Absorption and velocity of ultrasound in binary solutions of poly (ethylene glycol) and water

R. Esquivel-Sirvent, B. Tan, I. Abdelraziq, S. S. Yun, and F. B. Stumpf
Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701-2979

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The absorption and velocity of ultrasound were studied for solutions of 10 000 molecular-weight poly (ethylene glycol) and distilled water. The frequency used was 21 MHz and the concentration (by weight) ranged from 1% to 9% of poly (ethylene glycol) in water. The shear viscosity was also measured. Temperatures of 25, 30, 35, 40, 45 °C were used for the measurements. Observations showed that the ultrasonic absorption decreases with increasing temperature at a given concentration and also increases with concentration at a given temperature. The velocity increases with increasing temperature and concentration. Finally, the shear viscosity measurements show it decreasing with temperature but also increasing with concentration.

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INTRODUCTION

Poly (ethylene glycol) may be used as a flocculant to clarify water and thus has a potential for practical use. The ultrasonic measurements presented here should be helpful in gaining an understanding of this polymer–water solution. In addition, light scattering and perhaps other measurements can lead to a fuller knowledge of this polymer system as they have for other systems.[1,2] In previous years the ultrasonic velocity and absorption and also other properties have been studied in poly (ethylene glycol) and other related polymer solutions.[3–10] The measurements in the solutions presented here can be a valuable addition to these studies.

The poly (ethylene glycol) used here has a molecular weight of 10 000. An ethylene glycol monomer has a chemical formula $HOCH_2CH_2OH$ and a molecular weight of 62.

To make a solution the thin, white, polymer flakes were mixed with doubly distilled water and stirred for 18 h or more to make sure the polymer was in solution. The polymer was obtained from Aldrich Chemical Company and had a density of 1.070. Concentrations of 1% to 9% were carefully prepared by weight for the polymer in the water. The solution was then placed in the ultrasonic test cell that had its temperature controlled to a few hundredths of a degree centigrade. A Matec pulse-echo system (Matec-gating modulator 5100 system) and a liquid cell with a moveable reflector was used to measure the ultrasonic absorption and velocity at 21 MHz.[11] For the measurements, the reflector was carefully aligned and then moved with a precision micrometer. It was not necessary to correct for diffraction at the frequency used. The error for the absorption measurements is a few percent and that for the velocity is a few tenths of a percent. Each velocity and absorption value presented later in the tables is the result of averaging several data values.

The viscosity of the polymer–water solution was measured with a Brookfield rotating-cylinder viscometer attached to a temperature-controlled bath.[11] The error in the viscosity measurements is a few percent or less.

Very little, if any, settling of the polymer was seen over several weeks. The light scattering for the Tyndall effect observed was present but not very pronounced. Furthermore, the Weissenberg effect evidenced by the solution's climbing a rotating smooth rod was noted. This effect is found for polymeric fluids.[12] Finally, it was observed that the solutions were clear and colorless and remained so for several weeks.

I. ABSORPTION MEASUREMENTS

The values for α/f^2 are given in Table I. It is seen that α/f^2 at a given concentration is decreasing somewhat nonlinearly with increasing temperature. As the temperature remains constant α/f^2 increases with concentration. These two effects for α/f^2 as the temperature and concentration increase are perhaps related to the two generally similar effects for the shear viscosity to be discussed later. This seems to indicate that the classical viscous term may contribute significantly to the total absorption. Note that the range of values is less than one order of magnitude. Each table value is the average of several individual measurements. A check of our measured values for α/f^2 in water at 25 °C showed very good agreement with literature values.

TABLE I. Ultrasonic absorption (α/f^2) for different concentrations and temperatures for poly (ethylene glycol) and water. The units are 10^{-17} s^2/cm.

Conc.% by weight	25 °C	30 °C	35 °C	40 °C	45 °C
1	38	35	33	32	30
3	42	39	35	34	32
5	45	40	38	37	36
7	50	48	43	42	41
9	56	55	52	51	50

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TABLE II. Velocity for different concentrations and temperatures. The units are meter/second.

Conc.% by weight	25 °C	30 °C	35 °C	40 °C	45 °C
1	1501	1511	1521	1528	1535
3	1510	1518	1526	1533	1541
5	1518	1530	1538	1545	1549
7	1529	1537	1545	1554	1558
9	1544	1550	1556	1565	1568

TABLE III. Shear viscosity in centipoise for different concentrations and temperatures.

Conc.% by weight	25 °C	30 °C	35 °C	40 °C	45 °C
1	1.2	1.0	0.9	0.8	0.7
3	2.0	1.8	1.6	1.4	1.3
5	3.0	2.7	2.4	2.1	1.9
7	4.4	3.8	3.4	3.1	2.8
9	6.0	5.2	4.6	4.1	3.7

II. VELOCITY MEASUREMENTS

Velocity measurements are recorded in Table II. The dependence of the velocity on temperature shows a linear increase with increasing temperature and a linear increase with concentration. The values in the table are the average for several measurements. Our measurement of the velocity in pure water at 25 °C showed agreement with literature values to within a few meters per second. Since the density should increase with increasing concentration and also the velocity increases with increasing concentration, these seem to indicate a decrease in compressibility. This seems to indicate that as the concentration increases the molecules appear to be forming a more rigid system.

III. SHEAR VISCOSITY MEASUREMENTS

Table III presents the data for the shear viscosity. These data show that the viscosity at each concentration decreases linearly with increasing temperature. However, at 9% concentration there seems to be some small deviation from linearity. Shear viscosity versus increasing concentration shows a nonlinear increase at each temperature. The maximum range in viscosity values is slightly less than one order of magnitude. Each data point is an average of several measurements.

IV. CONCLUSION

In conclusion, the absorption measurements seem to indicate that shear viscosity may contribute in a significant way to the absorption. Since we are not aware of a good model for this binary liquid system, it is difficult to discuss other mechanisms that also may contribute to the absorption. Velocity studies show that as the polymer concentration increases a more rigid molecular structure is formed perhaps by bonding between the large polymer molecules. Measurements of density and for a range of frequencies may lead to a better understanding of the molecular mechanisms responsible for absorption and velocity such as relaxation.

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