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Temperature and frequency dependent studies of conductivity and dielectric properties of Polyaniline (PANI)

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Abstract: *The electric, dielectric and AC conductivity, relaxation time measurement of Polyaniline (PANI). The frequency dependent dielectric properties of the sample have been studied at low frequencies (100Hz to 500 Hz) for 20 ^0C and 30^0C temperature. The temperature dependent dielectric properties of the sample have been studied at 15^0C to 67^0Ctemperature for 500 Hz frequency. Finally the AC conductivity, permittivity, loss tangent and relaxation time calculations have been carried out by using the data available from dielectric measurement. The result shows a linear dependence on temperature and frequency.*

Keywords: *Dielectric constant, AC conductivity, permittivity, loss tangent and relaxation time.*

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I. Introduction

Traditionally polymers were used as good electrical insulators and most of their applications had related to their insulating properties [1]. However, now researchers showed that certain type of polymers exhibits semiconducting properties. Conducting polymer received much attention because of their electronics, dielectric, physical properties and their potential technological uses [2-5]. From the commercial point of view they have wide applications in devices such as solar cells, rechargeable batteries, light emitting diodes (LED), field effect transistors (FET) and sensors [6].

The aim of this paper is to discuss the temperature and frequency dependent studies of conductivity and dielectric properties of polyaniline (PANI) and also calculate the relaxation time.

II. Experiment Details

The Polyaniline was purchased from Sigma Aldrich (Purity 99.5%). The sample of polyaniline (PANI) used for frequency and temperature dependent of conductivity and dielectric measurement was obtain in the form of a disc of compressing in a die under a load 3 to 4 tons. The diameter of the pallet was 1 cm and thickness was 0.51 mm.

The sample holder was madeup of brass coated with nickel and has two parts. The sample was placed between the jaws of the two electrodes via a spring arrangement. The temperature and frequency dependence of the capacitance and loss tangent of the sample were measured by using Model No. 4255 WAYNEKER LCR meter in laboratory in frequency range 100 Hz to 500 Hz and temperature range 288^{0}K to 340^{0}K.

III. Results And Discussion

It is observed that the polyaniline (PANI) exhibits high conductivity. However the complex permittivity and conductivity of the sample prepared at different environmental conditions vary.

(A) Dielectric Properties:

The dielectric properties were measured by measuring equivalent capacitance (Cp), dissipation factor (DF) and the equivalent resistance (Rp) of the sample by using the equations.

$$\varepsilon' = \frac{C_P}{C_O},$$

$$D_F = \frac{\sigma}{\varepsilon\omega} and$$

$$R_P = \frac{\varepsilon'}{\omega\varepsilon'' C_P}$$

Where C_0(=0.08854 A/t, Pf) is the geometrical capacitance of the vacuum of the same dimensions as the sample. Cp is the capacitance measured in Pf, ε' and ε'' are the real and imaginary dielectric constant respectively. The thickness of pallet t = 0.51mm while the area and other preparation conditions are same. It is observed that at higher temperature data cannot be due to the electrode barriers [7]. These measurement are shown in table 1, 2 and 3 and graph 1-9.

(B) AC Conductivity and Relaxation Time:

The AC Conductivity measured as function of frequency at 293^0K given by relation

$$\sigma_M(\omega) = 2\pi f \varepsilon''$$

It is observed that measured AC conductivity shows peak at low frequency and fall up to 200Hz but increase therefore with increase in frequency. The calculated relaxation time shows increase relation with frequency. These measurements are shown in table 4-5.

(C) AC Conductivity and DC Conductivity as a function of temperature:

The variation of AC and DC conductivity with temperature at fixed frequency 500 Hz is shown in table-4, 5 and 6. The DC conductivity shows an exponential dependence one temperature while AC conductivity shows almost linear frequency dependence.

The measured AC conductivity $\sigma_M(\omega)$, DC conductivity σ_{dc} and AC AC conductivity are related by a relation

$$\omega e_o \varepsilon''_{ac} = \sigma_M(\omega) - \sigma_{dc} = \sigma_{ac}.$$

IV. Figures and Tables

Table-1: TEMPERATURE 20^0C

S. No.	Frequency (Hz)	Cap (Pf.)	C_0 (Pf)		
			ε'	ε''	Dssi
1	100	39.61	290.45	272.79	0.9392
2	200	20.62	151.2	27.61	0.1826
3	500	18.434	135.17	17.29	0.1279
4	1000	17.247	126.46	15.03	0.1189
5	2000	16.4185	120.39	15.995	0.1329
6	5000	15.0726	110.52	15.508	0.1403
7	10000	14.0722	103.18	13.803	0.1338
8	20000	13.209	96.85	11.126	0.1149
9	50000	12.398	90.91	7.55	0.0830
10	100000	11.974	87.8	5.083	0.0579
11	200000	11.84	86.81	3.715	0.0428
12	500000	11.685	85.68	2.613	0.0305

TABLE-2: TEMPERATURE 30^0C

S. No.	Frequency (Hz)	Cap (Pf.)	C_0 (Pf)		
			ε'	ε''	Dssi
1	300	17.585	128.946	18.655	0.1447
2	500	18.522	135.817	33.918	0.2497
3	1000	16.752	122.838	30.463	0.2480
4	1500	16.088	117.969	21.968	0.1862
5	2000	15.5525	114.042	19.419	0.1703
6	2500	15.161	111.171	18.732	0.1685
7	3000	14.9292	109.472	18.203	0.1663
8	4000	14.5194	106.467	17.162	0.1612
9	5000	14.1988	104.116	16.516	0.1586

TABLE-3: FIXED FREQUENCY 500HZ

S. No.	Temperature (^{0}C)	Cap (Pf.)	C_0 (Pf)		
			ε'	ε''	Dssi
1	67	23.556	172.686	93.506	0.5415
2	64	20.88	153.107	74.832	0.4888
3	61	20.092	147.329	65.903	0.4473
4	59	21.386	156.818	50.162	0.3199
5	56	18.45	135.289	53.109	0.3926
6	54	19.156	140.466	58.068	0.4134
7	51	18.038	132.268	47.018	0.3555

8	49	19.608	143.78	61.377	0.4269
9	46	18.038	132.268	52.782	0.3991
10	43	18.048	132.341	47.321	0.357568705
11	41	18.75	137.489	52.144	0.379259432
12	38	17.756	130.201	37.523	0.288192871
13	36	16.048	117.675	23.949	0.203518164
14	33	16.064	117.793	22.376	0.189960354
15	31	16.754	122.852	38.751	0.31542832
16	28	17.932	131.492	16.809	0.127832872
17	26	14.636	107.322	29.919	0.278777883
18	15	15.154	111.122	12.265	0.110374183

TABLE-4: RELAXATION TIME AT TEMPERATURE 20^{0}C

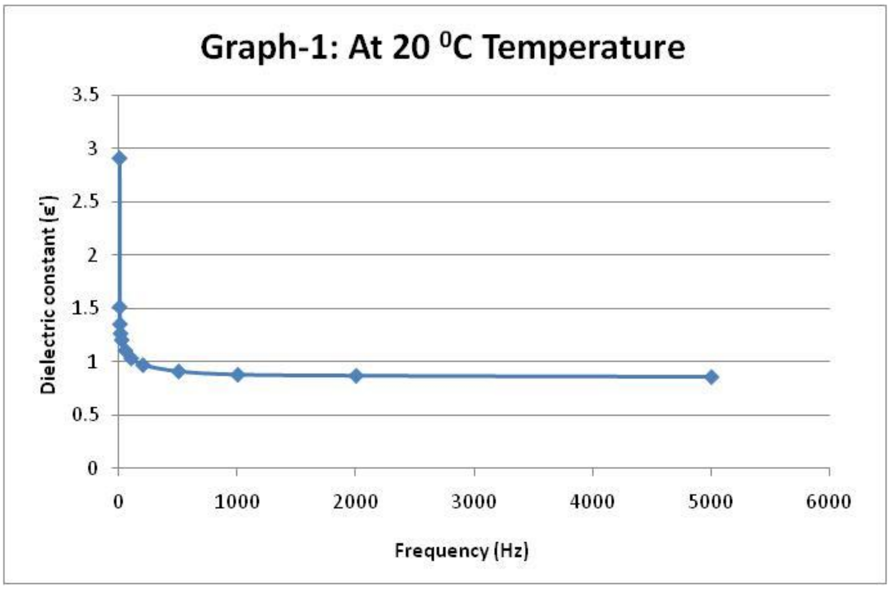
S. No.	Frequency (Hz)	ε''	Measured A.C. Conductivity	σ_{ac}	Relaxation Time
1	100	272.79	17.13x10^4	1.5x10^{-6}	0.001592357
2	200	27.61	3.47x10^4	0.30x10^{-6}	0.000796178
3	500	17.29	5.43x10^4	0.48x10^{-6}	0.000318471
4	1000	15.03	9.44x10^4	0.84x10^{-6}	0.000159236
5	2000	15.99	20.08x10^4	1.78x10^{-6}	7.96178x10^{-5}
6	5000	15.51	48.7x10^4	4.31x10^{-6}	3.18471 x10^{-5}
7	10000	13.8	86.66x10^4	7.67x10^{-6}	1.59236 x10^{-5}
8	20000	11.13	139.79x10^4	12.38x10^{-6}	7.96178 x10^{-5}
9	50000	7.55	237.07x10^4	21.00x10^{-6}	3.18471 x10^{-5}
10	100000	5.08	319.02x10^4	28.26x10^{-6}	1.59236 x10^{-5}
11	200000	3.72	467.23x10^4	41.39x10^{-6}	7.96178 x10^{-5}
12	500000	2.61	819.54x10^4	72.61x10^{-6}	3.18471 x10^{-5}

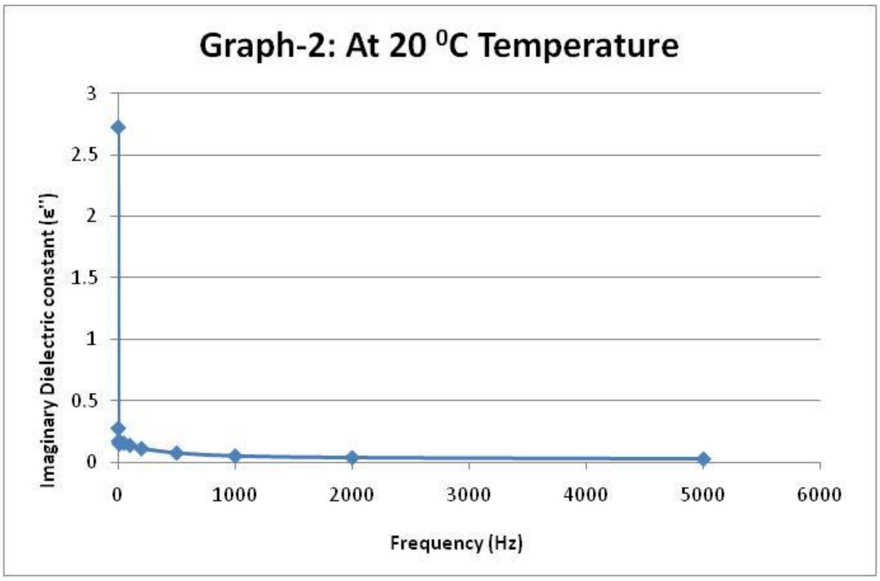
TABLE-5: RELAXATION TIME AT TEMPERATURE 30^{0}C

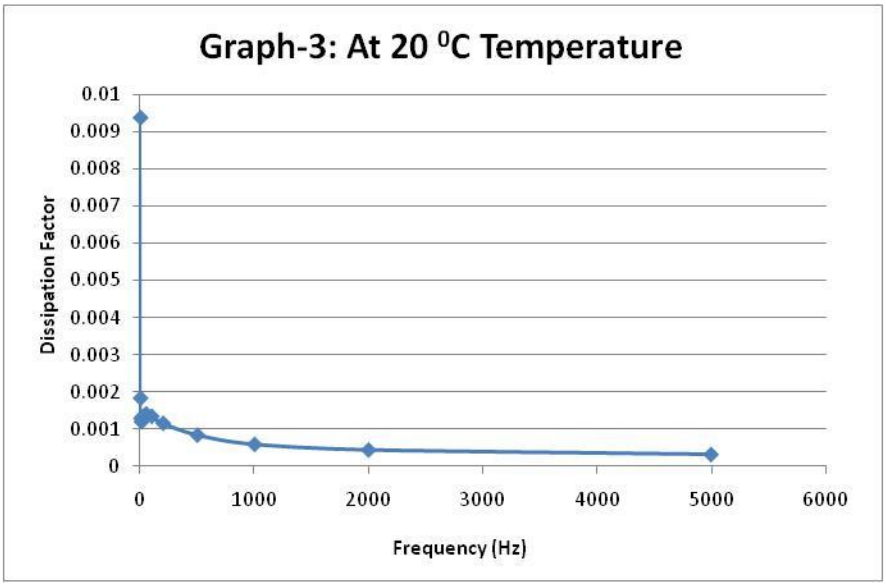
S. No.	Frequency (Hz)	ε''	Measured A.C. Conductivity	σ_{ac}	Relaxation Time
1	300	18.65	3.51x10^4	31.09x10^{-8}	0.000530786
2	500	33.92	10.65x10^4	94.36x10^{-8}	0.000318471
3	1000	30.46	19.13x10^4	169.49x10^{-8}	0.000159236
4	1500	21.97	20.69x10^4	183.31x10^{-8}	0.000106157
5	2000	19.42	24.39x10^4	216.09x10^{-8}	7.96178 x10^{-5}
6	2500	18.93	29.41x10^4	260.57x10^{-8}	6.36943 x10^{-5}
7	3000	18.2	34.29x10^4	303.81x10^{-8}	5.30786 x10^{-5}
8	4000	17.16	43.11x10^4	381.95x10^{-8}	3.98089 x10^{-5}
9	5000	16.52	51.87x10^4	459.57x10^{-8}	3.18471 x10^{-5}

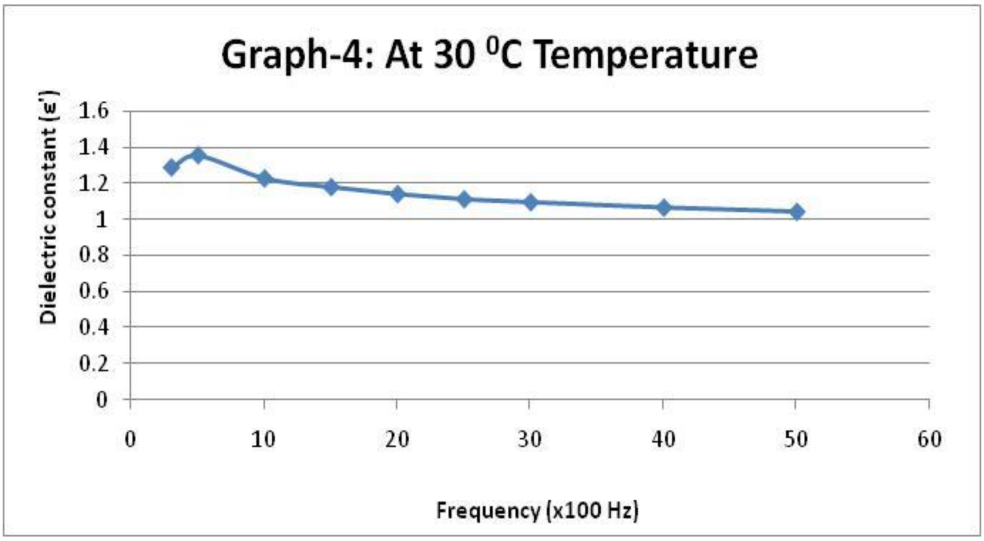
TABLE-6: MEASURED AC AND DC CONDUCTIVITY OF PANI AS FUNCTION OF TEMPERATURE

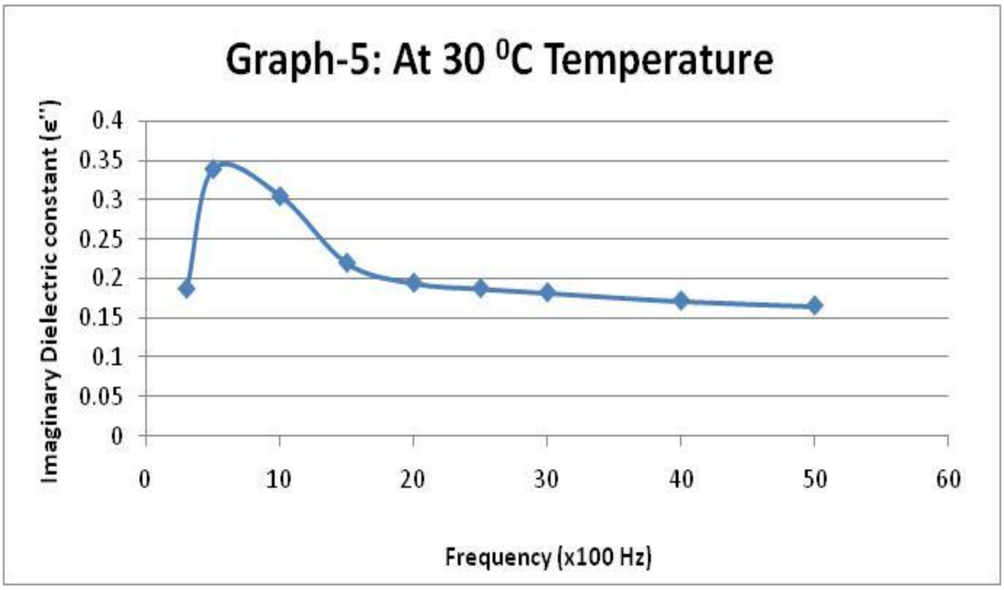
S. No.	Temperature (^{0}K)	σ_{dc}	$\sigma_m(\omega)$
1	288	0.170	3.84x10^4
2	299	0.190	9.39 x10^4
3	301	0.210	5.28 x10^4
4	304	0.212	12.17 x10^4
5	306	0.214	7.03 x10^4
6	309	0.300	7.52 x10^4
7	311	0.302	11.78 x10^4
8	314	0.303	16.37 x10^4
9	316	0.305	14.85 x10^4
10	319	0.306	16.57 x10^4
11	322	0.307	19.27 x10^4
12	324	0.308	14.76 x10^4
13	327	0.309	18.23 x10^4
14	329	0.400	16.68 x10^4
15	332	0.420	15.75 x10^4
16	334	0.440	20.69 x10^4
17	337	0.470	23.49 x10^4
18	340	0.500	29.36 x10^4

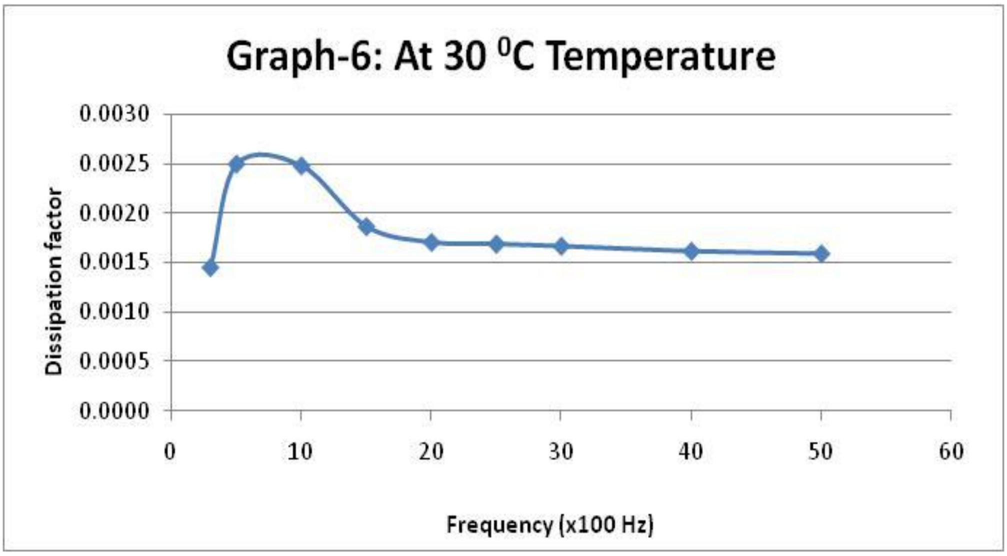

Graph-1: At 20 ⁰C Temperature
Dielectric constant (ε')
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5
0
1000
2000
3000
4000
5000
6000

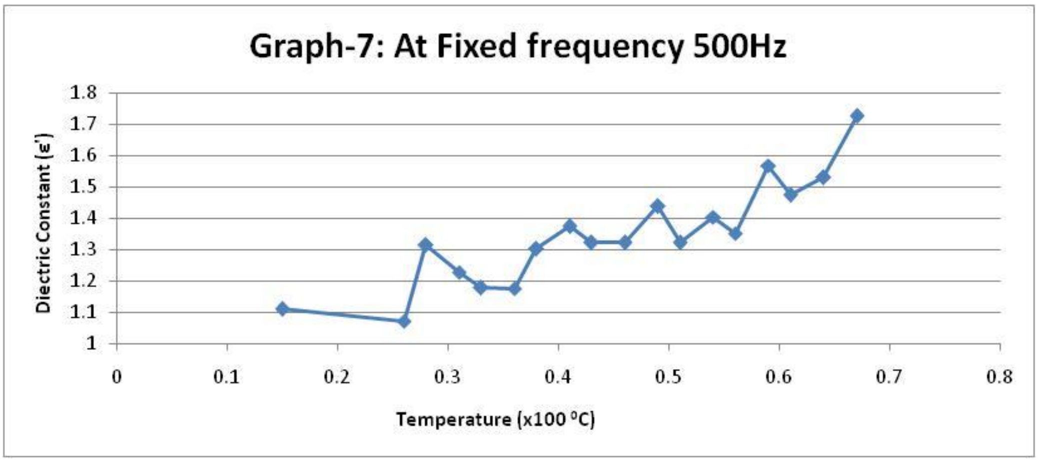

Graph-2: At 20 ⁰C Temperature
Imaginary Dielectric constant (ε'')
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
0
1000
2000
3000
4000
5000
6000

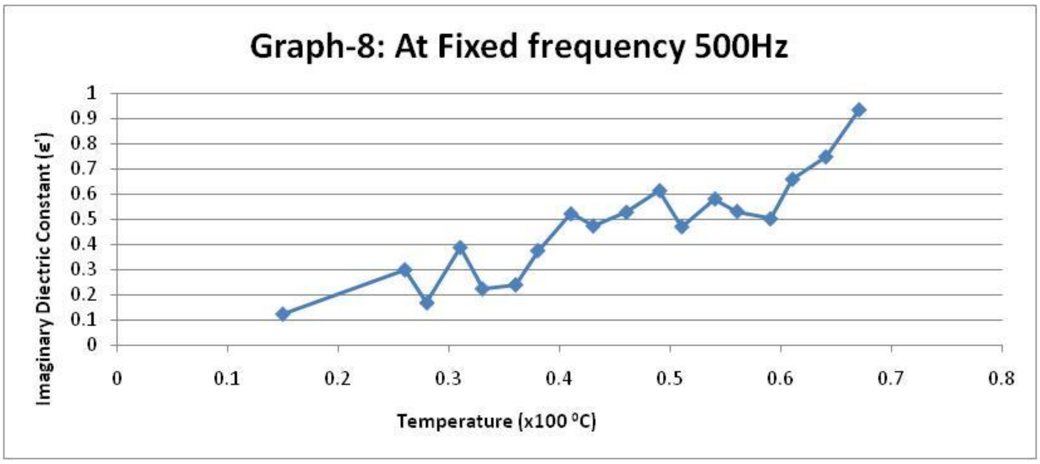

Graph-3: At 20 ⁰C Temperature
Dissipation Factor
Frequency (Hz)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
0
1000
2000
3000
4000
5000
6000

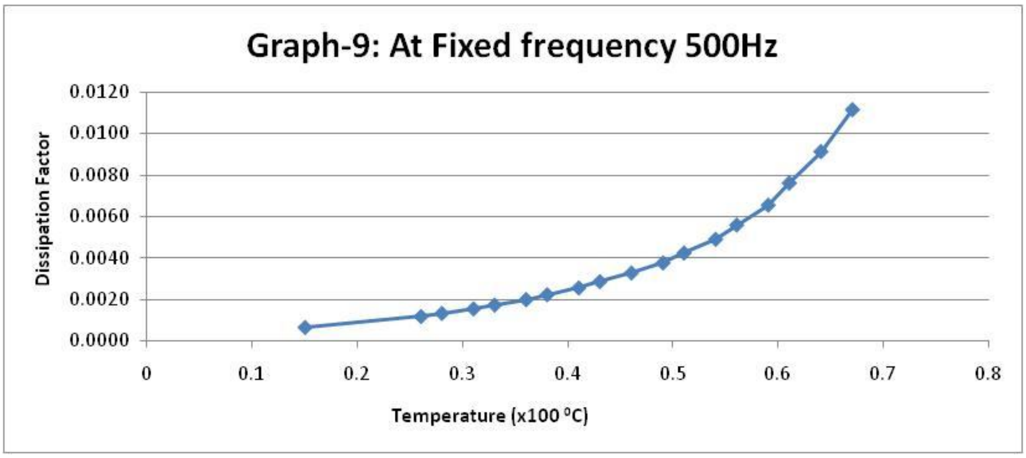

Graph-4: At 30 ^{0}C Temperature
Dielectric constant (ε')
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
Frequency (x100 Hz)


Graph-5: At 30 ^{0}C Temperature
Imaginary Dielectric constant (ε'')
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
Frequency (x100 Hz)


Graph-6: At 30 ^{0}C Temperature
Dissipation factor
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0
10
20
30
40
50
60
Frequency (x100 Hz)







V. Conclusion

It has been reported in literature [8] that the DC conductivity of conducting polymer depend on their morphology and certain other factors such as type of monomer, doping level, degree of crystallinity etc. The exponential increase in DC conductivity with temperature indicates the properties of disordered semiconductor. The analysis of temperature dependent conductivity data also give that the charge transport mechanism can be explained by the variable range called Variable Range Hopping (VRH) model.

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