Heat and mass transfer in binary fluids containing alcohols with the Soret effect

Mohammad Almasi (✉ almasi.mohammad@gmail.com)
malayer univesity <https://orcid.org/0000-0001-9771-8702>

Research Article

Keywords: Thermal Gradient, Thermal Diffusion, Mutual Diffusion, Soret Effect

Posted Date: March 8th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1415801/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Heat and mass transfer in binary fluids containing alcohols with the Soret effect

Mohammad Almasi*

Department of Applied Chemistry, Faculty of Science, Malayer University, Malayer, 65174, Iran.

Abstract

In this study, heat and mass transfer in binary systems containing methylcyclohexane and n-alkanol (1-pentanol, 1-hexanol, 1-heptanol, 1-octanol, 1-nonanol, and 1-decanol) at 293.15 K to 323.15 K was investigated considering the mutual diffusion coefficient, thermal diffusion coefficient, Soret effect, and the separation ratio. Soret coefficient S_T for methylcyclohexane is positive and indicates that this molecule is enriched in the colder regions of the liquids. Obtained results demonstrate that increasing the alkyl chain length reduces its tendency to move to the warmer regions. This behavior means that molecular forces are reinforced with the alcohol chain length. The new method's advantages over previous methods for calculating the thermal behavior of the mixtures are discussed.

Keywords: Thermal Gradient, Thermal Diffusion; Mutual Diffusion; Soret Effect

1. Introduction

The flow of fluids driven by temperature and concentration differences have been studied extensively because such processes exist in nature and have engineering applications. Thermophoresis is a phenomenon in which small size particles move toward decreasing temperature. It is a mechanism for the capture of particles in cold regions. This phenomenon has outstanding importance in many applications such as isotope separation in mixtures or in studying the particulate material deposition on turbine blades. In industrial and chemical engineering processes, concentrations vary from point to point, resulting in mass transfer. Soret coefficient is the ratio of the thermal diffusion coefficient to the mutual diffusion coefficient. This effect and mutual diffusion occur in many natural phenomena and are more significant in higher temperatures [1-6]. The positive value of the Soret coefficient S_T for component i , indicates that species i favor moving to the “cold” side [7]. The strength of the Soret effect in the mixture is parameterized by the separation ratio [8]

$$\psi = -S_T c(1-c) \frac{\beta}{\alpha} \quad (1)$$

* Corresponding Author
Email address : m.almasi@malayeru.ac.ir

c is concentration, $\alpha = \frac{-1}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_{P,x}$ and $\beta = \frac{-1}{\rho} \left(\frac{\partial \rho}{\partial x} \right)_{P,T}$ are thermal and concentration expansion coefficients, respectively. ρ is density, and ψ is a measure of concentration-induced density gradient to the temperature-induced density gradient. The motivation of this work as a continuation of our research program [9-23] is to evaluate thermal and composition effects on molecular interactions in binary mixtures of alcohols and other functional groups. As far as we know, the mentioned parameters are the first report for the above binary systems in the entire composition range at mentioned temperatures. The advantages of the method we used here are as follows. (i) It does not require complex apparatus to measure experimental quantities, and only a Stabinger viscometer is sufficient. (ii) Mutual and thermal diffusion coefficients can be calculated simultaneously in this method. (iii) The Soret coefficient for mixtures can be calculated by measuring the viscosity of the pure compounds. (iv) The agreement between outputs of this method and the earlier ones is reasonable.

2. Theory

2.1. Mutual Diffusion

Mutual diffusion is important in practical applications such as drug delivery and release systems. Understanding this phenomenon helps elucidate the above mechanisms. The movement of molecules due to the composition gradient in mixture is measured by mutual diffusion coefficient D_{12} or D . This motion in the mixture without a potential gradient is called self-diffusion coefficient D_i^* [24]. Values of the self-diffusion coefficients are calculated by the Wilke and Chang equation [25].

$$D_i^* = \frac{7.4 \times 10^{-8} (\zeta_j M_j)^{0.5} T}{\eta_j \times V_i^{0.6}} \quad (2)$$

η and M denote the viscosity and molecular weight of the solvent, respectively. ζ_j is a parameter for considering solvent association. While there are various methods in literature [5,6] for calculation of mutual diffusion behavior, inspired by some sources [26], values of D_i^* could be obtained via the molecular diffusion of coefficient i diluted in j species D_{ij}^∞ . Regarding this relation and using the experimental data of viscosity η_{mix} , the equation for calculating mutual diffusion coefficients in binary systems is [27]:

$$D = \frac{(x_1 \eta_1 D_{21}^\infty + x_2 \eta_2 D_{12}^\infty)}{\eta_{mix}} \Gamma^{0.64} \quad (3)$$

Γ is the thermodynamic factor and can be calculated by the following equation [28] :

$$\Gamma = \frac{x_1}{k_B T} \left(\frac{\partial \mu_1}{\partial x_1} \right)_{T,P} \quad (4)$$

k_B is the Boltzmann Constant, μ_1 and x_1 are the chemical potential and the mole fraction of component 1, respectively. The changes of chemical potential with concentration

$\left(\frac{\partial \mu_1}{\partial x_1} \right)_{T,P}$ were calculated through the following formula

$$\left(\frac{\partial \mu_1}{\partial x_1} \right)_{T,P} = RT \left(\frac{\partial \ln \varphi_1}{\partial x_1} \right)_{T,P} \quad (5)$$

φ_1 stands for the fugacity coefficient [29-31] and was calculated by the COSMO-RS model [32,33].

2.2 Thermal Diffusion

The thermal diffusion, also known as the Soret effect, describes the coupling between a temperature gradient and a resulting mass flux. In the steady-state, the Soret effect in binary fluids is defined by the flux of one of the components due to the temperature gradient. Thermal diffusion in liquid mixtures reflects some properties such as the mass and shape of the molecules and their interactions [34]. The relation among the thermal diffusion factor α , temperature T , and the Soret coefficient S_T is given by [6]

$$S_T = \frac{\alpha}{T} \quad (6)$$

α is thermodiffusion factor and can be obtained regarding the net heats of transport [35-36]:

$$\alpha = \frac{(Q_1^* - Q_2^*)}{x_1 \left(\frac{\partial \mu_1}{\partial x_1} \right)_{T,P}} \quad (7)$$

Q_i^* is the net heat of flow for diffusing components. A successful approximation, particularly for less-complex systems, is replacing the net heat of transport of each component with the activation energy of viscous flow E_i^{vis} in the pure condition $Q_i^* = E_i^{vis}$ [37,38]. The method is outlined in Eyring's book [37] and clearly in Ref. [39]. If the logarithm of the dynamic viscosity (more accurately viscosity multiplied by liquid molar volume) is plotted against $1/RT$, the obtained plot is a line whose slope is the activation energy of the viscous flow of that liquid.. For calculation of activation energy of binary mixtures ΔE_{mix}^{vis} , the following relation [40] was applied.

$$\Delta E_{mix}^{vis} = x_1 E_1^{vis} + x_2 E_2^{vis} \quad (8)$$

The Soret coefficient for binary mixtures was obtained by:

$$S_T = \frac{\alpha}{T} = \frac{x_1 E_1^{vis} + x_2 E_2^{vis}}{R \left(x_1 \left(\frac{\partial \ln \varphi_1}{\partial x_1} \right)_{T,P} \right)} \quad (9)$$

At last, values of thermal diffusion coefficients D_T were calculated from the relation

$$D_T = S_T D \quad (10)$$

3. Experimental section

All materials of the current work were supplied by the Merck Company and used as purchased. For MCH, the mass fraction purity is greater than 99%. The purity for 1-pentanol, 1-hexanol, 1-heptanol, and 1-decanol was 99.5%. For 1-octanol and 1-nonanol, the mass fraction purities were 99.6% and 99.7%, respectively. In the present study, density and viscosity of pure MCH were measured experimentally, but for pure alcohols were obtained from our previous papers [9-23].

Densities and viscosities for all binary systems at different temperatures are presented in Table 1. Density and viscosity values were measured by an automatic viscometer, namely SVM 3000. A thermoelectric thermostat in the SVM controls the dependency of viscosity and density on temperature. The distilled water and dry air are applied daily to calibrate the apparatus before measuring. SVM 3000 viscometer corrects the viscosity errors on density and measures the viscosity with the highest accuracy over the wide range of pressure and temperature.

The mixtures were prepared just before use by mass and were kept in glass bottles with a plastic cap to prevent evaporation. The weighing was performed by applying an electronic balance (Mettler AE 163, Switzerland) with a precision of ± 0.01 mg. Three sets of measurements were performed for each sample. The uncertainty in the mole fraction is 1×10^{-3} .

4. Results and Discussion

Experimental densities at different temperatures were used to calculate the thermal expansion coefficient α and the concentration expansion coefficient β in equation 1. Experimental viscosities for the binary mixtures η_{mix} were used to calculate the mutual diffusion coefficients D in equation 3. In addition, the pure viscosities η_i were applied to calculate the self-diffusion coefficients D_i^* .

values of D , S_T , D_T , and ψ for six binary fluids at various temperatures and mole fractions were calculated. Values of mutual diffusion coefficients D and thermal diffusion coefficients D_T at $T=303.15$ K are presented in Figs. 1 and 2. D and D_T are decreased as the alcohol chain length increases. This behavior shows that the methylcyclohexane mobility in the shorter alcohols is greater than the longer ones. Attractive forces among the methylcyclohexane molecules and longer alcohols are more significant. Methylcyclohexane is drawn through the solvent attractive forces, so its mobility reduces. Methylcyclohexane is a non-polar molecule, and its interaction with the higher chain alcohols is more favorable because, the longer chain alcohols have less polarity, and their structure is more similar to methylcyclohexane.

Values of the Soret coefficient for all studied mixtures at 303.15 K are presented in Fig.3. Positive values of the Soret coefficient demonstrate that the solute is thermophobic, and its molecules accumulate on the cold side. The positive Soret coefficient of methylcyclohexane in all binary systems shows that this molecule migrates to the cold side, and alcohols are enforced to move to the hot side. S_T for binary fluids containing heavier alcohols is less positive. The behavior demonstrates that methylcyclohexane in the low molecular weight alcohols tends more to move to the cold side and is indicative of the easier movement of methylcyclohexane in such alcohols. Thus, molecular forces in such binary mixtures are weaker. Rising temperature breaks the hydrogen bonds, and weakens molecular forces. The changes of the Soret coefficient with temperature for the binary mixtures of MCH + 1-decanol are indicated in Fig.4.

In the next step, values of the separation ratio ψ for studied systems were calculated and displayed in Fig.5. This parameter implies the mass fraction contribution to the buoyancy force relative to the thermal contribution. Positive values of the separation ratio are following the weak molecular interactions and the Soret effect. Higher values of ψ indicate greater values of mobility and weaker molecular interactions. ψ for methylcyclohexane +1-pentanol mixture has the maximum value and reduces when the alcohol chain enhances. Thus, reducing the alkyl chain length weakens the molecular forces.

Verification of model

Careful literature screening shows that mutual diffusion coefficients at 298.15 K for some binary mixtures studied in this paper are available [41]. We compared our D values with those reported in this reference. The finding indicates that two sets of data are consistent with each other. When the methylcyclohexane concentration increases or the chain length of 1-alkanol decreases, the mutual diffusion coefficient enhances. Comparisons are indicated in the SI (supplementary information) file.

The mentioned method in Ref. 41 for measuring the mutual diffusion coefficients is the diaphragm cell. In this method, a complicated apparatus is required to measure the mutual diffusion directly. This method has some restrictions such as (i) the given correlations for calculating the mutual diffusion coefficients have limitations in that each correlation applies only to the system concerned. (ii) The effect of temperature is ignored in the correlation, and hence the method is applicable only at the constant temperature. (iii) The limiting mutual diffusion coefficients cannot be evaluated by this method. Our applied method for the calculation of mutual diffusion coefficients is simple, has not the above limitations, applicable in various temperatures, and gives significant data.

Traditionally values of the Soret coefficient are measured by the Fontainebleau benchmark, Thermogravitational columns, Soret cells, Optical beam deflection, and all-optical techniques. The details of the mentioned methods are available in Ref. [42] and not discussed again here. Comparing our methodology with the above methods, it is clear that our approach is more straightforward than they are, and need not complicated and expensive apparatus such as thermo-gravimetric cells or optical cells. Outcomes of our process are reasonable and in the region of the Soret data which reported with the above methods. Furthermore, in the thermo-gravimetric cells and optical cells, only the thermodiffusion coefficient D_T can be

measured. To determine the Soret coefficient $S_T = D_T/D$, the mutual diffusion coefficient D must be obtained by some other means e.g., the symmetric sliding tube or the open-ended capillary technique. In the Soret cell technique, only the Soret coefficient could be obtained by the analytical solution of the time-dependent concentration field equation, and values of D or D_T are not obtained independently.

5. Conclusions

We have reported mutual diffusion coefficients, thermal diffusion coefficient, Soret coefficients, and separation ratio for six liquid solutions of methylcyclohexane and 1-alkanols. In such mixtures, thermodiffusion depends on the weak molecular forces among unlike molecules. Methylcyclohexane is a non-polar compound, and its mixing with polar alkanols makes the formation of weak bonds (Van der Waals type) in the binary fluids. The polarity of alcohol decreases as its alkyl chain increases so, the molecular forces among methylcyclohexane and greater chain alcohols are more appropriate. The alkyl chain has a fundamental role and reinforces the molecular interactions among unlike molecules.

Acknowledgments

The author gratefully acknowledges Malayer University for financial support.

ORCID

Mohammad Almasi: 0000-0001-9771-8702

Notes: The authors declare no competing financial interest.

References

- [1] Gupta, A. Soret effect on propagation of thermoconvective waves in a binary mixture. *Heat Mass Transfer* **35** (1999), 315–320
- [2] Partha, M. K. Thermophoresis particle deposition in a non-Darcy porous medium under the influence of Soret, Dufour effects. *Heat Mass Transfer* **44** (2008), 969–977.
- [3] Singh, A. K., Gorla, R.S.R. Free convection heat and mass transfer with Hall current, Joule heating and thermal diffusion. *Heat Mass Transfer* **45** (2009), 1341–1349.
- [4] Y. Yan, P. Blanco, M. Z. Saghir, M. M. Bou-Ali, An improved theoretical model for thermal diffusion coefficient in liquid hydrocarbon mixtures: Comparison between experimental and numerical results, *J. Chem. Phys.* **129** (2008) 194507.
- [5] H. J. V. Tyrrell. Diffusion and heat flow in liquids. Butterworth and Co. Ltd., London, 1961.
- [6] S. R. de Groot, P. Mazur. Non-equilibrium thermodynamics. North-Holland, 1969.
- [7] I. Prigogine, L. Debrouckere, R. Amand, Recherches sur la thermodiffusion en phase liquide 2, *Physica* **16** (1950) 851–860.
- [8] A. La Porta, C. M. Surko, Convective Instability in a Fluid Mixture Heated from Above, *Phys. Re. Lett.* **80** (1998) 3759–3762.
- [9] M. Almasi, Study of molecular interactions and preferential solvation in binary mixtures of methylcyclohexane and (C5-C10) 1-alkanol by Kirkwood-Buff integrals, *Fluid Phase Equilib.* **489** (2019) 1–7
- [10] M. Almasi, Densities and viscosities of binary mixtures containing ethyl formate and 2-alkanols: Friction theory and free volume theory, *J. Chem. Eng. Data* **60**, (2015)714–720
- [11] M. Almasi, Thermodynamic properties of binary mixtures containing dimethyl carbonate+2-alkanol: Experimental data, correlation and prediction by ERAS model and cubic EOS, *Physica B* **412** (2013)100-105.
- [12] M. Almasi, H. Iloukhani, Densities, viscosities, and refractive indices of binary mixtures of methyl ethyl ketone + pentanol isomers at different temperatures, *J. Chem. Eng. Data* **55**, (2010) 3918–3922.

- [13] M. Almasi, P. Monjezi, Studies on thermodynamic and transport properties of binary mixtures containing alcohols and aniline, *J. Chem. Eng. Data* **61**, (2016) 2510–2515.
- [14] M. Almasi, Thermodynamic study of interactions between 1-alkanol and butanone, *Chem. Phys.* **527** (2019) 110474.
- [15] Z. Khedri, M. Almasi, A. Maleki, Kirkwood-Buff integrals and structure factor for binary mixtures of ionic liquid with 1-alkanol, *J. Mol. Liq.* **296** (2019) 111767
- [16] B. Sarkoohaki, M. Almasi, M. Karimkhani, Correlation studies of cyclohexanone/(C5–C10) alkan-1-ol binary mixtures: PC-SAFT model and free volume theory, *J. Chem. Eng. Data* **63** (2018) 2257–2265.
- [17] S. Heydarian, M. Almasi, Z. Saadati, Thermophysical study of binary mixtures of 1-butyl-3-methylimidazolium nitrate ionic liquid + alcohols at different temperatures, *J. Chem. Thermodyn.* **135** (2019) 345–351.
- [18] M. Almasi, Temperature dependence and chain length effect on density and viscosity of binary mixtures of nitrobenzene and 2-alcohols, *J. Mol. Liq.* **209** (2015) 346–351
- [19] M. Almasi, Evaluation of thermodynamic properties of fluid mixtures by PC-SAFT model, *Thermochim. Acta* **591** (2014) 75–80.
- [20] Z. Khedri, M. Almasi, A. Maleki, Thermodynamic properties of 1-hexyl-3-methylimidazolium nitrate and 1-alkanols mixtures: PC-SAFT model, *Chem. Eng. Data.* **64** (2019) 4465–4473.
- [21] M. Almasi, H. Nasim, Thermodynamic and transport properties of binary mixtures; friction theory coupled with PC-SAFT model, *J. Chem. Thermodyn.* **89** (2015) 1–6.
- [22] M. Almasi, Thermodynamic properties of binary mixtures containing *N,N*-Dimethylacetamide + 2-Alkanol: experimental data and modeling, *J. Chem. Eng. Data* **59** (2014) 275–281.
- [23] M. Almasi, Some studies on the mutual diffusion, Joule–Thomson inversion curve and virial coefficients of binary mixtures containing diethylamine and (C5 – C9) 1-alkanol, *Fluid Phase Equilib.* **533** (2021) 112920.

- [24] G. Guevara-Carrion, T. Janzen, Y. M. Muñoz-Muñoz, J. Vrabec, Mutual diffusion of binary liquid mixtures containing methanol, ethanol, acetone, benzene, cyclohexane, toluene, and carbon tetrachloride, *J. Chem. Phys.* **144** (2016) 124501.
- [25] C. R. Wilke, P. Chang, Correlation of diffusion coefficients in dilute solutions, *AIChE J.* **1** (1955) 264–270.
- [26] T. Gaudin, H. Ma, The macroscopic viscosity approximation: A first-principle relationship between molecular diffusion and viscosity, *AIP Advances* **10** (2020) 035321.
- [27] Q. Zhu, C. D'Agostino, M. Ainte, M. D. Mantle, L. F. Gladden, O. Ortona, L. Paduano, D. Ciccarelli, G. D. Moggridge. Prediction of mutual diffusion coefficients in binary liquid systems with one self-associating component from viscosity data and intra-diffusion coefficients at infinite dilution. *Chem. Eng. Sci.* **147** (2016) 118–127.
- [28] D. Rosenberger, N. Lubbers, T. C. Germann, Evaluating diffusion and the thermodynamic factor for binary ionic mixtures, *Phys. Plasmas* **27** (2020) 102705.
- [29] R. K. Ghai , H. Ertl, F. A. L. Dullien, Liquid diffusion of nonelectrolytes: Part I, *AIChE J.* **19**(1973) 881–900.
- [30] R. Taylor, R. Krishna, Multicomponent mass transfer, 1st ed. Wiley- Interscience, New York, 1993.
- [31] A. Firoozabadi, Thermodynamics and applications in hydrocarbon energy production, 1st ed. McGraw-Hill, 2016.
- [32] A. Klamt, F. Eckert, COSMO-RS: a novel and efficient method for the a priori prediction of thermophysical data of liquids. *Fluid Phase Equilib.* **172** (2000) 43–72.
- [33] COSMOthermX Program, Cosmologic, GmbH&CoKG, Leverkusen, Germany, 2018.
- [34] P. Polyakov, J. Luettmer-Strathmann, S. Wiegand, Study of the thermal diffusion behavior of alkane/benzene mixtures by thermal diffusion forced Rayleigh scattering experiments and lattice model calculations, *J. Phys. Chem. B* **110** (2006) 26215-26224.
- [35] E. L. Dougherty, H. G. Drickamer, A theory of thermal diffusion in liquids *J. Chem. Phys.* **23** (1955) 295–302.

- [36] K. Shukla, A. Firoozabadi, A New Model of Thermal Diffusion Coefficients in Binary Hydrocarbon Mixtures, *Ind. Eng. Chem. Res.* **37** (1998) 3331–3342.
- [37] S. Glasstone, K. J. Laidler, H. Eyring, The theory of rate processes; the kinetics of chemical reactions, viscosity, diffusion and electrochemical phenomena, McGraw-Hill, NY, 1941.
- [38] J. Kotas, M. Valesova, Thermodynamic activation functions of viscous flow of non-polar liquids, *Rheol. Acta* **25** (1986) 326–330.
- [39] M. Eslamian, M.Z. Saghir, A Critical review of thermodiffusion models: role and significance of the heat of transport and the activation energy of viscous flow, *J. Non-Equilib. Thermodyn.* **34** (2) (2009) 97e131.
- [40] K. Shukla, A. Firoozabadi, A New Model of Thermal Diffusion Coefficients in Binary Hydrocarbon Mixtures, *Ind. Eng. Chem. Res.* **37** (1998) 3331–3342.
- [41] J. Winkelmann, M. D. Lechner, Diffusion in Gases, Liquids and Electrolytes, Subvolume B: Nonelectrolyte Liquids and Liquid Mixtures, Springer-Verlag GmbH Germany, 2018.
- [42] W. Köhler, K. I. Morozov, The Soret Effect in Liquid Mixtures – A Review, *J. Non-Equilib. Thermodyn.* **41** (3) (2016) 151–197

Table 1. Densities and viscosities for the binary mixtures of MCH and 1-alkanol at different Temperatures.

MCH (1) + 1-Pentanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8033	0.7996	0.7958	0.7920
0.0807	0.7985	0.7947	0.7910	0.7872
0.1596	0.7940	0.7903	0.7865	0.7826
0.2409	0.7896	0.7858	0.7820	0.7780
0.3500	0.7840	0.7802	0.7763	0.7722
0.4391	0.7797	0.7758	0.7719	0.7678
0.5597	0.7742	0.7702	0.7663	0.7620
0.6503	0.7703	0.7663	0.7623	0.7580
0.7393	0.7667	0.7626	0.7586	0.7542
0.8492	0.7625	0.7583	0.7542	0.7497
0.9422	0.7591	0.7548	0.7507	0.7460
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	2.65	2.33	2.05	1.81
0.0807	2.28	2.01	1.74	1.54
0.1596	1.97	1.76	1.52	1.35
0.2409	1.71	1.53	1.33	1.20
0.3500	1.41	1.25	1.13	1.02
0.4391	1.20	1.08	0.98	0.90
0.5597	0.98	0.89	0.82	0.76
0.6503	0.85	0.78	0.73	0.67
0.7393	0.76	0.69	0.65	0.60
0.8492	0.68	0.62	0.58	0.534
0.9422	0.63	0.585	0.55	0.51
1	0.61	0.57	0.54	0.51

MCH (1) + 1-Hexanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8079	0.8042	0.8006	0.7968
0.0809	0.8034	0.7996	0.7961	0.7922
0.1603	0.7990	0.7952	0.7916	0.7877
0.2419	0.7947	0.7909	0.7872	0.7833
0.3493	0.7888	0.7850	0.7812	0.7772
0.4406	0.7842	0.7803	0.7765	0.7723
0.5600	0.7781	0.7741	0.7702	0.7660
0.6493	0.7736	0.7695	0.7656	0.7613
0.7388	0.7692	0.7651	0.7611	0.7567
0.8500	0.7641	0.7599	0.7558	0.7513
0.9398	0.7599	0.7556	0.7515	0.7469
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	3.4	2.95	2.58	2.26
0.0809	2.89	2.52	2.19	1.94
0.1603	2.47	2.17	1.90	1.69
0.2419	2.11	1.88	1.653	1.47
0.3493	1.70	1.52	1.36	1.23
0.4406	1.43	1.29	1.16	1.06
0.5600	1.12	1.03	0.94	0.87
0.6493	0.93	0.87	0.80	0.75
0.7388	0.80	0.75	0.70	0.65
0.8500	0.68	0.644	0.606	0.56
0.9398	0.62	0.59	0.55	0.51
1	0.61	0.57	0.54	0.51

MCH (1) + 1-Heptanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8116	0.8080	0.8044	0.8007
0.0811	0.8073	0.8037	0.8001	0.7963
0.1605	0.8031	0.7994	0.7958	0.7920
0.2415	0.7988	0.7950	0.7914	0.7875
0.3491	0.7930	0.7892	0.7855	0.7815
0.4402	0.7881	0.7842	0.7804	0.7764
0.5611	0.7816	0.7777	0.7738	0.7696
0.6497	0.7767	0.7727	0.7688	0.7645
0.7385	0.7718	0.7677	0.7637	0.7593
0.8512	0.7656	0.7614	0.7574	0.7528
0.9396	0.7605	0.7563	0.7521	0.7475
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	4.3	3.71	3.21	2.79
0.0811	3.63	3.13	2.72	2.38
0.1605	3.07	2.69	2.36	2.08
0.2415	2.60	2.28	2.03	1.81
0.3491	2.10	1.84	1.66	1.49
0.4402	1.74	1.54	1.38	1.25
0.5611	1.34	1.20	1.09	1.01
0.6497	1.08	0.99	0.90	0.86
0.7385	0.90	0.826	0.78	0.72
0.8512	0.722	0.674	0.634	0.58
0.9396	0.634	0.60	0.555	0.51
1	0.61	0.57	0.54	0.51

MCH (1) + 1-Octanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8144	0.8109	0.8073	0.8037
0.0850	0.8102	0.8066	0.8030	0.7994
0.1595	0.8064	0.8028	0.7992	0.7955
0.2406	0.8022	0.7986	0.7949	0.7911
0.3503	0.7964	0.7927	0.7889	0.7850
0.4405	0.7915	0.7877	0.7839	0.7799
0.5612	0.7846	0.7807	0.7768	0.7727
0.6509	0.7793	0.7754	0.7714	0.7672
0.7428	0.7738	0.7697	0.7657	0.7614
0.8504	0.7670	0.7628	0.7588	0.7543
0.941	0.7611	0.7568	0.7527	0.7481
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	5.43	4.63	3.98	3.44
0.0850	4.52	3.92	3.33	2.90
0.1595	3.88	3.34	2.88	2.54
0.2406	3.27	2.80	2.46	2.19
0.3503	2.53	2.18	2.00	1.76
0.4405	2.05	1.80	1.65	1.47
0.5612	1.53	1.386	1.28	1.16
0.6509	1.24	1.136	1.06	0.97
0.7428	1.006	0.90	0.86	0.80
0.8504	0.81	0.753	0.70	0.64
0.941	0.70	0.64	0.59	0.55
1	0.61	0.57	0.54	0.51

MCH (1) + 1-Nonanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8171	0.8136	0.8101	0.8065
0.0809	0.8133	0.8098	0.8063	0.8026
0.1612	0.8095	0.8059	0.8023	0.7986
0.2397	0.8055	0.8019	0.7983	0.7945
0.3505	0.7997	0.7960	0.7923	0.7885
0.4388	0.7948	0.7911	0.7873	0.7834
0.5597	0.7877	0.7839	0.7801	0.7760
0.6502	0.7821	0.7782	0.7743	0.7701
0.7385	0.7763	0.7723	0.7683	0.764
0.8502	0.7685	0.7644	0.7603	0.7559
0.9397	0.7618	0.7576	0.7535	0.7489
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	6.61	5.59	4.78	4.10
0.0809	5.54	4.77	4.04	3.44
0.1612	4.66	4.03	3.41	2.96
0.2397	3.92	3.41	2.92	2.55
0.3505	3.04	2.64	2.31	2.07
0.4388	2.42	2.15	1.92	1.72
0.5597	1.76	1.61	1.45	1.31
0.6502	1.404	1.28	1.19	1.08
0.7385	1.13	1.045	0.98	0.89
0.8502	0.864	0.80	0.74	0.69
0.9397	0.70	0.65	0.604	0.574
1	0.61	0.57	0.54	0.51

MCH (1) + 1-Decanol (2)				
ρ (g. cm ⁻³)				
x_1	$T/K=308.15$	$T/K=313.15$	$T/K=318.15$	$T/K=323.15$
0	0.8193	0.8158	0.8124	0.8089
0.0802	0.8158	0.8123	0.8088	0.8049
0.1588	0.8122	0.8086	0.8051	0.8007
0.2410	0.8082	0.8046	0.8010	0.7965
0.3478	0.8027	0.7990	0.7954	0.7902
0.4392	0.7976	0.7938	0.7902	0.7849
0.5586	0.7905	0.7866	0.7829	0.7772
0.6502	0.7845	0.7806	0.7768	0.7711
0.7409	0.7782	0.7742	0.7703	0.7648
0.8502	0.7699	0.7658	0.7617	0.7563
0.9397	0.7625	0.7582	0.7541	0.7490
1	0.7565	0.7521	0.7479	0.7434
η (mPa.s)				
0	8.14	6.84	5.80	4.96
0.0802	6.75	5.86	4.87	4.19
0.1588	5.72	4.98	4.18	3.60
0.2410	4.76	4.18	3.54	3.09
0.3478	3.72	3.28	2.86	2.50
0.4392	2.97	2.63	2.34	2.06
0.5586	2.17	1.97	1.76	1.58
0.6502	1.67	1.54	1.40	1.26
0.7409	1.29	1.205	1.105	0.98
0.8502	0.936	0.865	0.80	0.72
0.9397	0.72	0.67	0.62	0.566
1	0.61	0.57	0.54	0.51

Figures

Figure 1

Mutual diffusions coefficients (points) for methylcyclohexane (MCH) + 1-alkanol at

$T = 303.15$ K. Solid lines guide the eye

Figure 2

Thermal diffusion coefficients (points) for methylcyclohexane (MCH) + 1-alkanol at

$T = 303.15$ K. Solid Lines guide the eye

Figure 3

Soret coefficients (points) for methylcyclohexane (MCH) + 1-alkanol at $T = 303.15$ K. Solid Lines guide the eye

Figure 4

Changes of the Soret coefficient with temperature for the binary mixtures of methylcyclohexane (MCH) + 1-decanol. Solid Lines guide the eye

Figure 5

Values of separation ratio (points) for methylcyclohexane (MCH) + 1-alkanol at $T = 303.15$ K. Solid Lines guide the eye

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Sl.doc](#)