PTFE polytetrafluoroethylene

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polytetrafluoroethylene	
CAS name	-	ethene, 1,1,2,2-tetrafluoro-, homopolymer	
Acronym	-	PTFE	
CAS number	-	9002-84-0	
EC number	-	204-126-9	
RTECS number	-	KX4025000	
Formula		$-[CF_2CF_2]_n-$	
HISTORY			
Person to discover	-	Roy Plunkett	Jones, R F; Antec, 2763-68, 1998.
Date	-	1938; 1945, 1946 (industrial production)	
Details	-	Plunkett accidentally discovered polymerization in experiment of production of new refrigerant (iron of container acted as a catalyst of polymerization); DuPont coined Teflon's name in 1945 and initiated industrial production in 1946; the first teflon-coated frying-pan was produced in 1961 by Marion Trozzolo	
SYNTHESIS			
Monomer(s) structure	-	$F_2C{=}CF_2$	
Monomer(s) CAS number(s)	-	116-14-3	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	100.02	
Monomer ratio	-	100%	
Formulation example	-	monomer, water persulfate initiator, dispersant	
Method of synthesis	-	granular resin, water dispersions, and powdered resins are produced by free radical polymerization in aqueous medium; TFE polymerizes linearly without branching; micropowders are produced by irradiation of PTFE by high energy electron beam or polymerization controlled to produce lower molecular weight	Drobny, J G, Fluoroplastics, Rapra, 2006.
Temperature of polymerization	°C	40-90	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoro-plastics, William Andrew, 2000.
Pressure of polymerization	MPa	0.03-3.5	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoro-plastics, William Andrew, 2000.
Heat of polymerization	$kJ\ mol^{-1}$	172	
Number average molecular weight, M_n	dalton, g/mol, amu	400,000-10,000,000	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoro-plastics, William Andrew, 2000.
Molar volume at 298K	$cm^3\ mol^{-1}$	41.2 (crystalline); 50 (amorphous)	
Van der Waals volume	$cm^3\ mol^{-1}$	32.0 (crystalline); 32.0 (amorphous)	
STRUCTURE			
Crystallinity	%	58-98	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoro-plastics, William Andrew, 2000.
Cell type (lattice)	-	triclinic (below 19°C), hexagonal (above 19°C)	Ebnesajjad, S, Fluoroplastics. Vol. 2. Melt Processible Fluoroplastics, William Andrew, 2003.

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Cell dimensions	nm	a:b:c=0.559:0.559:1.688	
Unit cell angles	degree	$\alpha:\beta:\gamma$=90:90:119.3	
Number of chains per unit cell	-	1	
Chain conformation	-	helix 13/6	
Entanglement molecular weight	dalton, g/mol, amu	calc.=5,580, exp.=3,700	
COMMERCIAL POLYMERS			
Some manufacturers	-	DuPont; Solvay	
Trade names	-	Teflon; Algoflon	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	2.16-2.20; 2.077 (amorphous); 2.187 (crystalline); 2.344 (triclinic)	
Bulk density at 20°C	g cm^{-3}	0.3-0.5	
Color	-	white powder	
Refractive index, 20°C	-	1.35-1.37	
Odor	-	odorless	
Melting temperature, DSC	°C	317-345 (irreversible)	
Decomposition temperature	°C	350 (weight loss 0.001%); 508 (decomposition onset temperature)	Patel, P; Hull, T R; McCabe, R W; Flath, D; Grasmeder, J; Percy, M, Polym. Deg. Stab., 95, 709-18, 2010.
Degradation temperature	°C	440	
Thermal expansion coefficient, 23-80°C	$°C^{-1}$	1.1-2.2E-4	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.234-0.25	Boudenne, A; Ibos, L; Gehin, E; Candau, Y, J. Phys. D: Appl. Phys., 37, 132-39, 2004.
Specific heat capacity	J K^{-1} kg^{-1}	1.2-1.5	
Heat of fusion	kJ kg^{-1}	82	Masirek, R; Piorkowska, E, Eur. Polym. J., 46, 1436-45, 2010.
Maximum service temperature	°C	-260 to 260	
Long term service temperature	°C	260	
Heat deflection temperature at 0.45 MPa	°C	122-132	
Heat deflection temperature at 1.8 MPa	°C	45-60	
Hansen solubility parameters, δ_D, δ_P, δ_H	$MPa^{0.5}$	16.2, 1.8, 3.4	
Interaction radius		3.9	
Hildebrand solubility parameter	$MPa^{0.5}$	12.7; 16.7	
Surface tension	mN m^{-1}	18.5-25.6	Wu, S, J. Macromol. Sci., C10, 1, 1974.
Dielectric constant at 100 Hz/1 MHz	-	2.1/2.1	
Dissipation factor at 100 Hz		0.0003	
Dissipation factor at 1 MHz		0.0003	
Volume resistivity	ohm-m	1E16	
Surface resistivity	ohm	1E16	

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PARAMETER	UNIT	VALUE	REFERENCES
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	19.7-60	
Surface arc resistance	s	>300	
Coefficient of friction	-	0.08 (static); 0.06 (dynamic); 0.24-0.31 (glass fiber); 0.20-0.24 (carbon fiber)	
Permeability to nitrogen, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	0.1	
Permeability to oxygen, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	0.32	
Permeability to water vapor, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	0.6	
Diffusion coefficient of oxygen	cm^2 s^{-1} $x10^6$	0.0152	
Diffusion coefficient of water vapor	cm^2 s^{-1} $x10^7$	1.47 (20°C); 5.73 (90°C)	Hansen, C M, Prog. Org. Coat., 42, 167-78, 2001.
Contact angle of water, 20°C	degree	108.9-120; 122 (adv) and 94(rec)	Lee, S; Park, J-S; Lee, T R, Langmuir, 24, 4817-26, 2008.
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	20-35; 19 (20% glass fiber); 13 (25% carbon fiber)	
Tensile modulus	MPa	400-550; 250 (20% glass fiber); 120 (25% carbon fiber)	
Elongation	%	300-550	
Flexural modulus	MPa	340-620; 1,200 (20% glass fiber); 1,100 (25% carbon fiber)	
Elastic modulus	MPa	482	
Compressive strength	MPa	34.5	
Izod impact strength, notched, 23°C	J m^{-1}	188	
Shear modulus	MPa	186	
Tenacity (fiber) (standard atmosphere)	cN tex^{-1} (daN mm^{-2})	5-14 (10-28)	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Tenacity (wet fiber, as % of dry strength)	%	100	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Fineness of fiber (titer)	dtex	5-25	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Length (elemental fiber)	mm	filament, staple	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Poisson's ratio	-	0.46-0.5	
Shrinkage	%	2-10	
Melt viscosity, shear rate=1000 s^{-1}	Pa s	1E10	

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Water absorption, equilibrium in water at 23°C	%	0	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	resistant (including fuming nitric acid, and *aqua regia*)	
Alcohols	-	resistant	
Alkalis	-	resistant (attacked by molten alkali metals)	
Aliphatic hydrocarbons	-	resistant	
Aromatic hydrocarbons	-	resistant	
Esters	-	resistant	
Greases & oils	-	resistant	
Halogenated hydrocarbons	-	resistant	
Ketones	-	resistant	
Good solvent	-	perfluorokerosene at 350°C	
Non-solvent	-	all other solvents	
FLAMMABILITY			
Ignition temperature	°C	494	
Autoignition temperature	°C	>530	
Limiting oxygen index	% O_2	>99.5	
Heat release	kW m^{-2}		
Burning rate (Flame spread rate)	mm min^{-1}	120	Padey, D; Walling, J; Wood A, Polymers in Defence and Aerospace 2007, Rapra, 2007, paper 15.
Char at 500°C	%	0	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g^{-1}	6,3806,680	Walters, R N; Hacket, S M; Lyon, R E, Fire Mater., 24, 5, 245-52, 2000.
Volatile products of combustion	-	CF_4, C_2F_4, C_3F_6	
UL 94 rating	-	V-0	
WEATHER STABILITY			
Spectral sensitivity	nm	well below 290	
Stabilizers	-	not known	
Low earth orbit erosion yield	cm^3 $atom^{-1}$ x 10^{-24}	0.142	Waters, D L; Banks, B A; De Groh, K K; Miller, S K R; Thorson, S D, High Performance Polym., 20, 512-22, 2008.
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	0/0/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
Mutagenic effect	-	not known	
Teratogenic effect	-	not known	
Reproductive toxicity	-	not known	
Oral rat, LD_{50}	mg kg^{-1}	1,250	

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PARAMETER	UNIT	VALUE	REFERENCES
ENVIRONMENTAL IMPACT			
Aquatic toxicity, *Daphnia magna*, LC_{50}, 48 h	mg l^{-1}	>1000	
PROCESSING			
Typical processing methods	-	casting, coating, compression molding, dip coating, film coating, fiber spinning, flow coating, isostatic molding, paste extrusion (mixed with lubricants and forced through cold die followed by lubricant evaporation and sintering), ram extrusion, sintering, solid phase forming, spraying	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoroplastics, William Andrew, 2000.
Processing temperature	°C	400	
Additives used in final products	-	alumina, attapulgite, boron nitride, bronze powder, carbon black, carbon fiber, carbon nanofiber, copper powder, diamond, glass fiber, graphite, molybdenum sulfide, Ni-Zn ferrite, silica, titanium dioxide	
Applications	-	aircraft insulated wires, bearings, dry lubricants, electric insulation applications, film, filtration membranes, friction reduction, gaskets, Gore-Tex^{TM} membranes, laboratory equipment, non-stick coatings, oils and greases, paints and coatings, pipes, piston rings, printing inks, seals, sutures, tank lining, tapes, tubes, valve and pump parts, vascular grafts, wear reduction	Ebnesajjad, S, Fluoroplastics. Vol. 1. Non-melt Processible Fluoroplastics, William Andrew, 2000.
Outstanding properties	-	chemical inertness, heat resistance, low coefficient of friction, insulating properties	
BLENDS			
Suitable polymers	-	FEP, PA6, PA66, PEEK, PI, POM, PPS	
ANALYSIS			
NMR (chemical shifts)	ppm	CF_2 – 122 (commercial only peak); branching – 130-138	Ikeda, S; Tabata, Y; Suzuki, H; Miyoshi, T; Kudo, H; Katsumura, Y, Radiation Phys. Chem., 77, 1050-56, 2008.
x-ray diffraction peaks	degree	18.6, 31.3	Gao, Y; Zhang, J; Xu, j; Yu, J, Appl. Surf. Sci., 254, 3408-11, 2008.