Effect of Gamma Irradiation on Thermal Properties of Poly(Vinyl Alcohol) Solutions

INTRODUCTION

The present work represents an investigation of thermal properties (λ, a and ρ_c) of poly(vinyl alcohol) in aqueous media in the temperature range 20–90°C at various polymer concentrations (10^{-4}–10^{-1} mol/L) using the hot-wire technique.[1]

The determination of these parameters helps much in understanding the thermal of conduction mechanism in such material. However, the measurement of heat conduction in liquids is a tedious task and is much more complicated than in solids, because of the presence of convective and radiative heat transfer together with conduction process. In addition, the effect of γ-radiation of different doses (1.0 and 1.5 Mrad) on the behavior of thermal properties of PVA solutions was also studied.

EXPERIMENTAL

An apparatus for measurement of the thermal conductivity of electrically insulating liquids by the AC heated wire technique is described in detail by Atalla et al. (1981).[1] The experimental setup used in this investigation helps to suppress the convective part of heat transfer and can at least account for the radiative part.

The calculated systematic errors of the thermal conductivity measurements in this work was 1.5% in the case of a strip heater and 2% in the case of a wire heater.

RESULTS AND DISCUSSION

Thermal Conductivity (λ)

Figure 1 illustrates the thermal conductivity (λ) of poly(vinyl alcohol) (PVA) solutions with various concentrations for unirradiated polymeric solutions as well as irradiated (1.0 and 1.5 Mrad) as a function of temperature. As clear λ was observed to increase with temperature and decrease by increasing the concentration of PVA in the solution, the same effects were observed for irradiated PVA solutions. However, for the latter the values of λ are less and decrease with increasing the radiation dose. This effect could be due to the increase of the molecular weight of PVA upon irradiation since an apparent increase in the viscosity of PVA solutions was observed after radiation and hence the value of λ decreases. This result was previously confirmed by the equation reported by Berman[2]:

$$\lambda\eta = \text{const}$$

where η is the viscosity of the investigated solution. This means that the values of λ depend mainly on the molecular weight of the investigated material. Also, the decrease in the values of λ with increasing the concentration of PVA is related to the decrease of the mean free path of PVA chains.

The mechanism of heat transfer of liquids is complicated because of the presence of convective and radiative heat transport accompanying the conduction process. About the radiative heat transport, we are concerned only with the measurement of the amplitude of the temperature oscillations. The formula

$$\lambda_r = \frac{\frac{16}{3}\sigma n^2 T^3 L}{1 + \frac{3}{4}L^{\alpha}}$$

derived by Poltz[3] and Schatz[4] for the steady state parallel plate apparatus, can be used to estimate the radiative part of thermal conductivity coefficient, λ_r, where σ is the Stefan–Boltzman constant, n is the refractive index of the liquid, α is the absorption coefficient of the liquid, T is

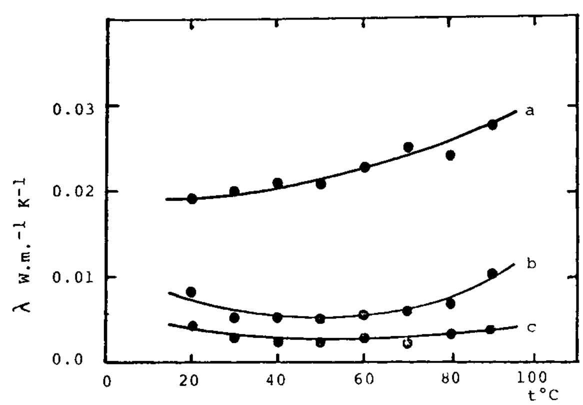

Figure 1 Variation of thermal conductivity of poly(vinyl alcohol) solution ([PVA] = 10^{-1} mol/L) with temperature at different doses: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

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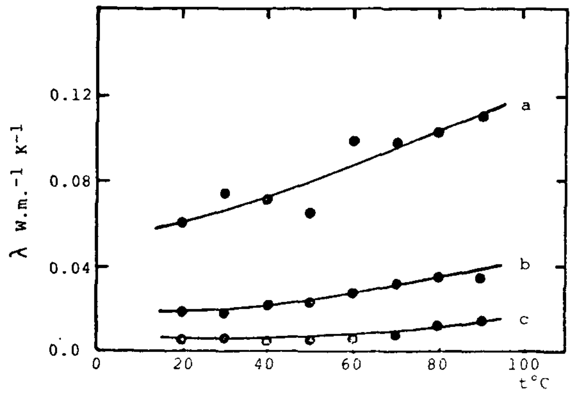

Figure 2 Variation of thermal conductivity of poly(vinyl alcohol) solution ([PVA] = 10^{-2} mol/L) with temperature at different doses: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

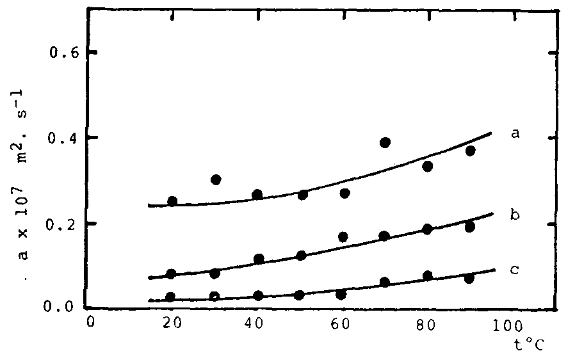

Figure 5 Variation of thermal diffusivity of poly(vinyl alcohol) solution ([PVA] = 10^{-2} mol/L) with temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

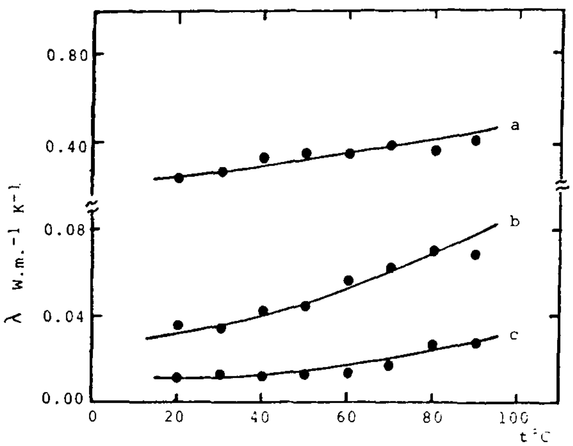

Figure 3 Variation of thermal conductivity of poly(vinyl alcohol) solution ([PVA] = 10^{-4} mol/L) with temperature at different doses: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

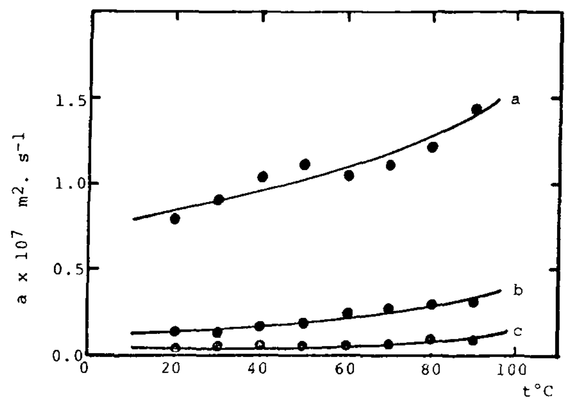

Figure 6 Variation of thermal diffusivity of poly(vinyl alcohol) solution ([PVA] = 10^{-4} mol/L) with temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

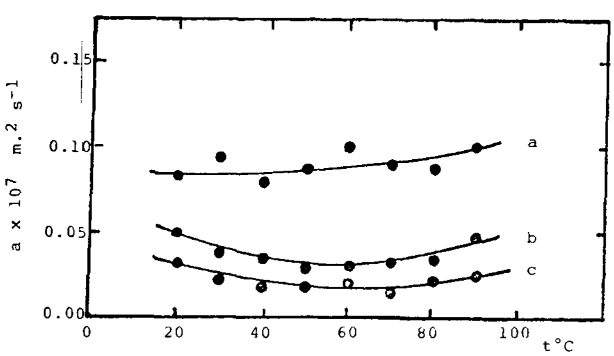

Figure 4 Variation of thermal diffusivity of poly(vinyl alcohol) solution ([PVA] = 10^{-1} mol/L) with temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

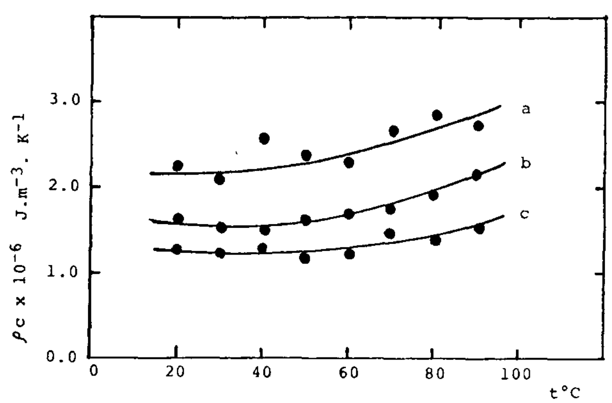

Figure 7 Dependence of volumetric heat capacity of poly(vinyl alcohol) solution ([PVA] = 10^{-1} mol/L) on temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

the mean temperature of the liquid, and L is the thickness of the effective layer around the sensor.

This formula can be used when the optical thickness, αL, of the investigated liquid is equal to or less a unity ($\alpha L \leq 1$), the condition which is fulfilled in our experiment. Therefore, we can conclude that the heat conduction mechanism of PVA in aqueous solution is due to conduction only, since the radiation part is negligible as mentioned.

Thermal Diffusivity (a)

The thermal diffusivity a of PVA solutions (unirradiated and irradiated) with temperature is illustrated in Figure 2. It was found that a increases as the temperature increases. Also it decreases as the radiation dose is increased.

Thermal diffusivity is related to the thermal conductivity by the relation

$$a = \lambda / \rho_c$$

From this relation we can conclude that the decrease of a is related to the decrease in λ. From the same figures it is clear that thermal diffusivity decreases by increasing the concentration of poly(vinyl alcohols).

Volumetric Heat Capacity (ρ_c)

The results of variation of heat capacity (ρ_c) with temperature of unirradiated and irradiated PVA are represented in Figure 3. We can see that ρ_c increases as the temperature increases while it decreases with increasing

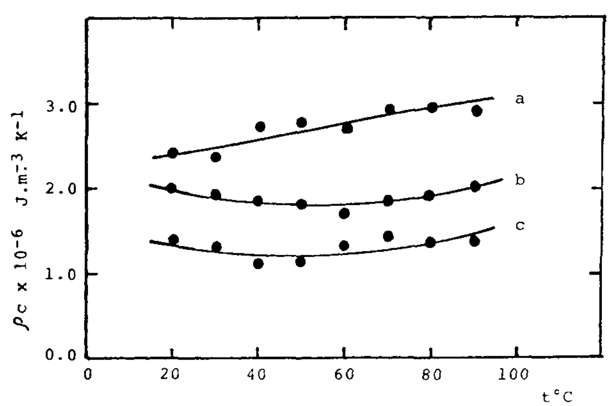

Figure 8 Dependence of volumetric heat capacity of poly(vinyl alcohol) solution ([PVA] = 10^{-2} mol/L) on temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

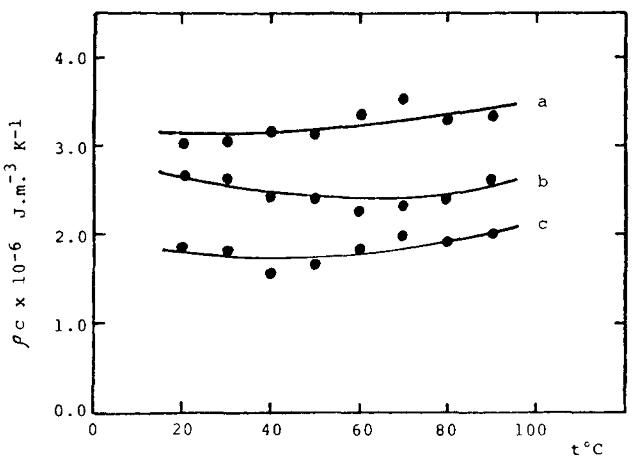

Figure 9 Dependence of volumetric heat capacity of poly(vinyl alcohol) solution ([PVA] = 10^{-4} mol/L) on temperature for: (a) unirradiated PVA solution; (b) irradiated PVA solution (1.0 Mrad); (c) irradiated PVA solution (1.5 Mrad).

the concentration of the PVA in the aqueous media. ρ_c values for irradiated samples are found to be less than that for unirradiated samples.

It could be concluded that the behavior of the thermal parameters, λ, a, and ρ_c, depends on the temperature as well as concentration of PVA in the solution. γ-Irradiation causes a decrease in such parameters which is due to increasing in molecular weight and hence the viscosity of the investigated material.

References

1. S. R. Atalla, A. A. El-Sharkawy, and F. A. Gasser, *Int. J. Thermophys.*, **2**(2), 155 (1981).
2. R. J. Berman, *J. Chem. Phys.*, **29**, 1278 (1958).
3. H. Poltz, *Int. Heat Mass Transfer*, **8**, 515 (1965).
4. J. Schatz and G. Simmons, *J. Appl. Phys.*, **43**, 178 (1972).

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