



SOLVAY

asking more from chemistry®



High-Performance Polymers for
Oil & Gas

**SPECIALTY
POLYMERS**



Supplying Long-Term Performance to a Demanding Industry

Application Matrix

Polidan® PEX

Cross-Linkable Compounds

Solef® PVDF

Polyvinylidene Fluoride

Solef® PVDF for Flexible Risers and Flowlines

Solef® PVDF for Umbilicals

Solef® PVDF for Pipe Liners

Solef® PVDF for Coatings:

Internal and External Protection of Pipelines

Halar® ECTFE

Ethylene-Chlorotrifluoro-Ethylene

Hyflon® PFA

Perfluoroalkoxy Fluorocarbon Resins

Hyflon® PFA for Downhole Cables and Control Lines

Hyflon® PFA for Corrosion Protection

Algoflon® and Polymist® PTFE

Polytetrafluoroethylene

4

Fomblin® PFPE

Perfluoropolyethers

5

What Makes Fomblin® Lubricants Better?

6

Tecnoflon® FKM/FFKM

Fluoro/Perfluoroelastomers

6

Tecnoflon® FKM Peroxide Curable and Base Resistant

7

Low Temperature Performance:

7

MOVE Technology

7

Tecnoflon® PFR FFKM: the Ultimate Performance

8

Ultra Polymers

KetaSpire® PEEK Polyetheretherketone

AvaSpire® PAEK Polyaryletherketone

9

Amodel® PPA

Polyphthalamide

9

Torlon® PAI

Polyamide-Imide

10

11

11

12

12

13

13

14

15

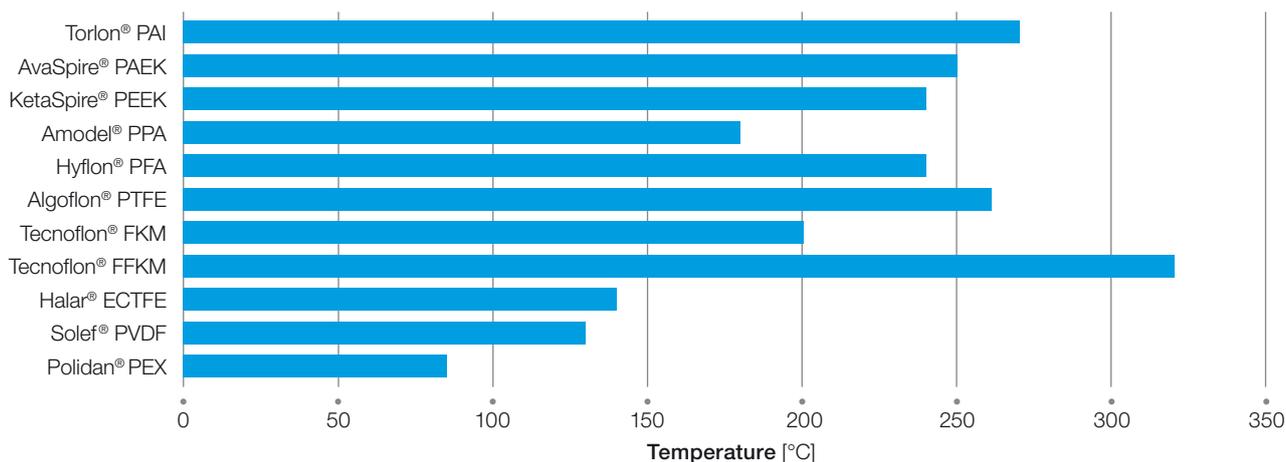
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Global energy demands continue to increase and the Oil & Gas industry turns to extreme regions with harsh operating conditions. Solvay Specialty Polymers offers the largest portfolio of high performance polymers that meet these demanding requirements.

The Oil & Gas industry offers challenging applications for most polymeric materials and demands high temperature performance, chemical resistance, chemical permeation resistance, toughness and flexibility even at low temperature, excellent electrical insulation and long-term reliability. Solvay Specialty Polymers provide a wide range of high performance polymers to meet Oil & Gas critical requirements.

Specialty polymers generally demonstrate excellent thermal aging with very little change in mechanical properties over time. However environmental factors such as load and chemical exposure may affect long-term performance and therefore end-use performance testing should be carried out to verify the acceptability of the polymers in each application.

Thermal ratings should be used as a general guideline for the maximum operating temperature in oil service.



Application Matrix

| Application | PEX | PVDF | ECTFE | PFA | PTFE | FKM FFKM | PFPE | PPA | PEEK | PAEK | PAI |
|----------------------------|-----|------|-------|-----|------|-------------|------|-----|------|------|-----|
| Flexible risers | | | | | | | | | | | |
| Pressure sheath | • | • | | | | | | | | | |
| Anti wear tapes | | • | | | | | | | • | • | |
| Umbilicals | • | • | | | | | | | • | • | |
| Pipe liners | • | • | • | • | • | | | | • | • | |
| RTPs | • | • | | | | | | | | | |
| Coatings | • | • | • | • | | | | | • | • | |
| Control line encapsulation | | • | • | • | | | | | | | |
| Power cables | • | • | • | • | • | | | | • | • | |
| Tubing | | • | | • | • | | | | • | • | |
| Seals & gaskets | | | | | • | • | | | • | • | |
| Compressor components | | | | | • | | | | • | • | • |
| Lubricants | | | | | | | • | | | | |
| Valves plates | | | | | | | | | • | • | • |
| Electrical connectors | | | | | | | | | • | • | • |
| Rod guides | | | | | | | | • | | | |
| Films | | • | • | • | | | | | • | • | |



Polidan® PEX

Cross-Linkable Compounds

In piping systems for hot fluid transport applications, materials must combine high pressure resistance together with excellent long-term performance at high temperatures. Traditional polyethylene is often limited.

Polidan® PEX grades are silane cross-linkable PE compounds manufactured according to the “SIOPLAS” system, which have been specifically developed to meet such requirements and offer an attractive alternative to insulated steels. Polidan® PEX grades are available in a range of densities from 0.900 to 0.960 kg/cm³.

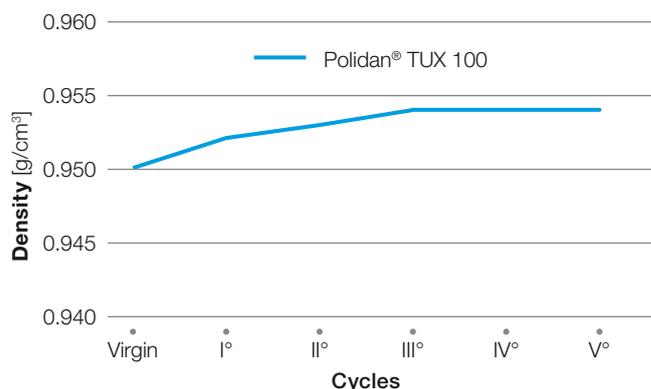
Cross-linked PE pipes manufactured from Polidan® PEX grades demonstrate the following outstanding properties:

- Excellent temperature resistance up to 90 °C
- Very high Environmental Stress Crack Resistance (ESCR) and notch resistance
- Very good chemical and corrosion resistance
- Very high resistance towards Rapid Crack Propagation (RCP)
- Excellent long-term strength
- No hydrolysis
- Excellent creep resistance up to 95 °C
- Excellent resistance to supercritical CO₂

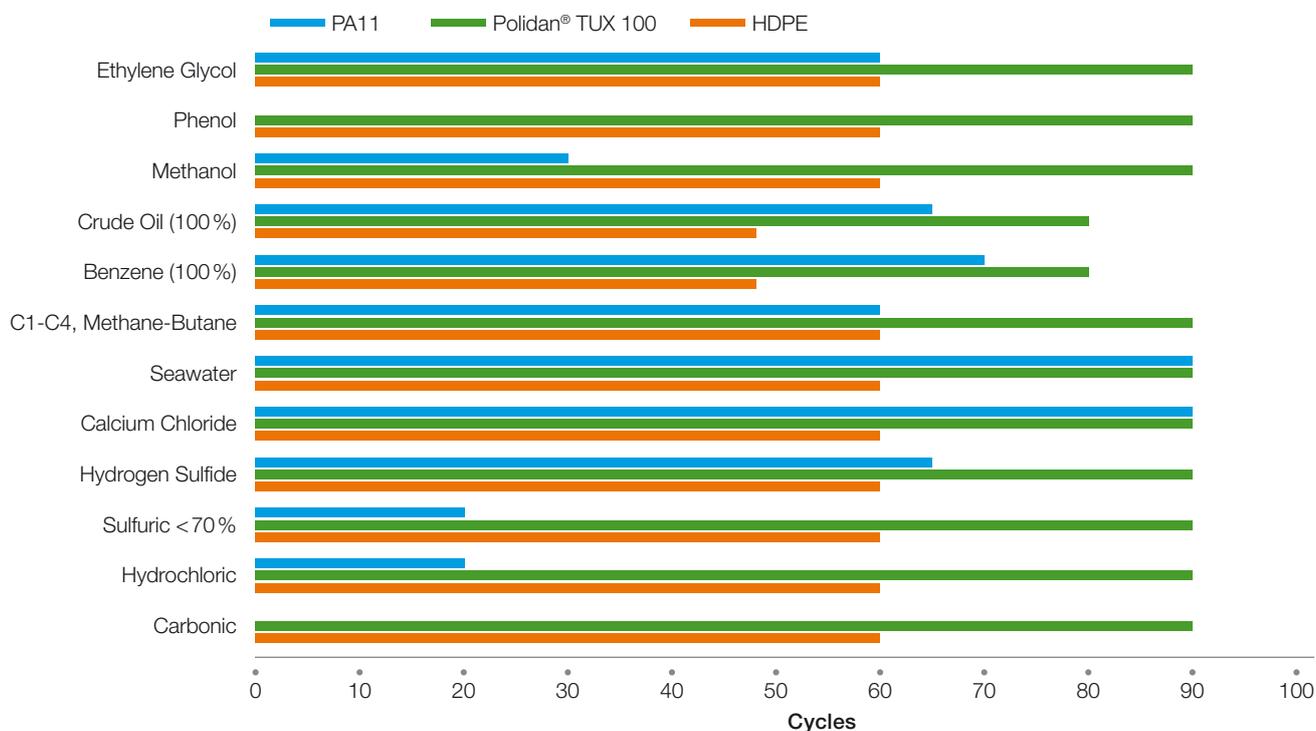
Typical applications:

- Barrier layer in flexible risers and RTPs
- Umbilical hoses
- Cable jacketing
- Self-supported pipes
- External coating layers
- Internal liners

PEX density variation during RGD cycles in supercritical CO₂



Thermo-chemical comparison



Solef® PVDF

Polyvinylidene Fluoride

Solef® PVDF is perhaps the best known fluoropolymer used in the Oil & Gas industry because of its extensive use in flexible risers and flowlines since the 1990's.

Typical properties:

- Continuous service temperature up to 130–150 °C
- Excellent chemical resistance
- Good mechanical properties
- Low permeability to most gases and liquids
- High abrasion resistance
- Excellent resistance to Rapid Gas Decompression (RGD)

Solef® PVDF for Flexible Risers and Flowlines

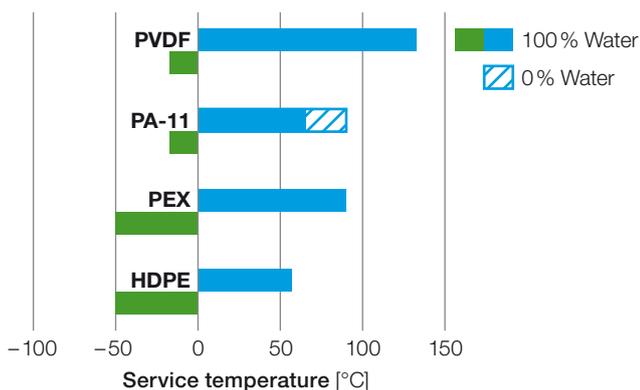
Solef® PVDF is perfectly suited to the demanding applications of deepwater subsea oil service. The complex pipe structures are designed to withstand the high pressures, temperatures and aggressive oil fluids, and Solef® PVDF is increasingly used as a barrier, thanks to its excellent long-term performance in exposure to these conditions.

Solef® PVDF is qualified to API17J up to a continuous service temperature of 130 °C for 20 years, and already has a strong proven track record in these applications.



Courtesy of NKT Flexibles

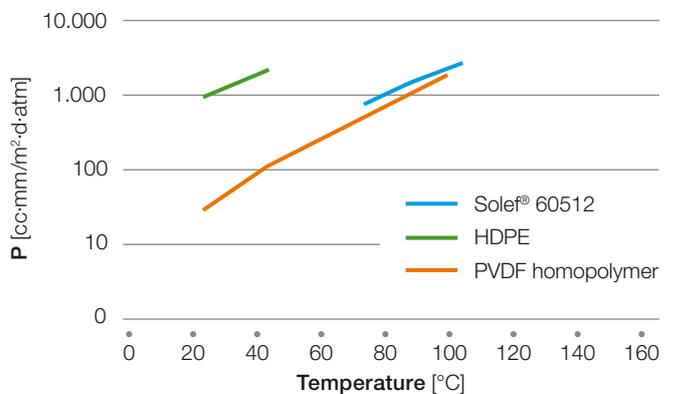
Temperature rating



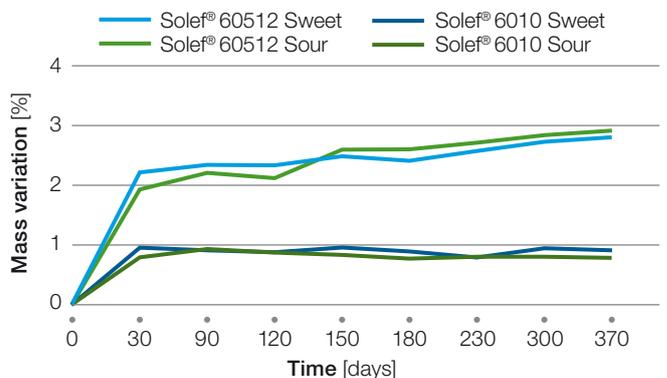
Increasingly an issue is the presence of supercritical CO₂ in oilfield fluids when it is used as a solvent in Enhanced Oil Recovery (EOR). Solef® PVDF was exposed to supercritical CO₂ at 130 °C and 150 bar to prove the chemical stability. Results showed low weight increase and low influence on mechanical properties. Fluoropolymers not only offer good chemical compatibility with supercritical CO₂ at high temperature and in polluted mixtures, but can also protect the surrounding metallic structures.

Many hydrocarbon producing regions of the world are significantly sour. H₂S in the presence of moisture is a serious problem for many metallic components, causing Sulphide Stress Corrosion Cracking (SSCC), Hydrogen Embrittlement (HE), Hydrogen Induced Cracking (HIC), or stress oriented HIC. Unbonded flexible pipes are an example of a product where negligible permeation of H₂S through the inner pressure sheath is highly desirable. Solef® PVDF has been submitted to an exposure program at several elevated temperatures and H₂S concentrations; test results confirm PVDF is only slightly affected in sour environments.

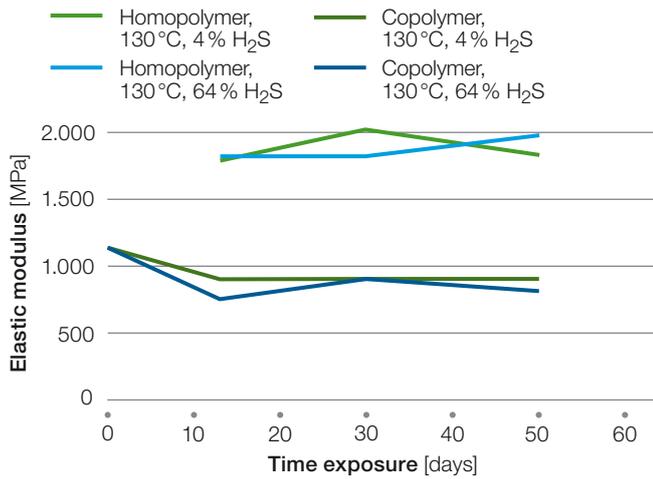
H₂S permeability



Swelling in sour environment



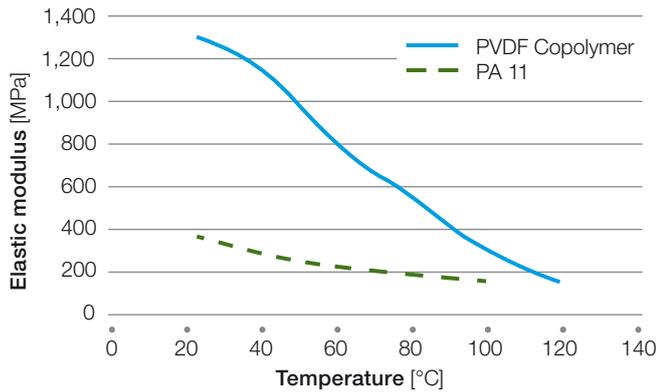
Elastic modulus in sour environment



Solef® PVDF for Umbilicals

Umbilical hoses are required to resist methanol and ethanol and have a very low permeability to such injection fluids. Solef® PVDF has been selected by high pressure hose manufacturer SPIR STAR® for these reasons, for use up to 150 °C and 1,125 bar.

Elastic modulus with temperature



Solef® PVDF for Pipe Liners

Fluids transported in flowlines are characterized by the presence of CO₂, H₂S and free water: these chemicals combined with the different flow parameters can generate a high corrosion rate of the pipelines. While corrosion can be controlled and mitigated by chemical additive injection, a small change of the chemical composition or of any flow parameters of the oil can drastically increase the corrosion rate. Polymer-lined carbon steel piping is an effective and economic alternative to the use of Corrosion Resistant Alloys (CRA), and can reduce the use of chemical injection and maintenance costs. Solef® PVDF is a material of choice for preventing corrosion and providing long-term reliability to hydrocarbon lines.

Solef® PVDF for Coatings: Internal and External Protection of Pipelines

Solvay Specialty Polymers have developed a new Solef® PVDF material designed for direct adhesion onto metals and allowing the construction of multilayer coating systems.

This new Solef® PVDF is available as a powder coating system and provides excellent adhesion and chemical compatibility with other Solef® PVDF grades, suitable for extrusion, providing thermal insulation and mechanical strength to the steel pipe. This two-layer system may be used for the external coating of pipelines.

The traditional Electrostatic Powder Coating (EPC) system based on PVDF resins, one layer of primer and several layers of top coat, can be used for internal coatings of pipelines.

Properties of Solef® PVDF coatings:

- Thermal stability from -30 °C to 150 °C
- Thermal conductivity lower than 0.2 W/m·K
- Water absorption < 0.02 %
- Low permeation to water over a wide range of temperature
- Excellent mechanical and impact strength
- Intrinsic weathering resistance
- Excellent electrical insulation
- Density: 1.78 g/cm³

Halar® ECTFE

Ethylene-Chlorotrifluoro-Ethylene

Halar® ECTFE provides a unique combination of characteristics and is well established wherever corrosion protection is required, in challenging conditions.

It is broadly used for thin or thick sheets, filters, pipes and films but also for cable jacketing and encapsulation in downhole applications.

Grades are available to serve various processing techniques, from melt extrusion to direct electrostatic powder coating. Coated parts exhibit an outstanding surface smoothness, on top of Halar® ECTFE properties.

Typical properties of Halar® ECTFE:

- Continuous service up to 150 °C
- Outstanding resistance against gases and chemicals
- Excellent abrasion resistance
- Non-flammability
- Exceptional surface smoothness

Main coating properties:

- High coating hardness
- Good adhesion to substrate
- Excellent barrier properties
- Low permeation
- Low wettability



Courtesy of Fisher Company



Hyflon® PFA

Perfluoroalkoxy Fluorocarbon Resins

Hyflon® PFA resins are a unique family of semi-crystalline melt processable perfluoropolymers that combine excellent mechanical characteristics with novel properties such as high and very low temperature resistance, chemical inertness, inherent flame resistance, low surface energy and exceptional dielectric properties.

Hyflon® PFA resins are used in several Oil & Gas downhole applications and for corrosion protection.

Typical properties:

- Mechanical properties and dimensional stability from –200 °C to 260 °C
- Excellent long-term aging resistance
- Good flexibility and ductility even down to –100 °C
- Universal chemical resistance
- Exceptional thermal stress crack resistance
- Good permeation resistance
- Excellent electrical properties and fire resistance
- No plasticizer, no additives
- Intrinsic UV resistance
- Good resistance to rapid gas decompression

Hyflon® PFA for Downhole Cables and Control Lines

Electro-mechanical cables carry power and data to monitor downhole operations and are exposed to harsh conditions. Hyflon® PFA provides hydrolytic stability and chemical resistance and can perform at very high temperatures.

Control lines consist of a steel tube that is encapsulated with a polymer to provide corrosion, abrasion and crush resistance. Hyflon® PFA is used extensively in this application.



Hyflon® PFA for Corrosion Protection

Steel pipes transporting crude hydrocarbons are increasingly exposed to high operating temperatures, high concentrations of corrosive fluids and gases, high water cut and must be designed and protected for safe and reliable operation.

Stainless steel and corrosion-resistant alloys are well established but costly solutions, and chemical inhibitors do not always offer reliable prevention at high temperature. Used for lining, Hyflon® PFA pipes provide high temperature corrosion protection, excellent erosion and abrasion resistance, as well as excellent resistance to H₂S and CO₂ also in supercritical phase. Its low coefficient of friction and surface tension can also prevent wax build-up and increase flow.

Typical applications:

- Electro-mechanical cables
- Heater cables
- Metal tubing encapsulation
- Piping
- Tank liners
- Valve linings

Hyflon® PFA M620

Sample Type IV (thickness: 1.5 mm) acc. ASTM D638

| Temperature [°C] | E [MPa] | Stress at Break [MPa] | Strain at Break [%] (Transverse) |
|------------------|---------|-----------------------|----------------------------------|
| 23 | 465 | 35.6 | 281 |
| 0 | 609 | 39.6 | 258 |
| –20 | 690 | 41.6 | 232 |
| –50 | 960 | 44.4 | 182 |
| –100 | 2,980 | 55.6 | 22.8 |

Algoflon® and Polymist® PTFE

Polytetrafluoroethylene

Algoflon® PTFE products offer outstanding chemical inertness in aggressive environments, thermal resistance, excellent electrical properties, and non-stick characteristics in a broad range of temperatures from cryogenic to 260 °C.

Typical applications include:

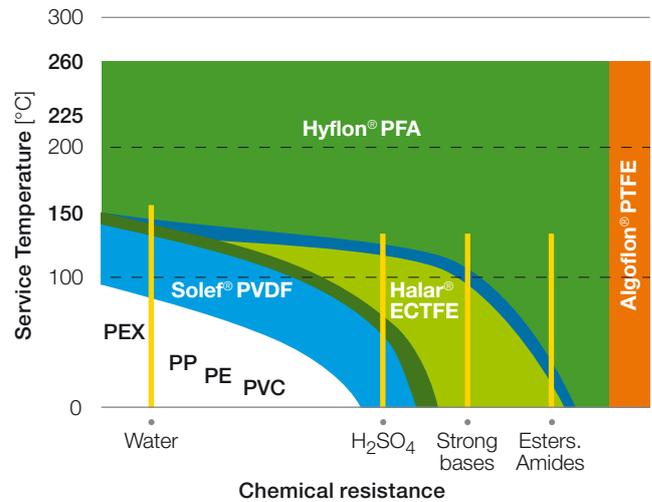
- Seals
- Gaskets
- Packers
- Valves
- Expansion joints
- Pipes and fittings

Algoflon® PTFE mechanical properties

| Temp. [°C] | Yield stress [MPa] | Stress at Break [MPa] | Elongation at Break [MPa] |
|------------|--------------------|-----------------------|---------------------------|
| 23 | 15 | 35 | 370 |
| 30 | 11 | 30 | 420 |
| 75 | 8 | 26 | 550 |
| 100 | 7 | 22 | 530 |
| 150 | 5 | 16 | 440 |
| 200 | 4 | 12 | 420 |
| 250 | 3 | 10 | 420 |
| 300 | 2 | 8 | 440 |

| Properties | Units | Algoflon® PTFE |
|--------------------------|-------------|------------------------|
| Dielectric constant | | 2.1 |
| Volume resistivity | Ohm · cm | 10 ¹⁸ |
| Dissipation factor | | < 3 · 10 ⁻⁴ |
| Dielectric strength | 1 mm, KV/mm | 25–30 |
| Flammability | | V-0 |
| Limit Oxygen Index (LOI) | % | > 95 |

Chemical resistance vs. temperature



Algoflon® L and Polymist® micronized powders are used as additives for coatings and greases in the Oil & Gas industry.

These materials are low molecular weight PTFE powders with small particle sizes that are used as additives in many different applications to enhance processing or end-use performance characteristics.

Polymist® powders, obtained through suspension polymerization, are composed of compact particles having sizes designed for the final application. Algoflon® L powders, obtained through dispersion polymerization, are agglomerates of smaller primary particles and for this reason they have higher specific surface area than Polymist® powders. All these micronized powders can be used at temperatures from –260 °C to 260 °C and have been designed to be easily dispersed in dry or liquid media.



Fomblin® PFPE

Perfluoropolyethers

Fomblin® PFPE lubricants, oils and greases are engineered for extreme applications where the up-time is a key element. Fomblin® PFPE products have an outstanding viscosity index, operate at low and very high temperatures, are chemically inert and do not dissolve in hydrocarbons. They are dense oils, UL listed as non-flammable and are not toxic.

What Makes Fomblin® Lubricants Better?

- Unmatched chemical and solvent resistance
- Excellent thermal resistance
- Excellent electrical resistance
- Non-reactive with metal, plastic, elastomers and rubber
- Inert to liquid and gaseous oxygen
- Excellent radiation hardness
- Good viscosity index
- Non flammable
- Extremely wide operating temperature range
- Low evaporation loss
- Excellent water washout properties
- Good low and high temperature wear properties
- Easily formulated into greases
- Environmentally safe
- Zero Ozone Depletion Potential (ODP)
- Non-Volatile Organic Chemicals (non-VOC)
- Non-toxic behavior

Specific grades of Fomblin® PFPE lubricants offer additional features such as:

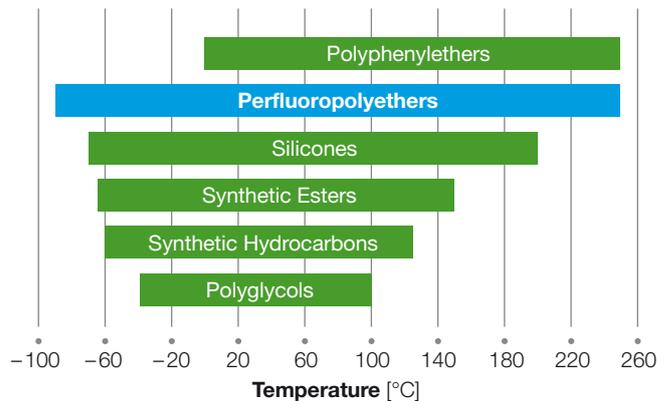
- Extremely high viscosity index (< 300)
- Excellent low temperature starting torque
- Improved evaporation characteristics

The availability of additivated Fomblin® PFPE fluids widens the range of applications for perfluorinated fluids and greases in fields demanding high anti-rust properties. These applications include lubrication of bearings, gears, turbine and liquid compressors that may be in contact with condensed water vapor.

These additives also provide an opportunity to use Fomblin® PFPE as a hydraulic fluid, filling fluid and solvents where anti-rust prevention is one of the primary product specifications.

Fomblin® PFPE lubricants are often formulated into greases for specific applications in need of high performance lubrication.

Service temperature range



Tecnoflon® FKM/FFKM

Fluoro/Perfluoroelastomers

Tecnoflon® FKM and Tecnoflon® PFR FFKM are fluorocarbon synthetic rubbers with high fluorine content that provide best-in-class thermal and chemical performance among all other elastomers.

The Tecnoflon® family of fluoroelastomers and perfluoroelastomers offers a wide portfolio of materials to withstand the rigors of downhole, subsea and surface environments in the Oil & Gas industry. Tecnoflon® materials feature rapid gas decompression resistance, resistance to H₂S and low temperature performance.

Typical applications in the Oil & Gas industry include stators for pumps and motors, packer elements and all types of sealing applications.

Tecnoflon® FKM/FFKM have a low compression set that is maintained at high temperature (> 150 °C) over time, resulting in better seals with higher and constant sealing force than materials like HNBR. This allows to increase the lifetime of the parts, reduce maintenance and shutdown times, and therefore decrease overall costs.

Tecnoflon® FKM Peroxide Curable and Base Resistant

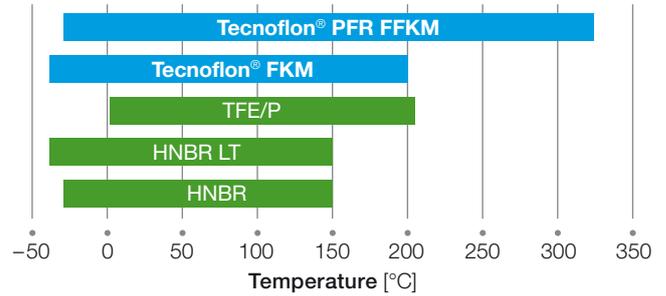
A full range of grades is available to match every specific requirement.

Chemical resistance comparison

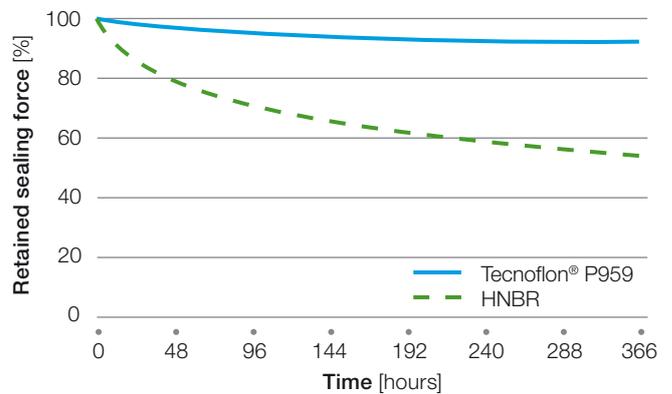
| | HNBR | FKM | Tecnoflon® PL 855 | Tecnoflon® P 757 | Tecnoflon® P 959 | TFE/P | Tecnoflon® BR 9151 | Tecnoflon® PFR 94 |
|-----------------------|-----------|---------------|-------------------------|------------------|----------------------------|-----------|------------------------|-------------------|
| | | BC, Copolymer | FKM PC, Low temperature | FKM PC, GP | FKM PC, chemical resistant | | FKM PC, base resistant | FFKM, GP |
| H ₂ S | Poor | Poor | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent |
| Steam | Poor | Poor | Medium | Medium | Excellent | Excellent | Excellent | Excellent |
| Aromatic hydrocarbons | Poor | Excellent | Excellent | Excellent | Excellent | Poor | Excellent | Excellent |
| Amines | Excellent | Poor | Poor | Poor | Poor | Excellent | Medium | Excellent |
| Oil | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent |
| Methanol | Medium | Poor | Poor | Medium | Excellent | Excellent | Excellent | Excellent |
| Sealing | Poor | Excellent | Excellent | Excellent | Excellent | Medium | Medium | Excellent |
| TR10 [°C] | -37/-30 | -17 | -30 | -15 | -7 | 3 | -7 | -2 |

BC: Bisphenol Curable, PC: Peroxide Curable, GP: General Purpose

Elastomers in Oil & Gas temperature range



Compression stress relaxation at 150 °C

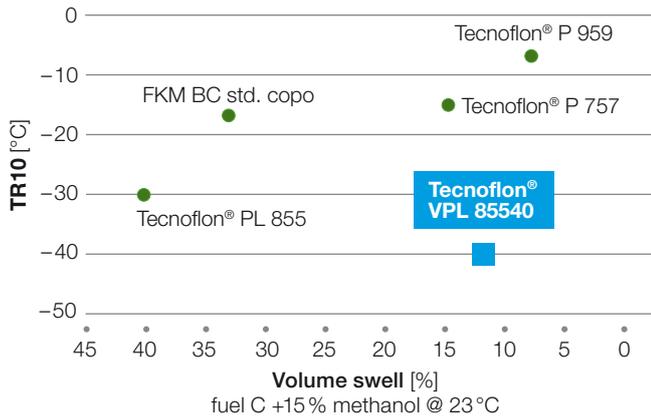


Low Temperature Performance: MOVE Technology

Tecnoflon® low temperature FFKMs are designed using Solvay's proprietary **MOVE** fully fluorinated monomer. These elastomers were developed for demanding applications, exposing them to aggressive chemicals and temperatures as low as -40°C .

Tecnoflon® VPL 85540 is the major exponent for the low temperature resistance technology.

Low temperature and chemical resistance behavior



Tecnoflon® PFR FFKM: the Ultimate Performance

Tecnoflon® PFR perfluoroelastomers are resistant to nearly every chemical class with some grades offering heat resistance over 300°C .

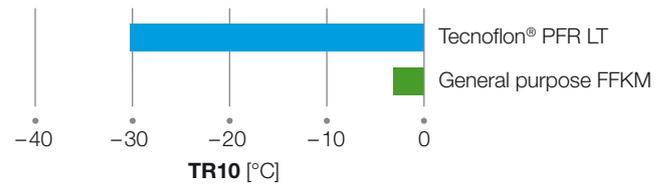
- **Tecnoflon® PFR 95HT** uses Solvay's proprietary cross-linking agent and will outperform triazinic curable FFKM's under water and steam at high temperatures.
- **Tecnoflon® PFR LT** uses Solvay's proprietary MOVE technology, combining the perfluoroelastomer outstanding chemical resistance with unrivalled extended low temperature flexibility, with its TR10 = -30°C .
- **Tecnoflon® PFR 06HC** exhibits the highest chemical resistance among all perfluoroelastomers. Specifically developed for the Oil & Gas industry, to withstand amines at high temperature and rapid gas decompression.

Thermal resistance

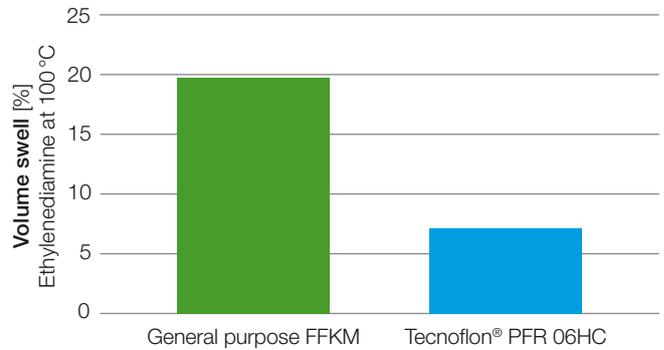


Effect of steam: 1 week @ 300°C

Minimum service temperature



Chemical resistance



Rapid gas decompression

Rapid gas decompression occurs when the external gas pressure decreases rapidly in operation and can result in splitting, internal cracking and blistering of the seal.

Thanks to Solvay's proprietary branching and pseudo-living technology, Tecnoflon® peroxide curable family of fluoroelastomers and perfluoroelastomers demonstrates excellent properties to withstand rapid gas decompression.

Most of Tecnoflon® FKM and Tecnoflon® PFR FFKM grades for the Oil & Gas industry were tested according to Norsok Standard M-710 Rev 2, and successfully passed the test.

Ultra Polymers

KetaSpire® PEEK Polyetheretherketone

AvaSpire® PAEK Polyaryletherketone

Today more than ever, engineers are turning to advanced materials to help them recover and process crude oil and natural gas. The move toward deeper drilling and deep water offshore reserves means higher temperatures, higher pressures, and often an aggressive chemical environment. Ultra polymers combine thermal performance, exceptional strength and stiffness, wear resistance, extreme hardness, chemical resistance, inherent flame resistance, high retention of mechanical properties in sour environment, good resistance to rapid gas decompression.

KetaSpire® PEEK is an easy-to-mold semi-crystalline polymer offering excellent thermal stability up to 240°C in continuous use, best-in-class fatigue resistance, and outstanding resistance to organics, acids, and bases.

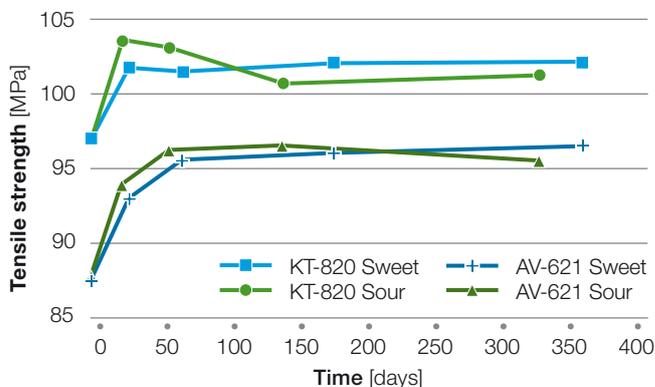
AvaSpire® PAEK is a family of proprietary formulations with unique advantages that bridge price and performance gaps. They offer improved toughness relative to PEEK, as well as higher mechanical performance between 150–240°C.

Typical applications:

- Compressor rings and plates
- Compressor poppets
- Back-up seal rings
- Electrical connectors
- Labyrinth seals
- Motor end plate
- Bearings
- Bushings
- Stock shapes
- Wear tapes for flexible risers

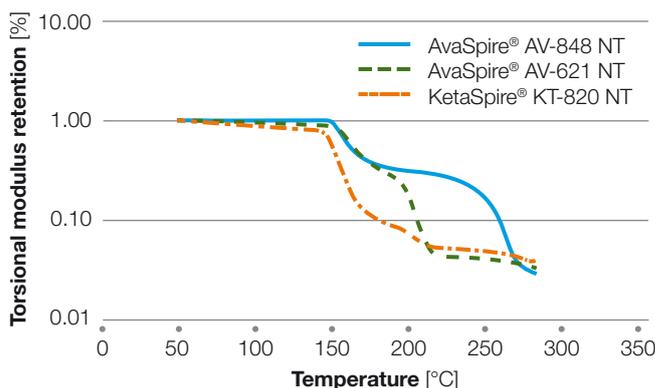


Tensile strength retention of PEEK and PAEK after one year of 20% H2S exposure



Tested at 2"/min, aging conditions:
170°C, 20% H₂S, NORSOK Oil

Modulus retention vs. temperature of unfilled PEEK and PAEK materials



Amodel® PPA

Polyphthalamide

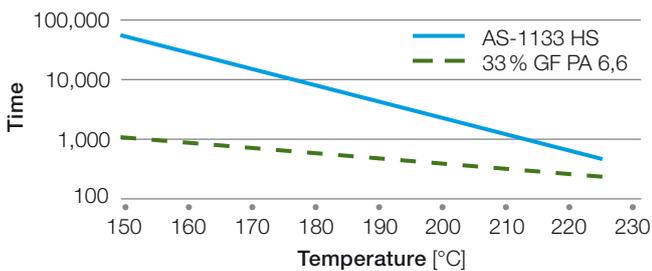
Amodel® PPA has been used in the Oil & Gas industry for over 20 years. The first downhole application using Amodel® PPA was developed for use in sucker rods. The main requirements for a thermoplastic rod guide include chemical resistance, temperature performance, dimensional stability, and wear/fatigue resistance.

Amodel® PPA was tested against PA 6,6 and PPS and demonstrated superior wear and practical toughness than PPS while providing the similar thermal performance. PPA outperforms PA 6,6 in chemical resistance, thermal performance, and dimensional stability.

Typical properties of Amodel® PPA:

- Thermal resistance, CUT up to 190 °C
- Outstanding electrical properties
- Excellent chemical resistance to hot oil, hot brine, sour crude, CO₂
- Abrasion resistance
- Corrosion resistance
- Dimensional stability
 - Less moisture absorption relative to conventional polyamides
 - Slower rate of moisture absorption
 - Lower Coefficient of Linear Thermal Expansion (CLTE) than PA 6,6 especially below 130 °C (266 °F)

Time to tensile strength half-life after heat aging (33% GF PPA vs. 33% GF PA 6,6)



| Reagent | Amodel® AS-1133 HS | PA 6,6 33% GF |
|-------------------------|--------------------|---------------|
| Toluene | Excellent | Excellent |
| Oils | Excellent | Excellent |
| Methylene Chloride | Excellent | Excellent |
| Chloro-Fluoro Carbons | Excellent | Excellent |
| Methyl Ethyl Ketones | Excellent | Medium |
| Sodium Chloride | Excellent | Medium |
| Phenols | Poor | Poor |
| Sulfuric Acids (36 %) | Excellent | Poor |
| Sodium Hydroxide (10 %) | Excellent | Medium |

30 day immersion @ 23 °C

Torlon® PAI

Polyamide-Imide

Torlon® PAI combines exceptional strength temperatures up to 275 °C with excellent resistance to creep, abrasion, wear and chemicals. It has low thermal expansion and high dielectric properties, and is cost-effective in comparison with machined thermosets.

Within the Oil & Gas industry Torlon® PAI is widely used in turbocompressors.

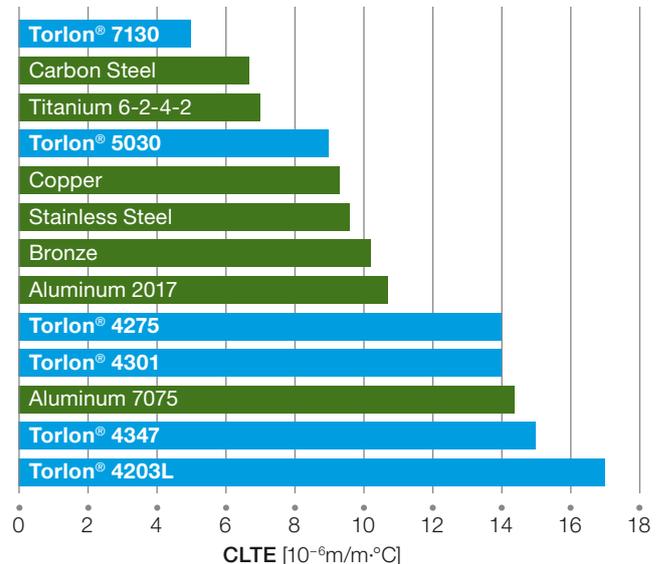
Typical properties of Torlon® PAI:

- Strength without reinforcement
- Toughness
- Cryogenic properties
- Low CLTE

Mechanical properties of Torlon® 4203L

| Properties | Units | -196 °C | 20 °C | 135 °C | 232 °C |
|---------------------|-------|---------|-------|--------|--------|
| Tensile strength | MPa | 218 | 192 | 117 | 66 |
| Elongation at break | % | 6 | 15 | 21 | 22 |
| Flexural strength | MPa | 287 | 244 | 174 | 120 |
| Flexural modulus | GPa | 7.9 | 5.0 | 3.9 | 3.6 |

Coefficient of linear thermal expansion





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