CHAPTER VI

VI Electrical Properties :

The electrical properties of polymers is a subject which is inherently interdisciplinary in nature, being closely allied with the mechanical properties of polymers on one hand, and with the semiconductive properties of inorganic substances on the other.

Polymers(70-74) are almost always good insulators, but that is not to say that a conducting plastic is not desirable ! The electrical insulating quality inherent in most polymers has long been exploited to constrain and protect currents flowing along chosen paths in conductors and to sustain high electric fields. Insulating polymeric materials for early electrical equipment were made from naturally occuring polymeric products for example, the first trans-Atlantic telephone cables laid in the 1860s were extracted from rubber trees. As synthetic high polymers became available in the twentieth century, the range of insulation was continually improved.

Polymeric materials usually display low electrical conductivity. A major use of polymers, as electrical insulating material depends upon this property.

Poly(vinyl chloride) (PVC) is known as a good electrical insulting material and its use in cable and other industries as insulator is also well known.

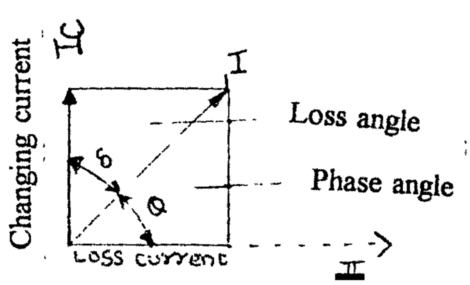
The electric and dielectric properties of modified PVC improve remarkably than that of parent. The unmodified PVC has low permittivity with a low dielectric loss owing to the immobility of C-Cl dipoles !

Biswas and Das(85) studied the dielectric behaviour of Poly-N-Vinylcarbazole 3,6-diphthalemide with-N-linkage, presence of nitrogen hetero atom probably important in dielectric polarizations.

Biswas and mazumder(86) studied behaviour of permittivity/dielectric factor (tan) versus frequency for PVC-anthracene and PVC-anthraquinone condensates.

Biswas and Moitra (87,88) studied the permittivity/dielectric factor of PVC-meta-Aminophenol, PVC-Bisphenol-A and PVC-Phenophthalein and suggest that the dielectric constant of PVC-Bisphenol A and PVC-Phenolphthalein remaining practically independent of the frequency.

The 'dielectric constant' or relative permittivity is defined as the ratio Cs/Co. Where Cs is the capacitance of a capacitor with a dielectric specimen filling the space between the metallic plates and Co is the capacitance with air (or in vacuum) replacing the material. However, when dielectric relaxation occurs an energy loss arises with alternating voltage V of frequency f applied to a capacitor with dielectric filling the space between the plates, the resultant alternating current I contains two components and is given by vector diagram for a capacitor with a dielectric exhibiting dielectric relaxation.



The current Ic (equal to jWCsV where W is the angular frequency equal to $2\pi f$) charges the capacitor to the required instantaneous voltage and leads the voltage by 90^0, as signified by the presence of j ($\equiv$ j-1) in front of WcsV, but the component I1 can not keep in phase with V. The current component I1 will also contain a component due to the dc conductivity of the material. In practice I is proportional to CoV and may be written, as

$$I = JW\ (\epsilon' - J\epsilon'')\ CoV$$

Where the quantity $\epsilon' - J\epsilon''$ is the complex dielectric constant or relative permittivity. The real part ϵ' is often called the dielectric constant or relative permittivity and ϵ'' is termed the loss factor. The loss tangent, tan is given by

$$\tan\delta = [I1 / Ic] = \epsilon''/\epsilon'$$

Relevance of resistivity

Plastics find many applications as insulating material, where high resistivity is required. Thus it is important to understand the mechanisms of conductivity in order to predict the effects of variation of temperature and of the presence of impurities on the conductivity and to design new polymers with very high resistivities. On the other hand, semi-conducting organic polymers might eventually be used in applications such as diodes in switching circuits and photo electric devices.

The volume resistivity ρ (75-77) of a homogeneous (isotropic) material is defined as the quotient of the potential gradient (or field strength) parallel to the direction of current i by the current density.

$$\rho = \frac{V/t}{i/a} = \frac{Va}{it} = \frac{Ra}{t}$$

Where V is the steady voltage applied, and R is the resistance of a rectangular block of cross-sectional area a and thickness t.

The quantity ρ is also the resistance between opposite faces of a unit cube. The unit used is commonly the ohm-centimeter.

The DC conductivity, $\sigma = 1/\rho$ is normally expressed in the corresponding units $(\Omega\ cm)^{1}$. These definitions assume that the current is proportional to the voltage, i.e. that oh's law is obeyed.

The surface resistivity is defined as the ratio of the potential gradient parallel to the current along its surface to the current per unit width of the surface, and is numerically equal to the surface resistance between opposite sides of a

square on the surface of the material; it is normally expressed in ohms.

Dielectric break down.

Dielectric break down of a solid signifies that permanent loss of insulating properties has been caused by application of excessive electric stress.

In practical insulation, breakdown is often caused

(a) by cumulative heating (thermal breakdown),

(b) by internal or surface discharges or as a result of progressive deterioration.

(c) by electro chemical effects,

(d) by surface tracking,

(e) by electromechanical breakdown or alternatively in certain circumstances,

(f) by electronic processes.

The electric strength E of material (78-83) is defined as V/t where V is the breakdown voltage for a specimen of thickness t, but the value obtained in practice will vary with different conditions of test because of breakdown from the different mechanisms listed above.

The present work also directed an evaluation of electric strength , volume resistivity and dielectric factor permittivity versus frequency of the applied voltage.

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Experimental :

Polymer sample was dried in an oven at 120^0c temperature for 6 hours and later powdered by crushing. The crushing and heating were repeated for a number of times until fine powder, was obtained.

(a) **Preparation of sample pellet :**

About 3.0 gm of fine powdered polymer sample was placed in a die of diameter 13.0mm. The die was then assembled and evacuated to a pressure of 3mm of mercury, and later it was subjected to a pressure of 9.0 to 9.5 ton for 10 minutes. This process resulted into a fine pellet which was removed from the die and used for various electrical studies (e.g. Dielectric factor, resistivity and electrical breakdown).

(b) **Dielectric measurements :**

Dielectric analysis (DEA) is rapidly evolving as an important thermal analysis technique for the characterization of polymeric materials because of its sensitivity and wide frequency range. Dielectric analysis complements the other major thermal analysis techniques (DSC, TMA, TGA, and DMA).

Dielectric measurements include dielectric factor & capacitance at various applied field frequency (20 Hz to 100,000 Hz).

All dielectric measurements were name at 25^0C by using RLC Digibridge instrument (Gen Red 1689 precision RLC Digibridge. Of

U.S.A. make) and cell containing guarded brass electrode of 12mm duaneter surrounded by teflon. Applied voltage was one volt AC and field frequency varies from 20 Hz to 100,000Hz.

Permittivity (ϵ) was calculated from the relation ϵ = Cs/Co , where , Cs = Capactitance at different field frequencies and Co = the geometrical capactitance.
The geometrical capacitance is related to the size of the pellet by the equation (15)

$$Co = 0.08854\ a/t\ pF.$$

Where, a= area of the pellet,
and t = thickness of the pellet.
(a and t were expressed in C.G.S. units)

The dielectric loss (tan δ) was directly recorded from the instrument at different field frequency.

(c) Volume Resistivity :

Electrical insulating resistance was measured at 25^0C temperature by using same cell and pellet (which was used for dielectric study) at 500 volts DC by Megohm meter (MEGGER, 6310438 sr.No. 1010 M 446000 1289 England make.) Volume resistivity (ρ) was calculated from the relation.

$$\rho = \frac{V\backslash t}{i\backslash a} = \frac{Va}{it} = \frac{Ra}{t}$$

Where, V is the steady voltage applied, and R is resistance of a circular pellet of cross-sectional area a and thickness t.

The unit used was the ohm-centimeter.

(d) **Break down voltage (V)** :

Break down voltage of polymer pellet was measured after above two studies. It was measured as per sub clause 7.1 of IEC publication 243 (Recommended methods of test for electric strength of solid insulating materials at power frequencies) except that rate of rise was 500 V/S. The instruments used for this measurement were indigenous step up transformer (Sr.No. 50203) and Biddle tester of U.S.A. make (Sr. No. 1047) The pellet was kept in between the two electrodes consisting of opposite cylindrical brass rodes of 6 mm diameter with edges rounded to a radius of 1 mm. The electrodes faces were smooth, parallel and held exactly opposite to one other. The electric strength E of a polymer was calculated by using the relation E = V/t. Where V is the break down voltage of a pellet of (thickness) t. The electric strength was expressed in volts per mm.

The above three properties were studied for modified polymers and resins synthesised from schiff base. The results are tabulated in table-6-1 to table-6-9 and plotted in figure-6-FAC-1 to fig-6-FAC-8.

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RESULTS AND DISCUSSION

The measured dielectric properties include the permittivity (ϵ) and loss factor ($\tan\delta$). the permittivity represents the degree of alignment of the molecular dipoles and/or trace ions to the applied electric field while the loss factor is a measure of the energy required to align the dipoles and move the trace ions.

The result of permittivity (ϵ) and dielectric factor with reference to frequency and plots of dielectric factor frequency of poly(vinyl alcohol) - aromatic phenolic derivatives type resins are shown in tables 6- -6 and figures 6-FA-1 and 6-FA-2 respectively.

These results and plots show that dielectric loss and permittivity are dependent on applied field frequency. These values decrease with increase in field frequency upto 500 HZ. Poly-A-βRes and Poly-A-PHyBe type resins have low dielectric factor and low permittivity. Permittivity follows following decreasing order.

Poly-A-Sali > Poly-A-8Hyqu > Poly-A-Hyqui > Poly-A-Pyro >
Poly-A-βRes > Poly-A-Galli > Poly-A-PHyBe.

Table 6-A-1 shows the values of volume resistivity and electric strength. Electric strength of Poly-A-βRes is higher than other resins, while volume resistivity of Poly-A-Sali is higher than other resins.

The dielectric values of poly(vinyl chloride) - aromatic phenolic derivative type resins is in table 6--7 and plots of the same are in figures 6-FC-3 and Fig 6-FAC-4. The trend of dielectic factor is

Poly-C-βRes > Poly-C-Anthra > Poly-C-Galli > Poly-C-Hyqui
Poly-C-Pyro > Poly-C-Sali > Poly-C-PHyBe > Poly-C-8Hyqui

and that of permittivity is

Poly-C-βRes > Poly-C-Pyro > Poly-C-Hyqui > Poly-Sali >
Poly-C-Galli > Poly-C-Anthra > Poly-C-8Hyqui > Poly-C-PHyBe

It is also observed that both dielectric factor and permittivity are dependent on applied field frequency.

Table-6--2 shows the values of volume resistivity and electric strength of resins synthesised from poly(vinyl chloride) - aromatic phenolic derivatives. The value of electric strength of Poly-C-Anthra, and Poly-C-PHyBe are higher than other resins, while the value of volume resistivity of Poly-C-BRes is higher than others.

Table 6- -8 and Figures 6-FAC-5 and Fig 6 - FAC-6 gives the dielectric behaviour of resins synthesised from poly(vinyl acetate) - aromatic phenolic derivatives.

The curves of dielectric factor versus applied field frequency show that the dielectric factor is dependent an applied frequency. It is observed that Poly-AC-Hyqui have higher value of dielectric factor and permittivity than other resins. Synthesis form some polymer. The trend of dielectric factor is as follows :

Poly-AC-Hyqui > Poly-AC-PHyBe > Poly-AC-βRes > Poly-AC-Pyro
> Poly-AC-Sali > Poly-AC-Galli > Poly-AC-Anthra

The value of volume resistivity and electric strength of resins synthesised from poly(vinyl acetate)- aromatic phenolic derivated are in table 6—3. It is observed that Poly-AC-BRes and Poly-AC-Anthra have higher value of electric strength than other resins. While Poly-AC-PHyBe and Poly-AC-Pyro have higher values of volume resistivity.

The value of dielectic factor and permittivity of resins synthesised from furfural -1, 4-phenylenediamine - aromatic phenolic acid derivatives are in table -6-SA-9 and the value of dielectric factor and permittivity of resins synthesised from furfural- benzidine - aromatic hydroxy acid derivatives are in table 6-SB-10. The curves of dielectric factor versus applied frequency are in figures 6-FAC-7 and Figures 6-FAC-8 for both series respectively . From these it is observed that dielectic factor of resins synthesised 1,4-phenylenediamine are comparatively higher than resins synthesised from benzidine.

In case of resins synthesised from 1,4-phenylenediamine, dielectic factor of Fu(PH)PHy higher than others. Fu(PH)Hy has low permmitivily than other resins permittivity and follows following decreasing order.

Fu(PH)PHy > Fu(PH)GA > Fu(PH)AN > Fu(PH)8Hy > Fu(PH)Py.
Fu(Ben)GA > Fu(Ben)SA > Fu(Ben)PHy > Fu(Ben)Hy

Electric strength and volume resistivity are given in table-6—4. Electrical strength of Fu(PH)8Hy has highest value and volume resistivity of Fu(PH)GA is higher than other resins.

In case of resins synthesised from benzidine Fu(Ben)Hy has lowest dielectric values. It follows following decreasing order for dielectric value.

Fu(Ben)GA > Fu(Ben)SA > Fu(Ben)PHy > Fu(Ben)Hy.

Fu(Ben)PHy has higher permittivity value then others resins.

Permittivity follows following decreasing order

Fu(Ben)PHy > Fu(Ben)GA > Fu(Ben)SA > Fu(Ben)Hy.

Electrical strength and volume resistivity are given in table 6—5. Fu(Ben)Hy resin have higher electrical strength, while Fu(Ben)SA has higher volume resistivity.

In general resins have low values of dielectric factor, permittivity, have high value of electric strength, while parent compound have high value of resistiveity When a polar resins is placed in an electric field, the polar group in the resin will tand to orient in that field. If the polymer is very flexibly or atleast if the polar groups are very flexibly attached to the resin, they will orient easily and quickly. If the resin is very rigid and the polar groups are rigidly attached to it, they will orient only slowly and with difficulty. Thus, in an alternating electric field, the polar groups in a polymer will orient and give high dielectric constant only when the frequency of alteration is low enough to permit motion and orientation of these polar groups with increasing frequency, in the alteration of the electric fields the polar groups will become less and less able to orient rapidly enough to affect the dielectric constant and at still higher frequencies, they will hardly be able to orient at all. Consequently the resin will exhibit a low dielectric constant. In the polymeric systems, different molecules are coiled in different ways and the time for orientation will be dependent on the particular disposition.

This will eventually lead to a broad distribution of the power loss frequency curve due to dispersion of orientation time (89) on application of an electric field. Complete dipole orientation is not possible because of spatial requirement imposed by the chain structure (89).

This may be due to varying degree of polarity. Pertinently, similar behaviour was also experienced by Biswas and das (85) in case of poly-N-vinyl carbazole 3,6 diphtalemide with-N-Linkage, PVC-meta-amino phenol.

TABLE-6-1

Electric Strength and volume resistivity of resins.

Resin	Electric Strength (KV/mm)	Volume Resistivity (ohm-cm)
Poly-A-Anthra	3.6	1.3×10^{12}
Poly-A-Galli	6.2	2.8×10^{12}
Poly-A-PHyBe	3.63	6.7×10^{11}
Poly-A-Pyro	2.7	2.3×10^{10}
Poly-A-8Hyqui	4.3	0.1×10^{12}
Poly-A-Sali	3.93	1.9×10^{12}
Poly-A-Hyqui	2.01	2.8×10^{12}
Poly-A-βRes	3.34	1.2×10^{11}

TABLE-6-2

Electric Strength and volume resistivity of resins.

Resin	Electric Strength (KV/mm)	Volume Resistivity (ohm-cm)
Poly-C-Anthra	7.26	4.3×10^{11}
Poly-C-Galli	5.46	8.9×10^{11}
Poly-C-PHyBe	8.01	5.8×10^{11}
Poly-C-Pyro	6.65	2.4×10^{12}
Poly-C-8Hyqui	6.41	2.9×10^{11}
Poly-C-Sali	3.13	3.9×10^{13}
Poly-C-Hyqui	4.16	7.5×10^{12}
Poly-C-βRes	3.87	3.6×10^{13}

TABLE-6-3

Electric Strength and volume resistivity of resins.

Resin	Electric Strength (KV/mm)	Volume Resistivity (ohm-cm)
Poly-AC-Anthra	6.30	5.4×10^{9}
Poly-AC-Galli	5.04	8.12×10^{10}
Poly-AC-PHyBe	4.80	5.3×10^{11}
Poly-AC-Pyro	3.50	6.4×10^{11}
Poly-AC-Sali	4.73	3.0×10^{10}
Poly-AC-Hyqui	3.40	1.2×10^{10}
Poly-AC-βRes	6.40	6.4×10^{8}

TABLE-6-SA-4

Electric Strength and volume resistivity of resins.

Resin	Electric Strength (KV/mm)	Volume Resistivity (ohm-cm)
Fu(PH)AN	3.01	2.2×10^{10}
Fu(PH)GA	1.01	1.2×10^{12}
Fu(PH)PHy	1.46	8.9×10^{11}
Fu(PH)Py	2.14	4.8×10^{10}
Fu(PH)8Hy	3.45	1.0×10^{11}

TABLE-6-SB-5

Electric Strength and volume resistivity of resins.

Resin	Electric Strength (KV/mm)	Volume Resistivity (ohm-cm)
Fu(Ben)AN	1.95	4.2×10^{9}
Fu(Ben)PHy	3.28	2.8×10^{8}
Fu(Ben)SA	1.75	1.0×10^{12}
Fu(Ben)Hy	4.12	8.8×10^{11}

TABLE-6-6

Dielectric Characteristics of resins

	Log f	1.30	2.00	2.70	3.00	3.70	4.0	4.7
	tanδ	24.61	6.94	1.21	0.85	0.10	0.04	0.01
Poly-A-Anthra	C(PS)	206.25	13.64	5.81	2.31	2.14	0.64	0.59
	=C/Co	267.34	17.69	7.54	2.99	2.78	0.84	0.77
	tanδ	0.69	0.14	0.07	0.06	0.05	0.05	0.01
Poly-A-Galli	C(PS)	5.4	4.87	4.93	4.63	4.46	4.20	4.06
	=C/Co	6.99	6.31	6.38	6.00	5.78	5.45	5.27
	tanδ	0.30	0.16	0.09	0.06	0.00	0.00	0.00
Poly-A-PHyBe	C(PS)	9.17	4.65	4.45	4.26	4.19	4.17	4.12
	=C/Co	11.88	6.03	5.77	5.53	5.44	5.40	5.34
	tanδ	0.893	0.20	0.14	0.07	0.02	0.01	0.00
Poly-A-Pyro	C(PS)	7.91	6.70	5.08	4.87	4.71	4.62	4.20
	=C/Co	10.25	8.59	6.59	6.31	6.11	5.99	5.45
	tanδ	4.84	2.23	1.24	0.93	0.48	0.14	0.00
Poly-A-8Hyqui	C(PS)	78.54	37.84	31.42	17.67	4.33	4.19	4.06
	=C/Co	101.8	49.05	40.74	22.90	5.60	5.43	5.26
	tanδ	2.41	0.30	0.07	0.03	0.03	0.03	0.02
Poly-A-Sali	C(PS)	42.51	6.24	5.16	5.07	5.07	5.04	5.00
	=C/Co	55.10	8.09	6.90	6.57	6.56	6.54	6.49
	tanδ	12.36	4.89	1.38	1.00	0.12	0.08	0.01
Poly-A-Hyqui	C(PS)	101.84	37.84	17.20	14.33	9.87	9.04	8.67
	=C/Co	132.00	49.05	22.29	18.58	12.79	11.73	11.24
	tanδ	0.52	0.12	0.07	0.02	0.01	0.01	0.00
Poly-A-βRes	C(PS)	16.84	7.89	6.424	5.81	5.25	5.12	5.03
	=C/Co	12.83	10.23	8.33	7.53	6.80	6.63	6.52

TABLE-6-7
Dielectric Characteristics of resins

	Log f	1.30	2.00	2.70	3.00	3.70	4.0	4.7
	tanδ	1.82	0.35	0.11	0.10	0.04	0.01	0.00
Poly-C-Anthra	C(PS)	8.91	7.17	7.17	7.15	7.10	7.02	7.05
	=C/Co	11.55	9.69	9.29	9.29	9.21	9.10	9.14
	tanδ	1.79	0.87	0.21	0.03	0.02	0.00	0.00
Poly-C-Galli	C(PS)	9.99	7.58	7.46	7.00	6.99	6.90	6.76
	=C/Co	12.95	9.83	9.68	9.07	9.06	8.94	8.75
	tanδ	0.37	0.35	0.29	0.24	0.02	0.01	0.00
Poly-C-PHyBe	C(PS)	5.63	5.52	4.67	4.28	4.22	4.13	4.07
	=C/Co	7.30	7.16	6.06	5.55	5.47	5.36	5.29
	tanδ	0.99	0.98	0.58	0.23	0.06	0.02	0.00
Poly-C-Pyro	C(PS)	25.34	21.34	19.53	13.80	11.13	9.41	9.31
	=C/Co	32.85	27.53	25.32	17.89	14.43	12.21	12.15
	tanδ	0.28	0.18	0.14	0.11	0.08	0.04	0.01
Poly-C-8Hyqui	C(PS)	6.73	6.64	5.84	5.89	5.66	5.56	5.54
	=C/Co	8.73	8.61	7.57	7.37	7.33	7.18	7.18
	tanδ	0.87	0.77	0.51	0.69	0.04	0.01	0.00
Poly-C-Sali	C(PS)	11.95	5.83	3.88	2.95	2.54	2.11	2.03
	=C/Co	15.49	7.56	5.04	3.82	3.29	2.74	2.64
	tanδ	1.24	0.28	0.14	0.08	0.06	0.02	0.01
Poly-C-Hyqui	C(PS)	16.37	7.38	4.04	3.86	3.57	3.44	3.40
	=C/Co	21.22	9.56	5.24	5.01	4.63	4.46	4.41
	tanδ	3.32	1.81	0.80	0.11	0.09	0.06	0.00
Poly-C-βRes	C(PS)	27.45	10.17	8.71	8.58	8.14	8.12	8.03
	=C/Co	35.58	13.18	11.29	11.12	10.55	10.53	10.48

TABLE-6-8
Dielectric Characteristics of resins

	Log f	1.30	2.00	2.70	3.00	3.70	4.0	4.7
	tanδ	0.15	0.04	0.03	0.02	0.02	0.02	0.00
Poly-AC-Anthra	C(PS)	5.16	4.46	4.67	4.12	4.04	3.96	3.90
	=C/Co	6.63	5.78	5.65	5.34	5.25	5.13	5.06
	tanδ	0.24	0.08	0.03	0.02	0.01	0.01	0.00
Poly-AC-Galli	C(PS)	5.13	5.09	4.69	4.60	4.53	4.49	4.34
	=C/Co	6.65	6.59	6.09	5.97	5.87	5.83	5.70
	tanδ	9.84	4.32	1.88	0.85	0.21	0.09	0.02
Poly-AC-PHyBe	C(PS)	85.85	39.89	31.52	29.98	28.12	24.41	20.04
	=C/Co	111.28	51.68	40.85	38.86	36.44	31.64	25.98
	tanδ	0.95	0.11	0.09	0.04	0.01	0.001	0.00
Poly-AC-Pyro	C(PS)	21.84	10.10	8.97	7.80	7.69	7.60	7.54
	=C/Co	28.31	13.09	11.63	10.11	9.98	9.85	9.78
	tanδ	0.27	0.15	0.08	0.05	0.04	0.03	0.01
Poly-AC-Sali	C(PS)	6.73	6.65	6.32	5.86	5.79	5.54	5.11
	=C/Co	8.72	8.61	8.19	7.60	7.51	7.18	6.63
	tanδ	29.38	2.23	1.88	0.87	0.21	0.08	0.03
Poly-AC-Hyqui	C(PS)	584.70	69.39	21.80	15.19	15.11	14.96	14.90
	=C/Co	757.87	89.94	28.26	19.64	19.59	19.39	19.32
	tanδ	1.86	0.93	0.37	0.11	0.09	0.01	0.00
Poly-AC-βRes	C(PS)	28.06	7.71	7.54	7.30	7.06	7.00	6.95
	=C/Co	36.37	10.00	9.18	9.46	9.15	9.07	9.02

TABLE-6-SA-9

Dielectric Characteristics of resins

	Log f	1.30	2.00	2.70	3.00	3.70	4.0	4.7
	tanδ	2.698	1.405	0.76	0.42	0.170	0.148	0.08
Fu(pH)AN	C(PS)	26.210	7.160	2.193	1.373	1.223	1.135	1.04
	=C/Co	33.97	9.28	2.84	1.78	1.58	1.47	1.35
	tanδ	6.284	2.978	1.650	1.621	0.849	0.761	0.12
Fu(pH)GA	C(PS)	56.66	12.30	7.63	2.94	2.36	1.83	1.13
	=C/Co	73.44	15.95	9.88	3.81	3.06	2.37	1.47
	tanδ	3.289	2.248	1.322	0.589	0.134	0.122	0.08
Fu(pH)PHy	C(PS)	98.32	36.81	17.134	9.237	6.397	3.082	2.81
	=C/Co	127.44	47.41	22.20	11.87	8.29	3.99	3.64
	tanδ	1.822	0.982	0.453	0.181	0.111	0.093	0.00
Fu(pH)Py	C(PS)	9.37	7.621	5.361	5.113	4.903	4.841	4.72
	=C/Co	12.14	10.14	6.95	6.63	6.35	6.27	6.12
	tanδ	1.982	1.112	0.702	0.398	0.00	0.028	0.01
Fu(pH)8Hy	C(PS)	21.81	9.04	6.12	2.62	1.04	0.87	0.67
	=C/Co	28.27	11.72	7.93	3.66	1.35	1.14	0.87

TABLE-6-SB-10

Dielectric Characteristics of resins

	Log f	1.30	2.00	2.70	3.00	3.70	4.0	4.7
	tanδ	2.884	1.084	0.818	0.354	0.113	0.084	0.06
Fu(Ben)GA	C(PS)	56.89	31.04	2.32	2.16	2.04	1.67	1.54
	=C/Co	73.74	40.24	3.01	2.80	2.65	2.17	2.00
	tanδ	1.414	0.783	0.332	0.272	0.167	0.123	0.01
Fu(Ben)PHy	C(PS)	146.64	18.21	10.14	8.95	6.98	6.50	5.98
	=C/Co	190.07	23.61	13.14	11.60	9.05	8.44	7.75
	tanδ	1.759	0.711	0.075	0.029	0.098	0.010	0.00
Fu(Ben)SA	C(PS)	6.25	5.268	4.138	3.989	3.964	3.734	3.54
	=C/Co	8.10	6.83	5.36	5.17	5.14	4.84	4.59
	tanδ	0.391	0.221	0.126	0.094	0.047	0.037	0.02
Fu(Ben)Hy	C(PS)	4.89	3.249	2.712	2.588	2.430	2.393	2.27
	=C/Co	6.34	4.21	3.51	3.35	3.15	3.10	2.95

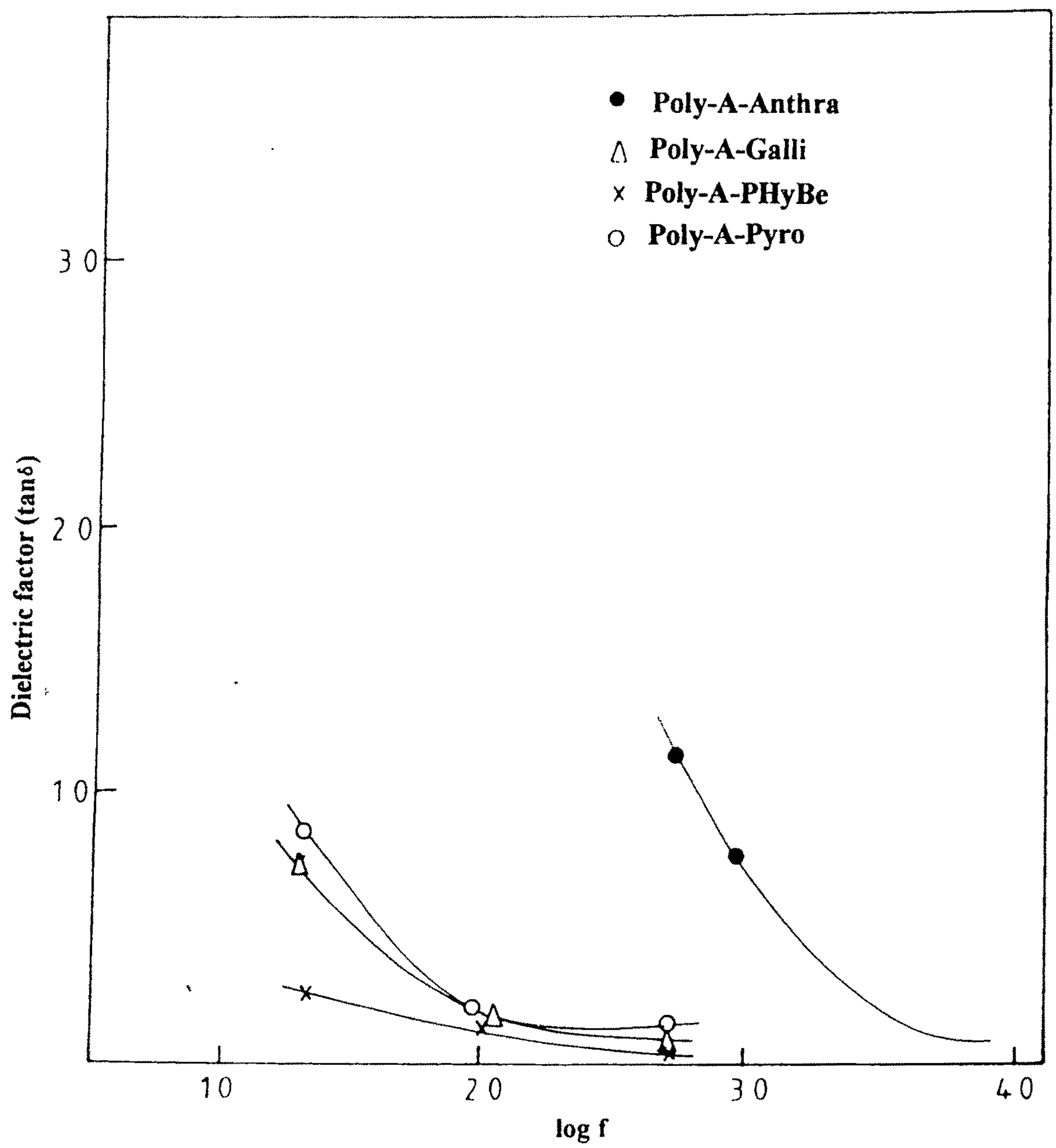
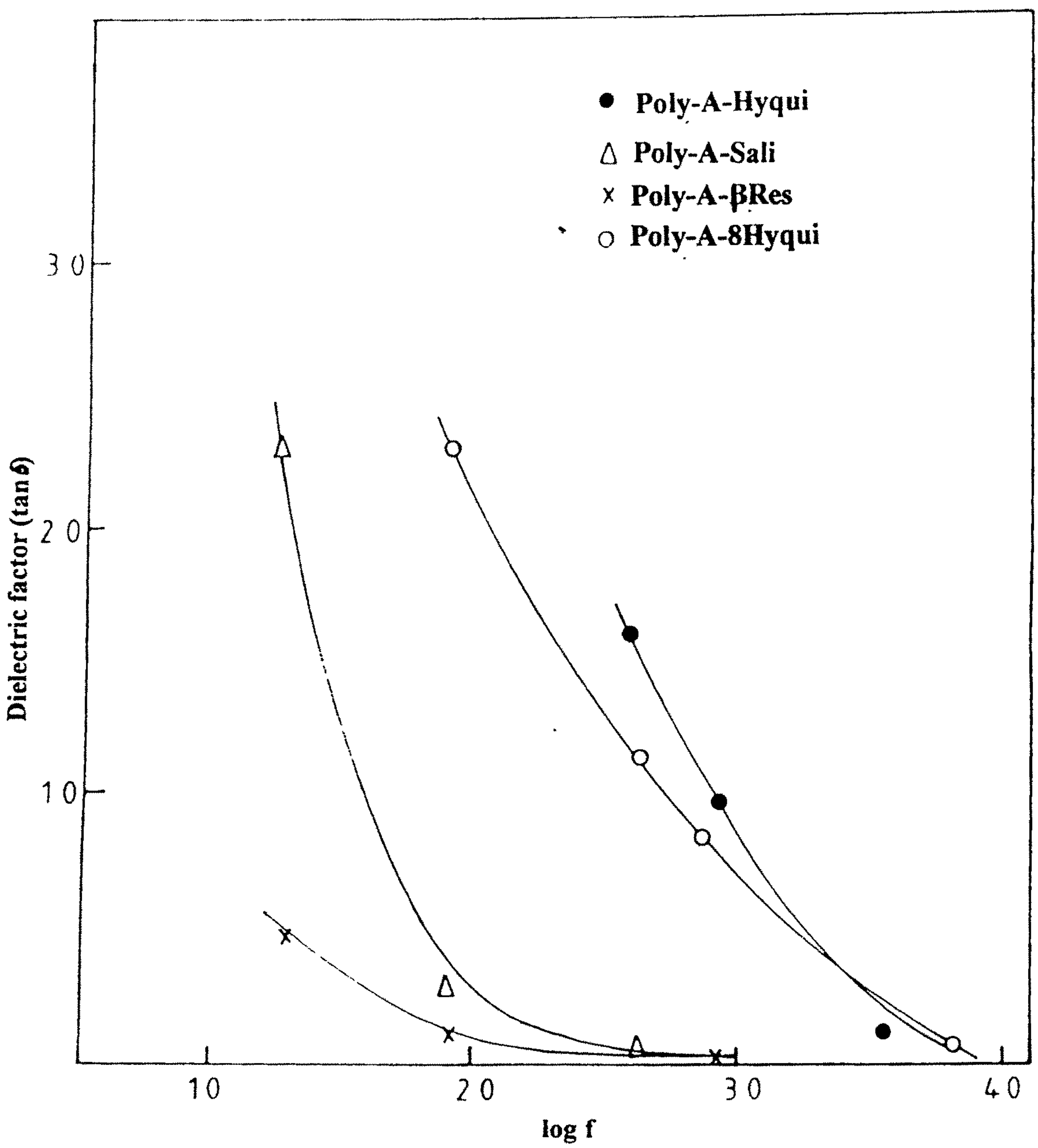

Poly-A-Anthra
Poly-A-Galli
Poly-A-PHyBe
Poly-A-Pyro
Dielectric factor (tanδ)
3 0
2 0
1 0
10
2 0
3 0
4 0
log f

Fig-6FAC-1



Poly-A-Hyqui
Poly-A-Sali
Poly-A-βRes
Poly-A-8Hyqui
3 0
2 0
1 0
Dielectric factor (tan δ)
10
2 0
3 0
4 0
log f

Fig-6FAC-2

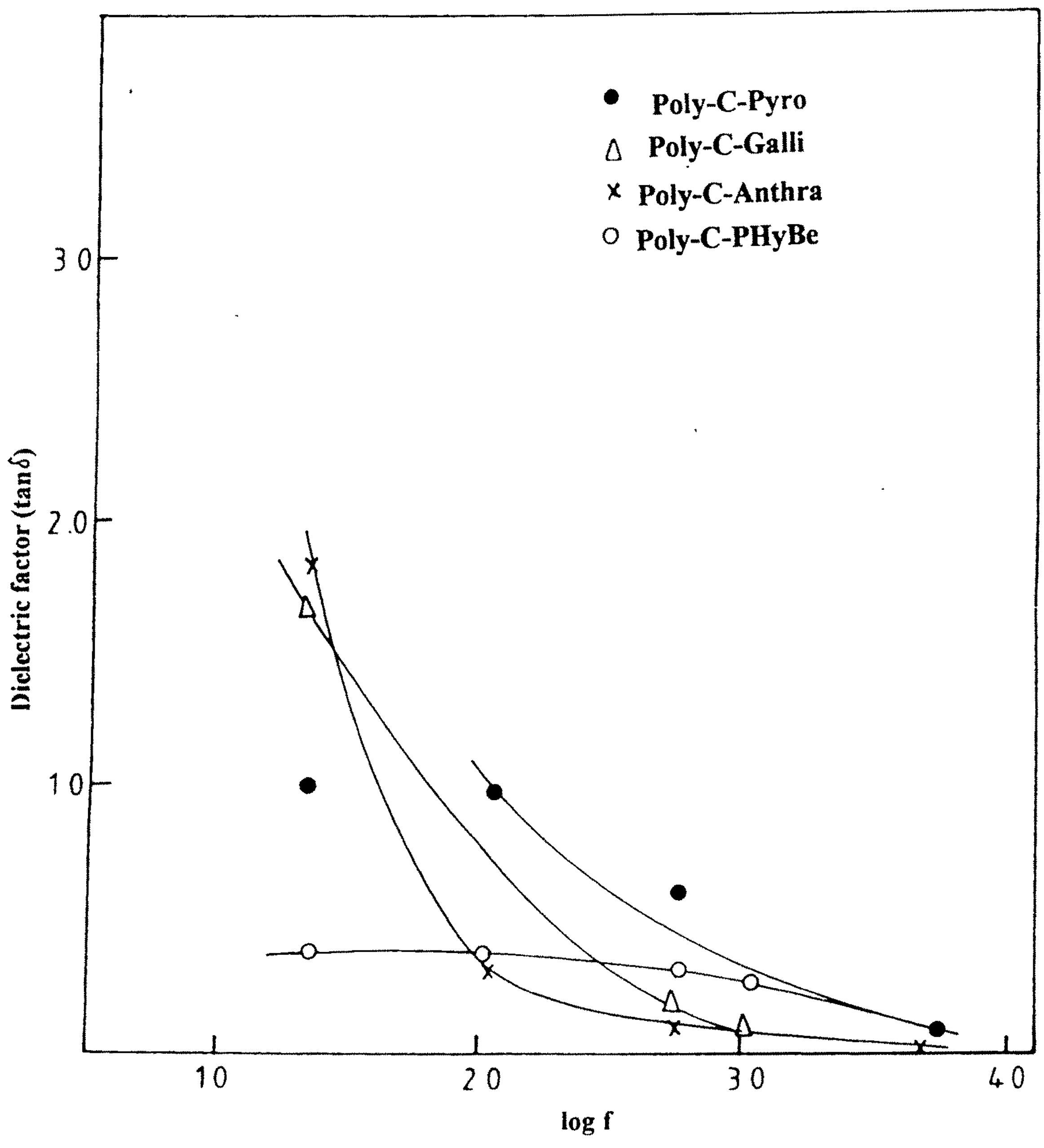
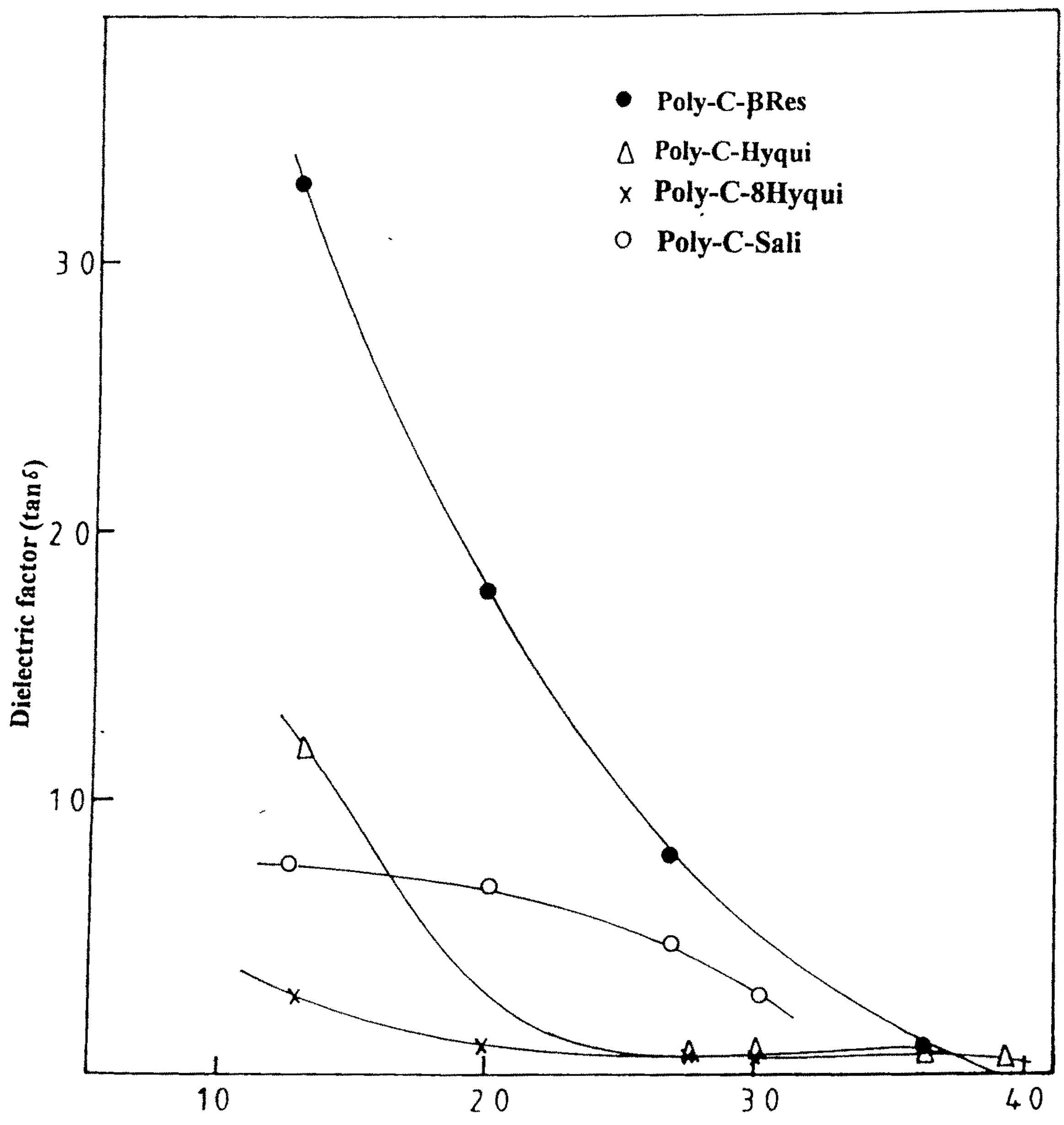

Poly-C-Pyro
Poly-C-Galli
Poly-C-Anthra
Poly-C-PHyBe
3 0
2.0
1 0
Dielectric factor (tanδ)
10
2 0
3 0
4 0
log f

Fig-6FAC-3



Poly-C-βRes
Poly-C-Hyqui
Poly-C-8Hyqui
Poly-C-Sali
Dielectric factor (tan δ)
3 0
2 0
1 0
10
2 0
3 0
4 0
log f

Fig-6FAC-4

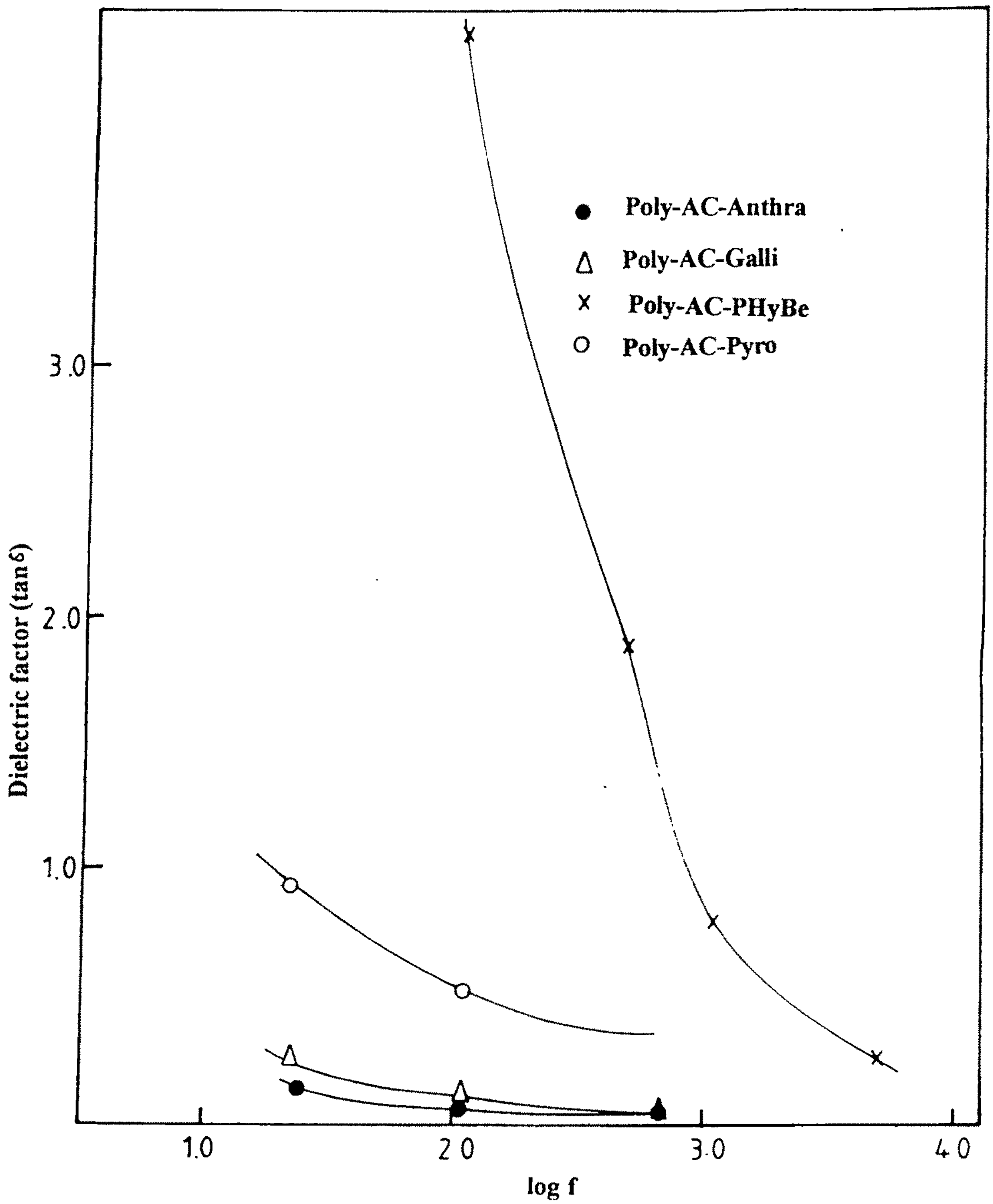

Poly-AC-Anthra
Poly-AC-Galli
Poly-AC-PHyBe
Poly-AC-Pyro
Dielectric factor (tan δ)
3.0
2.0
1.0
1.0
2.0
3.0
4.0
log f

Fig-6FAC-5

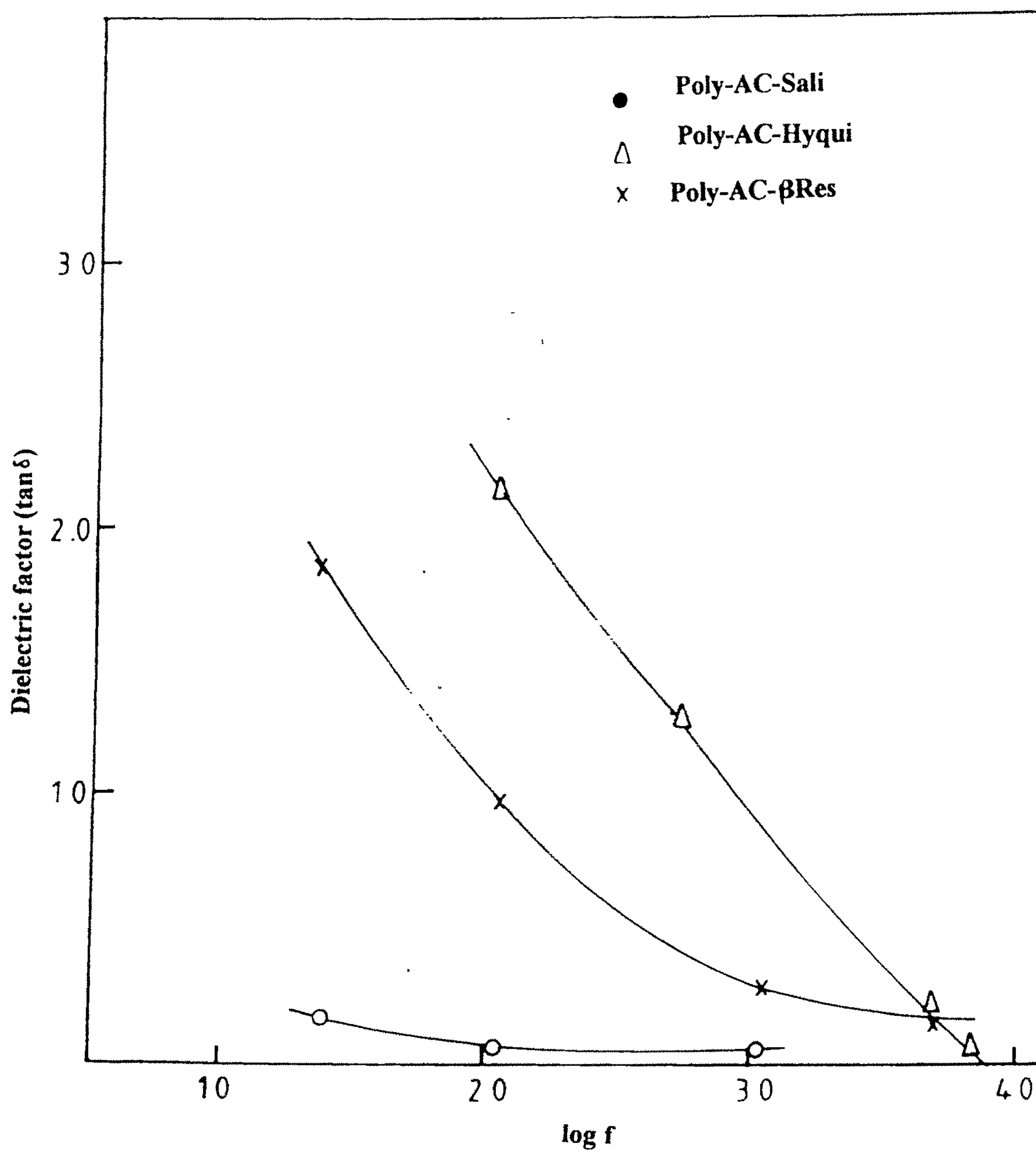
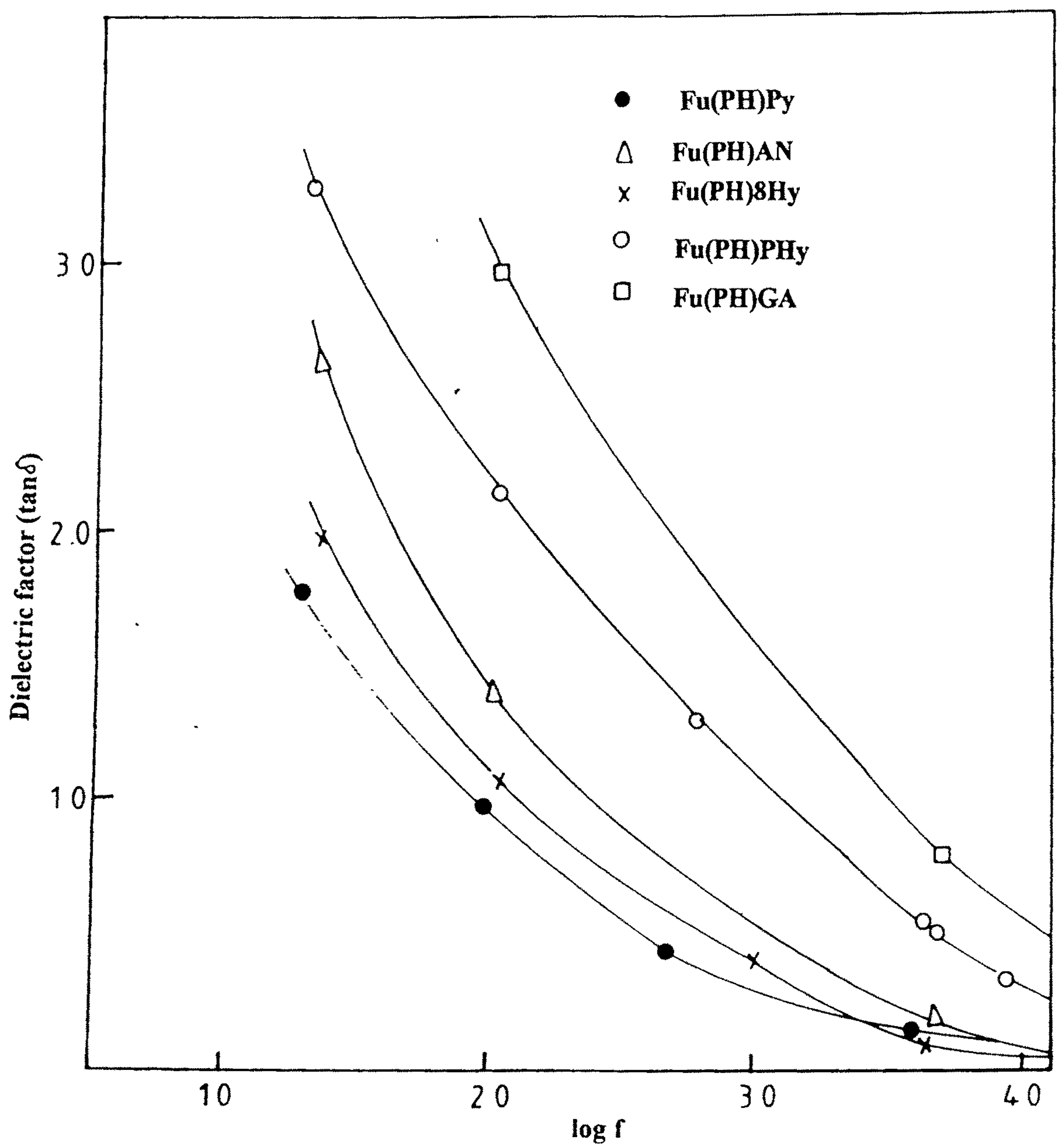
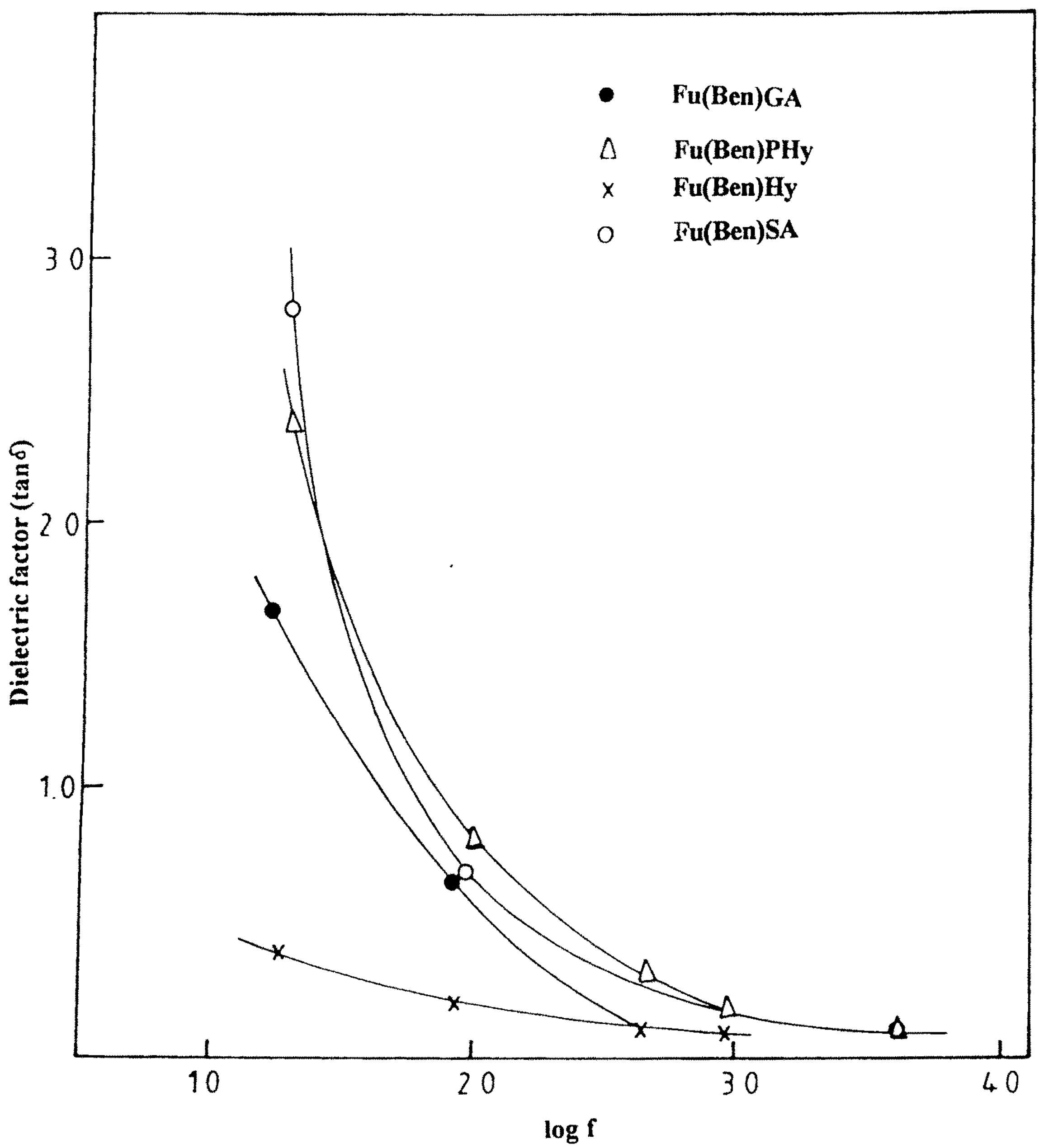

Poly-AC-Sali
Poly-AC-Hyqui
Poly-AC-βRes
3 0
2.0
1 0
Dielectric factor (tanδ)
10
2 0
3 0
4 0
log f

Fig-6FAC-6



Fu(PH)Py
Fu(PH)AN
Fu(PH)8Hy
Fu(PH)PHy
Fu(PH)GA
3 0
2.0
1 0
Dielectric factor (tanδ)
10
2 0
3 0
4 0
log f

Fig-6FAC-7



Fu(Ben)GA
Fu(Ben)PHy
Fu(Ben)Hy
Fu(Ben)SA
3 0
2 0
1.0
Dielectric factor (tanδ)
10
2 0
3 0
4 0
log f

Fig-6FAC-8

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