton ‘A’ family has the lowest fluorine content and best compression set resistance, while the progressively higher fluorine content ‘B’ and ‘F’ families have improved fuel resistance. Viton GLT, GBLT and GFLT all offer greater flexibility at low temperature.

## 5.a High Temperature Properties

Heat resistance is becoming more important in fuel system components because smaller engine compartments bring higher engine compartment temperatures. Temperature and heat history play key roles in the durability of an elastomer seal. Elasticity, flexibility, compression set and sealing force can all be adversely affected by elevated temperatures which can shorten the life of elastomer parts or even destroy them.

Fig. 21 shows the temperature limits of fluoroelastomer seals in continuous use. Laboratory tests confirm that Viton remains usefully elastic (elongation >100%) for well over 10000 hours when exposed to a temperature of 200°C. Conventional general purpose elastomers would become brittle after just one day at 200°C under the same test conditions. Other rubbers are generally limited to an operating ceiling of 150°C and for a substantially shorter period.

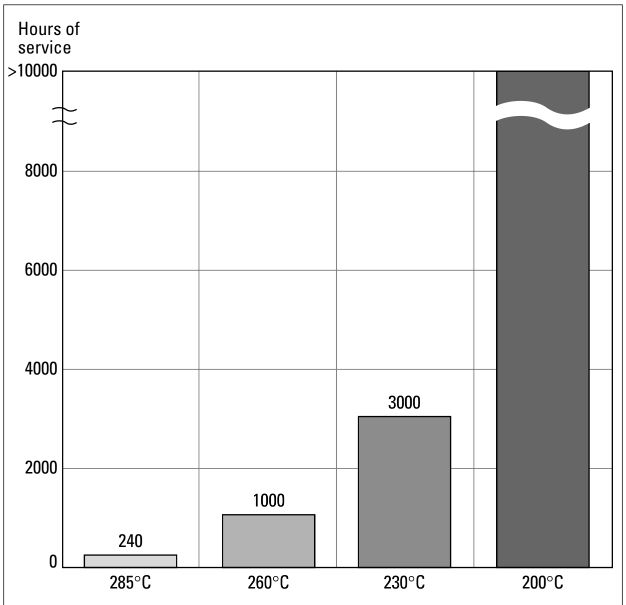



***Fig. 21. Heat resistance of Viton in air***

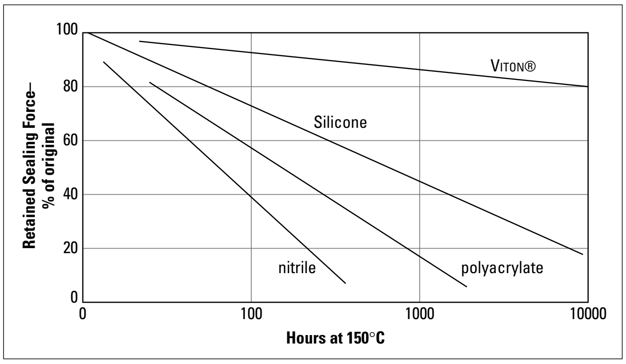



***Fig. 22. Retained sealing force of Viton and other elastomers***

Seals made of Viton remain resilient and retain an effective sealing force long after ordinary rubber seals have failed. Fig. 22 shows retained sealing force of O-rings made from Viton and other elastomers. After 100 hours under static conditions in air at 150°C, Viton retains over 90% of its original sealing force, while seals produced from fluorosilicone, polyacrylate and nitrile rubber retained 70%, 58% and 40%, respectively.

After 10000 hours, the retained sealing force of Viton was 77% while that of silicone, the only other rubber to survive the test, was 13%.

## 5.b Properties of Viton in Gasoline

### Gasoline Composition

Gasoline has undergone many changes since it was first commercially available soon after the First World War. Even with the refinement of today’s gasolines, there are still great variations in specific composition. Typically, gasoline consists of hydrocarbons ranging from 4 to 12 carbons in length and may include dissolved paraffins, olefin components, naphthenes and aromatics. Aromatic hydrocarbons (toluene, benzene, xylenes) cause more swelling and more adversely affect physical properties than either aliphatic or olefinic hydrocarbons.

The increasing use of oxygenates (alcohols and ethers) to boost the effective octane rating in gasoline further extends the range of composition variations possible in gasoline. Oxygenate-rich gasolines exhibit higher volatility which is correlated with increased permeation through elastomeric materials. Oxygenated additives cause swelling and property deterioration of elastomers as well. Ethers such as methyl- and ethyl-tetrabutyl ether (MTBE and

ETBE) are preferable oxygenates to alcohols from an environmental point of view; they are less volatile but have similar octane boosting characteristics. They also cause less swelling and property deterioration in elastomers than alcohols at the most frequently used levels (around 15%).

Physical property change usually goes hand in hand with volume swell: the greater the volume swell, the greater the expected loss of other properties. Consistent with its low volume swell, Viton® provides excellent retention of physical properties after fuel immersion.

In fact, compounds of Viton exhibit lower volume swell in fuels than any other class of elastomers except for perfluoroelastomers such as Kalrez®. High fluorine types of Viton are especially well suited for service in fuels containing oxygenates. Testing also indicates that Viton is suitable for service in low sulphur and bio-diesel rapeseed methyl ester (RME) fuels.

## Resistance to Various Flex Fuels: Swell and other Physical Properties

### Chemical Attack

Non-reversible chemical changes may occur in elastomers as a result of exposure to fuels. Viton is especially resistant to these effects and to the additional aggressive nature of additives and fuel oxidation by-products in gasoline and traditional diesel fuels.

### Volume Change

Volume swell of an elastomer by a fuel can precede seal leakage and failure or compromise the accuracy of fuel metering systems. Compounds of Viton exhibit lower volume swell in fuels than any other class of elastomers used commercially (See Fig. 23).

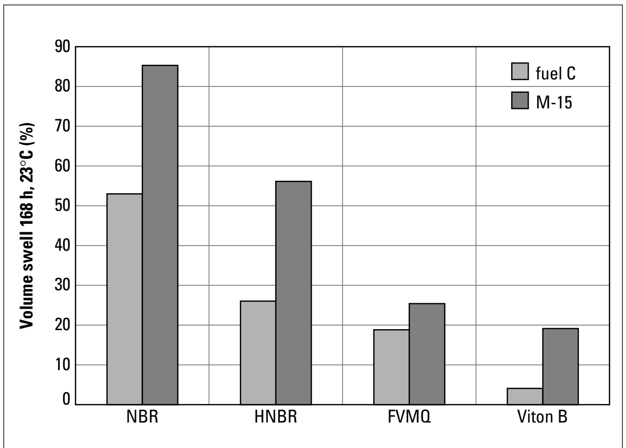



***Fig. 23. Swell in fuel mixtures***

### Fuel Blends

The superior resistance of Viton parts to blends of gasoline alcohol and aromatic additives enables these components to deliver dependable performance with minimum swell, low compression set, minimal dimensional change and superior flexibility.

Figs. 24 and 24a demonstrate the superior low-swell characteristics of Viton in typical blends of gasoline/methanol and gasoline/ethanol.

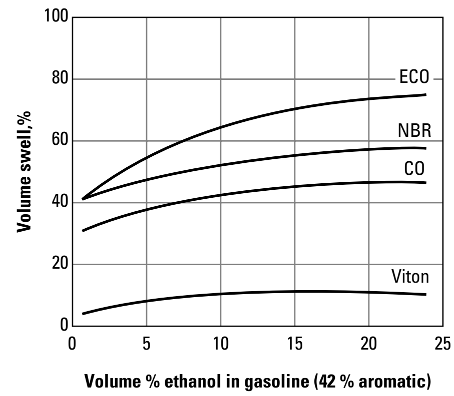



***Fig. 24. Equilibrium volume swell at 21°C versus ethanol concentration***

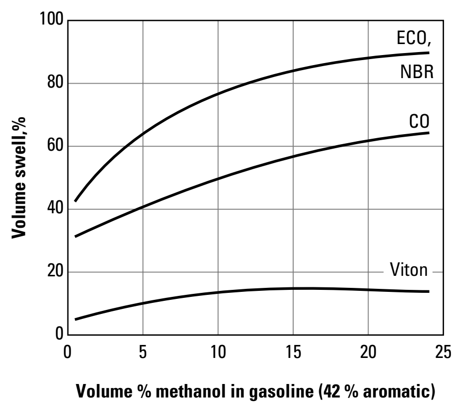



***Fig. 24a. Equilibrium volume swell at 21°C versus methanol concentration***

## Fuel Variables Challenge the Automotive Engineer

Fuel system components must be designed to accommodate the most adverse of anticipated conditions. The trend to one-design components that can perform in any of the world's wide-ranging fuel compositions challenges the automotive engineer. Besides the normal hydrocarbon variations inherent in gasolines, the designer must contend with fuel mixtures designed for regional climatic conditions, a wide range of blends with oxygenates and "sour" gasoline generated in the fuel system.

The selection guide on page 18 lists the performance of different types of Viton® in various fuels. It is important to select the right type of Viton for demanding applications such as aggressive methanol fuel blends or for sealability at temperatures to –40°C.

## Effect of Aromatic Content

As noted in Figs. 25 and 26, the aromatic content of Reference Fuels A, B and C spans the range encountered in commercial gasoline.

| Type of fuel | | Aromatic content (%) |
|---|---|---|
| Leaded | – regular | 7-34 |
| | – premium | 5-34 |
| Unleaded | – regular | 5-42 |
| | – premium | 17-46 |

***Fig. 25. Aromatic content of commercial gasoline***

| (shares in vol. %) | ASTM D471/ISO 1817 | | | | DIN 51604 | | |
|---|---|---|---|---|---|---|---|
| | Fuel A | Fuel B | Fuel C | Fuel D | Fam. A | Fam. B | Fam. C |
| Non aromatic HC | 100 | 70 | 50 | 60 | 30,0 | 25,4 | 12,0 |
| Aromatic HC | 0 | 30 | 50 | 40 | 50,0 | 42,3 | 20,0 |
| Alcohol | 0 | 0 | 0 | 0 | 5,0 | 19,2 | 60,0 |
| Iso-octane | 100 | 70 | 50 | 60 | 30,0 | | |
| Toluene | 0 | 30 | 50 | 40 | 50,0 | | |
| Ethanol | | | | | 5,0 | | |
| Diiso-butylene | | | | | 15,0 | | |
| Fam. A | | | | | | 84,5 | 40,0 |
| Methanol | | | | | 0,0 | 15,0 | 58,0 |
| Deionized $H_2O$ | | | | | 0,0 | 0,5 | 2,0 |

***Fig. 26. Compositions of reference fuels***

Aromatic content plays a major role in the effect a fuel has on elastomers. Fuel C with 50% aromatic content has a substantially greater effect on volume change and property retention of most elastomers than either Fuels A or B with 0% and 30% aromatic content, respectively. In all of these fuels, volume change of Viton is minimal, and strength retention is excellent.

## Effects of Oxygenated Fuels / Fuel Alcohol Blends

Blends of gasoline with oxygen-containing additives such as ethanol, methanol or MTBE are common today, and in the future, other additives such as ETBE may appear. These blends, categorized as gasoline/alcohol or gasoline/ether, burn cleaner and emit fewer air pollutants.

The graph below (see Fig. 27) shows the swell of four test fuels of NBR, ECO, FVMQ (fluorosilicone) and two types of Viton. The compounds of Viton have the lowest swell profiles in any of the fuel blends, and higher fluorine-content types such as Viton B600 and GF have very low swell in all the test fuels.

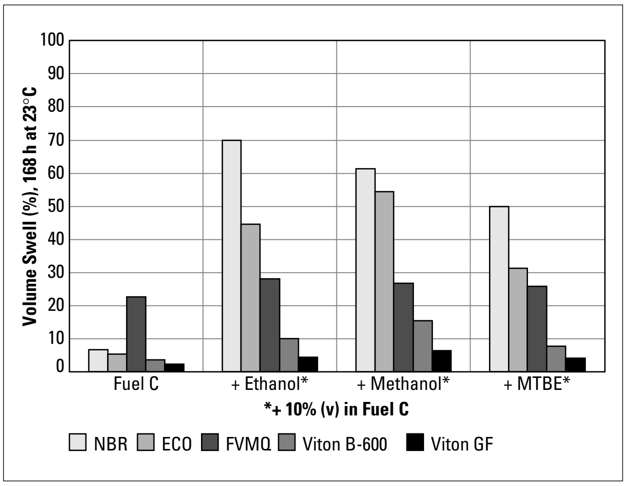



***Fig. 27. Swell in fuel mixtures – Influence of type of oxygenated additives***

## Alternate Fuel Blends

Automobile manufacturers have studied the concept of vehicles fueled with gasoline, methanol or blends. These so called "alternate" or "flexible" fuels place severe demands on elastomeric seals, O-rings and hoses.

The chart below (Fig. 28) shows the swell results of five types of Viton immersed in five different blends of Fuel C and methanol. Lower-fluorine types of Viton such as GLT and the 'A' family resist Fuel C and 85/15 Fuel C/methanol blends, but as methanol content increases, so does volume swell.

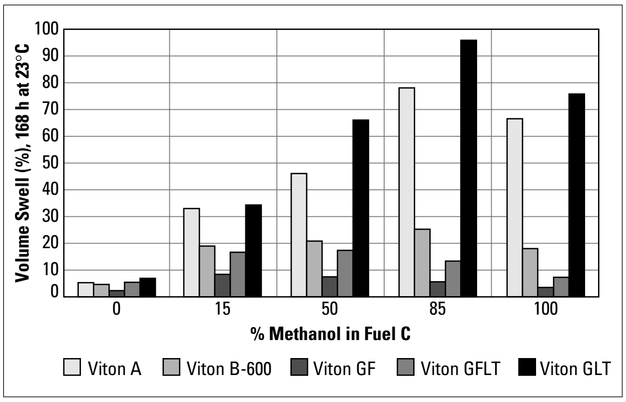



***Fig. 28. Swell in fuel mixture***

High fluorine types of Viton such as B600, GF and GFLT show only a modest increase in swell when up to 50% methanol is used. In blends above 50%, volume swell of these types usually decreases; consequently, they are recommended for use in systems where flexible fuels are used.

### "Sour" Fuel

Fuel "sours" or becomes stale when oxygen reacts with it to form hydroperoxides. These unstable species decompose, forming free radicals that may attack some elastomers. This attack can cause either "reversion" (rubber softening), or further crosslinking, resulting in embrittlement. The olefinic portions of "cracked" gasoline are the most susceptible to oxidative attack, and gasoline blended with alcohol also tends to be unstable.

The results of immersion of Viton® and other elastomers in "sour" fuels for three weeks at 54°C are shown in Fig. 29. Viton shows very little change and excellent resistance compared to FVMQ and NBR. ECO "reverted" in less than two weeks, and its results are not reported. NBR became brittle in a short period of time while Viton remained virtually unaffected by the sour fuel.

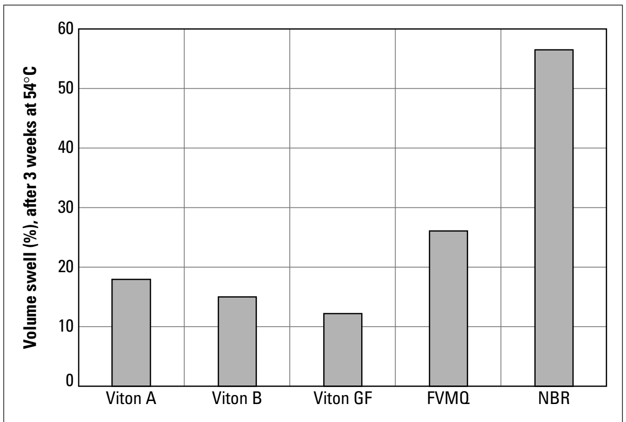



***Fig. 29. Swell in sour fuel C (Peroxide number 100)***

Fuel containing hydroperoxides can cause dramatic changes in the properties of some elastomers in a short time, as indicated. Under the same conditions, Viton remains unaffected and can be considered a prime candidate for fuel systems handling "sour" fuels.

## 5.c Low Temperature Properties

An elastomer seal works by exerting a pressure against its housing greater than that of the contained fluid.

This sealing force of an elastomer is time and temperature dependent and will gradually decrease due to physical and chemical effects. Retention of sealing force at lower temperatures depends on the ability of the elastomer to recover from the applied deformation at that temperature. As temperature decreases, the rubber becomes stiffer, loses its elastic recovery, and finally becomes hard and brittle.

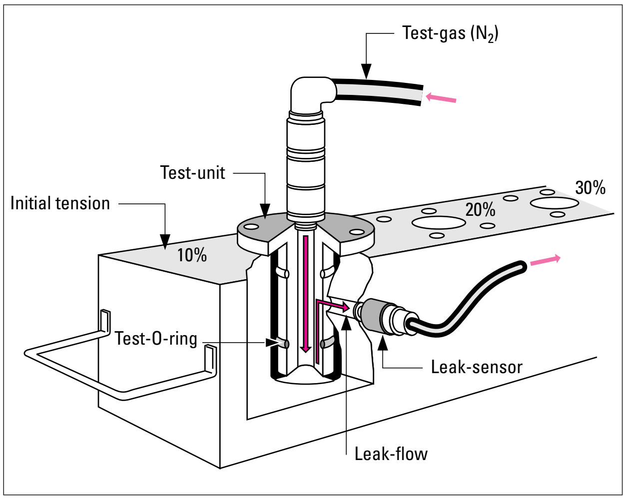



***Fig. 30. Low temperature O-ring leakage test***

Results of O-ring leakage testing and the TR-10 test on different types of Viton demonstrate the temperature at which leakage commences and the behaviour variations in low temperature flexibility. Viton GLT, which was designed specifically for low temperature performance, shows the best results in both tests. (See Fig. 31).

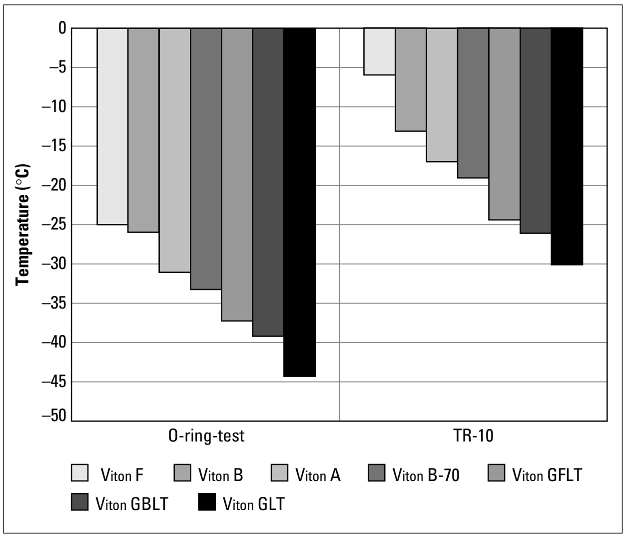



***Fig. 31. Low temperature flexibility. Comparison of different test methods***

The TR-10 test provides an indication of low temperature elastomeric performance of a polymer by measuring the onset of elastomeric behaviour as the temperature is gradually raised from a point at which the specimen is frozen. The behaviour of Viton types is seen to closely follow the order of the O-ring test results, with the LT types having the best low temperature performance.

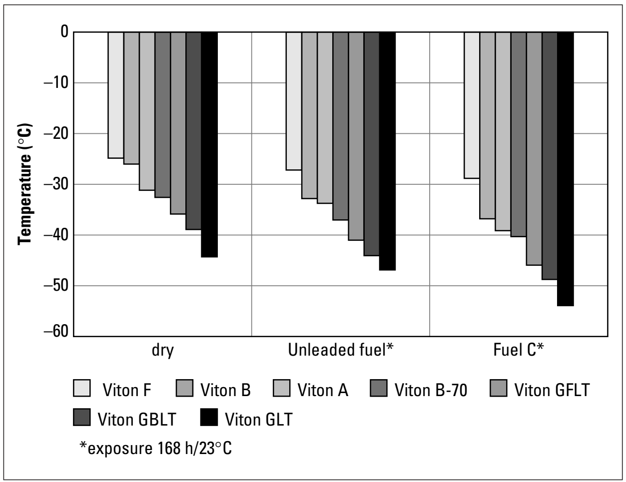



***Fig. 32. Low temperature flexibility. Leakage temperature during O-ring test***

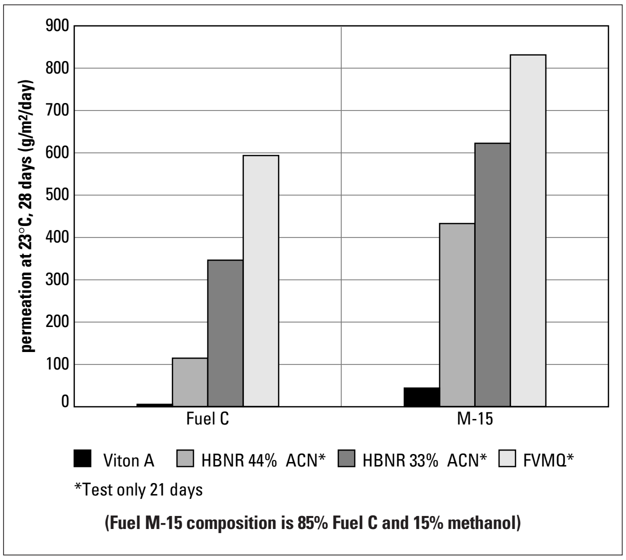



***Fig. 33. Permeation resistance according to Thwing Albert Test – Viton versus other materials (Fuel C/M-15)***

Fig. 32 shows the low temperature sealing ability of seven fluoroelastomer compounds tested for sealing of nitrogen at 1,4 MPa (200 psi) at 10% compression, when dry, immersed in unleaded fuel and immersed in Fuel C. Results show a significant difference in sealing force retention among the types of Viton®, with Viton GLT demonstrating the superior performance under these conditions. Following immersion in such fuels, Viton fluoroelastomer type GFLT exhibits the best combination of low volume swell and good low temperature sealing.

Fuel seals in engines run on 'flex fuel' blends of unleaded gasoline with methanol are among the most challenging of all automotive sealing applications. In addition to flex fuel resistance, O-rings in fuel injector and quick-connect systems are required to have at least –40°C static sealing capability.

Even though certain types of Viton may not possess specific low temperature properties they can often be used successfully when immersed in fuels at low temperature. The small absorption of fuel into the seal made of Viton actually improves low temperature properties by plasticisation of the elastomer. For functionality in a dry system, the special low temperature types of Viton should be used.

## 5.d Permeability Versus other Elastomers

All elastomers are permeable to some degree to fuels, in gas and liquid form, but the degree of permeability varies widely depending on the elastomer type. Fluoroelastomers such as Viton have the lowest permeability to fuel of all elastomers used commercially in automotive fuel systems, enabling these materials to meet the most stringent of current and expected emission regulations.

Fig. 33 shows the permeation rates of Viton versus other polymers used in fuel lines, filler neck hose and seals using the modified ASTM E96-66 "Thwing Albert" cup permeation test method (a recognized and commonly used test for permeation of elastomers). The data are presented in permeation rate units, and show that Viton A has a permeation rate less than 3 g/m$^2$/day in Fuel C (50% iso-octane/50% toluene) compared to 125-600 g/m$^2$/day for HNBR, NBR and FVMQ. In addition these high permeation rates for the other materials are observed after only 21 days.

The results of similar testing in Fuel M-15 have also been shown to dramatically favour Viton, with a permeation rate of approximately 50 g/m$^2$/day compared to the extreme of over 800 g/m$^2$/day for FVQM.

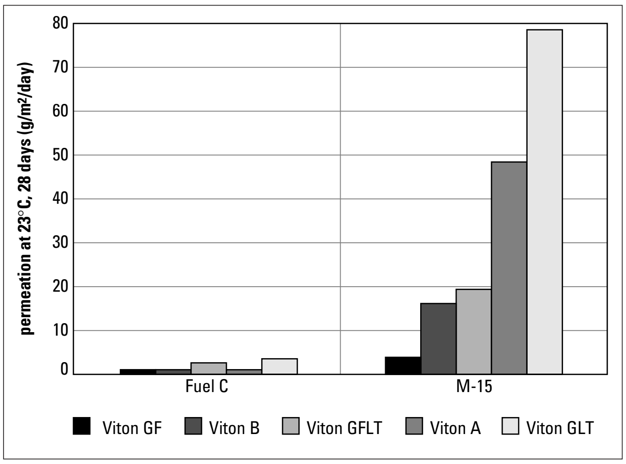



***Fig. 34. Permeation resistance according to Thwing Albert Test of different types of Viton (fuel C/M-15)***

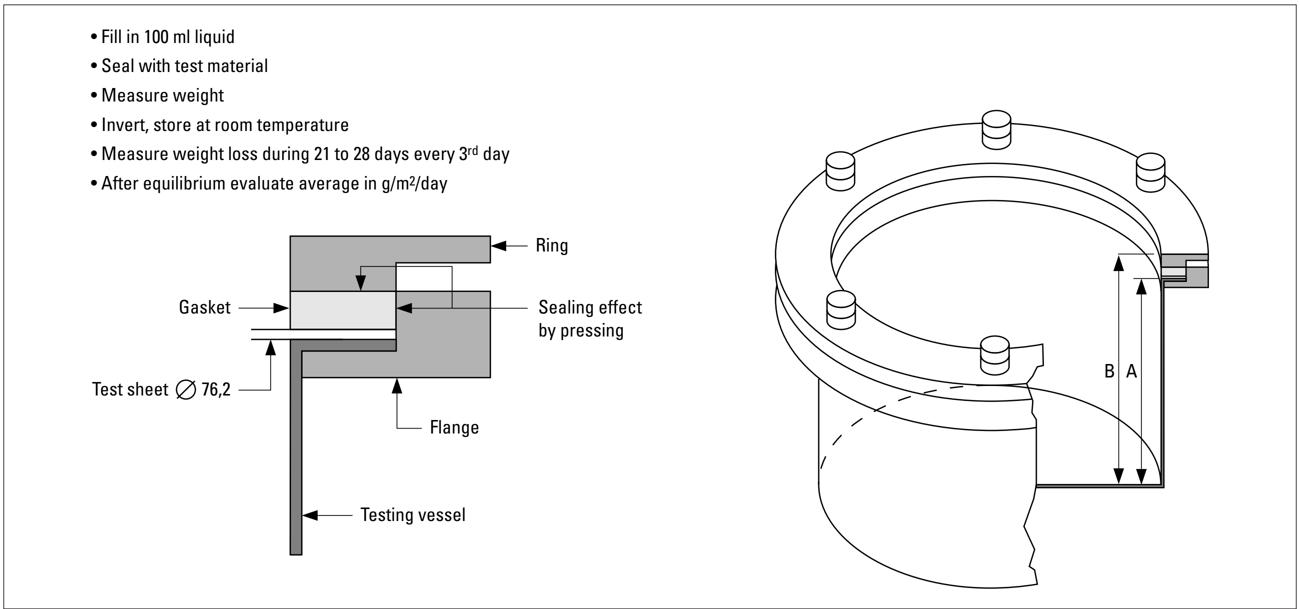



*Fig. 35. Thwing Albert permeation test procedure*

Fig. 34 shows the permeation rates of different types of Viton® in the same test fuels using the modified ASTM E96-66 "Thwing Albert" cup permeation test method. All types perform very well in ASTM Fuel C, while Viton GF performs best when immersed in M-15.

# 6. Performance of Viton in Diesel Engines

### Applications:

- Direct injector O-ring seals
- Rotary pump seals
- Control diaphragms
- Fuel hose

Diesel fuel is used in compression ignition engines, which generally have improved thermal efficiency compared with spark-ignited gasoline engines. Diesel fuel has a higher boiling point range than gasoline fuels, hence it is less prone to evaporative emissions.

Diesel engines are used to power a significant and growing proportion of all vehicles. This is particularly true in Europe where most heavy goods vehicles and many passenger cars are diesel powered. The rubber components used in the fuel systems of diesel powered vehicles have traditionally not needed high performance elastomers such as Viton since diesel fuels are not as aggressive to elastomers as is gasoline.

Nevertheless, both gasoline and diesel powered vehicles are subject to regulations governing tolerable limits of air polluting emissions (see page 8). The goals in the case of diesels are to reduce aromatic hydrocarbon content, reduce sulphur content (typically from 1000 ppm to 200 ppm) and to increase cetane number used to quantify the ignition characteristics of diesel fuel, thereby providing increased engine efficiency for lower levels of emissions.

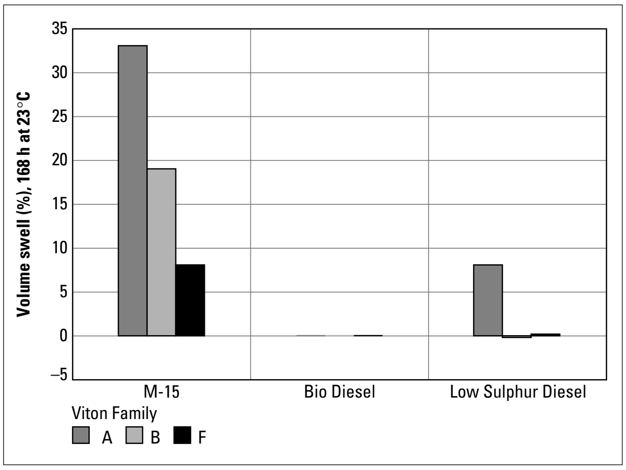



*Fig. 36. Swell of various families of Viton in M-15, bio-diesel and low sulphur diesel fuel*

"Low sulphur diesel fuel" and "bio-diesel fuel" define specific compositions, but they are also terms used to describe a range of diesel fuel compositions. Esters made via trans-esterification of rapeseed oil (producing RME bio-diesel) are becoming more popular as an alternative to diesel from fossil sources, either used in blends or as fossil fuel replacement. Expectations that most of the diesel engines in passenger cars would run with "bio-diesel" have not materialized, although a number of commercial vehicles available today are designed to run with non-fossil fuels.

While the use of bio-diesel in passenger cars is still relatively small, trucks and off-road vehicles are using some RME and similar products.

Testing of Viton® has shown its excellent resistance to swelling and property deterioration in both low sulphur and bio-diesel fuels (Fig. 36). This performance identifies Viton as an excellent candidate for diesel fuel system components in the future.

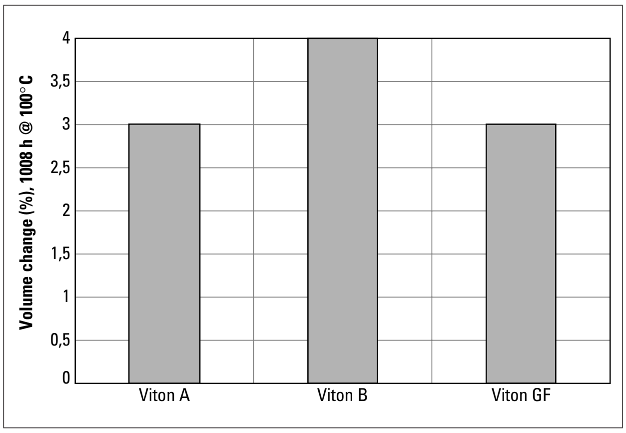



***Fig. 37. Viton fluoroelastomers aged in Connediesel RME 99/-8***

Fig. 37 confirms the very low swell over extended periods (4% or less after 1008 hours in RME at 100° C) of bisphenol-cured Viton A and B families and type GF.

**Note:** Specific curing systems must be used with Viton for applications in RME diesel. For guidance, contact your local DuPont Dow customer service office or authorized distributor.

# 7. Seal Design for Engineers

The following notes offer a guide in the use of elastomers in sealing systems for automotive engineers.

## Designing with Elastomers

Designers having more experience and familiarity with metals and alloys than with polymers may have experienced failures with elastomeric seals even though the elastomer was well suited to the conditions. This common experience is often traced to the fact that such parts were designed into the application without full consideration of the fundamental design requirements of elastomeric materials.

In the case of new applications, or performance or design upgrades of existing ones, the first course of action is to define the requirements in use, in terms of both performance and economics. Selection of a polymer underdesigned for the use results in premature failure; overdesign is costly.

The checklist for performance should include:

- A full description of the functional requirements of the application;
- Temperature range, and cycling times if known;
- Media exposure within the temperature range (specific fuel composition, for example);
- Pressure(s) or vacuum to be sealed;
- Desired lifetime;
- Mechanical stresses/strains including static or dynamic flex requirements;
- Colour code needs;
- Electrical properties;
- In the case of fuels, desired permeation levels in cyclic conditions.

Special consideration should be given to the fuel itself. It should neither affect, nor be affected by, the elastomer component in contact with it.

## Common Seal Failure Modes

Other than inappropriate selection of elastomer type, seal failure can result from a number of design factors related to the surface, cavity or groove to be sealed:

- Sharp corners or acute angles, causing rupture as the elastomer flexes under pressure and/or as a result of thermal effects;
- Poor surface finish (especially important for gases and against vacuum);
- Excessive cavity tolerance and part width, allowing 'weeping' of seal;
- Insufficient compression of the seal, allowing leakage at lower temperatures, and poor low pressure gas retention;
- High compression, causing seal splitting at high temperatures, and excessive compression set;
- Poor fitting technique, resulting in twisted O-ring sections;
- Cavity volume inadequate for thermal and fluid expansion, leading to extrusion of the seal or gasket (Fig. 38);
- Lack of back-up rings, precipitating extrusion at high pressure (Fig. 39).

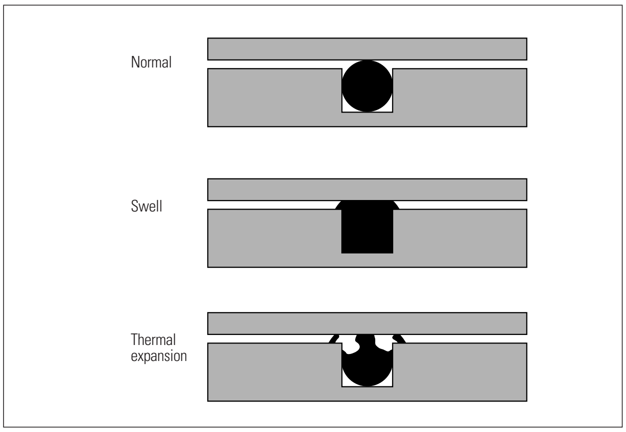



***Fig. 38. Swell/thermal expansion***

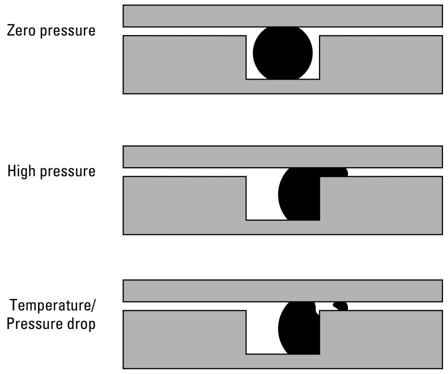



***Fig. 39. Extrusion effects***

Your DuPont Dow Elastomers development engineer can help with the choice of elastomer type and compound to meet the operating requirements of your application.

## Designing with Viton® Fluoroelastomers

Viton fluoroelastomers are capable of sealing automotive fuels at much higher temperatures and for longer periods than almost any other elastomer. The high fluorine levels that make such performance possible also influence seal design. For example, fluoroelastomers demonstrate higher thermal expansion and contraction than most other elastomers, and any small swell in fuels or other media is augmented by these thermal effects. Also, like most polymers, fluoroelastomers have a tendency to soften at higher temperatures.

Therefore, when designing for wide temperature fluctuations, part size, compression and seal cavity volume may have to be adjusted to optimise performance (Fig. 40). Special consideration should also be given to parts exposed to rapid temperature cycling.

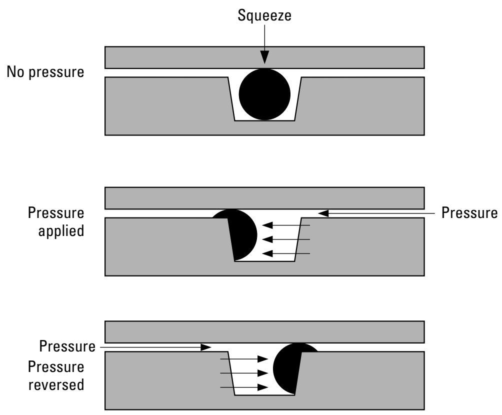



***Fig. 40. How the O-ring seals***

While high service temperatures can lead to some softening of the fluoroelastomer, coincidental high pressures can lead to displacement of the fluoroelastomer and possible extrusion and leakage of the part. The rubber chemist can help minimize these effects through the selection of a high modulus or high hardness formulation, but the use of back-up rings and cavity volume adjustment may be necessary. (Fig. 41)

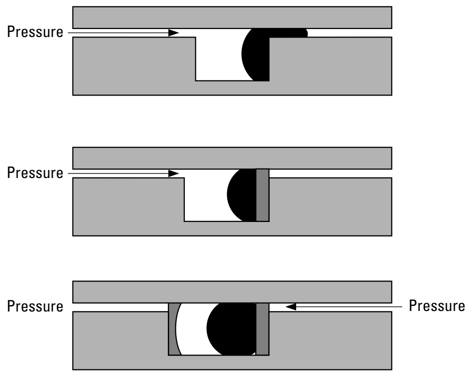



***Fig. 41. Anti-extrusion***

## Limits of Elastomer Stress / Strain Properties

Finite element design, backed by experience of millions of parts, has led to some basic 'use and abuse' rules which apply to most elastomers. For example, elastomers in seal or gasket applications should never be subjected to greater than 25% compression or strain. Higher compression can create stress fields within the part which may exceed the ultimate strength of the material, leading to high compression set and reduced seal life.

A nominal O-ring compression of 18% is sufficient for most applications, allowing for a degree of tolerance in seal cavity and part size. Even lower compression, in the order of 11%, can be used for gaskets. Gaskets do not need the compressive force of other parts due to the comparatively thin sections and high surface-to-volume ratio.

O-rings seated in position should never be stretched by more than 5% of original internal diameter (over a piston groove, for example) particularly if the part is in a dynamic use.

## Permeation of Elastomers

Permeation by a fluid into a polymer is governed by solubility parameters, pressures of the fluid, compression of the part, and temperature. Permeation is inversely proportional to part thickness. Thus, gaskets will be more permeation resistant if designed with increased cross-section, as will O-rings with increased section diameter. For optimum performance, selection of polymer to task is critically important.

## Design Service

Your DuPont Dow Elastomers automotive development engineer will be pleased to assist you with sealing proposals and solutions. Please call or fax one of DuPont Dow's regional headquarters listed on the back of this publication.

# Appendix

## Selection Guide for Viton®

The following tables will help the automotive fuel system engineer select the correct family or type of Viton for a specific application.

### A summary of families and types of Viton for use in Automotive Fuel Systems

| Application | Service Requirements | Viton Family |
|---|---|---|
| In Tank Hose and Tubing | Fuel Resistance<br>Compression Set Resistance<br>Low Swell | B, F |
| Filler Neck Hose<br>Fuel Line Hose<br>F-200 Veneers | Fuel Resistance<br>Permeation Resistance<br>Compression Set Resistance | B, F |
| Quick Connect Seals | Fuel Resistance<br>Permeation Resistance<br>Compression Set Resistance<br>Stress Relaxation Resistance<br>Low Swell | A, AL |
| Quick Connect Seals | Low Temperature Sealing | GLT, GFLT, GBLT |
| Fuel Injector Seals | Fuel Resistance<br>Compression Set Resistance<br>Stress Relaxation Resistance<br>Low Temperature Sealing | AL, B |
| Fuel Injector Seals<br>(Low Temperature) | Fuel Resistance<br>Compression Set Resistance<br>Stress Relaxation Resistance<br>Low Temperature Sealing | GLT,<br>GBLT,<br>GFLT |
| Fuel Pump Seals | Fuel Resistance<br>Compression Set Resistance<br>Low Swell | A, B |
| Diaphragms | Fuel Resistance | A, B |
| Diaphragms<br>(Low Temperature) | Fuel Resistance and<br>Low Temperature Flex Life | GLT, GBLT, GFLT |
| Emission Control Devices | Heat Resistance | A, B |
| Air Intake Manifold Gaskets | Heat Resistance<br>Compression Set Resistance | A |

The table below lists the primary families and types of Viton and their performance in various fuels at both high and low temperatures.

### Rating of families and types of Viton by performance parameter

| | Viton Family | | | | | |
|---|---|---|---|---|---|---|
| | A | B | F | GLT | GBLT | GFLT |
| **Polymer Characteristics** | | | | | | |
| Polymer Type(s) | Di | Ter | Ter/Tetra | Tetra | Tetra | Tetra |
| Fluorine Level | 66 | 68 | 70 | 65 | 66 | 67 |
| **Fluids Resistance – Fuels** | | | | | | |
| Unleaded Gasoline | E | E | E | E | E | E |
| 'Sour' Gasoline (80 PN) | E | E | E | E | E | E |
| Gasohol – (U.Gas/10% Ethanol) | G | E | E | G | E | E |
| **Unleaded Gasoline/Methanol Blends** | | | | | | |
| • 5-10% Methanol | G | E | E | G | E | E |
| • 11-30% Methanol | F | G | E | F | G | E |
| • >30% Methanol | P-F | G | E | P-F | G | E |
| Methanol 100% | P | G | E | P | G | E |
| MTBE 100% | P | P | P | P | P | P |
| U.Gas/MTBE-Blends/(5-20%) | G-E | E | E | G-E | G-E | E |
| **Permeability** | | | | | | |
| Unleaded Gasoline | E | E | E | E | E | E |
| U.Gas/Methanol Blends | F | G | E | F | G | E |
| **Heat Resistance** | | | | | | |
| To 150°C | E | E | E | E | E | E |
| To 204°C | E | E | E | E | E | E |
| To 275°C | F-G | G | F | F | F | F |
| **Compression Set Resistance** | | | | | | |
| At 150°C | E | E | G-E | E | G-E | E |
| At 200°C | E | G-E | F-G | G | G | F-G |
| At –20°C | P-F | P | P | G | G | G |
| **Low Temperature Properties** | | | | | | |
| Flexibility at 0°C | E | E | F | E | E | E |
| At –20°C | F | F-P | P | E | G-E | G-E |
| **Static Seal Ability** | | | | | | |
| At –20°C | G | F-G | P-F | E | E | E |
| At –40°C | P-F | P | P | G | G | G |
| **Low Temperature Retraction** (ASTM D-1329) | | | | | | |
| TR-10, °C | –17 | –14 | –7 | –30 | –26 | –24 |
| O-Ring Leakage Test, °C | –32 | –26 | –25 | –45 | –40 | –37 |

Rating Scale: **E** = Excellent, **G** = Good, **F** = Fair, **P** = Poor

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## Suggested Reading


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