

Study the Rheological and Mechanical Properties of PVA/NH₄Cl 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 NH₄Cl 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 NH₄Cl 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-Bermamy 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 NH₄Cl 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 NH₄Cl for all concentrations using Ostwald viscometer with accuracy of $\pm 1.05\%$, the method of measurement has been described by (Al-Bermamy E.2004), elsewhere different types of shear viscosity were determined before and after the adding of NH₄Cl 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):

$$\frac{\eta_s}{\eta_o} = \frac{t \rho}{t_o \rho_o} \dots\dots\dots (1)$$

Where (ρ) and (η_s) are the solution density and viscosity respectively, (ρ_o) and (η_o) are density and viscosity of distilled water respectively, Relative viscosity (η_{rel}) was calculated by the following equation.

$$\eta_{rel} = \frac{t}{t_o} = \frac{\eta_s}{\eta_o} \dots\dots\dots (2)$$

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

$$\eta_{sp} = \frac{(\eta_s - \eta_o)}{\eta_o} = \eta_{rel} - 1 \dots\dots\dots (3)$$

$$\eta_{red} = \frac{\eta_{sp}}{C} \dots\dots\dots (4)$$

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 (α) was calculated from Lambert – Beer law (Zong fang *et. al.* 2011):

$$A/A_0 = e^{(-\alpha x)} \dots\dots (5)$$

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):

$$T = I / I_0 \dots\dots\dots (6)$$

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):

$$v = x / t \dots\dots (7)$$

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:

$$D = \alpha / f^2 \dots\dots\dots (8)$$

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

$$Z = \rho v \dots\dots\dots (9)$$

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):

$$B = \rho v^2 \dots\dots\dots (10)$$

Compressibility (β) 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):

$$\beta = (\rho v^2)^{-1} \dots\dots\dots (11)$$

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

$$\tau = 4 \eta_s / 3 \rho v^2 \dots\dots\dots (12)$$

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-Bermamy 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_4Cl 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_4Cl 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-Bermamy E. 2004) & Hassun and Rahman 1990) for other polymers, adding NH_4Cl 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-Bermamy K.J. 2010). Adding NH_4Cl 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-Bermamy 2009) for other polymers and attributed to the fact that ultrasonic energy depends on viscosity thermal conductivity, scattering and intermolecular processes, thermal conductivity and scattering effects are known to be negligible (Abdul-Kareem *et. al.* 2011 & Josef and Herbert 1990) 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-Bermamy 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 are inverse proportionality between compressibility and ultrasonic velocity and the bulk modulus is decreasing with concentration (Fig.13).

4. Conclusion

Adding NH_4Cl 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_4Cl .The polymer molecules absorbed the sound waves according to Lambert-Beer Law which is biased on concentration so reducing velocity and transmittance.

References

Abdul-Kareem J. Rashid and Burak Y. Kadem (2011) "Effect of variable ultrasonic frequencies on some physical properties of Iraqi palm fiber PVA composite" *Journal of Asian Scientific Research*, 1(7).359-365

Abdul-Kareem J. Rashid, Ehssan Dhiaa Jawad and Burak Y. Kadem (2011) "A Study of Some Mechanical Properties of Iraqi Palm Fiber-PVA Composite by Ultrasonic" *European Journal of Scientific Research*, 61 (2). 203-209.

Al-Bermamy K.J. (2009) "Enhancement mechanical and rheological properties and some its different industrial applications" *journal of college of education*, 4(3).380-384.

Al-Bermamy E.(2004) "Gamma radiation effect in some physical properties of polymer zanthan cellulose" *M.Sc. thesis*, Baghdad university, Iraq.

Al-Bermamy K.J.(2010) "Enhancement of mechanical properties using gamma radiation for HEC polymer" , *Journal of college of Education* ,Babylon university,1(5).10-15.

B. Boro Djordjevi (2009) "Ultrasonic characterization of advanced composite materials" the 10th *International Conference of the Slovenian Society for Non- Destructive Testing* (Application of Contemporary Non-Destructive Testing in Engineering), Ljubljana, Slovenia, 47-57.

D. Ingle, Jr. and Stanley R. Crouch (1988) "Spectrochimica Acta Part A: Molecular Spectroscopy" *Prentice Hall*, Englewood Cliffs, New Jersey, 44(11). 1229-1230

Dipak Basu (2001) *Dictionary of Material Science and High Energy Physics*, CRC Press, Chapter 26.

Fromageau, J., Brusseau, E., Vray, D., Gimenez, G. and Delachartre, P. (2003) "Characterization of PVA Cryogel for Intravascular Ultrasound Elasticity Imaging" *Transactions on Ultrasonic, Ferroelectrics and Frequency Control*, *IEEE* ,50(10). 1318 - 1324.

Hassun S.K. and Rahman,K.(1990), Ultrasonic Study of Molecular Association of High Impact Polystyrene Solutions in Toluene, *Iraqi Journal of Science*, 31(3),24 -30.

Herbert B. Callen (1985) "Thermodynamics and an Introduction to Thermo statistic", (2nd Ed.) New York: *John Wiley & Sons*. P.99.

Hassina Khelladi, Frédéric Plantier, Jean Luc Daridon and Hakim Djelouah, (2009) "Measurements under High Pressure of Ultrasonic Wave Velocity in Glycerol", *IEEE International Ultrasonic Symposium Proceedings*, ,1567-1570.

Josef and Herbert Krautkrämer (1990) "Ultrasonic testing of materials" 4th edition, *Springer*.

Jarth Mc-Hugh (2008). *a thesis PhD Bundesanstalt für Materialforschung und - prüfung (BAM)*, Germany.

Jayanta Chakraborty, Jayashri Sarkar, Ravi Kumar and Giridhar Madra (2004) "Ultrasonic Degradation of Polybutadiene and Isotactic Polypropylene", *Polymer Degradation and Stability*, Elsevier, 85(1), 555-558.

Khalida,H.H. (2004) "Study of Structural and Visco-Relaxation of Polycarbonates Solutions by Ultrasonic Technique, *Journal of Al-Qadisiya of Pure Sciences*, 9(3),188-122.

Kumagai, Naoichi; Sadao Sasajima and Hidebumi Ito (1978), *Journal of the Society of Materials Science* (Japan) (Japan Energy Society) 27 (293): 157–161.

Subhi K. Hassun, Kadhim H. Hussain and Najiba A. Hassan (1990), Visco- Relaxation Studies of Polystyrene Solutions in Different Solvents by Ultrasonic , *Acta Polymerica*, 41(8),438-441

Tomasz Hornowski, Arkadiusz Józefczak ,Andrzej Skumiel and Mikołaj Łabowski (2010)" Effect of Poly(Ethylene Glycol) Coating on the Acoustic Properties of Biocompatible Magnetic Fluid", *International Journal of Thermophysics.*, Springerlink, 31(1),70–76.

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.

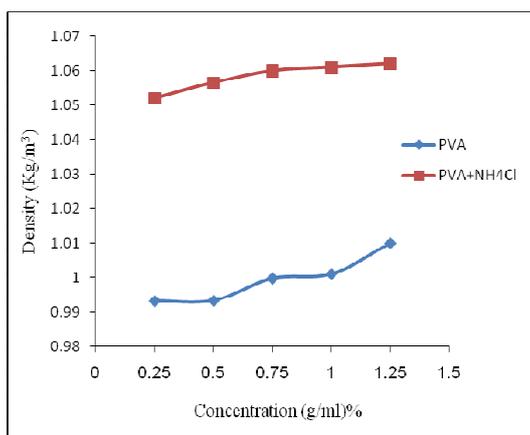


Figure 1. Density due to concentration

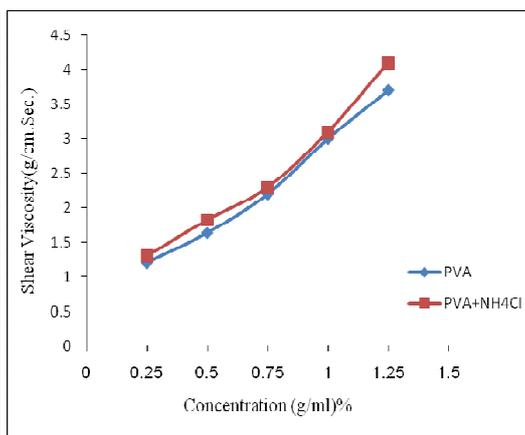


Figure 2. Shear viscosity due to concentration

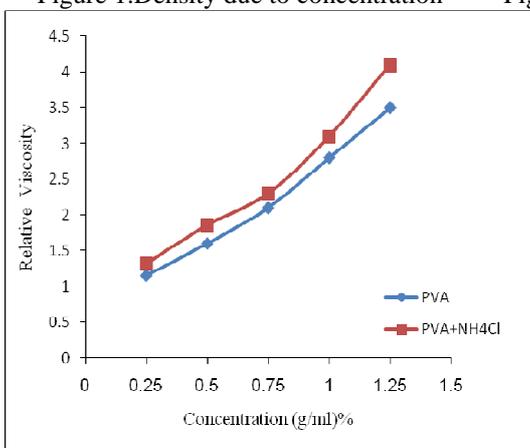


Figure 3. Relative viscosity due to concentration

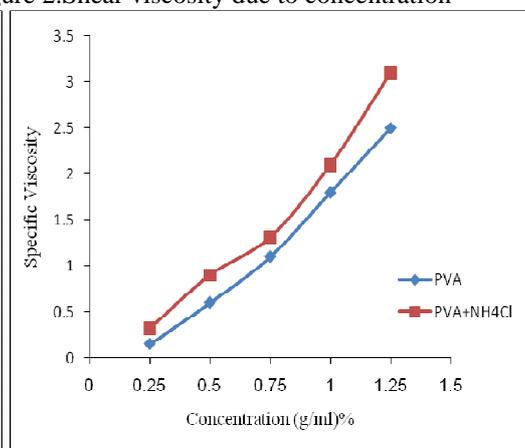


Figure 4. Specific viscosity due to concentration

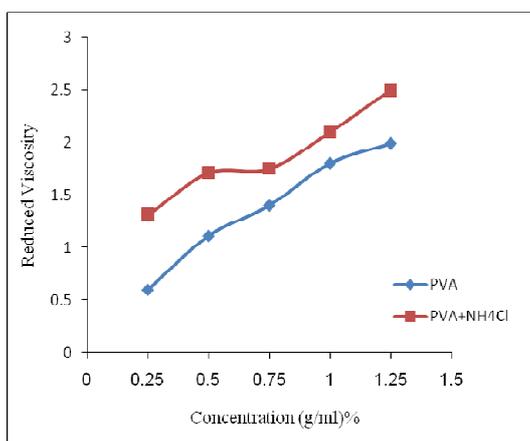


Figure 5. Reduce viscosity due to concentration

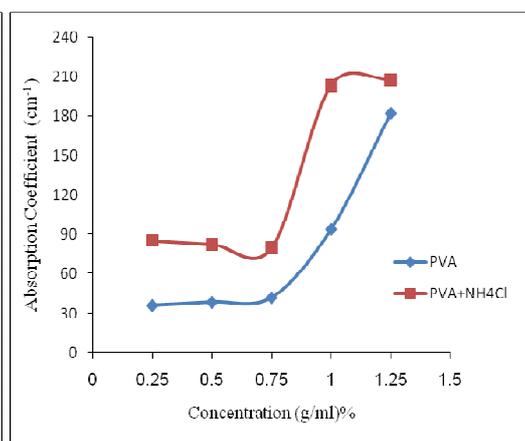


Figure 6. Absorption coefficient due to concentration

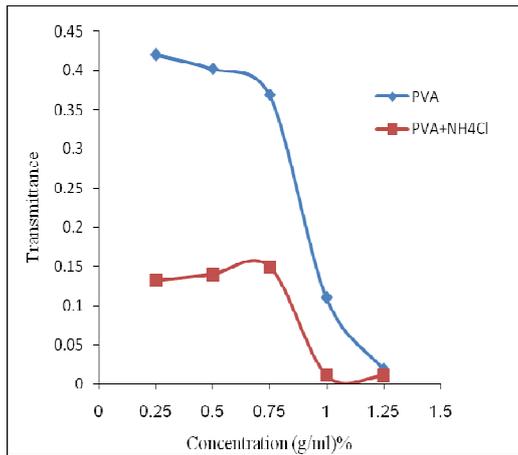


Figure 7. Transmittance due to concentration

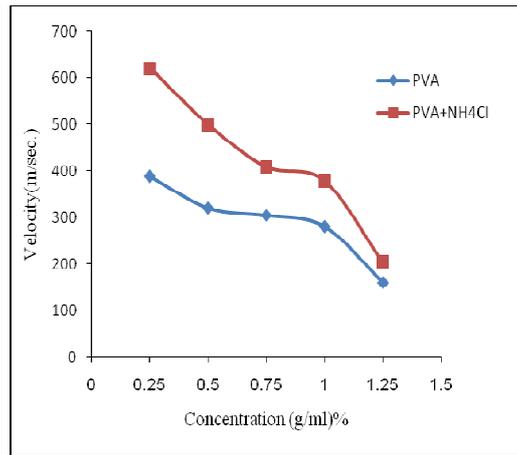


Figure 8. Velocity due to concentration

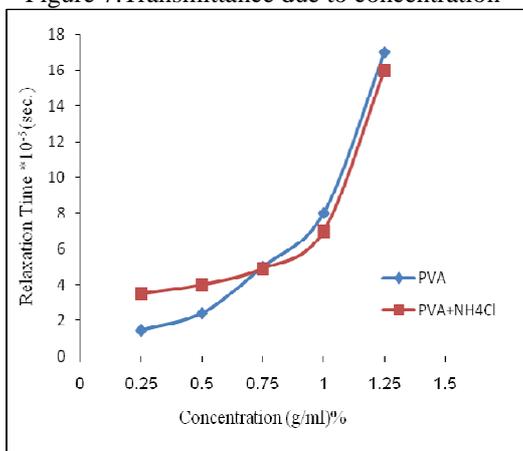


Figure 9. Relaxation time due to concentration

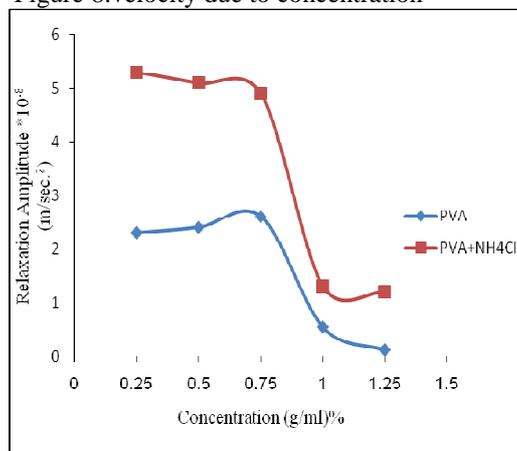


Figure 10. Relaxation amplitude due to concentration

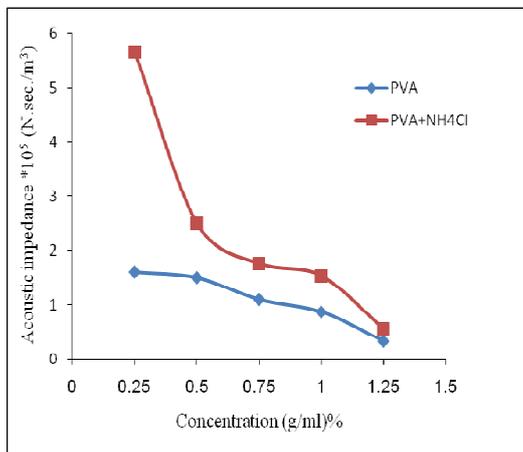


Figure 11. Acoustic impedance due to concentration

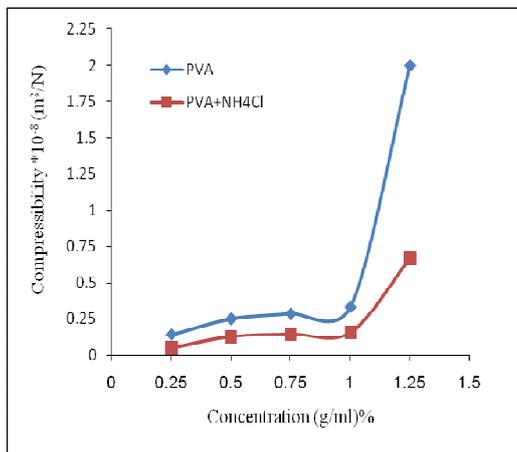


Figure 12. Compressibility due to concentration

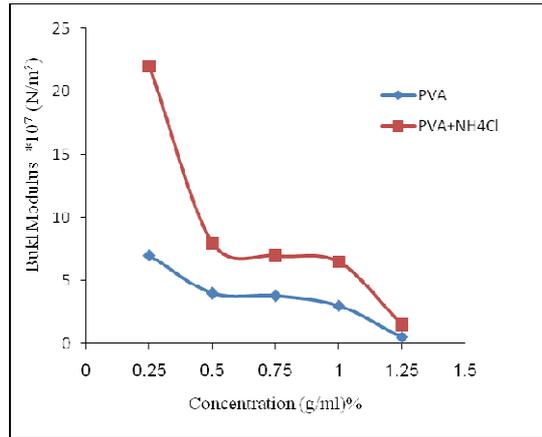


Figure 13. Bulk modulus due to concentration