Pharmaceutical Sciences
December 2018, 24, 324-331
doi: 10.15171/PS.2018.46
http://ps.tbzmed.ac.ir/

Research Article

Apparent Specific Volumes of Sucrose in Different Aqueous Cosolvent Mixtures at 298.2 K

Darío A. Tinjacá[1], María M. Muñoz[1], Fleming Martínez[1]*, Abolghasem Jouyban[2,3], William E. Acree, Jr.[4]

[1]*Grupo de Investigaciones Farmacéutico-Fisicoquímicas, Departamento de Farmacia, Facultad de Ciencias, Universidad Nacional de Colombia -Sede Bogotá, Cra. 30 No. 45-03, Bogotá, D.C., Colombia.*

[2]*Pharmaceutical Analysis Research Center and Faculty of Pharmacy, Tabriz University of Medical Sciences, Tabriz, Iran.*

[3]*Kimia Idea Pardaz Azarbayjan (KIPA) Science Based Company, Tabriz University of Medical Sciences, Tabriz, Iran.*

[4]*Department of Chemistry, University of North Texas, Denton, TX 76203-5070, USA.*

Article Info

Article History:
Received: 27 July 2018
Revised: 2 September 2018
Accepted: 15 September 2018
ePublished: 30 December 2018

Keywords:
-Sucrose
-Cosolvents
-Density
-Apparent specific volume

ABSTRACT

Background: Sucrose is the most widely used sweetener in foods and pharmaceuticals. Apparent specific volumes of this excipient in aqueous cosolvent mixtures are not available. Thus, the main objective of this research was to determine this property by measuring the density of several solutions of sucrose in {cosolvent + water} mixtures at 298.2 K.

Methods: Sucrose dissolutions were prepared gravimetrically and a thermostatically controlled digital oscillatory method was used to measure the dissolutions density.

Results: From density values of sucrose dissolutions and cosolvent mixtures the apparent specific volumes of sucrose were calculated and analyzed based on the sucrose and cosolvent proportions in the mixtures.

Conclusion: Useful density values of sucrose solutions at different concentrations in several aqueous cosolvent mixtures are reported at 298.2 K. Finally, a mean apparent specific volume value of 0.632 $cm^3.g^{-1}$ for sucrose in different aqueous-cosolvent mixtures could be adequate for practical purposes in pharmaceutical industries.

Introduction

Sucrose is considered as the most important sweetener ingredient in food and pharmaceutical industries everywhere. In the pharmaceutical industries, this compound is used to develop solid and liquids dosage forms.[1] Regarding the liquid products intended for peroral administration, sucrose is mainly used as natural sweetener, as volume contributor in vehicles like officinal syrups and elixirs, as water evaporation regulator, and even as an osmotic antimicrobial preservative agent.[1] In particular, medicinal syrups and elixirs normally contain high proportions of sucrose.[2,3] For this reason, some physicochemical properties of this natural excipient in aqueous cosolvent mixtures, like equilibrium solubility and volumetric contributions, are very important from a practical point of view to facilitate the duties of pharmaceutical scientists during all the stages related to dosage forms design and development.[4,5]

Although sucrose as additive has been used for centuries in several industries, and some reports about its apparent specific and/or molar volume in water or cosolvent mixtures have been reported in the literature,[4-10] the information about its volumetric physicochemical behavior in mixed aqueous solutions is still far to be complete.[4,5] Particularly, up to the best of our knowledge, no apparent specific volumes of sucrose as a function of sucrose concentration in aqueous cosolvent mixtures have been reported in the literature. In this way, only apparent specific volumes of sucrose at saturation in the most common aqueous cosolvent mixtures have been reported.[4,5]

It is noteworthy that the volumes of components in solution are not additive owing the different intermolecular interactions and/or differences in molar volumes. Therefore, the real volumetric contribution of each component is expressed by the partial molar or specific volumes, which depend on temperature and mixtures compositions, and thus, normally are not known for the vast majority of compounds. This is also valid for drugs and excipients in every liquid pharmaceutical dosage form. Nevertheless, in a good approximation, the use of apparent specific volumes constitutes a good tool in design of liquid products, in contraposition of the well-known Latin term “Quantum satis”, i.e. “the amount which is enough”, because it could allow the calculation of the volumetric contribution of each component of the medicinal formulation.[2,3]

With all this in mind, in the present research the apparent specific volumes of sucrose (the solute identified as component 3) as a function of the solute concentration in different {cosolvent (component 1) + water (component 2)} mixtures were studied at 298.2 K. Cosolvents studied

***Corresponding Author:** Fleming Martínez, E-mail: fmartinezr@unal.edu.co

were ethanol, propylene glycol, glycerol, and polyethylene glycols 200 and 400 (PEG 200 and PEG 400). Pharmaceutical literature reports a lot of applications and medicinal products were these cosolvents are used as excipients.[11,12] Thus, this research expands the information reported previously with this pharmaceutical sweetener agent in several {cosolvent (1) + water (2)} mixtures.[4,5]

Materials and Methods

Reagents

Sucrose (IUPAC name: (2*R*,3*R*,4*S*,5*S*,6*R*)-2-[(2*S*,3*S*,4*S*,5*R*)-3,4-dihydroxy-2,5-bis(hydroxymethyl)ox-olan-2-yl]oxy-6-(hydroxymethyl)oxane-3,4,5-triol; CAS number: 57-50-1; molar mass: 342.30 g.mol^{-1};[13] mass fraction purity: 0.995; Ingenio Riopaila, Colombia), ethanol (EtOH, CAS number: 64-17-5; molar mass: 46.07 g.mol^{-1};[13] mass fraction purity: 0.995; Merck, Germany), propylene glycol (PG, CAS number: 57-55-6; molar mass: 76.10 g.mol^{-1};[13] mass fraction purity: 0.992; Dow Chemical Co., USA), glycerol (G, CAS number: 56-81-5; molar mass: 92.09 g.mol^{-1};[13] mass fraction purity: 0.990; Dow Chemical Co., USA), polyethylene glycol 200 (PEG 200; CAS number: 25322-68-3; mean molar mass: 200 g.mol^{-1};[13] mass fraction purity: 0.990; Dow Chemical Co., USA), polyethylene glycol 400 (PEG 400; CAS number: 25322-68-3; mean molar mass: 400 g.mol^{-1};[13] mass fraction purity: 0.992; Dow Chemical Co., USA), and distilled water with conductivity < 2 µS.cm^{-1}, were used in this research. Molecular sieve (numbers 3 and 4, Merck, Germany) was also used.

Sucrose cosolvent mixtures preparation

All {cosolvent (1) + water (2)} mixtures were prepared by gravimetric method in quantities of 60.00 g by using an analytical balance (Ohaus Pioneer TM PA214, USA, sensitivity ±0.1mg). The mass fractions of cosolvent (w_1^{o}) of the five binary mixtures studied varied by $w_1^{\mathrm{o}} = 0.10$ from $w_1^{\mathrm{o}} = 0.10$ to $w_1^{\mathrm{o}} = 0.50$. After that, six dissolutions of sucrose at different concentrations were gravimetrically prepared in neat water and the {cosolvent (1) + water (2)} mixtures. Sucrose concentrations were chosen based on the solubility exhibited by this compound in the respective aqueous cosolvent mixtures to cover a wide range of compositions.[4,5] Moreover, these are the concentrations commonly used to design liquid dosage forms mainly intended for the oral administration route.[2,3]

Density determinations

Dissolution density was measured by using a digital density meter (DMA 45 Anton Paar, Austria) directly connected to a recirculating thermostatic bath operating at 298.2 K (Neslab RTE 10 Digital One Thermo Electron Company, USA). Densities were used to calculate the apparent specific volumes of sucrose (ϕ_V^{sp}), according to the following equation:[14]

$$\phi_V^{\mathrm{sp}} = \frac{w_3 + w_{1+2}(1-\rho_{1+2+3}/\rho_{1+2})}{w_3\rho_{1+2+3}} \qquad \text{Eq. (1)}$$

Here, w_3 and w_{1+2} are the mass fractions of sucrose (3) and the cosolvent mixture (1+2) in the respective dissolution, respectively. ρ_{1+2+3} and ρ_{1+2} are the densities of the sucrose dissolution and the cosolvent mixture free of solute, respectively. All density values of the {cosolvent (1) + water (2)} cosolvent mixtures free of solute at 298.2 K were taken from the literature.[15-19]

Results and Discussion

Density of the sucrose dissolutions and apparent specific volumes of sucrose at 298.2 K are reported in Tables 1 to 3 for water, aqueous-alcoholic and aqueous polymeric mixtures, respectively. Besides, for illustration the density of the sucrose dissolutions in neat water and also in {ethanol (1) + water (2)} mixtures as a function of the sucrose proportion expressed as mass fraction (w_3) at 298.2 K is shown in Figure 1. Moreover, just as an example, the density of sucrose dissolutions in the five {cosolvent (1) + water (2)} mixtures, with a cosolvent proportion of 0.30 (w_1^{o} = 0.30) in the mixtures free of sucrose, as a function of the sucrose mass fraction (w_3) at 298.2 K, is shown in Figure 2.

Table 1. Density of water and sucrose solutions (ρ) and apparent specific volume of sucrose (ϕ_V^{sp}) in water at 298.2 K.

w_2 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]
0.0000	0.9970	
0.1429	1.0555	0.614
0.2502	1.1019	0.621
0.4000	1.1740	0.625
0.5001	1.2275	0.627
0.5714	1.2665	0.630
0.6252	1.2974	0.632
	Mean	0.625
	Std. dev.	0.006
	RSD	1.00%

[a] w_2 is the mass fraction of sucrose (compound 2) in the binary mixtures with water (compound 1).
[b] Mean uncertainty in density of dissolutions is 0.0003 g.cm^{-3}; mean uncertainty in apparent specific volume of sucrose is 0.002 cm^3.g^{-1}.

By considering the sucrose behavior in neat water (Table 1), the dissolution density increase with the sucrose proportion by following a parabolic trend. Moreover, the ϕ_V^{sp} values also increase with the sucrose proportion following a third degree regular polynomial (Figure 3). Besides, a mean ϕ_V^{sp} value of 0.625 (±0.006) cm^3.g^{-1}, with relative standard deviation (RDS) of 1.00%, is obtained if considering the six individual values. Therefore, despite the sweetener concentration, this mean value could be considered as useful for sucrose in neat water at 298.2 K in development stages of liquid dosage forms, because uncertainties or deviations lower than 1.0% are normally considered as acceptable in pharmaceutical industries.[20]

Table 2. Density of cosolvent mixtures free of sucrose and sucrose solutions (ρ) and apparent specific volume of sucrose (ϕ_V^{sp}) in different {cosolvent (1) + water (2)} mixtures at 298.2 K.

w_3 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]	w_3 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]	w_3 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]
Ethanol (1) + water (2)			**Propylene glycol (1) + water (2)**			**Glycerol (1) + water (2)**		
w_1^o = 0.10 [c]								
0.0000	0.9802 [d]		0.0000	1.0043 [e]		0.0000	1.0207 [f]	
0.2312	1.0810	0.609	0.2309	1.1000	0.621	0.2304	1.1067	0.649
0.3755	1.1505	0.618	0.3750	1.1660	0.628	0.3754	1.1747	0.638
0.4443	1.1846	0.624	0.4442	1.2026	0.626	0.4448	1.2116	0.633
0.4999	1.2129	0.629	0.4998	1.2320	0.627	0.4996	1.2385	0.635
0.5428	1.2388	0.628	0.5465	1.2559	0.631	0.5449	1.2664	0.631
0.5831	1.2629	0.629	0.5834	1.2772	0.631	0.5831	1.2848	0.634
	Mean	0.623		Mean	0.627		Mean	0.637
	Std. dev.	0.008		Std. dev.	0.004		Std. dev.	0.007
	RSD	1.27%		RSD	0.60%		RSD	1.04%
w_1^o = 0.20 [c]								
0.0000	0.9666 [d]		0.0000	1.0128 [e]		0.0000	1.0453 [f]	
0.1949	1.0494	0.616	0.1939	1.0902	0.626	0.2288	1.1332	0.632
0.3246	1.1143	0.612	0.3242	1.1474	0.630	0.3718	1.1967	0.631
0.4187	1.1593	0.624	0.4173	1.1932	0.630	0.4739	1.2444	0.634
0.4897	1.2000	0.624	0.4896	1.2277	0.634	0.5451	1.2818	0.633
0.5451	1.2313	0.627	0.5455	1.2614	0.631	0.5997	1.3085	0.636
0.5860	1.2516	0.633	0.5899	1.2860	0.632	0.6356	1.3297	0.635
	Mean	0.622		Mean	0.630		Mean	0.633
	Std. dev.	0.007		Std. dev.	0.003		Std. dev.	0.002
	RSD	1.19%		RSD	0.44%		RSD	0.27%
w_1^o = 0.30 [c]								
0.0000	0.9509 [d]		0.0000	1.0213 [e]		0.0000	1.0707 [f]	
0.1803	1.0244	0.633	0.1661	1.0840	0.638	0.1807	1.1325	0.652
0.3060	1.0815	0.637	0.2859	1.1340	0.639	0.3055	1.1855	0.638
0.3975	1.1298	0.633	0.3750	1.1761	0.635	0.3988	1.2231	0.642
0.4684	1.1690	0.633	0.4444	1.2111	0.634	0.4527	1.2494	0.639
0.5239	1.2029	0.631	0.5005	1.2417	0.632	0.5238	1.2848	0.637
0.5687	1.2359	0.625	0.5657	1.2757	0.634	0.5690	1.3070	0.637
	Mean	0.632		Mean	0.635		Mean	0.641
	Std. dev.	0.004		Std. dev.	0.003		Std. dev.	0.006
	RSD	0.60%		RSD	0.42%		RSD	0.90%
w_1^o = 0.40 [c]								
0.0000	0.9321 [d]		0.0000	1.0290 [e]		0.0000	1.0971 [f]	
0.1304	0.9874	0.612	0.1523	1.0856	0.639	0.1525	1.1491	0.641
0.2307	1.0307	0.628	0.2646	1.1288	0.647	0.2644	1.1970	0.624
0.3104	1.0711	0.624	0.3504	1.1657	0.647	0.3415	1.2269	0.629
0.3750	1.1031	0.629	0.4187	1.2001	0.641	0.4171	1.2547	0.637
0.4285	1.1331	0.629	0.4739	1.2248	0.644	0.4738	1.2812	0.635
0.4737	1.1627	0.624	0.5188	1.2511	0.639	0.5192	1.3043	0.633
	Mean	0.624		Mean	0.643		Mean	0.633
	Std. dev.	0.007		Std. dev.	0.004		Std. dev.	0.006
	RSD	1.05%		RSD	0.55%		RSD	0.96%
w_1^o = 0.50 [c]								
0.0000	0.9100 [d]		0.0000	1.0348 [e]		0.0000	1.1238 [f]	
0.1151	0.9584	0.617	0.1253	1.0798	0.645	0.1151	1.1592	0.653
0.2064	0.9997	0.621	0.2187	1.1176	0.639	0.2059	1.1904	0.648
0.2806	1.0388	0.613	0.2959	1.1519	0.634	0.2809	1.2184	0.644
0.3411	1.0676	0.623	0.3594	1.1778	0.640	0.3367	1.2402	0.642
0.3938	1.0948	0.628	0.3907	1.1937	0.637	0.3939	1.2634	0.640
0.4382	1.1212	0.626	0.4505	1.2221	0.638	0.4381	1.2807	0.641
	Mean	0.621		Mean	0.639		Mean	0.645
	Std. dev.	0.006		Std. dev.	0.004		Std. dev.	0.005
	RSD	0.91%		RSD	0.55%		RSD	0.79%

[a] w_3 is the mass fraction of sucrose (compound 3) in the {cosolvent (compound 1) + water (compound 2)} mixtures.
[b] Mean uncertainty in density of dissolutions is 0.0003 g.cm^{-3}; mean uncertainty in apparent specific volume of sucrose is 0.002 cm^3.g^{-1}.
[c] w_1^o is the mass fraction of cosolvent (1) in the {cosolvent (1) + water (2)} mixtures free of sucrose (3).
[d] Data from Ref. [15].
[e] Data from Ref. [16]. [f] Data from Ref. [17].

Table 3. Density of cosolvent mixtures free of sucrose and sucrose solutions (ρ) and apparent specific volume of sucrose (ϕ_V^{sp}) in {PEG 200 (or 400) (1) + water (2)} mixtures at 298.2 K.

w_3 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]	w_3 [a]	ρ / g.cm^{-3} [b]	ϕ_V^{sp} / cm^3.g^{-1} [b]
PEG 200 (1) + water (2)			**PEG 400 (1) + water (2)**		
w_1^o = 0.10 [c]					
0.0000	1.0116 [d]		0.0000	1.0131 [e]	
0.1663	1.0728	0.649	0.1672	1.0764	0.640
0.2859	1.1249	0.640	0.2855	1.1281	0.635
0.4083	1.1870	0.631	0.4119	1.1910	0.629
0.4735	1.2198	0.632	0.4740	1.2255	0.626
0.5238	1.2486	0.630	0.5242	1.2492	0.631
0.5625	1.2707	0.630	0.5655	1.2747	0.629
	Mean	0.636		Mean	0.632
	Std. dev.	0.008		Std. dev.	0.005
	RSD	1.23%		RSD	0.77%
w_1^o = 0.20 [c]					
0.0000	1.0272 [d]		0.0000	1.0298 [e]	
0.2194	1.1156	0.622	0.1936	1.1061	0.625
0.3595	1.1767	0.629	0.3217	1.1634	0.624
0.4568	1.2215	0.635	0.4185	1.2087	0.628
0.5283	1.2622	0.630	0.4896	1.2439	0.630
0.5833	1.2910	0.632	0.5448	1.2721	0.632
0.6002	1.2965	0.637	0.5871	1.2953	0.632
	Mean	0.631		Mean	0.628
	Std. dev.	0.005		Std. dev.	0.003
	RSD	0.81%		RSD	0.52%
w_1^o = 0.30 [c]					
0.0000	1.0432 [d]		0.0000	1.0471 [e]	
0.1526	1.1017	0.625	0.1536	1.1044	0.632
0.2648	1.1460	0.634	0.2646	1.1506	0.630
0.3506	1.1824	0.637	0.3506	1.1876	0.633
0.4184	1.2152	0.634	0.3974	1.2118	0.628
0.4737	1.2443	0.632	0.4736	1.2456	0.634
0.5237	1.2674	0.635	0.5193	1.2674	0.635
	Mean	0.633		Mean	0.632
	Std. dev.	0.004		Std. dev.	0.002
	RSD	0.65%		RSD	0.39%
w_1^o = 0.40 [c]					
0.0000	1.0591 [d]		0.0000	1.0650 [e]	
0.1303	1.1075	0.628	0.1303	1.1123	0.633
0.2248	1.1465	0.624	0.2309	1.1483	0.644
0.3103	1.1786	0.636	0.3105	1.1844	0.634
0.3750	1.2066	0.636	0.3754	1.2124	0.635
0.4286	1.2285	0.640	0.4286	1.2350	0.637
0.4736	1.2525	0.636	0.4739	1.2555	0.638
	Mean	0.633		Mean	0.637
	Std. dev.	0.006		Std. dev.	0.004
	RSD	0.98%		RSD	0.64%
w_1^o = 0.50 [c]					
0.0000	1.0750 [d]		0.0000	1.0821 [e]	
0.0977	1.1111	0.621	0.0909	1.1148	0.626
0.1778	1.1412	0.627	0.1665	1.1425	0.631
0.2449	1.1669	0.631	0.2307	1.1667	0.634
0.3016	1.1891	0.634	0.2857	1.1880	0.636
0.3506	1.2098	0.635	0.3335	1.2087	0.634
0.3926	1.2293	0.633	0.3742	1.2259	0.634
	Mean	0.630		Mean	0.632
	Std. dev.	0.005		Std. dev.	0.004
	RSD	0.84%		RSD	0.56%

[a] w_3 is the mass fraction of sucrose (compound 3) in the {PEG (compound 1) + water (compound 2)} mixtures.
[b] Mean uncertainty in density of dissolutions is 0.0003 g.cm^{-3}; mean uncertainty in apparent specific volume of sucrose is 0.002 cm^3.g^{-1}.
[c] w_1^o is the mass fraction of PEG (1) in the {PEG (1) + water (2)} mixtures free of sucrose (3).
[d] Data from Ref. [18].
[e] Data from Ref. [19].

It is important to note that reported ϕ_V^{sp} value at saturation in neat water is 0.632 $cm^3.g^{-1}$ (equilibrium solubility is $w_3 = 0.6879$)[4,5] which is just coincident with that obtained in the mixture of $w_3 = 0.6252$ (Table 1).

Table 2 summarizes the sucrose behavior in aqueous cosolvent mixtures of ethanol, propylene glycol and glycerol, which are the non-polymeric cosolvents more used in pharmaceutics of liquid medicines. As observable, in all cases the dissolution densities increase with the sucrose proportion as expected because this compound is the densest agent among all the studied compounds. In contrast to aqueous systems, in these systems no regular behavior is observed with ϕ_V^{sp} values as the sucrose concentration increases. This is shown in Figure 3 for all the {ethanol (1) + water (2)} mixtures and also in Figure 4 for the five different {cosolvent (1) + water (2)} systems with $w_1^o = 0.30$ as a function of the sucrose mass fraction. Apparent specific and molar volume magnitudes depend on solute-solute and solvent-solute interactions and normally follow regular trends with the solute concentration in the mixtures. Nevertheless, this is not observed in Figures 3 and 4, except for water. This could be a consequence of the use of only four decimal places in our density measurements, which propagates high uncertainties in ϕ_V^{sp} values, as compared with some other studies reported in the literature, where six decimal places have been reported for density in ternary mixtures finding regular trends.[20,21] Nevertheless, it is important to keep in mind that our main objective is to know the apparent volumetric contribution of sucrose, rather than deepen in the respective intermolecular interactions. In this way, in similar way to aqueous dissolutions, in these mixtures the RDS is lower than 1.0% in almost all cases, except in {ethanol (1) + water (2)} mixtures of $w_1^o = 0.10$, 0.20 and 0.40. Moreover, Table 4 shows that the general RDS in each aqueous cosolvent mixtures is lower than 1.3% despite the sucrose or cosolvent proportion. Otherwise, it is interesting to note that the ϕ_V^{sp} values increase with the polarity of every non-polymeric cosolvent as described by the Hildebrand solubility parameter, i.e. 26.5, 30.2 and 36.1 $MPa^{1/2}$ for ethanol, propylene glycol and glycerol, respectively.[22]

Table 3 shows the sucrose behavior in aqueous cosolvent mixtures of PEG 200 and PEG 400, which are the polymeric cosolvents more used in design and development of peroral and parenteral drug products. As expected, in all cases the density values also increase with the sucrose concentration in the mixtures. In these mixtures the RDS is also lower than 1.0% in almost all cases, with the only exception of the {PEG 200 (1) + water (2)} mixture of $w_1^o = 0.10$.

Besides, Table 4 shows that the general RDS in each one of the aqueous PEG mixtures is almost lower than 1.0% despite the sucrose or PEG proportion in the mixtures.

Finally, if all the ϕ_V^{sp} values reported in Tables 1 to 3 are considered a mean value of 0.632 (±0.008) $cm^3.g^{-1}$, with RDS = 1.20%, is obtained. Although this RDS value is slightly higher than 1.0%, within a good approximation, for practical purposes at room temperature an apparent volumetric contribution of 0.632 $cm^3.g^{-1}$ could be considered as adequate for sucrose in those liquid mixtures that involve these cosolvents and water. Moreover, this value is close to those reported at saturation for sucrose in the same mixtures (0.636 and 0.637 $cm^3.g^{-1}$).[4,5] This is very important because the pharmaceutical formulations involves several components including active ingredients and excipients, which makes them real multicomponent systems. Therefore, an exhaustive study about the individual contribution of every agent during preparation of liquid mixtures would be expensive in time and economic resources at industrial level.

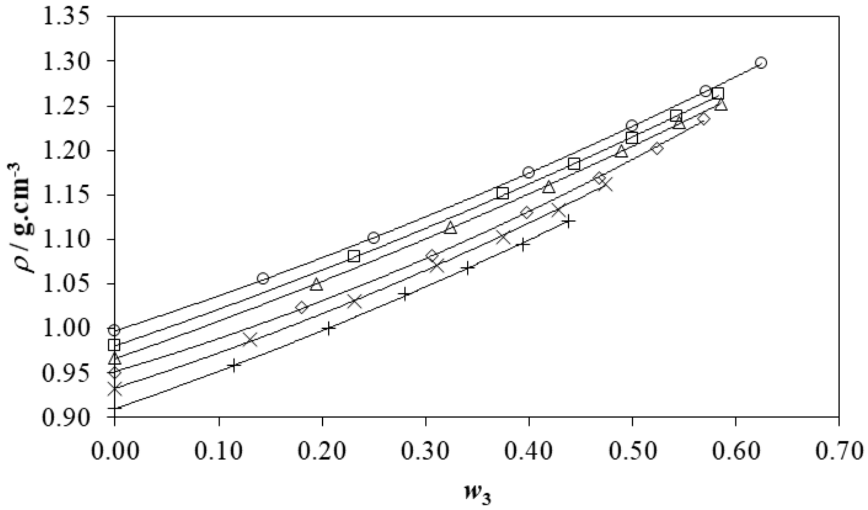

Figure 1. Density of sucrose dissolutions in neat water and in {ethanol (1) + water (2)} mixtures as a function of the sucrose mass fraction at 298.2 K. ○: Neat water; □: $w_1^o = 0.10$; Δ: $w_1^o = 0.20$; ◊: $w_1^o = 0.30$; ×: $w_1^o = 0.40$; +: $w_1^o = 0.50$.

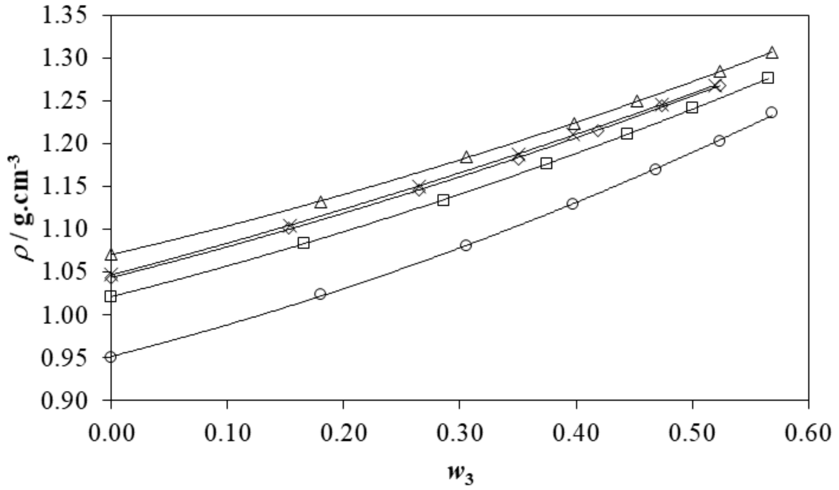

Figure 2. Density of sucrose dissolutions in different {cosolvent (1) + water (2)} mixtures with w_1^{o} = 0.30 as a function of the sucrose mass fraction at 298.2 K. ○: Ethanol (1) + water (2); □: propylene glycol (1) + water (2); Δ: glycerol (1) + water (2); ◊: PEG 200 (1) + water (2); ×: PEG 400 (1) + water (2).

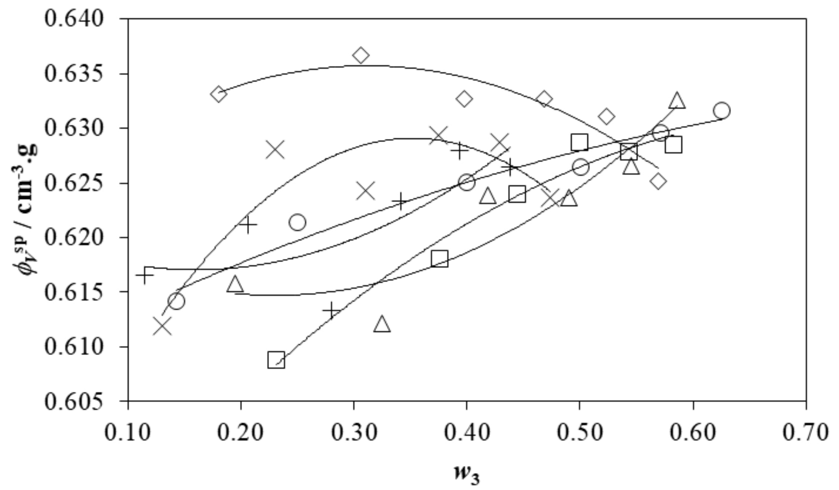

Figure 3. Apparent specific volume of sucrose in neat water and in {ethanol (1) + water (2)} mixtures as a function of the sucrose mass fraction at 298.2 K. ○: Neat water; □: w_1^{o} = 0.10; Δ: w_1^{o} = 0.20; ◊: w_1^{o} = 0.30; ×: w_1^{o} = 0.40; +: w_1^{o} = 0.50.

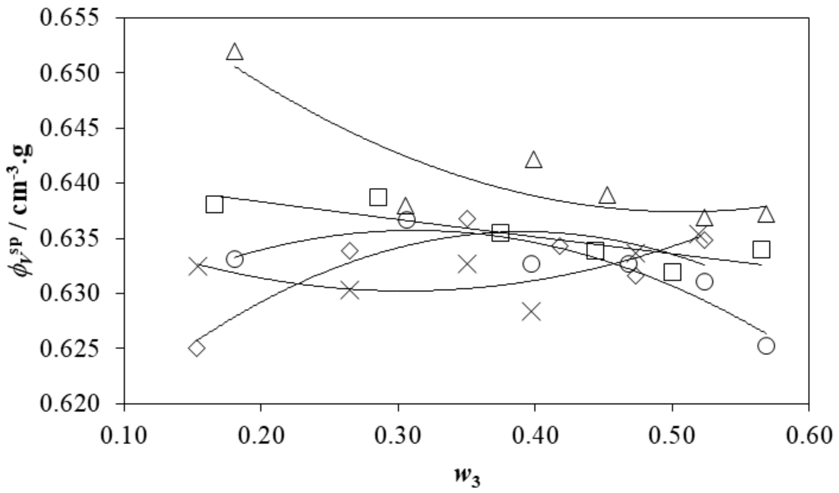

Figure 4. Apparent specific volume of sucrose in different {cosolvent (1) + water (2)} mixtures with w_1^{o} = 0.30 as a function of the sucrose mass fraction at 298.2 K. ○: Ethanol (1) + water (2); □: propylene glycol (1) + water (2); Δ: glycerol (1) + water (2); ◊: PEG 200 (1) + water (2); ×: PEG 400 (1) + water (2).

Table 4. Mean apparent specific volume of sucrose (ϕ_V^{sp}) in different {cosolvent (1) + water (2)} mixtures at 298.2 K.[a]

Parameter	EtOH + W	PG + W	G + W	PEG 200 + W	PEG 400 + W
Mean ϕ_V^{sp} value / $cm^3.g^{-1}$	0.625	0.633	0.636	0.631	0.631
Std. dev. / $cm^3.g^{-1}$	0.007	0.007	0.008	0.006	0.005
RSD	1.10%	1.17%	1.29%	1.02%	0.87%

[a] EtOH is ethanol, PG is propylene glycol, G is glycerol and PEG is polyethylene glycol.

Conclusion

In this research, useful apparent specific volumes of sucrose at different concentrations in several aqueous cosolvent mixtures are reported at 298.2 K involving polymeric and non-polymeric cosolvents. Moreover, a mean ϕ_V^{sp} value of 0.632 $cm^3.g^{-1}$ for sucrose in aqueous-cosolvent mixtures could be considered as adequate for practical purposes in pharmaceutical industries.

Acknowledgements

We thank the Department of Pharmacy of the Universidad Nacional de Colombia for facilitating the equipment and laboratories used.

Conflict of interests

The authors claim that there is no conflict of interest.

References

1. Rowe RC, Sheskey PJ, Owen SC, editors. Handbook of pharmaceutical excipients. 5th ed. Grayslake: Pharmaceutical Press and American Pharmacists Association; 2006.
2. Aulton ME. Pharmaceutics. The Science of Dosage Forms Design. 2nd ed. London: Churchill Livingstone; 2002. p. 309-22.
3. Allen LV Jr, Popovich NG, Ansel HC. Ansel's Pharmaceutical Sosage Forms and Drug Delivery Systems. 8th ed. Baltimore: Lippincott Williams & Wilkins; 2005. p. 336-84.
4. Tinjacá DA, Muñoz MM, Rahimpour E, Jouyban A, Martínez F, Acree WE Jr. Solubility and apparent specific volume of sucrose in some aqueous polyethylene glycol mixtures at 298.2 K. Pharm Sci. 2018;24(2):163-7. doi:10.15171/ps.2018.24
5. Tinjacá DA, Muñoz MM, Jouyban A, Martínez F, Acree WE Jr. Equilibrium solubility, preferential solvation and apparent specific volume of sucrose in some {cosolvent (1) + water (2)} mixtures at 298.2 K. Phys Chem Liquids. 2018; 56(1):1-15. doi:10.1080/00319104.2018.1439028
6. Fucaloro AF, Pu Y, Cha K, Williams A, Conrad K. Partial molar volumes and refractions of aqueous solutions of fructose, glucose, mannose, and sucrose at 15.00, 20.00, and 25.00 °C. J Solution Chem. 2007;36(1):61-80. doi:10.1007/s10953-006-9100-7
7. Garrod JE, Herrington TM. Apparent molar volumes and temperatures of maximum density of dilute aqueous sucrose solutions. J Phys Chem. 1970;74(2):363-70. doi:10.1021/j100697a023
8. Brown BR, Ziemer SP, Niederhauser TL, Woolley EM. Apparent molar volumes and apparent molar heat capacities of aqueous D(+)-cellobiose, D(+)-maltose, and sucrose at temperatures from (278.15 to 393.15) K and at the pressure 0.35 MPa. J Chem Thermodyn. 2005;37(8):843-53. doi:10.1016/j.jct.2004.12.004
9. Nikam PS, Kapadnis KH, Kharat SJ. Densities and partial molar volumes of fructose and sucrose in water and 0.05M (NaCl, NaBr, KCl, and KBr) aqueous solutions at 303.15K. Phys Chem, Indian J. 2009; 4(2):93-5.
10. Amutha PS, Rajkumar XR. Apparent molal volumes and partial molar volumes of aqueous solutions of some biologically important compounds at 308 and 318 K. Asian J Chem. 2011;23(3):1360-2.
11. Rubino JT. Cosolvents and cosolvency. In: Swarbrick JC, Boylan J, editors. Encyclopedia of Pharmaceutical Technology. New York: Marcel Dekker; 1988. vol 3. p. 375-98.
12. Yalkowsky SH. Solubility and Solubilization in Aqueous Media. New York: American Chemical Society and Oxford University Press; 1999.
13. Budavari S, O'Neil MJ, Smith A, Heckelman PE, Obenchain Jr JR, Gallipeau JAR, et al. The Merck index, an encyclopedia of chemicals, drugs, and biologicals. 13th ed. Whitehouse Station (NJ): Merck & Co., Inc.; 2001.
14. Pérez DC, Guevara CC, Cárdenas CA, Pinzón JA, Barbosa HJ, Martínez F. Solubility and displacement volumes of acetaminophen in binary mixtures formed by propylene glycol, ethanol, and water at 25.0 °C. Rev Colomb Cienc Quím Farm. 2003;32:116-36.
15. Jiménez J, Manrique J, Martínez F. Effect of temperature on some volumetric properties for ethanol + water mixtures. Rev Colomb Cienc Quím Farm. 2004;33(2):145-55.
16. Jiménez J, Martínez F. Study of some volumetric properties of 1,2-propanediol + water mixtures at several temperatures. Rev Colomb Cienc Quím Farm. 2005;34(1):46-57.
17. Cristancho DM, Delgado DR, Martínez F, Fakhree MAA, Jouyban A. Volumetric properties of glycerol + water mixtures at several temperatures and correlation with the Jouyban-Acree model. Rev Colomb Cienc Quím Farm. 2011;40(1):92-115.
18. Rodríguez GA, Holguín AR, Martínez F, Khoubnasabjafari M, Jouyban A. Volumetric properties of (PEG 400 + water) and (PEG 400 + ethanol) mixtures at several temperatures and

correlation with the Jouyban-Acree model. Rev Colomb Cienc Quím Farm. 2012;41(2):187-202.
19. Muñoz MM, Tinjacá DA, Jouyban A, Martínez F, Acree WE Jr. Volumetric properties of {PEG 200 (or 300) (1) + water (2)} mixtures at several temperatures and correlation with the Jouyban-Acree model. Phys Chem Liquids. 2018;56(1):100-9. doi:10.1080/00319104.2017.1303700
20. Shekaari H, Zafarani-Moattar MT, Mirheydari SN. Thermodynamic study of aspirin in the presence of ionic liquid, 1-hexyl-3-methylimidazolium bromide in acetonitrile at T = (288.15 to 318.15) K. J Mol Liq. 2015;209:138-48. doi:10.1016/j.molliq.2015.05.032
21. Shekaari H, Zafarani-Moattar MT, Mokhtarpour M. Solubility, volumetric and compressibility properties of acetaminophen in some aqueous solutions of choline based deep eutectic solvents at T=(288.15 to 318.15) K. Eur J Pharm Sci. 2017;106:121-30. doi:10.1016/j.ejps.2017.07.021
22. Martin A, Bustamante P, Chun AHC. Physical Chemical Principles in the Pharmaceutical Sciences. 4th ed. Philadelphia: Lea & Febiger; 1993.