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Dielectric Study of Pure Propan-1-OL and Propan-2-OL Using Debye Relaxation Method

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Authors' contributions

This work was carried out in collaboration between both authors. Authors MYO and JTI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MYO and JTI managed the analyses of the study. Author JTI managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The Debye relaxation equation and its derivatives were used to analyze the experimental permittivity data of high purityPropan-1-ol and Propan-2-ol over the frequency up to 10GHz and temperature range of 10ºC to 50ºC. The plots of dielectric constant ε' and loss factor ε'' against the frequency were found useful in determining how well experimental data fits the Debye equation and these methods were also found capable of reproducing good results of fitted data using double-Debye. The dielectric constant of Propan-1-ol was found to decrease as the temperature increases beyond 10ºC whereas that of Propan-2-ol increased at the temperature 20ºC. It then decreased as the temperature increased beyond 20ºC. The loss factor on the other hand was found decreasing as the temperature increases for both Propan-1-ol and Propan-2-ol. This work also reveals that Propan-2-ol at 20ºC followed Debye relaxation equation only at frequency range$\leq$ 5GHz.

Keywords: Debye relaxation; permittivity; dielectric constant; loss factor; propan-1-ol and propan-2-ol.

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1. INTRODUCTION

The study of dielectric properties of liquid mixtures has gained importance because it provides opportunity of bringing together molecules of different compounds and allows them to interact with one another [1-5]. However, the dielectric properties of reference materials (like Propan-1-ol and Propan-2-ol) required for calibrating, testing instruments that are used for dielectric measurement are rare. Pure liquids make particularly good reference materials, as they are of completely uniform and homogeneous and if they are of sufficient purity their properties vary negligibly from one sample to another [6]. At radio and microwave frequencies polar liquids such as Propan-1-ol and Propan-2-ol exhibit high permittivity and loss and a distinctive relaxation behaviour that can usually be described empirically using simple formulae such as those derived from the Debye equation. Propan-1-ol and Propan-2-ol has been fitted using double-Debye at frequency $\leq 5GHz$ [6]. In this work, attempts are made to fit the same for both Propan-1-ol and Propan-2-ol using dielectric susceptibility approach and frequency$\leq 10GHz$.

Propan-1-ol is a primary alcohol with molecular formula C_3H_8O and it sometimes called 1-Propanol, 1-Propyl alcohol, n-Propyl alcohol, n-Propanol or simply Propanol with abbreviation 1PN. It is formed naturally in small quantities during several fermentation processes. It is an isomer of Propan-2-ol and it is widely used as solvent in the pharmaceutical industry, and for manufacturing resins and cellulose esters.

Propan-2-ol on the other hand it is a secondary alcohol with molecular formula C_3H_8O. It is also known as isopropyl alcohol and 2-Propanol with abbreviation IPA. It is a colourless, flammable chemical compound with a strong odour. In this compound, the alcohol carbon is attached to two other carbons sometimes shown as $(CH_3)_2CHOH$. As a biological specimen preservative, propan-2-ol provides a comparatively non-toxic alternative to formaldehyde and other synthetic preservatives. Propan-2-ol solutions of concentration 90-99% are optical for preserving specimens, although concentration as low as 70% can be used in emergencies.

The equation used in this work for computation of dielectric constant is:

$$\varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_S - \varepsilon_\infty)}{(1+\omega^2\tau^2)} \quad (1)$$

Where ε' = dielectric constant, ε_∞ = complex permittivity, ε_s = static permittivity, ω = angular frequency and τ = relaxation time and that of the loss factor is

$$\varepsilon'' = \frac{(\varepsilon_S - \varepsilon_\infty)\omega\tau}{(1+\omega^2\tau^2)} \quad (2)$$

Where ε''= the loss factor

Detail of the mathematical derivation of the above equations is shown in our previous paper [7]. The results obtained from our computation at various temperatures and frequencies are shown in the tables in Appendix A.

2. DISCUSSION

The dielectric constant and the loss factor of pure Propan-1-ol and Proan-2-ol were computed using Debye relaxation method. The results revealed that the dielectric constant ε' of both Propan-1-ol and Propan-2-ol is higher at low frequencies Figs. 1 and 3 shown in above.However, as the temperature increases beyond 20ºC the dielectric constant of Propan-1-ol at $f = 0.1GHz$ decreases as the temperature increases Fig. 1 but that of Propan-2-ol increased at temperature 20oc for the frequency $f = 0.1GHz$ and then decreased as the temperature increased above 20ºC. This decreased in the dielectric constant as the result of increased in the temperature may be due tothe relaxation time which has been found to be fast at high temperatures and increases dramatically at low temperatures, suggesting a freezing of electric dipoles at low temperatures [8]. The dielectric constant of both Propan-1-ol and Propan-2-ol however, increases as the temperature increases for other values of the frequencies as shown in Figs. 1 and 3. This is because as the temperature increases, the orientation of dipoles is facilitated and this increases the dielectric constant [9]. The loss factor on the other hand was found decreasing throughout in our calculation for both Propan-1-ol and Propan-2-ol as shown in Figs. 2 and 4.

The higher value of dielectric constant ε' at low frequencies may be due to the effect of ionic conductivity which varies inversely proportional to the frequency. Propan-1-ol has the highest value of dielectric constant when compared with Propan-2-ol at the same frequencies and temperatures see Tables 1-10 in Appendix A. This implies that Propan-1-ol is a better solvent than Propan-2-ol. It was also observed thatPropan-2-ol at temperature 20ºC did not fit well into our computation most especially at frequency beyond $5GHz$ as shown in Fig. 3 above. This showed that Propan-2-ol can only work well at frequency$\leq 5GHz$. The higher value of dielectric constant $\varepsilon^{'}$ as observed in this work at low frequencies may be because of the overall conductivity which consists of different conduction mechanisms. The most prevalent one in moist materials is the ionic conductivity.

The graphs of dielectric constant $\varepsilon^{'}$ and loss factor $\varepsilon^{''}$ against the frequency in gigahertz at various temperatures revealed that the dielectric constant $\varepsilon^{'}$ of Propan-1-ol have higher value of dielectric constant $\varepsilon^{'}$ at low frequencies then decreased sharply with increasing frequency and after that it remains almost constant over the entire frequency range except for Propan-2-ol at 20ºC. The loss factor$\varepsilon^{''}$ which is believed to be dominant by the influence of electrolytic conduction caused by free ions which exist in the presence of a solvent behave very similar in nature like the dielectric constant$\varepsilon^{'}$. The loss factor $\varepsilon^{''}$ on the other hand decreased rapidly and becomes almost constant afterwards as shown in Figs. 2 and 4. This behaviour indicates a normal behaviour of the dielectric as the same has been reported by [10].

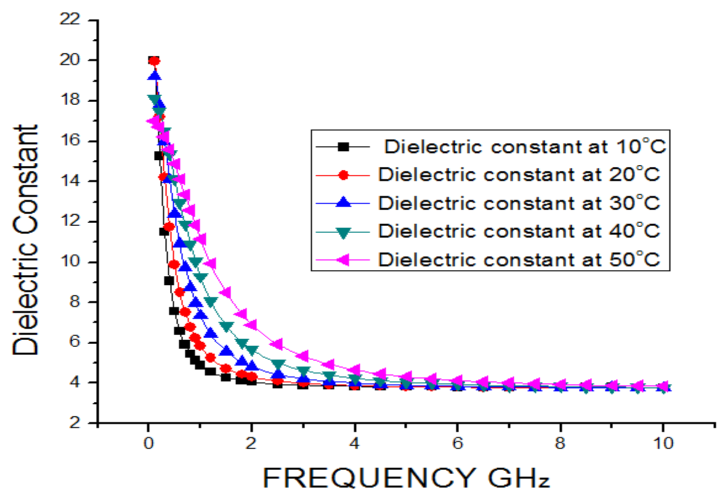

Fig. 1. The graph of dielectric constant of propan-1-ol at temperature between 10ºC to 50ºC against the frequency

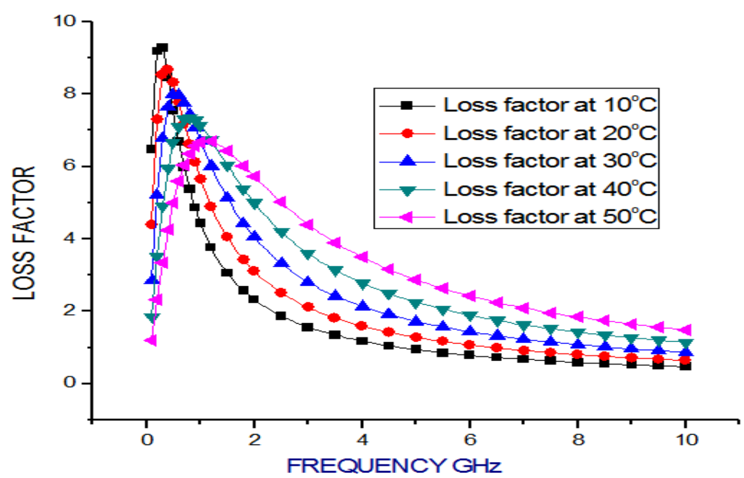

Fig. 2. The graph of loss factor of Propan-1-ol at temperature between 10ºC to 50ºC against the frequency

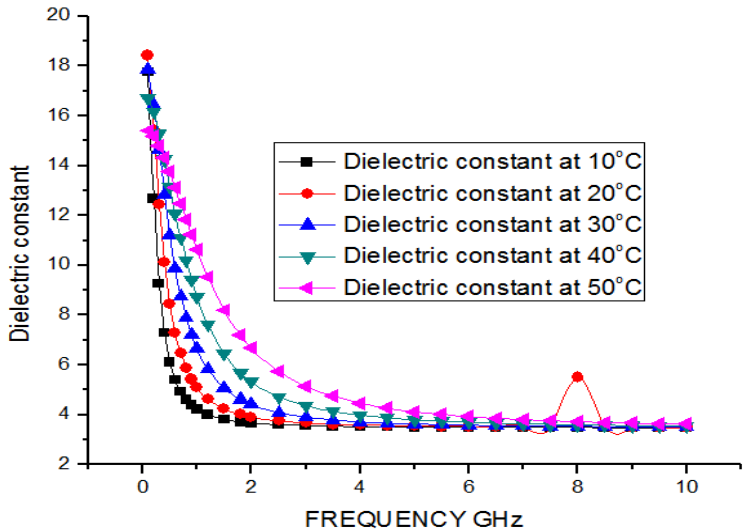

Fig. 3. The graph of dielectric constant of propan-2-ol at temperature between 10ºC to 50ºC against the frequency

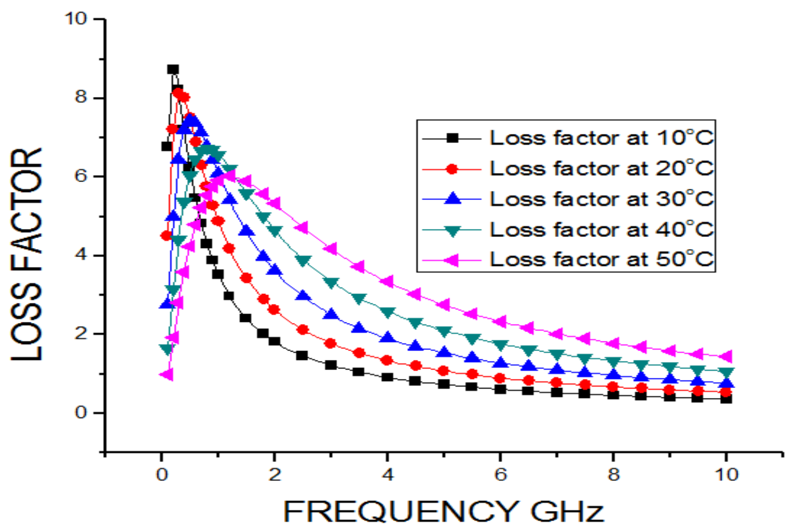

Fig. 4. The graph of loss factor of propan-2-ol at temperature between 10ºC to 50ºC against the frequency

The decrease of dielectric constants in higher frequency range for both Propan-1-ol and Propan-2-ol may be due to the fact that the dipoles cannot follow up the fast variation of the applied field. The higher values of ε' and ε'' at lower frequencies may be due to the contribution from all the four types of polarization (i.e. space charge, dipole, ionic and electronic polarization) [11]. Observed that at higher frequencies, only the ionic and electronic polarizations contribute. The decrease of dielectric constant ε' with increasing frequency means that, the response of the permanent dipoles decreases as the frequency increases and the contribution of the charge carriers (ions) towards the dielectric constant decreases [12,13].

3. CONCLUSION

The Debye equation and its derivatives have been used to compute the dielectric constant and loss factor for both Propan-1-ol and Propan-2-ol. The results revealed that within the frequency range of $0.1 \leq f \leq 10GHz$ only Propan-2-ol at temperature 20^{o}c did not followed Debye relaxation method beyond the frequency> $5GHz$.

This showed that the Debye relaxation method and its derivative are capable of mimicking good results for both the coaxial cells and work done using double-Debye.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Petong P, Pottel R, Kaatze R. Dielectric relaxation of H-Bonded liquids. Mixtures of ethanol and n-Haxanol at different composition and temperatures. J. Phys. Chem. A. 1999;103:6114-6121.
2. Lone BG, Undre PB, Patil SS, Khirade PW, Mehrotra SC. Dielectric Study of methanol-ethanol mixtures using TDR method. Journal of Molecular Liquids. 2008;141: 47-53.
3. Navarkhele VV, Bhanarkar MK. Microwave dielectric response of binary miture of N,N-dimethylformamide with propylene glycol using TDR method. An international journal at the interface between Chemistry and Physics; 2009. Available:http://www.tandfonline.com/loi/tmph20
4. Sunil A, Ajay C, Milind L, Mehrotra SC. Complex permittivity spectra of binary pyridine-amide mixtures using time-domain reflectometry. Journal of Solution Chemistry. 1998;27(11):993-1008.
5. Peter WL, Nils B, Alexander S, Richard B, Thomas L, Kawon O. Dielectric relaxation and ultrafast transient absorption spectroscopy of $|C_6min^{+}||Tf_2N|^{-}/$ acetonitrile mixtures. J. Phys. Chem. 2012; 14:3596-3603.
6. Gregory AP, Clarke RN. Tables of the complex permittivity of dielectric reference liquids at frequencies up to 5GHz. NPL REPORT MAT 23; 2012.
7. Ikyumbur TJ, Gbaorun F, Hemba EC, Bash JA. Calculation of the dielectric properties of water using Debye equations. Journal of the Nigerian Association of Mathematical Physics. 2014;28(2):485-492.
8. Ahmad MM, Yamada K. Superionic $PbSnF_4$: A giant dielectric constant material. Appl. Phys. Lett. 2007;19(5): 052912-3.
9. Yadav VS, Sahu DK, Singh Y, Dhubkarya DC. The effect of frequency and temperature on dielectric properties of pure poly vinylidene fluoride (PVDF) thin films. Proceedings of the International Multi-Conference of Engineers and Computer Scientists. 2010;3.
10. Karmakar A, Mitra UK, Dutta K, Sit SK, Acharyya S. Dielectric relaxation Phenomena of some aprotic polar liquids under gigahertz electric field. Indian J. of Pure & Appl. Phys. 2006;44:856-866.
11. Salman F, Khalil R, Hazaa H. Dielectric Studies and Cole-Cole plot Analysis of Silver-ion conducting glasses. Adv. J. Phys. Sc. 2014;3(1):1-9.
12. Bergo P, Pontuschka WM, Prison JM. Dielectric Properties of $P_2O_5 - N_{a_2}O - L_{i_2}O$ glasses containing $WO_3, C_oO \; or \; F_{e_2}O_3$. Solid State Communicaions. 2007;141(10): 545-547.
13. Graca M, Valente MA, Ferreira da Silva MG. Electrical Properties of lithium niobium silicate glasses. J. Non-Cryst. Solids. 2003;325(1-3):267-274.

APPENDIX A

Tables of dielectric constant and loss factor

Table 1. The dielectric constant and loss factor of propan-1-olat 10ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	20.0202	6.4863	20.32	6.15
0.2	15.2761	9.1841	15.90	9.01
0.3	11.5109	9.2661	12.18	9.35
0.4	9.0796	8.4719	9.67	8.71
0.5	7.5530	7.5422	8.04	7.86
0.6	6.5699	6.6956	6.97	7.05
0.7	5.9125	5.9742	6.25	6.33
0.8	5.4563	5.3703	5.74	5.73
0.9	5.1288	4.8647	5.38	5.22
1.0	4.8867	4.4389	5.10	4.79
1.2	4.5612	3.7670	4.73	4.11
1.5	4.2859	3.0596	4.41	3.40
1.8	4.1327	2.5710	4.22	2.91
2.0	4.0658	2.3222	4.14	2.67
2.5	3.9622	1.8682	3.99	2.22
3.0	3.9054	1.5616	3.89	1.93
3.5	3.8710	1.3409	3.82	1.72
4.0	3.8486	1.1747	3.76	1.57
4.5	3.8332	1.0451	3.71	1.45
5.0	3.8221	0.9411	3.66	1.35
5.5	3.8140	0.8559		
6.0	3.8078	0.7849		
6.5	3.8029	0.7247		
7.0	3.7991	0.6730		
7.5	3.7960	0.6283		
8.0	3.7934	0.5891		
8.5	3.7913	0.5545		
9.0	3.7896	0.5237		
9.5	3.7881	0.4962		
10.0	3.7868	0.4714		

Table 2. The dielectric constant and loss factor of propan-1-ol at 20ºC

f(GHz)	ε'(this work)	ε''(This work)	ε'[6]	ε''[6]
0.1	19.9606	4.3924	20.12	4.10
0.2	17.2017	7.2907	17.66	6.97
0.3	14.2283	8.5208	14.87	8.36
0.4	11.7510	8.6778	12.44	8.70
0.5	9.8848	8.3207	10.54	8.49
0.6	8.5229	7.7722	9.11	8.04
0.7	7.5300	7.1857	8.05	7.51
0.8	6.7976	6.6256	7.25	6.98
0.9	6.2482	6.1148	6.65	6.49
1.0	5.8287	5.6538	6.18	6.04
1.2	5.2454	4.8948	5.52	5.28
1.5	4.7341	4.0417	4.94	4.42
1.8	4.4423	3.4279	4.59	3.80
2.0	4.3131	3.1090	4.44	3.48
2.5	4.1108	2.5171	4.18	2.89

f(GHz)	ε'(this work)	ε''(This work)	ε'[6]	ε''[6]
3.0	3.9989	2.1113	4.03	2.49
3.5	3.9307	1.8169	3.92	2.20
4.0	3.8862	1.5939	3.84	1.99
4.5	3.8555	1.4193	3.74	1.82
5.0	3.8335	1.2790	3.73	1.68
5.5	3.8171	1.1638		
6.0	3.8047	1.0676		
6.5	3.7950	0.9861		
7.0	3.7873	0.9160		
7.5	3.7811	0.8553		
8.0	3.7760	0.8020		
8.5	3.7718	0.7550		
9.0	3.7683	0.7132		
9.5	3.7653	0.6782		
10.0	3.7627	0.6421		

Table 3. The dielectric constant and loss factor of propan-1-ol at 30ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	19.2230	2.8578	19.30	2.65
0.2	17.8315	5.2024	18.08	4.89
0.3	15.9953	6.7879	16.44	6.50
0.4	14.1039	7.6555	14.68	7.46
0.5	12.3870	7.9866	13.02	7.92
0.6	10.9302	7.9723	11.58	8.02
0.7	9.7355	7.7590	10.36	7.91
0.8	8.7702	7.4435	9.36	7.67
0.9	7.9933	7.0847	8.54	7.37
1.0	7.3665	6.7161	7.86	7.04
1.2	6.4423	6.0145	6.85	6.38
1.5	5.5768	5.1245	5.89	5.52
1.8	5.0578	4.4268	5.29	4.83
2.0	4.8217	4.0481	5.02	4.45
2.5	4.4443	3.3204	4.57	3.73
3.0	4.2312	2.8055	4.31	3.21
3.5	4.0998	2.4251	4.13	2.83
4.0	4.0133	2.1337	4.01	2.55
4.5	3.9535	1.9038	3.92	2.32
5.0	3.9104	1.7181	3.84	2.14
5.5	3.8733	1.5651		
6.0	3.8539	1.4369		
6.5	3.8348	1.3279		
7.0	3.8196	1.2343		
7.5	3.8074	1.1529		
8.0	3.7973	1.0815		
8.5	3.7890	1.0184		
9.0	3.7820	0.9622		
9.5	3.7761	0.9119		
10.0	3.7710	0.8666		

Table 4. The dielectric constant and loss factor of propan-1-ol at 40ºC

f(GHz)	ε'(This work)	ε''(This work)	ε'[6]	ε''[6]
0.1	18.1491	1.8443	18.20	1.71
0.2	17.5027	3.5197	17.63	3.28
0.3	16.5241	4.9053	16.78	4.62
0.4	15.3662	5.9500	15.74	5.68
0.5	14.1526	6.6640	14.63	6.44
0.6	12.9735	7.0950	13.53	6.95
0.7	11.8826	7.3040	12.47	7.25
0.8	10.9045	7.3501	11.51	7.38
0.9	10.0449	7.2827	10.65	7.39
1.0	9.2983	7.1401	9.88	7.31
1.2	8.0993	6.7340	8.62	7.00
1.5	6.8548	6.0380	7.28	6.39
1.8	6.0439	5.3851	6.39	5.78
2.0	5.6575	4.9982	5.96	5.40
2.5	5.0150	4.2001	5.23	4.62
3.0	4.6380	3.5987	4.79	4.02
3.5	4.4003	3.1379	4.52	3.56
4.0	4.2416	2.7768	4.34	3.20
4.5	4.1307	2.4876	4.21	2.92
5.0	4.0502	2.2514	4.11	2.69
5.5	3.9902	2.0553		
6.0	3.9441	1.8901		
6.5	3.9081	1.7490		
7.0	3.8794	1.6273		
7.5	3.8561	1.5213		
8.0	3.8370	1.4281		
8.5	3.8212	1.3455		
9.0	3.8079	1.2719		
9.5	3.7966	1.2059		
10.0	3.7869	1.1464		

Table 5. The dielectric constant and loss factor of propan-1-ol at 50ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	17.0040	1.1880	17.02	1.10
0.2	16.6960	2.3211	16.76	2.16
0.3	16.2130	3.3524	16.34	3.13
0.4	15.5941	4.2490	15.80	4.00
0.5	14.8829	4.9941	15.17	4.74
0.6	14.1211	5.5853	14.49	5.35
0.7	13.3445	6.0313	13.78	5.83
0.8	12.5807	6.3479	13.06	6.20
0.9	11.8490	6.5541	12.37	6.46
1.0	11.1617	6.6693	11.70	6.63
1.2	9.9418	6.6975	10.50	6.77
1.5	8.4965	6.4383	9.02	6.64
1.8	7.4371	6.0252	7.90	6.32
2.0	6.8945	5.7268	7.32	6.06
2.5	5.9323	5.0130	6.26	5.40
3.0	5.3295	4.4028	5.58	4.82
3.5	4.9336	3.9007	5.13	4.33
4.0	4.6620	3.4892	4.82	3.93
4.5	4.4688	3.1497	4.60	3.60
5.0	4.3268	2.8665	4.44	3.32

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
5.5	4.2197	2.6278		
6.0	4.1370	2.4242		
6.5	4.0719	2.2490		
7.0	4.0198	2.0967		
7.5	3.9775	1.9632		
8.0	3.9426	1.8454		
8.5	3.9136	1.7407		
9.0	3.8892	1.6470		
9.5	3.8684	1.5628		
10.0	3.8507	1.4866		

Table 6. The dielectric constant and loss factor of propan-2-ol at 10ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	17.7580	6.7735	18.55	6.91
0.2	12.6850	8.7357	13.39	9.07
0.3	9.2601	8.2313	9.81	8.65
0.4	7.2793	7.2178	7.70	7.65
0.5	6.1162	6.2648	6.45	6.68
0.6	5.3977	5.4732	5.67	5.87
0.7	4.9298	4.8332	5.15	5.21
0.8	4.6107	4.3123	4.80	4.67
0.9	4.3856	3.8862	4.55	4.23
1.0	4.2189	3.5325	4.37	3.86
1.2	3.9981	2.9825	4.12	3.30
1.5	3.8131	2.4120	3.90	2.72
1.8	3.7109	2.0220	3.77	2.32
2.0	3.6664	1.8245	3.71	2.13
2.5	3.5976	1.4654	3.60	1.77
3.0	3.5600	1.2238	3.53	1.54
3.5	3.5373	1.0504		
4.0	3.5225	0.9198		
4.5	3.5123	0.8181		
5.0	3.5051	0.7366		
5.5	3.4997	0.6698		
6.0	3.4956	0.6142		
6.5	3.4924	0.5670		
7.0	3.4899	0.5266		
7.5	3.4878	0.4916		
8.0	3.4861	0.4609		
8.5	3.4848	0.4338		
9.0	3.4836	0.4097		
9.5	3.4826	0.3882		
10.0	3.4818	0.3688		

Table 7. The dielectric constant and loss factor of propan-2-ol at 20ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	18.4293	4.5111	18.87	4.37
0.2	15.4364	7.2169	16.05	7.14
0.3	12.4444	8.1179	13.12	8.20
0.4	10.1178	8.0168	10.76	8.24
0.5	8.4562	7.5152	9.02	7.83
0.6	7.2897	6.9073	7.77	7.27
0.7	6.4627	6.3122	6.88	6.69
0.8	5.8647	5.7710	6.22	6.16

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.9	5.4227	5.2926	5.73	5.68
1.0	5.0889	4.8740	5.36	5.26
1.2	4.6302	4.1884	4.84	4.56
1.5	4.2330	3.4385	4.38	3.79
1.8	4.0084	2.9068	4.12	3.25
2.0	3.9094	2.6325	4.00	2.97
2.5	3.7550	2.1265	3.80	2.46
3.0	3.6699	1.7815	3.67	2.12
3.5	3.6181	1.5319		
4.0	3.5843	1.3432		
4.5	3.5611	1.1957		
5.0	3.5444	1.0772		
5.5	3.5321	0.9800		
6.0	3.5227	0.8989		
6.5	3.5153	0.8301		
7.0	3.5095	0.7711		
7.5	3.5048	0.7199		
8.0	5.5010	0.6750		
8.5	3.4978	0.6355		
9.0	3.4951	0.6003		
9.5	3.4928	0.5688		
10.0	3.4909	0.5404		

Table 8. The dielectric constant and loss factor of propan-2-ol at 30ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	17.8389	2.7629	17.92	2.56
0.2	16.4507	4.9922	16.71	4.70
0.3	14.6503	6.4500	15.09	6.19
0.4	12.8322	7.2019	13.39	7.05
0.5	11.2130	7.4462	11.82	7.42
0.6	9.8617	7.3768	10.47	7.47
0.7	8.7686	7.1353	9.35	7.32
0.8	7.8951	6.8114	8.43	7.06
0.9	7.1983	6.4573	7.68	6.76
1.0	6.6402	6.1019	7.07	6.44
1.2	5.8238	5.4388	6.17	5.81
1.5	5.0661	4.6138	5.32	4.99
1.8	4.6149	3.9753	4.80	4.35
2.0	4.4104	3.6331	4.57	4.00
2.5	4.0845	2.9725	4.19	3.33
3.0	3.9011	2.5089	3.98	2.87
3.5	3.7881	2.1673		
4.0	3.7139	1.9060		
4.5	3.6625	1.7002		
5.0	3.6256	1.5340		
5.5	3.5981	1.3972		
6.0	3.5772	1.2825		
6.5	3.5609	1.1852		
7.0	3.5479	1.1015		
7.5	3.5374	1.0288		
8.0	3.5288	0.9651		
8.5	3.5216	0.9087		
9.0	3.5156	0.8586		
9.5	3.5106	0.8137		
10.0	3.5062	0.7732		

Table 9. The dielectric constant and loss factor of protan-2-ol at 40ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	16.7234	1.6557	16.75	1.53
0.2	16.1398	3.1657	16.25	2.95
0.3	15.2735	4.4241	15.50	4.16
0.4	14.2421	5.3839	14.58	5.13
0.5	13.1540	6.0508	13.59	5.84
0.6	12.0895	6.4638	12.59	6.32
0.7	11.0982	6.6750	11.64	6.61
0.8	10.2042	6.7360	10.76	6.75
0.9	9.4143	6.6907	9.97	6.77
1.0	8.7251	6.5739	9.26	6.71
1.2	7.6119	6.2215	8.10	6.45
1.5	6.4485	5.5986	6.85	5.91
1.8	5.6858	5.0050	6.01	5.35
2.0	5.3211	4.6506	5.60	5.01
2.5	4.7128	3.9154	4.91	4.29
3.0	4.3549	3.3584	4.50	3.73
3.5	4.1288	2.9304		
4.0	3.9777	2.5944		
4.5	3.8719	2.3249		
5.0	3.7952	2.1047		
5.5	3.7380	1.9275		
6.0	3.6940	1.7617		
6.5	3.6596	1.6356		
7.0	3.6332	1.5220		
7.5	3.6100	1.4230		
8.0	3.5918	1.3358		
8.5	3.5766	1.2587		
9.0	3.5639	1.1899		
9.5	3.5531	1.1282		
10.0	3.5439	1.0725		

Table 10. The dielectric constant and loss factor of protan-2-ol at 50ºC

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
0.1	15.4184	0.9882	15.43	0.91
0.2	15.1801	1.9370	15.23	1.80
0.3	14.8034	2.8121	14.90	2.62
0.4	14.3149	3.5881	14.48	3.37
0.5	13.7451	4.2500	13.98	4.02
0.6	13.1255	4.7929	13.42	4.57
0.7	12.4827	5.2202	12.84	5.02
0.8	11.8397	5.5412	12.25	5.38
0.9	11.2133	5.7684	11.66	5.65
1.0	10.6154	5.9157	11.09	5.84
1.2	9.5309	6.0242	10.03	6.04
1.5	8.2059	5.8892	8.69	6.03
1.8	7.2058	5.5806	7.64	5.80
2.0	6.6838	5.3386	7.09	5.60
2.5	5.7412	4.7275	6.06	5.05
3.0	5.1395	4.1825	5.39	4.54
3.5	4.7394	3.7234		
4.0	4.4628	3.3418		
4.5	4.2648	3.0237		
5.0	4.1187	2.7567		

f(GHz)	ε'(this work)	ε''(this work)	ε'[6]	ε''[6]
5.5	4.0082	2.5305		
6.0	3.9227	2.3369		
6.5	3.8553	2.1697		
7.0	3.8012	2.0240		
7.5	3.7572	1.8962		
8.0	3.7209	1.7832		
8.5	3.6907	1.6826		
9.0	3.6653	1.5925		
9.5	3.6437	1.5115		
10.0	3.6252	1.4381		

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