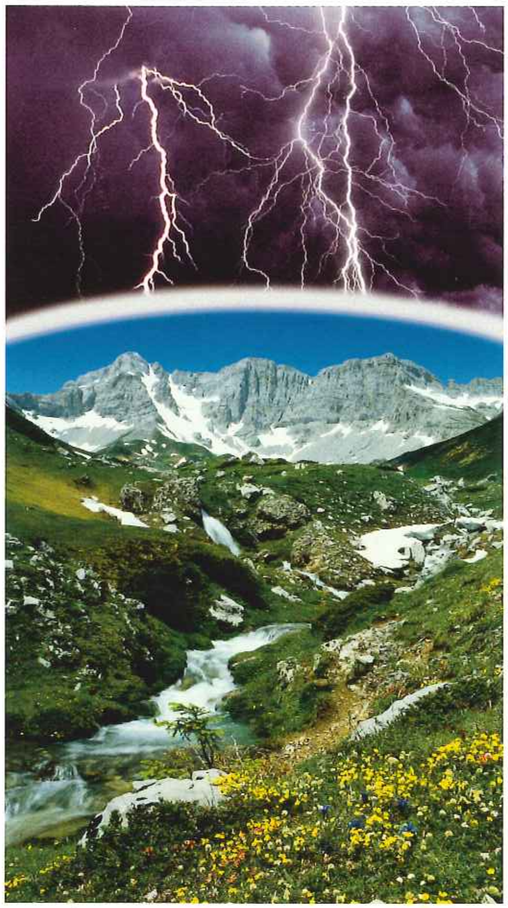
Shell Chemicals

OIL AND GAS APPLICATIONS

Corrosion Control and Chemical Resistance



Carilon®
Thermoplastic Polymers

EXPAND YOUR HORIZONS

CARILON® Thermoplastic Polymers are a recent innovation from Shell Chemicals' continuing research and development program. Shell has assembled a global sales and technical support team that is ready to assist you, anywhere in the world. So expand your horizons with CARILON Polymers.

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CARILON® THERMOPLASTIC POLYMERS — TOUGH ENOUGH FOR OIL AND GAS APPLICATIONS

CARILON® Polymers are a new class of engineering thermoplastics — semi-crystalline aliphatic polyketones (PK). The resulting molecular chains are linear, perfectly alternating carbon monoxide and alpha olefin structures that possess a unique balance of strength, chemical resistance and barrier properties, making CARILON Polymers well-suited for a broad range of applications.

CARILON Polymers give you the ability to do more than you may have thought possible with other polymers. The unique structure of this new ETP makes it resistant to problems that plague other polymers: swelling, sensitivity to hydrolysis and limited barrier performance properties.

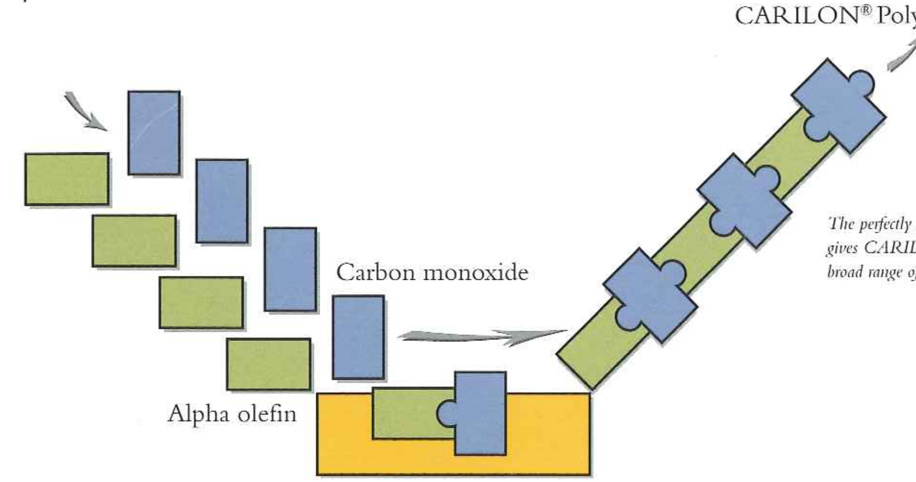
CARILON Polymers' advanced extrusion grades have been designed to maintain dimensional stability under demanding conditions, including elevated temperatures and harsh chemical environments. These qualities make CARILON Polymers well-suited for many industrial corrosion control applications.

A UNIQUE BALANCE OF PERFORMANCE PROPERTIES

- Chemical resistance and barrier performance
- Corrosion protection at elevated temperatures
- Balance of strength, toughness and resilience
- Dimensional stability in harsh chemical environments

TABLE 1: PHYSICAL PROPERTIES OF CARILON® POLYMERS

Family	Aliphatic polyketone (PK)
Melting point	220 °C (428 °F)
Crystallinity	30-40%
Specific gravity	1.24 g/cc



The perfectly alternating structure gives CARILON Polymers its broad range of performance properties.

HARSH CHEMICALS? NO PROBLEM

CARILON® Polymers are tough. With few known solvents, this new class of aliphatic polyketones has good barrier properties and chemical resistance — even when exposed to extreme temperatures.

CARILON Polymers are particularly resistant to:

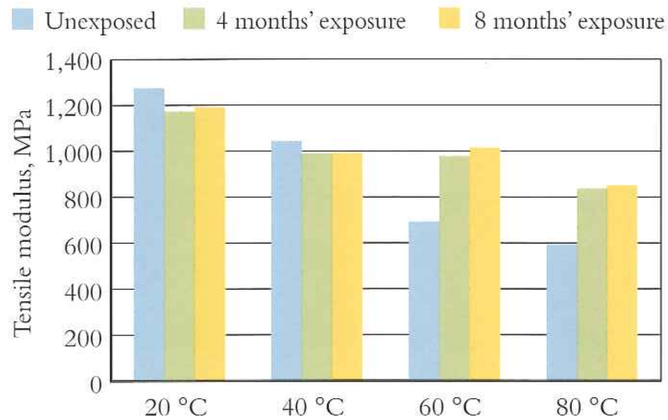
- Salt solutions
- Hydrocarbons
- Oilfield chemicals
- Weak acids and bases
- Soaps and detergents

The chemical resistance and barrier performance properties of CARILON Polymers are made possible by strong interchain forces, a hydrolytically stable structure and the presence of crystallinity. This chemical structure also gives CARILON Polymers the strength to resist swelling when exposed to aqueous and oxygenated hydrocarbon solvents.

After eight months' exposure to a multicomponent hydrocarbon solution in testing, CARILON Polymers' tensile modulus, yield stress and yield strain were relatively unaffected. Even at temperatures up to 80 °C, CARILON Polymers maintained mechanical integrity.

Testing also indicates that CARILON Polymers have better chemical resistance than PA11 to commercial corrosion inhibitors, as shown in Figure 2. After nine months' exposure in an oilfield chemical solution, CARILON Polymers retained more of their original yield strain upon exposure. In contrast, the tensile modulus of PA11 showed an increase in stiffness associated with the extraction of plasticizers.

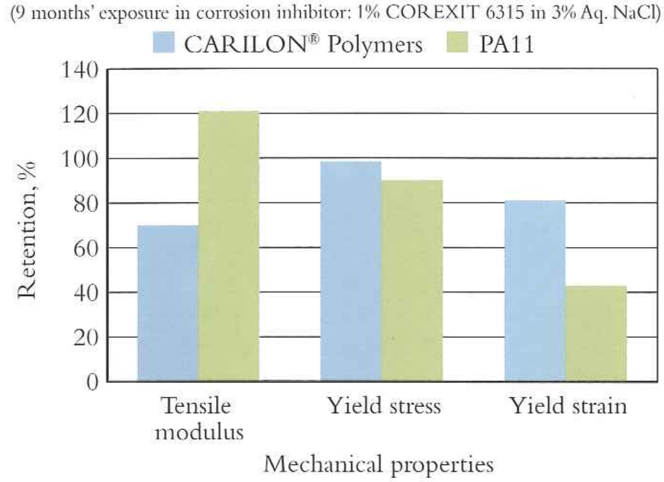
FIGURE 1a: MULTICOMPONENT LIQUID EXPOSURE – TENSILE MODULUS OF CARILON® POLYMERS



Multicomp. liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C_4-C_5 17%; C_6-C_{10} 42%; C_{11} 10%.
Tensile bars were cut from extruded samples.

The environmental stress crack resistance (ESCR) test was conducted on CARILON Polymers according to ASTM's D1693 and F1248 standards. Table 2 shows a list of the environments and test conditions. These results show that CARILON Polymers demonstrated very good chemical resistance under stress in a variety of oilfield environments.

FIGURE 2: OILFIELD CHEMICAL EXPOSURE AT 80 °C
(9 months' exposure in corrosion inhibitor: 1% COREXIT 6315 in 3% Aq. NaCl)



Tests were conducted on standard ASTM tensile bars.

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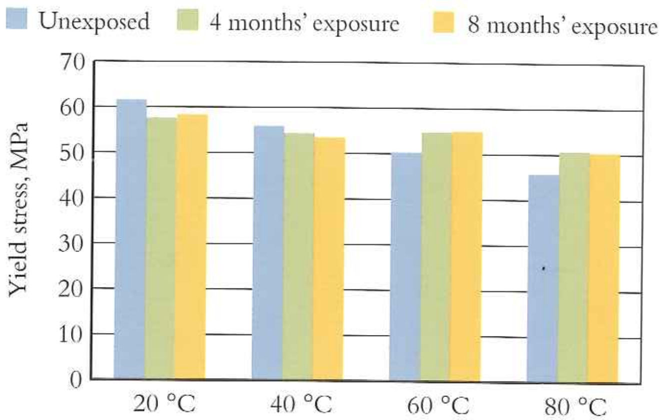
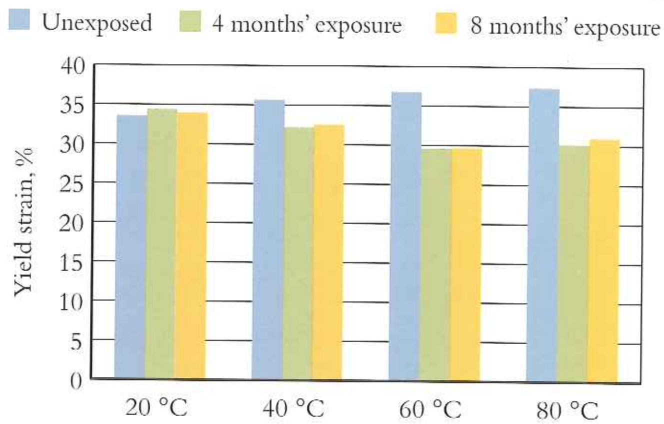
FIGURE 1b: MULTICOMPONENT LIQUID EXPOSURE – YIELD STRESS OF CARILON® POLYMERS



Multicomp. liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C_4-C_5 17%; C_6-C_{10} 42%; C_{11} 10%.
Tensile bars were cut from extruded samples.

FIGURE 1c: MULTICOMPONENT LIQUID EXPOSURE – YIELD STRAIN OF CARILON® POLYMERS



Multicomp. liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C_4-C_5 17%; C_6-C_{10} 42%; C_{11} 10%.
Tensile bars were cut from extruded samples.

TABLE 2: ENVIRONMENTAL STRESS CRACK RESISTANCE OF CARILON® POLYMERS

Environment	Temperature °C	Total time, hrs
ASTM D1693		
Soap solution: Igepal 25%	50	>5000
Soap solution: Igepal 100%	50 100	>5000 >2400
Multicomponent liquid*	25	>2700
Drilling mud	25 80	>2700 >2400
Corrosion inhibitor: oil-based polyamine, Tetrolite EC1110A in 3% aq NaCl	25 80	>2700 >2400
Corrosion inhibitor: water-based imidazoline salts, COREXIT 6315 in 3% aq NaCl	25 80	>2700 >2400
Toluene	25 80	>2700 >2000
Xylene	25	>3000
Methyl Ethyl Ketone	25	>5000
1.5% HF/7.5% HCl	25 80	>2700 >2400
10% NaOH	25	>2200
ASTM F1248		
Soap solution: Igepal 25%	50	>3600
Soap solution: Igepal 100%	50	>3600

THERMAL PERFORMANCE

CARILON® POLYMERS CAN TAKE THE HEAT—AND THE COLD

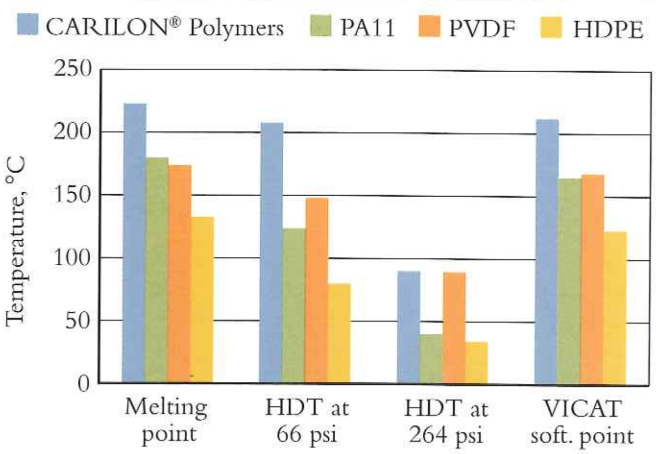
While many engineering thermoplastics perform well at room temperature, CARILON® Polymers were designed to work in the real world. CARILON Polymers maintain strength, toughness and barrier control properties over a broad temperature range.

TABLE 3: TYPICAL THERMAL PROPERTIES OF CARILON® POLYMERS

	ASTM Test Methods	ASTM Values	ISO Test Methods	ISO Values
Melting temperature		220 °C (428 °F)		220 °C
VICAT softening point	D1525		306/B50	
	5 kg	210 °C (410 °F)	50 N	205 °C
Heat deflection temperature	D648		75	
	66 psi	210 °C (410 °F)		
	264 psi	105 °C (221 °F)	1.8 MPa	100 °C

The hotter you go, the fewer material choices you have. Based on testing, CARILON® Polymers appear to have better thermal properties than polyamide-11 (PA11), polyvinylidene fluoride (PVDF) and high density polyethylene (HDPE)—with a higher melt point, VICAT softening point and heat deflection temperatures (Figure 3). Under ASTM standards, CARILON Polymers have a heat deflection temperature of 210 °C (410 °F) at 66 psi, well above that of competing materials.

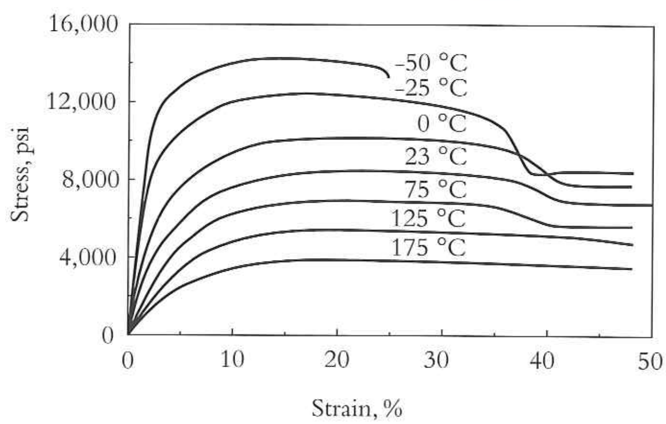
FIGURE 3: THERMAL PROPERTIES



Tests were conducted according to ASTM Test Methods as indicated in Table 3.

CARILON Polymers retain toughness and impact resistance, even in extreme temperatures. The stress-strain curves (Figure 4) demonstrate CARILON Polymers' good balance of strength and ductility at temperatures ranging from -50 to 175 °C.

FIGURE 4: STRESS-STRAIN CURVES FOR CARILON® POLYMERS AT VARIOUS TEMPERATURES



THE MECHANICS OF CARILON® POLYMERS

Industrial applications demand strength and uncompromising performance. CARILON® Polymers exhibit a unique balance of mechanical properties relative to other ETPs—with very good impact strength (notched Izod 270 J/m) and flexural modulus (1.6 GPa). By combining elements not usually found together in one material—high yield strain and high modulus—CARILON Polymers offer an impressive 25 percent elongation at yield with a modulus of 1.6 GPa.

TABLE 4: MECHANICAL PROPERTIES OF CARILON® POLYMERS MEASURED AT 23 °C (74 °F)

	ASTM Test Methods	ASTM Values	ISO Test Methods	ISO Values
Tensile strength at yield	D638	59 MPa (8500 psi)	527-1	60 MPa
Tensile strength at break	D638	63 MPa (9200 psi)	527-1	60 MPa
Tensile modulus	D638	1.6 GPa (230 kpsi)	527-1	1.4 GPa
Tensile elongation at yield	D638	22-25%	527-1	25%
Tensile elongation at break	D638	230-300%	527-1	>300%
Flexural modulus	D790	1.6 GPa (230 kpsi)	178	1.4 GPa
Unnotched Izod impact strength	D256	No Break	180/1A	No Break
Notched Izod impact strength	D256	270 J/m (5.0 ft-lb/in)	180/1A	20 kJ/m²

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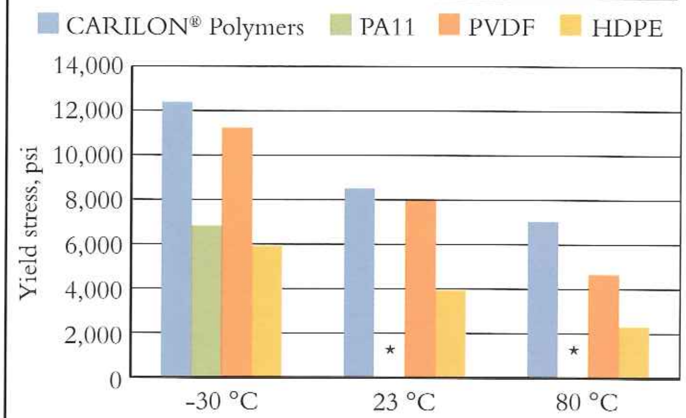
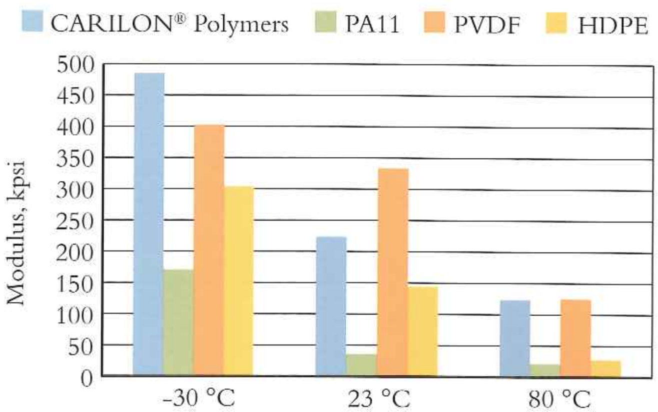
CARILON® Polymers are stiff and strong materials, as shown by their high modulus and yield stress (Figures 5 and 6). These properties are especially good when comparing CARILON Polymers to other materials at extreme temperatures. CARILON Polymers absorb larger amounts of energy prior to yield, evidenced by the high yield strains at correspondingly high yield stresses (Figures 6 and 7). Other beneficial properties include good resilience, creep resistance and abrasion resistance, which enhance CARILON Polymers' suitability in many oilfield and chemical process industry applications.

FIGURE 6: MECHANICAL PROPERTIES – YIELD STRESS



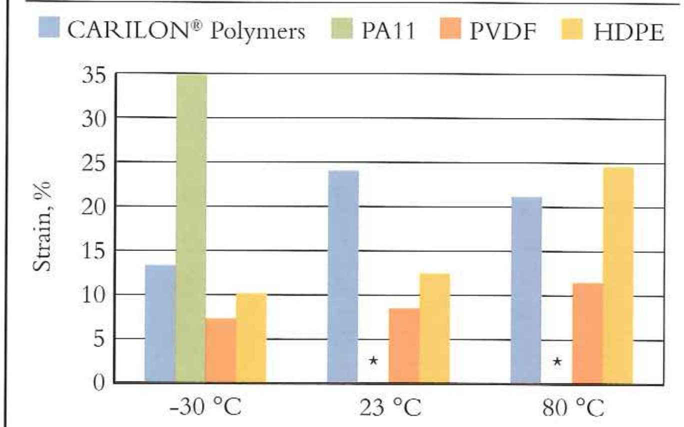
* No yield point was observed for PA11.

FIGURE 5: MECHANICAL PROPERTIES – TENSILE MODULUS



Tests were conducted on ASTM tensile bars as indicated in Table 4.

FIGURE 7: MECHANICAL PROPERTIES – YIELD STRAIN



* No yield point was observed for PA11.

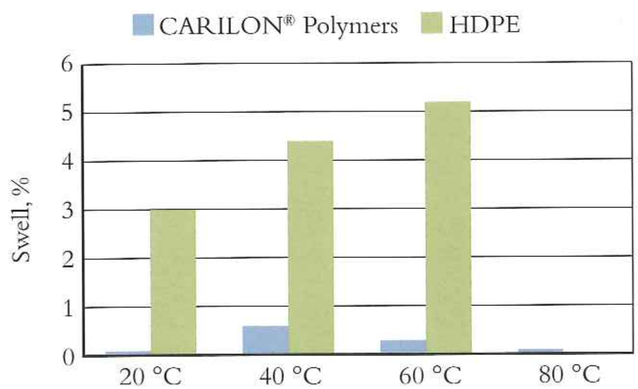
STRUCTURAL INTEGRITY UNDER DEMANDING CONDITIONS

CARILON® Polymers are dimensionally stable. Simply put, they perform under demanding conditions—including exposure to harsh chemicals, extreme temperatures, high pressure or a combination of all three. CARILON Polymers also resist hydrolysis, dissolution and plasticization in a broad range of severe chemical environments.

Plasticization can be detrimental to polymers, causing dimensional changes such as swelling and reduction in strength. CARILON Polymers retain dimensional stability when exposed to harsh hydrocarbon environments, as demonstrated in Figures 8a and 8b. In this exposure test, CARILON Polymers exhibited negligible swelling and weight gain when compared to HDPE.

FIGURE 8a: MULTICOMPONENT LIQUID TESTING – SWELL

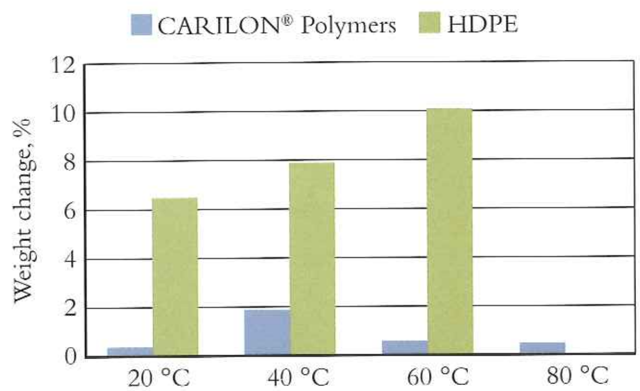
(8 months' exposure)



Multicomp. liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C_4-C_5 17%; C_6-C_{10} 42%; C_{11} 10%.

FIGURE 8b: MULTICOMPONENT LIQUID TESTING – WEIGHT CHANGE

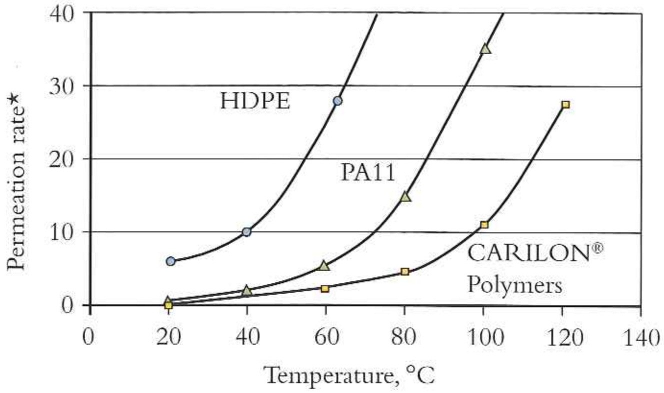
(8 months' exposure)



Multicomp. liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C_4-C_5 17%; C_6-C_{10} 42%; C_{11} 10%.

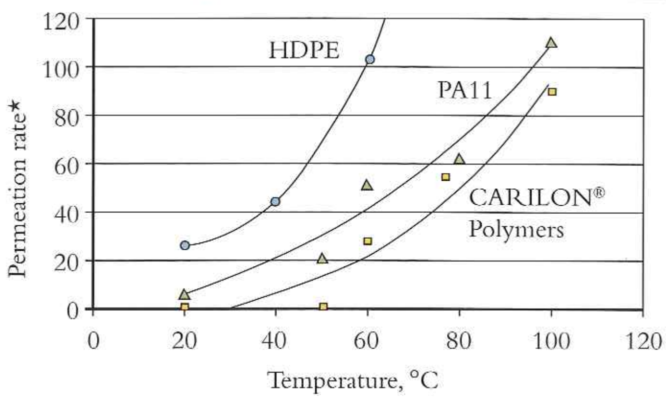
Resistance to hydrolysis, swelling and permeation give CARILON Polymers good dimensional stability when exposed to aggressive hydrocarbon environments. In addition, CARILON Polymers exhibit very good barrier properties, outperforming competing materials in gas permeation tests with CH_4, CO_2 and H_2S (Figures 9a, 9b and 9c).

FIGURE 9a: CH_4 PERMEATION



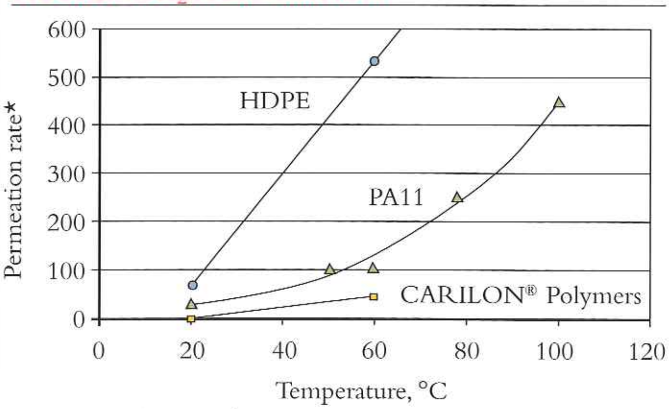
*unit = 10^9 cm^3 - cm/cm^2 s bar

FIGURE 9b: CO_2 PERMEATION



*unit = 10^9 cm^3 - cm/cm^2 s bar

FIGURE 9c: H_2S PERMEATION



*unit = 10^9 cm^3 - cm/cm^2 s bar

Perhaps the ultimate evaluation of a polymer's stability is the explosive decompression test. This demanding test consists of placing specimens, in this case CARILON Polymers and other polymers, in a CO_2 environment under 5000 psi pressure at 100 °C for a predetermined time. This high-pressure treatment is repeated for several cycles. At the end of each cycle, pressure is released at 2000 psi/minute and the specimen is checked for blisters, crack formations, discoloration and the percent of weight change. CARILON Polymers exhibited no damage and outperformed PA11 in the CO_2/deionized water environment and HDPE in both the CO_2 gas phase and in the more aggressive CO_2/deionized water environment. In both phases of this test, CARILON Polymers performed as well as PVDF.

TABLE 5a: EXPLOSIVE DECOMPRESSION RESISTANCE OF THERMOPLASTICS – CO_2 GAS PHASE

Material	144 Hrs	456 Hrs	600 Hrs
CARILON® Polymers	No damage	No damage	No damage
PA11	No damage	No damage	No damage
PVDF	No damage	No damage	No damage
HDPE	No damage	No damage	Blisters observed

TABLE 5b: EXPLOSIVE DECOMPRESSION RESISTANCE OF THERMOPLASTICS – CO_2 AND DEIONIZED WATER

Material	168 Hrs	312 Hrs	624 Hrs
CARILON® Polymers	No damage	No damage	No damage
PA11	Blisters observed on samples exposed to liquid	Blisters observed on samples exposed to gas	
PVDF	No damage	No damage	No damage

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