Chapter 1

Polyoxymethylene (Acetal)

Category: Engineering Resin

General Description: Acetal, chemically known as polyoxymethylene (POM), is a versatile engineering resin. The chemical composition, regular molecular structure, and high degree of crystallinity give acetals excellent resistance to moisture, gasoline, solvents, and many other neutral chemicals.[2001]

Processing Methods: Injection molding, extrusion (rod, slab, sheeting, small diameter tubing). Parts can be machined or stamped.[2001]

Applications: Aerosol containers, gas caps, chemical sprayers, soap dispersers, paint mixing paddles, plumbing components, gears, tough and creep resistance housings, and wear surfaces.[2001]

Permeability to Oxygen and Other Gases: Test results show that above 10 mil film thickness the permeability of both Ticona Celcon acetal unfilled and glass-reinforced grades are approximately the same.[2002]

Permeability to Water and Other Liquids: DuPont Delrin has good impermeability to many substances including aliphatic, aromatic, and halogenated hydrocarbons, alcohol, and esters. Permeability characteristics and strength properties of Delrin make it suitable material for containers, particularly of the aerosol type.[2001]

Exceptional resistance to long-term exposure to high humidity and hot water is a primary reason why Ticona Celcon acetal is so widely used for many plumbing related applications. See manufacturer's literature for more detail.[2002]

Permeability Data by Material Supplier Trade Name: See Tables 1-01 through 1-06.

Table 1-01. Cologne, Shampoo, and Hair Spray Through DuPont Delrin Acetal Resin

Material Family	ACETAL RESIN					
Material Supplier/Grade	DUPONT DELRIN					
Reference Number	201					
TEST CONDITIONS						
Penetrant	cologne		hair spray		shampoo	
Penetrant Note	various formulations					
Temperature (°C)	23	38	23	38	23	38
Relative Humidity (%)	50		50		50	
PERMEABILITY (source document units)						
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.6	4.5	0.8	6.0	2.4	8.5
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.24	1.77	0.32	2.36	0.95	3.35
PERMEABILITY (normalized units)						
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.24	1.77	0.31	2.36	0.94	3.35

Table 1-02. Gasoline, Freon Propellant, Motor Oil, and Ethyl Alcohol Through DuPont Delrin Acetal Resin

Material Family	**ACETAL RESIN**
Material Supplier/Grade	**DUPONT DELRIN**
Reference Number	201

TEST CONDITIONS

Penetrant	ethyl alcohol			Freon 12				gasoline	motor oils
Concentration (%)	90	70		30		20			
	with 10% water	with 30% water		with 70% Freon 11; propellant		with 80% Freon 114; propellant			
Temperature (°C)	23		38	23	38	23	38	23	38
Relative Humidity (%)	50			50		50		50	

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.25	1.5	7.8	0.2	0.54	0.2	0.42	0.1	0

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.1	0.59	3.07	0.08	0.21	0.08	0.17	0.04	0

Table 1-03. Methyl Salicylate, Nitrogen, Perchloroethylene, Trichloroethylene, Toluene, Carbon Dioxide, and Oxygen through DuPont Delrin Acetal Resin

Material Family	**ACETAL RESIN**
Material Supplier/Grade	**DUPONT DELRIN**
Reference Number	201

TEST CONDITIONS

Penetrant	methyl salicylate	nitrogen (@ 620 kPa)	perchloro-ethylene	trichloroethylene		toluene	carbon dioxide	oxygen
Temperature (°C)	23			23	38	23		
Relative Humidity (%)	50					50		

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.3	0.05	0.2	25	56	0.6		
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)							37 - 50	12 - 17

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)							14.6 - 19.7	4.7 - 6.7
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.12	0.02	0.08	9.84	22.05	0.24		

Table 1-04. Mineral Oils, Vegetable Oils, Tar Remover, and Road Oil Remover Through DuPont Delrin Acetal Resin

Material Family	ACETAL RESIN
Material Supplier/ Grade	DUPONT DELRIN
Reference Number	201

TEST CONDITIONS

Penetrant	mineral oils		vegetable oils		tar remover		road oil remover	
Temperature (°C)	23	38	23	38	23	38	23	38
Relative Humidity (%)	50		50		50		50	

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0		0.03	0.19	0.03	0.19
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0		0.01	0.07	0.01	0.07

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0		0.01	0.07	0.01	0.07

Table 1-05. Air and Oxygen through Ticona Acetal Copolymer Film

Material Family	ACETAL COPOLYMER					
Material Supplier	TICONA					
Grade	CELCON M90	CELCON M25	CELCON M270	CELCON M90	CELCON M25	CELCON M270
Product Form	FILM					
Features	general purpose grade	high molecular weight	high flow, low molecular weight	general purpose grade	high molecular weight	high flow, low molecular weight
Reference Number	210					

MATERIAL CHARACTERISTICS

Melt Flow Index	9.0 g/10 min.	2.5 g/10 min.	27.0 g/10 min.	9.0 g/10 min.	2.5 g/10 min.	27.0 g/10 min.
Sample Thickness (mm)	0.15					

TEST CONDITIONS

Penetrant	air	oxygen

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	2.2 - 3.2	5.0 - 7.4

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.87 - 1.3	2.0 - 2.9

Table 1-06. Nitrogen and Carbon Dioxide Through Ticona Acetal Copolymer Film

Material Family	ACETAL COPOLYMER					
Material Supplier	TICONA					
Grade	**CELCON M90**	**CELCON M25**	**CELCON M270**	**CELCON M90**	**CELCON M25**	**CELCON M270**
Product Form	FILM					
Features	general purpose grade	high molecular weight	high flow, low molecular weight	general purpose grade	high molecular weight	high flow, low molecular weight
Reference Number	210					

MATERIAL CHARACTERISTICS

Melt Flow Index	9.0 g/10 min.	2.5 g/10 min.	27.0 g/10 min.	9.0 g/10 min.	2.5 g/10 min.	27.0 g/10 min.
Sample Thickness (mm)	0.15					

TEST CONDITIONS

Penetrant	carbon dioxide	nitrogen

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	144 - 174	2.2 - 3.2

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	56.7 - 68.5	0.87 - 1.3

Acrylonitrile-Methyl Acrylate Copolymer (AMA)

Category: Nitrile

General Description: Intended primarily for packaging use, acrylonitrile-based resins are sometimes called *barrier resins.* AMA is a clear, rubber modified acrylonitrile with excellent chemical resistance and gas barrier as well as high modulus or stiffness.[1004] The permeability of AMA is dependent upon the presence or absence of additives as well as the chemical composition with respect to type of nitrile and comonomer.[1005]

BP Chemicals Barex is an acrylonitrile-methyl acrylate copolymer grafted onto a nitrile rubber. Barex 210 and 218 are high barrier, impact modified copolymer resins. Barex 218 contains a high portion of impact modifier.[2003]

Processing Methods: Thermoforming, film extrusion, sheet extrusion, extrusion blow molding, calendering, injection molding, injection blow molding, injection stretch blow molding.[2003]

Applications:

- *Food Packaging.* Processed meats, fish, cheese, spices, sauces, extracts, and juice concentrates.
- *Medical Packaging.* Pharmaceutical, transdermal patches.
- *Personal Care.* Cosmetic packs, mouthwash, perfume.[2003]

Permeability to Oxygen and Other Gases: Barex resins have the lowest oxygen permeability of any plastic material used for single layer packages, frequently outperforming multilayer structures containing EVOH and PVDC and doing so at lower costs.

Extended shelf life is most often accomplished by sealing in beneficial gases such as nitrogen and carbon dioxide while preventing oxygen from entering the package. Barex offers extended shelf life, retention of natural flavors and aromas without flavor scalping.[2003]

Barex resins offer a high barrier to oxygen at all levels of relative humidity. Barrier performance is, however, negatively impacted by increasing temperature.

See *Collected Comparative Barrier Properties of Plastics and Elastomers,* for more information.

Permeability to Water Vapor and Other Liquids: Water vapor barrier properties of Barex resins are comparable to other plastic packaging materials except polyolefins, which are less permeable for water vapor. In applications where exclusion of moisture is critical, the water vapor barrier of Barex packages can be enhanced by orientation or lamination to a polyolefin, giving excellent combination of gas and moisture barrier.[2003]

See *Collected Comparative Barrier Properties of Plastics and Elastomers,* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 2-01 and 2-02, and Graphs 2-01 through 2-03.

Table 2-01. Water Vapor and Oxygen Through BP Chemicals Barex Acrylonitrile-Methyl Acrylate Copolymer

Material Family	ACRYLONITRILE-METHYL ACRYLATE COPOLYMER							
Material Supplier/ Trade Name	BP CHEMICALS BAREX							
Grade	210	218	210	218	210	218	210	218
Features	barrier properties, impact modified	barrier properties, high impact, impact modified	barrier properties, impact modified	barrier properties, high impact, impact modified	barrier properties, impact modified	barrier properties, high impact, impact modified	barrier properties, impact modified	barrier properties, high impact, impact modified
Applications	packaging							
Reference Number	296							

TEST CONDITIONS

Penetrant	oxygen		nitrogen		carbon dioxide		water vapor	
Temperature (°C)	23							
Relative Humidity (%)	100		100		0		100	
Test Method	ASTM D3985						ASTM F1249	

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/\ 100\ in^2 \cdot bar \cdot day$)	0.8	1.6	0.2	0.4	1.6	1.6		
Vapor Transmission Rate ($g \cdot mil/\ 100\ in^2 \cdot bar \cdot day$)							5.0	7.5

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.32	0.64	0.08	0.16	0.64	0.64		
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day \cdot atm$)							1.99	2.99

Table 2-02. Water Vapor and Oxygen vs. Humidity Through BP Chemicals Barex Acrylonitrile-Methyl Acrylate Copolymer

Material Family	**ACRYLONITRILE-METHYL ACRYLATE COPOLYMER**	
Material Supplier/Grade	**BP CHEMICALS BAREX 210**	**BP CHEMICALS BAREX 218**
Features	barrier properties, impact modified	barrier properties, high impact, impact modified
Applications	packaging	
Reference Number	296	

TEST CONDITIONS

Penetrant	oxygen		water vapor	oxygen	water vapor
Temperature (°C)	22.8		37.8	22.8	37.8
Relative Humidity (%)	0	90		0	90
Test Method	ASTM D3895		ASTM F1249	ASTM D1434	ASTM F1249

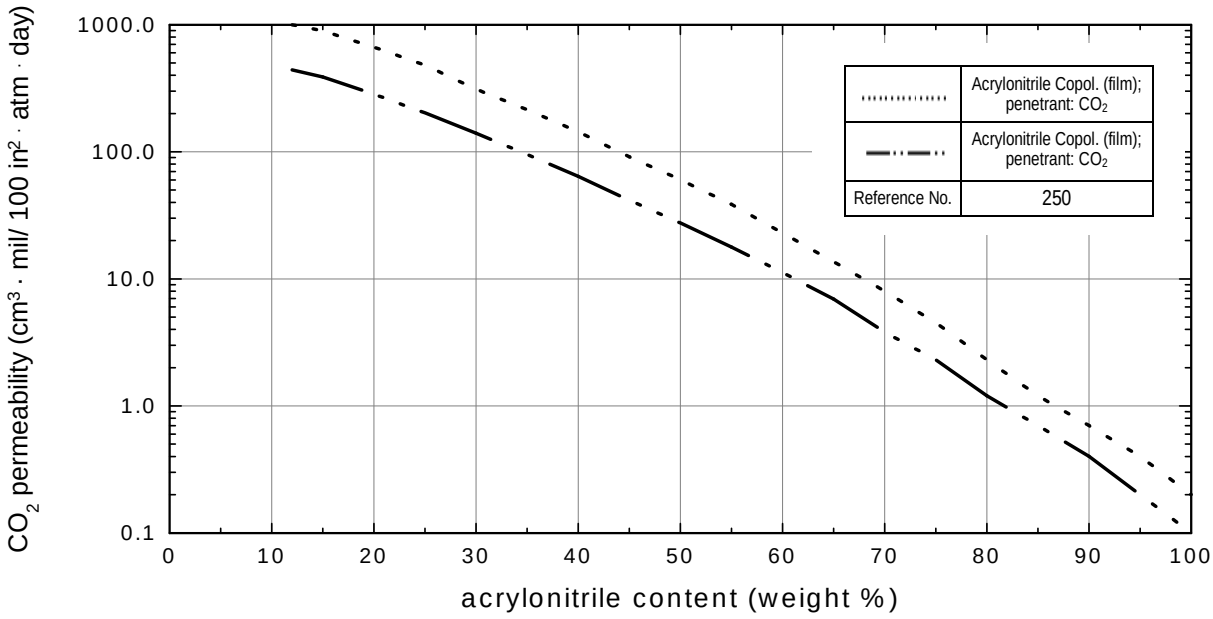
PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/ 100\ in^2 \cdot day\ \ bar$)	0.8	0.8		1.6	
Vapor Transmission Rate ($g \cdot mil/ 100\ in^2 \cdot day\ \ bar$)			5.5		7.5

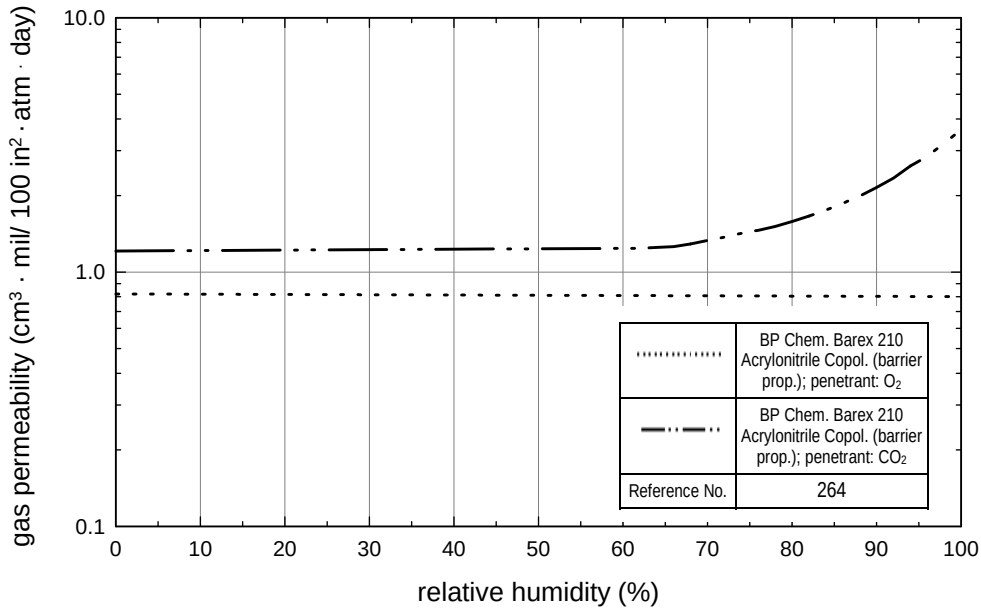
PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.32	0.32		0.64	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)			2.19		2.99

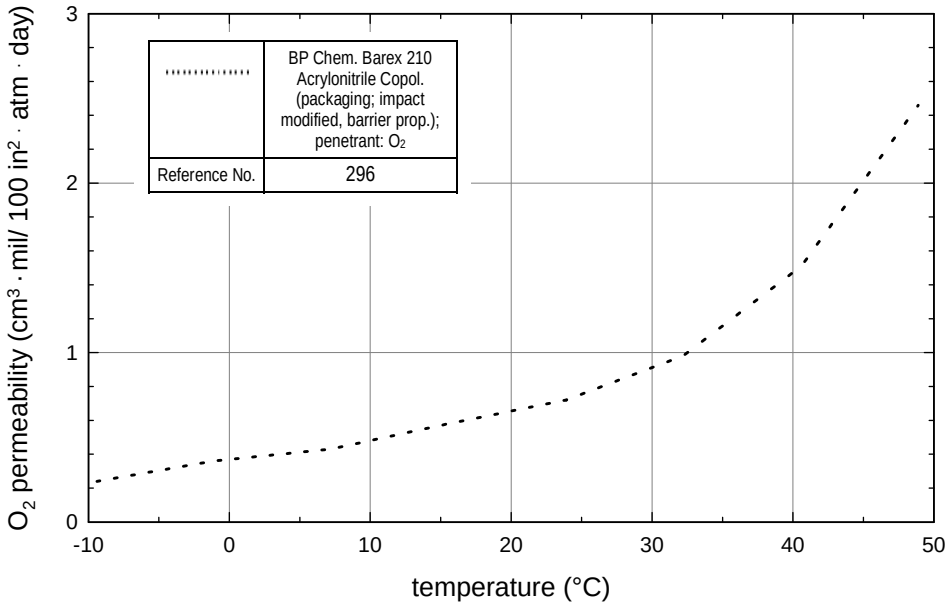
Graph 2-01. Carbon dioxide vs. acrylonitrile content through acrylonitrile-methyl acrylate copolymer.



Graph 2-02. Carbon dioxide and oxygen vs. relative humidity through acrylonitrile-methyl acrylate copolymer.



Graph 2-03. Oxygen vs. temperature through acrylonitrile-methyl acrylate copolymer.



Chapter 3

Cellulosic

Category: Cellulosic

General Description: Cellulosic plastics are made primarily from cellulose acetate. Cellulose is probably the best known of the cellulosic films.[1052]

Processing Methods: Cellophane is cast through a thin slit spinneret into a bath of sulphuric acid to form a film. The cellophane forms a film that is flimsy and opaque. Further treatment including coating with metal or other chemicals, is required to yield a film that is transparent, soft, and plastic. This treatment will alter the film's permeability to air and water.[1052]

Applications: Cellulosic film applications include tapes and labels, photographic film, coatings for paper, glass, and plastic. Medical applications for cellulosic films include dialysis membranes.[1052]

Cellophane is the most common food packaging material after paper and cardboard; over 50% of all twist-wrapped sweets are packaged in cellophane.[1052]

Cellulose acetate is widely used in photographic films, recording tapes, packaging, and matte adhesive tape.[1052]

Permeability to Oxygen and Other Gases and Water Vapor: Cellophane is considered a high barrier polymer.

Permeability Data by Material Supplier Trade Name: See Tables 3-01 through 3-03.

Table 3-01. Water Vapor and Oxygen Through Coated Cellophane Film

Material Family	CELLULOSIC PLASTIC		
Reference Number	1005		
TEST CONDITIONS			
Penetrant	oxygen	carbon dioxide	moisture vapor
Temperature (°C)	23		
Relative Humidity (%)	50		100
PERMEABILITY (source documents units)			
Gas Permeability [mol/(m ·s ·PA) ·10^{17}]	0.1 – 0.16	0.2 – 1.2	1 – 335
PERMEABILITY (normalized units)			
Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)	0.2 – 0.31	0.4 – 3.4	1.96 – 657

Table 3-02. Water Vapor and Oxygen Through Coated Cellophane Film

Material Family	**CELLULOSIC PLASTIC**				
Product Form	**FILM**				
Reference Number	268				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.023				
MATERIAL COMPOSITION					
Note	PVDC coated				
TEST CONDITIONS					
Penetrant	water vapor	oxygen			
Temperature (°C)	40	35	20		
Relative Humidity (%)	90	0	65	85	100
Test Method	JIS Z0208	JIS Z1707	ASTM D3985		
PERMEABILITY (source document units)					
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	1				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		0.07	0.26	0.71	2.06
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.03	0.1	0.28	0.81
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.39				

Table 3-03. Various Gases Through Cellulose (Cellophane)

Material Family	**CELLULOSIC**							
Reference Number	1113							
TEST CONDITIONS								
Penetrant	helium	hydrogen	nitrogen	oxygen	carbon dioxide	H_2S	SO_2	H_2O
Temperature (°C)	20	25				45	25	
PERMEABILITY (source document units)								
Gas Permeability [$cm^3 \cdot cm/(cm^3 \cdot sec \cdot Hg) \cdot 10^{10}$]	0.0005	0.0065	0.0032	0.0021	0.0047	0.0006	0.0017	1900
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	N/A without thickness							

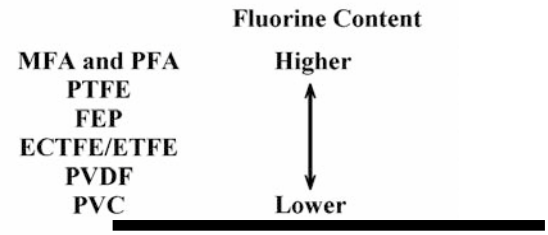
Chapter 4

Fluoropolymer

General Description: Fluoropolymers are a class of paraffinic thermoplastic polymers where some or all of the hydrogen has been replaced by fluorine. The result is either is a fully fluorinated polymer such as PTFE, FEP, MFA, or PFA, or a partially fluorinated polymer such as ECTFE, PCTFE, ETFE, and PVDF. By varying the fluorine content of the polymer, the balance of mechanical properties and overall cost can be tailored for different end use applications.[2004]

Fluoropolymers are inert to most chemicals and maintain their properties when exposed to high temperatures. When reinforced with glass fibers, for example, molybdenum disulfide fillers, their generally low mechanical properties are considerably improved.[1004]

Fluoropolymer products:[2004]



Applications: Protective coatings and linings, extruded products such as monofilament, rod, tubing, wire and cable insulation, pumps, filter cartridges, nonwoven fiber for filter media, and composite laminates.[2004]

Permeability Data by Material Supplier Trade Name: See Tables 4-01 through 4-10.

Table 4-01. Chlorine Gas Through Fluoroplastic Films

Material Family	FLUOROPLASTIC					
Material Type	Granular PTFE			Fine Powder PTFE		
Reference Number	1069					
TEST CONDITIONS						
Penetrant	chlorine gas					
Temperature (°C)	25					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.25	2.25	4.45	0.25	2.25	4.45
PERMEABILITY (source documents units)						
Gas Permeability (g/m^2 /24 hr)	1.974	0.358	0.255	5.55	0.369	0.289
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.493	0.801	1.001	1.387	0.830	1.286

Table 4-02. Chlorine Gas Through Fluoroplastic Films

Material Family	FLUOROPLASTIC									
Material Type	FEP	PFA		ETFE			ECTFE	PVDF		
Reference Number	1069									
TEST CONDITIONS										
Penetrant	chlorine gas									
Temperature (°C)	25									
MATERIAL CHARACTERISTICS										
Sample Thickness (mm)	4.45	0.250	2.250	4.450	0.250	2.250	4.450	4.450	0.250	5.250
PERMEABILITY (source document units)										
Gas Permeability (g/m^2 /24 hrs)	0.190	1.605	0.569	0.265	1.164	0.254	0.250	0.199	1.018	0.167
PERMEABILITY (normalized units)										
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.846	0.401	1.280	1.179	0.291	0.571	1.112	0.885	0.254	0.877

Table 4-03. Nitric Acid Through Fluoroplastic Films at 25°C

Material Family	FLUOROPLASTIC							
Material Type	Granular PTFE	PFA	ETFE		ECTFE		PVDF	
Reference Number	1069							
TEST CONDITIONS								
Penetrant	nitric acid							
Temperature (°C)	25							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.25	0.25	0.25	2.25	0.250	2.25	0.250	2.225
PERMEABILITY (source document units)								
Gas Permeability (g/m^2/24 hrs)		0.397	0.469	0.035	0.072	0.061	0.344	
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.992	0.117	0.787	0.018	0.137	0.086	

Table 4-04. Nitric Acid Through Fluoroplastic Films at 45°C

Material Family	FLUOROPLASTIC							
Material Type	**Granular PTFE**	**PFA**	**ETFE**	**ETFE**	**ECTFE**	**ECTFE**	**PVDF**	**PVDF**
Reference Number	1069							
TEST CONDITIONS								
Penetrant	nitric acid							
Temperature (°C)	45							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.25	0.25	0.25	2.25	0.250	2.25	0.250	2.250
PERMEABILITY (source document units)								
Gas Permeability (g/m^2/24 hrs)	0.395		0.610		1.453	0.037	3.703	0.265
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.099		0.152		0.363	0.083	0.926	0.596

Table 4-05. Methylene Chloride Through Fluoroplastic Films at 25°C

Material Family	FLUOROPLASTIC						
Material Type	**Granular PTFE**	**Fine Powder PTFE**	**PFA**	**ETFE**	**ECTFE**	**PVDF**	**Polypropylene**
Reference Number	1069						
TEST CONDITIONS							
Penetrant	methylene chloride						
Temperature (°C)	25						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.250						
PERMEABILITY (source document units)							
Gas Permeability (g/m^2/24 hrs)	3.85	20.6	2.34	33.1	59.5	8.55	504.2
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.962	5.15	0.587	8.275	14.875	2.137	126.05

Table 4-06. Methylene Chloride Through Fluoroplastic Films at 45°C

Material Family	FLUOROPLASTIC						
Material Type	**Granular PTFE**	**Fine Powder PTFE**	**PFA**	**ETFE**	**ECTFE**	**PVDF**	**Polypropylene**
Reference Number	1069						
TEST CONDITIONS							
Penetrant	methylene chloride						
Temperature (°C)	45						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.250						
PERMEABILITY (source document units)							
Gas Permeability (g/m^2/24 hrs)	9.08	60.8	10.6	113.6	634.6	36.06	2250
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.27	15.2	2.65	28.4	158.65	9.015	562.5

Table 4-07. Phenol Through Fluoroplastic Films at 25°C

Material Family	FLUOROPLASTIC						
Material Type	**Granular PTFE**	**Fine Powder PTFE**	**PFA**	**ETFE**	**ECTFE**	**PVDF**	**Polypropylene**
Reference Number	1069						
TEST CONDITIONS							
Penetrant	phenol						
Temperature (°C)	25						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.250						
PERMEABILITY (source document units)							
Gas Permeability (g/m^2/24 hrs)	0.050	0.084	0.013	0.158	0.067	0.218	0.027
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.012	0.021	0.003	0.039	0.067	0.054	0.007

Table 4-08. Phenol Through Fluoroplastic Films at 45°C

Material Family	FLUOROPLASTIC						
Material Type	**Granular PTFE**	**Fine Powder PTFE**	**PFA**	**ETFE**	**ECTFE**	**PVDF**	**Polypropylene**
Reference Number	1069						
TEST CONDITIONS							
Penetrant	phenol						
Temperature (°C)	45						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.250						
PERMEABILITY (source document units)							
Gas Permeability ($g/m^2/24hrs$)	0.247	0.991	0.237	1.562		3.394	0.734
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.062	0.248	0.060	0.690		0.848	0.183

Table 4-09. Benzene Through Fluoroplastic Films at 25°C

Material Family	FLUOROPLASTIC					
Material Type	**Granular PTFE**			**ETFE**		
Reference Number	1069					
TEST CONDITIONS						
Penetrant	benzene					
Temperature (°C)	25					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.250	2.250	4.450	0.250	2.250	4.450
PERMEABILITY (source document units)						
Gas Permeability ($g/m^2/24hrs$)	2.591	0.777	0.0335	5.326	0.118	0.068
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.648	1.748	0.149	1.331	0.266	0.303

Table 4-10. Methyl Ethyl Ketone Through Fluoroplastic Films at 25°C

Material Family	FLUOROPLASTIC									
Material Type	Granular PTFE			ETFE			ECTFE		PVDF	
Reference Number	1069									
TEST CONDITIONS										
Penetrant	methyl ethyl keytone									
Temperature (°C)	25									
MATERIAL CHARACTERISTICS										
Sample Thickness (mm)	0.250	2.250	4.450	0.250	2.250	4.450	0.250	2.250	0.250	2.250
PERMEABILITY (source document units)										
Gas Permeability (g/m^2/24 hrs)	7.726	0.306	0.028	6.882	0.034	0.023	27.6	0.033	482.1	0.168
PERMEABILITY (normalized units)										
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.931	0.689	0.125	1.720	0.075	0.102	6.90	0.0742	120.5	0.378

Ethylene-Chlorotrifluoroethylene Copolymer (ECTFE)

Category: Fluoropolymer

General Description: Ausimont Halar ECTFE is a melt-processible fluoropolymer with a 1:1 alternating copolymer structure of ethylene and chlorotrifluoroethylene.[2005]

Processing Methods: Extrusion, compression molding, rotomolding, and blow molding.[2005]

Applications:

- *Chemical.* Diaphragms, protective linings/coatings, pumps, valves, hoods, tank and filter house linings, and non-woven filtration fibers.
- *Food Processing.* Additives, contact with acidic food and fruit juice processing.[2005]

Permeability to Oxygen and Other Gases: Barrier properties are 10 to 100 times better than PTFE or FEP to oxygen, carbon dioxide, chlorine gas, and hydrochloric acid.[2006]

Permeability to Water and Other Liquids: Halar fluoropolymer has low permeability to water vapor and various other gases. Water vapor permeability measured at 100°F (38°C) and at 90% RH was found to be 0.15 g mil/100 in^2 in 24 hrs. At elevated surface temperatures, Halar has superior moisture vapor impermeability compared to other fluoropolymers at the same conditions.[2005]

Permeability Data by Material Supplier Trade Name: See Tables 5-01 through 5-03 and Graphs 5-01 through 5-05.

Table 5-01. Hydrogen vs. Temperature and Pressure Through Ausimont Halar ECTFE

Material Family	ETHYLENE-CHLOROTRIFLUOROETHYLENE COPOLYMER (ECTFE)								
Material Supplier/Grade	AUSIMONT HALAR								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.02								
TEST CONDITIONS									
Penetrant	hydrogen								
Temperature (°C)	-22	25	66	-20	25	67	-21	25	68
Pressure Gradient (kPa)	1724			3447			6895		
Test Method	mass spectrometry and calibrated standard gas leaks developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	1.19×10^{-10}	1.21×10^{-9}	6.58×10^{-9}	1.18×10^{-10}	1.25×10^{-9}	6.65×10^{-9}	1.18×10^{-10}	1.23×10^{-9}	6.74×10^{-9}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	10.4	106	576	10.3	109	582	10.3	108	590

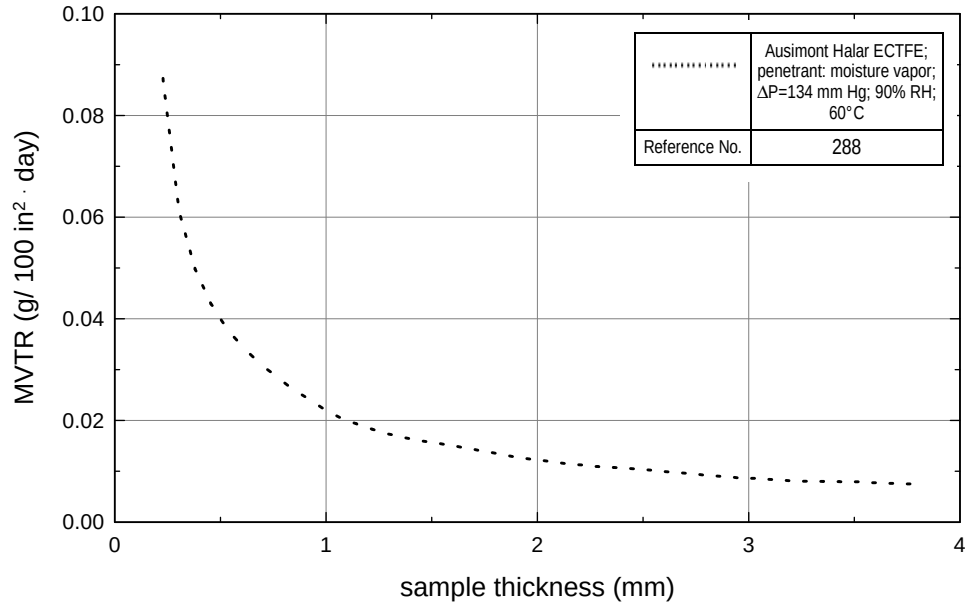
Table 5-02. Nitrogen vs. Temperature and Pressure Through Ausimont Halar ECTFE

Material Family	**ETHYLENE-CHLOROTRIFLUOROETHYLENE COPOLYMER (ECTFE)**								
Material Supplier/Grade	**AUSIMONT HALAR**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.02								
TEST CONDITIONS									
Penetrant	nitrogen								
Temperature (°C)	11	25	71	10	25	72	10	25	68
Pressure Gradient (kPa)	1724	1724	1724	3447	3447	3447	6895	6895	6895
Test Method	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	5.53×10^{-12}	1.29×10^{-11}	2.43×10^{-10}	5.53×10^{-12}	1.49×10^{-11}	4.27×10^{-10}	6.09×10^{-12}	1.43×10^{-11}	2.48×10^{-10}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.48	1.13	21.3	0.48	1.3	37.4	0.53	1.25	21.7

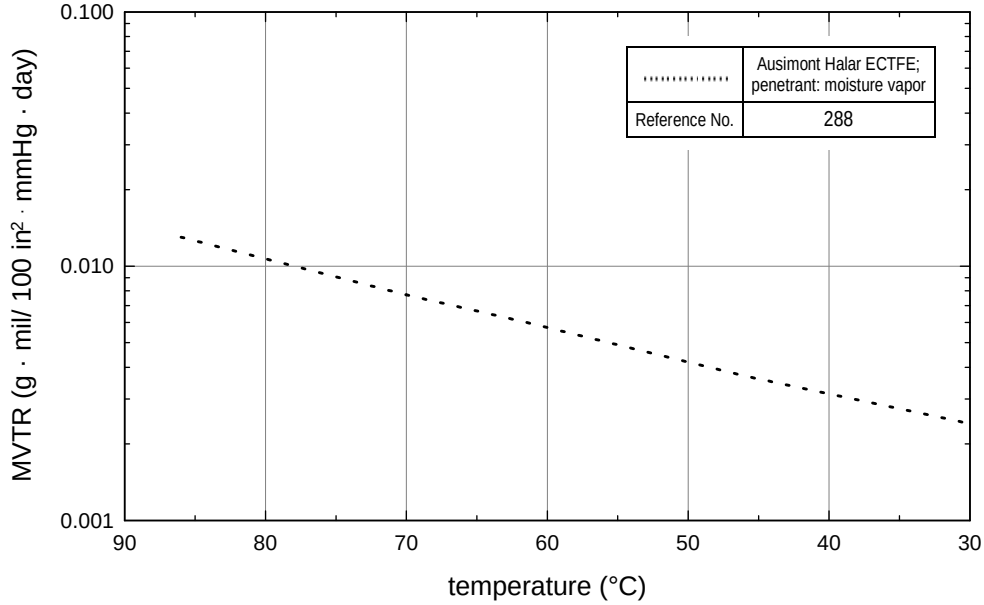
Table 5-03. Oxygen and Ammonia Through Ausimont Halar ECTFE

Material Family	**ETHYLENE-CHLOROTRIFLUOROETHYLENE COPOLYMER (ECTFE)**								
Material Supplier/Grade	**AUSIMONT HALAR**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.02								
TEST CONDITIONS									
Penetrant	ammonia			oxygen					
Temperature (°C)	-1	25	65	-18	25	55	-15	25	56
Pressure Gradient (kPa)	965			1724			3447		
Test Method	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	3.73×10^{-10}	1.29×10^{-9}	7.05×10^{-9}	5.52×10^{-12}	1.16×10^{-10}	5.16×10^{-10}	5.73×10^{-12}	1.1×10^{-10}	5.26×10^{-10}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	32.6	113	617	0.48	10.2	45.2	0.5	9.6	46.0

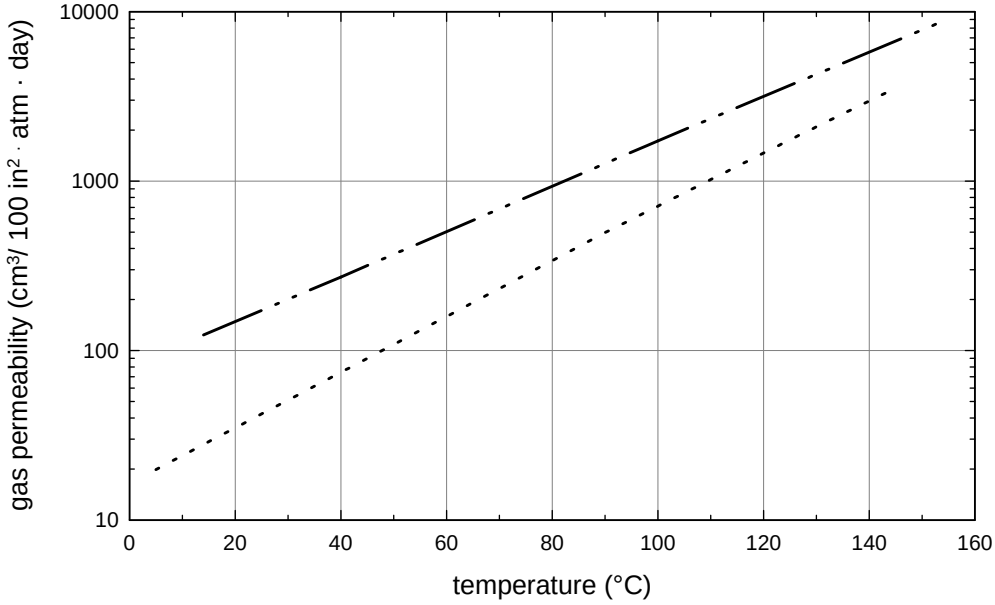
Graph 5-01. Moisture vapor vs. thickness Tthrough Ausimont Halar ECTFE.



Graph 5-02. Moisture vapor vs. temperature through Ausimont Halar ECTFE.

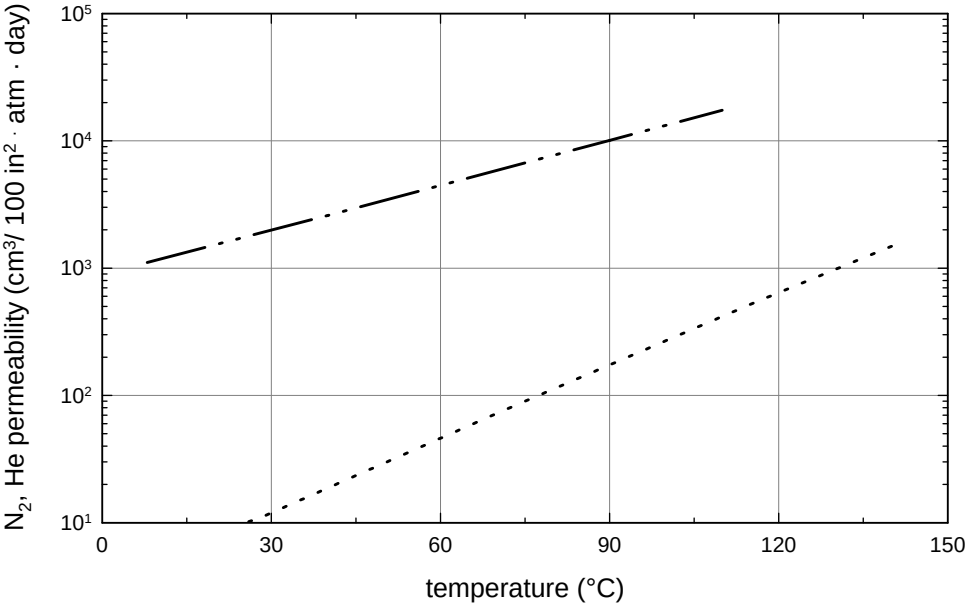


Graph 5-03. Carbon dioxide and oxygen through Ausimont Halar ECTFE.



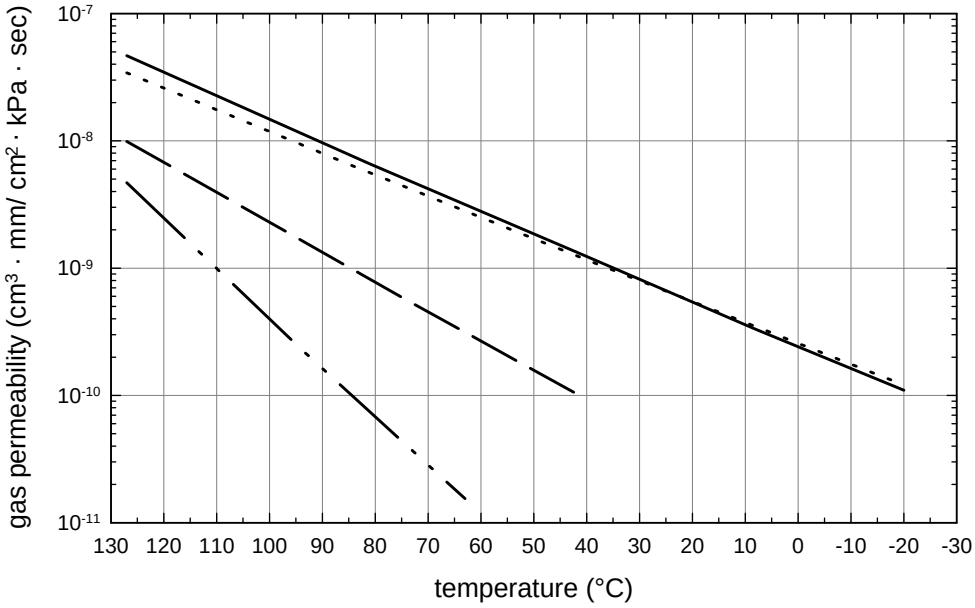
·····	Ausimont Halar ECTFE (0.058 mm thick; film); penetrant: O_2
—·—·—	Ausimont Halar ECTFE (0.058 mm thick; film); penetrant: CO_2
Reference No.	288

Graph 5-04. Nitrogen and helium vs. temperature through Ausimont Halar ECTFE.



·····	Ausimont Halar ECTFE (0.058 mm thick; film); penetrant: N_2
—·—·—	Ausimont Halar ECTFE (0.058 mm thick; film); penetrant: He
Reference No.	288

Graph 5-05. Various gases vs. temperature through Ausimont Halar ECTFE.



.....	Ausimont Halar ECTFE (0.02 mm thick); penetrant: H_2
—·—·—	Ausimont Halar ECTFE (0.02 mm thick); penetrant: N_2
– – –	Ausimont Halar ECTFE (0.02 mm thick); penetrant: O_2
———	Ausimont Halar ECTFE (0.02 mm thick); penetrant: NH_3
Reference No.	306

Ethylene-Tetrafluoroethylene Copolymer (ETFE)

Category: Fluoropolymer

General Description: ETFE is a related copolymer to ECTFE, consisting of ethylene and tetrafluoroethylene. DuPont Tefzel resins are modified ETFE (ethylene-tetrafluoroethylene) fluoropolymer available as pellets or as powder for rotational molding. Tefzel combines superior mechanical toughness with an outstanding chemical inertness.[2008]

DuPont T^2 Films of Tefzel ETFE represent a family of patented, uniaxially oriented fluoropolymer films possessing a unique combination of properties. In addition to the benefits of fluoropolymer film, including high temperature capability and chemical resistance, these films have added strength and toughness. Chemical and moisture barrier properties are improved by orientation. ETFE films have unusually high strength. T^2 films are uniaxially oriented in the machine direction.[2007]

Processing Methods: Tefzel, as a thermoplastic polymer, can be processed by injection molding, compression molding, rotational molding, and extrusion. Tefzel film can be heat-sealed, thermoformed, welded, heat-laminated, and coated. Films are uniaxially oriented in the machine direction (tensiled) and heat-toughened.[2007][2008]

Applications: Pressure-sensitive tapes, flexible printed circuits, liquid pouches, and other applications demanding high flex life/crack resistance, exposure to high temperatures, and wear.

Permeability Data by Material Supplier Trade Name: See Tables 6-01 through 6-04.

Table 6-01. Carbon Dioxide, Nitrogen, Oxygen, Helium, and Water Vapor Through DuPont Tefzel

Material Family	**ETHYLENE-TETRAFLUOROETHYLENE COPOLYMER (ETFE)**				
Material Supplier/Grade	**DUPONT TEFZEL**				
Product Form	**FILM**				
Reference Number	205				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.102				
TEST CONDITIONS					
Penetrant	carbon dioxide	nitrogen	oxygen	helium	water vapor
Temperature (°C)	25				
Test Method	ASTM D1434				ASTM E96
PERMEABILITY (source document units)					
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)					1.65
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	250	30	100	900	
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	98.4	11.8	39.4	354	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					0.65

Table 6-02. Water Vapor Through DuPont Tefzel T² Film

Material Family	**ETHYLENE-TETRAFLUOROETHYLENE COPOLOYMER (ETFE)**
Material Supplier/Grade	**DUPONT TEFZEL T² FILM**
Reference Number	2007
TEST CONDITIONS	
Penetrant	water vapor
PERMEABILITY (source document units)	
Vapor Permeability ($g/m^2 \cdot d \cdot mm$)	0.3
Vapor Permeability ($g/100\ in^2 \cdot d \cdot mil$)	0.8
PERMEABILITY (normalized units)	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.3

Table 6-03. Oxygen, Carbon Dioxide, and Nitrogen Through Dyneon 6235G ETFE

Material Family	**ETHYLENE-TETRAFLUOROETHYLENE COPOLOYMER (ETFE)**								
Material Supplier/Grade	**DYNEON 6235G**								
Reference Number	1128								
TEST CONDITIONS									
Penetrant	oxygen			carbon dioxide			nitrogen		
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.1								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot 100\mu m/m^2 \cdot day \cdot bar$)	666	1550	6020	3790	5870	16100	217	580	1540
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	67	157	610	384	595	1631	22	59	156

Table 6-04. Water Vapor Through Dyneon 6235G ETFE

Material Family	**ETHYLENE-TETRAFLUOROETHYLENE COPOLOYMER (ETFE)**		
Material Supplier/Grade	**DYNEON 6235G**		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor	water vapor	water vapor
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.2		
PERMEABILITY (source document unit)			
Vapor Permeability ($g \cdot 100\mu m/m^2 \cdot day$)	1.03	3.13	26.9
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.10	0.31	2.69

Fluorinated Ethylene-Propylene Copolymer (FEP)

Category: Fluoropolymer

General Description: FEP, a melt-processible fluorocarbon, is a copolymer of TFE and hexafluoropropylene. FEP and TFE yield similar properties with the exception of TFE's lower melt viscosity.[1004]

FEP produces a transparent thermoplastic film.[2009]

Processing Methods: FEP resins are processed by conventional melt-extrusion techniques and by injection, compression, transfer, and blow-molding processes. Films may be thermoformed, vacuum formed, heat sealed, heat bonded, welded, metalized, or laminated.[2009]

Applications: Applications requiring excellent chemical resistance, superior electrical properties, and high service temperatures. Release films, tubing, cable insulation and jacketing.

Permeability: Low permeability to liquids, gases, moisture, and organic vapors.[2009]

Permeability Data by Material Supplier Trade Name: See Tables 7-01 through 7-06, and Graphs 7-01 through 7-02.

Table 7-01. Carbon Dioxide, Hydrogen, Nitrogen, and Oxygen Through DuPont Fluorocarbon FEP Film

Material Family	FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)			
Material Supplier/Grade	DUPONT FEP FLUOROCARBON FILM			
Reference Number	2009			
TEST CONDITIONS				
Penetrant	carbon dioxide	hydrogen	nitrogen	oxygen
Temperature (°C)	25			
Test Method	ASTM D1434			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025			
PERMEABILITY (source document units)				
Gas Permeability ($cm^3/m^2 \cdot 24hrs \cdot atm$)	25.9×10^3	34.1×10^3	5.0×10^3	1.6×10^3
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2$ day $\cdot$ atm)	648	853	125	40

Table 7-02. Acetic Acid, Acetone, Benzene, and Carbon Tetrachloride Through DuPont Fluorocarbon FEP Film

Material Family	**FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)**			
Material Supplier/Grade	**DUPONT FEP FLUOROCARBON FILM**			
Reference Number	2009			
TEST CONDITIONS				
Penetrant	acetic acid	acetone	benzene	carbon tetrachloride
Temperature (°C)	25			
Test Method	ASTM E96			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025			
PERMEABILITY (source document units)				
Vapor Permeability ($g/m^2 \cdot day$) ($g/100\ in^2 \cdot day$)	6.3 0.41	14.7 0.95	9.9 0.64	4.8 0.31
PERMEABILITY (normalized units)				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.158	0.368	0.248	0.12

Table 7-03. Ethyl Alcohol, Hexane, and Water Through DuPont Fluorocarbon FEP Film

Material Family	**FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)**		
Material Supplier/Grade	**DUPONT FEP FLUOROCARBON FILM**		
Reference Number	2009		
TEST CONDITIONS			
Penetrant	ethyl alcohol	hexane	water
Temperature (°C)	25		
Test Method	ASTM E 96		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.025		
PERMEABILITY (source document units)			
Vapor Permeability ($g/m^2 \cdot day$)	10.7	8.7	7.0
Vapor Permeability ($g/100\ in^2 \cdot day$)	0.69	0.56	0.4
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.268	0.218	0.175

Table 7-04. Hydrogen vs. Temperature and Pressure Through DuPont Teflon FEP Copolymer

Material Family	**FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)**								
Material Supplier/ Grade	**DUPONT TEFLON**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.05								
TEST CONDITIONS									
Penetrant	hydrogen								
Temperature (°C)	-15	25	68	-13	25	67	-16	25	67
Pressure Gradient (kPa)	1724			3447			6895		
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	9.06×10^{-10}	4.41×10^{-9}	1.87×10^{-8}	9.64×10^{-10}	4.35×10^{-9}	1.77×10^{-8}	8.77×10^{-10}	4.4×10^{-9}	1.8×10^{-8}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	79.3	386	1637	84.4	381	1550	76.8	385	1576

Table 7-05. Nitrogen vs. Temperature and Pressure Through DuPont Teflon FEP Copolymer

Material Family	**FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)**								
Material Supplier/ Grade	**DUPONT TEFLON**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.05								
TEST CONDITIONS									
Penetrant	nitrogen								
Temperature (°C)	-9	25	71	-7	25	66	-5	25	68
Pressure Gradient (kPa)	1724			3447			6895		
Test Method	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	5.06×10^{-11}	3.8×10^{-10}	3.79×10^{-9}	5.64×10^{-11}	3.86×10^{-10}	3.85×10^{-9}	6.39×10^{-11}	3.85×10^{-10}	3.8×10^{-9}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	4.4	33.3	332	4.9	33.8	337	5.6	33.7	333

Table 7-06. Oxygen and Ammonia vs. Temperature and Pressure Through DuPont Teflon FEP Copolymer

Material Family	**FLUORINATED ETHYLENE-PROPYLENE COPOLYMER (FEP)**
Material Supplier/Grade	**DUPONT TEFLON**
Reference Number	306

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

TEST CONDITIONS

Penetrant	ammonia			oxygen					
Temperature (°C)	0	25	66	-16	25	52	-16	25	53
Pressure Gradient (kPa)	965			1724			3447		
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

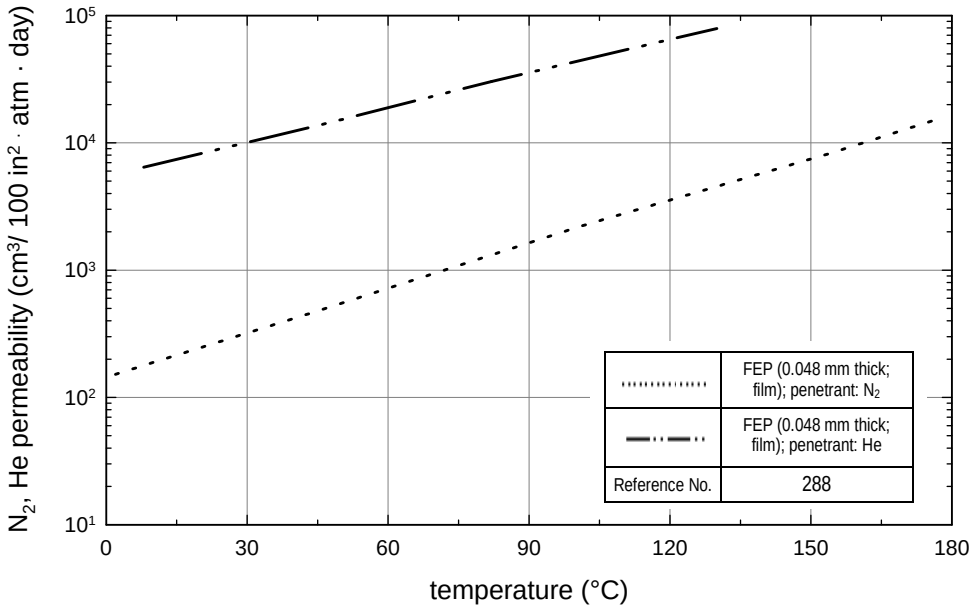
PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	3.31×10^{-10}	1.15×10^{-9}	6.3×10^{-9}	1.04×10^{-10}	1.33×10^{-9}	5.16×10^{-9}	1.03×10^{-10}	1.15×10^{-9}	5.31×10^{-9}

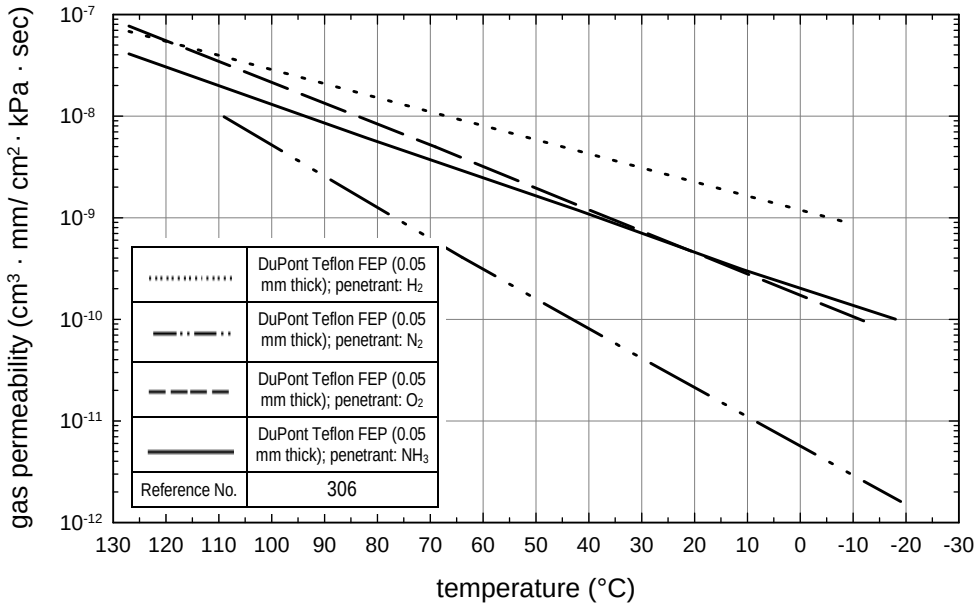
PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	29.0	101	552	9.1	116	452	9.0	101	465

Graph 7-01. Nitrogen and helium vs. time after retort through FEP copolymer.



Graph 7-02. Gas vs. temperature through FEP copolymer.



Chapter 8

Perfluoroalkoxy Resin (PFA & MFA)

Category: Fluoropolymer

General Description: PFA is similar to FEP but with higher temperature resistance.[1004] Ausimont Hyflon MFA and PFA are semicrystalline fully-fluorinated melt- processible fluoropolymers. Hyflon MFA belongs to the class of PFA (perfluoroalkoxy) having a lower melting point than standard PFA grades. The unique chemistry of MFA allows for a very cost competitive product, giving improved economics whenever PFA type performance is required.[2012]

Hyflon grades are available in different physical forms including pellets and powder.

DuPont Teflon resin is available in pellet or powder.

DuPont PFA film is a transparent thermoplastic film.[2007]

Processing Methods: Powder coating, sheet lining, extruded lining, dual laminate, rotational lining, electrostatic coating and rotomolding/rotolining, and liquid dispersions for coating and impregnation.

DuPont PFA film can be heat sealed, thermoformed, vacuum formed, heat bonded, welded, metallized, laminated (combined with dozens of other materials), and used as an excellent hot-melt adhesive.[2007]

Applications: Lined and coated processing equipment, vessels and housings, high purity chemical storage and transport, down-hole components in harsh well environments.

Permeability: See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 8-01 through 8-05.

Table 8-01. Carbon Dioxide, Nitrogen, Oxygen, and Water Vapor Through DuPont Teflon PFA Film

Material Family	**PERFLUOROALKOXY (PFA)**			
Material Supplier/Grade	**DUPONT TEFLON PFA FILM**			
Reference Number	2011			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.05			
TEST CONDITIONS				
Penetrant	carbon dioxide	nitrogen	oxygen	water vapor
Temperature (°C)	25			
Test Method	ASTM D1434			ASTM E96
PERMEABILITY (source document units)				
Gas Permeability ($cm^3/m^2 \cdot 24hrs \cdot atm$)	14,000	2,000	6,700	
Vapor Permeability ($g/m^2 \cdot day$)				2
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2\ day \cdot atm$)	700	100	335	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				0.1

Table 8-02. Oxygen vs. Temperature, R22, and Chlorine Through Ausimont Hyfalon MFA 620

Material Family	**MFA**					
Material Supplier/Grade	**AUSIMONT HYFALON MFA 620**					
Reference Number	2012					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.05	0.1	0.1	0.1	0.1	0.7
TEST CONDITIONS						
Penetrant	oxygen	oxygen	oxygen	oxygen	R22	chlorine
Temperature (°C)	23	23	40	50	10	50
Test Method	Swedish Corrosion Institute					
PERMEABILITY (source document units)						
Gas Permeability ($cc \cdot mm/m^2 \cdot 24hrs \cdot atm$)	300	270	380	540	36	567
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	300	270	380	540	36	567

Table 8-03. Oxygen vs. Temperature, R22, and Chlorine Through Ausimont Hyfalon PFA 420

Material Family	**PERFLUOROALKOXY (PFA)**					
Material Supplier/Grade	**AUSIMONT HYFALON PFA 420**					
Reference Number	2012					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.05	0.1				0.7
TEST CONDITIONS						
Penetrant	oxygen				R22	chlorine
Temperature (°C)	23	40	50		10	50
Test Method	Swedish Corrosion Institute					
PERMEABILITY (source document units)						
Gas Permeability (cc · mm/m^2, 24 hrs · atm)	380	280	450	570	40	625
PERMEABILITY (normalized units)						
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	380	280	450	570	40	625

Table 8-04. Oxygen, Carbon Dioxide, and Nitrogen Through Dyneon 6510N PFA

Material Family	**PERFLUOROALKOXY (PFA)**								
Material Supplier / Grade	**DYNEON 6510N**								
Reference Number	1128								
TEST CONDITIONS									
Penetrant	oxygen			carbon dioxide			nitrogen		
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.1								
PERMEABILITY (source document units)									
Gas Permeability (cm^3 · 100µm/m^2 · day · bar)	2740	4910	15100	8650	12600	29400	792	2010	4780
PERMEABILITY (normalized units)									
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	277	497	1530	876	1276	2978	80	204	484

Table 8-05. Water Vapor Through Dyneon 6510N PFA

Material Family	PERFLUOROALKOXY (PFA)		
Material Supplier/Grade	DYNEON 6510N PFA		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.1		
PERMEABILITY (source document units)			
Vapor Permeability ($g \cdot 100\mu m/m^2 \cdot day$)	0.223	1.02	12.3
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.002	0.102	1.23

Polychlorotrifluoroethylene (PCTFE)

Category: Fluoropolymer

General Description: Aclar films are crystal clear films made from fluorinated-chlorinated resins that demonstrate excellent moisture barrier properties.[2014] Homopolymer: Aclar Rx series. Copolymers: Aclar 22A, 33C, and Cx.

Processing Methods: Through the use of conventional thermoplastic processing techniques, PCTFE can be molded as well as extruded into transparent film and sheet,[1004] laminated, heat-sealed, printed thermoformed, metallized, and sterilized.[2013]

Applications:

- *Aclar 11A.* Industrial and electronics packaging.
- *Aclar 22A, Rx 160, SupRx 900, UltRx 2000 & 3000.* Pharmaceutical packaging, and blister packages.
- *Aclar 22C.* Encapsulating film for clean room packaging and electroluminescent lamps.
- *Aclar 33C.* Military and industrial packaging as either a monolayer film or as a chemical and moisture barrier in laminate structures.
- *Aclar Cx 130E.* Moisture protection.[2014]

Permeability to Water and Other Liquids: Medium, high and ultrahigh moisture barrier properties are available ranging from 0.78 g/m^2/day to 0.08 g/m^2/day (without sample thickness these values can not be "normalized"). Aclar films have an outstanding ability to prevent the passage of water vapor and liquids providing product protection. Because of it transparency, these films permit inspection viewing of the product while protecting the product from moisture.[2013]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 9-01 through 9-04 and Graph 9-01.

Table 9-01. Water Vapor Through Honeywell Aclar PCTFE Film

Material Family	POLYCHLOROTRIFLUOROETHYLENE (PCTFE)								
Material Supplier	HONEYWELL ACLAR FILM								
Grade	11A	11A	11A	22A	22C	22C	33C	33C	Rx
Reference Number	2014								

TEST CONDITIONS

Penetrant	water vapor								
Temperature (°C)	37.8								
Relative Humidity (%)	100								
Test Method	ASTM F1249								

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.015	0.0225	0.05	0.0375	0.05	0.125	0.0187	0.195	0.0007

PERMEABILITY (source document units)

Vapor Permeability ($g/m^2 \cdot day$)							0.42	0.047	0.42
($g/100\ in^2 \cdot day$)	0.027	0.017	0.008	0.022	0.019	0.007	0.027	0.003	

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.0064	0.0060	0.0063	0.013	0.015	0.014	0.008	0.009	0.0003

Table 9-02. Water Vapor Through Honeywell Aclar PCTFE Film

Material Family	**POLYCHLOROTRIFLUOROETHYLENE (PCTFE)**		
Material Supplier	**HONEYWELL ACLAR FILM**		
Grade	**SupRx**	**UltRx 2000**	**UltRx 3000**
Reference Number	2014		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	37.8		
Relative Humidity (%)	100		
Test Method	ASTM F1249		
MATERIAL CHARACTERISTIC			
Sample Thickness (mm)	0.0225	0.05	0.075
PERMEABILITY (source document units)			
Vapor Permeability ($g/m^2 \cdot day$)	0.26	0.12	0.077
($g/100\ in^2 \cdot day$)	0.017	0.008	0.005
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.31	0.006	0.0056

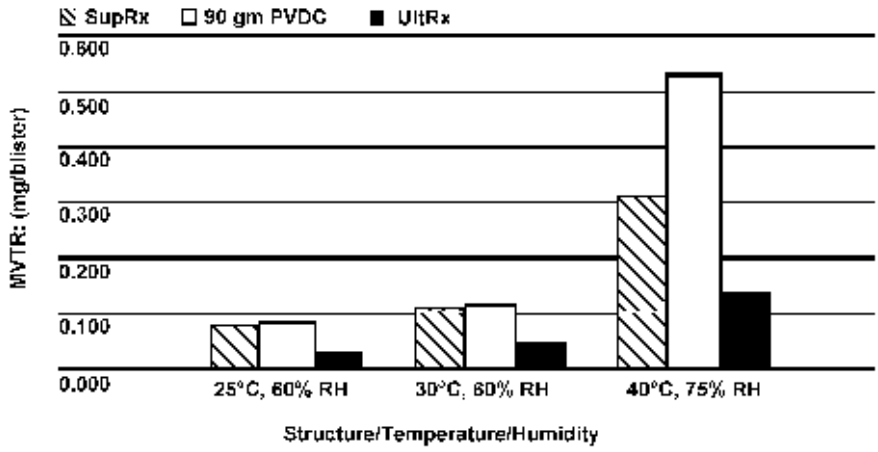
Table 9-03. Water Vapor Through Honeywell Aclar PCTFE Film

Material Family	**POLYCHLOROTRIFLUOROETHYLENE (PCTFE)**			
Material Supplier/Grade	**HONEYWELL ACLAR FIIM Cx 130E**			
Reference Number	2014			
TEST CONDITIONS				
Penetrant	water vapor			
Temperature (°C)	25	30	40	37.8
Relative Humidity (%)	60	60	75	100
Test Method	ASTM F1249			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.0325			
PERMEABILITY (source document units)				
Vapor Permeability ($g/m^2 \cdot day$)	0.078	0.155	0.51	0.78
($g/100\ in^2 \cdot day$)	0.005	0.01	0.033	0.05
PERMEABILITY (normalized units)				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.0025	0.005	0.0166	0.025

Table 9-04. Oxygen, Carbon Dioxide, and Nitrogen Through Honeywell Aclar PCTFE Film

Material Family	**POLYCHLOROTRIFLUOROETHYLENE (PCTFE)**							
Material Supplier	**HONEYWELL ACLAR**							
Grade	**33C**		**22C**			**22A**		
Product Form	FILM							
Features	transparent							
Reference Number	138							
TEST CONDITIONS								
Penetrant	oxygen	carbon dioxide	oxygen	nitrogen	carbon dioxide	oxygen	nitrogen	carbon dioxide
Temperature (°C)	25							
Test Note	STP conditions							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	7	16	15	2.5	40	12	2.5	30
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.8	6.3	5.9	1.0	15.7	4.7	1.0	11.8

Graph 9-01. Effect of temperature on high barrier structures (formed blisters).[2015]



Chapter 10

Polytetrafluoroethylene (PTFE)

Category: Fluoropolymer

General Description: PTFE is extremely heat resistant and has outstanding chemical resistance.

- *DuPont Teflon PTFE.* Granular powders and aqueous dispersions.
- *Teflon NXT.* Granular powders.[2016]

Processing Methods:

- *Teflon PTFE.* Compression molding and sintering followed by machining, ram extrusion, isostatic molding, and sintering. Surfaces are coated by applying dispersion and baking.
- *Teflon NXT.* Same as PTFE with the addition of heat welding and thermoforming.[2016]
- *Dyneon PTFE.* Compression molding, skived film.[1128]

Applications: Pipe liners, fittings, valves, pumps, and other components used for transferring aggressive, ultrapure fluids.

Permeability to Oxygen and Other Gases: Teflon NX T was developed to provide higher permeation resistance, as well as other property improvements.[2016]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 10-01 through 10-10.

Table 10-01. Hydrogen vs. Temperature and Pressure Through DuPont Teflon PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**								
Material Supplier/Grade	**DUPONT TEFLON**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.03								
TEST CONDITIONS									
Penetrant	hydrogen								
Temperature (°C)	-16	25	68	-17	25	67	-18	25	63
Pressure Gradient (kPa)	1724	1724	1724	3447	3447	3447	6895	6895	6895
Test Method	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	1.7×10^{-9}	6.34×10^{-9}	1.88×10^{-8}	1.63×10^{-9}	5.9×10^{-9}	1.86×10^{-8}	1.59×10^{-9}	5.94×10^{-9}	1.64×10^{-8}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	149	555	1646	143	516	1628	139	520	1436

Table 10-02. Nitrogen vs. Temperature and Pressure Through DuPont Teflon PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**								
Material Supplier/Grade	**DUPONT TEFLON**								
Reference Number	306								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.03								
TEST CONDITIONS									
Penetrant	nitrogen								
Temperature (°C)	-23	25	71	-25	25	70	-23	25	68
Pressure Gradient (kPa)	1724	1724	1724	3447	3447	3447	6895	6895	6895
Test Method	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	9.46×10^{-11}	7.87×10^{-10}	2.9×10^{-9}	8.89×10^{-11}	7.88×10^{-10}	2.89×10^{-9}	9.47×10^{-11}	7.84×10^{-10}	2.87×10^{-9}
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	8.3	68.9	254	7.8	69	253	8.3	68.6	251

Table 10-03. Oxygen and Ammonia vs. Temperature and Pressure Through DuPont Teflon PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**
Material Supplier/Grade	**DUPONT TEFLON**
Reference Number	306

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.03

TEST CONDITIONS

Penetrant	ammonia			oxygen					
Temperature (°C)	-3	25	63	-17	25	51	-17	25	51
Pressure Gradient (kPa)	965	965	965	1724	1724	1724	3447	3447	3447
Test Method	mass spectrometry and calibrated standard gas leaks developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	4.71×10^{-10}	1.73×10^{-9}	8.62×10^{-9}	5.27×10^{-10}	2.55×10^{-9}	5.38×10^{-9}	4.55×10^{-10}	2.54×10^{-9}	5.46×10^{-9}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	41.2	151	755	46.1	223	471	39.8	222	478

Table 10-04. Hydrogen vs. Temperature and Pressure Through Carbon Filled DuPont Teflon PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**
Material Supplier/Grade	**DUPONT TEFLON**
Reference Number	306

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

MATERIAL COMPOSITION

Note	carbon filled

TEST CONDITIONS

Penetrant	hydrogen								
Temperature (°C)	-15	25	68	-11	25	67	-14	25	65
Pressure Gradient (kPa)	1724	1724	1724	3447	3447	3447	6895	6895	6895
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	3.95×10^{-9}	1.34×10^{-8}	3.53×10^{-8}	4.51×10^{-9}	1.27×10^{-8}	3.42×10^{-8}	4.17×10^{-9}	1.23×10^{-8}	3.32×10^{-8}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	346	1173	3090	395	1112	2994	365	1077	2906

Table 10-05. Nitrogen vs. Temperature and Pressure Through Carbon Filled DuPont Teflon PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**
Material Supplier/Grade	**DUPONT TEFLON**
Reference Number	306

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

MATERIAL COMPOSITION

Note	carbon filled

TEST CONDITIONS

Penetrant	nitrogen								
Temperature (°C)	-14	25	68	-17	25	71	-17	25	67
Pressure Gradient (kPa)	1724	1724	1724	3447	3447	3447	6895	6895	6895
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	2.5×10^{-10}	1.46×10^{-9}	5.28×10^{-9}	2.34×10^{-10}	1.52×10^{-9}	5.32×10^{-9}	2.34×10^{-10}	1.42×10^{-9}	4.78×10^{-9}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	21.9	128	462	20.5	133	466	20.5	124	418

Table 10-06. Comparative Permeation Rates for Teflon NXT and Conventional PTFE[2016]

Permeant	Specimen Thickness (mm)	Vapor		Liquid		Gas	
		PTFE	**Teflon NXT**	**PTFE**	**Teflon NXT**	**PTFE**	**Teflon NXT**
Perchloroethylene	1	5.5	2	13	4	--	--
	2	1.4	0.1	0.019	0.005	--	--
	4	0.08	0.05	0.006	0	--	--
	5	0.055	0.050	--	--	--	--
Hexane	2	3.4	0.2	23.4	0	--	--
	5	0.045	0.015	--	--	--	--
MEK	2	36.3	23.3	49.4	34.2	--	--
	5	22.6	20.8	35.5	25.2	--	--
HCl (20%)	1	0.4	0.1	--	--	--	--
Helium	2	--	--	--	--	93	1
	5	--	--	--	--	0.18	0.12

The above information is intentionally published by DuPont without units. For more information contact DuPont.

Table 10-07. Oxygen, Carbon Dioxide, and Nitrogen Through Dyneon TFM 1700 PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**								
Material Supplier/Grade	**DYNEON TFM 1700**								
Reference Number	1128								
TEST CONDITIONS									
Penetrant	oxygen	oxygen	oxygen	carbon dioxide	carbon dioxide	carbon dioxide	nitrogen	nitrogen	nitrogen
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.2								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot 200um/m^2 \cdot day \cdot bar$)	879	1557	3550	2405	3653	6698	316	637	1676
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	178	316	720	487	740	1358	64	129	340

Table 10-08. Water Vapor Through Dyneon TFM 1700 PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**		
Material Supplier/Grade	**DYNEON TFM 1700**		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTIC			
Sample Thickness (mm)	0.2		
PERMEABILITY (source document units)			
Vapor Permeability ($g \cdot \mu m/m^2 \cdot day$)	0.090	0.348	4.827
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.0045	0.0174	0.241

Table 10-09. Oxygen, Carbon Dioxide, and Nitrogen Through Dyneon TF 1750 PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**								
Material Supplier/Grade	**DYNEON TF 1750**								
Reference Number	1128								
TEST CONDITIONS									
Penetrant	oxygen			carbon dioxide			nitrogen		
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.2								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot 200\ \mu m/m^2 \cdot day \cdot bar$)	1259	2054	4685	3551	4982	8490	437	814	2086
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	255	416	849	720	1010	1721	89	165	423

Table 10-10. Water Vapor Through Dyneon TF 1750 PTFE

Material Family	**POLYTETRAFLUOROETHYLENE (PTFE)**		
Material Supplier/Grade	**DYNEON TF 1750**		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.2		
PERMEABILITY (source document units)			
Vapor Permeability ($g \cdot 200\mu m/m^2 \cdot day$)	0.085	0.435	6.01
Permeability (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.0425	0.022	0.30

Chapter 11

Polyvinyl Fluoride (PVF)

Category: Fluoropolymer

General Description: PVF is available only in film form. DuPont Tedlar films are available in clear, translucent, or opaque white film and in several surface finishes.[2017]

Applications: Release films for epoxies, phenolics, polyesters and rubber compounds. Printed circuit boards, molded parts, resin overflow containment, resurfacing of rubber laminating and printing rolls.[2017]

Permeability Data by Material Supplier Trade Name: See Table 11-01.

Table 11-01. Water Vapor, Nitrogen, and Carbon Dioxide Through PVF

Material Family	POLYVINYL FLUORIDE (PVF)			
Reference Number	138			
TEST CONDITIONS				
Penetrant	water vapor	oxygen	nitrogen	carbon dioxide
Temperature (°C)	37.8	25	25	25
Relative Humidity (%)	90			
Test Note		STP conditions		
PERMEABILITY (source document units)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		3.0	0.25	11
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		1.2	0.10	4.3
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	3.24			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	1.3			
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		1.2	0.1	4.3
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.3			

Chapter 12

Polyvinylidene Fluoride (PVDF)

Category: Fluoropolymer

General Description: PVDF is a semicrystalline, engineering polymer containing fluorine. Some grades are melt processible. Atofina Kynar is available as granules or powder.[1130] Solvay Solef offers homopolymers with high crystallinity and copolymers with high flexibility.[1131] Ausimont Hylar MP series are homopolymers, having high crystallinity, and Hylar FX and FX H are copolymers.[1132]

Processing Methods: Extrusion, compression molding, injection molding.

Applications: Coatings, piping for ultrahigh purity water and hot concentrated acids, high purity pharmaceutical grade chemicals, pumps, tubing, and automotive fuel systems.

Permeability: The crystalline content of Kynar provides it with low permeability to gases and fluids.[1130] Solef has average permeability to small molecules such as carbon dioxide, nitrogen, oxygen, water, and nitrous oxide.[1133]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 12-01 through 12-06, and Graphs 12-01 through 12-08.

Table 12-01. Oxygen, Nitrogen, Helium, Carbon Dioxide, Air, and Water Vapor Through Atofina Kynar PVDF

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**					
Material Supplier/Grade	**ATOFINA KYNAR**					
Reference number	1134					
TEST CONDITIONS						
Penetrant	oxygen	nitrogen	helium	carbon dioxide	air	water vapor
Temperature (°C)	23					
Test Method	ASTM D1434				DIN 53122	
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.1					
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	20	30	600	100	7	
Vapor Permeability ($g/m^2 \cdot day \cdot bar$)						2
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.96	2.94	58.8	9.8	0.69	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)						0.196

Table 12-02. Ammonia, Helium, Chlorine, and Hydrogen Through Solvay Solef PVDF Film

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**			
Material Supplier/Grade	**SOLVAY SOLEF**			
Product Form	**FILM**			
Manufacturing Method	cast film			
Reference Number	125			

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.1

TEST CONDITIONS

Penetrant	ammonia	helium	chlorine	hydrogen
Temperature (°C)	23			
Test Method	ASTM D1434			

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot N / m^2 \cdot day \cdot bar$)	65	850	12	210

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	6.6	86	1.2	21.3

Table 12-03. Carbon Dioxide, Nitrogen, Oxygen, and Water Vapor Through Solvay Solef 1008 PVDF Film

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**
Material Supplier/Grade	**SOLVAY SOLEF 1008**
Product Form	**FILM**
Features	translucent
Reference Number	125

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.1

TEST CONDITIONS

Penetrant	carbon dioxide	nitrogen	oxygen	water vapor
Temperature (°C)	23			38
Test Method	ASTM D1434			ASTM E96, proc. E

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)				7.5
Gas Permeability ($cm^3 \cdot N/ m^2 \cdot day \cdot bar$)	70	30	21	

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	7.09	3.04	2.13	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				0.75

Table 12-04. Freon, Nitrous Oxide, Hydrogen Sulfide, and Sulfur Dioxide Through Solvay Solef PVDF Film

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**
Material Supplier/Grade	**SOLVAY SOLEF**
Product Form	**FILM**
Manufacturing Method	cast film
Reference Number	125

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.025

TEST CONDITIONS

Penetrant	Freon 12	Freon 114	Freon 115	Freon 318	nitrous oxide	hydrogen sulfide	sulfur dioxide
Temperature (°C)	23						
Test Method	ASTM D1434						

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot N / m^2 \cdot day \cdot bar$)	6.3	10	4	7	900	60	60

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm / m^2 \cdot day \cdot atm$)	0.16	0.25	0.1	0.18	22.8	1.52	1.52

Table 12-05. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through PVDF

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**
Reference Number	138

TEST CONDITIONS

Penetrant	water vapor	oxygen	nitrogen	carbon dioxide
Temperature (°C)	23	25		
Relative Humidity (%)	90			
Test Note		STP conditions		

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		1.4	9	5.5
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.55	3.5	2.2
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	2.6			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	1.0			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.55	3.5	2.2
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.0			

Table 12-06. Water Vapor, Oxygen, and Carbon Dioxide Through Atochem Foraflon PVDF Film

Material Family	**POLYVINYLIDENE FLUORIDE (PVDF)**				
Material Supplier/Grade	**ATOCHEM FORAFLON**				
Product Form	**EXTRUDED FILM**				
Reference Number	89				

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.02	0.028	0.04	0.037	0.034

TEST CONDITIONS

Penetrant	water vapor		oxygen	carbon dioxide
Temperature (°C)	38		30	
Test Method	NFH 00044		ISO 2556	

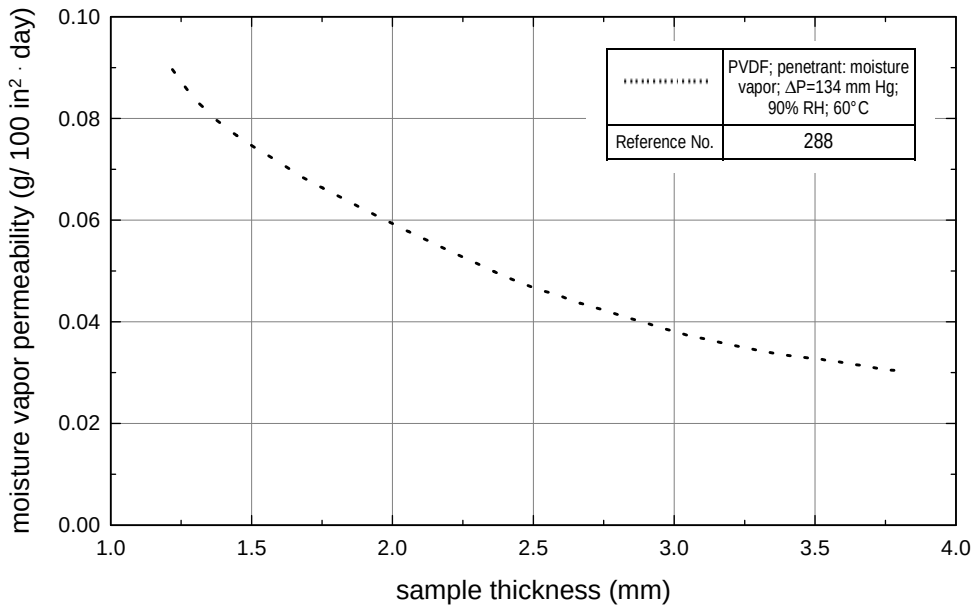
PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)	34	22	16		
Gas Permeability ($cm^3/m^2 \cdot day$)				140	890

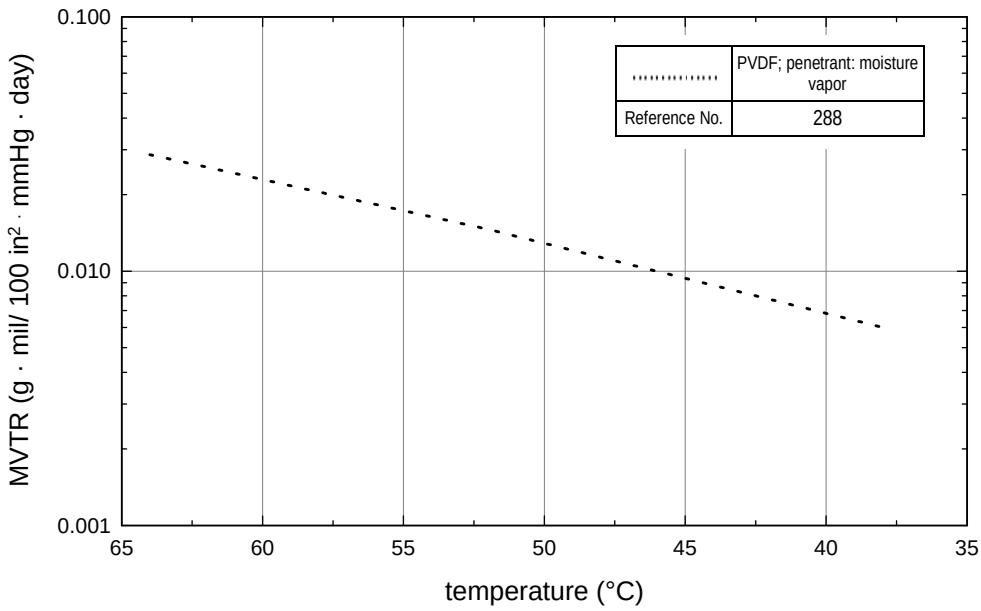
PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)				5.18	30.26
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.68	0.62	0.64		

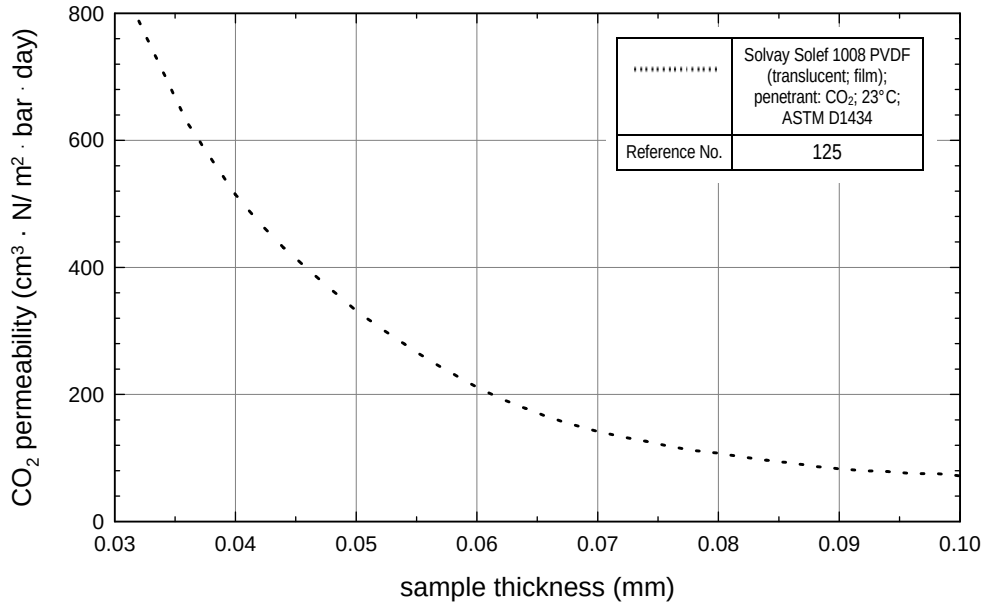
Graph 12-01. Moisture vapor vs. thickness through PVDF.



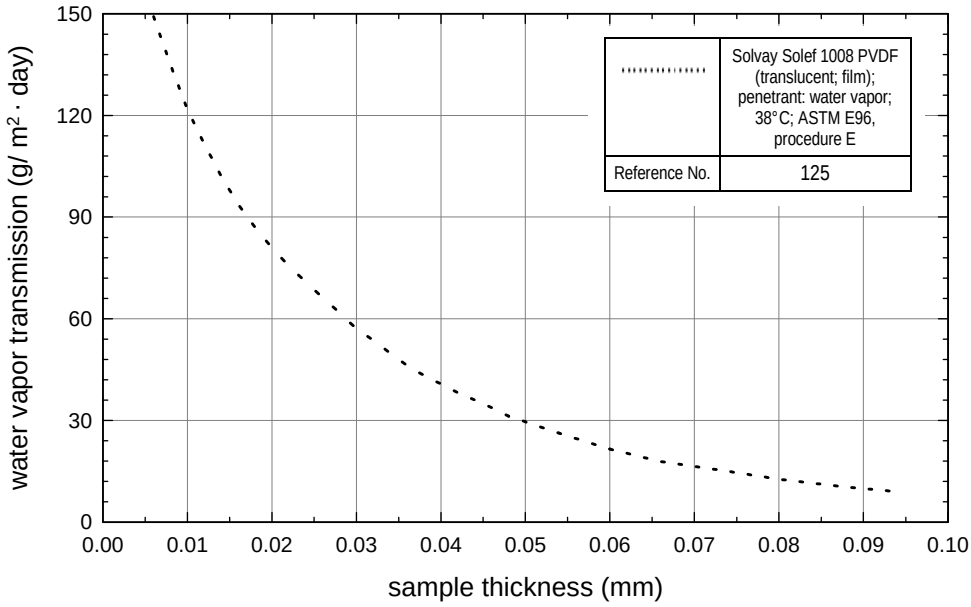
Graph 12-02. Moisture vapor vs. temperature through PVDF.



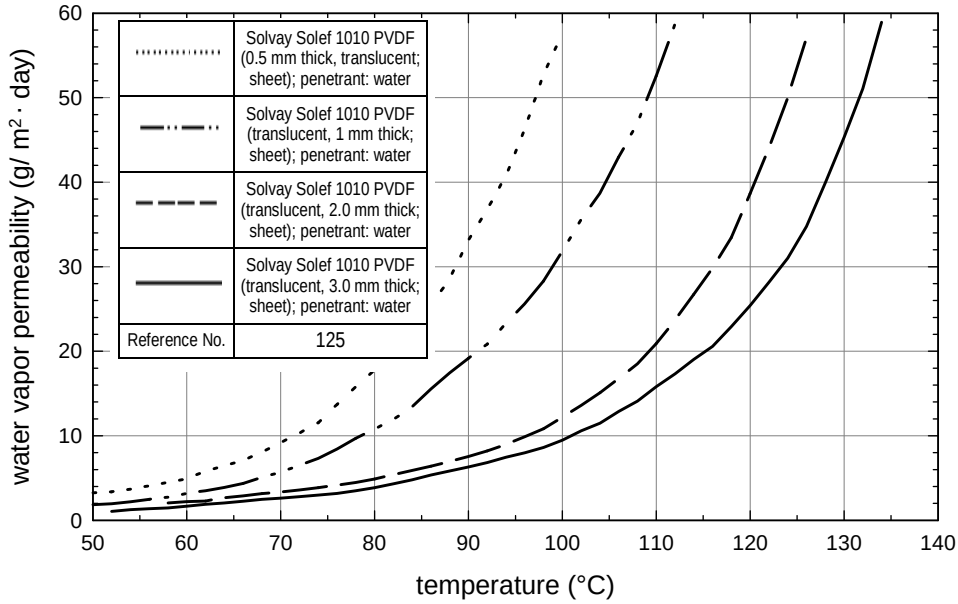
Graph 12-03. Carbon dioxide vs. thickness through PVDF.



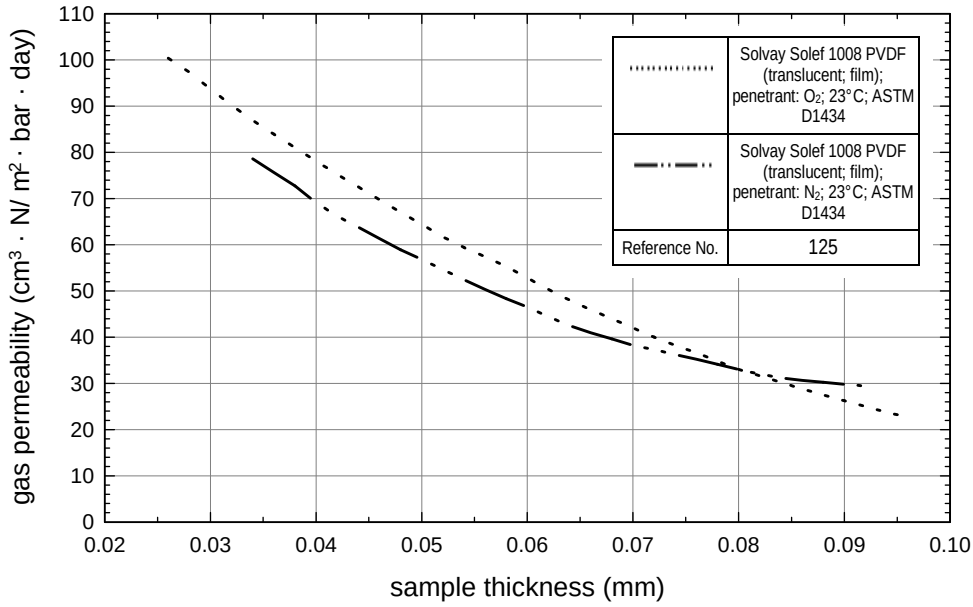
Graph 12-04. Water vapor vs. thickness through PVDF.



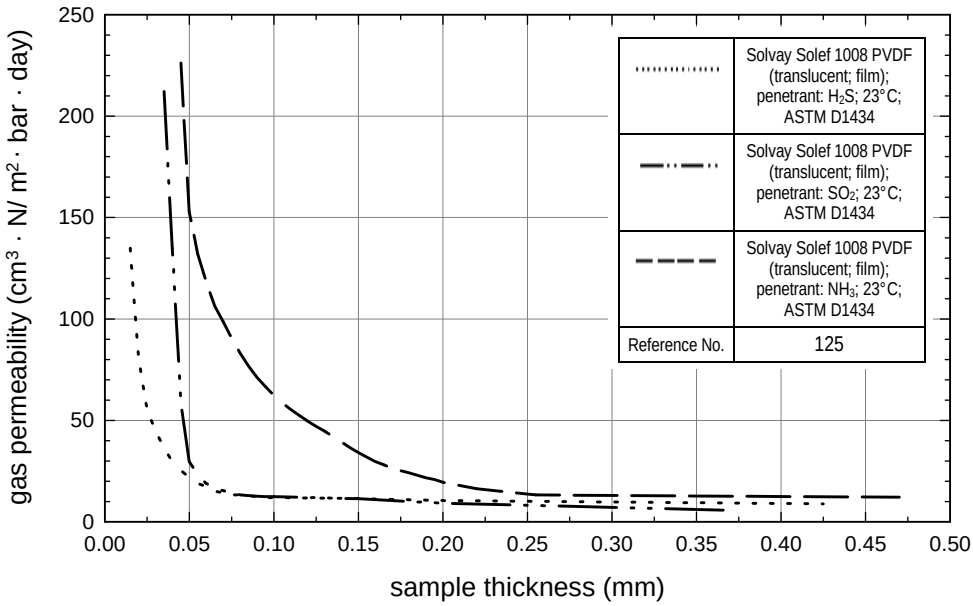
Graph 12-05. Water vapor vs. temperature through PVDF.



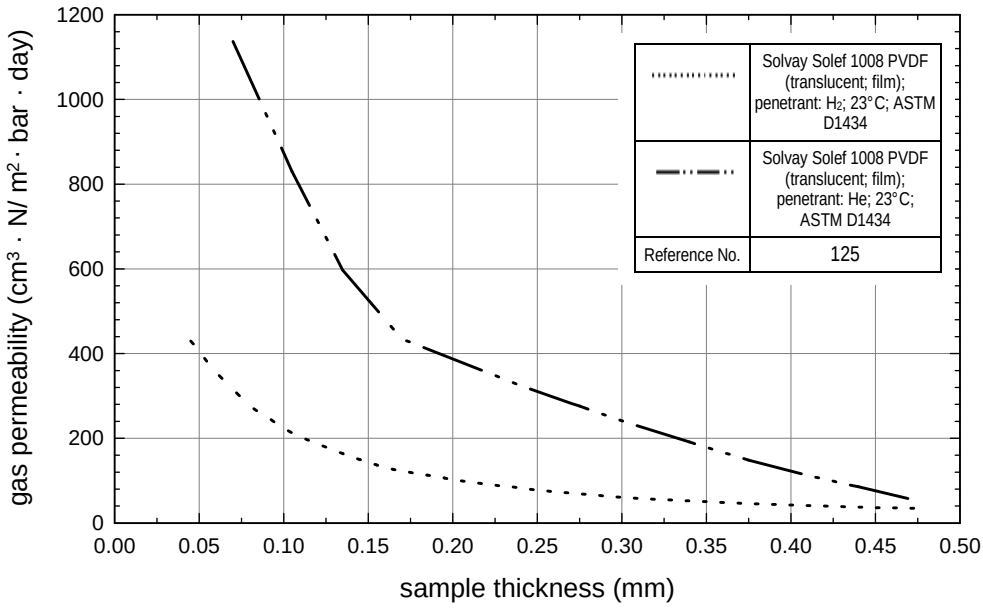
Graph 12-06. Nitrogen and oxygen vs. thickness through PVDF.



Graph 12-07. Gas permeability vs. thickness through PVDF.



Graph 12-08. Helium and hydrogen vs. thickness through PVDF.



Hexafluoropropylene, Tetrafluoroethylene, Ethylene (HTE)

Category: Fluoropolymer

General Description: HTE is a terpolymer of hexafluoropropylene, tetrafluoroethylene, and ethylene.[1128]

Processing Methods: Extrusion, co-extrusion, injection molding, blow molding, film laminating and coating.

Applications: Pipe, tube, film, sheet, tank lining.

Permeability Data by Material Supplier Trade Name: See Tables 13-01 through 13-02.

Table 13-01. Oxygen, Carbon Dioxide, and Nitrogen Through Dyneon 1700 HTE

Material Family	HEXAFLUOROPROPYLENE, TETRAFLUOROETHYLENE, ETHYLENE (HTE)								
Material Supplier/Grade	DYNEON 1700								
Reference Number	1128								
TEST CONDITIONS									
Penetrant	oxygen			carbon dioxide			nitrogen		
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.1								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot 100\ \mu m/m^2 \cdot day \cdot bar$)	801	1540	6990	4270	7400	35900	194	453	2920
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	81	156	708	433	750	3637	20	46	296

Table 13-02. Water Vapor Through Dyneon 1700 HTE

Material Family	**HEXAFLUOROPROPYLENE, TETRAFLUOROETHYLENE, ETHYLENE (HTE)**		
Material Supplier/Grade	**DYNEON 1700**		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.2		
PERMEABILITY (source document units)			
Vapor Permeability ($g \cdot 100\mu m/m^2 \cdot day$)	1.17	2.56	36.8
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.117	0.256	3.68

Tetrafluoroethylene, Hexafluoropropylene, Vinylidene Fluoride Terpolymer (THV)

Category: Fluoropolymer

General Description: Dyneon THV is a polymer of tetrafluoroethylene, hexafluoropropylene, and vinylidene fluoride. Advantages include low processing temperature, ability to bond to elastomers and hydrocarbon-based plastics, flexibility, and optical clarity. These combined advantages create new opportunities to make multilayer hoses, tubing, film, sheet, seals, and containers.

Processing Methods: Extrusion, co-extrusion, injection molding, blow molding, film laminating and coating.

Applications: Multilayer hoses, tubing, film, sheet, seals, and containers. These products are used in a variety of markets and applications such as automotive (low-permeation fuel systems), chemical processing industry, semiconductor, solar energy, polymer optical fiber and architectural and protective coatings.[1128]

Permeability Data by Material Supplier Trade Name: See Tables 14-01 through 14-02.

Table 14-01. Oxygen, Carbon Dioxide and Nitrogen Through Dyneon 500 THV

Material Family	TETRAFLUOROETHYLENE, HEXAFLUOROPROPYLENE, VINYLIDENE FLUORIDE TERPOLYMER (THV)								
Material Supplier/Grade	DYNEON 500								
Reference	1128								
TEST CONDITIONS									
Penetrant	oxygen			carbon dioxide			nitrogen		
Temperature (°C)	20	40	80	20	40	80	20	40	80
Test Method	DIN 53380 Part 4.1.2								
MATERIAL CHARACTERISTICS									
Sample Thickness (mm)	0.1								
PERMEABILITY (source document units)									
Gas Permeability ($cm^3 \cdot 100\ \mu m/m^2 \cdot day \cdot bar$)	696	1930	13100	2060	5680	29800	217	675	5280
PERMEABILITY (normalized units)									
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	71	196	1327	209	575	3019	22	68	535

Table 14-02. Water Vapor Through Dyneon 500 THV

Material Family	**TETRAFLUOROETHYLENE, HEXAFLUOROPROPYLENE, VINYLIDENE FLUORIDE TERPOLYMER (THV)**		
Material Supplier/Grade	**DYNEON 500**		
Reference Number	1128		
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	20	40	80
Test Method	DIN 53122 Part 2		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.1		
PERMEABILITY (source document units)			
Vapor Permeability ($g \cdot 100\ \mu m/m^2 \cdot day$)	1.73	7.38	137
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.173	0.738	13.7

Chapter 15

Ionomer

Category: Ethylene Acid Copolymer

General Description: DuPont Surlyn ionomer resins are crystal clear and are used alone or in combination with other resins.

Processing Methods: Injection molding, extrusion, foaming, thermoformed or used as powder-coating or resin modifier.

Applications: Packaging films and sealants, glass coatings, and abrasion resistant surfaces.

Permeability: Although Surlyn resins do not possess high gas barrier properties, they can improve the barrier properties of structures containing foil or PVDC. In structures of paper/PVDC/Surlyn, the ionomer reduces the number of pinholes in the extremely thin foil used in flexible packaging. In the case of foil structures, Surlyn again reduces the number of pinholes which appear in the brittle PVDC layer when flexed.[279]

Surlyn also improves the barrier of flexible structures against aggressive products and chemicals such as alcohols, sauces, toothpaste, grease, and fruit juices. Each aggressive product should be tested individually at normal exposure conditions. For example, a very aggressive chili pepper/oil mixture could not be packaged in a composite of foil/Surlyn but instead contained in a co-extrusion of nylon/Surlyn.[279]

Surlyn improves the barrier performance of a companion thin PVDC layer by providing the same flex protection as with foil and by improving forming in vacuum packaging systems. For processed meat and natural cheese, a forming web of nylon/Surlyn is generally sufficient and replaces nylon/PE.[279]

Permeability Data by Material Supplier Trade Name: See Tables 15-01 through 15-03.

Table 15-01. Oxygen Through DuPont Surlyn Zinc Ion Type Ionomer Film

Material Family	IONOMER						
Material Supplier/Trade Name	DUPONT SURLYN						
Grade	**1650**	**1652**	**1702**	**1705**	**F1706**	**F1801**	**F1855**
Manufacturing Method	blown film						
Reference Number	280						
MATERIAL CHARACTERISTICS							
Density (g/cm^3)	0.950	0.94	0.94	0.950	0.960	0.960	0.960
Melt Flow Index (g/10 min)	1.6	5.0	14.0	5.5	0.7	1.0	1.0
Sample Thickness (mm)	0.051						
Ion Type	zinc						
TEST CONDITIONS							
Penetrant	oxygen						
PERMEABILITY (source document units)							
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	220	180	175	170	185	215	295
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	174	142	138	134	146	170	233

Table 15-02. Water Vapor and Oxygen Through DuPont Surlyn Sodium Ion Type Ionomer Film

Material Family	IONOMER									
Material Supplier/Trade Name	DUPONT SURLYN									
Grade	**1601**	**1603**	**F1605**	**1707**	**F1856**	**1601**	**1603**	**F1605**	**1707**	**F1856**
Manufacturing Method	blown film									
Reference Number	280									
MATERIAL CHARACTERISTICS										
Density (g/cm^3)	0.94	0.94	0.950	0.950	0.950	0.94	0.94	0.950	0.950	0.950
Melt Flow Index (g/10 min)	1.3	1.7	2.8	0.9	1.0	1.3	1.7	2.8	0.9	1.0
Sample Thickness (mm)	0.051									
MATERIAL COMPOSITION										
Ion Type	sodium									
TEST CONDITIONS										
Penetrant	water vapor					oxygen				
PERMEABILITY (source document units)										
Vapor Transmission Rate (g/day · 100 in^2)	0.8	0.65	0.8	0.8	1.2					
Gas Permeability (cm^3/100 in^2 · day · atm)						265	190	200	165	290
PERMEABILITY (normalized units)										
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)						209	150	158	130	229
Vapor Transmission Rate (g · mm/m^2 · day)	0.63	0.51	0.63	0.63	0.95					

Table 15-03. Water Vapor Through DuPont Surlyn Zinc Ion Type Ionomer Film

Material Family	IONOMER						
Material Supplier/ Trade Name	DUPONT SURLYN						
Grade	**1650**	**1652**	**1702**	**1705**	**F1706**	**F1801**	**F1855**
Manufacturing Method	blown film						
Reference Number	280						
MATERIAL CHARACTERISTICS							
Density (g/cm^3)	0.950	0.94	0.94	0.950	0.960	0.960	0.960
Melt Flow Index (g/10 min)	1.6	5.0	14.0	5.5	0.7	1.0	1.0
Sample Thickness (mm)	0.051						
MATERIAL COMPOSITION							
Ion Type	zinc						
TEST CONDITIONS							
Penetrant	water vapor						
PERMEABILITY (source document units)							
Vapor Transmission Rate (g/day · 100 in^2)	0.75	0.6	0.7	0.7	0.7	0.7	1.0
PERMEABILITY (normalized units)							
Vapor Transmission Rate (g · mm/m^2 · day)	0.59	0.47	0.55	0.55	0.55	0.55	0.79