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# Refractive Indices for the Binary Mixtures of *N,N*-Dimethylformamide with 2-Butanol and 2-Pentanol at Temperatures 303.15 K, 313.15 K, and 323.15 K

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**Abstract:** The refractive index values have been measured as a function of composition range at temperatures 303.15 K, 313.15 K, and 323.15 K and at ambient pressure and reported here. From these data, refractive index deviations, $\Delta n_D$, excess molar refraction, $R_m^E$, were calculated and correlated by the Redlich-Kister-type polynomial equation to derive the coefficients and estimated the standard deviation values. For both systems, $\Delta n_D$ were found to be both positive and negative. Excess molar refraction, $R_m^E$, versus mole fraction, $x_1$, of *N,N*-dimethylformamide curves were calculated and found as sigmoid at all temperatures. The variation of these properties with composition and temperature of the binary mixtures were discussed in terms of intermolecular interactions.

**Keywords:** *N,N*-Dimethylformamide, 2-Butanol, 2-Pentanol, Refractive Index Deviations, Molecular Interactions

## 1. Introduction

Refractive index, $n_D$, is an important physical quantity for analysis, because many substances can be easily identified by knowing its $n_D$ value. It is also used for theoretical purposes due to the fact that it gives information about the electronic configuration of the different ions and molecules forming the liquid [1]. The excess refractive indices ($\Delta n_D$) of the solvent-solvent interaction processes depend on the nature of the solvent and on its physical properties such as the dielectric constant, the dipole moment and the donor number [2]. Also, these properties have been used to study the structure of binary mixtures with water and aliphatic alcohols and cyclic ethers [3]. Properties such as refractive indices and their variation with temperature and composition of the binary mixtures are useful to design engineering processes and in chemical and biological industries [4].

*N, N*-dimethylformamide (DMF) is primarily used as an industrial solvent. Pure DMF is aprotic and unassociated [5] in its pure liquid state. It belongs to the so-called super solvents, owing to its miscibility with almost all common polar and non-polar solvents [6], probably due to its high polarity with large dipole moment ($\mu$ = 3.8D) and moderately high dielectric constant ($\varepsilon$ = 36.76) [7]. Several topics and examples of thermodynamic studies are depicted on the basis of the structural behavior of DMF for binary mixtures of non-electrolytes [8].

Alkanols are important compounds in both industry and science. Alkanols can also be used in the synthesis of many other organic compounds. Some industrial applications of alkanols consist of perfumes, cosmetics, paints, varnishes, drugs, fuels, explosives, fats, waxes, resins, plastics, rubber, and detergents [9-12].

In recent past, several workers [13-18] have applied various mixing rules in binary and ternary liquid mixtures. In this paper we present the results of experimental measurements of the refractive indices for binary mixtures of *N, N*-dimethylformamide with two polar solvents. Here, we reported the refractive index, $n_D$, refractive index deviations, $\Delta n_D$, excess molar refraction, $R_m^E$, as the function of

composition range at temperatures (303.15, 313.15, and 323.15) K and at ambient pressure. The findings of this study can be utilized in having a better insight into molecular interactions between the components of the systems.

# 2. Experimental Section

### *2.1. Chemicals Used*

DMF (Aldrich, purity HPLC grade 99.9+%), 2-BuOH (Aldrich, purity 99+%) and 2-PnOH (Aldrich, purity 98%) were used without further treatment. The structures of the chemicals are shown in Figure 1. The densities and refractive indexes of pure chemicals were compared with literature values, which showed satisfactory agreements (Table 1).

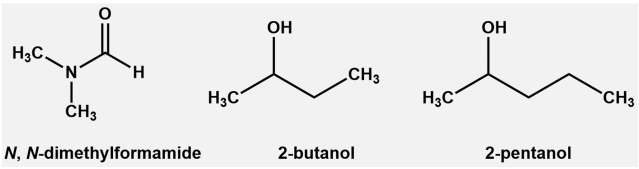


***Figure 1.*** *Chemical structures of the compounds used in the experiments.*

### *2.2. Materials and Methods*

The refractive indices of pure components and the mixtures were determined by using an Abbe refractometer (Abbe 60/ED). The samples were prepared by mixing the pure components at different proportions up to ±0.0001g, which was then converted into mole fraction. All the molar quantities used in the experiments are based on the IUPAC relative atomic mass table [19].

# 3. Results and Discussion

### *3.1. Refractive Index and Molecular Polarizability*

Refraction index can be defined as the ratio of speed of light in vacuum to its speed in the medium, i.e.

$$n_D = \frac{C}{\upsilon}$$

Where $n_D$ is the refractive index of the binary liquid mixture of the medium, $C$ is the speed of the light in vacuum and $\upsilon$ is the speed of the light in the binary liquid mixture.

Assessment of the purity of substances and molecular interaction in a liquid mixture, calculation of molecular electronic polarizability, estimation of boiling point by Meissner's Method [20] and the estimation of other thermodynamic parameters can be done from the refractive index [21-24]. The detection of structural properties of liquid-liquid mixtures is possible by the use refractive index.

Refractive indices ($n_D$) of the two binary systems were measured in the whole range of composition, $0 \leq x_1 \leq 1$, among 303.15 K, 313.15 K and 323.15 K maintaining 10 K interval, where, $x_1$ represents the mole fraction of DMF. The measured refractive index, $n_D$, of the pure liquids are placed (Table 1) together with a number of reported data. Their comparison also shows that there is quite satisfactory agreement between the experimental and literature values.

***Table 1.*** *Experimental and literature values of refractive index ($n_D$) of the pure N, N-dimethylformamide (DMF), 2-butanol (2-BuOH) and 2-pentanol (2-PnOH) at different temperatures.*

| Component | Temp. T / K | Refractive Index, $n_D$ values | |
|---|---|---|---|
| | | Experimental | Literature |
| 2-BuOH | 303.15 | 1.39188 | |
| | 313.15 | 1.38725 | 1.3903 [25] |
| | 323.15 | 1.38333 | |
| 2-PnOH | 303.15 | 1.40125 | |
| | 313.15 | 1.39649 | |
| | 323.15 | 1.39180 | |
| DMF | 303.15 | 1.42466 | |
| | 313.15 | 1.41998 | 1.4264 [26] |
| | 323.15 | 1.41625 | |

The refractive indices, ($n_D$), were fitted to the polynomial equation of the following form:

$$n_D = \sum_{i=0} a_i x_1^i \quad (1)$$

Here, $a_i$ is the $i^{th}$ fitting coefficient and $x_1$ is the mole fraction of DMF. By using 'Excel', the coefficients, $a_i$ and values of $r^2$ for the systems at different compositions and temperatures were computed and all of them are summarized (Table 2). The relevant $r^2$ values were very close to unity indicates the excellent fitting for all the experimental data.

***Table 2.*** *Fitting coefficients, $a_i$ of polynomial Eq. (1) and the values of $r^2$ for the systems of DMF ($x_1$) + 2-BuOH ($x_2$) and + 2-PnOH ($x_2$) at different temperatures.*

*DMF ($x_1$) + 2-BuOH ($x_2$)*

| T/K | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $r^2$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | 1.391 | 0.025 | 0.043 | -0.165 | 0.323 | -0.305 | 0.999 |
| 313.15 K | 1.387 | 0.023 | 0.052 | -0.168 | 0.297 | -0.267 | 0.999 |
| 323.15 K | 1.383 | 0.016 | 0.110 | -0.394 | 0.736 | -0.674 | 0.999 |

*DMF ($x_1$) + 2-PnOH ($x_2$)*

| T/K | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $r^2$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | 1.401 | 0.016 | 0.045 | -0.158 | 0.286 | -0.250 | 0.999 |
| 313.15 K | 1.396 | 0.010 | 0.070 | -0.247 | 0.442 | -0.382 | 0.999 |
| 323.15 K | 0.1391 | 0.011 | 0.069 | -0.222 | 0.404 | -0.375 | 0.999 |

### *3.2. Deviation in Refractive Index*

For each system, the deviation in refractive index ($\Delta n_D$) of a particular composition is calculated by using the following equation:

$$\Delta n_D = n_D - \sum \varphi_i n_{Di} \quad (2)$$

Here, $\varphi_i$ and $n_{Di}$ represent the volume fraction and the refractive index, respectively of the $i^{th}$ component and $n_D$ is the observed refractive index of the mixtures. All $\Delta n_D$ values are listed (Table 3).

***Table 3.*** *Densities, (ρ), volume fraction of DMF ($\phi_1$), refractive index, ($n_D$), deviations in refractive index, ($\Delta n_D$), molar refraction, ($R_m$), excess molar refraction ($R_m^E$) of the systems DMF ($x_1$) + 2-BuOH ($x_2$) and + 2-PnOH ($x_2$) for different molar ratios at 303.15K, 313.15K and 323.15K.*

*T=303.15K*
*DMF+2-BuOH*

| 3 | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 798.683 | 0.000000 | 1.39188 | 0.00000 | 22.09285 | 0.00000 |
| 0.0506 | 804.205 | 0.042348 | 1.39341 | 0.00014 | 22.00189 | 0.01206 |
| 0.0997 | 810.160 | 0.085046 | 1.39467 | 0.00000 | 21.88714 | 0.01346 |
| 0.1515 | 815.793 | 0.128358 | 1.39631 | 0.00022 | 21.80106 | 0.02575 |
| 0.2000 | 821.967 | 0.172031 | 1.39790 | 0.00038 | 21.69937 | 0.02479 |
| 0.2497 | 828.575 | 0.219703 | 1.39966 | 0.00058 | 21.59475 | 0.02720 |
| 0.2909 | 834.597 | 0.263784 | 1.40094 | 0.00041 | 21.48535 | 0.03162 |
| 0.3510 | 841.410 | 0.310189 | 1.40261 | 0.00056 | 21.37507 | 0.02415 |
| 0.3999 | 848.374 | 0.358350 | 1.40421 | 0.00058 | 21.25903 | 0.01926 |
| 0.4494 | 855.730 | 0.406386 | 1.40586 | 0.00066 | 21.13760 | 0.00438 |
| 0.5003 | 863.058 | 0.456253 | 1.40742 | 0.00058 | 21.01436 | -0.00313 |
| 0.5491 | 871.791 | 0.505906 | 1.40894 | 0.00048 | 20.85786 | -0.04483 |
| 0.6002 | 880.089 | 0.556955 | 1.41068 | 0.00054 | 20.72416 | -0.07040 |
| 0.6500 | 888.162 | 0.611440 | 1.41236 | 0.00044 | 20.59465 | -0.07868 |
| 0.7000 | 895.575 | 0.661847 | 1.41399 | 0.00041 | 20.48156 | -0.08486 |
| 0.7499 | 902.987 | 0.715092 | 1.41555 | 0.00023 | 20.36665 | -0.08174 |
| 0.7999 | 910.279 | 0.770199 | 1.41699 | -0.00014 | 20.25077 | -0.07014 |
| 0.8500 | 917.420 | 0.826344 | 1.41878 | -0.00019 | 20.15468 | -0.05236 |
| 0.9000 | 924.083 | 0.882983 | 1.42066 | -0.00016 | 20.07416 | -0.02315 |
| 0.9500 | 931.500 | 0.941050 | 1.42236 | -0.00037 | 19.97085 | - 0.00654 |
| 1.0000 | 939.496 | 1.000000 | 1.42466 | 0.00000 | 19.88139 | 0.00000 |

*T=313.15K*
*DMF+2-BuOH*

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 789.992 | 0.000000 | 1.38725 | 0.00000 | 22.10151 | 0.00000 |
| 0.0506 | 795.526 | 0.042320 | 1.38834 | -0.00030 | 21.98745 | 0.01069 |
| 0.0997 | 801.469 | 0.084993 | 1.39003 | 0.00000 | 21.89371 | 0.01132 |
| 0.1515 | 807.356 | 0.128282 | 1.39153 | 0.00008 | 21.79330 | 0.01577 |
| 0.2000 | 813.213 | 0.171934 | 1.39279 | -0.00009 | 21.68335 | 0.02224 |
| 0.2497 | 819.776 | 0.219587 | 1.39477 | 0.00033 | 21.59006 | 0.02471 |
| 0.2909 | 825.751 | 0.263652 | 1.39600 | 0.00012 | 21.47872 | 0.02934 |
| 0.3510 | 832.513 | 0.310044 | 1.39800 | 0.00060 | 21.38475 | 0.02203 |
| 0.3999 | 839.423 | 0.358193 | 1.39914 | 0.00017 | 21.24752 | 0.01733 |
| 0.4494 | 846.723 | 0.406221 | 1.40104 | 0.00049 | 21.13838 | 0.00262 |
| 0.5003 | 854.077 | 0.456084 | 1.40254 | 0.00036 | 21.01082 | -0.00670 |
| 0.5491 | 862.573 | 0.505736 | 1.40426 | 0.00046 | 20.86796 | -0.04416 |
| 0.6002 | 870.920 | 0.556787 | 1.40601 | 0.00054 | 20.73244 | -0.07228 |
| 0.6500 | 878.920 | 0.611278 | 1.40730 | 0.00004 | 20.58624 | -0.07998 |
| 0.7000 | 886.292 | 0.661695 | 1.40906 | 0.00015 | 20.47912 | -0.08631 |
| 0.7499 | 893.641 | 0.714953 | 1.41051 | -0.00014 | 20.36006 | -0.08274 |
| 0.7999 | 900.874 | 0.770078 | 1.41213 | -0.00032 | 20.25252 | -0.07078 |
| 0.8500 | 907.973 | 0.826246 | 1.41402 | -0.00027 | 20.16104 | -0.05293 |
| 0.9000 | 914.536 | 0.882913 | 1.41599 | -0.00016 | 20.08605 | -0.02225 |
| 0.9500 | 922.000 | 0.941012 | 1.41723 | -0.00082 | 19.96163 | -0.00752 |
| 1.0000 | 929.906 | 1.000000 | 1.41998 | 0.00000 | 19.89243 | 0.00000 |

*T=323.15K*
*DMF+2-BuOH*

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 780.886 | 0.000000 | 1.38333 | 0.00000 | 22.15788 | 0.00000 |
| 0.0506 | 786.481 | 0.042272 | 1.38419 | -0.00053 | 22.02895 | 0.00833 |
| 0.0997 | 792.462 | 0.084901 | 1.38579 | -0.00033 | 21.92862 | 0.00715 |
| 0.1515 | 798.271 | 0.128150 | 1.38730 | -0.00025 | 21.82982 | 0.01306 |
| 0.2000 | 804.217 | 0.171765 | 1.38871 | -0.00027 | 21.72372 | 0.01651 |
| 0.2497 | 810.763 | 0.219384 | 1.39036 | -0.00019 | 21.61374 | 0.01873 |
| 0.2909 | 816.723 | 0.263422 | 1.39201 | 0.00001 | 21.52217 | 0.02321 |
| 0.3510 | 823.461 | 0.309790 | 1.39339 | -0.00014 | 21.39795 | 0.01576 |
| 0.3999 | 830.349 | 0.357921 | 1.39519 | 0.00008 | 21.29151 | 0.01097 |

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.4494 | 837.585 | 0.405935 | 1.39687 | 0.00018 | 21.17242 | -0.00291 |
| 0.5003 | 844.925 | 0.455790 | 1.39851 | 0.00018 | 21.05041 | -0.01261 |
| 0.5491 | 853.420 | 0.505440 | 1.39984 | -0.00013 | 20.88799 | -0.05104 |
| 0.6002 | 861.642 | 0.556494 | 1.40179 | 0.00014 | 20.76336 | -0.07705 |
| 0.6500 | 869.598 | 0.610997 | 1.40328 | -0.00016 | 20.62571 | -0.08442 |
| 0.7000 | 876.922 | 0.661430 | 1.40503 | -0.00007 | 20.51813 | -0.09021 |
| 0.7499 | 884.201 | 0.714711 | 1.40659 | -0.00027 | 20.40427 | -0.08552 |
| 0.7999 | 891.412 | 0.769868 | 1.40816 | -0.00051 | 20.29386 | -0.07342 |
| 0.8500 | 898.461 | 0.826076 | 1.40976 | -0.00076 | 20.18998 | -0.05470 |
| 0.9000 | 905.015 | 0.882790 | 1.41153 | -0.00086 | 20.10599 | -0.02393 |
| 0.9500 | 912.100 | 0.940947 | 1.41358 | -0.00073 | 20.02318 | -0.00119 |
| 1.0000 | 920.277 | 1.000000 | 1.41625 | 0.00000 | 19.94388 | 0.00000 |

*T=303.15K*
*DMF+2-PnOH*

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 801.295 | 0.000000 | 1.40125 | 0.00000 | 26.7426 | 0.00000 |
| 0.0506 | 805.702 | 0.036327 | 1.40215 | 0.00005 | 26.4188 | 0.02010 |
| 0.0997 | 810.540 | 0.072636 | 1.40310 | 0.00015 | 26.0933 | 0.02551 |
| 0.1515 | 816.272 | 0.112126 | 1.40442 | 0.00055 | 25.7512 | 0.01636 |
| 0.2000 | 821.868 | 0.150253 | 1.40546 | 0.00069 | 25.4159 | 0.00594 |
| 0.2497 | 828.337 | 0.190535 | 1.40644 | 0.00073 | 25.0491 | -0.02149 |
| 0.2909 | 833.318 | 0.224899 | 1.40751 | 0.00100 | 24.7738 | -0.02803 |
| 0.3510 | 841.237 | 0.276684 | 1.40879 | 0.00106 | 24.3428 | -0.04941 |
| 0.3999 | 847.995 | 0.320340 | 1.40985 | 0.00110 | 23.9890 | -0.06890 |
| 0.4494 | 854.694 | 0.365999 | 1.41120 | 0.00138 | 23.6534 | -0.07823 |
| 0.5003 | 861.886 | 0.414565 | 1.41217 | 0.00122 | 23.2835 | -0.08943 |
| 0.5491 | 868.917 | 0.462746 | 1.41350 | 0.00142 | 22.9496 | -0.09734 |
| 0.6002 | 876.136 | 0.514989 | 1.41449 | 0.00118 | 22.5888 | -0.09499 |
| 0.6500 | 883.479 | 0.567791 | 1.41590 | 0.00136 | 22.2550 | -0.09397 |
| 0.7000 | 890.808 | 0.622665 | 1.41692 | 0.00109 | 21.9072 | -0.08542 |
| 0.7499 | 898.243 | 0.679607 | 1.41798 | 0.00082 | 21.5634 | -0.07288 |
| 0.7999 | 905.546 | 0.738772 | 1.41940 | 0.00086 | 21.2432 | -0.05060 |
| 0.8500 | 913.278 | 0.800317 | 1.42080 | 0.00081 | 20.9158 | -0.03162 |
| 0.9000 | 921.494 | 0.864233 | 1.42172 | 0.00024 | 20.5618 | -0.01712 |
| 0.9500 | 929.400 | 0.930740 | 1.42306 | 0.00002 | 20.2373 | 0.01141 |
| 1.0000 | 939.496 | 1.000000 | 1.42466 | 0.00000 | 19.8814 | 0.00000 |

*T=313.15K*
*DMF+2-PnOH*

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 792.841 | 0.000000 | 1.39649 | 0.00000 | 26.7440 | 0.00000 |
| 0.0506 | 797.301 | 0.036314 | 1.39736 | 0.00002 | 26.4159 | 0.01713 |
| 0.0997 | 802.145 | 0.072612 | 1.39834 | 0.00014 | 26.0911 | 0.02108 |
| 0.1515 | 807.889 | 0.112091 | 1.39950 | 0.00038 | 25.7386 | 0.01006 |
| 0.2000 | 813.304 | 0.150208 | 1.40051 | 0.00049 | 25.4066 | 0.00391 |
| 0.2497 | 819.826 | 0.190481 | 1.40166 | 0.00070 | 25.0464 | -0.02681 |
| 0.2909 | 824.859 | 0.224838 | 1.40272 | 0.00095 | 24.7682 | -0.03610 |
| 0.3510 | 832.691 | 0.276614 | 1.40399 | 0.00100 | 24.3379 | -0.05671 |
| 0.3999 | 839.281 | 0.320265 | 1.40519 | 0.00118 | 23.9950 | -0.07292 |
| 0.4494 | 845.990 | 0.365918 | 1.40645 | 0.00136 | 23.6535 | -0.08402 |
| 0.5003 | 853.098 | 0.414481 | 1.40740 | 0.00117 | 23.2835 | -0.09444 |
| 0.5491 | 859.934 | 0.462660 | 1.40872 | 0.00136 | 22.9533 | -0.09861 |
| 0.6002 | 867.282 | 0.514902 | 1.40982 | 0.00123 | 22.5931 | -0.10116 |
| 0.6500 | 874.535 | 0.567706 | 1.41096 | 0.00113 | 22.2477 | -0.09918 |
| 0.7000 | 881.790 | 0.622584 | 1.41237 | 0.00126 | 21.9189 | -0.09022 |
| 0.7499 | 889.234 | 0.679532 | 1.41354 | 0.00109 | 21.5786 | -0.07923 |
| 0.7999 | 896.660 | 0.738705 | 1.41477 | 0.00093 | 21.2457 | -0.06103 |
| 0.8500 | 904.314 | 0.800261 | 1.41595 | 0.00066 | 20.9095 | -0.04136 |
| 0.9000 | 912.550 | 0.864192 | 1.41710 | 0.00031 | 20.5637 | -0.02852 |
| 0.9500 | 920.623 | 0.930718 | 1.41834 | -0.00001 | 20.2303 | -0.00469 |
| 1.0000 | 929.906 | 1.000000 | 1.41998 | 0.00000 | 19.8924 | 0.00000 |

*T=323.15K*
*DMF+2-PnOH*

| $x_1$ | $\rho$ /kg m$^{-3}$ | $\phi_1$ | $n_D$ | $\Delta n_D$ | $R_m \times 10^6$/m$^3$ mol$^{-1}$ | $R_m^E \times 10^6$/m$^3$ mol$^{-1}$ |
|---|---|---|---|---|---|---|
| 0.0000 | 784.055 | 0.000000 | 1.39180 | 0.00000 | 26.7601 | 0.00000 |
| 0.0506 | 788.606 | 0.036289 | 1.39260 | -0.00009 | 26.4236 | 0.01314 |
| 0.0997 | 793.497 | 0.072563 | 1.39341 | -0.00016 | 26.0863 | 0.01454 |
| 0.1515 | 799.188 | 0.112018 | 1.39459 | 0.00005 | 25.7357 | 0.00407 |
| 0.2000 | 804.939 | 0.150115 | 1.39567 | 0.00020 | 25.3960 | -0.01373 |
| 0.2497 | 810.993 | 0.190368 | 1.39678 | 0.00033 | 25.0470 | -0.03110 |
| 0.2909 | 816.199 | 0.224710 | 1.39766 | 0.00037 | 24.7529 | -0.04659 |
| 0.3510 | 823.970 | 0.276467 | 1.39909 | 0.00053 | 24.3318 | -0.06675 |
| 0.3999 | 830.635 | 0.320105 | 1.40058 | 0.00095 | 24.0011 | -0.08626 |
| 0.4494 | 837.197 | 0.365748 | 1.40160 | 0.00086 | 23.6501 | -0.09413 |
| 0.5003 | 844.144 | 0.414302 | 1.40275 | 0.00082 | 23.2934 | -0.10121 |
| 0.5491 | 850.907 | 0.462478 | 1.40399 | 0.00088 | 22.9600 | -0.10442 |
| 0.6002 | 858.055 | 0.514719 | 1.40530 | 0.00092 | 22.6140 | -0.10283 |
| 0.6500 | 865.240 | 0.567526 | 1.40658 | 0.00090 | 22.2755 | -0.10022 |
| 0.7000 | 872.564 | 0.622411 | 1.40769 | 0.00067 | 21.9293 | -0.09396 |
| 0.7499 | 880.001 | 0.679372 | 1.40891 | 0.00050 | 21.5900 | -0.08376 |
| 0.7999 | 887.533 | 0.738563 | 1.40999 | 0.00013 | 21.2465 | -0.06892 |
| 0.8500 | 895.210 | 0.800144 | 1.41150 | 0.00014 | 20.9234 | -0.05056 |
| 0.9000 | 903.473 | 0.864106 | 1.41277 | -0.00016 | 20.5808 | -0.03910 |
| 0.9500 | 911.572 | 0.930670 | 1.41399 | -0.00056 | 20.2446 | -0.01643 |
| 1.0000 | 920.277 | 1.000000 | 1.41625 | 0.00000 | 19.9439 | 0.00000 |

### *3.3. Molar Refraction*

The presence of short range interaction between similar and dissimilar molecules can be known from the molar refraction. The following equation is used to calculate the molar polarization. The calculation of the molar refraction, $R_m$, was carried out by using the following equation:

$$R_m = \{(n_D^2-1)/(n_D^2+2)\}\ [\{(x_1M_1 + x_2M_2)/\rho_{mix}\} \quad (3)$$

### *3.4. Excess Properties*

The variation of excess parameters like excess molar refraction with mole fractions is also studied. The excess molar refractions ($R_m^E$) are estimated as the following equation:

$$R_m^E = \{(n_D^2-1)/(n_D^2+2)\}\ [\{(x_1M_1 + x_2M_2)/\rho_{mix}\} - \{x_1M_1/\rho_1 + x_2M_2/\rho_2\}] \quad (4)$$

The excess values were fitted by the Redlich-Kister type [27] polynomial equation as shown below:

$$\Delta n_D = x_1 x_2 \sum_{i=0} A_i (2x_2 - 1)^i \quad (5)$$

Where, $A_i$ is the relevant $i^{th}$ fitting coefficient of the Redlich-Kister polynomial equation and all the other terms have their usual significance.

The relevant standard deviations, $\sigma$, were calculated by using the following relation:

$$\sigma = \left[ \sum \frac{\left(Y_{exp}^E - Y_{cal}^E\right)^2}{n-p-2} \right]^{1/2} \quad (6)$$

Where, n and p are the number of experimental points and number of parameters retained respectively.

All the coefficients, $A_i$, of Eq. 5 and their relevant $\sigma$ values by using Eq. 6 are listed (Table 4 and Table 5).

***Table 4.*** *Fitting coefficients, $A_i$, of Redlich-Kister polynomial Eq. (5) and the values of standard deviation, $\sigma$, ($\Delta n_D$) for the systems DMF ($x_1$) + 2-BuOH ($x_2$), + 2-PnOH ($x_2$) at different temperatures.*

*DMF (x1) + 2-BuOH (x2)*

| T/K | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $\sigma$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | 0.0024 | -0.0006 | -0.0009 | -0.0031 | -0.0067 | -0.008 | 0.00010 |
| 313.15 K | 0.0017 | -0.0009 | -0.0029 | -0.0003 | -0.9978 | -0.0037 | 0.00022 |
| 323.15 K | 0.0003 | 0.0003 | -0.0017 | -0.0049 | -0.0136 | -0.0003 | 0.00012 |

*DMF (x1) + 2-PnOH (x2)*

| T/K | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $\sigma$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | 0.0051 | 0.0009 | 0.0005 | 0.0006 | -0.0058 | -0.0017 | 0.00013 |
| 313.15 K | 0.0050 | 0.0003 | 0.0015 | 0.0101 | -0.0085 | -0.0137 | 0.00007 |
| 323.15 K | 0.0036 | 0.0011 | -0.0029 | 0.0031 | -0.0093 | -0.0108 | 0.00012 |

***Table 5.*** *Fitting coefficients, $A_i$, of Redlich-Kister polynomial Eq. (5) and the values of standard deviation, $\sigma$ , ($R_m^E$) for the systems DMF ($x_1$) + 2-BuOH ($x_2$), + 2-PnOH ($x_2$) at different temperatures.*

*DMF ($x_1$) + 2-BuOH ($x_2$)*

| T/K | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | σ |
|---|---|---|---|---|---|---|---|
| 303.15 K | -0.0675 | -0.9053 | -0.5423 | 1.3707 | 0.9010 | -0.6445 | 0.00547 |
| 313.15 K | -0.0734 | -0.9138 | -0.5661 | 1.4967 | 0.8948 | -0.7561 | 0.00470 |
| 323.15 K | -0.0962 | -0.8874 | -0.5945 | 1.3668 | 0.9655 | -0.5342 | 0.00479 |

*DMF ($x_1$) + 2-PnOH ($x_2$)*

| T/K | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | σ |
|---|---|---|---|---|---|---|---|
| 303.15 K | -0.3565 | -0.2987 | 0.3685 | -0.1047 | 0.4969 | 0.3099 | 0.00380 |
| 313.15 K | -0.3770 | -0.2872 | 0.3778 | -0.1161 | 0.2842 | 0.1308 | 0.00313 |
| 323.15 K | -0.4062 | -0.2054 | 0.3914 | -0.3044 | -0.0787 | 0.1334 | 0.00182 |

The refractive indices, ($n_D$), of the systems DMF + 2-BuOH and DMF + 2-PnOH in the whole range of composition at three different temperatures (303.15 K, 313.15 K and 323.15 K) are displayed (Table 2) and presented graphically in Figure 2 and 3.

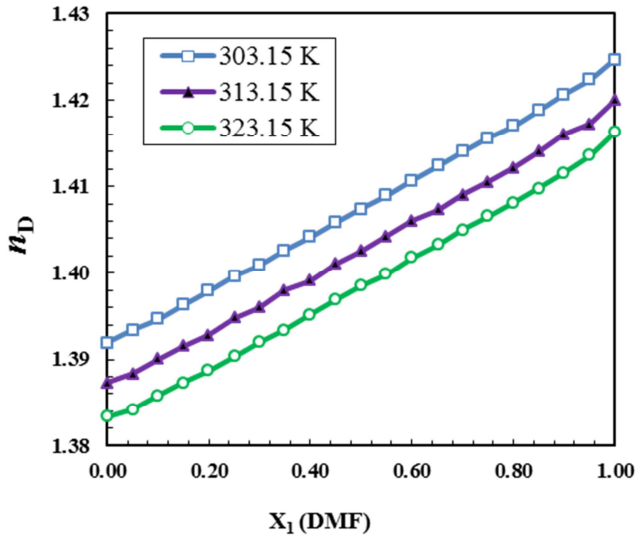


***Figure 2.*** *Refractive index, $n_D$ of DMF ($x_1$) + 2-BuOH ($x_2$) system for different molar ratios at different temperatures.*

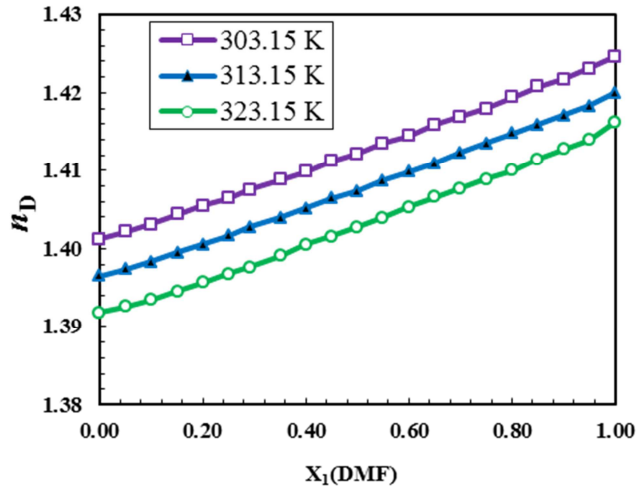


***Figure 3.*** *Refractive index, $n_D$ of DMF ($x_1$) + 2-PnOH ($x_2$) system for different molar ratios at different temperatures.*

The variations of $\Delta n_D$ with mole fraction $x_1$, of DMF at three temperatures, along with the smoothed $\Delta n_D$ values by using Eq. 5, are presented graphically in Figure 4 and 5.

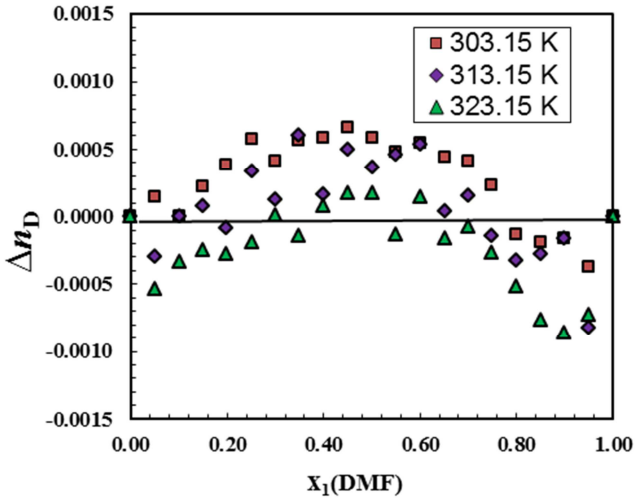


***Figure 4.*** *Deviation in refractive index ($\Delta n_D$) of DMF ($x_1$) + 2-BuOH ($x_2$) system for different molar ratios at different temperatures.*

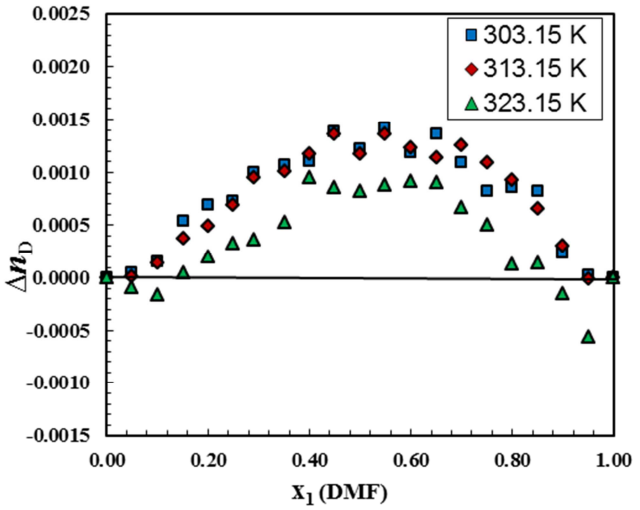


***Figure 5.*** *Deviation in refractive index ($\Delta n_D$) of DMF ($x_1$) + 2-PnOH ($x_2$) system for different molar ratios at different temperatures.*

The calculated values of $\Delta n_D$ are presented (Table 2) and Figure 6 and 7 also.

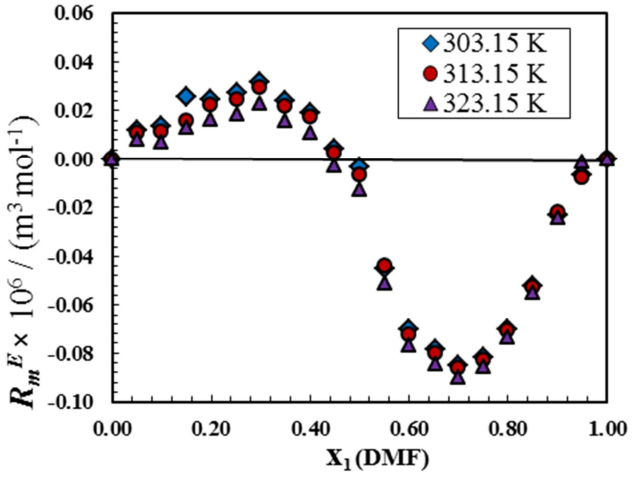


***Figure 6.*** *Excess molar refraction (RmE) of DMF (x1) + 2-BuOH (x2) system for different molar ratios at different temperatures.*

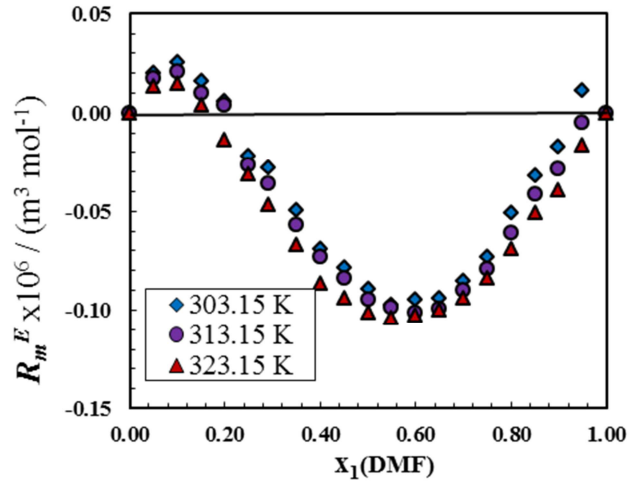


***Figure 7.*** *Excess molar refraction ($R_m^E$) of DMF ($x_1$) + 2-PnOH ($x_2$) system for different molar ratios at different temperatures.*

The $n_D$ versus $x_1$ curves for both systems followed a similar trend. The refractive index values, $n_D$ increased almost linearly with the concentration of the DMF. The increment of $n_D$ with respect to $x_1$ follows the order: 2-PnOH + DMF > 2-BuOH + DMF. Effect of temperature on $n_D$ values is large, but with the rise of temperature, $n_D$ values decreased. For 2-PnOH + DMF system, the $\Delta n_D$ values were positive except only the small negative values of $x_1$ = 0.05~0.10 & 0.90~0.95 at lower temperatures, whereas, for 2-BuOH + DMF, $\Delta n_D$ were found to be both positive and negative. For both systems $R_m^E$ versus $x_1$ curves were found to be sigmoid at all temperatures. The magnitude of negative $R_m^E$ follows the order: 2-PnOH + DMF > 2-BuOH + DMF. The refractive index, ($n_D$) is a parameter which also depends on the nature of incident light, density and molecular polarizability of the substance. Therefore, at a fixed frequency (Na D-line), $n_D$ or any deviation of $n_D$ is expected to have close similarity to the respective $\rho$. Moreover, positive excess refractive indices were obtained which indicates the presence of specific molecular interactions between the unlike components. The sign of $R_m^E$ of solutions depends upon the relative magnitude of expansion and contraction on mixing up of the components. If the factors causing expansion out to weigh the factors causing contraction, the values of $R_m^E$ becomes positive. But when the contractive factors are dominant over the expansive factors, the overall $R_m^E$ becomes negative.

## 4. Conclusions

In the present study, the refractive indices, $n_D$, of the binary mixtures of *N, N*-dimethylformamide with 2-butanol and 2-pentanol have been experimentally measured at T= (303.15, 313.15, 323.15) K. From the values of refractive index, deviations in refractive index, $\Delta n_D$, excess molar refraction, $R_m^E$, were determined. The Redlich-Kister polynomial equation was used to correlate the results. The deviations in refractive index, $\Delta n_D$, were found to be both positive and negative. Excess molar refraction, $R_m^E$ versus mole fraction, $x_1$, of *N, N*-dimethylformamide curves were calculated and found as sigmoid at all temperatures. The variation pattern of $n_D$, $\Delta n_D$ and $R_m^E$ were due to respective density and molecular polarizability.

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