

# PVDF-HFP poly(vinylidene fluoride-co-hexafluoropropylene)

PARAMETER	UNIT	VALUE	REFERENCES
<b>GENERAL</b>			
Common name	-	poly(vinylidene fluoride-co-hexafluoropropylene)	
CAS name	-	1-propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene	
Acronym	-	PVDF-HFP	
CAS number	-	9011-17-0	
<b>HISTORY</b>			
Person to discover	-	Moran, A L	Moran, A L, US Patent 2,951,832, DuPont, Sept. 6, 1960.
Date	-	1960	
<b>SYNTHESIS</b>			
Monomer(s) structure	-	$\text{H}_2\text{C}=\text{CF}_2$ $\text{F}_3\text{CCF}=\text{CF}_2$	
Monomer(s) CAS number(s)	-	75-38-7; 116-15-4	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	64.04; 150.02	
Monomer(s) expected purity(ies)	%	99.998; 99.998	
Monomer ratio	-	3.5 (ranges from 11 mol% to 42 mol% of hexafluoropropylene)	
Fluorine content	%	<61-66	
Formulation example	-	in addition to monomer and water surfactant and initiator system (usually persulfate-sulfite) are used; copper salts are used as catalysts	Moore, A L, Fluoroelastomers Handbook. The Definitive User's Guide and Databook, William Andrew, 2006.
Method of synthesis	-	emulsion polymerization occurs by formation of monomer swollen polymer particles having size of 100-1000 nm	Moore, A L, Fluoroelastomers Handbook. The Definitive User's Guide and Databook, William Andrew, 2006.
Temperature of polymerization	°C	100-120	
Time of polymerization	h	2-4	
Pressure of polymerization	MPa	2-7	
Activation energy of polymerization	kJ mol <sup>-1</sup>	-142	Moore, A L, Fluoroelastomers Handbook. The Definitive User's Guide and Databook, William Andrew, 2006.
Heat of polymerization	J g <sup>-1</sup>	1340	Moore, A L, Fluoroelastomers Handbook. The Definitive User's Guide and Databook, William Andrew, 2006.
Number average molecular weight, $M_n$	dalton, g/mol, amu	110,000-380,000	
Mass average molecular weight, $M_w$	dalton, g/mol, amu	98,000-480,000	
Polydispersity, $M_w/M_n$	-	1.5-4.1	
<b>STRUCTURE</b>			
Crystallinity	%	31	
Cell dimensions	nm	a:b:c=0.496:0.964:0.462 ( $\alpha$ )	Abbrent, S; Plestil, J; Hlavata, D; Lindgren, J; Tegenfeldt, J; Wend-sjo, A, Polymer, 42, 1407-16, 2001.
Polymorphs	-	$\alpha$ , $\beta$ , $\gamma$ , $\delta$	Abbrent, S; Plestil, J; Hlavata, D; Lindgren, J; Tegenfeldt, J; Wend-sjo, A, Polymer, 42, 1407-16, 2001.

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Chain conformation	-	<i>trans-gauche-trans-gauche'</i> ( $\alpha$ ) (the most common phase); zig-zag, all <i>trans</i> ( $\beta$ )	Abbrent, S; Plestil, J; Hlavata, D; Lindgren, J; Tegenfeldt, J; Wend-sjo, A, Polymer, 42, 1407-16, 2001.
Heat of crystallization	kJ kg <sup>-1</sup>	28-37	
Rapid crystallization temperature	°C	98-134	
<b>COMMERCIAL POLYMERS</b>			
Some manufacturers	-	DuPont; Westlake Plastics	
Trade names	-	Viton; Kynar	
<b>PHYSICAL PROPERTIES</b>			
Density at 20°C	g cm <sup>-3</sup>	1.77-1.86	
Color	-	silver gray to amber	
Refractive index, 20°C	-	1.41	
Odor		odorless	
Melting temperature, DSC	°C	125-164	
Decomposition temperature	°C	>204; >330; 330-370 (TGA)	
Thermal expansion coefficient, 23-80°C	10 <sup>-4</sup> °C <sup>-1</sup>	1.5-1.7	
Thermal conductivity, 23°C	W m <sup>-1</sup> K <sup>-1</sup>	0.18	
Glass transition temperature	°C	-5 to -40	
Specific heat capacity	J K <sup>-1</sup> kg <sup>-1</sup>	1,200	
Heat of fusion	kJ mol <sup>-1</sup>	39	
Maximum service temperature	°C	>200	
Long term service temperature	°C	-40 to 200	
Heat deflection temperature at 0.45 MPa	°C	100	
Heat deflection temperature at 1.8 MPa	°C	39-52	
Vicat temperature VST/A/50	°C	131-150	
Enthalpy of fusion	J g <sup>-1</sup>	36.0-65.0	Mekhilef, N, Antec, 1821-26, 2000.
Hansen solubility parameters, $\delta_D$ , $\delta_P$ , $\delta_H$	MPa <sup>0.5</sup>	17.2, 12.5, 8.2	Wongchitphimon, S; Wang, R; Jir-aratananon, R; Shi, L; Loh, C H, J. Membrane Sci., 369, 329-38, 2011.
Hildebrand solubility parameter	MPa <sup>0.5</sup>	23.2	Wongchitphimon, S; Wang, R; Jir-aratananon, R; Shi, L; Loh, C H, J. Membrane Sci., 369, 329-38, 2011.
Dielectric constant at 100 Hz/1 MHz	-	7.6-10.6/7.0	
Dissipation factor at 1 MHz	E-4	2000	
Volume resistivity	ohm-m	1E12	
Surface resistivity	ohm	1E14	
Coefficient of friction	-	0.25 (dynamic); 0.3 (static)	
Contact angle of water, 20°C	degree	152	
<b>MECHANICAL &amp; RHEOLOGICAL PROPERTIES</b>			
Tensile strength	MPa	20-45	
Tensile modulus	MPa	500-1,100	

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Tensile stress at yield	MPa	15-35	
Elongation	%	200-650	
Tensile yield strain	%	10-18	
Flexural strength	MPa	40	
Flexural modulus	MPa	400-1,000	
Abrasion resistance (ASTM D1044)	mg/1000 cycles	10	
Shore D hardness	-	65-72	
Shrinkage	%	2-3	
Brittleness temperature (ASTM D746)	°C	-17 to -62	
Intrinsic viscosity, 25°C	dl g <sup>-1</sup>	1.0-1.7	
Melt index, 230°C/2.16 kg	g/10 min	1.3-8	
Water absorption, 24h at 23°C	%	0.04	
<b>CHEMICAL RESISTANCE</b>			
Acid dilute/concentrated	-	resistant (only dilute)	
Alcohols	-	resistant	
Alkalis	-	non resistant	Mitra, S; Ghanbari-Siahkali, A; Kingshott, P; Almdal, K; Rehmeier, H K; Christensen, A G, Polym. Deg. Stab., 83, 195-206, 2004.
Aliphatic hydrocarbons	-	resistant	
Aromatic hydrocarbons	-	resistant	
Esters	-	non resistant	
Greases & oils	-	resistant	
Halogenated hydrocarbons	-	resistant	
Ketones	-	non resistant	
Good solvent	-	carbon dioxide, C <sub>3</sub> F <sub>3</sub> , CClF <sub>3</sub>	
<b>FLAMMABILITY</b>			
Ignition temperature	°C	>204	
Limiting oxygen index	% O <sub>2</sub>	44-56	
Volatile products of combustion	-	CO, CO <sub>2</sub> , HF, perfluoroolefins	
UL 94 rating	-	V-0	
<b>WEATHER STABILITY</b>			
Excitation wavelengths	nm	510	
Emission wavelengths	nm	647, 645	
<b>BIODEGRADATION</b>			
Stabilizers	-	poly(4-vinyl-N-alkylpyridinium bromide)	Yao, C; Li, X; Neoh, K G; Shi, Z; Kang, E T, Appl. Surface Sci., 255, 3854-58, 2009.
<b>TOXICITY</b>			
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
OSHA	mg m <sup>-3</sup>	5 (respirable), 15 (total)	

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Oral rat, LD <sub>50</sub>	mg kg <sup>-1</sup>	>5,000	
<b>ENVIRONMENTAL IMPACT</b>			
Aquatic toxicity, <i>Daphnia magna</i> , LC <sub>50</sub> * 48 h	mg l <sup>-1</sup>	>205	
<b>PROCESSING</b>			
Typical processing methods	-	calendering, coating, compression molding, electrospinning, extrusion, injection molding, spinning, transfer molding	
Processing pressure	kPa	50 (spinning)	
Applications	-	aircraft, aerospace, chemical processing and transportation, food and pharmaceutical, oil and gas, petroleum refining; typical products: caulks, coatings, gaskets, membranes, o-rings, seals, vibration dampers, wire & cable	
<b>BLENDS</b>			
Suitable polymers	-	PE	
<b>ANALYSIS</b>			
FTIR (wavenumber-assignment)	cm <sup>-1</sup> /-	C-F – 1287; CF <sub>2</sub> – 882; CH <sub>2</sub> – 842	Saikia, D; Wu, H-Y; Pan, Y-C; Lin, C-P; Huang, K-P; Chen, K-N; Fey, G T K; Kao, H-M, J. Power Sources, 196, 2826-34, 2011.
NMR (chemical shifts)	ppm	CH <sub>2</sub> – 43.2; CF <sub>3</sub> – 164; CF <sub>2</sub> – 118.5	Saikia, D; Wu, H-Y; Pan, Y-C; Lin, C-P; Huang, K-P; Chen, K-N; Fey, G T K; Kao, H-M, J. Power Sources, 196, 2826-34, 2011.
x-ray diffraction peaks	degree	18.3, 20, 26.6, 39	Zalewska, A; Walkowiak, M; Niedzicki, L; Jesionowski, T; Langwald, N, Electrochim. Acta, 55, 1308-13, 2010.