

Study the Rheological and Mechanical Properties of PVA/NH$_4$Cl by Ultrasonic

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Abstract

Some of physical properties of polyvinyl alcohol dissolves in distilled water had been studied at different concentration (0.25%, 0.5%, 0.75%, 1.0%, and 1.25%) before and after adding 1gm from NH$_4$Cl for all concentrations, the Rheological properties such as shear viscosity, relative viscosity and reduced viscosity are measured and after that the ultrasonic velocity had been measured by ultrasonic waves system at frequency 40 KHz, other mechanical properties had been calculated such as absorption coefficient of ultrasonic waves, relaxation time, relaxation amplitude, specific acoustic impedance, compressibility and bulk modules. Another acoustic mechanical properties were measured and calculated at a same time such as the ultrasonic wave amplitude before and after absorption by solution were showed on oscilloscope ,then we calculated absorption coefficient. The results show that all these properties are increasing with the increase of the polymer concentration except velocity is decreasing with increase the concentration; results also show that when adding NH$_4$Cl these properties are increasing.

Keywords: PVA solution, mechanical properties, rheological properties, ultrasound technique.

1. Introduction

PVA is a water-soluble synthetic polymer, due to the characteristics of easy preparation, good biodegradability, excellent chemical resistance, and good mechanical properties, polyvinyl alcohol is used mainly as a solution in water but its solubility in water depends on its degree of polymerization and degree of hydrolysis of its precursor (poly vinyl acetate). Solvent effects might therefore be expected to influence the ultrasonic relation behavior, the absorption of ultrasonic in liquid polymer systems is governed by local modes of motion (segmental conformation change) and cooperative whole molecule movement (normal or Rouse modes), because of the existence of strong intermolecular interaction within the polymer it should be possible to observe cooperative motion in the ultrasonic range (Jayanta et. al. 2004). Acoustic relaxation measurements on other polymers have been reported by several workers (Tomasz et. al. 2010, Hassun et. al. 1990 & Khalida 2004). Ultrasonic technique is good method for studying the structural changes associated with the information of mixture assist in the study of molecular interaction between two species; some of mechanical properties of different polymers were carried by some workers using ultrasonic technique. (Al-Bermany E.2004 & B. Boro 2009).

2. Experimental:

2.1 Preparation of Solutions:

The solution was prepared by soluble PVA with different weights (1, 2, 3, 4 and 5) gm in (400 ml) distilled water under stirring and 70°C for (1 hour) the resulting solution was stirred continuously until the solution mixture became a homogeneous, the PVA concentrations were (0.25%, 0.5%, 0.75%, 1.0% and 1.25%); after that (1gm) of NH$_4$Cl is adding to all concentrations to study the addition affect.

2.2 Density and Rheological measurements:

The density of the solution (ρ) was determined by density bottle method and their viscosities measured before and after adding 1gm from NH$_4$Cl for all concentrations using Ostwald viscometer with accuracy of ± 1.05%, the method of measurement has been described by (Al-Bermany E.2004), elsewhere different types of shear viscosity were determined before and after the adding of NH$_4$Cl by the following equations (Abdul-Kareem J. Rashid and Burak 2011). The Shear viscosity had been
calculated by the following equation (Subhi et al. 1990):

\[ \frac{\eta_s}{\eta_o} = \frac{t}{t_o} \frac{\rho}{\rho_o} \]  

(1)

Where \( \rho \) and \( \eta_s \) are the solution density and viscosity respectively, \( \rho_o \) and \( \eta_o \) are density and viscosity of distilled water respectively, Relative viscosity \( \eta_{rel} \) was calculated by the following equation.

\[ \eta_{rel} = \frac{t}{t_o} = \frac{\eta_s}{\eta_o} \]  

(2)

The specific viscosity \( \eta_{sp} \) and reduced viscosity \( \eta_{red} \) was calculated by the equations where \( C \) is the concentration:

\[ \eta_{sp} = \left( \frac{\eta_s - \eta_o}{\eta_o} \right) = \eta_{rel} - 1 \]  

(3)

\[ \eta_{red} = \frac{\eta_{sp}}{C} \]  

(4)

2.3 Ultrasonic measurements:

Ultrasonic measurements were made by pulse technique of sender-receiver type (SV-DH-7A/SVX-7 velocity of sound instrument) with different frequencies (25, 30,35,40,45 and 50 kHz) in our study the frequency fixed at (40 KHz), the receiver quartz crystal mounted on a digital vernier scale of slow motion, the receiver crystal could be displaced parallel to the sender and the samples were put between sender and receiver. The sender and receiver pulses (waves) were displaced as two traces of cathode ray oscilloscope, and the digital delay time \( t \) of receiver pulses were recorded with respect to the thickness of the samples \( x \). The pulses height on oscilloscope (CH1) represents incident ultrasonic wave’s amplitude \( A_0 \) and the pulses height on oscilloscope (CH2) represents the receiver ultrasonic wave’s amplitude \( A \).

2.4 Theoretical calculation:

The absorption coefficient \( \alpha \) was calculated from Lambert – Beer law (Zong fang et al. 2011):

\[ \frac{A}{A_0} = e^{-\alpha x} \]  

Where \( A_0 \) is the initially amplitude of the ultrasonic waves, \( A \) is the wave amplitude after absorption and \( x \) is the thickness of the sample, the transmittance \( T \) is the fraction of incident wave at a specified wavelength that passes through a sample was calculated from the following equation (Dipak 2001):

\[ T = \frac{I}{I_0} \]  

(6)

Where \( I_0 \) is the initially intensity of the ultrasonic waves and \( I \) is the received intensity. The ultrasonic wave velocity \( v \) was calculated using the following equation (Abdul-Kareem et al. 2011):

\[ v = \frac{x}{t} \]  

(7)

Where \( t \) is time that the waves need to cross the samples (digital obtained from the instrument).

Attenuation is generally proportional to the square of sound frequency so the relaxation amplitude \( D \) was calculated from the following equation (Josef and Herbert 1990) where \( f \) is the ultrasonic frequency:

\[ D = \frac{\alpha}{f^2} \]  

(8)

The acoustic impedance of a medium \( Z \), it was calculated by equation (Jarth 2008):

\[ Z = \rho v \]  

(9)

Bulk modulus \( B \) is the substance’s resistance to uniform compression, it is defined as the pressure increase needed to decrease the volume; it was calculated by Laplace equation (Al-Bermany E.2004):

\[ B = \rho v^2 \]  

(10)

Compressibility \( \beta \) is a measure of the relative volume change of a fluid or solid as a response to a pressure (or mean stress) change, it was calculated by the following equation (Hassina et al. 2009):

\[ \beta = \frac{(\rho v^2)^{-1}}{} \]  

(11)

The relaxation time \( \tau \) was calculated from the equation (Herbert 1985):

\[ \tau = \frac{4}{3} \frac{\eta_s}{3\rho v^2} \]  

(12)

3. Results and Discussion:
3.1 Rheological properties:
The density is increasing with the increase of polymer concentration as shown in (Fig.1) since the density defined as mass per unit volume and we adding different weight of polymer to fixed volume of solvent so there are linear increment for density. Shear Viscosity is increasing with concentration as shown in (Fig.2) this attributed to the mechanism that hydrogen bonding of water attached to oxygen sites, this leads to salvation sheaths and increase in the size of the molecules, so its viscosity (Subhi et. al. 1990) furthermore water act as plasticizer will reduce tensile strength and increase its chains (Al-Bermany 2010). Relative, specific and reduced viscosities showed in (Fig.3), (Fig.4) and (Fig.5) respectively posses the same behaviors of shear viscosity because they derived from it as shown in equations (2, 3), adding NH$_4$Cl made enhancement for these viscosities, this attributed that there are intermolecular interactions and network formation between the two types of molecules as a result of adding NH$_4$Cl so increasing the size of macromolecules that increasing shear viscosity (Kumagai et. al. 1978).

3.2 Mechanical properties:
(Fig.6) shows that absorption coefficient is increasing with concentration this attributed to the fact that when polymer concentration increase there will be more molecules in solution this lead to more attenuation against wave propagation, the attenuation can be attributed to the friction and heat exchange between the particles and the surrounding medium as well as to the decay of the acoustic wave in the forward direction due to scattering by the Particles (Tomasz et. al. 2010), this behavior same to that give by (Al-Bermany E. 2004) & Hassun and Rahman 1990) for other polymers, adding NH$_4$Cl enhances absorption coefficient by increasing its values. The transmittance is decreasing with increasing concentration as shown in (Fig.7) this attributed that the polymer molecules absorbed the sound waves according to Lambert-Beer Law which is biased on concentration (Ingle and Stanley 1988). Ultrasonic velocity is decreasing with increasing concentration as shown in (Fig.8) this because structural or volume relaxation it occurs in associated liquids such as polymers, a liquid when at rest has a lattice structure similar to that possessed by solid when waves are propagated through it, the resultant periodic changes of wave pressure causes molecules to flow into vacancies in the lattice during compression phase and to return to their original positions in the lattice during rarefaction so when concentration increases the velocity will be decrease, because there are more attenuation of polymer molecules to ultrasound waves (Al-Bermany K.J. 2010). Adding NH$_4$Cl reduces the velocity because of increasing network formation between polymer chains against the ultrasonic velocity waves. Ultrasonic relaxation time was calculated by using equation no. (12) Shown in (Fig.9) and the relaxation amplitude shown in (Fig.10) calculated from equation no.(8) their values are increasing with concentration, this behavior same to that give by (Hassun and Rahman 1990) & Al-Bermany 2009) for other polymers and attributed to the fact that ultrasonic energy depends on viscosity thermal conductivity, scattering and intermolecular processes so viscosity is responsible for the increase of relaxation amplitude for this reason absorption coefficient commonly known as visco –absorption. Specific acoustic impedance shown in (Fig.11) is decreasing with concentrations this behavior same to that given by (Al-Bermany 2009) & Subhi et. al. 1990) for other polymers and attributed to the equation no. (9) has only one variable parameter which is velocity and density has very small variations with respect to that of velocity. The compressibility is increasing with the increase of concentration (Fig.12) and attributed to the fact that in Laplace equation no. (10) there is inverse proportionality between compressibility and ultrasonic velocity and the bulk modulus is decreasing with concentration (Fig.13).

4. Conclusion
Adding NH$_4$Cl made enhancement for the viscosity, the viscosity is responsible for the increase of relaxation amplitude, this study shows that intermolecular processes are responsible for the relaxation, and indicating increase in the size of molecules in bath of ultrasonic waves then reducing the velocity. When concentration increases the velocity decreases there will be complexes molecules were formed in the solution by the effect of peroxide and roots that rebounded to formations between polymer chains when adding NH$_4$Cl. The polymer molecules absorbed the sound waves according to Lambert-Beer Law which is biased on concentration so reducing velocity and transmittance.

References


Zong fang Wu1 and Dong C. Liu (2011) “Method of improved scatterer size estimation without attenuation known a priori” *Bioinformatics and Biomedical Engineering (iCBBE), 4th International Conference*, *IEEE*, 8(10).1- 4.
Figure 1. Density due to concentration

Figure 2. Shear viscosity due to concentration

Figure 3. Relative viscosity due to concentration

Figure 4. Specific viscosity due to concentration

Figure 5. Reduced viscosity due to concentration

Figure 6. Absorption coefficient due to concentration
Figure 7. Transmittance due to concentration

Figure 8. Velocity due to concentration

Figure 9. Relaxation time due to concentration

Figure 10. Relaxation amplitude due to concentration

Figure 11. Acoustic impedance due to concentration

Figure 12. Compressibility due to concentration
Figure 13. Bulk modulus due to concentration