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Optical constants of polyacrylamide solution in the infrared between 20 and 70 °C

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ABSTRACT

The optical properties of polyacrylamide(PAM) solution play an important role in measuring PAM concentration of the solution in the polymer flooding of oilfield based on optical methods. Transmittance spectra of optical cell filled with PAM solution in the infrared wavenumber range from 400 to 4000 cm^{-1} at normal incidence were measured at the temperature range of 20–70 °C by an infrared spectrometer IRTracer-100. Then the optical constants of PAM solution were calculated by the transmission method combined with Kramers-Kronig(*K-K*) relation. The results show that the absorption index of PAM solution decreases with solution temperature increasing, and the values of absorption index of PAM solution are in the range of 1.56E-3–5.83E-3. The refractive index of PAM solution increases with the increase of temperature, and the values of refractive index of PAM solution are in the range of 1.32–1.38.

1. Introduction

With the increase of oil demand, the application range of polymer flooding technology has gradually expanded in most oilfield of China for increasing the oil production, however the amount of wastewater containing polymer increases gradually [1–5]. The toxicity of acrylamide is produced by the PAM hydrolysis, which poses a serious challenge to human beings and environment [6–8]. The optical properties of PAM solution are the basis of optical measurement of polymer wastewater [9,10], and optical measurement has attracted more attention due to its fast measurement speed and non-contact characteristics. Optical constants are the key parameters in determining the optical properties of PAM solution [11–14].

There are a lot of factors to affect the optical properties of PAM solution. For example the temperature of PAM solution is an essential factor to the optical properties of PAM solution. So far, many scholars have studied the spectral characteristics of liquids at different temperature [15–19], but there are few references of optical properties of PAM solution at different temperature to the author knowledge. Zelsmann [15] obtained the far infrared absorption spectra of pure water and heavy water at the temperature range of −5.6 to 81.4 °C by using FTIR interferometer, and calculated the optical constants at different temperatures by using *K-K* relation. Yi et al. [16] studied the fluorescence spectral characteristics of oily wastewater at the temperature range of 5–55 °C, and the research results show that temperature has influence on the fluorescence intensity of oily wastewater, but do not change the position of fluorescence peak. Li et al. [17] analyzed the optical properties

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of nine different edible oil samples in the wavelength range of 300–2500 nm between 20 and 80 °C. The authors claimed that the refractive index of different edible oils decreases with the increase of temperature, which confirms the linear relationship between the refractive index of edible oil and temperature, and the absorption index of edible oil decrease with the increase of temperature in the range from 500 to 1100 nm. Ai et al. [18] measured the total transmission ratio of the three-layer structure with the window-liquid-window based on the transmission method, and established a liquid hydrocarbon fuel radiation parameter inversion model combined with the *K-K* relation, and obtained the absorption index and the refractive index of the Chinese hydrocarbon liquid fuel in the near infrared band in the temperature range of 300–400 K, whose results show that the absorption index decreases with the increase of temperature, while the refractive index varies with temperature slightly.

In this work, the spectral properties of PAM solutions were experimentally studied, and the optical constants of PAM solutions at different temperature were obtained by the transmission method combined with *K-K* relation.

2. Experimental method

2.1. Model to determine the optical constants of PAM solution

The optical constants of the PAM solution can usually be represented by the absorption index (attenuation coefficient k) and refractive index (n). The *K-K* relation is a process that obtaining the refractive index n in the case when the absorption index k is known. The complex optical constants of PAM solution are defined by [15]

$$\hat{n}(\lambda) = n(\lambda) + ik(\lambda) \tag{1}$$

Where, $\hat{n}$ is the complex refraction index. λ is the wavelength. The real part of the complex refractive index is the usual refractive index n, and the imaginary part is the absorption index k.

Transmittance T and absorbance A of PAM solutions for a given sample thickness l are expressed as

$$T = \frac{I_0}{I_t} = \exp(-\alpha l) \tag{2a}$$

$$A = -\alpha l \log_{10}(e) \tag{2b}$$

Where, I_0 is the incident light intensity, I is the outgoing light intensity, α is the absorption coefficient of the PAM solution. The absorption index k can obtained from Eqs. (2a) and (2b) as

$$k(\lambda) = \frac{\alpha(\lambda)\lambda}{4\pi} \tag{3}$$

The real part $n(\lambda)$ is connected to the imaginary part $k(\lambda)$ by the principle of causality by the *K-K* relations, which is given by

$$n\left(\lambda'\right) - n_\infty = 2\int_0^{+\infty} X''\left(\delta\right)\cos\left(2\pi\lambda'\delta\right)d\delta \tag{4a}$$

$$X''\left(\delta\right) = 2\int_0^{+\infty} k\left(\lambda'\right)\sin\left(2\pi\lambda'\delta\right)d\lambda' \tag{4b}$$

$$k\left(\lambda'\right) = 2\int_0^{+\infty} X'\left(\delta\right)\sin\left(2\pi\lambda'\delta\right)d\delta \tag{4c}$$

$$X'\left(\delta\right) = 2\int_0^{+\infty} n\left(\lambda'\right)\cos\left(2\pi\lambda'\delta\right)d\lambda' \tag{4d}$$

Where, $\hat{X}\left(\delta\right) = X'\left(\delta\right) + iX''\left(\delta\right)$ is the generalized response function.

The total transmittance T_{1+2+3} of optical cell filled with PAM solution at normal incidence is as [20]

$$T_{1+2+3} = \frac{{T_g}^2 T_l}{1 - R_g - R_g R_l + {R_g}^2 R_l + R_g R_l {T_l}^2} \tag{5}$$

Where, R_g and R_l are the reflectance of glass slab and PAM solution at normal incidence, respectively. ρ_g and ρ_l are the interface reflectance for surface between air and glass, and for surface between PAM solution and glass, respectively. k_g and k_l are the extinction coefficients of glass and PAM solution, respectively. l and L are the thickness of glass slab and PAM solution, respectively. λ is the wavelength.