

The Electrical Properties of Some Crosslinked Isophthalic Polyesters

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Introduction

Polyester-styrene copolymers continue to be extensively used as insulating materials. Although there is information in the literature^{1,2} about the mechanical properties of both the resins and their copolymers, information on electrical properties is more limited. In particular, there are very few data that relate electrical properties to composition.

Many types of polyesters could be investigated. However, since California Research Corp. was engaged in the synthesis and study of the mechanical properties of isophthalic polyesters and their styrene copolymers, these Laboratories decided to investigate the electrical properties of the same materials. The polyester-styrene copolymers for which the electrical properties are herein reported were prepared by California Research Corp. using the preparation techniques reported by Carlston et al.³

There is no exact theory which can be used to predict the a.c. electrical properties of crosslinked polymers at varied frequencies and temperatures. However, by relating the chemical composition and structure to the general theory for the electrical properties of materials containing permanent dipoles, some trends can be predicted. Three simple changes can be made in the basic structure of a styrene-cross linked polyester made from maleic anhydride, isophthalic acid, a diol, and styrene. They are: (1) the ratio of isophthalic acid, to maleic anhydride, (2) the length of the diol chains between the acid groups, and (3) the styrene content.

When the ratio of isophthalic acid to maleic anhydride is increased, two competing effects should be expected. The molecule should be somewhat stiffened by the rigid backbone of the isophthalic acid, and this should lead to higher heat distortion points of the finished polymer and increased steric

hindrance of dipolar rotation in electric fields. However, if there is sufficient styrene to react with all the maleic anhydride and thus nearly remove unsaturation, the former effect should be small compared with the flexibilizing effect of reducing the maleic anhydride and thereby reducing the number of crosslinked points. Therefore, the net effect of increasing the ratio of isophthalic (IP) acid to maleic anhydride (MA) should be an increase in the flexibility of the copolymer, and, at a given frequency, a decrease in the temperature at which the electrical losses attain a maximum.

When the number of carbon atoms between the acid groups in isophthalic acid is increased, the flexibility of the copolymer should increase and hindrance to dipolar orientation decrease. This increased compliance as carbons atoms are added should asymptotically approach a maximum value beyond which the addition of more carbon atoms could begin to stiffen the copolymer. With enough carbon atoms added, the properties of the polymer should approach those of polyethylene. Kolb and Isard⁴ have found that the melting points of polyester polymers are consistent with these qualitative considerations.

The addition of sufficient styrene to remove unsaturation would increase the stiffness of the polyester-styrene copolymer. The number of styrene molecules in the resultant copolymer would probably be slightly greater than the number of maleic anhydride molecules or actually, after isomerization,⁵ of fumaric acid molecules. Excess styrene would form dimer and trimer crosslinking units between fumaric groups and act as a nonpolar diluent. In small amounts, this diluent should reduce the steric hindrance to polar group orientation and also reduce the polarization of the copolymer. For a large excess, it should begin to increase steric hindrance.

Processing variables such as type and amount of curing agent, curing time, curing temperature, and impurities also should affect the a.c. electric prop-

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erties, primarily by changing the degree of cross-linking.

In preceding work in these Laboratories, a few isophthalic polyester-styrene copolymer were examined. In these resins, only two different diols were employed (1,5-pentanediol and 1,3-butanediol) and the styrene concentration was in all cases constant. In the present work, the wider variations in composition permit a more definitive analysis of the effects of such variations on the electrical properties of the copolymers.

Experimental Methods

Preparation of Samples

The compositions of the samples of crosslinked polyester are tabulated in Tables I and II. The resins listed in Table I were experimental materials and those listed in Table II were production samples.

Details of the method of preparation of these resins have been reported elsewhere.³ Here it will

TABLE I

Composition^a of Crosslinked Isophthalic Polyesters in Which the Chain Length of the Diol and the Concentration of Styrene Are Varied

DOFL sample No.	Manuf.'s sample		Styrene, %	Catalyst, % ^b
	No. 21948	Diol		
1472	13	1,2-Propanediol	30	ATC ^c
1473	14		30	CHP ^d
1474	15		40	ATC
1475	16		40	CHP
1476	17		50	ATC
1477	18		50	CHP
1460	1	1,3-Butanediol	30	ATC
1461	2		30	CHP
1462	3		40	ATC
1463	4		40	CHP
1465	6		50	CHP
1466	7	1,5-Pentanediol	30	ATC
1467	8		30	CHP
1468	9		40	ATC
1469	10		40	CHP
1470	11		50	ATC
1471	12		50	CHP

^a Mole ratio of isophthalic acid to maleic anhydride = 1:1; excess diol = 5%.

^b All samples copolymerized with 500 ppm of *p-tert*-butyl catechol stabilizer.

^c Here ATC = 50% benzoyl peroxide in tricresyl phosphate.

^d Here CHP means cumene hydroperoxide.

TABLE II

Composition^a of Crosslinked Isophthalic Polyesters in Which the Mole Ratio of Isophthalic Acid to Maleic Anhydride and the Styrene Concentration Are Varied

DOFL sample No.	Manuf.'s sample		Styrene, %	Catalyst, % ^b
	No. 21948	IP:MA mole ratio		
1478	19	1:1	30	ATC ^c
1479	20		30	CHP ^d
1481	22		40	CHP
1483	24		50	CHP
1484	25	2:1	30	ATC
1485	26		30	CHP
1486	27		40	ATC
1487	28		40	CHP
1488	29		50	ATC
1489	30		50	CHP
1490	31	3:1	30	ATC
1491	32		30	CHP
1492	33		40	ATC
1493	34		40	CHP
1494	35		50	ATC
1495	36		50	CHP

^a All samples esterified with a 5% excess of 1,2-propanediol.

^b All samples copolymerized with 500 ppm of *p-tert*-butyl catechol stabilizer.

^c Here ATC = 50% benzoyl peroxide in tricresyl phosphate.

^d Here CHP means cumene hydroperoxide.

suffice to say that the esterification reaction was a two-step procedure in which the isophthalic acid was first esterified with the diol to a low acid number, and then the maleic anhydride was added and esterification continued. The esterification was carried out at 215°C. for 11 hr. Each resin was then powdered, dissolved in styrene containing stabilizer, and copolymerized with one or another of two different peroxide catalysts by heating for 4 hr. at 65°C., followed by another hour at 121°C.

Dielectric Measurements

Samples were machined into discs 2 in. in diameter and approximately 0.100 in. in thickness. Electrodes of air-drying silver were painted on each side. The dielectric constant and loss index of each sample were determined from measurements made on a modified Schering bridge at the following frequencies: 50, 100, 200, 10³, 2 × 10³, 10⁴, 2 × 10⁴, and 10⁵ cycles/sec. These measurements were made in accordance with the two-terminal method of determining the electrical properties of insulation

materials, ASTM method No. D150-47T. Measurements were made over the temperature range approximately -60°C . (-76°F .) to a temperature above that of the absorption peak temperature for each given sample. A special thermostated sample holder was employed (see Fig. 1).

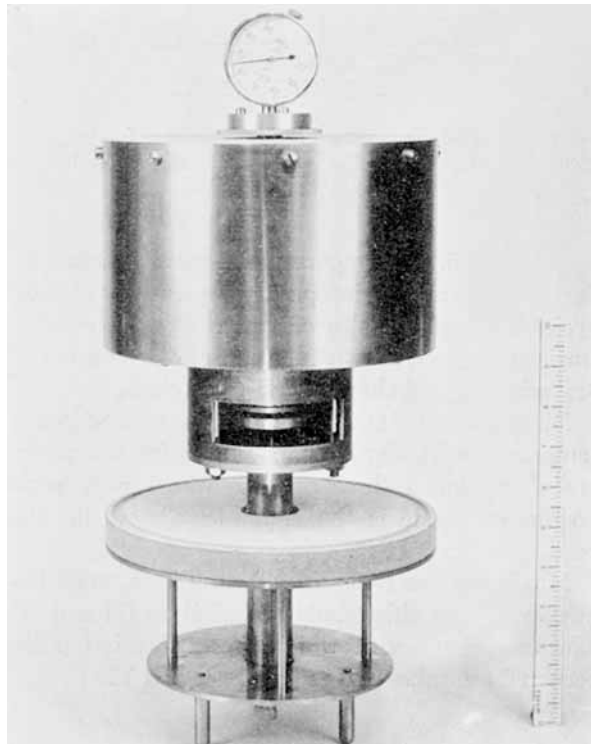


Fig. 1. High-temperature dielectric sample holder, oven raised for sample insertion.

Data

Loss index is plotted as a function of temperature at frequencies from 50 to 10^6 cycles/sec. in Figures 2, 3, and 4 for three samples whose only composition variable is the chain length of the diol used.

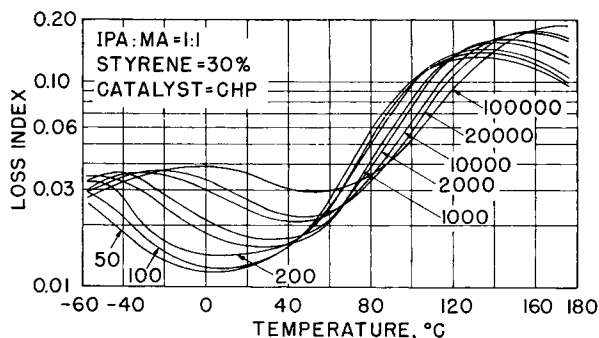


Fig. 2. Loss index vs. temperature for polyester containing 1,2-propanediol (frequency range 50-100,000 cycles/sec.).

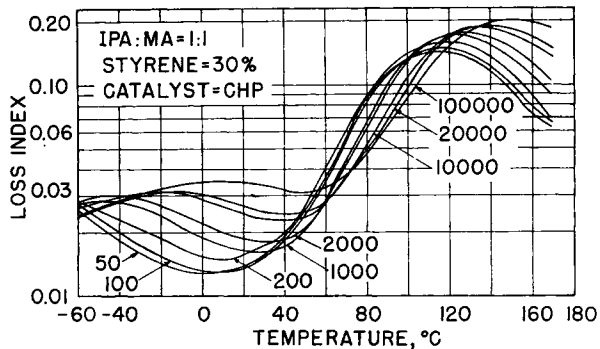


Fig. 3. Loss index vs. temperature for polyester containing 1,3-butanediol (frequency range 50-100,000 cycles/sec.).

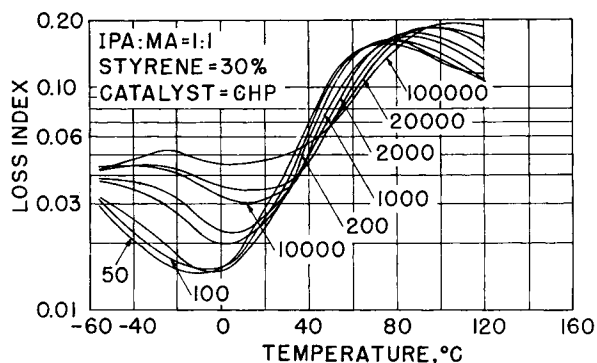


Fig. 4. Loss index vs. temperature for polyester containing 1,5-pentanediol (frequency range 50-100,000 cycles/sec.).

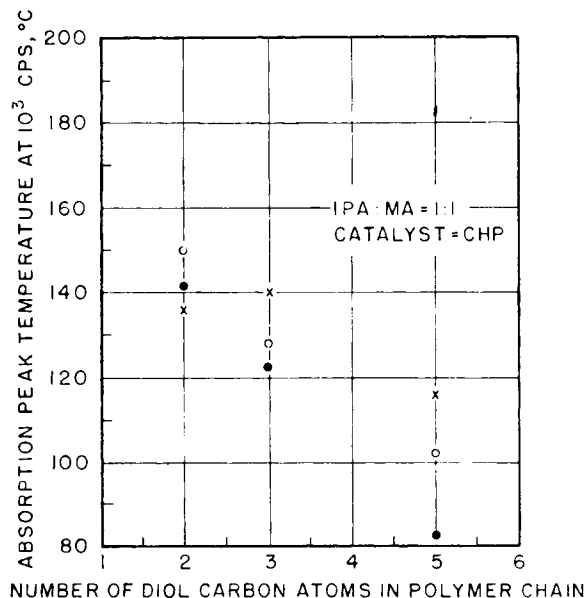


Fig. 5. Absorption peak temperature as a function of the number of diol carbon atoms in the polymer chain: (●) 30% styrene, (○) 40% styrene, and (×) 50% styrene.

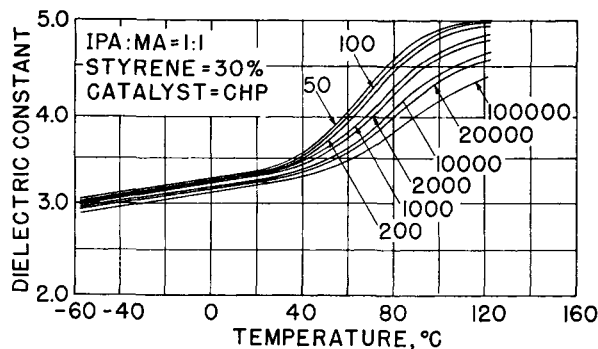


Fig. 6. Dielectric constant vs. temperature for polyester containing 1,2-propanediol (frequency range 50–100,000 cycles/sec.).

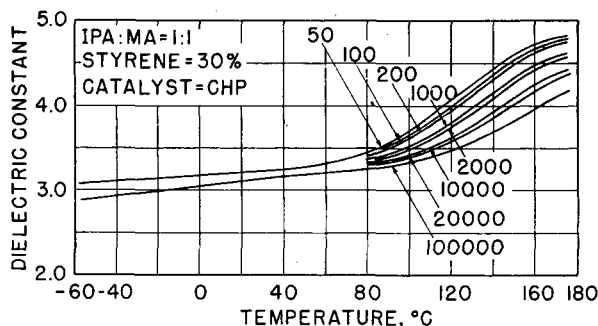


Fig. 7. Dielectric constant vs. temperature for polyester containing 1,3-butanediol (frequency range 50–100,000 cycles/sec.).

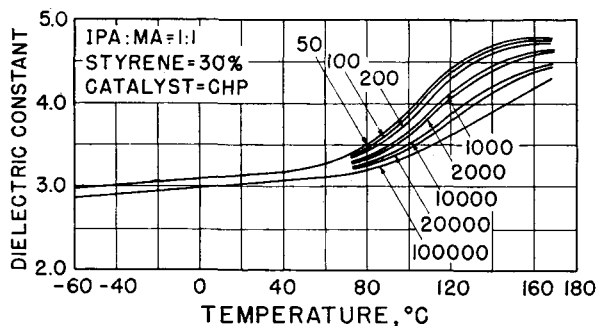


Fig. 8. Dielectric constant vs. temperature for polyester containing 1,5-pentanediol (frequency range 50–100,000 cycles/sec.).

In Figure 5, the temperature of maximum loss index (i.e., the absorption peak temperatures at 1000 cycles/sec.) of samples of varied styrene concentrations is plotted as a function of the number of diol carbon atoms in the copolymer chain.

Dielectric constant is plotted as a function of temperature in Figures 6, 7, and 8 for the previously mentioned three samples whose only composition variable is the chain length of the diol used.

Maximum loss index for all samples at each frequency measured is tabulated in Tables III and IV. The temperatures at which the absorption peaks occurred are tabulated in Tables V and VI.

TABLE III
Maximum Loss Index of Crosslinked Isophthalic Polyesters^a in Which the Chain Length of the Diol and the Concentration of Styrene Are Varied

Sample No.	Diol	Styrene, %	Maximum, ϵ''							
			Frequency, cycles/sec.							
			50	100	200	10^3	2×10^3	10^4	2×10^4	10^5
13	1,2-Propanediol	30	0.140	0.148	0.160	0.160	0.170	0.178	0.180	0.190
14		30	0.130	0.136	0.150	0.155	0.161	0.171	0.172	0.190
15		40	0.120	0.128	0.130	0.136	0.138	0.150	0.150	0.160
16		40	0.120	0.127	0.130	0.138	0.142	0.149	0.149	0.160
17		50	0.110	0.114	0.114	0.120	0.120	0.128	0.130	0.132
18		50	0.110	0.112	0.116	0.120	0.125	0.128	0.129	0.139
1	1,3-Butanediol	30	0.150	0.155	0.158	0.168	0.170	0.180	0.186	0.200
2		30	0.140	0.147	0.156	0.167	0.175	0.185	0.186	0.201
3		40	0.130	0.135	0.140	0.145	0.150	0.158	0.160	0.166
4		40	0.130	0.132	0.140	0.146	0.150	0.158	0.159	0.170
6		50	0.118	0.125	0.130	0.138	0.138	0.151	0.140	0.148
7	1,5-Pentanediol	30	0.141	0.148	0.150	0.160	0.161	0.170	0.176	0.182
8		30	0.155	0.159	0.167	0.169	0.176	0.189	0.190	0.195
9		40	0.132	0.140	0.142	0.145	0.149	0.157	0.158	0.166
10		40	0.130	0.135	0.135	0.142	0.144	0.150	0.150	0.158
11		50	0.110	0.118	0.124	0.127	0.130	0.133	0.138	0.141
12		50	0.118	0.122	0.122	0.122	0.122	0.124	0.122	0.128

^a Mole ratio of isophthalic acid to maleic anhydride = 1:1; excess diol = 5%.

TABLE IV
Maximum Loss Index of Crosslinked Isophthalic Polyesters* in Which the Mole Ratio of Isophthalic Acid to Maleic Anhydride and the Styrene Concentration Are Varied

Sample No.	IP:MA mole ratio	Styrene, %	Maximum, ϵ''							
			Frequency, cycles/sec.							
			50	100	200	10^3	2×10^3	10^4	2×10^4	10^5
19	1:1	30	0.138	0.142	0.150	0.158	0.165	0.170	0.172	0.183
20		30	0.118	0.125	0.130	0.140	0.145	0.158	0.160	0.172
22		40	0.100	0.105	0.110	0.118	0.125	0.132	0.135	0.145
24		50	0.098	0.102	0.106	0.110	0.115	0.120	0.120	0.130
25	2:1	30	0.205	0.215	0.220	0.230	0.230	0.235	0.235	0.242
26		30	0.218	0.220	0.225	0.240	0.245	0.250	0.250	0.258
27		40	0.190	0.190	0.200	0.200	0.210	0.210	0.210	0.212
28		40	0.185	0.190	0.192	0.200	0.200	0.210	0.210	0.215
29		50	0.170	0.178	0.180	0.182	0.185	0.190	0.188	0.190
30		50	0.160	0.160	0.170	0.170	0.175	0.175	0.175	0.180
31	3:1	30	0.260	0.260	0.260	0.265	0.270	0.270	0.270	0.270
32		30	0.290	0.290	0.295	0.295	0.295	0.300	0.300	0.305
33		40	—	0.225	0.230	0.235	0.240	0.240	0.250	0.250
34		40	0.225	0.230	0.230	0.235	0.240	0.240	0.240	0.250
35		50	0.198	0.198	0.205	0.205	0.200	0.200	0.200	0.205
36		50	0.195	0.195	0.200	0.200	0.205	0.205	0.210	0.215

* All samples esterified with a 5% excess of 1,2-propanediol.

TABLE V
Temperature of Absorption Peak for Crosslinked Polyester* in Which the Chain Length of the Diol and the Concentration of Styrene Are Varied

Sample No.	Diol	Styrene, %	Absorption peak temperature, °C.							
			Frequency, cycles/sec.							
			50	100	200	10^3	2×10^3	10^4	2×10^4	10^5
13	1,2-Propanediol	30	128	130	132	142	144	154	156	170
14		30	130	132	134	142	146	154	156	172
15		40	138	142	144	148	156	158	166	176
16		40	142	144	146	150	154	158	166	174
17		50	142	144	148	154	156	164	166	182
18		50	124	126	128	136	142	148	152	160
1	1,3-Butanediol	30	111	112	114	122	124	136	136	148
2		30	113	115	118	122	127	134	140	151
3		40	120	126	126	136	136	144	148	160
4		40	120	124	126	128	134	140	144	150
6		50	130	132	136	140	146	146	154	164
7		1,5-Pentanediol	30	72	74	80	84	88	96	100
8	30		72	74	80	82	90	94	98	108
9	40		82	84	86	90	96	100	102	110
10	40		96	96	98	102	110	112	114	120
11	50		72	76	80	82	84	92	96	100
12	50		106	108	112	116	120	126	128	142

* Mole ratio of isophthalic acid to maleic anhydride = 1:1; excess diol = 5%.

In Figures 9–13, the properties of samples of varied composition are compared over a temperature range. Figure 9 compares the dielectric constant and loss index of samples in which the chain length of the diol is changed. Figures 10 and 12 show the change in dielectric properties and in

transition temperatures with change in the mole ratio of isophthalic acid to maleic anhydride. Figure 11 compares samples in which the polymerization catalyst differed, and Figure 13 samples in which the per cent styrene is varied.

On plotting measured frequencies against the

TABLE VI
Temperature of Absorption Peak for Crosslinked Polyesters^a in Which the Mole Ratio of Isophthalic Acid to Maleic Anhydride and the Styrene Concentration Are Varied

Sample No.	IP:MA mole ratio	Styrene, %	Absorption peak temperature, °C.							
			Frequency, cycles/sec.							
			50	100	200	10 ³	2 × 10 ³	10 ⁴	2 × 10 ⁴	10 ⁵
19	1:1	30	132	136	140	150	154	166	168	184
20			146	148	150	158	160	166	170	182
22			156	158	160	164	166	178	180	190
24			148	150	154	160	164	170	176	182
25	2:1	30	112	114	116	124	130	138	144	156
26			118	120	124	132	136	142	150	162
27			114	116	120	128	132	142	146	158
28			122	126	130	136	138	148	152	164
29			100	104	110	116	120	132	138	148
30			122	124	128	134	138	144	148	160
31	3:1	30	104	106	118	120	132	134	148	150
32			108	110	112	120	124	132	136	146
33			—	112	114	122	124	132	136	148
34			108	112	114	120	124	132	136	148
35			50	94	100	106	110	120	126	138
36			50	110	112	116	122	126	134	150

^a All samples esterified with a 5% excess of 1,2-propanediol.

reciprocal of the absolute temperatures at which the absorption peaks occurred, the approximate activation energies of the samples can be compared as shown in Figures 14, 15, and 16.

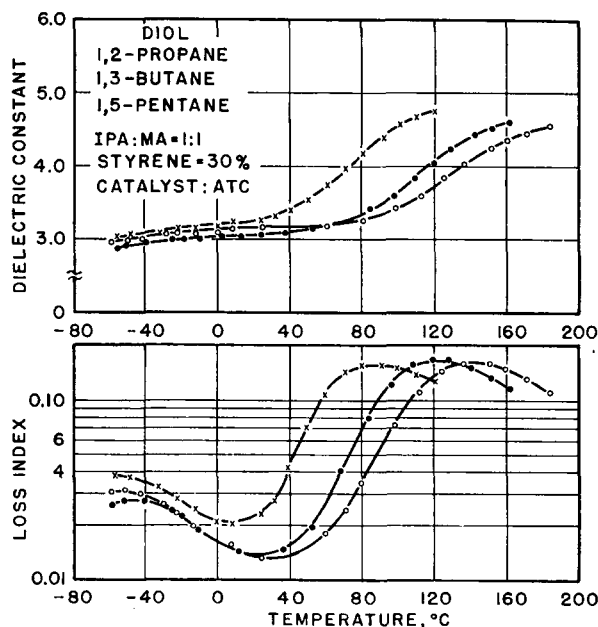


Fig. 9. Dielectric properties at 10³ cycles/sec. vs. temperature for polyesters in which the chain length is varied: (O) 1,2-propanediol, (●) 1,3-butanediol, and (×) 1,5-pentanediol.

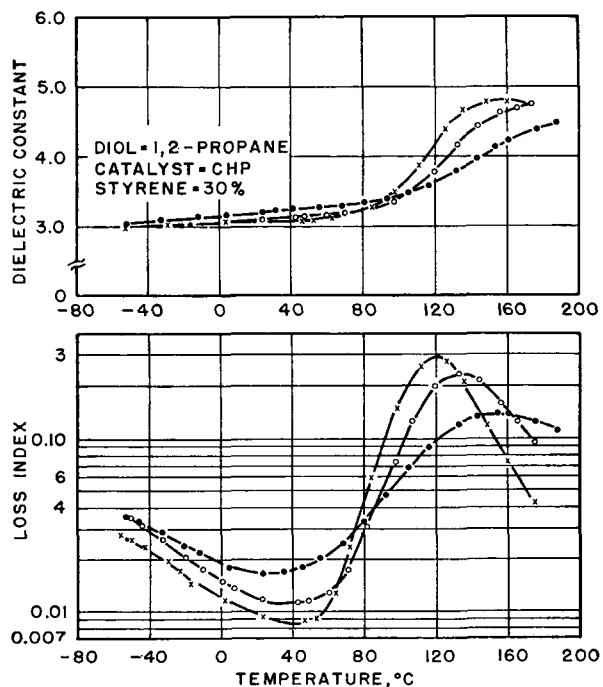


Fig. 10. Dielectric properties at 10³ cycles/sec. vs. temperature for polyesters in which the mole ratio of isophthalic acid to maleic anhydride is varied. IP:MA ratio: (●) 1:1, (O) 2:1, and (×) 3:1.

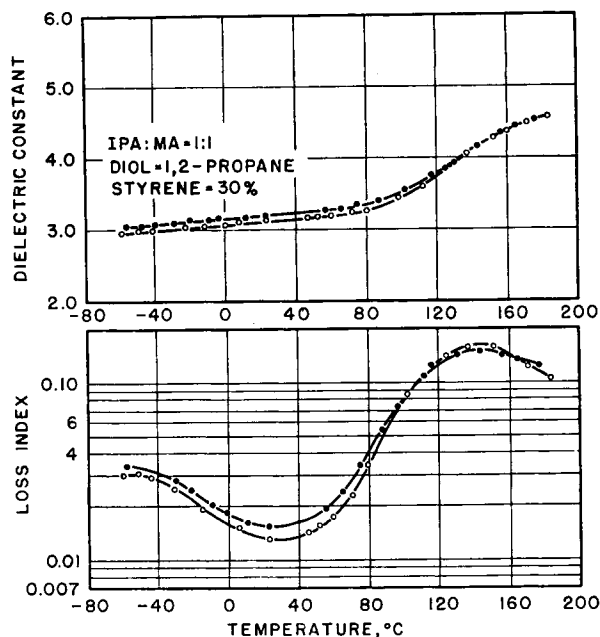


Fig. 11. Dielectric properties at 10^3 cycles/sec. vs. temperature for polyesters copolymerized with different catalysts. Peroxide catalyst: (O) ATC and (●) CHP.

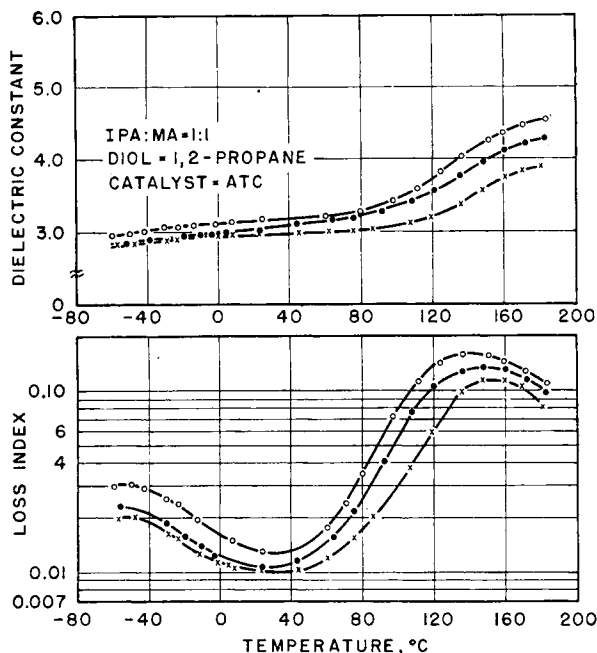


Fig. 13. Dielectric properties at 10^3 cycles/sec. vs. temperature for polyesters copolymerized with varied amounts of styrene: (O) 30% styrene, (●) 40% styrene and (×) 50% styrene.

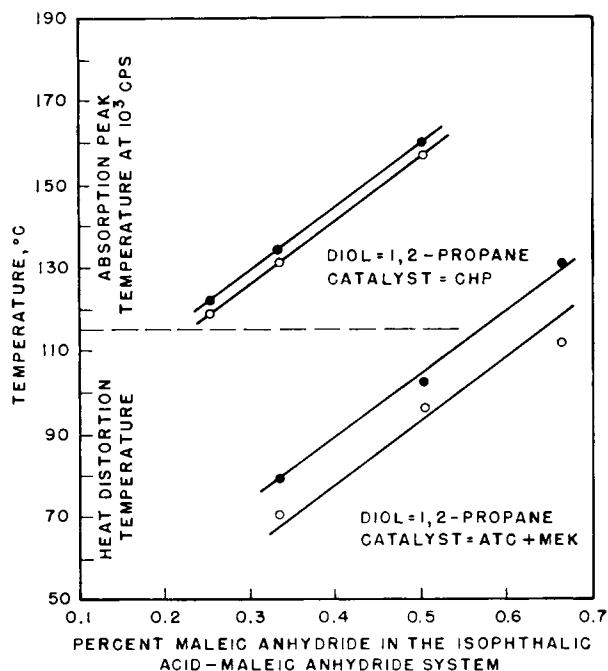


Fig. 12. Transition temperatures as a function of the number of possible crosslinking sites in copolymer. (a) Upper: (●) 50% styrene and (O) 30% styrene. (b) Lower: from ref. 3 (●) 50% styrene and (O) 30% styrene.

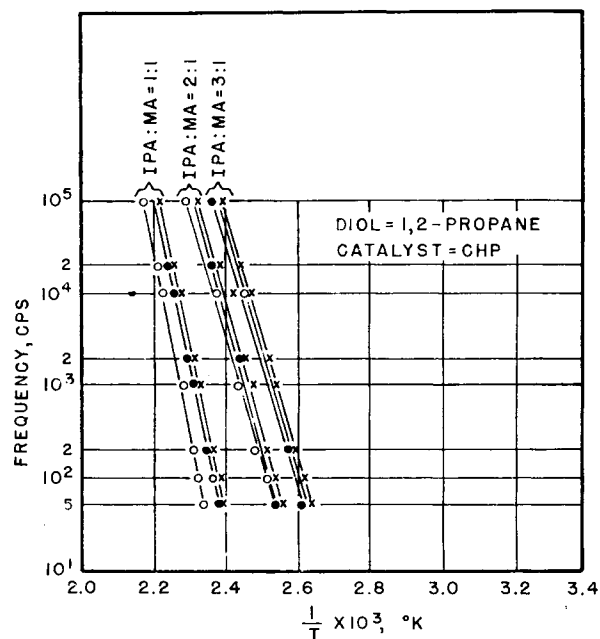


Fig. 14. Frequency vs. absorption peak temperature for polyesters in which the ratio of isophthalic acid to maleic anhydride and the concentration of styrene are varied: (×) 30% styrene, (O) 40% styrene, and (●) 50% styrene.

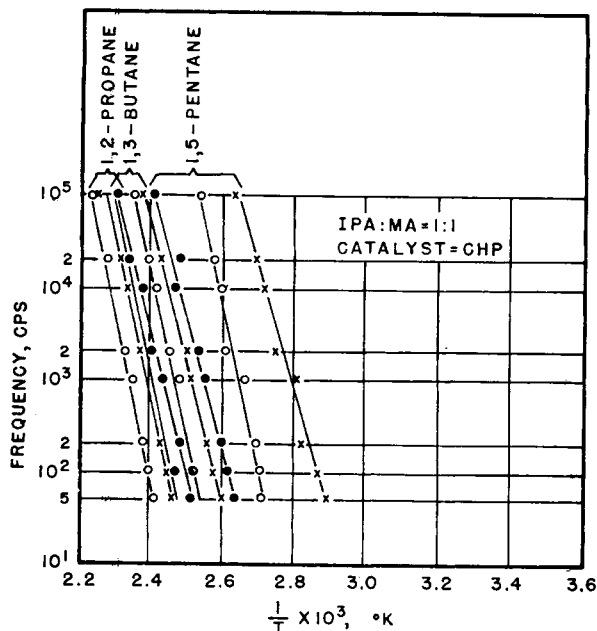


Fig. 15. Frequency vs. absorption peak temperature for polyesters in which the chain length of the diol and the concentration of styrene are varied: (X) 30% styrene, (O) 40% styrene, and (●) 50% styrene.

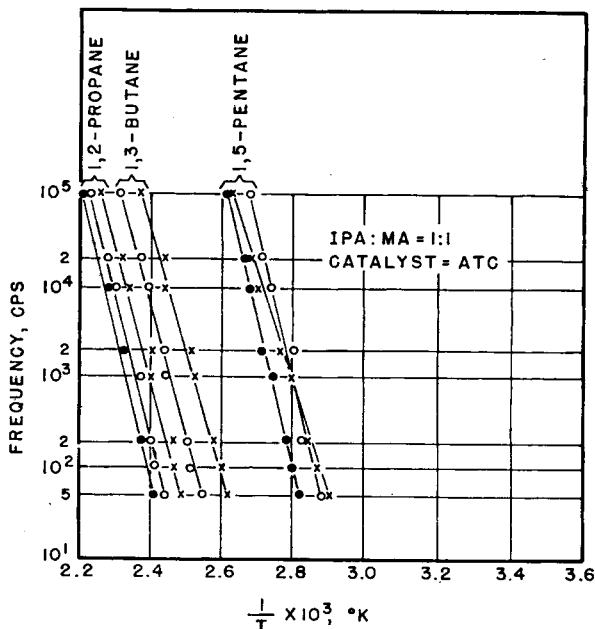


Fig. 16. Frequency vs. absorption peak temperature for polyesters in which the chain length of the diol and the concentration of styrene are varied: (X) 30% styrene, (O) 40% styrene, and (●) 50% styrene.

Discussion

Figures 2, 3, and 4 are included in order to show the general shape of the curves of loss index vs.

temperature at various frequencies. The temperatures of maximum loss index (i.e., the absorption peak temperatures) can be read off these curves and a comparison of Figures 2, 3, and 4 immediately indicates that these temperatures increase as the chain length of the diol decreases.

Of course, the chain length of the diol itself is less important than the actual number of diol carbon atoms which appear in the copolymer backbone. However, when the absorption peak temperature at a given frequency is plotted against the number of these carbon atoms (see Fig. 5), it still appears that these temperatures do increase as the number of diol carbon atoms in the chain decreases.

Figures 6, 7, and 8 show the general shape of the curves of dielectric constant vs. temperature at various frequencies. Comparisons of these curves show that the temperatures of maximum dielectric constant also increase as the chain length of the diol decreases.

The above conclusions are based on measurements made on materials which were copolymerized with cumene hydroperoxide. These conclusions apply equally well to materials copolymerized with benzoyl peroxide, as can be seen by reference to Figure 9.

Figure 10 shows that the temperatures of maximum loss index and maximum dielectric constant increase as the mole ratio of isophthalic acid to maleic anhydride is decreased. Figure 11 shows that these temperatures were not affected by changing the catalyst from benzoyl peroxide to cumene hydroperoxide.

When the mole ratio of isophthalic acid to maleic anhydride is decreased, the per cent of maleic anhydride in the total acid used is, of course, increased and the number of possible crosslinking sites of the copolymer is correspondingly increased. In Figure 12 the temperatures of maximum losses and of heat distortion are plotted as a function of the per cent of maleic anhydride in the total acids used. These curves clearly indicate that the loss process is related to the heat distortion temperature and that both increase as the number of possible crosslinking sites in the copolymer is increased.

Figure 13 shows that the temperatures of maximum loss index also increase as the styrene concentration is increased from 30 to 50%. Since 30% styrene should satisfy the unsaturation in these copolymers, an increase from 30 to 50% serves only to increase the concentration of nonpolar diluent and hence somewhat decrease the flexibility of the copolymer. However, a decrease in dielec-

tric constant with increasing styrene concentration is also shown in Figure 13 and clearly indicates a decrease in polarization per unit volume. A satisfactory correlation between variations in styrene concentration and the electrical properties of the copolymer would involve a much wider range of styrene concentrations. Goto and Nakajima⁶ have varied the styrene content of several polyesters from 15 to 50% and found that as the styrene content was increased the temperature for maximum losses increased until the styrene was slightly in excess of that required to saturate the copolymer.

In general, the results show that the electrical behavior of these copolymers fits the behavior that was predicted in the Introduction from consideration of the chemical structure of the copolymers.

One point that was not discussed in the Introduction was the possibility that chemical structure could affect the dispersion resulting from the presence of permanent dipoles that can change orientation with respect to the main chain of the molecule. Dipoles of this type are present in these copolymers as they are in other similar polyesters. One such dipole accounts for the low-temperature loss peak which appears in Figures 2, 3, and 4 in the general vicinity of 0°C. When the activation energies for this dipole are calculated from plots of loss index vs. frequency (these plots are not included in this report), a value of 8.5 kcal./mole is obtained. The resultant low-temperature dispersion is independent of the changes in structure studied here. In comparison, the activation energy of the dipole that causes the high-temperature dispersion was calculated to be 53.9 kcal./mole, and this dispersion is dependent on chemical structure. The activation energies of both dipoles are independent of the changes in chemical structure, as can be seen from comparison of the slopes of the curves in Figures 14, 15, and 16.

Conclusions

It is concluded that the electrical properties of crosslinked isophthalic polyesters are essentially predictable. To obtain optimum electrical properties, the data suggest the use of isophthalic acid:maleic anhydride ratios less than 1:1, short-chain diols such as 1,2-propanediol, and styrene exceeding 50% by weight.

The authors wish to thank California Research Corp. for preparation of the samples studied herein, C. H. Hickok for assistance in the construction of the sample holder shown in Figure 2, and E. F. Horsey and M. Schwarz for review of the chemical aspects of this paper.

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Synopsis

The a.c. electrical properties (dielectric constant and loss index) of several series of crosslinked isophthalic polyester resins were investigated over the frequency range 50 to 10⁶ cycles/sec. and over the temperature range -60°C. to above the temperature for maximum loss index. In one series of these resins, the ratio of isophthalic acid to maleic anhydride was varied, in another the chain length of the diol was varied, and in another the concentration of styrene was varied. The temperatures at which the maximum values of the electrical properties occurred are shown to be related to the heat distortion temperature, and within the range of compositions studied, could be predicted from chemical structure. The data suggest that a ratio of isophthalic acid to maleic anhydride of less than 1:1, short-chain diols, such as 1,2-propanediol, and more than 50% by weight of styrene will yield the best electrical properties in polyesters of the type studied.

Résumé

Les propriétés électriques a-c (constante diélectrique et indice de perte) de plusieurs séries de résines de polyesters isophthaliques réticulés, ont été étudiées dans un domaine de fréquences allant de 50 à 10⁶ cycles/sec et dans un domaine de températures allant de -60°C à la température supérieure, correspondant à un maximum de "l'indice de perte." Dans une série d'expériences sur ces résines, on a fait varier le rapport acide isophthalique/anhydride maléique, dans une autre série on a fait varier la longueur de chaîne du diol, et dans une autre la concentration en styrène. Les températures pour lesquelles les valeurs maxima des propriétés électriques sont atteintes, peuvent être reliées à la température de la chaleur de distorsion, et peuvent être prévues, dans le domaine des compositions étudiées, à partir de la structure chimique. Les résultats nous montrent que les polyesters présentent les meilleures propriétés électriques, lorsque le rapport acide isophthalique/anhydride maléique est inférieur à 1:1, dans le cas des diols possédant une courte chaîne, telle que le 1,2-propanediol, et lorsque la concentration en styrène est supérieure à 50% en poids.

Zusammenfassung

Die elektrischen Eigenschaften bei Wechselspannung (Dielektrizitätskonstante und Verlustfaktor) einiger Serien

vernetzter Isophthalsäurepolyesterharze wurden in einem Frequenzbereich von 50 bis 10^6 Hertz und in einem Temperaturbereich von -60°C bis zu einer Temperatur oberhalb des maximalen Verlustfaktors untersucht. In einer Versuchsreihe wurde das Verhältnis von Isophthalsäure zu Maleinsäureanhydrid im Harz, in einer anderen die Kettenlänge des Diols und in einer dritten die Konzentration von Styrol variiert. Es wird gezeigt, dass die Temperaturen, bei denen die Maximalwerte der elektrischen Eigenschaften auftraten, im Zusammenhang mit der Wärmebeständig-

keitstemperatur stehen; sie konnten innerhalb des untersuchten Zusammensetzungsbereichs aus der chemischen Struktur vorausgesagt werden. Die Ergebnisse weisen darauf hin, dass ein Verhältnis von Isophthalsäure zu Maleinsäureanhydrid von weniger als 1:1, kurzkettige Diole wie 1,2-Propandiol und mehr als 50 Gewichtsprozent Styrol die besten elektrischen Eigenschaften in Polyestern des untersuchten Typs ergeben.

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