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Water and water-ethanol mixtures (alcoholic beverages) viscosity measurements by dynamic light scattering with use of silica nanoparticles as a seed

V N Kuryakov

Oil and Gas Research Institute of RAS (OGRI RAS), Gubkina Street, 3, 119333, Moscow, Russia

E-mail: vladimir.kuryakov@gmail.com

Abstract. The dynamic viscosity of several alcoholic drinks was studied via determinations of the translational particle diffusion coefficient by dynamic light scattering (DLS). For temperatures from 3 to 80 ^{o}C at atmospheric pressure, the dynamic viscosity values of clear water, several brands of vodka, and one brand of cognac were obtained with the uncertainty of less than 10%. Measured viscosity agrees well with literature.

1. Introduction

One of the most intrigue applications of dynamic light scattering (DLS) is the liquids viscosity measurement. Dynamic light scattering is an experimental technique which allows measuring the hydrodynamic radius of Brownian particles through the measurement of their diffusion coefficient by using the Einstein-Stokes equation [1]. In a case when the studied liquid viscosity is known, one can calculate the radius of particles and in opposite case when the radius of particles is known in advance the viscosity can be calculated through DLS measurements. To measure the liquid viscosity by DLS, it is necessary to add the standard sample of nanoparticles with known size into the studied liquid. Here are the main conditions for successful viscosity measurements using DLS: added nanoparticles have to be stable in studied liquid; added dry nanoparticles or added suspension with nanoparticles do not have to influence on viscosity of studied liquid; measured light scattering intensity in studied liquid has to be mostly from added nanoparticles; the particles must be spherical and noninteracting.

One can find several papers with application of DLS for measurements of viscosity of different liquids. Water viscosity measurements were done by M.A. Anisimov and co-workers [2] at different temperatures and by S. Will and co-workers [3] at one fixed temperature. They used latex particles of 234 nm and polystyrene particles of 102 nm respectively. S. Will also applied DLS to measure the viscosity of n-heptane at different temperatures and to measure the viscosity of some alcohols, alkanes, and the refrigerant R123 at fixed temperature using silica particles as a seed [4, 5]. I.K. Yudin and M.A. Anisimov measured temperature dependence of the viscosity of crude oil by DLS using a natural dilute microemulsion of water in oil (stable water droplets of 70 nm) as seed. In this paper measurements of the temperature dependence of the viscosity of several alcoholic beverages and distilled water are presented. The measurements performed by DLS with using SiO_2 nanoparticles of 110 nm diameter as seed.

2. Materials and methods

For this study, the author used the bi-distilled water (medical water for injection sealed in plastic ampoules 5 ml, Solopharm, Russia). Colloidal silica slurry was used as a seed, which has spherical particles and excellent particle uniformity. The content of SiO_2 in initial colloid was 40% weight. Average particle size (hydrodynamic radius) diluted in a water sample measured by DLS was 55 nm. Four-milliliter glass vials with screw caps were used for DLS measurements. Each vial was filled up to the brim with the sample. The one microliter of initially concentrated silica slurry was added into the studied samples of alcoholic drinks in vials. The measurements of temperature dependence of viscosity were done at heating. At each temperature, the time for the equilibrium was about 3 minutes and after that, the correlation function of the intensity of light scattering was measured three times with accumulation time of 100 seconds each. The author used one of them with minimal standard deviation for viscosity determination. The Cumulant Analysis method (DynaLS software, Alango Ltd.) was used for processing the correlation functions of the intensity of scattered light. The value of the viscosity in the Einstein-Stokes equation was variated to obtain the correct size of particles 55 nm as a result of processing. Thus, the viscosity values at each temperature for all studied samples were determined. Dynamic light scattering measurements were performed on particle size and zeta potential analyzer Photocor Compact (Russia). Scattering angle was 90 degree, laser power and wavelength were 25 mW and 654 nm correspondingly.

Three brands of vodka from different manufacturers and one brand of cognac were chosen for the studies. Information on the composition and some properties of the studied alcoholic beverages are presented in Table 1.

Table 1. Properties and composition of the studied alcoholic beverages.

Sample	Alcohol by volume, % (ABV)	Type of the spirit	Calorie in 100 ml, kJ (kcal)	Additives
Vodka Morosha №2	40	Alpha	930 (220)	infusion of alcohol flax, honey
Vodka Derevenka Solodovaya	40	Alpha	930 (220)	sugar syrup, infusion of alcohol cranberries and rye
Vodka Bulbash Honey and pepper	40	Luxe	940 (230)	cognac, sugar, chili pepper, sugar dye №6, alcohol extract of pepper, pollen and honey
Cognac Stone Land №3	40	Cognac spirits of 3 years old	955 (228)	E150a

3. Results and discussion

The intensity of the scattered light in all samples prior to the addition of nanoparticles was 7k-9k counts per second, and no particles were observed by the method of dynamic light scattering. After the addition of nanoparticles, the scattering intensity became about 500k counts per second, and the correlation function of scattered light intensity was measured using the DLS method. Previously, the author carried out the temperature dependence of water viscosity measurements using the DLS method. The obtained results of measuring the water viscosity by the DLS method at different temperatures are in good agreement with the data of the International Association for the Properties of Water and Steam (IAPWS) (see figure 1). Relative viscosity deviation measured by DLS from IAPWS viscosity is 2-6%. The author could not find the published data on the temperature dependence of viscosity for vodka or brandy. In Industrial Solvents Handbook [7], there are data for the temperature dependence of water-ethanol mixture viscosity. Figure 1 presents data from [7] for an ethanol-water mixture of 35% by weight, since 40% ABV (alcohol by volume) is about 35% ethanol-water by weight.

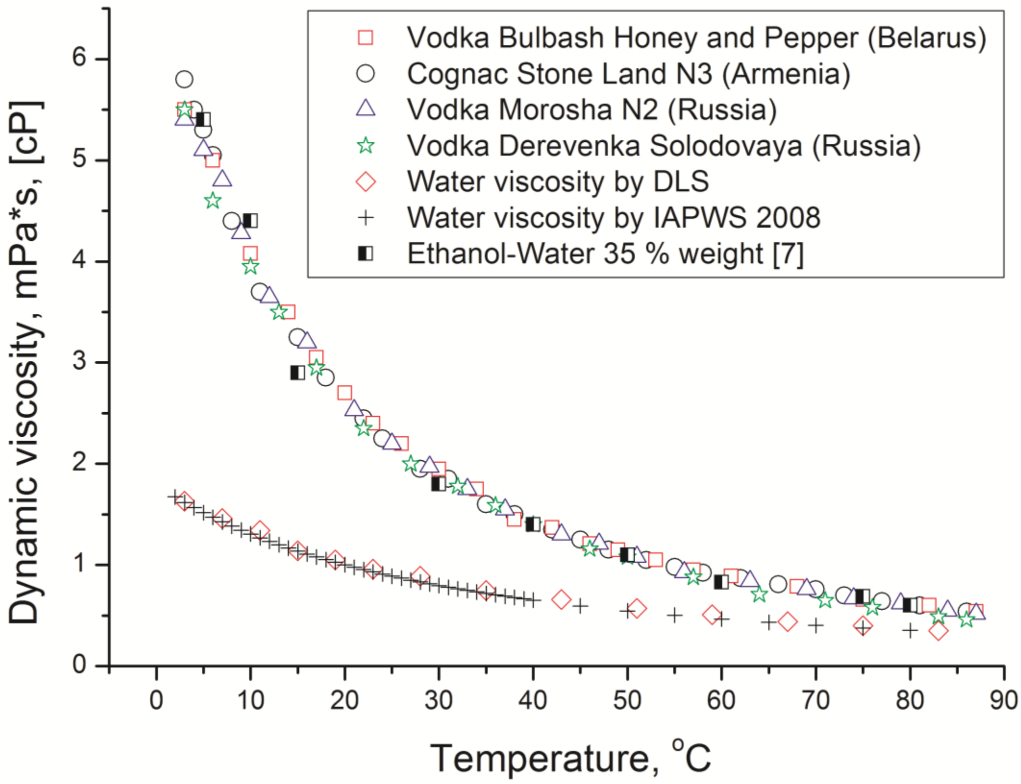

Figure 1. Temperature dependences of water and samples of alcoholic beverages viscosity

For all temperature dependences of viscosity measured, the coefficients in the Vogel equation were determined. The Vogel equation coefficients for the studied alcoholic beverages are presented in Table 2.

Table 2. Vogel equation coefficients for the studied alcoholic beverages.

Sample	A	B	C	Reduced χ^2	Coefficient of Determination (R^2)
Bulbash	-3.80446	629.86574	-162.06264	0.00279	0.99881
Stone Land	-2.66369	342.15898	-198.72735	0.00241	0.99922
Morosha	-3.92005	656.08887	-159.58485	0.00523	0.99821
Derevenka	-4.19805	709.63518	-155.5317	0.00264	0.999

4. Conclusion

Using the method of dynamic light scattering and silica nanoparticles, the temperature dependences of the water and several alcoholic beverages viscosity were measured.

The volume content of ethanol in all drinks is the same, the type of alcohol and additives are different. It can be concluded that the additives and the type of alcohol in the studied samples do not have a significant effect on the viscosity in the investigated temperature range.

5. References

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