Kirk-Othmer Encyclopedia of Chemical Technology.

FLUORINE-CONTAINING POLYMERS, PERFLUORINATED ETHYLENE-PROPYLENE COPOLYMERS

Perfluorinated ethylene–propylene (FEP) resin [25067-11-2] is a copolymer of tetrafluoroethylene [116-14-3] (TFE) and hexafluoropropylene [116-15-4] (HFP); thus its branched structure contains units of $-CF_2-CF_2-$ and units of $-CF_2-CF(CF_3)-$. It retains most of the desirable characteristics of polytetrafluoroethylene (PTFE) but with a melt viscosity low enough for conventional melt processing. The introduction of hexafluoropropylene lowers the melting point of PTFE from 325°C to about 260°C.

The desire for a resin with polytetrafluoroethylene properties yet capable of being fabricated by conventional melt processing led to the discovery of this product (1). It allows melt extrusion of wire insulations of longer continuous lengths than the batchwise paste extrusion of PTFE as well as the injection molding of intricately shaped parts. The FEP polymer is melt-fabricable without severe sacrifice in mechanical properties because the perfluoromethyl side groups on the main polymer chain reduce crystallinity, which varies between 30 and 45%. This change in the crystallinity causes FEP and other copolymer particles to behave differently form PTFE particles; they do not fibrillate like PTFE particles and therefore do not agglomerate easily.

As a true thermoplastic, FEP copolymer can be melt-processed by extrusion and compression, injection, and blow molding. Films can be heat-bonded and sealed, vacuum-formed, and laminated to various substrates. Chemical inertness and corrosion resistance make FEP highly suitable for chemical services; its dielectric and insulating properties favor it for electrical and electronic service; and its low frictional properties, mechanical toughness, thermal stability, and nonstick quality make it highly suitable for bearings and seals, high temperature components, and nonstick surfaces.

Mechanical properties are retained up to 200°C, even in continuous service, which is better than with most plastics. At high temperatures, these copolymers react with fluorine, fluorinating agents, and molten alkali metals. They are commercially available under the Du Pont trademark Teflon FEP fluorocarbon resin. A similar product is manufactured by Daikin Kogyo of Japan and sold under the trademark Neoflon. The People's Republic of China also manufactures some FEP products.

1. Monomers

1.1. Preparation

The preparation, properties, and uses of tetrafluoroethylene have been described (see Fluorine compounds, organic–polytetrafluoroethylene).

Hexafluoropropylene (HFP) was initially prepared by pyrolysis of PTFE (2, 3) and by fluorination of 1,2,3-trichloropropane followed by dehalogenation (4). A number of other routes are described in the patent literature (5–10). Hexafluoropropylene can be prepared in high yield by thermally cracking TFE at reduced pressure at 700–800°C (11, 12). Pyrolysis of PTFE at 860°C under vacuum gives a 58% yield of HFP (13). Fluorination of 3-chloropentafluoro-1-propene [79-47-0] at 200°C over activated carbon catalyst yields HFP (14).

Table 1. Properties of Hexafluoropropylene[a]

Property	Value
molecular weight	150.021
boiling point at 101 kPa,[b] °C	−29.4
freezing point, °C	−156.2
critical temperature, °C	85
critical pressure, kPa[b]	3254
critical density, g/cm^3	0.60
vapor pressure at K, kPa[b]	
$243.75 < T < 358.15$	$\log P(\text{kPa}) = 6.6938 - 1139.156/T$
liquid density, g/cm^3	
60°C	1.105
20°C	1.332
0°C	1.419
−20°C	1.498
heat of formation for ideal gas at 25°C, ΔH, kJ/mol[c]	−1078.6
flammability limits in air at 101 kPa[b]	nonflammable for all mixtures of air and hexafluoropropylene
heat of combustion, kJ/mol[c,d]	879
toxicity, LC_{50} (rat), 4 h, ppm[e]	3000

[a] Ref. 4.

[b] To convert kPa to mm Hg, multiply by 7.5.

[c] To convert kJ to kcal, divide by 4.184.

[d] Ref. 19.

[e] Ref. 20.

Decomposition of fluoroform [75-46-7] at 800–1000°C in a platinum-lined nickel tube is another route (15). The thermal decomposition of sodium heptafluorobutyrate [2218-84-4], $CF_3CF_2CF_2CO_2Na$ (16), and copyrolyses of fluoroform and chlorotrifluoroethylene [79-38-9] (17), and chlorodifluoromethane [75-45-6] and 1-chloro-1,2,2,2-tetrafluoroethane [2837-89-0] (18) give good yields of HFP.

1.2. Properties and Reactions

The properties of HFP are shown in Table 1. It does not homopolymerize easily and hence can be stored as a liquid. It undergoes many addition reactions typical of an olefin. Reactions include preparation of linear dimers and trimers and cyclic dimers (21, 22); decomposition at 600°C with subsequent formation of octafluoro-2-butene and octafluoroisobutylene (23); oxidation with formation of an epoxide (24), an intermediate for a number of perfluoroalkyl perfluorovinyl ethers (25, 26); and homopolymerization to low molecular weight liquids (27, 28) and high molecular weight solids (29, 30). Hexafluoropropylene reacts with hydrogen (31), alcohols (32), ammonia (33), and the halogens and their acids, except I_2 and HI (31, 34–36). It is used as a comonomer to produce elastomers and other copolymers (37–41). The toxicological properties are discussed in Reference 42.

2. Copolymers

Hexafluoropropylene and tetrafluoroethylene are copolymerized, with trichloracetyl peroxide as the catalyst, at low temperature (43). Newer catalytic methods, including irradiation, achieve copolymerization at different temperatures (44, 45). Aqueous and nonaqueous dispersion polymerizations appear to be the most convenient routes to commercial production (1, 46–50). The polymerization conditions are similar to those of TFE

Table 2. Properties of Teflon FEP Fluorocarbon Resin[a]

Mechanical property	ASTM method	Teflon 110	Teflon 100	Teflon 140	Teflon 160
melt flow number, g/10 min	D2116		7.0	3.0	1.5
specific gravity	D792	2.13–2.17	2.13–2.17	2.13–2.17	2.13–2.17
tensile strength,[b] MPa[c]	D1708	20	23	30	31
elongation,[b] %	D1708	300	325	325	305
compressive strength, MPa[c]	D695		21	21	23
flexural strength,[b] MPa[c]	D790		18	18	18
impact strength,[b] J/m[d]	D256		no break	no break	no break
flexural modulus,[b] MPa[c]	D790	655	620	620	586
hardness durometer, Shore D	D2240	55	56	56	57
coefficient of friction, metal–film	D1894		0.27	0.27	0.235
deformation under load,[e] %	D621	1.8	0.5	0.5	0.5
water absorption, 24 h, %	D570	<0.01	0.004	0.004	0.004
linear coefficient of expansion per °C × 10^{-5}	E381				
0–100°C			13.5	13.9	7.6
100–150°C			20.8	21.2	11.5
150–200°C			26.6	27.0	14.2

[a] Compression-molded specimens; property data on extruded wire specimens are similar.

[b] At 23°C

[c] To convert MPa to psi, multiply by 145.

[d] To convert J/m to ft·lbf/in., divide by 53.38.

[e] At 23°C, 6.9 MPa,[c] 23 h.

homopolymer dispersion polymerization. The copolymer of HFP–TFE is a random copolymer; that is, HFP units add to the growing chains at random intervals. The optimal composition of the copolymer requires that the mechanical properties are retained in the usable range and that the melt viscosity is low enough for easy melt processing.

Hexafluoropropylene–tetrafluoroethylene copolymers are available in low melt viscosity, extrusion grade, intermediate viscosity, high melt viscosity, and as dispersions. The low melt viscosity (MV) resin can be injection molded by conventional thermoplastic molding techniques. It is more suitable for injection molding than other FEP resins (51).

The extrusion grade is suitable for tubing, wire coating, and cable jacketing. It is less suitable for injection molding than the low MV resin because of its relatively high melt viscosity. The intermediate MV (Teflon FEP-140) resin is used for insulation of wires larger than AWG 12 (American wire gauge) and applications involving smaller wire sizes, where high current loads or excessive thermal cycling may occur. It is also ideal for jacketing wire braid construction, such as coaxial cables, and for heater cable jackets.

The high MV resin is used as liners for process equipment. Its melt viscosity is significantly higher than that of other resins and therefore it is unsuitable for conventional injection molding. Stress-crack resistance and mechanical properties are superior to those of the other three products (52) (Table 2).

Both high and low color concentrates are available for pigmenting extruded coatings of FEP resins. The concentrates are prepared for melt dispersion in extrusion applications. The pigments are purified, thermally stable, and carefully selected to meet electrical, mechanical, and thermal end use specifications. Color concentrate pellets are easily dispersed among clear pellets by conventional tumbling. The ratio of concentrate to natural resin varies, depending on the wire size, insulation thickness, and color intensity desired.

An FEP copolymer dispersion is available as a 55-wt % aqueous dispersion containing 6% nonionic surfactant (on a solids basis) and a small amount of anionic dispersing agent. Its average particle size is ca 0.2 μm.

2.1. Properties

The crystallinity of FEP polymer is significantly lower than that of PTFE (70 vs 98%). The structure resembles that of PTFE, except for a random replacement of a fluorine atom by a perfluoromethyl group (CF_3). The crystallinity after processing depends on the rate of cooling the molten polymer. The presence of HFP in the polymer chain tends to distort the highly crystallized structure of the PTFE chain and results in a higher amorphous fraction.

In the free-radical polymerization of FEP copolymers, chain termination occurs by binary coupling of chain ends, thus contributing to high molecular weights. Linear viscoelastic properties of these polymers in the amorphous melts were measured by dynamic rheometry. The FEP samples had high molecular weights and were found to verify the relation of zero shear viscosity vs $(\text{mol wt})^3$ predicted by the reptation theory. At lower molecular weights, the empirical relation of viscosity vs $(\text{mol wt})^{3.4}$ holds (53).

2.1.1. Transitions and Relaxations

Only one first-order transition is observed, the melting point. Increasing the pressure raises mp. At low pressure, the rate of increase in the melting point is ca 1.74°C/MPa (0.012°C/psi); at high pressures this rate decreases to ca 0.725°C/MPa (0.005°C/psi). Melting increases the volume by 8%. In the presence of the HFP comonomer, crystal distortion occurs with an increase in intramolecular distance that, in turn, reduces the melting point (54).

The relaxation temperature appears to increase with increasing HFP content. Relaxation involves 5–13 of the chain carbon atoms. Besides α and γ relaxations, one other dielectric relaxation was observed below $-150^\circ C$, which did not vary in temperature or in magnitude with comonomer content or copolymer density (55). The α relaxation (also called Glass I) is a high temperature transition (157°C) and γ relaxation (Glass II) (internal friction maxima) occurs between -5 and 29°C.

2.1.2. Thermal Stability

The polymer is thermally stable and can be processed at ca 270°C. Thermal degradation is a function of temperature and time, and the stability is therefore limited. The melt-flow rate (thermal degradation) increases significantly for short periods above 280°C, and degradation occurs at lower temperatures with longer hold times. The hourly weight loss is 0.0004% at 230°C, 0.001% at 260°C, 0.01% at 290°C, 0.02% at 320°C, 0.08% at 340°C, and 0.3% at 370°C. Degradation is not significant if the change in melt-flow rate during molding is $<10\%$. Physical strength decreases after prolonged exposure above 205°C, which accounts for the lower temperature rating of FEP resins (56).

2.1.3. Radiation Effects

The primary effect of radiation is the degradation of large molecules to small molecules. Molecular weight reduction can be minimized by excluding oxygen. If FEP is lightly irradiated at elevated temperatures in the absence of oxygen, cross-linking offsets molecular breakdown (55, 57).

The degree to which radiation exposure affects FEP resins is determined by the energy absorbed, regardless of the type of radiation. Changes in mechanical properties depend on total dosage, but are independent of dose rate. The radiation tolerance of FEP in the presence or absence of oxygen is higher than that of PTFE by a factor of 10:1.

2.1.4. Mechanical Properties

Extensive lists of the physical properties of FEP copolymers are given in References (58–63). Mechanical properties are shown in Table 3. Most of the important properties of FEP are similar to those of PTFE; the main difference is the lower continuous service temperature of 204°C of FEP compared to that of 260°C of PTFE. The flexibility at low temperatures and the low coefficients of friction and stability at high temperatures are relatively independent of fabrication conditions. Unlike PTFE, FEP resins do not exhibit a marked change in volume at room temperature, because they do not have a first-order transition at 19°C. They are useful above -267°C and are highly flexible above -79°C (64).

Static friction decreases with an increase in load, and the static coefficient of friction is lower than the dynamic coefficient. The tendency to creep must be considered carefully in FEP products designed for service under continuous stresses. Creep can be minimized by suitable fillers. Fillers are also used to improve wear resistance and stiffness. Compositions such as 30% bronze-filled FEP, 20% graphite-filled FEP, and 10% glass-fiber-filled FEP offer high PV values ($\sim$400(kPa·m)/s) and are suitable for bearings.

Articles fabricated from FEP resins can be made bondable by surface treatment with a solution of sodium in liquid ammonia, or naphthalenyl sodium in tetrahydrofuran (64) to facilitate subsequent wetting. Exposing the surface to corona discharge (65) or amines at elevated temperatures in an oxidizing atmosphere (66) also makes the resins bondable. Some of the more recent work is described in References (67–69).

Vibration-dampening properties at sonic and ultrasonic frequencies are excellent. However, the thickness of the resin must be sufficient to absorb the energy produced; this is usually determined experimentally.

2.1.5. Electrical Properties

Because of excellent electrical properties, FEP is a valuable and versatile electrical insulator. Within the recommended service temperature range, PTFE and FEP have identical properties as electrical insulators. Volume resistivity, which is $>10^{17}\ \Omega/\mathrm{cm}$, remains unchanged even after prolonged soaking in water; surface resistivity is $>10^{15}\ \Omega/\mathrm{sq}$.

At low frequencies, the dielectric constant of FEP remains the same (~ 2). However, at >100 MHz the constant drops slightly with increasing frequency. As a true thermoplastic, FEP has a void content of zero and most of the fabricated material has a density of 2.14–2.17 g/cm^3. The National Bureau of Standards has selected Teflon FEP resins for dielectric reference specimens because of the stability of their dielectric constant. The dissipation factor has several peaks as a function of temperature and frequency (3×10^{-4} at 100 kHz; 7×10^{-4} at 1 MHz). The magnitude of the dissipation factor peak is greater for FEP than for PTFE because the molecular structure of the former is less symmetrical. The dissipation factor is hardly affected by irradiation annealing (70) and unaffected by humidity. The dielectric strength is high (80 GV/mm for 0.25 mm film at 23°C) and unaffected by thermal aging at 200°C. At high frequencies, the dielectric properties deteriorate in the presence of corona. If the voltage stress is not high enough to cause corona ignition, an infinitely long dielectric life is expected at any frequency. Corona discharges on the surface or in a void initiate dielectric breakdown (71). The FEP resins are recommended for continuous service up to 205°C. Although they begin to melt flow at 270°C, they retain some structural integrity up to 250°C (70).

2.1.6. Chemical Properties

The FEP resin is inert to most chemicals and solvents, even at elevated temperatures and pressures. However, it reacts with fluorine, molten alkali metal, and molten sodium hydroxide. Acids or bases are not absorbed at 200°C and exposures of one year. The absorption of organic solvents is less than 1% at elevated temperatures and long exposure times. Absorption of chemicals or solvents has no effect on the chemical integrity of the FEP molecule and is a reversible physical process.

Gases and vapors permeate FEP resin at a rate that is considerably lower than that of most plastics. Because FEP resins are melt processed, they are void-free and permeation occurs only by molecular diffusion. Variation in crystallinity and density is limited, except in unusual melt-processing conditions.

Because of its low permeability, FEP polymer is used extensively in the chemical industry. Its permeation characteristics are similar to those of PTFE (Table 4). An inverse relationship between permeability and film thickness applies to FEP.

Table 3. Mechanical Properties of FEP[a]

Property	Value	ASTM method
specific gravity	2.14–2.17	D792-50
thermal conductivity, W/(m·K)		Cenco-Fitch
−129 to 182°C	2.4	
−253°C	1.4	
water absorption in 24 h, 3.175-mm thick sample		D570-547
% wt increase	<0.1	
dimensional change at 23°C	none	
coefficient of thermal expansion per °C		D696-44
>23°C	9.3×10^{-5}	
<23°C	5.7×10^{-5}	
specific heat, kJ/(kg·K)[b]		
20°C	1.09	
100°C	1.17	
260°C	1.30	
heat distortion, °C		D648-56
455 kPa[c]	70	
1820 kPa[c]	51	
tensile yield strength, av, MPa[d]		D638-527
−251°C	165	
−73°C	62	
23°C	12	
121°C	3.5	
tensile modulus, MPa[d]		
−251°C	57	
−73°C	24	
23°C	4	
100°C	1	
tensile elongation, %		D638-527
−251°C	4	
−73°C	200	
23°C	350	
flexural modulus, MPa[d]		D747-50
−251°C	5300	
−101°C	3200	
23°C	660	
55°C	340	
compressive strength, MPa[d]		D695
−251°C	251	
23°C	15	
100°C	3.4	
Izod impact strength, notched, J/m[e]		D256-56
23°C	no break	
hardness, Durometer		D2240-T
23°C	D59	
Taber abrasion, g/MHz, 100-g load		
CS-17 wheel	7.5	

[a] Measured on Teflon FEP T-100.
[b] To convert kJ to kcal, divide by 4.184.
[c] To convert kPa to atm, multiply by 0.01.
[d] To convert MPa to psi, multiply by 145.
[e] To convert J/m to ft·lbf/in., divide by 53.38.

Table 4. Permeability of FEP Fluorocarbon Resins to LiquidVapors and Gases

	Permeability constant,[a,b] mol/(m·s·Pa) × 10^{15}		
Permeant	23°C	35°C	50°C
	Liquid vapors		
acetic acid		9.07	
acetone	0.37		3.23
benzene	0.75		
carbon tetrachloride	0.24	0.41	
decane	112.18		33.48
dipentene	23.50		10.67
ethyl acetate	0.27	2.06	4.09
ethanol	1.61	4.66	
H_2SO_4, 98%	21.70		
toluene	5.38		
water	8.14	20.32	18.26
	Gases[c]		
oxygen	18.69		
helium	113.47		
nitrogen	6.10		
hydrogen	40.15		
methane	3.17		

[a] Ref. 60. Test method ASTM E96-35T (at vapor pressure; for 25.4-μm filmthickness). Values are averages only and not for specification purposes.

[b] Original data converted to SI units using vapor pressure data from Ref. 72.

[c] At 20°C.

2.1.7. Weathering

Articles fabricated from FEP are unaffected by weather, and their resistance to extreme heat, cold, and uv irradiation suits them for applications in radar and other electronic components. For example, after 15 years of solar exposure in Florida, the tensile strength (73) and light transmission (96%) of a 25-μm thick film was unchanged and the film remained crystal clear. Elongation increased slightly for the first 5 to 7 years of outdoor exposure, probably as a result of stress relaxation. Beyond 10 years, a small decrease was observed.

2.1.8. Optical Properties

Teflon FEP fluorocarbon film transmits more ultraviolet, visible light, and infrared radiation than ordinary window glass. The refractive index of FEP film is 1.341–1.347 (74).

3. Fabrication

Standard thermoplastic processing techniques can be used to fabricate FEP. Thermal degradation must be avoided, and a homogeneous structure and good surface quality must be maintained.

3.1. Injection Molding

Compared to most thermoplastic products, even the low MV resin has a significantly higher melt viscosity and therefore requires higher processing temperatures, slower injection rates, special mold design, and corrosion-resistant material of construction. When the flow velocity in melt processing exceeds a critical value, melt fracture occurs. The critical shear rate of FEP is much lower than that of other thermoplastics.

Recommendations for materials of construction and the screw design, valves, smear heads, nozzle, operating conditions, and mold design are given in Reference 52.

Pigments (thermally stable at processing temperature) are dry blended with the resin before molding. At loadings of 0.1–1%, pigments have no appreciable effect on the dielectric strength, dielectric constant, or mechanical properties. The dissipation factor of pigmented resin varies with the pigment and its amount (75).

3.2. Extrusion

Conventional melt-extrusion equipment is used in processing FEP resins. Commercial pigments are mixed with the resin before extrusion into wire coating, tubing, rods, molding, beading channels, etc. Coating thicknesses of 0.076–2.54 mm have been extruded over such materials as silicone rubber, poly(vinyl chloride), glass braid, metal-shielded cables, twisted conductors, and parallel multiconductor cables.

For primary insulation or cable jackets, high production rates are achieved by extruding a tube of resin with a larger internal diameter than the base wire and a thicker wall than the final insulation. The tube is then drawn down to the desired size. An operating temperature of 315–400°C is preferred, depending on holdup time. The surface roughness caused by melt fracture determines the upper limit of production rates under specific extrusion conditions (76). Corrosion-resistant metals should be used for all parts of the extrusion equipment that come in contact with the molten polymer (77).

Tubing is made in a wide range of sizes and is used as slip-on electrical insulation, instrument tubing, and for hoses. Small tubing, called spaghetti tubing, can be produced by a free-extrusion technique, whereas hose-size tubing is produced by conventional forming-box techniques; FEP also is extruded into films.

3.3. Dispersion Processing

The commercial aqueous dispersion of FEP contains 55 wt % of hydrophobic, negatively charged FEP particles and ca 6 wt % (based on FEP) of a mixture of nonionic and anionic surface-active agents. The average particle size is ca 0.2 μm. The dispersion is processed by the same technique used for PTFE dispersion. For example, the fabric is coated with FEP dispersion, the water is evaporated from the coating, the wetting agent is removed, and the FEP layer is fused with the fabric.

Dispersion is used as a coating for glass fabric, chemical barriers, and wire-insulating tapes; as adhesive coatings for bonding seals and bearings of PTFE to metallic and nonmetallic components; and as antifriction or antistick coatings for metals. The fusion of FEP to provide a continuous film depends on a time–temperature relationship; 1 min at 400°C or 40 min at 290°C are sufficient to achieve good fusion (78).

3.4. Other Techniques

The FEP resin is bonded to metal surfaces by the application of heat and pressure; it can be heat sealed or hot-gas welded. Heating FEP at 260°C and allowing it to cool slowly results in stress relieving, or annealing. The FEP film is used to weld PTFE-coated surfaces.

3.5. Effects of Fabrication on Product Properties

Extrusion conditions have a significant effect on the quality of the product (77). Contamination can be the result of corrosion, traces of another resin, or improper handling. Corrosion-resistant Hastelloy C parts should be used in the extruder. Surface roughness is the result of melt fracture or mechanical deformation. Melt fracture can be eliminated by increasing the die opening, die temperature, and the melt temperature and reducing the extrusion rate. Bubbles and discoloration are caused by resin degradation, air entrapment, or condensed moisture. Excessive drawdown, resin degradation, or contamination can result in pinholes, tears, and cone breaks. The blisters are caused by degassing of primary coatings, and loose coatings are caused by rapid cooling and long cones.

3.6. Testing and Standards

Requirements for extrusion and molding grades are cited in ASTM specifications (79) and in Federal specification LP-389A of May 1964 (80). For fabricated shapes, FEP film and sheet are covered by Aeronautical Material Specifications (AMS) 3647 and LP-523 (81). Besides the specifications covered by the Fluorocarbons Division of the Society of the Plastics Industry, Inc. (82), other specifications are listed in Reference 83.

4. Economic Aspects

Because of the high cost of hexafluoropropylene, FEP is more expensive than PTFE. In the United States in 1992, FEP sold at prices up to $28.3 kg, depending on the type and quantity. Most grades are marketed in a colorless, translucent, extruded pellet form. The dispersion containing about 55% solids is priced at ca $33 kg. During the 1980s FEP sales increased rapidly because of usage in plenum cable, but since there are other polymers that can be used in this application the growth rate for FEP is expected to slow down.

5. Health and Safety

The safety precautions required in handling TFE–HFP copolymers are the same as those applied to handling PTFE. Large quantities have been processed safely by many different fabricators in a variety of operations. With proper ventilation, the polymer can be processed and used at elevated temperatures without hazard. The fumes from heated FEP or its thermal decomposition products are toxic in high concentrations, like the fumes or decomposition products of other polymers. Ventilation should be provided in areas where the resin is at processing temperature (270–400°C). At ambient temperatures, FEP resin is essentially inert. Inhalation of fumes given off by heated FEP resin may result in influenza-like symptoms. They may occur several hours after exposure and disappear within 35–48 hours, even in the absence of treatment; the effects are not cumulative (52). Such attacks usually follow exposure to vapors evolved from the polymer without adequate ventilation or from smoking tobacco or cigarettes contaminated with the polymer. Toxicology study of the particulates and fumes is reported in Reference 84.

6. Applications

The principal electrical applications include hook-up wire, interconnecting wire, coaxial cable, computer wire, thermocouple wire, plenum cable, and molded electrical parts. Principal chemical applications are lined pipes and fittings, over-braided hose, heat exchangers, and laboratory ware. Mechanical uses include antistick applications, such as conveyor belts and roll covers. A recent development of FEP film for solar collector windows takes advantage of light weight, excellent weatherability, and high solar transmission. Solar collectors made of FEP film are efficient, and installation is easy and inexpensive.

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