High Performance Films

DuPont FEP

fluorocarbon film

Teflon® as Film

DuPont FEP fluorocarbon film offers the outstanding properties of Teflon® in a convenient, easy-to-use form. It can be heat-sealed, thermoformed, welded, metallized, and laminated to many other materials or serve as a hot melt adhesive.

This combination of unique properties and easy-to-use form offers design and fabrication opportunities for a wide variety of end uses.

FEP Is Unique Among Plastics

- Most chemically inert of all plastics
- Withstands both high- and low-temperature extremes
- Superior antistick/low friction properties
- Outstanding weather resistance
- Excellent optical characteristics
- Superior electrical properties
- Free of plasticizers or additives
- Excellent processibility with conventional thermoplastic methods

DuPont FEP Film Is Offered

- In thicknesses from 12.5–4750 µm (0.5–190 mil)
- In custom slit widths up to 1.2–1.6 m (46–63 in) depending on thickness
- In various size rolls wound on 7.6 cm or 15.2 cm (3 in or 6 in) cores

DuPont FEP film affords the engineer/designer a wide range of opportunities to take advantage of these properties with minimal and convenient fabrication techniques.

The ability of DuPont FEP film to be easily cut, thermoformed, heat sealed, and welded permits ready application as diaphragms, gaskets, protective linings, or thermoformed pouches or containers, wherever high temperature and/or chemical resistance is required.

The excellent optical properties and resistance to weathering and ultraviolet degradation have led to the use of DuPont FEP film in such varied applications as environmental growth chambers, solar energy collectors, and radome windows.

Its superior dielectric properties have been used in flexible, flat cable insulation, printed circuits, and electronic components for computers and aircraft.

The nonstick properties of DuPont FEP film have found use in conveyor belts, process roll covers, and as mold release films.

Special grades of DuPont FEP film offer specific properties such as cementability or high stress crack resistance under extreme environmental conditions.

A complete listing of FEP film grades and their availability in different thicknesses is given in **Table 1**.

In addition to FEP, DuPont offers films of PFA, for use at temperatures up to 260°C (500°F), and Tefzel® fluoropolymer for increased toughness and resistance to tear propagation.

DuPont FEP film offers unique properties in a convenient form requiring minimal fabrication. Consider it for your next project.

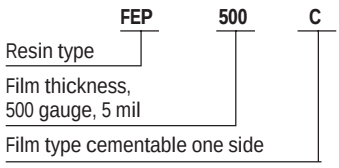
For additional information, call (800) 237-4357.

Types and Gauges

Table 1
Types and Gauges of DuPont FEP Fluorocarbon Film

Gauge	50	100	200	300	500	750	1000	1500	2000	3000	6000	9000	12500	19000
Thickness, mil	0.5	1	2	3	5	7.5	10	15	20	30	60	90	125	190
Thickness, µm	12.5	25	50	75	125	190	250	375	500	750	1500	2300	3125	4750
Approximate area factor, ft^2/lb	180	90	45	30	18	12	9	6.0	4.5	3	1.5	1	0.72	0.47
Approximate area factor, m^2/kg	36	18	9	6	4	2.5	2	1.2	1	0.6	0.3	0.2	0.14	0.09
Availability														
Type A—FEP, general-purpose	X	X	X	X	X	X	X	—	X	—	—	—	—	—
Type C—FEP, one side cementable	X	X	X	X	X	—	—	—	—	—	—	—	—	—
Type C-20—FEP, both sides cementable	X	X	X	—	X	—	—	—	—	—	—	—	—	—
Type L—FEP, high stress crack resistance in extreme environments	—	—	—	—	X	—	X	X	X	X	X	X	X	X

Note: Each roll of DuPont film is clearly identified as to resin type, film thickness, and film type.



Mechanical and Thermal Properties

DuPont FEP films perform well over a wide range of temperatures. DuPont FEP film has a continuous service temperature range from –240 to 205°C (–400 to 400°F), and it can be used in intermittent service at temperatures as high as 260°C (500°F). See **Tables 2** and **3**.

Tensile Properties

Figures 1–3 show how tensile properties of DuPont FEP film vary with temperature. FEP films retain useful mechanical properties over a wide range from cryogenic to high temperatures.

Dimensional Stability

There are three components to the property of dimensional stability—hygroscopic expansion, residual shrinkage, and thermal expansion.

Hygroscopic Expansion

Because the moisture absorption of DuPont FEP fluorocarbon film is less than 0.01% when totally immersed in water, changes in relative humidity have little effect on the film.

Figure 1. Tensile Stress vs. Elongation of DuPont FEP Film

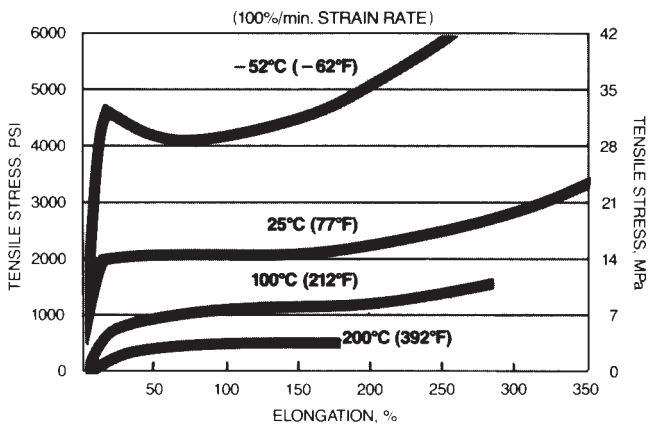


Figure 2. Tensile Properties of DuPont FEP Film vs. Temperature

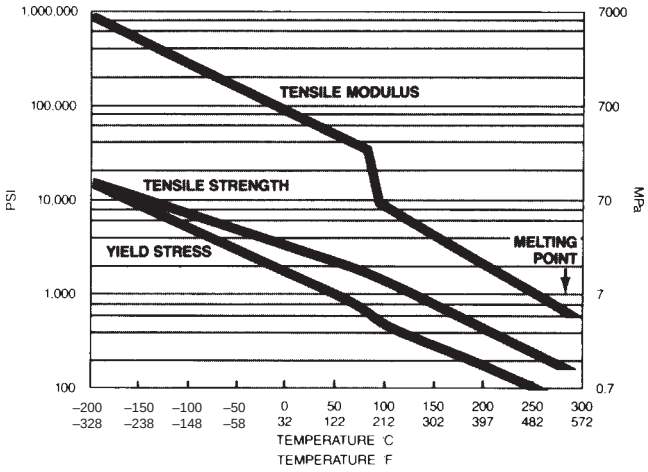
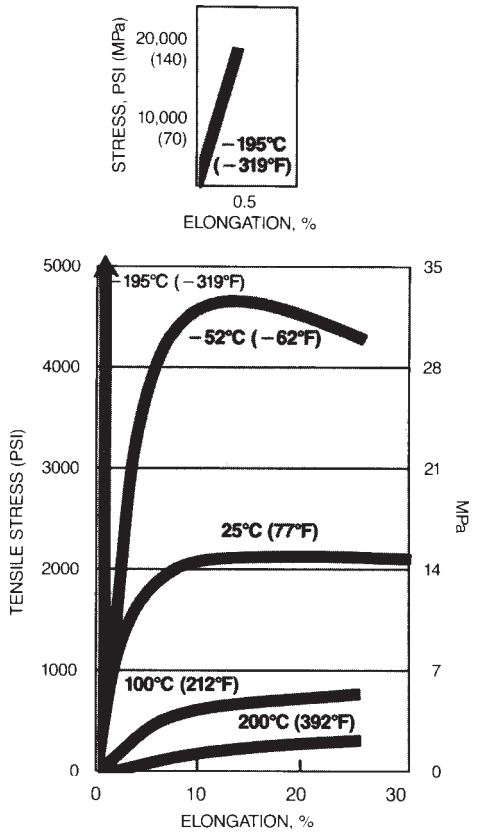


Figure 3. Tensile Stress vs. Elongation of DuPont FEP Film



Residual Shrinkage

Stresses set up in the film during manufacturing or converting can cause shrinkage in unrestrained film when exposed to high temperatures.

Exposure of film to an elevated temperature, and the attendant shrinkage, will relieve this stress, and no further shrinkage will occur at lower temperatures.

Thermal Expansion

After residual shrinkage has been removed, DuPont FEP film will expand and contract according to its normal coefficient of thermal expansion (see **Figures 4** and **5**). Note that this coefficient increases with temperature.

Figure 4. Shrinkage of DuPont FEP 100A Film vs. Temperature

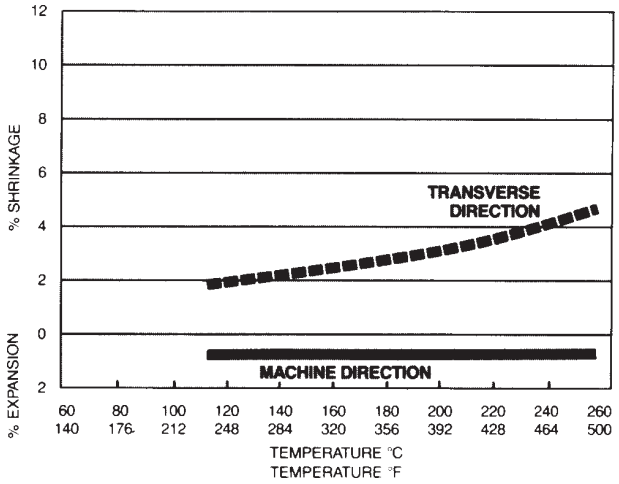


Table 2
Typical Mechanical Properties of DuPont FEP Film*

Property	ASTM Method	SI Units	English Units
Tensile strength (at break)	D-882-81	21 MPa	3000 psi
Elongation at break	D-882-81	300%	300%
Elastic modulus	D-882-81	480 MPa	70 000 psi
Yield point	D-882-81	12 MPa	1700 psi
Stress to produce 5% strain	D-882-81	12 MPa	1700 psi
Folding endurance (MIT)	D-2176-69	10,000 cycles	10,000 cycles
Initial tear strength (Graves)	D-1004-66	5.3 N	1.2 lbf
Propagating tear strength (Elmendorf)	D-1922-67	2.5 N	250 g
Bursting strength**	D-774-67 (Mullen)	76 kPa	11 psi
Density	D-1505-68	2150 kg/m^3	134 lb/ft^3
Coefficient of friction kinetic (film to steel)	D-1894-61	0.3	0.3

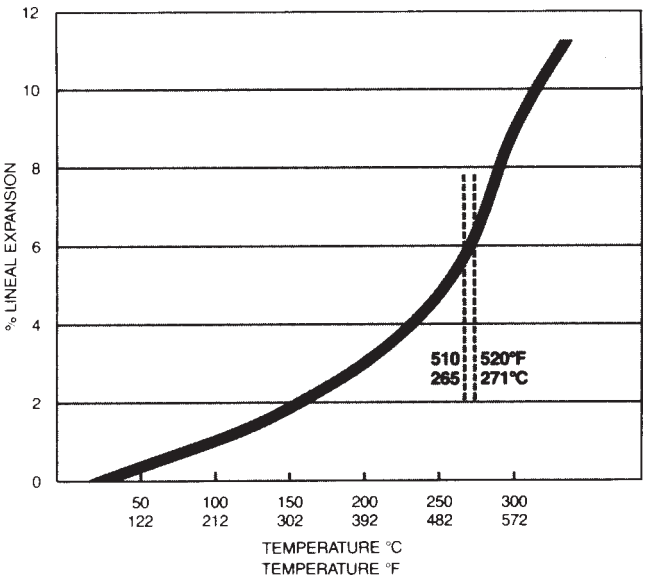
*200 gauge unless otherwise noted
**100 gauge film

Table 3
Typical Thermal Properties of DuPont FEP Film*

Property	ASTM Method	SI Units	English Units
Melt point	D-3418 (DTA)	260–280°C	500–536°F
Maximum continuous service temperature		205°C	400°F
Zero strength** temperature	***	255°C	490°F
Specific heat		1172 J/kg·K	0.28 Btu/lb·°F
Coefficient of thermal conductivity		0.195 W/m·K	1.35 $\frac{\text{Btu·in}}{\text{h·ft}^2\text{·°F}}$
Coefficient of linear thermal expansion	D-696-79	$9.4 \times 10^{-5} \frac{\text{mm}}{\text{mm·°C}}$	$5.4 \times 10^{-5} \frac{\text{in}}{\text{in·°F}}$
Flammability classification	ANSI/UL-94	VTM-0	VTM-0
Oxygen index	D-2863-77	95%	95%
Dimensional stability MD	30 min at 150°C (302°F)	0.7% expansion	0.7% expansion
Dimensional stability TD		2.2% shrinkage	2.2% shrinkage

*200 gauge unless otherwise noted
**100 gauge film
***Temperature at which film supports a load of 0.14 MPa (20 psi) for 5 sec

Figure 5. Thermal Expansion of DuPont FEP Film



Electrical Properties

FEP fluorocarbon films exhibit excellent electrical properties over a wide range of frequencies and temperatures. **Table 4** shows how initial properties are retained even after long-term exposure to extreme environmental conditions.

Table 4
Typical Electrical Properties of DuPont FEP Fluorocarbon Film 25 μm (1 mil) Thickness

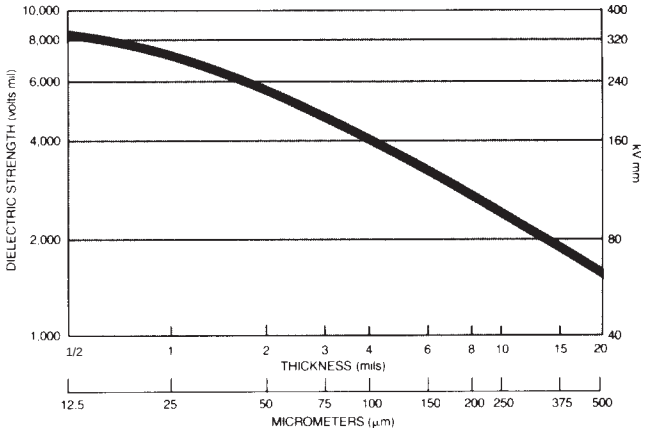
Property	ASTM Method	SI Units	English Units
Dielectric strength	D-149A-81 [6.4 mm (0.25 in) electrode in air, 60 Hz]	260 kV/mm	6500 V/mil
Dielectric constant	D-150-81 (1 kHz)	2.0	2.0
Dissipation factor	D-150-81 (1 kHz)	0.0002	0.0002
Volume resistivity	D-257-78	1×10^{16} ohm·m	1×10^{18} ohm·cm
Surface resistivity	D-257-78	1×10^{16} ohm (per square)	1×10^{16} ohm (per square)
Surface arc resistance	D-495-73	>165 s*	>165 s*

*Samples melted in arc did not track.

Dielectric Strength

Figure 6 shows how the dielectric strength of DuPont FEP film is a function of film thickness; thinner films exhibit greater dielectric strength.

Figure 6. Dielectric Strength vs. Film Thickness of DuPont FEP Film



Dielectric Constant

For DuPont FEP film, dielectric constant is independent of film thickness. There is no difference between Type A and Type C films.

At a constant frequency, the dielectric constant of DuPont FEP film decreases with rise in temperature due to thermal expansion (see **Figure 7**).

At a constant temperature, the dielectric constant falls slightly with an increase in frequency above 10^7 Hz (see **Figure 8**).

Figure 7. Dielectric Constant vs. Temperature of DuPont FEP Film at 1 kHz and 100 kHz

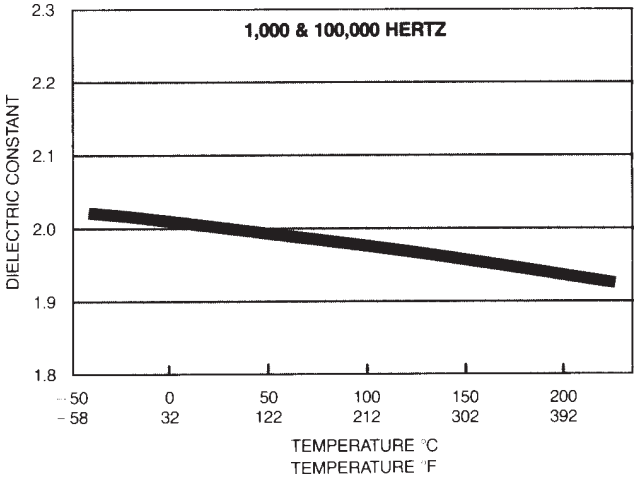
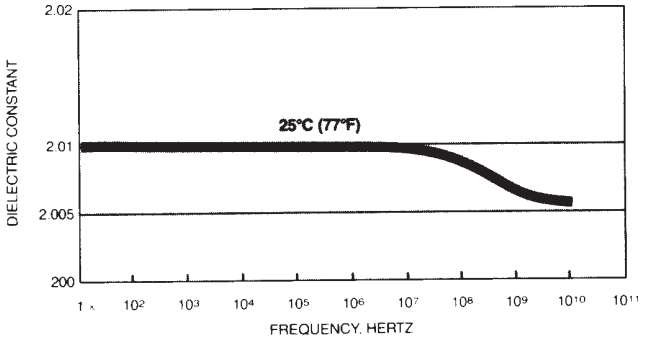


Figure 8. Dielectric Constant vs. Frequency



Dissipation Factor

The consistently low value of the dissipation factor over a broad range of temperature and frequency makes FEP fluorocarbon film ideal in applications where electrical losses must be minimized (see **Figure 9**).

At a constant temperature, this dissipation factor of FEP films varies as noted in **Figure 10**. Absolute values remain low in comparison with many other dielectric materials.

Figure 9. Dissipation Factor vs. Temperature of DuPont FEP Film

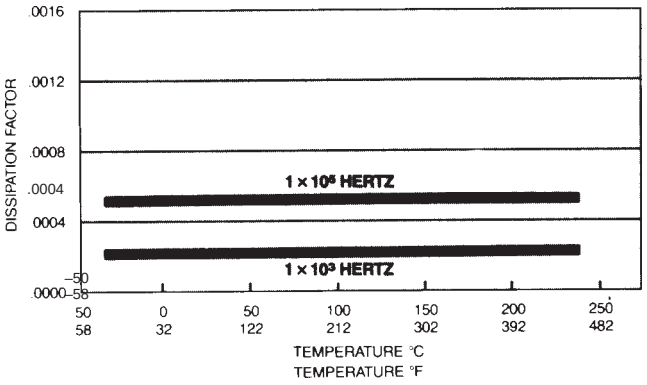
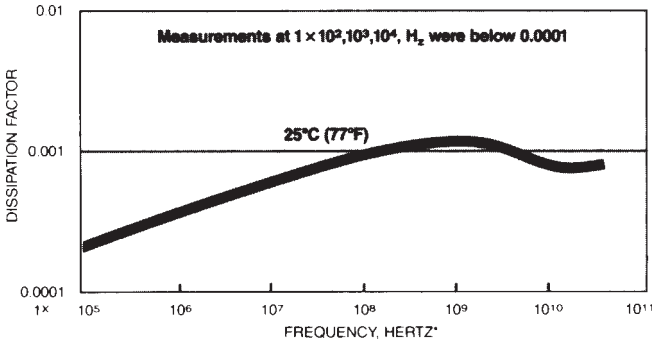


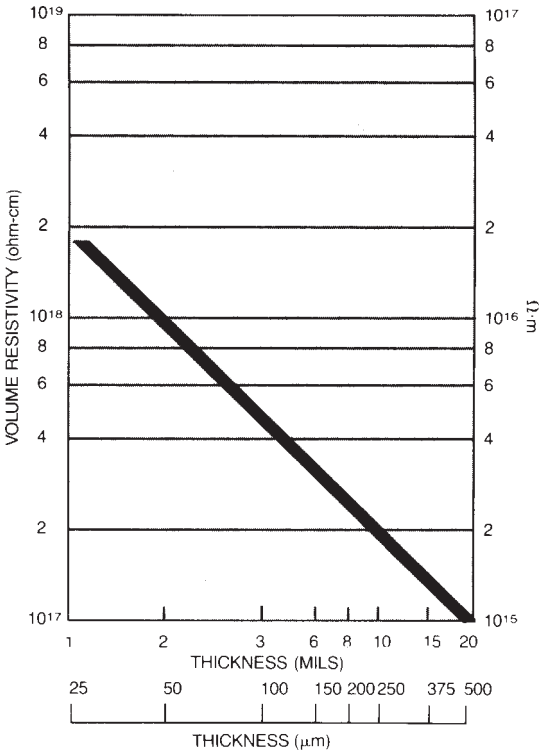
Figure 10. Dissipation Factor vs. Frequency of DuPont FEP Film



Volume Resistivity

Volume resistivity of DuPont FEP film decreases slightly as the film thickness increases (see **Figure 11**).

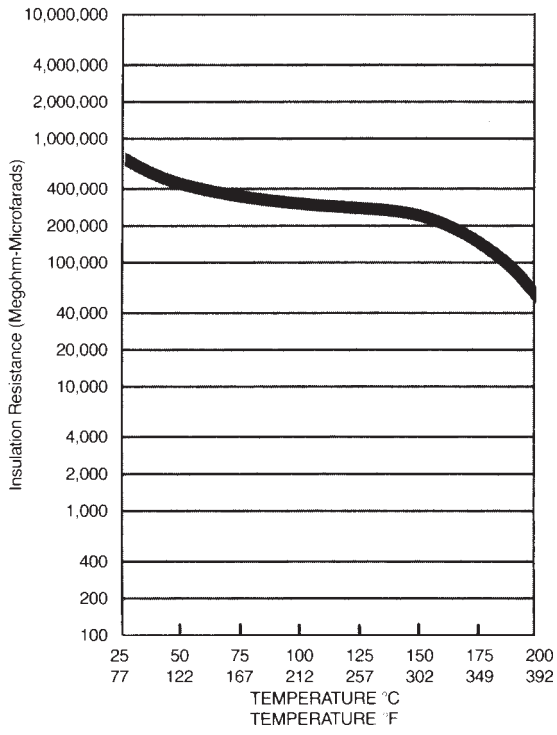
Figure 11. Volume Resistivity vs. Thickness (at 175°C [347°F])



Insulation Resistance

Even at 200°C (392°F), the insulation resistance of DuPont FEP film (65,000 megohm-microfarad) is higher than most conventional dielectric materials at room temperature (see **Figure 12**).

Figure 12. Insulation Resistance vs. Temperature
(125 μm/0.5 mil DuPont FEP film)



Chemical Properties

DuPont FEP fluorocarbon film is chemically inert and solvent resistant to virtually all chemicals except molten alkali metals, fluorine at elevated temperatures, and certain complex halogenated compounds such as chlorine trifluoride at elevated temperatures and pressures.

In circumstances where end-use temperatures are close to the upper service limit 205°C (400°F), 80% sodium hydroxide, metal hydrides, aluminum chloride, ammonia, and certain amines ($R\text{-}NH_2$) may attack the film in a manner similar to molten alkali metals. Special testing is required when such extreme reducing or oxidizing conditions are evident.

With these exceptions noted, DuPont FEP fluorocarbon films exhibit a very broad range of chemical and thermal serviceability.

Due to the many complex aspects of performance in severe environments, final selection should be based on functional evaluations or experience under actual end-use conditions.

The chemical substances listed in **Table 5** are representative of those with which DuPont FEP film has been found to be nonreactive.

Table 5
Typical Chemicals with Which DuPont FEP Film is Nonreactive*

Abietic acid	Cyclohexanone	Hydrofluoric acid	Phthalic acid
Acetic acid	Dibutyl phthalate	Hydrogen peroxide	Pinene
Acetic anhydride	Dibutyl sebacate	Lead	Piperidene
Acetone	Diethyl carbonate	Magnesium chloride	Polyacrylonitrile
Acetophenone	Diethyl ether	Mercury	Potassium acetate
Acrylic anhydride	Dimethyl formamide	Methyl ethyl ketone	Potassium hydroxide
Allyl acetate	Di-isobutyl adipate	Methacrylic acid	Potassium permanganate
Allyl methacrylate	Dimethylformamide	Methanol	Pyridine
Aluminum chloride	Dimethylhydrazine, unsymmetrical	Methyl methacrylate	Soap and detergents
Ammonia, liquid	Dioxane	Naphthalene	Sodium hydroxide
Ammonium chloride	Ethyl acetate	Naphthols	Sodium hypochlorite
Aniline	Ethyl alcohol	Nitric acid	Sodium peroxide
Benzonitrile	Ethyl ether	Nitrobenzene	Solvents, aliphatic and aromatic**
Benzoyl chloride	Ethyl hexoate	2-Nitro-butanol	Stannous chloride
Benzyl alcohol	Ethylene bromide	Nitromethane	Sulfur
Borax	Ethylene glycol	Nitrogen tetroxide	Sulfuric acid
Boric acid	Ferric chloride	2-Nitro-2-methyl propanol	Tetrabromoethane
Bromine	Ferric phosphate	n-Octadecyl alcohol	Tetrachlorethylene
n-Butyl amine	Fluoronaphthalene	Oils, animal and vegetable	Trichloracetic acid
Butyl acetate	Fluoronitrobenzene	Ozone	Trichlorethylene
Butyl methacrylate	Formaldehyde	Perchlorethylene	Tricresyl phosphate
Calcium chloride	Formic acid	Pentachloro-benzamide	Triethanolamine
Carbon disulfide	Furane	Perfluoroxylene	Vinyl methacrylate
Cetane	Gasoline	Phenol	Water
Chlorine	Hexachlorethane	Phosphoric acid	Xylene
Chloroform	Hexane	Phosphorus pentachloride	Zinc chloride
Chlorosulfonic acid	Hydrazine		
Chromic acid	Hydrochloric acid		
Cyclohexane			

*Based on experiments conducted up to the boiling points of the liquids listed. FEP resins have normal service temperatures up to 205°C (400°F). Absence of a specific chemical does not mean that it is reactive with FEP film.

**Some halogenated solvents may cause moderate swelling.

Physical Properties

Absorption

Almost all plastics absorb small quantities of certain materials with which they come in contact. Submicroscopic voids between polymer molecules provide space for the material absorbed without chemical reaction. This phenomenon is usually marked by a slight weight increase and sometimes by discoloration.

DuPont FEP fluorocarbon films have unusually low absorption compared with other thermoplastics. They absorb practically no common acids or bases at temperatures as high as 200°C (392°F) and exposures of up to one year. Even the absorption of solvents is extremely small. Weight increases are generally less than 1% when exposed at elevated temperatures for long periods. In general, aqueous solutions are absorbed very little by DuPont FEP film. *Moisture absorption is typically less than 0.01% at ambient temperature and pressure.*

Permeability

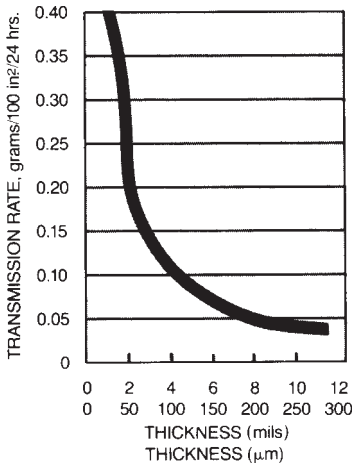
Many gases and vapors permeate FEP films at a much lower rate than for other thermoplastics (see **Figure 13**). In general, permeation increases with temperature, pressure, and surface contact area and decreases with increased film thickness. **Table 6** lists rates at which various gases are transmitted through DuPont FEP fluorocarbon film, while **Table 7** lists rates of vapor permeability for some representative substances. Note that the pressure for each material is its vapor pressure at the indicated temperature.

Table 6
Typical Gas Permeability Rates of DuPont FEP Fluorocarbon Film, 25 μm (1 mil) Thickness
(Test Method: ASTM D-1434 at 25°C [77°F])

Gas	Permeability Rate* $cm^3/(m^2 \cdot 24\ h \cdot atm)$
Carbon Dioxide	25.9×10^3
Hydrogen	34.1×10^3
Nitrogen	5.0×10^3
Oxygen	11.6×10^3

*To convert to $cm^3/(100\ in^2 \cdot 24\ h \cdot atm)$, multiply by 0.0645.

Figure 13. Water Vapor Transmission Rate of DuPont FEP Film at 40°C (104°F) per ASTM E-96 (Modified)



Notes: Values are averages only and not for specification purposes. To convert the permeation values for 100 in^2 to those for 1 m^2, multiply by 15.5.

Table 7
Typical Vapors Transmission Rates of DuPont FEP Fluorocarbon Film, 25 μm (1 mil) Thickness
(Test Method: Modified ASTM E-96)

	Temperature		Vapor Transmission Rate	
Vapor	°C	°F	SI Units ($g/m^2 \cdot d$)	English Units ($g/100\ in^2 \cdot d$)
Acetic Acid	35	95	6.3	0.41
Acetone	35	95	14.7	0.95
Benzene	35	95	9.9	0.64
Carbon Tetrachloride	35	95	4.8	0.31
Ethyl Acetate	35	95	11.7	0.76
Ethyl Alcohol	35	95	10.7	0.69
Freon® F-12	23	73	372.0	24.0
Hexane	35	95	8.7	0.56
Hydrochloric Acid	25	77	<0.2	<0.01
Nitric Acid (Red Fuming)	25	77	160.0	10.5
Sodium Hydroxide, 50%	25	77	<0.2	<0.01
Sulfuric Acid, 98%	25	77	2×10^{-4}	1×10^{-5}
Water	39.5	103	7.0	0.40

Optical Properties

DuPont FEP films transmit a high percentage of ultraviolet and visible light and are much more transparent to the infrared spectrum than glass (see **Figures 14–16**).

Other optical properties of FEP films of interest are:

	FEP
Solar Transmission (ASTM E-424)	96%
Refractive Index (ASTM D-542)	1.341–1.347

Figure 14. Transmission Spectrum for DuPont FEP Film

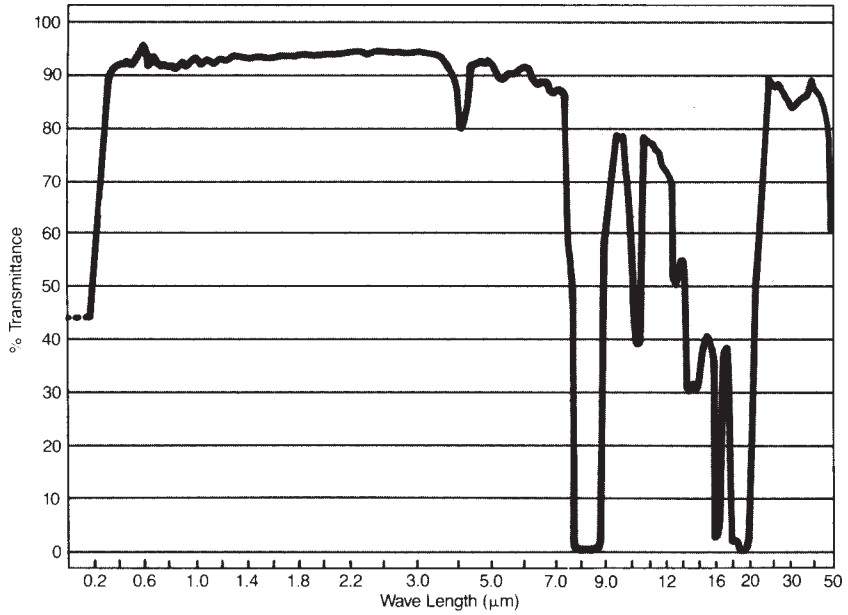


Figure 15. Transmittance at Normal Incidence of Solar Radiation through DuPont FEP Films for Various Thicknesses

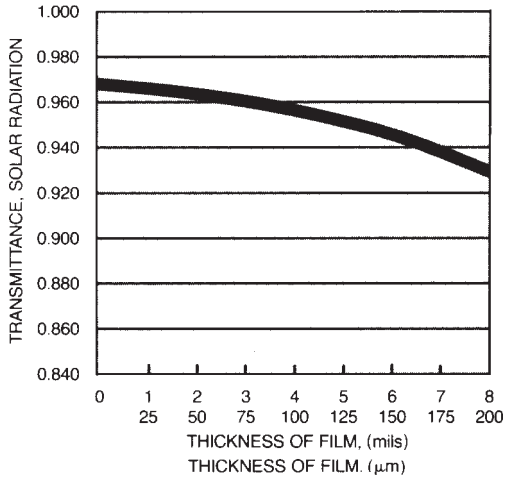
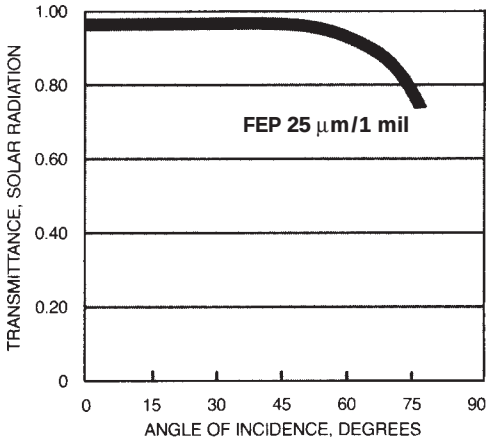


Figure 16. Transmittance of Solar Radiation through 25 μm (1 mil) DuPont FEP Film for Various Angles of Incidence



Miscellaneous Properties

Cryogenic Service

FEP has performed satisfactorily in cryogenic service at temperatures below that of liquid nitrogen. DuPont FEP fluorocarbon film is normally inert to liquid oxygen (LOX) when the film is free of contamination, pigmentation, or fillers for reinforcement.

FDA Compliance

Clear DuPont FEP fluorocarbon film complies with Part 177 of Title 21 of the Food & Drug Administration regulations for safe use as articles or components of articles for producing, manufacturing, processing, preparing, treating, packaging, transporting, or holding food in accordance with Regulation 177.1550.

USDA Acceptance

Clear DuPont FEP fluorocarbon film is acceptable as a component of materials for use in slaughtering, processing, transporting, or storage areas in direct contact with meat or poultry food product prepared under federal inspection.

Mildew (Fungus) Resistance

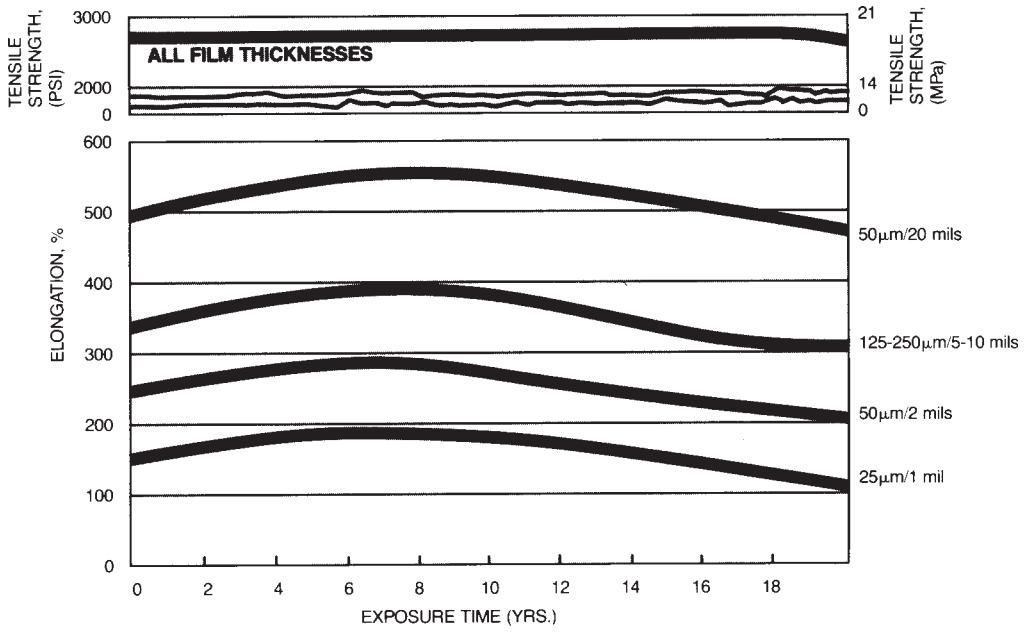
FEP has been shown to be completely resistant to mildew growth by testing both in humidity chamber exposure inoculated with a mixed spore suspension and a soil burial test for three months.

Weatherability

In contrast to most other clear thermoplastic films, DuPont FEP film remains essentially unchanged after 20 years of outdoor exposure (see **Figure 17**). There is no evidence of discoloration, ultraviolet degradation, or strength loss. This outstanding performance is due to the structure of the polymer molecule and is not the result of chemical additives.

Types C and C-20 DuPont FEP film are not recommended for outdoor applications because ultraviolet radiation may adversely affect the treated surface.

Figure 17. The Effects of Florida Weathering on DuPont FEP Film



Safety and Handling

Unheated FEP fluorocarbon is essentially inert. Animal tests indicate that FEP is nonirritating and nonsensitizing to the skin. Dust generated by cutting, grinding, or machining the unheated film should be avoided, as with any other nuisance dusts that are regulated by OSHA at 15 mg/m^3 in air (29 CFR 1910:1000).

Care should be taken to avoid contamination of smoking tobacco or cigarettes with fluorocarbon resins.

DuPont FEP film can be processed and used at elevated temperatures without hazard if proper ventilation is used. Ventilation should be provided at processing temperatures of 275°C (525°F) or above.

Additional details on safety in handling and use are available in bulletin H-48633, "Guide to the Safe Handling of Fluoropolymer Resins, 2nd Edition," available from DuPont.

Other related literature available from DuPont:

Bulletin	Title
E-80413-2	DuPont PFA Film—Specification Bulletin (T62-3)
H-55003-2	DuPont FEP Film—Specification Bulletin (T62-1)
H-55008-2	DuPont FEP Film—Properties Bulletin

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