LLDPE linear low density polyethylene

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	linear low density polyethylene; poly(ethylene-co-1-octene); poly(ethylene-co-1-butene); poly(ethylene-co-1-hexene)	
IUPAC name	-	polyethylene	
Acronym	-	LLDPE	
CAS number	-	26221-73-8 (octene); 25087-34-7 (butene); 25213-02-9 (hexene; metallocene)	
SYNTHESIS			
Monomer(s) structure	-	$H_2C=CH_2$; $CH_3CH_2CH=CH_2$; $CH_3(CH_2)_3CH=CH_2$	
Monomer(s) CAS number(s)	-	74-85-1; 106-98-9; 592-41-6	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	28.05; 56.11; 84.16	
Monomer(s) expected purity(ies)	%	99.9	
Method of synthesis	-	Ziegler or Philips catalysts are used in solution or gas phase reactions to obtain LLDPE. Octene copolymer with ethylene is obtained in solution process and butene and hexene are copolymerized with ethylene in gas phase reactors; also metallocene catalyst are in use	
Catalyst	-	Ziegler, Philips, metallocene	
Typical additives	ppm	3,000 (antiblock), antioxidant (e.g., Tuflin)	
Mass average molecular weight, M_w	dalton, g/mol, amu	94,000-208,000	
Polydispersity, M_w/M_n	-	1.6-35	
Degree of branching	mol%	2-4	
STRUCTURE			
Crystallinity	%	30-53; 46 (DSC); 52-59 (NMR)	Lu, J; Zhao, B; Sue, H-J, Metallocene Technology in Commercial Applications, Benedikt, G M, Ed., WilliamAndrew, Norwich, 1999.
Cell type (lattice)	-	orthorhombic	
Cell dimensions	nm	a:b:c=0.748:0.497:0.257	
Spherulite size	nm	2,000-12,000	Ruksakulpiwat, Y, Antec, 582-6, 2001.
Spacing between crystallites	nm	8.0-36.9	
Lamellae thickness	nm	4.3-16.3	
Rapid crystallization temperature	°C	107-123 (injection molding grades)	
COMMERCIAL POLYMERS			
Some manufacturers	-	DOW; ExxonMobil; LyondellBasell	
Trade names	-	Aspun (fiber grades), Dowlex, Tuflin, LLDPE; LLDPE; Starflex	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	0.905-0.942	
Bulk density at 20°C	g cm^{-3}	0.35-0.38	
Color	-	clear to white	
Refractive index, 20°C	-	1.49-1.52	
Haze	%	1-19	
Gloss, 60°, Gardner (ASTM D523)	%	47-92	

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Odor	-	odorless to mild hydrocarbon odor	
Melting temperature, DSC	°C	120-136; 94 (injection molding grades)	
Thermal expansion coefficient, 23-80°C	$^oC^{-1}$	1.6-5E-4	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.55	
Glass transition temperature	°C	-110	
Heat of fusion	kJ mol^{-1}	1.37-2.18	
Maximum processing temperature	°C	300 (Booster)	
Heat deflection temperature at 0.45 MPa	°C	43-59	
Heat deflection temperature at 1.8 MPa	°C	38	
Vicat temperature VST/A/50	°C	94-123	
Surface tension	mN m^{-1}	22.4-24.0	Tinson, A; Takacs, E; Vlachopoulos, J, Antec, 870-74, 2004.
Dielectric constant at 100 Hz/1 MHz	-	2.3	
Coefficient of friction	-	0.6 (itself, dynamic)	
Contact angle of water, 20°C	degree	97.1-99.1	Jeon, H J; Kim, M N, Eur. Polym. J., 52, 146-53, 2014.
Speed of sound	m s^{-1}	717-1009	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	25-45; 33-71 (MD) and 25-54.2 (TD) for 0.02-0.25 mm thick film; 30-55 (MD) and 29-53.6 (TD) for 0.051 mm thick film; 7.6-15.5 (injection molding grades)	
Tensile modulus	MPa	260-520	
Tensile stress at yield	MPa	8.1-32.4 (MD) and 7.7-29.0 (TD) for 0.02-0.025 mm thick film; 9.3-15.2 (MD) and 10.0-16.4 (TD) for 0.051 mm thick film; 11-750-830 (film grade); 16.5 (injection molding grades)	
Elongation	%	300-830 (MD); 610-890 (TD); 50-800 (injection molding grades)	
Tensile yield strain	%	2-18	
Flexural modulus	MPa	280-735; 310-700 (injection molding grades)	
Izod impact strength, notched, 23°C	J m^{-1}	54 to NB	
Dart drop impact (film thickness in mm)	g	43-470 (0.02); 130-610 (0.051)	
Film puncture resistance (film thickness in mm)	J cm-3	7.7-30.8 (0.02); 7.0-24.0 (0.051	
Toughness	J cm-3	63-303 (MD) and 76-353 (TD) for 0.02-0.025 mm thick film; 84-346 (MD) and 87-361 (TD) for 0.051 mm thick film	
Elmendorf tear strength (film thickness in mm)	g	15-370 (MD) and 210-700 (TD) for 0.02-0.025 mm thick film; 470-950 (MD) and 1,100-1,300 (TD) for 0.051 mm thick film	
Puncture force	N	30-43	
Shore D hardness	-	55-56; 44-53 (injection molding grades)	
Shrinkage	%	2.0-2.5	
Brittleness temperature (ASTM D746)	°C	-20 to -100 (injection molding grades)	

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Melt viscosity, shear rate=0 s^{-1}	kPa s	2.9 (190°C); 25.5 (150°C)	Tinson, A; Takacs, E; Vlachopoulos, J, Antec, 870-74, 2004; Hertel, D; Valette, R; Muenstedt, H, J. Non-Newtonian Fluid Mech., 153, 82-94, 2008.
Melt index	g/10 min	0.2-2000	Tornuk, F; Hancer, M; Sagdic, O; Yetim, H, LTW - Food Sci. Technol., 64, 540-6, 2015.
Water absorption	%	0.005-0.01	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	very good	
Alcohols	-	good	
Alkalis	-	very good	
Aliphatic hydrocarbons	-	poor	
Aromatic hydrocarbons	-	poor	
Esters	-	poor	
Greases & oils	-	good to poor	
Halogenated hydrocarbons	-	poor	
Ketones	-	poor	
Good solvent	-	cyclohexene, decalin, toluene, xylene	
Non-solvent	-	o-dichlorobenzene, 1,2-dichloropropane, methylene chloride	
FLAMMABILITY			
Ignition temperature	°C	340-343	
Autoignition temperature	°C	350	
Limiting oxygen index	% O_2	<20	
Heat of combustion	J g^{-1}	47,740	
Volatile products of combustion	-	CO, CO_2, aldehydes, benzene	
UL 94 rating	-	HB	
WEATHER STABILITY			
Spectral sensitivity	nm	<300	
Activation wavelengths	nm	300, 330-360	
Excitation wavelengths	nm	230, 265, 275, 290, 292	
Emission wavelengths	nm	295, 312, 330, 344, 358, 450	
Important initiators and accelerators	-	unsaturations, aromatic carbonyl compounds (deoxyanisoin, dibenzocycloheptadienone, flavone, 4-methoxybenzophenone, 10-thioxanthone), hydrogen bound to tertiary carbon at branching points, aromatic amines, groups formed on oxidation (hydroperoxides, carbonyl, carboxyl, hydroxyl) substituted benzophenones, complexes with ground-state oxygen, quinones (anthraquinone, 2-chloroanthraquinone, 2-tert-butylathraquinone, 1-methoxyanthraquinone, 2-ethylanthraquinone, 2-methylanthraquinone), transition metal compounds (Ni < Zn < Fe < Co), ferrocene derivatives, titanium dioxide (anatase), ferric stearate, polynuclear aromatic compounds (anthracene, phenanthrene, pyrene, naphthalene	
Products of degradation	-	free radicals, hydroperoxides, carbonyl groups, chain scission, crosslinking	

PARAMETER	UNIT	VALUE	REFERENCES
Stabilizers	-	UVA: 2-hydroxy-4-octyloxybenzophenone; phenol, 2-(5-chloro-2H-benzotriazole-2-yl)-6-(1,1-dimethylethyl)-4-methyl-; 2,2'-methylenebis(6-(2H-benzotriazol-2-yl)-4-1,1,3,3-tetramethylbutyl)phenol; 2,4-di-tert-butyl-6-(5-chloro-2H-benzotriazole-2-yl)-phenol; reaction product of methyl 3(3-(2H-benzotriazole-2-yl)-5-t-butyl-4-hydroxyphenyl propionate/ PEG 300; 2-[4,6-bis(2,4-dimethylphenyl)-1,3,5-triazin-2-yl]-5-(octyloxy) phenol; Screener: titanium dioxide; zinc oxide; carbon black; Acid scavenger: hydrotalcite; Fiber: carbon nanotube; HAS: 1,3,5-triazine-2,4,6-triamine, N,N'''[1,2-ethane-diyl-bis[[[4,6-bis[butyl(1,2,6,6-pentamethyl-4-piperidinyl)amino]-1,3,5-triazine-2-yl]imino]-3,1-propanediyl] bis[N',N''-dibutyl-N',N''-bis(1,2,2,6,6-pentamethyl-4-piperidinyl)-; bis(1,2,2,6,6-pentamethyl-4-piperidyl)sebacate + methyl-1,2,2,6,6-pentamethyl-4-piperidyl sebacate; 2,2,6,6-tetramethyl-4-piperidinyl stearate; reaction products of N,N'-ethane-1,2-diylbis(1,3-propanediamine), cyclohexane, peroxidized 4-butylamino-2,2,6,6-tetramethylpiperidine and trichloro-1,3,5-triazine; poly[[(6-[1,1,3,3-tetramethylbutyl) amino]-1,3,5-triazine-2,4-diyl][2,2,6,6-tetramethyl-4-piperidinyl) imino]-1,6-hexanediyl[2,2,6,6-tetramethyl-4-piperidinyl)imino]]; 1,6-hexanediamine- N,N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-polymer with 2,4,6-trichloro-1,3,5-triazine, reaction products with N-butyl-1-butanamine an N-butyl-2,2,6,6-tetramethyl-4-piperidinamine; butanedioic acid, dimethylester, polymer with 4-hydroxy-2,2,6,6-tetramethyl-1-piperidine ethanol; alkenes, C20-24-.alpha.-, polymers with maleic anhydride, reaction products with 2,2,6,6-tetramethyl-4-piperidinamine; 1,6-hexanediamine, N,N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-, polymers with morpholine-2,4,6-trichloro-1,3,5-triazine reaction products, methylated; Phenolic antioxidant: 2,6,-di-tert-butyl-4-(4,6-bis(octylthio)-1,3,5,-triazine-2-ylamino) phenol; pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionate); octadecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)-propionate; 3,3',3',5,5',5'-hexa-tert-butyl-a,a',a'-(mesitylene-2,4,6-triyl)tri-p-cresol; 2-(1,1-dimethylethyl)-6-[[3-(1,1-dimethylethyl)-2-hydroxy-5-methylphenyl] methyl-4-methylphenyl acrylate; 1,3,5-tris(3,5-di-tert-butyl-4-hydroxybenzyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione; 3,4-dihydro-2,5,7,8-tetramethyl-2-(4,8,12-trimethyltridecyl)-2H-1-benzopyran-6-ol; 2',3-bis[[3-[3,5-di-tert-butyl-4-hydroxyphenyl]propionyl]]propionohydrazide; isotridecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionate; 2,2'-ethylidenebis (4,6-di-tert-butylphenol); ethylene bis[3,3-bis[3-(1,1-dimethylethyl)-4-hydroxyphenyl]butanoate];1,3,5-tris(4-tert-butyl-3-hydroxy-2,6-dimethylbenzyl)-1,3,5-triazine-2,4,6-(1H,3H,5H)-trione; 2,2'-methylenebis(4-methyl-6-tertbutylphenol); 3,5-bis(1,1-dimethyethyl)-4-hydroxy-benzenepropanoic acid, C13-15 alkyl esters; 2,2'-isobutylidenebis(2,4-dimethylphenol); 1,1,3-tris(2'methyl-4'-hydroxy-5'tert-butylphenyl)butane; Phosphite: bis-(2,4-di-t-butylphenol) pentaerythritol diphosphite; tris (2,4-di-tert-butylphenyl)phosphite; trinonylphenol phosphite; distearyl pentaerythritol diphosphite; trilauryl trithiophosphite; Thiosynergist: didodecyl-3,3'-thiodipropionate; dioctadecyl 3,3'-thiodipropionate; 2,2'-thiodiethylene bis[3-(3,5-ditert-butyl-4-hydroxyphenyl)propionate]; 4,4'-thiobis(2-t-butyl-5-methylphenol); 2,2'-thiobis(6-tert-butyl-4-methylphenol); pentaerythritol tetrakis(b-laurylthiopropionate); Quencher: (2,2'-thiobis(4-tert-octyl-phenolato))-N-butylamine-nickel(II); Optical brightener: 2,2'-(2,5-thiophenediyl)bis(5-tert-butylbenzoxazole)	

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PARAMETER	UNIT	VALUE	REFERENCES
BIODEGRADATION			
Typical biodegradants	-	*Bacillus*	Abrusci, C; Pablos, J L; Corrales, T; Lopez-Marin, J; Marin, I; Catalina, F, Int. Biodet. Biodeg., 65, 451-59, 2011.
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	0/1/0	
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}	>5,000	
Skin rabbit, LD_{50}	mg kg^{-1}	>2,000	
ENVIRONMENTAL IMPACT			
Cradle to grave non-renewable energy use	MJ/kg	69-73	
Cradle to pellet greenhouse gasses	kg CO_2 kg^{-1} resin	1.8-2.0	
PROCESSING			
Typical processing methods	-	blown film, blow molding, coating, extrusion, injection molding, slot cast extrusion	
Processing temperature	°C	180-327; 180-220 (extrusion of blown film); 200-240 (injection)	
Processing pressure	MPa	20-60 (holding)	
Additives used in final products	-	Antistatics: carbon black, copper complex of polyacrylic acid, ethoxylated amines, fatty diethanol amines, glycerol monostearate, graphite, ionomer, lauric diethanolamide, polyethylene glycol, quaternary ammonium compound, trineoalkoxy zirconate; Antiblocking: diatomaceous earth, natural silica, siloxane spheres, synthetic silica, talc, zeolite; Blowing agents; Release: stearyl erucamide; Slip: erucamide, ethylene bisoleamide, oleamide; Process aid; Thermal stibulizers; UV stabilizers	
Applications	-	automotive parts, agricultural film, bags, bottles, cast film, cling film, closures, diaper backsheet, drum liners, film, greenhouse film, hoses, lids, melt strength enhancer (Booster); overwrap film, parts of industrial containers, playground equipment, point of display cabinets, potable water tanks, toys, trash cans, tubing	
Outstanding properties	-	tear strength, toughness, processability, stiffness	
BLENDS			
Suitable polymers	-	EPDM, EVA, EVOH, LDPE, NR, PA6, PC, PLA, PMMA, PP, PVC, SBS, starch	