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Chevron Phillips Chemical Company LP
The Woodlands, Texas

MARLEX® POLYETHYLENE
PREMIUM EXTRUSION AND RIGID PACKAGING RESINS

PE TSM-1

ENGINEERING PROPERTIES OF MARLEX® RESINS

INTRODUCTION

It is sometimes necessary to have information about high density polyethylene (HDPE) that does not normally appear on the typical resin data sheet. This Technical Service Memorandum (TSM) supplies data on many of the infrequently published physical, chemical and electrical properties of our Marlex® resins. In this Memorandum, we will briefly discuss many of these test procedures and provide available information concerning particular resin properties as well as comparing Marlex HDPE to other resin types.

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ACOUSTICAL

Sound Velocity in Polyethylene - The sound velocity in Marlex HDPE is 2.21 x 10^3 m/sec.*

*Data from Naval Weapons Laboratory in Dahlgren, Virginia

CHEMICAL

Fungus Resistance

The fungus resistance of Marlex HDPE was determined using a test method described in Military Specification, MIL-E-5262A. In this procedure, tensile bars were sprayed with a suspension containing a specified mixture of five groups of fungi drawn from 16-day old cultures. The exposed tensile specimens were suspended over water in a vessel that was then sealed. To produce 95 ± 5% relative humidity in the chamber, the entire assembly was heated up to 86 ± 2°F (30° ± 1°C) and so maintained for a period of 28 days. After conditioning, the exposed samples were washed in alcohol, wiped dry and tested for tensile strength according to standard ASTM procedures. As a control, unexposed samples were conditioned and tested in the same manner.

Marlex HDPE showed no evidence of deterioration or corrosion due to fungus exposure.

TABLE 1

Fungus Resistance of Marlex High Density Polyethylene

	Control	Tensile Bars Sprayed with Fungus* Suspension
Tensile, psi (MPa)	4530 (31.2)	4530 (31.2)
Elongation, %	21	21

*Group I	Chaetonium globosum
Group II	Rhizopus higricans
Group III	Aspergillus flavus
Group IV	Penicillium funiculosum
Group V	Fusarium moniliforme

Chemical Resistance

Marlex polyethylenes are very resistant to chemical attack. However, they are sometimes affected by aggressive chemical environments. A few strong oxidizing agents and mineral acids can react with the resins. Other low molecular weight chemicals and oils absorb into and permeate through the resins. The absorption of liquid can affect appearance and dimensional accuracy of formed parts. When dispersed throughout the HDPE, a few liquids can act as an internal lubricant and reduce its toughness and mechanical strength. To determine the effects of most typical commercial and industrial chemicals, Marlex HDPE has been tested before and after immersion in a number of liquid chemicals selected to represent most of the types in common use. Both chemical reactivity and absorption depend heavily on temperature so the entire test procedure was conducted at room and elevated temperatures to quantify that dependency.

Effect of Chemicals on Tensile and Elongation - Tensile specimens as specified by ASTM D638 were immersed in various test liquids contained in glass jars. The jars were then sealed and brought to test temperatures in forced draft ovens held at 80°, 120° and 150°F (27, 49 and 66°C). After exposure for three months, the specimens were removed and tested on an Instron tensile testing machine. Unexposed samples were tested for control. A rapid strain rate of 20 inches (508 mm) per minute was employed to emphasize any decay of strength.

Most significant changes in mechanical strength were accompanied by some visible change in appearance. Oxidizing acids may not only cause a slight increase in weight but also cause color changes to occur. For example, concentrated sulfuric acid at 150°F (66°C) oxidized the samples so much that they turned black. Concentrated nitric acid caused yellowing.

To determine the extent of absorption, the change in weight was determined. A coupon measuring 1 inch x 2 inch (25.4 x 50.8 mm) was weighed and then immersed for three months at a temperature of 80°, 120° or 150°F (27, 49 or 66°C) in the test material. After exposure, the coupon was removed, wiped dry and weighed. Most of the organic chemicals that were used caused an increase in weight of the specimens due to a permeability of the chemical into the HDPE sample.

An examination of this data reflects the excellent chemical resistance of Marlex HDPE. Exposure periods longer than 3 months result in very little additional change in properties.

TABLE 2

Ultimate Tensile Strength, Elongation and Absorption of Marlex® HDPE after Three Months

	Temp.		Tensile Strength			Elongation		% Weight
Chemical	°F	°C	psi.	MPa	% Change	% Elong.	% Change	Change
Battery Acid (36%)	80	27	4480	30.9	-2.6	22	-4.3	-0.01
	120	49	4360	30.0	-5.2	27	+17.4	-0.01
	150	66	4670	32.2	+1.5	31	+34.8	-0.03
Nitric Acid (70%)	80	27	4670	32.2	+1.5	20	-13.0	+1.09
Hydrofluoric Acid	80	27	4460	30.7	-3.1	26	+13.0	+0.01
(52 – 55%)	120	49	4500	31.0	-2.1	28	+21.7	–
Phosphoric Acid (85%)	80	27	4580	31.6	-0.4	23	+0.0	+0.00
	120	49	4490	31.0	-2.3	30	+30.4	+0.00
	150	66	4680	32.2	-1.7	29	+26.1	-0.06
Chromic Acid (25%)	80	27	4610	31.8	+0.2	23	+0.0	-0.55
	120	49	4500	31.0	-2.2	28	+21.7	-0.07
	150	66	4300	29.6	-5.9	31	+34.8	-0.51
Hydrochloric Acid (37%)	80	27	4620	31.8	-0.4	22	-4.3	+0.04
	120	49	4370	30.1	-5.1	20	-13.0	+0.07
	150	66	4590	31.6	-0.2	30	+30.4	-0.03
Glacial Acetic Acid	80	27	4580	31.6	-0.4	26	+13.0	+0.81
	120	49	4440	30.6	-3.4	32	+39.1	+0.73
	150	66	4550	31.4	-1.0	33	+43.5	+0.39
NaOH (50%)	80	27	4590	31.6	-0.3	24	+4.3	+0.07
	120	49	4320	29.8	-0.6	24	+4.3	+0.09
	150	66	4650	32.0	-1.0	33	+43.5	-0.02
Nitrobenzene	80	27	4420	30.5	-3.9	30	+30.4	+2.25
	120	49	4070	28.0	-11.6	41	+78.3	+2.94
	150	66	4410	30.4	-4.1	40	+73.9	+3.47
Phenol	80	27	4590	31.6	-0.2	24	+4.3	+2.70
	120	49	4540	31.3	-1.3	28	+21.7	+0.41
	150	66	4730	32.6	+2.8	29	+26.1	+0.54
10 Wt. Motor Oil	80	27	4440	30.6	-3.5	28	+21.7	+1.87
	120	49	3770	26.0	-8.0	49	+113.0	+6.31
	150	66	4130	28.5	-10.1	53	+130.4	+6.86
Hydrogen Peroxide (30%)	80	27	4440	30.6	-3.4	25	+8.7	+0.01
	120	49	4410	30.4	-4.1	26	+13.0	-0.05
	150	66	4710	32.5	+0.5	32	+39.1	-0.03
Clorox	80	27	4550	31.4	-1.0	25	+1.1	+0.01
	120	49	4520	31.1	-1.8	25	+8.7	-0.06
	150	66	4580	31.5	-0.5	37	+60.9	-0.24
Methyl Salicylate	80	27	4260	29.4	-7.3	32	+39.1	+3.76
	120	49	4050	27.9	-12.0	42	+82.6	+4.92
	150	66	4110	28.3	-10.7	47	+104.3	+6.63
Ethylene Glycol	80	27	4520	31.1	-1.8	21	-4.3	+0.01
	120	49	4450	30.6	-3.3	27	+17.4	-0.06
	150	66	4710	32.5	-2.4	30	+30.4	-0.01
Tetralin	80	27	4020	27.7	-12.7	42	+82.6	+7.08
	120	49	3590	24.7	-22.0	53	+130.4	+7.08
	150	66	3620	24.9	-6.9	48	+108.7	+16.06
Benzaldehyde	80	27	4280	29.5	-7.0	27	+17.6	+2.08
	120	49	4130	28.5	-10.2	37	+61.0	+2.76
	150	66	4280	29.5	-6.9	37	+65.2	+16.06

TABLE 2 - continued

Ultimate Tensile Strength, Elongation and Absorption of Marlex® HDPE after Three Months

	Temp.		Tensile Strength			Elongation		% Weight
Chemical	**°F**	**°C**	**psi**	**MPa**	**% Change**	**% Elong.**	**% Change**	**Change**
Acetophenone	80	27	4200	28.9	-8.7	33	+43.5	+2.13
	120	49	4110	28.3	-10.7	37	+61.0	+2.79
	150	66	4250	29.3	-7.5	37	+60.9	+3.90
Chlorobenzene	80	27	4280	29.5	-6.9	31	+34.8	+5.33
	120	49	3980	27.4	-13.5	43	+87.0	+4.91
	150	66	4150	28.6	-9.7	40	+73.9	+9.25
Butyl Carbitol	80	27	4390	30.2	-4.6	27	+17.6	+0.53
	120	49	4420	30.5	-3.8	29	+26.1	+1.38
	150	66	4150	28.6	-9.7	40	+73.9	+1.66
Toluene	80	27	4060	28.0	-11.8	36	+56.5	+4.40
	120	49	3950	27.2	-11.9	43	+87.0	+3.86
	150	66	4110	28.3	-2.0	43	+87.0	+5.58
Mineral Oil	80	27	4510	31.1	-2.0	29	+26.0	+0.82
	120	49	4200	29.0	-8.8	45	+95.7	+5.70
	150	66	4040	27.9	12.1	55	+139.1	+5.86
Aniline	80	27	4520	31.1	-1.7	24	+4.3	+0.76
	120	49	4300	29.6	-6.5	30	+30.4	+1.15
	150	66	4530	32.0	-1.6	37	+60.9	+1.45
Xylene	80	27	3980	27.4	-13.3	49	+113.0	+5.29
	120	49	3900	26.9	-15.2	44	+91.3	+5.02
	150	66	4040	27.9	-12.1	44	+91.3	+7.07
Diethylene Triamine	80	27	4440	30.6	-3.5	22	-4.3	+0.17
	120	49	4410	30.4	-4.1	32	+39.1	+0.39
	150	66	4610	31.8	-2.1	31	+34.6	+0.23
5% Soap Solution	80	27	4460	30.8	-3.0	30	+30.4	+0.06
	120	49	4620	31.9	+0.5	23	+0.0	+0.10
	150	66	4740	32.7	+3.0	30	+30.4	+0.04
Water	80	27	4530	31.2	-1.5	25	+8.7	+0.02
	120	49	4570	31.5	-0.7	28	+21.7	+0.02
	150	66	4620	31.8	+0.4	32	+39.1	+0.02
Air	80	27	4590	31.6	-0.3	23	+0.0	-0.03
	120	49	4430	30.5	-3.8	25	+8.7	+0.02
	150	66	4710	32.4	-2.3	27	+17.4	-0.02
Ethyl Alcohol	80	27	4580	31.6	-0.4	27	+17.4	+0.26
Amyl Acetate	80	27	4110	28.3	-10.6	47	+104.3	+3.31
Diethyl Ether	80	27	4200	29.0	-8.8	49	+113.0	+3.07
Turpentine	80	27	3970	27.4	-13.6	58	+152.2	+6.65
Tetrachloroethane	80	27	4110	28.3	-10.7	40	+74.0	+8.59
N-Heptane	80	27	4100	28.3	-10.8	45	+95.7	+4.99
Cyclohexane	80	27	3940	27.1	-14.3	45	+95.7	+6.52
Ethyl Acetate	80	27	4260	29.4	-7.4	45	+95.7	+2.23
Carbon Tetrachloride	80	27	4070	28.1	-11.5	34	+47.8	+14.00
Benzene	80	27	4300	29.6	-6.5	24	+4.3	+5.50
Bromine Water	80	27	4530	31.2	-1.6	24	+4.3	+3.75
NH_4OH (28%)	80	27	4640	32.0	+0.9	23	+0.0	+0.02

Additional information regarding the chemical resistance of Marlex polyethylene is presented in other PTC documents. This data is provided for use only as a guideline in the preliminary determination of packageability, because chemical compatibility is highly dependent on storage and use conditions. Furthermore, many products are combinations of chemicals, so the ultimate compatibility with the packaging material involves testing the combination of the product material and its proposed container.

ELECTRICAL

Dielectric Strength (ASTM D149)

The dielectric strength of an insulating material may be defined as the voltage gradient or dielectric stress through the material at which electrical failure or breakdown occurs. The total breakdown voltage is determined by placing electrodes on opposite surfaces of a specimen disc and increasing the potential difference between the electrodes until the material can no longer resist the flow of current. The dielectric strength is obtained by dividing that total breakdown voltage by the thickness of the specimen and generally reported in volts per mil of specimen thickness.

Dielectric breakdown is usually accompanied by arcing between the electrodes and leaves a permanent conductive path through the material and/or a puncture hole. It is an important measure of the material's ability to insulate against electrical stress without permanent conductive failure. This ability is critical in the primary functions of insulation which are the mechanical support and electrical isolation of circuit components at different potentials to ground or each other. Proof-tests of dielectric withstand capability are required of most electrical equipment by the various electrical codes and certifying laboratories. Many require proof - testing of electrical appliances at twice the rated voltage plus 900 or 1000 volts applied for a specified time between current carrying parts and all grounded or dead metal components. If the insulating material can withstand abnormally high dielectric stress, it is presumed capable of withstanding service conditions and transient voltage surges by an ample margin of safety.

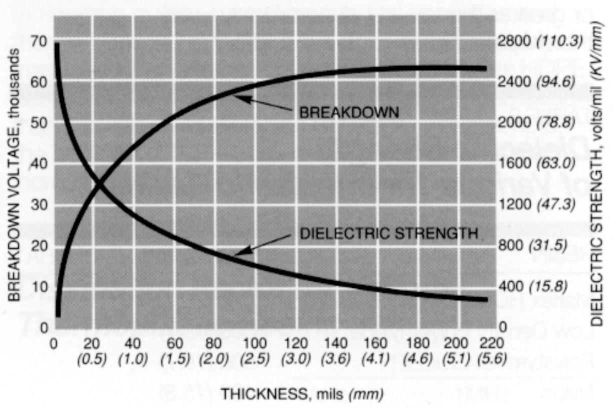
The dielectric strength of an insulating material depends heavily on three classes of variables: the electrical characteristics of the circuit, the molded configuration of the end product or generic specimen and the environmental conditions of service. In general, the most critical variable of typical AC circuitry is its frequency.

The dielectric strength of most insulating materials decreases substantially with increasing frequency. At frequencies ranging up to 100 Hertz, the decline of dielectric strength can be considered negligible. At audio or radio frequencies ranging from 10^3 to 10^7 Hertz, however, dielectric strength may be only a small fraction of that at 60 Hertz. Dielectric strength also varies with the form and size of test electrodes, the rate and duration of voltage application and the surrounding medium.

Dielectric strength can vary substantially with the molded configuration of the end part or standard test specimen. The most critical variable is specimen thickness. Even though reported in volts per mil (kV/mm), dielectric strength increases dramatically with decreasing specimen thickness. Apparently the ratio of surface interface to intervening bulk is critical. For example, the dielectric strength in volts per mil of a thin film often proves about double that of 60 mil (1.5 mm) specimens. The effect of specimen thickness on dielectric strength in volts per mil (kV/mm) of Marlex HDPE is presented graphically in Figure 1.

FIGURE 1

Effect of Thickness on Dielectric Strength and Breakdown Voltage



Dielectric strength also varies with environmental conditions, particularly temperature and humidity. Since it does not absorb significant moisture, the dielectric strength of Marlex HDPE remains much more stable than that of hygroscopic materials. In any case, the only significant way to compare materials at widely varying service conditions is to determine the dielectric strength of specimens conditioned in representative environments.

Since the property is affected by so many variables, no practical lab test for dielectric strength can be accurately representative of all varying service conditions and electrical parameters. Definitive values are needed, however, for comparison of different materials and for specification purposes. Therefore, the dielectric strength of Marlex HDPE has been determined according to the procedure specified in ASTM D149. The test specimens were discs measuring 3 11/32 inch in diameter and 1/8 inch thick.

They were conditioned until stable at standard laboratory atmosphere (50% RH at room temperature) then placed between one-inch diameter brass electrodes. The assembly was immersed in transformer oil to eliminate breakdown around the sample. The voltage between the electrodes was increased at the rate of 0.5 - 1.0 KV per second until breakdown occurred. The electrode potential was controlled by a high voltage breakdown tester model PA 50-1005-R-JX manufactured by Industrial Instruments, Inc. The maximum voltage possible with this equipment is 1.0 x 10^5 volts.

The dielectric strength of Marlex HDPE is equal to or greater than nearly all commonly used thermoplastic resins.

TABLE 3

Dielectric Strength of Various Thermoplastic Resins

RESIN	Dielectric Strength V/mil	(kV/mm)
Marlex HDPE	510	(20.1)
Low Density Polyethylene	500	(19.7)
Polystyrene	500	(19.7)
Nylon 400	400	(15.8)
Cellulose Acetate	350	(13.8)
Polyvinyl Chloride (Rigid)	425 -1300	(16.7 - 51.2)
Polytetrafluoroethylene	480	(18.9)

Dielectric Constant (ASTM D150)

Dielectric constant is a measure of the extent to which a dielectric or insulating material polarizes when placed in an electric field of specified intensity. Though several mechanisms of polarization occur, the dielectric constant reflects principally the dislocation of negative electron charges relative to positive nuclear charges in the atom as well as some distortion of atomic positions within the molecules. When the material is placed in an electric field, the atomic and distortional polarization occurs almost instantaneously and thus it changes in phase with the alternating field in AC circuitry. Furthermore, the energy required to polarize the atoms and molecules is released as their polarity reverses. In effect, that energy is stored in the insulating material as a simple capacitor. In quantitative terms, therefore, dielectric constant is defined as the capacitance of a capacitor using the test material as insulation compared to that of an identical capacitor using air as the dielectric.

Dielectric constant is significant because it affects the amount of energy stored in the circuit itself. Although a small added capacitance might have no ill effects, it is usually preferable to minimize dielectric constant rather than compensate for it throughout the circuit. Thus low dielectric constant is particularly desirable for communications and electronic circuits that rely on crisp transmission of low-intensity signals. In particular, those circuits often employ a wide range of frequency so the dielectric constant should remain stable throughout the range.

Because of their essentially non-polar and symmetrical molecular structure, Marlex polyolefins exhibit a low dielectric constant throughout the range of frequencies from 10^2 to 10^{11} Hertz. There are very few other polymers for which the dielectric constant remains even approximately constant over this frequency range. The most commonly used thermoplastics are tabulated below:

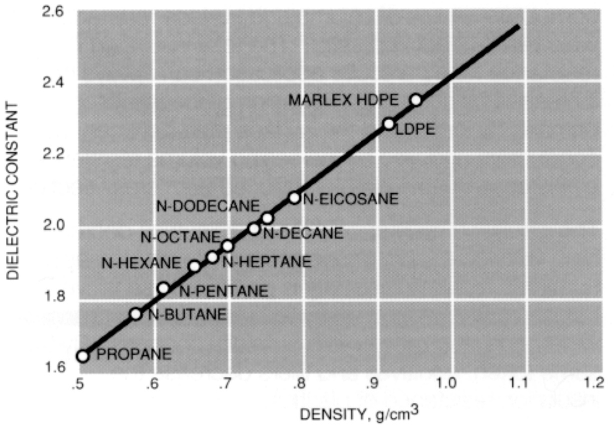
TABLE 4

Dielectric Constants of Various Thermoplastic Resins

	Frequency	
	1kHz	1 MHz
Marlex High Density Polyethylene	2.35	2.35
Low Density Polyethylene	2.28	2.28
Polystyrene	2.5 - 2.6	2.5 - 2.6
Nylon	4.00	3.40
Cellulose Acetate	3.5 - 7.0	3.2 - 7.0
Polyvinyl Chloride (Rigid)	3.0 - 3.3	2.8 - 3.1
Polytetrafluoroethylene	2.00	2.00
Ethylene-Propylene Copolymer	2.40	2.40

Compared to Marlex HDPE, the dielectric constant for LDPE is somewhat lower due to its lower density. The relationship of dielectric constant to density of several non-polar symmetrical hydrocarbons is presented graphically in Figure 2. The low dielectric constant of Marlex HDPE may be reduced further by blending it with low density polyethylene (LDPE) or other polymers which are also good dielectrics and which decrease its density. Most other fillers increase the dielectric constant of Marlex HDPE. For example, as little as 2.5% carbon black increases the dielectric constant of Marlex from 2.35 to 2.6 at 1 kHz.

FIGURE 2
Dielectric Constant Versus Density



Dissipation Factor (ASTM D150)

Dissipation factor is closely related to dielectric constant. As discussed earlier, dielectric constant reflects the instantaneous polarization expressed as energy stored in the system. Some polarization mechanisms do not occur instantaneously. For example, the orientation of dipolar molecules or segments of molecules must overcome the mechanical hindrance of adjacent segments and molecules. Since that reorientation takes time, it lags behind the alternating polarity of the AC field, which can reverse before all the polarization energy is released. That lost energy is dissipated as heat in the insulating material. In that sense, dissipation factor is the ratio of energy dissipated as heat compared to the energy stored in the system, both factors averaged over a cycle. In conventional terms, it is defined as the ratio of current that is in phase compared to the current that is 90° out of phase. The energy required to reorient the dipoles depends on their number and strength and the time required depends on their mobility. For a given material, therefore, the time lag remains constant. As frequency increases, however, the out-of-phase component of polarization becomes more significant and more energy is dissipated as heat. Thus dissipation factor is dependent on frequency.

Highly polar compounds such as polyvinyl chloride, cellulose acetate, nylon and the like are highly susceptible to the phenomenon of field induced orientation and thus dissipate substantial energy as heat. Non-polar compounds such as polyethylene and polystyrene, on the other hand, exhibit much lower dissipation factor. The low dissipation factor is desirable in electrical insulation because it minimizes not only the waste of energy but also the immediate and cumulative effects of heat on the material. Materials with low dissipation factor are not readily heated by dielectric heating methods.

Some polar materials do exhibit a range of dissipation factor depending on the amount of residual impurities in different lots. Marlex HDPE, however, is subjected to rigorous quality control on residual impurities and thus its dissipation factor does not vary appreciably from one lot to another. Fillers added to Marlex HDPE can affect the dissipation factor even more dramatically than they affect its dielectric constant. For example, the addition of 2.5% carbon black causes a tenfold increase in dissipation factor at 1 kHz.

TABLE 5
Dissipation Factor for Various Thermoplastic Resins

	Frequency	
	1kHz	1MHz
Marlex HDPE	0.0002	0.0003
LDPE	0.0003	0.0003
Polystyrene	0.0001 - 0.0003	0.0001 - 0.0003
Nylon	0.02	0.04
Cellulose Acetate	0.01-0.06	0.01-0.10
Polyvinyl Chloride (Rigid)	0.0009 - 0.017	0.006 - 0.019
Polytetrafluoroethylene	<0.0002	0.0002
Ethylene-Propylene Copol.	0.00017	0.00021

Loss Factor (ASTM D150)

The loss factor of electrical insulating materials is the product of the dissipation factor "D" and dielectric constant "K". It is proportional to the energy loss per Hertz per squared potential gradient per unit volume of insulation.

In AC circuits, insulation with low loss factor and low dielectric constant are desirable to minimize power losses. Therefore, high polymers (especially Marlex HDPE) are superior to inorganic materials.

Furthermore, absorbed moisture can dramatically reduce insulation performance and thus the low moisture absorption by Marlex HDPE makes it a superior insulator.

TABLE 6

Loss Factor of Various Thermoplastic Resins

	Frequency	
	1 kHz	1 MHz
Marlex HDPE	0.0005	0.0007
LDPE	0.0007	0.0007
Polystyrene	0.0003 - 0.0008	0.0003 - 0.0008
Nylon	0.08	0.14
Cellulose Acetate	0.03 - 0.38	0.03 - 0.33
Polyvinyl Chloride (Rigid)	0.027- 0.051	0.017- 0.053
Polytetrafluoroethylene	<0.0004	<0.0004

Volume Resistivity, Insulation Resistance (ASTM D257)

The volume resistivity is a measure of the internal electrical resistance, i.e., resistance to the steady passage of current (not resistance to puncture), and thus is a measure of the suitability to serve as an insulator. Leakage at power frequencies, such as might occur in electrical appliances, may be a shock hazard, and the physiological effect of even a minute fraction of an ampere is sufficient to affect the utility of an appliance and its safety. High performance requires good insulation resistance, especially at audio and radio frequencies. In actual test it is determined to be the resistance in ohms between opposite faces of a centimeter cube.

TABLE 7

Volume Resistivity of Various Thermoplastic Resins

	Volume Resistivity ohm ● cm
Marlex HDPE	>6 x 10^{15}
LDPE	6 x 10^{15}
Polystyrene	1 x 10^{17} - 1 x 10^{19}
Nylon	4.5 x 10^{13}
Cellulose Acetate	1 x 10^{10} - 1 x 10^{12}
Polyvinyl Chloride (Rigid)	1 x 10^{16}
Polytetrafluoroethylene	>1 x 10^{16}

"Insulation Resistance" is used to describe the composite effects of volume and surface resistance, which always act in parallel. The total insulation resistance for a particular application can always be increased by changing the design of the insulators, primarily by increasing the surface path between the conductors and also by increasing volume resistance by increased path length or reduced path cross section.

The insulation resistance of solid dielectrics decreases both with increasing temperature and with increasing humidity. Volume resistivity is particularly sensitive to temperature changes while surface resistivity changes widely and very rapidly with humidity changes. By the same token, additives and fillers decrease the insulation resistance of plastics.

Since the prime requirement of an insulating material is high electrical resistance under a variety of conditions, a high value of volume resistivity is desired.

FLAMMABILITY

Arcing Ignition Underwriters Laboratories, UL 746

The specimen is subjected to 40 applications per minute, for a maximum of 5 minutes, of an electric arc between electrodes supplied by a 33-amp current at 240 volts. The average number of arcs required to ignite or melt the specimen is reported at several electrode locations on and above the specimen surface.

TABLE 8

Number of Arcs Required to Ignite

	Distance of Electrodes from the Surface, inches (mm)			
	0	1/16 (1.57)	1/4 (6.35)	1/2 (12.7)
HDPE	79 - 182	49 - 57	70 - 200	200+
MDPE	77 - 120	88 - 103	200+	-
Polypropylene	81 - 170	33 - 51	27 - 200	200+
ABS, High Heat	18 - 65	19 - 30	30 - 52	200+
Nylon 6	200+	-	-	-
Polycarbonate	40 - 131	60 - 125	200+	-

Burn Rate

A. By ASTM D635 (horizontal mounting of test bar) polyethylene is classified as burning with a rate of 1 in. (25.4 mm) per minute.

B. By MVSS 302 (>50 mil thick specimen) - 1 in. (25.4 mm) per minute.

C. By ASTM E-84 Tunnel Test - Flame Spread 97.8(a)
Fuel Contribution 30
Smoke Density 350

(a) Red Oak Control rated at 100. The lower the number, the slower the flame spread.

Ignition Temperature (ASTM D1929)

	Flash, ˚F (ºC)	Self-Ignition, ˚F (ºC)
Polyethylene	645 (341)	660 (349)

Oxygen Index* (ASTM D2863)

The relative flammability of plastics is rated by the oxygen index. The percent oxygen or oxygen index is the minimum concentration of oxygen that will just support combustion.

Polyethylene	17.4

*Flammability Handbook for Plastics - Union Carbide Corporation

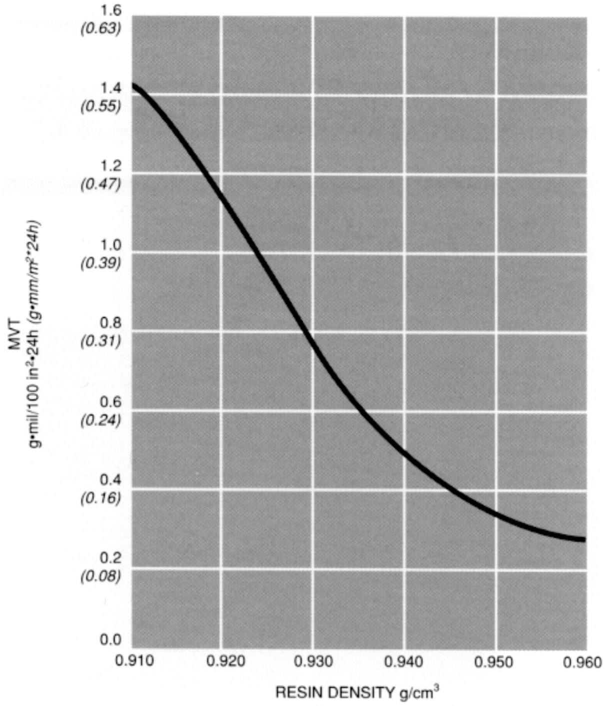
PERMEABILITY

Moisture Vapor Transmission (ASTM E96 - Desiccant Method)

This procedure employs a desiccant, such as anhydrous calcium sulfate, sealed in an aluminum dish by a film sample with its outer surface exposed to the environment. The assembly is conditioned in a humidity cabinet that circulates air maintained at 100°F (38°C) having 90 percent relative humidity. The weight gained over a period of time is attributed to water captured by the desiccant from which the water vapor transmission rate is determined. Increasing polyethylene density significantly reduces the rate at which moisture vapor permeates film (Figure 3).

FIGURE 3

Effect of Resin Density on Moisture Vapor Transmission (MVT)



Permeability to Gases of Marlex HDPE (ASTM D1434)

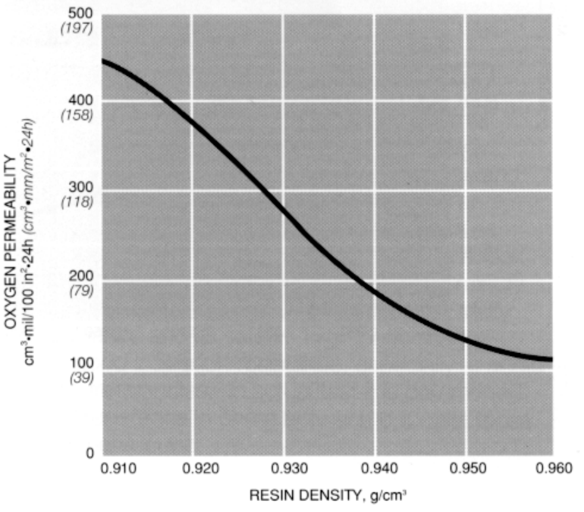
In this test, the polyethylene sample acts as a membrane between two pressure vessels. The vessel on one side of the sample is charged with the test gas and maintained at a specific temperature and at one atmosphere pressure. The vessel on the other side of the sample is evacuated and so maintained under vacuum. The volume of test gas that passes through the sample is recorded periodically until a steady rate is established.

	Rate	
Gas	**cm^3•mil/100 in^2•24 h**	**(cm^3•mm/m^2•24 h)**
Carbon Dioxide	345	136
Hydrogen	321	126
Oxygen	111	44
Helium	247	97
Ethane	236	93
Natural Gas	113	44
Freon 12	95	37
Nitrogen	53	21

Again, as density increases the polyethylene becomes more resistant to permeation as shown in Figure 4.

FIGURE 4

Effect of Resin Density on Oxygen (O_2) Permeability



PHYSICAL AND MECHANICAL

Abrasion Resistance - Taber Abrader (ASTM D1044)

The resistance of plastics to wearing or abrasion can be determined by several methods, one of which uses the Taber abrader. An abrasive wheel (CS-10) is rotated against a flat specimen for a specified number of revolutions. The wheel is loaded with a 1000-gram (1 kg) weight. The value reported is the weight loss in milligrams per 1000 revolutions.

Abrasion Resistance depends to a great extent on the hardness of the material and the texture of the abrasive. For instance, a coarse abrasive may not abrade a soft material (such as LDPE) as much as it will a hard material (such as styrene) because the soft material will deflect rather than abrade. The converse is often found to be true as well. That is, a fine abrasive will attack a soft material to a greater extent than it will a hard material. Obviously, abrasion tests are difficult to interpret and in order to obtain definitive data for a given application it is desirable to run an actual use test in the final service of the item.

Typical results for Marlex polyethylenes usually run between 1-5 mg/1000 revolutions depending on molecular weight, density and possibly other factors.

Apparent (Bulk) Density (ASTM D1895)

The determination of bulk density is made using methods similar to ASTM Method D1895. Apparent, or bulk, density is the weight per unit volume of the pelleted resin, including the voids between the pellets. A typical range for Marlex HDPE pellets is 35-38 lbs/ft^3 (0.56-0.61 g/cm^3).

Coefficient of Friction

A. Horizontal Sliding Block (ASTM D1894)

A 2.5 in. (64 mm) square, 0.25 in. (6.4 mm) thick steel block is pulled across the surface of a 5 x 10 in. (127 x 254 mm) rectangular sheet of resin at a speed of 5 in. (127 mm) per minute. The forces required to start and continue the block in motion are used to calculate coefficients of friction (static and kinetic).

	Static	**Kinetic**
Polyethylene	0.31	0.22

B. Steel Wheel Rotating Against a Block of Resin
A stainless steel wheel under load was rotated at several velocities against a flat block of resin, 0.620 x 0.25 x 0.5 in. (15.7 x 6.4x 12.7 mm). Typical friction values are:

	15 lb. (6.8 kg) load for 2 minutes			
rpm	0	40	100	190
Marlex HDPE	0.15-0.30	0.30-0.35	0.30-0.40	0.30-0.40

	90 lb. (40.8 kg) load for 10 minutes
rpm	90
Marlex HDPE	0.15 - 0.20

Coefficient of Linear Thermal Expansion (ASTM E831)

The change of the linear dimension of Marlex HDPE at different temperatures is an important factor for structural applications as well as in all types of forming. The coefficient of thermal expansion was determined according to ASTM E831 using a thermo mechanical analyzer. Typical CLTE values for Marlex HDPE follow:

Temperature Range, °F (°C)		in/in/°F (cm/cm/°C)	
-100 to 100	(-73 to 38)	5.34×10^{-5}	(9.6×10^{-5})
100 to 180	(38 to 82)	7.87×10^{-5}	(14.2×10^{-5})
180 to 250	(82 to 121)	10.0×10^{-5}	(18.0×10^{-5})

These figures are important in establishing the usefulness of high density polyethylene in close tolerance applications where a known temperature variation will be encountered.

Compressive Properties of Polyethylene (ASTM D695, ASTM D621)

These tests provide information on the deformation under compression of molded plastic materials primarily intended for structural and insulating purposes. In the case of Marlex HDPE, the deformation under sufficient load is a dimensional change due to flow.

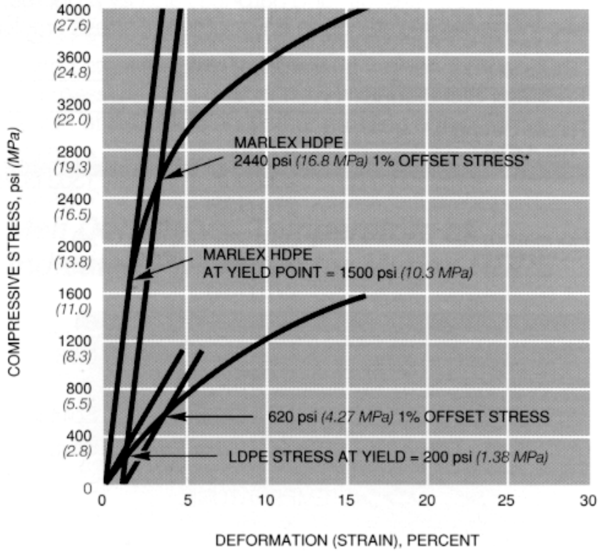
Compressive Properties of Rigid Plastics (ASTM D695) - This procedure employs a prism having a length dimension that is twice its width and with ends which are parallel within 0.0005 inches (0.5 x 0.5 x 1 inch). It is subjected to a constant rate of compressive straining [0.050 inches (1.3 mm) per minute] between two parallel crossheads of a Baldwin hydraulic testing machine. The performance of Marlex HDPE and conventional LDPE has yielded compressive stress versus strain (deformation) data presented graphically in Figure 5.

The compressive yield stress is defined as the stress at which the stress-strain curve departs from linearity. The stress at which the stress-strain curve departs from linearity by 1 percent deformation is the compressive stress at 1 percent offset. Both of these values are indicated on the compressive stress-strain curve. Below the compressive yield stress of 1500 psi (10.3 MPa) Marlex HDPE resin will tend to regain its original form when the load is removed. This elastic action is a function of the duration of load application. Perfect elasticity should not be expected if the load exists for an appreciable length of time.

The compressive modulus of elasticity is the ratio of compressive stress to strain over the linear part of the stress-strain curve.

FIGURE 5

Compressive Stress/Strain Curve Marlex HDPE, LDPE at Room Temperature



* The tests were stopped at 17% deformation because the curves beyond that point were found to be meaningless due to a rapid increase in cross-sectional area as a result of specimen cold flow.

Deformation of Plastics Under Load (ASTM D621)

Method A: Rigid Plastics - A 1/2 in (12.7 mm) cubical specimen is maintained under a constant compressive force of 500 pounds (227 kg) between the parallel plates of a device manufactured by the Luster Jordan Company. The whole assembly is enclosed in a constant temperature oven at 122°F (50°C). The change in thickness is observed over a period of 24 hours and reported as follows:

Polyethylene Material	Original Height, in. (cm)	Deformed Height, in. (cm)	Deformation, Percent	Time Elapsed, Hours	Pressure, psi (MPa)	Temperature, °F (°C)
High Density	0.506 (1.27)	0.465 (1.18)	8.1	22	2000 (13.8)	122 (50)
Low Density	0.509 (1.30)	0.425 (1.08)	16.5	24	2000 (13.8)	122 (50)

Method B: Non-Rigid Plastics - Method B is essentially the same as Method A except that (1) the test specimen is in the shape of a cylinder 1.129 in (28.7 mm) in diameter and 0.250 in (6.4 mm) thick having the two flat surfaces parallel; (2) the pressure is 100 psi (0.69 MPa): and (3) the test period is 3 hours. The results of testing by Method B are as follows:

Polyethylene Material	Original Height, in. (cm)	Deformed Height, in. (cm)	Deformation, Percent	Time Elapsed, Hours	Pressure, psi (MPa)	Temperature, °F (°C)
High Density	0.483 (1.23)	0.483 (1.23)	0	3	100 (0.69)	122 (50)
Low Density	0.498 (1.26)	0.496 (1.25)	5	3	100 (0.69)	122 (50)

Irradiation - Effects on Properties of HDPE of Gamma and Beta Irradiation

Data indicate that polymer crosslinking occurs with beta or gamma irradiation accompanied by an increase in density, tensile strength and hardness and by a decrease in solubility. Irradiation of Marlex high density polyethylene also increases resistance to environmental stress cracking.

Typical Properties	Temperature,		Beta Irradiation Dosage (Megarads)				
	°F	(°C)	0	5	10	15	50
Tensile Strength, psi (MPa)	82	(28)	4110 (28.3)	4217 (29.1)	4293 (30)	4400 (30.3)	4560 (31.4)
	200	(93)	1303 (8.98)	1567 (10.8)	1640 (11.3)	1120 (7.7)	1477 (10.8)
	270	(132)	-	180 (1.2)	212 (1.46)	455 (3.13)	745 (5.13)
Elongation, %	82	(28)	20	18	22	20	20
	200	(93)	167	375	520	505	133
	270	(132)	-	510	445	385	110
Hardness, Shore D			64	67	67	68	70
Density, g/cm^3			0.96	0.96	0.96	0.96	0.96
Solubility, Tetralin, 266°F (130°C)			Soluble	Insoluble	Insoluble	Insoluble	Insoluble
Color			White	White	Ivory	Ivory	Tan

Typical Properties	Temperature,		Gamma Irradiation Dosage (Megarads)			
	°F	(°C)	0	1	10	100
Tensile Strength, psi (MPa)	82	(28)	5840 (40.2)*	7007 (51.7)	7120 (49.1)	8360 (57.6)
Elongation, %	82	(28)	13	15	15	1
Hardness, Shore D			64	68	70	70
Density, g/cm^3			0.952	0.955	0.955	0.967
Solubility, Tetralin 266°F (130°C)			Soluble	Insoluble	Insoluble	Insoluble

'Measured by different laboratories.

TABLE 9

Effect of Gamma and Beta Irradiation of Marlex HDPE on Environmental Stress Cracking in IGEPAL CO-630 at 122°F (50°C)

Type of Irradiation	F_{50} Values, h	
Dosage, Rads	Gamma	Beta
None	20	20
$1x10^6$	20	-
$3x10^6$	24	-
$6x10^6$	110	40
$1x10^7$	700	350
$3x10^7$	350	350
$1x10^8$	1	-

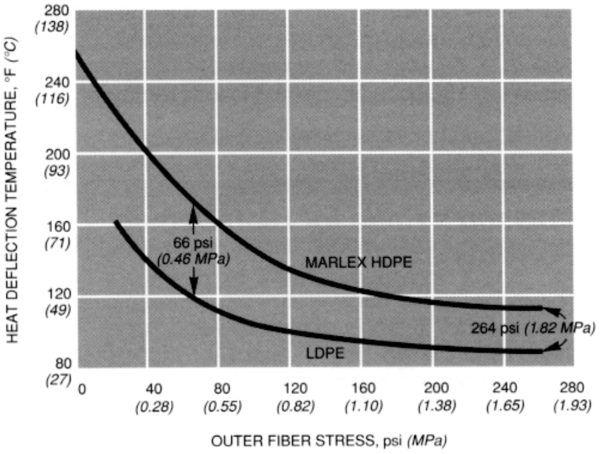
Heat Deflection Temperature (ASTM D648)

This test is primarily intended to determine the temperature at which an arbitrary deformation occurs when specimens are subjected to a specific fiber stress. It is used to indicate the behavior of plastic material at elevated temperatures in applications that are similar to the test procedure. Although this test is designed for more rigid materials like polystyrene, unplasticized vinyl polymers and nylon, it is especially useful in comparing Marlex HDPE with other polyethylenes.

Injection molded bars 5 in. (127mm) long, 0.5 in. (12.7 mm) wide and 0.25 in. (6.4 mm) thick are supported along the 0.25 in. edge between two points 4 in. (102 mm) apart. Weight is applied at the center of the span to impose a fiber stress of 66 psi (0.46 MPa). The bars are immersed in silicone oil and the bath temperature increased at a rate of 3.6°F (2°C) per minute. The bath temperature at the instant the specimen deflects (bends) 0.010 in. (0.254 mm) is the heat deflection temperature. In a more stringent test that was originally designed for thermosetting resins, a heavier weight is used to impose a 264 psi (1.8 MPa) fiber stress. Therefore, care should be taken to designate the load involved when interpreting heat deflection data. Figure 6 compares the heat deflection temperature of a typical Marlex high density polyethylene with low density polyethylene at various loadings.

FIGURE 6

Effect of Loading on Heat Deflection Temperature

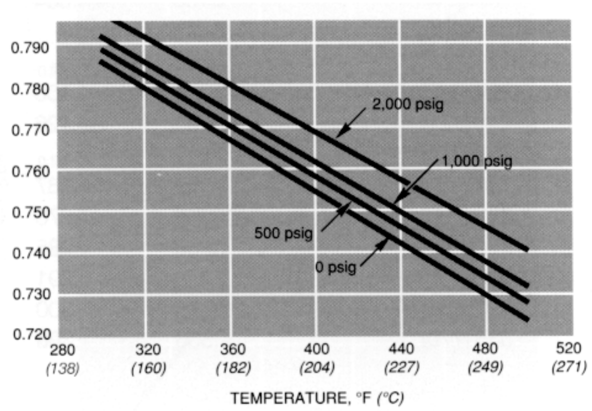


Melt Density

The density of molten Marlex HDPE differs from its density in the solid form. Unlike the solid density, which covers a broad range depending upon resin morphology, the density of all Marlex HDPEs in the melted state is about the same at a given temperature and pressure. The melt density may be useful in the design of extruders and other molding equipment.

FIGURE 7

Melt Density vs. Temperature at Indicated Pressures for Marlex HDPE



Hardness, Rockwell R (ASTM D785)

The indentation hardness of plastics and electrical insulating materials can be determined by a Rockwell hardness instrument which subjects the specimen to “penetrator" under 60 kg load for a specified time period. The instrument measures the indentation remaining 15 seconds after the load is removed. Marlex resins cover a range from 40 - 80.

Poisson's Ratio for High Density Polyethylene

This is the ratio of transverse strain (a contraction for tensile stress) to longitudinal strain (elongation). It is a measure of the reduction in specimen cross section which accompanies stretching. The Poisson's ratio for Marlex HDPE is typically 0.40 - 0.45.

Specific Volume - Temperature Relationship for Various Polyethylene

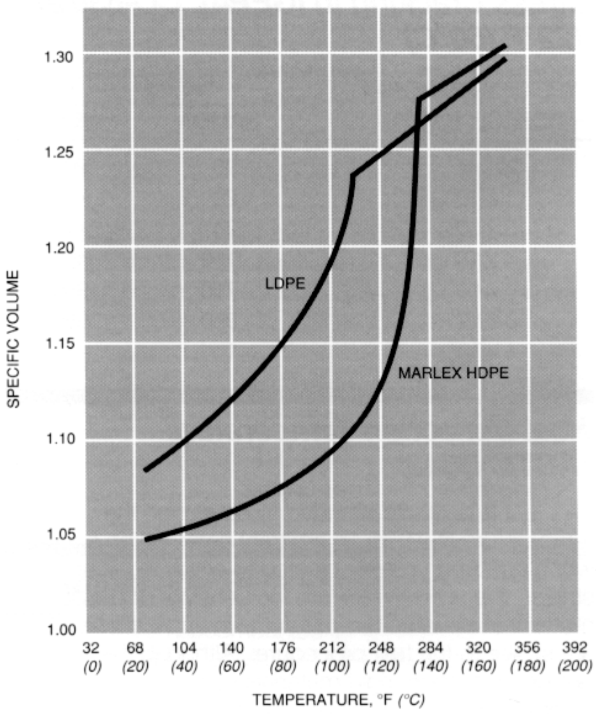
The effect of temperature on specific volume of LDPE and Marlex HDPE is presented in the following table and in Figure 8.

$$\text{Specific Volume} = \frac{1}{\text{Specific Gravity}}$$

Temperature, ˚F	(˚C)	LDPE	HDPE
77	(25)	1.083	1.046
86	(30)	1.089	1.047
122	(50)	1.111	1.057
158	(70)	1.134	1.070
194	(90)	1.166	1.084
212	(100)	1.191	-
221	(105)	1.206	-
230	(110)	1.240	1.106
248	(120)	1.249	1.126
257	(125)	-	-
266	(130)	1.260	1.187
275	(135)	-	1.278
284	(140)	1.269	1.285
302	(150)	1.278	1.291
320	(160)	1.288	1.300
338	(170)	1.300	1.308

FIGURE 8

Specific Volume – Temperature Relationship for Various Polyethylenes



Shear Strength (ASTM D732)

Shear strength is the maximum load required to shear the specimen in such a manner that the sheared or moving portion has completely cleared the stationary portion. Shear strength of Marlex resins covers a range of 2800 - 4500 psi (19.3 - 31.0 MPa).

Stiffness (ASTM D1043, D747)

Torsional, ASTM D1043	**psi (MPa)**
LDPE	30,000 - 35,000 (207 - 241)
HDPE	50,000 - 60,000 (345 - 413)

Cantilever Beam, ASTM D747	**psi (MPa)**
HDPE	95,000 -170,000 (655 - 1171)

Critical Surface Tension of High Density Polyethylene and Other Resins

The critical surface tension for spreading defines the wetability of a solid surface by noting the lowest surface tension a liquid can have and still exhibit a contact angle greater than zero degrees on that solid. The constant is expressed in units of dynes per centimeter and the temperature is specified. The following values are based on measurements made at 68 - 77°F (20 - 25°C).

Material	Critical Surface Tension dynes•cm^{-1}
Polyethylene	31
Polystyrene	33 - 35
Polytetrafluoroethylene	18.5
Polyvinyl chloride	39
Polymethyl methacrylate	33 - 44
Polyethylene terephthalate	43

Tensile Impact (ASTM D1822)

The energy to fracture by shock in tension is determined by measuring the kinetic energy expended by the pendulum of an impact machine in the process of breaking the specimen. One end of the specimen is mounted in the pendulum. The other end of the specimen is gripped by a crosshead that travels with the pendulum until it develops maximum kinetic energy. At that instant, the crosshead is arrested and the specimen breaks. As the pendulum completes its swing, it indicates the amount of its remaining kinetic energy.

Marlex HDPE (general purpose extrusion grade) typically runs in a range of 50 - 250 ft•lbf/in^2 (105 - 370 kJ/m^2). The value will depend upon the density and molecular weight of the resin.

Tensile Yield Strength of Marlex® High Density Polyethylene at Various Temperatures (ASTM D638)

Temperature,		Tensile Yield Strength,	
˚F	(˚C)	psi	(Mpa)
200	(93)	1200	(8.27)
180	(82)	1500	(10.3)
120	(49)	2800	(19.3)
80	(27)	3400	(23.4)
0	(-18)	5800	(40.0)

THERMAL PROPERTIES

Decomposition Temperature Range*

Material	˚F	(˚C)
Polyethylene	635 – 842	(335 - 450)
Polypropylene	622 - 770	(328 - 410)
Polystyrene	572 - 752	(300 - 400)
Poly(tetrafluoroethylene	946 - 1000	(508 - 538)
Nylon 6 and 6/6	590 - 716	(310 - 380)

*Flammability Handbook for Plastics - Union Carbide Corporation

Glass Transition Temperature*

Material	Tg, ˚F	(˚C)
Polyethylene	-193	(-125)
Polypropylene	-4	(-20)
Polystyrene	212	(100)

Heat of Combustion*

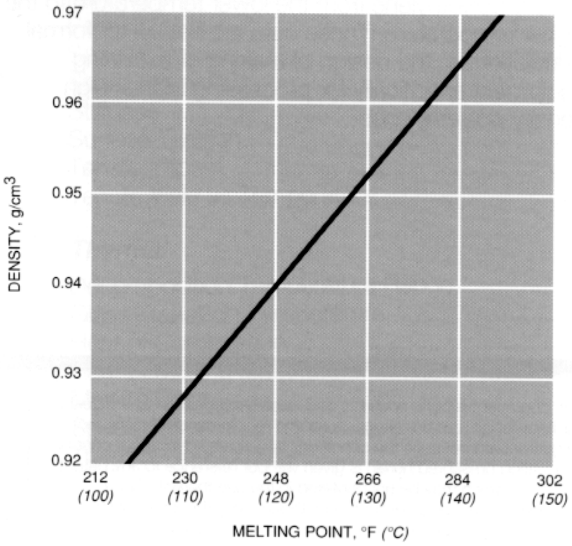
For polyethylene, the heat of combustion value is 19,400 Btu/lb. (45,100 kJ/kg).

Heat of Melting

Polyethylene Resin	Heat of Melting, Cal/g
High Density	60
Low Density	34

FIGURE 9

Melting Point of Polyethylene



Specific Heat

The specific heat of Marlex high density polyethylene, which is the amount of heat required to raise one gram of the polymer one degree Centigrade, was determined with a standard bomb type calorimeter. Since the specific heat increases with elevating temperature it is necessary to specify the temperature.

The specific heat of Marlex high density polyethylene at temperatures other than 77°F (25°C) can be approximated with the following formula:

$Cp = A + Bt$ ($t = {}^\circ C$)
$Cp = Cal/g/{}^\circ C$

This formula is useful over a limited range of temperatures.

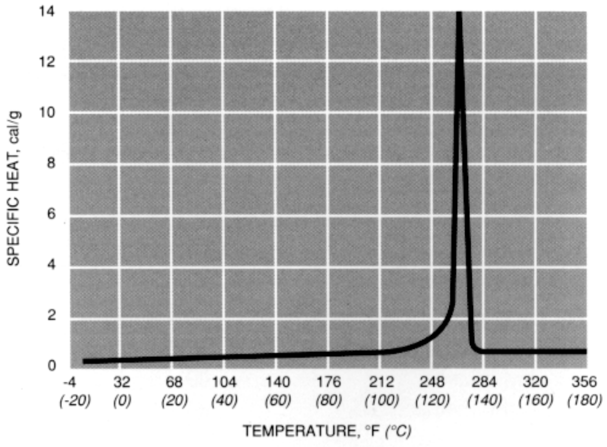
The constants, A and B, have been determined for Marlex high density polyethylene plastic for the straight-line portions of the specific heat versus temperature curve which comprises the range of usefulness of the above formula.

	Temperature,			
Marlex HDPE	**˚F**	**(˚C)**	**A**	**B**
Solid	1 to 200	(-17 to 93)	0.383	0.002
Molten	284 to 356	(140 to 180)	0.545	0.00053

A graph of the complete specific heat versus temperature curve for Marlex high density polyethylene from 1°F to 356°F (-17°C to 180°C) is shown in Figure 10. The curve is plotted so as to include the heat of fusion. Therefore, by integrating the curve (measuring the area under the curve) between the temperature limits desired, one may obtain a value for the quantity of heat required to raise the temperature of Marlex high density polyethylene from the lower temperature to the higher temperature. These data are helpful for formal calculations in the design of making or extruding equipment specifically for processing Marlex high density polyethylene.

FIGURE 10

Effect of Temperature on the Specific Heat of Marlex HDPE



Thermal Conductivity

The rate at which Marlex HDPE will transfer heat was determined by inserting thermocouples between polyethylene compression molded sheets of various thicknesses and compressing the sandwich between platens in a press (one platen cold, the other hot). The rate of temperature change through the sandwich is used to calculate the thermal conductivity value.

Typical Marlex HDPE thermal conductivities are 2.1 - 2.8 $Btu \cdot in/h \cdot ft^2 \cdot {}^\circ F$ (0.30 - 0.40 $W/m \cdot {}^\circ K$) in the temperature range from 104 to 199°F (40 to 93°C). This data is useful in the calculation of heat transfer through Marlex high density polyethylene in such applications as refrigerator liners, air conditioning and heating ducts, chemical process piping, thermos bottles, and the like.

Contact Information for CPChem's Polyethylene Group is available at this web site http://www.cpchem.com/index.asp, along with links to our polyethylene resins and MSDS sheets.

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