THERMAL AND ELECTRICAL PROPERTIES OF PE

THERMAL PROPERTIES

The thermal properties of polyethylenes do not vary significantly with molecular weight and density, the exception being the melting point. The data given in Table 1 lists some average thermal properties measured at 20°C.

Vicat Softening Point

The temperature at which polyethylene softens – as distinct from melts – varies with both molecular weight and density. The most convenient softening point test is the Vicat penetration test (ISO 306, ASTM D1525). The Vicat softening point occurs at a lower temperature than the crystalline melting point as measured by Differential Scanning Calorimetry.

Typical Vicat softening points for a range of *Alkathene* LDPE and *Alkatuff* LLDPE grades of different MFIs and densities are given in Table 2. The temperature defined by this test gives a practical guideline to the upper temperature limit at which a stressed sample of polyethylene may be used.

Table 1: Thermal Properties of Polyethylene at 20°C

Property	Value
Thermal Conductivity	0.34 W/m K
Specific Heat (at 20°C)	2.3 kJ/kg K
Specific Heat (above melting point)	2.5 kJ/kg K
Coefficient of Linear Thermal Expansion	2.2 x 10^{-4} cm/cm K
Decomposition Temperature (in vacuo)	280 – 300°C
Calorific Value	406 kJ/g

Table 2: Typical Vicat Softening Points for Alkathene LDPE, Alkatuff LLDPE, Alkatane HDPE at Various MFI and Density

	Vicat Softening Point (°C)								
	Alkathene LDPE			*Alkatuff* LLDPE			*Alkatane* HDPE		
	Density (g/cm³)								
	0.920	0.925	0.930	0.920	0.925	0.935	0.954	0.955	0.960
MFI (g/min)									
0.35							127		
0.7		103		112	114				
1.0	96.5			109				127	129
2.5	92.5		104			118.5			
4.0								125	
5.0 – 7.0	88.5	93				116			
20.0	84.0		97	98	104				

Thermal Conductivity

The thermal conductivity of plastic materials (i.e. their ability to conduct heat) varies with the degree of crystallinity and hence density. Figure 1 shows the thermal conductivity of several grades of polyethylene with different densities as a function of temperature. At 20°C the thermal conductivity of low density polyethylene is about 0.34 W/m K.

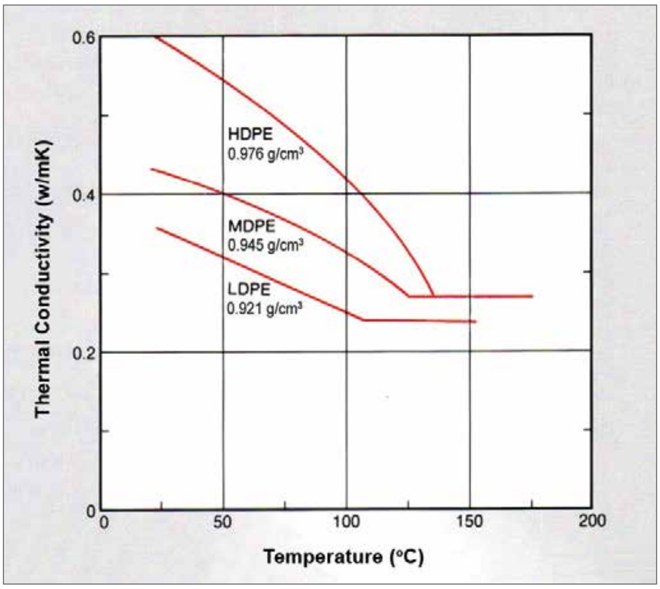

Figure 1: Thermal Conductivity of Several Polyethylenes of Specified Densities

Thermal Diffusivity

In any calculations of the heat transfer or temperature profiles in a material under non-steady state conditions, an important quantity is the thermal diffusivity. This parameter is related to the other thermal properties by the equation:

$\alpha = k / (\rho . C_p)$

Where α = Thermal Diffusivity

k = (Thermal Conductivity)

ρ = Density

Cp = Specific Heat

Figure 2 shows the thermal diffusivity of *Alkathene* LDPE, *Alkatuff* LLDPE and *Alkatane* HDPE as a function of temperature.

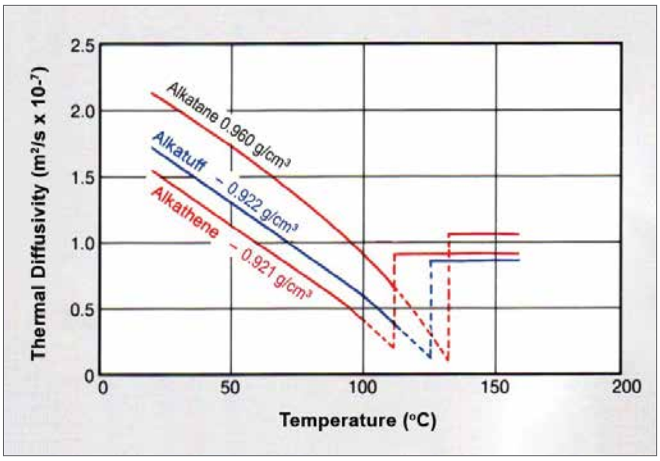

Figure 2: Thermal Diffusivity of *Alkathene* LDPE (density 0.921 g/cm³), *Alkatuff* LLDPE (density 0.922 g/cm³) and *Alkatane* HDPE (density 0.960 g/cm³)

Coefficient of Thermal Expansion

The linear coefficient of thermal expansion of low density polyethylene is approximately 2 x 10-4 °C^{-1} at 20°C. This coefficient, however, does not remain constant with temperature, but increases to about 3.5 x 10-4 °C^{-1} at 80°C.

A related property is the specific volume expansion which, for an isotropic material, is taken to be three times the linear coefficient.

The specific volume (reciprocal of the density) is also temperature dependent, as indicated in Figure 3 for both low and high density polyethylene. An important point to note is that the melt density of low density polyethylene is much lower than the solid density, being 0.760 g/cm³ at 200°C.

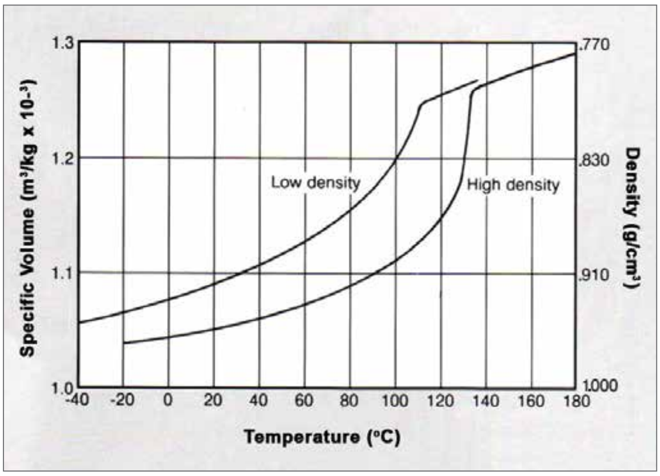

Figure 3: Variation of Specific Volume with Temperature for Low and High Density Polyethylene

ELECTRICAL PROPERTIES

The electrical properties of polyethylene are outstandingly good, it is one of the best insulating materials available. It has low dielectric losses, low permittivity, high resistivity, high dielectric strength and good resistance to tracking. With such electrical properties, it is used in many insulating applications in the cable industry, from submarine telecommunication cables to low power electrical distribution cables and telecommunications wiring.

These electrical properties do not vary appreciably with MFI and only slightly with density, and are very similar for branched and linear polyethylenes. Typical values (determined at 20°C) are given in Table 3.

Table 3: Electrical Properties of Polyethylene at 20°C

Property	Test Method	Value
Dielectric Loss (Power Factor)	IEC 250	50-200 microradians
Permittivity for 920 kg/m³	IEC 250	2.285
Permittivity for 940 kg /m³	IEC 250	2.325
Volume Resistivity (1000 sec polarisation)	IEC 93	approx. 1019 ohm cm
Surface Resistivity (at 75% R.H.)	IEC 93	> 1016 ohm
Dielectric Strength under oil, specimen 3 mm thick	IEC 243	20 kV/mm
Comparative Tracking Index	IEC 112	> 600

Permittivity and Dielectric Loss

The dielectric losses in polyethylene arise from the interaction of the polar groups in the material with the electric field. Some of these groups are intrinsic to the polyethylene molecule, while others arise from purposely added stabilisers, pigments, carbon black, etc. and from adventitious process and catalyst residues.

Additive-free low density polyethylene has a very low dielectric loss, amongst the lowest of any plastics, and virtually at the limits of measurement resolution. Values for the dissipation (power) factor or loss angle (tan delta) for a 0.923 g/cm³ density polyethylene at 23°C remain below 100 micro radians (0.0001) up to 10^7 Hz, and then generally increase with a slight maximum at 10^9 Hz (see Figure 4). The dielectric loss does not change markedly with temperature in the range 20 to 80°C, but decreases slightly with an increase in density.

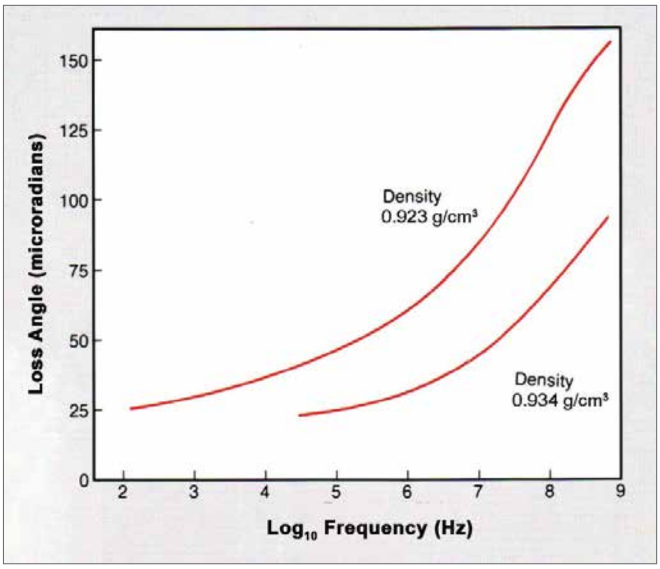

Figure 4: Dielectric loss (loss angle) of Polyethylene as a function of Frequency, Measured at 23°C

The dielectric loss is very sensitive to slight degrees of oxidation, such as may occur if processing has been faulty or if antioxidants have not been used correctly. Excess antioxidant and the wrong choice of antioxidant are both detrimental to the loss properties. Grades of polyethylene recommended for cable applications contain antioxidant sufficient to protect them during normal processing. The presence of any polar additives in the polymer will also markedly increase the values for tan delta. Dielectric loss properties are very sensitive to the small level of catalyst residues which may be present in polymers such as *Alkatuff* LLDPE made by low-pressure polymerisation processes.

The permittivity or dielectric constant of polyethylene (the ratio of the capacitance of polyethylene as the dielectric compared with the equivalent capacitance of a vacuum) increases slightly with increasing density, by about 0.0002 per 0.01 g/cm³; values are 2.285 for polymer of density 0.920 g/cm³ and 2.325 for polymer of density 0.940 g/cm³ (measured at 20°C and 10 kHz). Permittivity does not vary appreciably with frequency but does decrease slightly with increasing temperature, the temperature coefficient at 20°C being approximately -0.0012 per °C.

Because the water absorption of polyethylene is very low, its dielectric properties are not affected appreciably by humidity.

Dielectric loss and permittivity properties can be measured according to the methods in IEC 250 and ASTM D150.

Volume and Surface Resistivity

The resistivity of polyethylene is so high that true measurements are difficult to make. It increases with time of electrification due to polarisation effects. At testing times greater than 1,000 seconds, values of 10^{16} to 10^{17} ohm-m (at 20°C) are obtained for the volume resistivity.

The surface resistivity is strongly affected by the nature of the surface being measured, e.g. its cleanliness, surface finish and any additives which have exuded to the surface. The values obtained for various grades of polyethylene are of the order of 10^{16} ohms.

Measurement of the surface resistivity is often used to assess the effects of antistatic or antifog additives in film made from polyethylene. Addition of these additives results in a significant decrease in the surface resistivity values, and these values are very sensitive to the relative humidity.

Volume and surface resistivity are measured according to the test methods given in IEC 93 or ASTM D257.

Dielectric Strength

The dielectric strength of polyethylene subjected to either DC or low frequency AC voltages depends very markedly on the nature of the specimen and the conditions of testing. The satisfactory performance under high electrical stress depends on achieving a good contact between the polyethylene and the conductor. Without this, partial discharges will occur between the conductor and the polyethylene, leading to heat generation, degradation of the plastic and ultimate breakdown of the component. In practice, electrical components insulated with polyethylene should be designed for freedom from discharges.

Dielectric strength values measured according to standard test methods such as IEC 243 or ASTM D149 are short-term values obtained in the presence of excessive discharging and therefore cannot be used directly as design criteria.

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