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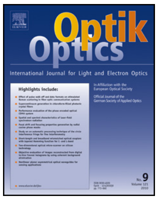

Full length article

Optical properties of paraffin at temperature range from 40 to 80 °C

Da Zhao[a], Guojun Zhang[b], Xinyan Zhang[a,*], Dong Li[b]

[a] *College of Science, Heilongjiang Bayi Agricultural University, Daqing 163319, China*
[b] *School of Architecture and Civil Engineering, Northeast Petroleum University, Daqing 163318, China*

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ABSTRACT

The transmittance spectrum of paraffin at temperature range from 40 to 80 °C was experimentally measured by a TU-19 FTIR spectrometer, and the optical constants of paraffin in the wavelength 250–850 nm were obtained based on transmittance spectra modeling. The optical properties of paraffin were calculated. The results show that the spectral transmittance of liquid paraffin in the region of UV and visible bands is bigger compared with solid paraffin. The extinction coefficients of the solid paraffin are between 1×10^{-5} and 3×10^{-5}, and the refractive index of the solid paraffin decreases sharply with the wavelength increasing. Compared with solid paraffin, the extinction coefficients of liquid paraffin are smaller and the refractive index of liquid paraffin is mainly 1–1.4. And with the temperature increasing, the optical constants of liquid paraffin are different.

1. Introduction

The energy consumption of buildings is a key factor in the fossil fuel utilization, which is still increasing with the improvement of living standard [1–4]. Glass envelope occupies the biggest portion of the total energy consumption of enclosure structures. It is important to improve the thermal performance of glass envelope. To incorporate PCM in the glass envelope is viewed as an effective approach to increase the thermal mass of glass envelope and to improve the thermal performance of glass envelope. For example, double glazing unit filled with paraffin material aims to absorb part of the solar radiation for thermal energy storage [5–8], meanwhile to let visible radiation into the indoor environment for day lighting [9–11]. It is important to research solar energy transfer in this unit for development of the paraffin-filled glass envelope, while optical properties of paraffin are the basic optical parameters for analyzing the energy transfer [12,13].

Some researchers have paid attention to the optical properties of PCM [14–18]. Hee et al. [16] provided a comprehensive review of the impacts on glazed window for the energy and day lighting performances of building. Goia et al. [17] measured the spectral transmission, reflection and absorption coefficients of the glazing system with paraffin materials in the wavelength 400–2000 nm. However, there are few references about optical properties of paraffin. The recent studies of Goia et al. [17,18] and Gowreesunker et al. [19–22] contributed a lot to the fundamental aspect of optical properties of paraffin-filled double glazing units. Goia et al. [18] investigated the effect of PCM glazing sample thickness on the spectral and angular behavior, which utilized commercial spectrophotometer, a dedicated optical test bed and a large integrating sphere with a

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[*] Corresponding author.
E-mail address: hljzd@163.com (X. Zhang).

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diameter of 0.75 m. However, much researching work indicates that the effect of refractive indices of paraffin in solid and liquid states have big effect on the thermal performance of double glazing unit.

In the present work, the transmittances of paraffin-filled double glazing unit were experimentally measured, and the optical constants of paraffin in solid and liquid states were obtained in the wavelength 250–850 nm.

2. Experimental method

Spectrophotometric measurements at normal incidence were made using a U-19 FTIR spectrometer with a wavelength range from 250 to 850 nm. Light from the FTIR's internal light source was focused through an iris, collimated, and passed into a Michelson interferometer that caused each wavelength to be modulated. This modulated beam was then passed through glass slabs and focused onto a detector. The detector signal was analyzed by the manufacture's software, which uses Mertz phase correction and boxcar apodization without zero filling to provide spectrally resolved transmitted intensity. For each measurement, the transmittance is as a function of the transmitted and incident intensity as follows.

$$T = \frac{I}{I_0} \tag{1}$$

Where, I and I_0 are the incident (baseline) and transmitted intensities, respectively. The incident intensity was measured with the paraffin-filled glazing unit removed from the beam's path. The transmitted intensity was measured with the paraffin-filled glazing unit placed in the optical path.

The paraffin-filled glazing unit with three layers is used to test optical properties of paraffin. First and third layers of double glazing unit are glass, and second layer is paraffin in solid or liquid states. Transmittances of paraffin-filled double glazing unit with different thickness were measured. The transmittances T_1 and T_2 of the paraffin with the layer thickness L_1 and L_2 can be calculated by

$$L_1 = L_{\mathrm{PCM2}} - L_{\mathrm{PCM1}} \tag{2a}$$

$$L_2 = L_{\mathrm{PCM3}} - L_{\mathrm{PCM1}} \tag{2b}$$

$$T_1 = \frac{T_{\mathrm{gl-PCM2}}}{T_{\mathrm{gl-PCM1}}} \tag{3}$$

$$T_2 = \frac{T_{\mathrm{gl-PCM3}}}{T_{\mathrm{gl-PCM1}}} \tag{4}$$

Where, L_{PCM1}, L_{PCM2} and L_{PCM3} stand for different paraffin layer thicknesses, which should satisfy $L_{\mathrm{PCM1}} < L_{\mathrm{PCM2}} < L_{\mathrm{PCM3}}$. $T_{\text{gl-PCM1}}$, $T_{\text{gl-PCM2}}$ and $T_{\text{gl-PCM3}}$ stand for transmittance with L_{PCM1}, L_{PCM2} and L_{PCM3}, and $T_{\text{gl-PCM1}} > T_{\text{gl-PCM2}}$, $T_{\text{gl-PCM1}} > T_{\text{gl-PCM3}}$.

If the optical constants of paraffin are known, transmittances of paraffin with layer thickness L_1 and L_2 can also be calculated by

$$T_1 = \frac{(1-\rho_l)^2 \exp(\frac{-4\pi k_l L_1}{\lambda})}{1-\rho_l{}^2 \exp(\frac{-8\pi k_l L_1}{\lambda})} \tag{5}$$

$$T_2 = \frac{(1-\rho_l)^2 \exp(\frac{-4\pi k_l L_2}{\lambda})}{1-\rho_l{}^2 \exp(\frac{-8\pi k_l L_2}{\lambda})} \tag{6}$$

The interface reflectance ρ_l is calculated based on Fresnel's relations.

$$\rho_l = \frac{(n_l-1)^2 + k_l{}^2}{(n_l+1)^2 + k_l{}^2} \tag{7}$$

When T_1 and T_2 are obtained by Eqs. (3) and (4), the absorption index k_l can be calculated by combination of Eqs. (5) and (6),

$$k_l = \frac{\lambda}{4\pi L_2} \ln\left[(1+\sqrt{1+4c^2\rho_l{}^2})/(2m)\right] \tag{8}$$

where $m = \frac{T_2}{(1-\rho_l)^2}$.

From Eqs. (5)–(7), the interface reflectance ρ_l and the refractive index n_l can be calculated by

$$\rho_l = \frac{1-\sqrt{T_1{}^2 + T_1\left[\exp(4\pi k_l L_1/\lambda) - \exp(-4\pi k_l L_1/\lambda)\right]}}{1+T_1\exp(-4\pi k_l L_1/\lambda)} \tag{9}$$

$$n_l = \frac{(1+\rho_l) + \sqrt{(1+\rho_l)^2 - (1-\rho_l)^2(1+k_l{}^2)}}{1-\rho_l} \tag{10}$$