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**Research Article**

# Evaluation of Molar Sound Velocity and Molar Compressibility for Binary System of 1-Butanol + Hexadecane and 1- Butanol + Squalane

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## Abstract

The molar sound velocity and molar compressibility of binary liquid systems of 1-Butanol + Hexadecane and 1-Butanol + Squalane have been studied over the entire range of composition at 298.15, 303.15 and 308.15 K. The nature and extent of molecular interactions for respective systems are studied by using the values of Rao constant (R) and Wada constant (W). The linearity of Rao's constant and Wada's constant is also proven.

**Keywords:** Molar sound velocity, molar compressibility, molecular interaction, 1-butanol, squalane, hexadecane

## 1. Introduction

The study of ultrasonic, volumetric and viscometric properties of liquid system is increased considerably in recent years due to extensive application owing to their ability of characterising physiochemical behavior of liquid systems. Besides such studies enable evaluation of some useful thermodynamic and transport parameters which can be used to explain the nature and extent of molecular interactions qualitatively; because the properties of pure substances are different from their mixtures. The properties of liquid systems can be altered continuously within a reasonable range by varying the concentration till an optimum value of some desired parameter is attained. The pure liquid lacks such flexibility. The studies of properties of binary liquid systems find direct application in chemical and biochemical industries [1].

In this paper, using the experimental ultrasonic velocity and density [2], we have calculated the theoretical values of molar sound velocity and molar compressibility for the binary liquid system of 1-Butanol + Hexadecane and 1-Butanol + Squalane, by using Nomoto's relation and Wada's theory at ( 298.15, 303.15 and 308.15 ) K, over the entire composition range.

From literature survey, we come to know that these parameters are used by many workers [3-10] for the acoustical studies of binary liquid systems. The previous investigation reveals that the excess thermodynamic properties of binary liquid systems of Hexadecane and squalane with hydrocarbons have been reported by several workers [11-21]. The increasing importance of the molar sound velocity and molar compressibility of binary liquid systems and the deviations from Rao's and Wada's rules have inspired us to investigate some binary liquid systems in detail.

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## 2. Theory

The ultrasonic studies provide a wealth of information about the state of liquids. The molar sound velocity and molar compressibility are two important parameters which are widely used for investigating the physiochemical behavior of liquid systems. Compressibility receives increasing attention in the studies on molecular interactions and on the structure of pure liquids and solutions. In 1940, Rao [22] showed empirically that the following expression hold approximately true for many liquids,

$$1 / U\ (\partial U / \partial t) = 3\ (1/\rho)\ (\partial \rho / \partial t)$$

And, $(M / \rho)\ U^{1/3} = R$

Or, $V_m U^{1/3} = R$ ---------------------------------------------------------------------------(1)

Where , U = Sound velocity , ρ = density , t = temperature (in $^oC$) , and $V_m$ =molar volume .

Molar sound velocity or Rao Constant is denoted by R . Rao molar sound velocity relation has been extensively used and verified by a number of workers [22,23] .

The Molar compressibility, W, was defined by Wada [24] as ,

$$W = M / \rho\ .\ \beta s^{-1/7}$$

Or, $W = V_m\ .\ \beta s^{-1/7}$ ------------------------------------------------------------------------(2)

Where , βs = adiabatic compressibility . The compressibility factor depends upon the structure of the liquid.

In case of inorganic melts, the molar sound velocity can be calculated from the equation written below ,

$R = MU^{1/3} / \rho$ -----------------------------------------------------------------------(3)

Employing the relation,

$$\beta s = 1 / U^2 \rho$$

W can be written as ,

$$W = M / \rho^{6/7}\ .\ U^{2/7}$$

Or, $W = M^{1/7}\ .\ R^{6/7}$ ------------------------------------------------------------------------(4)

Such liquids that satisfies the relation, R (T, P) = constant are called as Rao liquid or "Rao – Wada liquid". Such liquid system represents the average liquids, organic and inorganic, except highly associated systems. In the thermodynamic and physiochemical study of binary liquid systems, the molar sound velocity (R) and molar compressibility (W) are very important parameters.

Assuming the linearity of the molar sound velocity, Nomoto [25] established the following relation for molar sound velocity in binary liquid systems:

$R = x1\ R1 + x2\ R2$ ------------------------------------------------------------------(5)

Where, x1 and x2 are mole fractions of component 1 and 2 respectively.

R1 and R2 are molar sound velocity of component 1 and 2 respectively of the binary liquid system.

On the other hand molar compressibility of binary liquid system can be determined by the formula,

$W = x1\ W1 + x2\ W2$ -------------------------------------------------------------------(6)

Where W1 and W2 are the molar compressibilities of component 1 and 2 of the binary liquid system respectively.

In the acoustical studies of binary liquid systems Nomoto has done extensive work. Whereas Rao's law has been derived thermodynamically [26] from Maxwell's equation and its molecular interpretation was given. Its experimental validity is also proven. Theoretical analysis of this relation plays a very important role in the acoustical studies of liquids.

## 3. Result and Discussion

Molar sound velocity (R) and molar compressibility (W) are determined by means of Nomoto's relation and Wada's theory at (298.15, 303.15 and 308.15) K for ($C_4H_9OH + C_{16}H_{34}$) and ($C_4H_9OH + C_{30}H_{62}$) are reported in Table 1 and 2 respectively.

It is evident from table 1 that in all cases , the values of both molar sound velocity and molar compressibility decreases with the increase in mole fraction of 1-Butanol in the binary liquid system of 1-Butanol and Hexadecane . Thus molecular interactions are observed, this may be due to the presence of weak forces of attractions operating in the system of unlike molecules. As the temperature increases the rate of collision increases gradually, but such change is not constant because when a perticular temperature is attained then interactions becomes weaker, so we can see the variations in the values of molar sound velocity and molar compressibilities when the temperature changes from 303.15 to 308.15 K.

**Table 1: Density, ρ, Speed of Sound, U, Molar Sound Velocity, R and Molar Compressibility for (x1 $C_4H_9OH$ + x2 $C_{16}H_{34}$) at several temperatures**

AT 298.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.770456 | 1338.6 | 3.2391 | 2.2149 |
| 0.0899 | 0.770953 | 1332.4 | 3.0365 | 2.0771 |
| 0.1048 | 0.771053 | 1331.2 | 3.0029 | 2.0541 |
| 0.1516 | 0.771517 | 1328.2 | 2.8972 | 1.9823 |
| 0.2017 | 0.772074 | 1324.9 | 2.7842 | 1.9053 |
| 0.2494 | 0.772705 | 1321.9 | 2.6766 | 1.8321 |
| 0.3382 | 0.774083 | 1315.8 | 2.4763 | 1.6958 |
| 0.4147 | 0.775524 | 1310.6 | 2.3040 | 1.5785 |
| 0.5057 | 0.777651 | 1303.9 | 2.0990 | 1.4390 |
| 0.5845 | 0.779950 | 1297.6 | 1.9216 | 1.3183 |
| 0.6980 | 0.784249 | 1287.4 | 1.6662 | 1.1444 |
| 0.7945 | 0.789246 | 1276.8 | 1.4491 | 0.9965 |
| 0.8497 | 0.792847 | 1269.5 | 1.3249 | 0.9120 |
| 0.8963 | 0.796346 | 1262.7 | 1.2204 | 0.8408 |
| 0.9530 | 0.801232 | 1252.3 | 1.0934 | 0.7543 |
| 1.0000 | 0.805907 | 1240.5 | 0.9882 | 0.6826 |

AT 303.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.766981 | 1320.0 | 3.2386 | 2.2146 |
| 0.0899 | 0.767402 | 1313.4 | 3.0360 | 2.0768 |
| 0.1048 | 0.767499 | 1312.2 | 3.0023 | 2.0538 |
| 0.1516 | 0.767916 | 1309.2 | 2.8969 | 1.9821 |
| 0.2017 | 0.768482 | 1305.8 | 2.7837 | 1.9051 |
| 0.2494 | 0.769093 | 1302.9 | 2.6762 | 1.8319 |
| 0.3382 | 0.770439 | 1296.9 | 2.4760 | 1.6957 |
| 0.4147 | 0.771883 | 1291.6 | 2.3036 | 1.5783 |
| 0.5057 | 0.773952 | 1285.5 | 2.0991 | 1.4391 |
| 0.5845 | 0.776223 | 1279.2 | 1.9217 | 1.3183 |
| 0.6980 | 0.780452 | 1269.2 | 1.6664 | 1.1445 |
| 0.7945 | 0.785434 | 1258.5 | 1.4491 | 0.9966 |
| 0.8497 | 0.789093 | 1251.4 | 1.3249 | 0.9120 |
| 0.8963 | 0.792717 | 1244.8 | 1.2202 | 0.8407 |
| 0.9530 | 0.797973 | 1235.8 | 1.0930 | 0.7541 |
| 1.0000 | 0.803155 | 1226.5 | 0.9879 | 0.6824 |

AT 308.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.763520 | 1301.7 | 3.2382 | 2.2144 |
| 0.0899 | 0.763863 | 1294.9 | 3.0357 | 2.0766 |
| 0.1048 | 0.763961 | 1293.8 | 3.0021 | 2.0537 |
| 0.1516 | 0.764360 | 1290.3 | 2.8963 | 1.9817 |
| 0.2017 | 0.764874 | 1287.3 | 2.7835 | 1.9050 |
| 0.2494 | 0.765462 | 1284.4 | 2.6761 | 1.8319 |
| 0.3382 | 0.766796 | 1278.2 | 2.4757 | 1.6955 |
| 0.4147 | 0.768201 | 1273.1 | 2.3035 | 1.5783 |
| 0.5057 | 0.770240 | 1266.9 | 2.0990 | 1.4390 |
| 0.5845 | 0.772472 | 1260.9 | 1.9217 | 1.3183 |
| 0.6980 | 0.776353 | 1251.1 | 1.6666 | 1.1446 |
| 0.7945 | 0.781597 | 1240.6 | 1.4493 | 0.9967 |
| 0.8497 | 0.785172 | 1233.7 | 1.3252 | 0.9121 |
| 0.8963 | 0.788760 | 1227.4 | 1.2205 | 0.8409 |
| 0.9530 | 0.794054 | 1218.5 | 1.0933 | 0.7542 |
| 1.0000 | 0.799249 | 1209.8 | 0.9882 | 0.6825 |

**Table 2: Density, ρ, Speed of Sound, U, Molar Sound Velocity, R and Molar Compressibility for (x1 $C_4H_9OH$ + x2 $C_{30}H_{62}$) at several temperatures**

AT 298.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.805122 | 1381.9 | 5.8496 | 4.0192 |
| 0.0451 | 0.804881 | 1379.5 | 5.6305 | 3.8687 |
| 0.1077 | 0.804649 | 1376.1 | 5.3257 | 3.6596 |
| 0.1346 | 0.804573 | 1374.8 | 5.1949 | 3.5698 |
| 0.1888 | 0.804447 | 1371.7 | 4.9308 | 3.3886 |
| 0.2231 | 0.804377 | 1369.7 | 4.7637 | 3.2740 |
| 0.3059 | 0.804273 | 1365.1 | 4.3607 | 2.9974 |
| 0.4052 | 0.804097 | 1358.8 | 3.8780 | 2.6661 |
| 0.5039 | 0.803949 | 1350.9 | 3.3979 | 2.3367 |
| 0.6118 | 0.803817 | 1340.5 | 2.8736 | 1.9768 |
| 0.7056 | 0.803732 | 1328.8 | 2.4181 | 1.6641 |
| 0.7998 | 0.803836 | 1312.5 | 1.9604 | 1.3499 |
| 0.8546 | 0.803989 | 1299.5 | 1.6942 | 1.1672 |
| 0.9035 | 0.804336 | 1284.3 | 1.4564 | 1.0040 |
| 0.9669 | 0.805126 | 1258.5 | 1.1487 | 0.7928 |
| 1.0000 | 0.805907 | 1240.5 | 0.9882 | 0.6826 |

AT 303.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.801912 | 1364.1 | 5.8477 | 4.0180 |
| 0.0451 | 0.801658 | 1361.7 | 5.6287 | 3.8677 |
| 0.1077 | 0.801402 | 1358.3 | 5.3242 | 3.6587 |
| 0.1346 | 0.801318 | 1356.5 | 5.1928 | 3.5686 |
| 0.1888 | 0.801160 | 1353.8 | 4.9294 | 3.3878 |
| 0.2231 | 0.801070 | 1351.8 | 4.7624 | 3.2732 |
| 0.3059 | 0.800898 | 1347.1 | 4.3598 | 2.9969 |
| 0.4052 | 0.800714 | 1340.8 | 3.8771 | 2.6656 |
| 0.5039 | 0.800528 | 1332.6 | 3.3970 | 2.3361 |
| 0.6118 | 0.800347 | 1322.5 | 2.8731 | 1.9765 |
| 0.7056 | 0.800179 | 1310.9 | 2.4179 | 1.6640 |
| 0.7998 | 0.800194 | 1294.8 | 1.9605 | 1.3499 |
| 0.8546 | 0.800335 | 1281.8 | 1.6942 | 1.1672 |
| 0.9035 | 0.800708 | 1266.8 | 1.4563 | 1.0040 |
| 0.9669 | 0.801896 | 1241.4 | 1.1481 | 0.7924 |
| 1.0000 | 0.803155 | 1226.5 | 0.9879 | 0.6824 |

AT 308.15 K

| X1 | ρ | U | R | W |
|---|---|---|---|---|
| 0.0000 | 0.798709 | 1346.5 | 5.8458 | 4.0169 |
| 0.0451 | 0.798397 | 1343.0 | 5.6257 | 3.8659 |
| 0.1077 | 0.798084 | 1340.2 | 5.3224 | 3.6577 |
| 0.1346 | 0.797991 | 1338.9 | 5.1918 | 3.5680 |
| 0.1888 | 0.797826 | 1335.9 | 4.9281 | 3.3870 |
| 0.2231 | 0.797731 | 1333.9 | 4.7611 | 3.2725 |
| 0.3059 | 0.797543 | 1329.3 | 4.3587 | 2.9963 |
| 0.4052 | 0.797320 | 1322.8 | 3.8761 | 2.6650 |
| 0.5039 | 0.797098 | 1314.8 | 3.3963 | 2.3357 |
| 0.6118 | 0.796857 | 1304.6 | 2.8726 | 1.9762 |
| 0.7056 | 0.796621 | 1293.1 | 2.4176 | 1.6638 |
| 0.7998 | 0.796558 | 1277.1 | 1.9604 | 1.3499 |
| 0.8546 | 0.796660 | 1264.2 | 1.6942 | 1.1672 |
| 0.9035 | 0.796979 | 1249.1 | 1.4563 | 1.0040 |
| 0.9669 | 0.798060 | 1224.4 | 1.1483 | 0.7925 |
| 1.0000 | 0.799249 | 1209.8 | 0.9882 | 0.6825 |

Similarly Table 2 shows the results of molar sound velocity and molar compressibility of binary liquid system of 1-Butanol and squalane at three different temperatures. Here also the values of molar sound velocity and molar compressibility decrease with the increase in the concentration of 1-Butanol in the binary liquid system of 1-Butanol and Squalane. So, the results of the present investigation, show the molecular interactions (like dipole – dipole, dipole – induced dipole and dispersive forces) in these binary liquid systems.

Figures a, b, and c represents the variation of R and W with the mole fraction of 1-Butanol at three temperatures (298.15, 303.15 and 308.15) K respectively for the binary liquid system of 1-Butanol + Hexadecane, while figure d, e and f shows the variation of R and W with the mole fraction of 1-Butanol at three temperatures (298.15, 303.15 and 308.15) K for the binary liquid system of 1-Butanol + Squalane. It gives an idea of extent of interactions taking place between the molecules of these systems very clearly. These graphs are linear for both the system which proves the linearity of Rao's constant and Wada's constant.

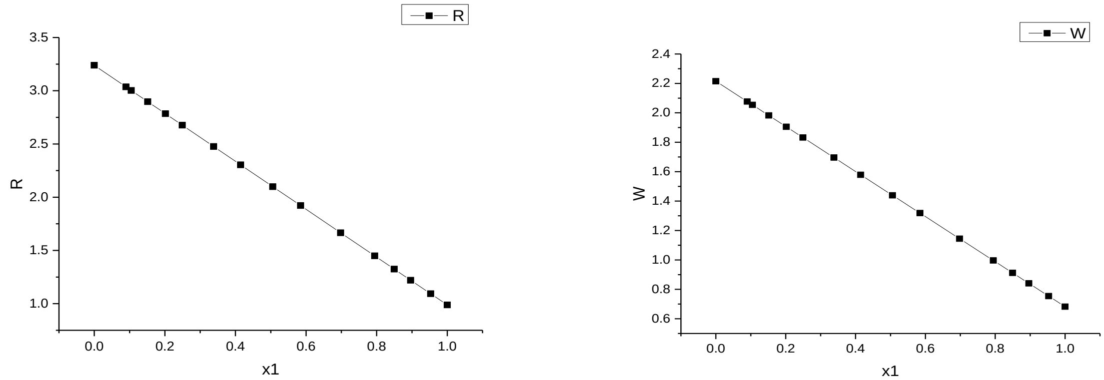


**Figure 1a: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{16}H_{34}$), at temperature 298.15 K.**

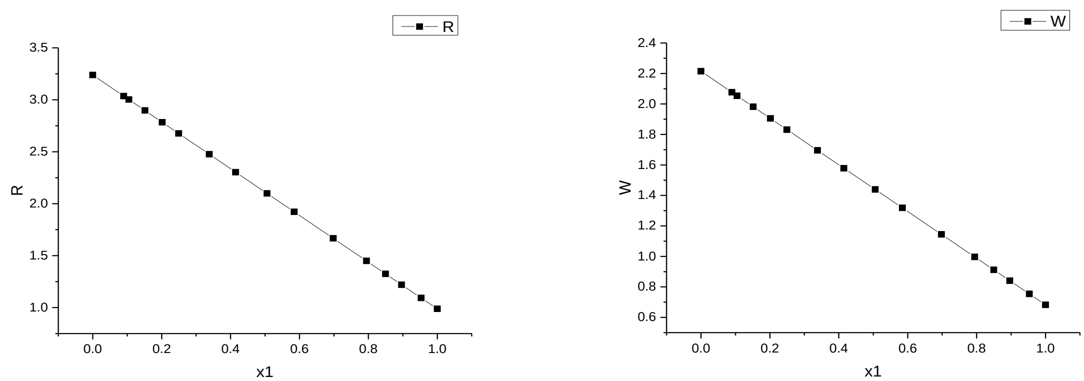


**Figure 1b: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{16}H_{34}$), at temperature 303.15 K.**

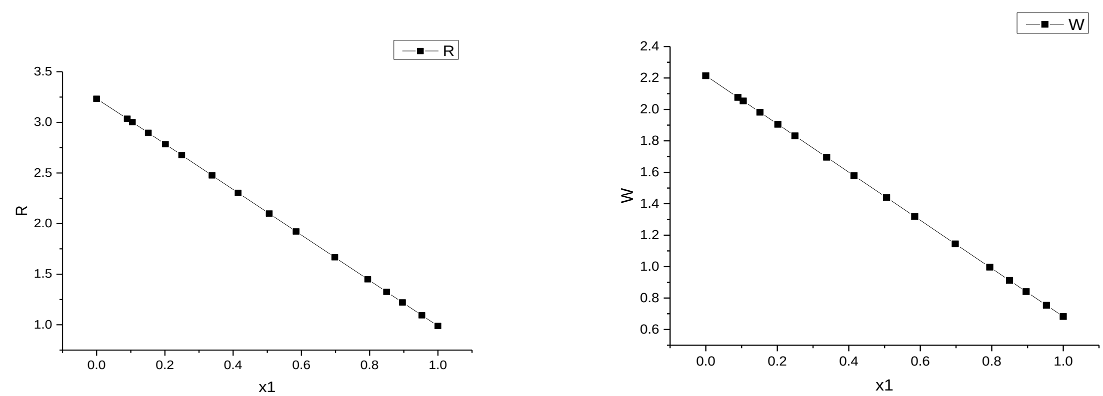


**Figure 1c: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{16}H_{34}$), at temperature 308.15 K.**

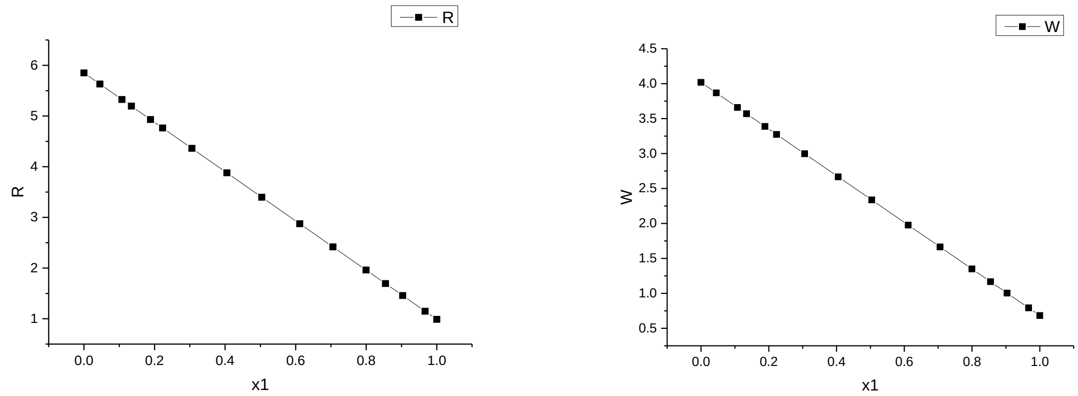


**Figure 1d: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{30}H_{62}$), at temperature 298.15 K.**

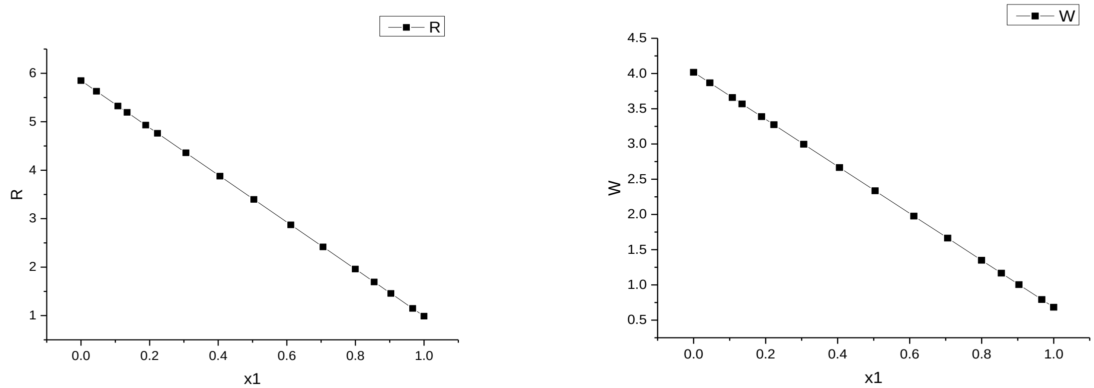


**Figure 1e: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{30}H_{62}$), at temperature 303.15 K.**

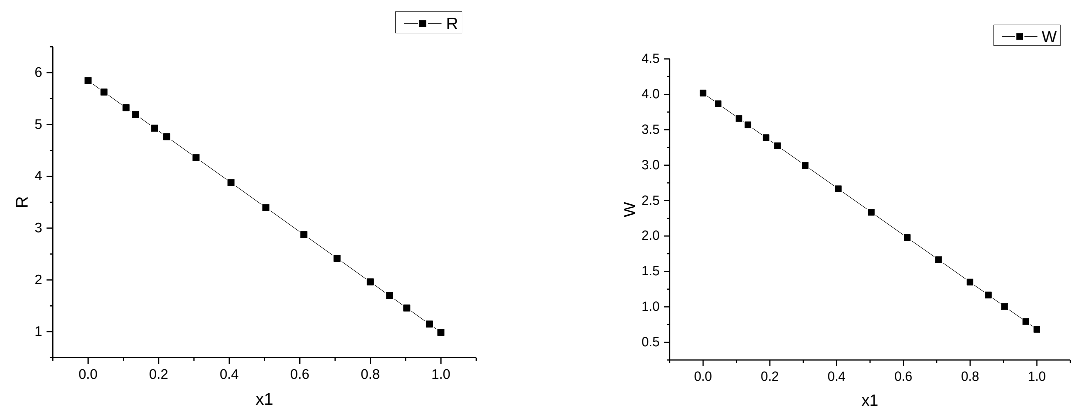


**Figure 1f: Plots of molar sound velocity (R) vs x1 and molar compressibility (W) vs x1 for the studied system (x1 $C_4H_9OH$ + x2 $C_{30}H_{62}$) , at temperature 308.15 K**

## 4. Conclusion

It is obvious that, there exist a molecular interaction between the components of the binary liquid systems of ($C_4H_9OH$ + $C_{16}H_{34}$) and ($C_4H_9OH$ + $C_{30}H_{62}$). In specific weak molecular interaction (like dipole – dipole, dipole – induced dipole and dispersive forces) are found to exist between components of respective systems. The parameters studied in this paper are discussed in the light of molecular interactions in the systems of ($C_4H_9OH$ + $C_{16}H_{34}$) and ($C_4H_9OH$ + $C_{30}H_{62}$). Thus the linearity of Rao's constant and Wada's constant is also proven.

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