Journal of Molecular Liquids 196 (2014) 244–248

Contents lists available at ScienceDirect

Journal of Molecular Liquids

journal homepage: www.elsevier.com/locate/molliq

Ultrasonic study of thermo-acoustic parameters of the polysorbate 20, 40, 60 and 80 liquid surfactants at different temperatures

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ARTICLE INFO

Article history:
Received 9 February 2014
Received in revised form 18 March 2014
Accepted 26 March 2014
Available online 13 April 2014

Keywords:
Polysorbates 20, 40, 60 and 80
Thermo-acoustic parameters
Isentropic compressibility
Intermolecular free length
Molar volume and available volume

ABSTRACT

Ultrasonic velocities (u) and densities (ρ) have been measured at different temperatures ranging from 298 K to 353 K for non-ionic (NIC) surfactants like polyoxyethylene (20) sorbitan monolaurate (Tween-20), polyoxyethylene (20) sorbitan palmitate (Tween-40), polyoxyethylene (20) sorbitan monostearate (Tween-60) and polyoxyethylene (20) sorbitan monooleate (Tween-80). From these isentropic compressibility (β), intermolecular free length (L_f), acoustic impedance (Z), molar volume (V), available volume (V_a), molar sound velocity (R_a) and molar compressibility (W) have been calculated. The focuses on the review of the chemical structure of polysorbates and the influence of the temperature on acoustical parameters have been employed to discuss molecular packing, molecular movement, structure alterations and molecular interactions.

1. Introduction

In recent years, more and more investigations have been carried out with an intention to get our knowledge enriched with respect to the behavior of surfactants in water and other solvents [1–11]. These researches were focused on elucidating the role of the solvent properties in the micellization phenomenon of these amphiphiles. Methods like tensiometry, conductometry, viscometry, light scattering, fluorimetry and spectrometry were successfully adopted for this purpose. But literature survey has revealed that, the investigations on the structural analysis of NIC surfactant liquids like polysorbates (Tween) 20, 40, 60 and 80 based on the ultrasonic methods are very rare. This prompted us to carry out research on thermo-acoustical properties of different kinds of Tween surfactants in liquid form.

Non-ionic surfactants belonging to the Tween series, find their applications in food, bio-technical, pharmaceutical, industrial, domestical, chemical and bio-chemical applications [3,11,12,17]. Washing, cleaning, wetting, dispersing, emulsifying and foaming are some of the practical applications due to which, they are the topics of interest for the investigations [3,11,12]. Some of these surfactants are known for their assistance in separating the pollutants such as hydrophobic organic compounds from water and soils [13,14]. Tweens are clear, non-odorous, readily pourable liquids at room temperature. Their low toxicity and acceptable degree of bio-degradability are responsible for their extensive utility [13]. Most of the studies [1–14] examined the influence of solvent environment and temperature on the critical micelle concentration, aggregation number, volume of micelle, etc. Tween 20 and Tween 80 surfactants exhibit lyotropic liquid crystal properties at certain concentrations and temperature, when dissolved in appropriate solvents [10,29–31]. However, enough information is not available in the literature on the thermodynamic and thermo-acoustic properties and parameters of these polysorbate 20, 40, 60 and 80 liquids are studied using ultrasonic waves as probing agents. This provides a well established technique in examining the changes in the physical properties related to the macrolevel. The knowledge of the acoustical properties of pure liquid [16] furnishes information on molecular structure, nature and strength of molecular interactions. Kinetic behavior and structural equilibrium of a pure liquid sample are influenced by the changes in temperature [16] as a result the high frequency ultrasonic velocity (u) in pure liquid sample is affected. The acoustic parameters are more significant than ultrasonic velocity and density individually [15]. Therefore, the aim of the present investigation is to measure experimentally the ultrasonic velocity and the density in each one of these pure Tween surfactant liquids at different temperatures, with an intention to compute the acoustical parameters at these temperatures.

2. Materials

An extensive survey of the literature [3,7,11–13,17–23] and a study on the structure of polysorbates 20, 40, 60 and 80 provide the necessary

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http://dx.doi.org/10.1016/j.molliq.2014.03.039
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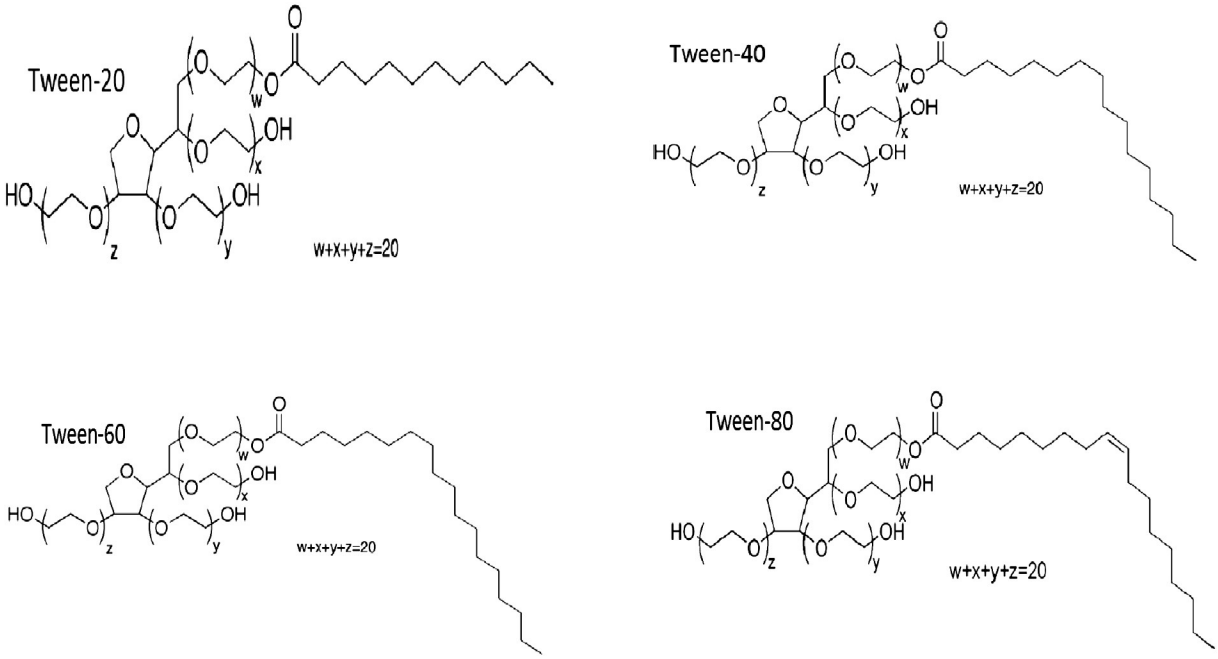

Fig. 1. Chemical structure of Tweens (polysorbates).

insight to describe their structure with the help of the ultrasonic technique adopted here which explains the influence of temperature on the behavior of the pure surfactants under investigation. These NIC amphiphiles have similar chemical structures with a hydrophilic, polar head and different hydrophobic, non-polar tails in each one of them. The head consists of 4 polyoxyethylene (CH_2CH_2O) polymer groups with three of them attached at three different hydroxyl (OH) positions and the fourth group at the w-position of the structure in the form of a sorbitan ring with five sides. The fatty acid moieties in the form of hydrocarbon chains are attached at the fourth polyoxyethylene polymer position (w-position) to form the tail of the structure. The total number of polyoxyethylene subunits present at the z, y, x and w positions of each one of the polysorbates is 20 ($w + x + y + z = 20$). The molecular formula for Tweens 20, 40, 60 and 80 are $C_{58}H_{114}O_{26}$; $C_{62}H_{122}O_{26}$; $C_{64}H_{126}O_{26}$ and $C_{64}H_{124}O_{26}$ respectively. The molecular formulae are also expressed as $C_{18}H_{34}O_6(CH_2CH_2O)_n$; $C_{22}H_{42}O_6(CH_2CH_2O)_n$; $C_{24}H_{46}O_6(CH_2CH_2O)_n$, and $C_{24}H_{44}O_6(CH_2CH_2O)_n$ respectively with a value of $n = 20$. Most of the time, polysorbates are generally sold [3] as fatty acid mixtures. The fatty acid, mainly present in Tween 20 is lauric acid, hence it is called polyoxyethylene (20) sorbitan monolaurate. The fatty acid mainly present in Tween 40 is palmitic acid, hence it is named as polyoxyethylene (20) sorbitan monopalmitate. In Tween 60, the main fatty acid is stearic acid therefore, it is called polyoxyethylene (20) sorbitan monostearate. The main fatty acid present in Tween 80 is oleic acid therefore it is named as polyoxyethylene (20) sorbitan monooleate. Polysorbates are the substances prepared by the reaction of sorbitan fatty acid esters with ethylene oxides [20]. The main difference in the case of these surfactant structures is in respect of their fatty acid side chain lengths. Tween 20 has a straight chain hydrocarbon structure whereas Tween 80 contains a double-bond forming a kink in the hydrocarbon chain [3]. The structures of these are shown [19] in Fig. 1. The number of carbon atoms in hydrophilic/lyophilic and hydrophobic/lyophobic parts of the molecules, their chain length and their temperature, control their physico-chemical nature, spectral behavior and thermo-acoustic properties.

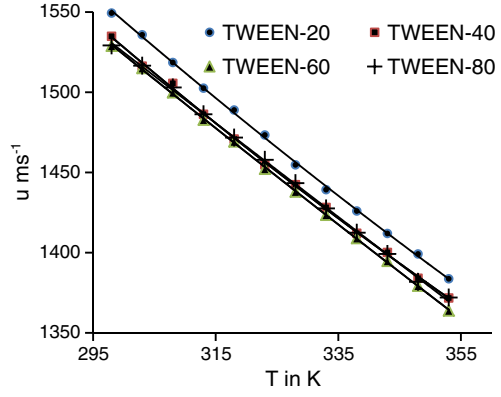

Fig. 2. Variation of u with T.

3. Defining equations

Acoustic parameters like isentropic compressibility (β), intermolecular free length (L_f), acoustical impedance (Z), molar volume (V), available volume (V_a), molar sound velocity (R_a) and molar compressibility (W) are the derived physical quantities related to ultrasonic velocity (u) and density (ρ) of the liquid. The equations for these parameters are [16],

$$\beta = \left(1/u^2\rho\right) \tag{1}$$

$$L_f = K\beta^{1/2} \tag{2}$$

$$Z = \rho u \tag{3}$$

$$V = M/\rho \tag{4}$$

$$V_a = (1-u/u_\infty)V \tag{5}$$

$$R_a = Vu^{1/3} \tag{6}$$

$$W = V\beta^{-1/7}. \tag{7}$$