Spectral properties of diesel fuel droplets[☆]

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Abstract

Absorption spectra of several types of diesel fuel are studied experimentally. Index of refraction of these fuels is calculated using subtractive Kramers–Krönig analysis. The ageing process of fuels is simulated by prolonged boiling. Radiative properties of diesel fuel droplets are calculated using the Mie theory and a simplified approach, based on approximations of absorption and scattering efficiency factors. It is pointed out that the accuracy of the simplified approach is sufficient for practical applications in the visible and infrared ranges, for various types of diesel fuel, and for droplet radii in the range from 5 to 50 μm. The monodisperse approximation is shown to be applicable for the analysis of infrared radiative properties of realistic polydisperse diesel fuel sprays. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The importance of absorption and scattering of thermal radiation by fuel droplets in diesel engines has been widely discussed in the literature [1,2]. Absorption of thermal radiation by droplets leads to their heating, evaporation and affects the autoignition of fuel vapour [3–5]. These processes are controlled by a number of parameters, including gas temperature, soot concentration and infrared radiative properties of fuel droplets. Experimental studies and computer simulations of temperature and soot concentration distribution in combustion chambers have been reported in many papers [6–8]. On the other hand, much less attention has been focused on the study of infrared properties of diesel fuels. Friedman and Churchill [9] were one of the first to report the results of calculation of the JP-4 fuel droplet absorption coefficient from the transmission data using the Bouguer–Beer law. Tuntomo et al. [10] presented the results of measurements of indices of absorption and refraction of heptane and decane in the wavelength range from 2.6 to 15 μm. Kelly et al. [11] reported the results of measurements of absorbance of *n*-

heptane, benzene, isooctane, and a number of samples of unleaded petrol in the range 0.66–1.215 μm. Thermophysical and chemical properties of some of these fuels (heptane, decane) are close to those of diesel fuels. For example, the results of experiments with *n*-heptane have been widely used in studies of autoignition in diesel engines [12,13]. At the same time, comparison of the absorption spectrum of a realistic diesel fuel measured in Ref. [3] and that of heptane and decane reported in Ref. [10] shows that the former can differ substantially from the latter two, presumably due to the contribution of various additives. Spectra of heptane and decane, on the other hand, are rather similar.

In Ref. [3], the results of the measurements of the index of absorption of a diesel fuel were used for the development of a simplified model for the thermal radiation absorption by semi-transparent diesel fuel droplets. This model was shown to be more accurate than the models based on approximation of opaque droplets [14–17]. Recently, in Ref. [18], it was shown that for droplets, the grey medium approach, used in Ref. [3] can lead to noticeable errors both in estimated absorption and scattering of thermal radiation, emitted in a non-isothermal enclosure, and in the integral thermal radiation flux to combustion chamber walls. The errors introduced by the grey approximation are related to the fact that fuel droplets absorb and scatter thermal radiation from

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the high temperature regions of the engine, and the spectrum of the incident radiation turns out to be considerably different from the blackbody one at local temperature.

Considerably better results were obtained in Refs. [18, 19], based on the so called 'box' model [20] with constant absorption and scattering coefficients in several wide spectral bands. The calculations in Refs. [18,19] were performed using the Mie theory [21,24] and, alternatively, using simple analytical expressions for the absorption and transport scattering efficiency factors. The latter approach led to considerable simplification of calculations of radiative characteristics of droplets, with acceptable loss in accuracy. Moreover, it was shown that calculations of polydisperse sprays can be reliably performed using a monodisperse approximation with droplet radii equal to an average radius of droplets in a polydisperse spray [18,19].

In this paper, a further analysis of spectral properties of diesel fuel droplets is performed. The main approximations of the calculation procedure suggested in Ref. [18] are investigated using data for several diesel fuels. Spectral index of absorption is measured for four samples of diesel fuels, including two samples for which the 'ageing' process of fuels was simulated by prolonged boiling. The spectral index of refraction is determined from the subtractive Kramers–Krönig analysis. The values of the indices of absorption and refraction are used in wide range calculations of absorption and scattering of radiation by fuel droplets. The results can be applied to various problems including heating of droplets, attenuation of radiation by droplets and sprays, and optical diagnostics of sprays [22].

In Section 2, the results of measurements and calculations of indices of absorption and refraction are presented. Basic equations and approximations used in the calculations of absorption and extinction coefficients are discussed in Section 3. Results of the calculations are reported in Section 4. The main results of the paper are summarized in Section 5.

2. Optical constants

The index of absorption of diesel fuels was measured in the ranges $0.2–1.1$ and $2–10$ μm. Ultraviolet–near-infrared spectra $(0.2–1.1$ μm) were obtained using UV–visible spectrophotometer Shimadzu, model 1601. The spectra were recorded versus n-hexane as a background. Infrared spectra $(2–10$ μm) were obtained using Fourier Transform Infrared (FTIR) spectrometer Perkin Elmer 1720-X, at 4 cm^{-1} resolution, four scans, in a NaCl cell with 0.011 mm optical path. The error of measurements of absorbance was about 5% across the whole range of wavelengths. The lower threshold for measurements in this spectral range is higher when compared with the measurements reported in Ref. [3] where it was 1.39 μm. The measurements using conventional UV–vis and IR spectrophotometers in the range $1.39–2$ μm are less reliable than those for longer wavelengths and they have not been performed. The absorption in

the range $1.1–2.0$ μm is expected to be small (most substances do not absorb in the near infrared range). Nevertheless, the data in this range would have been important for applications as the intensity of radiation in this range of wavelengths is maximal for the range of temperatures $1500 < T < 3000$ K. This range plays an important role in the thermal radiation transfer in diesel engines [25]. In the absence of these data, the linear interpolation of the values of the index of absorption in this range has been used.

Diesel fuels have relatively high absorption below 0.4 μm, exceeding the measuring limit of the instrument. In this range, the spectrum was recorded in a 1 cm quartz cell for samples diluted with n-hexane. The latter is transparent in the studied range of wavelengths. In the ranges of $3.33–3.53$ and $6.76–6.94$ μm, where absorption of the samples exceeded the instrument measuring limit, the spectra were recorded for samples diluted with chloroform and correction for dilution was made. All measurements have been carried out at room temperature.

Assuming the validity of the Bouguer–Beer law, the absorption coefficient k_λ was calculated from the measured absorbance A_λ [24]. Then the index of absorption was calculated as $\kappa = k_\lambda \lambda/(4\pi)$.

The index of refraction of diesel fuel can be calculated by using the Kramers–Krönig relation [23,24]:

$$n(\lambda) = 1 + \frac{2\lambda^2}{\pi} \int_0^\infty \frac{\kappa(\lambda')\mathrm{d}\lambda'}{\lambda'(\lambda^2 - \lambda'^2)}. \qquad (1)$$

For practical calculations it is more convenient to use the so called subtractive Kramers–Krönig analysis [26]. This analysis is based on the calculation of the difference between $n(\lambda)$ and the measured value of refractive index at a certain wavelength λ_1:

$$n(\lambda) - n(\lambda_1) = \frac{2(\lambda_1^2 - \lambda^2)}{\pi} \int_0^\infty \frac{\lambda'\kappa(\lambda')\mathrm{d}\lambda'}{(\lambda^2 - \lambda'^2)(\lambda_1^2 - \lambda'^2)}, \qquad (2)$$

Eq. (2) is less sensitive to the limitation of the range of integration when compared with Eq. (1) [26]. For numerical integration in a limited spectral range Eq. (2) has been rearranged to

$$n(\lambda) = n(\lambda_1) + \frac{2(\lambda_1^2 - \lambda^2)}{\pi} \left[\int_{\lambda_{\min}}^{\lambda_1 - \delta} f(\lambda, \lambda')\mathrm{d}\lambda' \right.$$
$$\left. + \int_{\lambda_1 + \delta}^{\lambda - \delta} f(\lambda, \lambda')\mathrm{d}\lambda' + \int_{\lambda + \delta}^{\lambda_{\max}} f(\lambda, \lambda')\mathrm{d}\lambda' \right] + \mathrm{O}(\delta), \qquad (3)$$

where

$$f(\lambda, \lambda') = \frac{\lambda'\kappa(\lambda')}{(\lambda^2 - \lambda'^2)(\lambda_1^2 - \lambda'^2)},$$

δ is a small parameter, the choice of $\lambda_{\min}$ and $\lambda_{\max}$ is determined by the location of the main absorption bands in the spectrum. Our calculations are based on Eq. (3) with $\lambda_{\min} = 0.2$ μm and $\lambda_{\max} = 10$ μm.

The measurements have been performed for diesel fuel used in cars (yellow) and diesel fuel used in off road equipment in which dye has been added for legislative purposes (pink). Similar measurements have been repeated for these diesel fuels after they have undergone a simulation of ageing process by prolonged (6 h) boiling. Density of the yellow fuel has been experimentally determined as 816 kg/m^3 and the boiling point in the range of 458–468 K, whereas density of the pink fuel is 827 kg/m^3 and boiling point in the range of 468–478 K.

Results of the measurements of the index of absorption for several fuels in the infrared spectral range are shown in Fig. 1. The fuels shown are: diesel fuel analysed in our previous paper [3], 'yellow' and 'pink' diesel fuels, described above, and heptane and decane, studied in Ref. [10]. Note that Fig. 4 in Ref. [3] refers to k_λ and not to κ as indicated in text of the paper (all calculations were based on the correct values of κ). The fuel used in Ref. [3] was with dye, but taken from a different supplier.

As can be seen in Fig. 1, the dependence of the index of absorption κ on the type of diesel fuel is noticeable, especially in the range of semi-transparency $4 < \lambda < 6$ μm. Peaks of absorption for all types of diesel fuel practically coincide. At the same time, the indices of absorption of heptane and decane are less than those of diesel fuels in the whole spectral range under consideration.

Results of the measurements of the index of absorption for fuels in the ultraviolet–near-infrared spectral range are shown in Fig. 2. The fuels are the same as in Fig. 1 except that we do not have results of measurements of decane, and heptane is replaced by n-heptane [11]. As can be seen in this figure, the difference between indices of absorption of diesel fuels in this spectral range is more pronounced when compared with the range shown in Fig. 1. In particular, the diesel fuel studied in Ref. [3] has the peak of the index of absorption about an order of magnitude less than yellow and pink diesel fuels. The indices of absorption for n-heptane and diesel fuels differ by not more than an order of magnitude. Note, however, that the measurements for
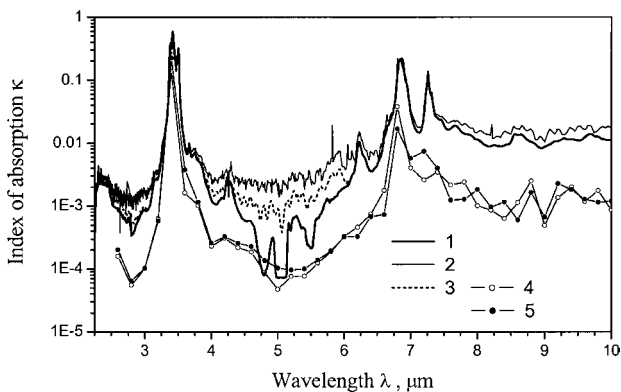

Fig. 2. Spectral distribution of the index of absorption κ in the ultraviolet–near-infrared range: diesel fuel investigated in Ref. [3] (1); yellow diesel fuel unboiled (2); pink diesel fuel unboiled (3); n-heptane [11] (4).

n-heptane are not available in the range where the peak in absorption of diesel fuels is observed. In the whole, the absorption of fuels in the ultraviolet–near-infrared spectral range is much weaker than in the infrared range shown in Fig. 1.

The influence of the ageing process (boiling) on the spectral distribution of the index of absorption is demonstrated in Fig. 3. As can be seen in this figure, the influence

Fig. 3. The influence of the ageing process on the spectral distribution of the index of absorption κ in the ultraviolet–near-infrared (a) and infrared (b) ranges: yellow diesel fuel unboiled (1); yellow diesel fuel boiled (2); pink diesel fuel unboiled (3); pink diesel fuel boiled (4).

Fig. 1. Spectral distribution of the index of absorption κ in the infrared range: diesel fuel investigated in Ref. [3] (1); yellow diesel fuel unboiled (2); pink diesel fuel unboiled (3); heptane [10] (4); decane [10] (5).
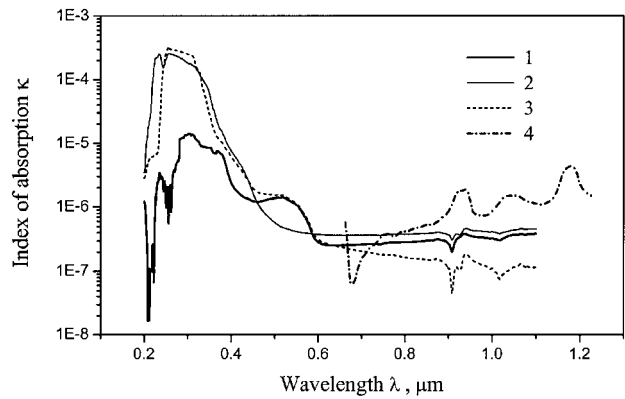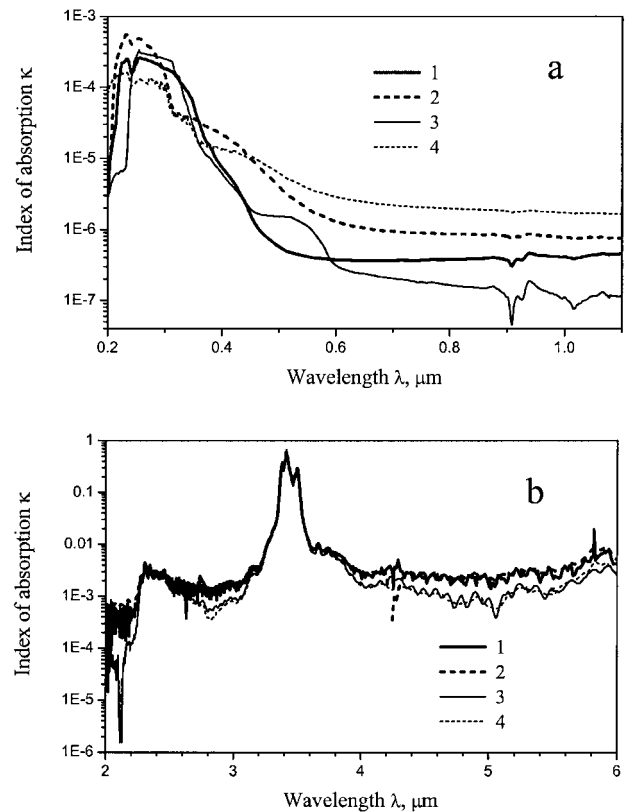
of boiling on the index of absorption in the infrared range is relatively small (compared with the difference between diesel fuel used in Ref. [3] and yellow and pink diesel fuels). At the same time, the absorption of the boiled fuels in the ultraviolet–near-infrared spectral range is noticeably larger than that of the unboiled fuels.

The values of $n(\lambda_1)$ required for calculations based on Eq. (3) were measured at the triple blue mercury line ($\lambda_1 = 0.4358\ \mu m$) for all four types of fuels. Refractive index of the samples was obtained at room temperature using a Hilger Watts Abbe Refractometer. In this apparatus, the refractive index is measured by turning a dual prism combination through an angle, which is proportional to the refractive index of a liquid placed between the two prisms. The emergent angle of light from the combination of prisms is measured using a telescope that moves over a calibrated refractive index scale. The telescope is focussed on the edge of the light beam, which shows up as a dark edge in the field of view. The values found for the samples were: $n(\lambda_1) = 1.459 \pm 0.001$ (yellow diesel fuel unboiled); $n(\lambda_1) = 1.461 \pm 0.001$ (pink diesel fuel unboiled); $n(\lambda_1) = 1.462 \pm 0.001$ (yellow diesel fuel boiled); $n(\lambda_1) = 1.461 \pm 0.001$ (pink diesel fuel boiled). For our calculations it will be assumed that $n(\lambda_1) = 1.46$ for all four types of fuel. These values are close to the values used in Ref. [27] at $\lambda \approx 0.5\ \mu m$. They are expected to decrease with temperature (n for diesel oil dropped from 1.45 to 1.43 when temperature increased from 293 to 423 K [28]; the wavelength of measurement was not specified by the authors of Ref. [28] but it looks as if they referred to the visible range). These effects will not be accounted for.

Results of calculations of the spectral distribution of the index of refraction of the diesel fuel investigated in Ref. [3] are shown in Fig. 4. The values of $n = 1.46$ at $\lambda_1 = 0.4358\ \mu m$ have been used. As expected, the frequency dependence of n is particularly strong in the vicinity of the absorption peaks at $\lambda = 3.5$ and $6.8\ \mu m$. Since the extinction and, especially, absorption of thermal radiation
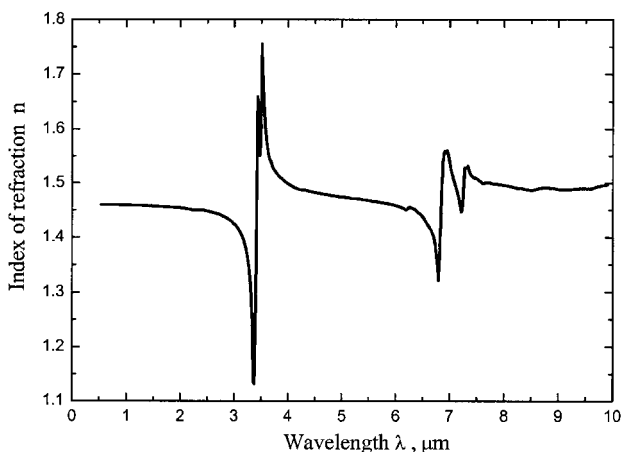

Fig. 4. Spectral distribution of the index of refraction n of the diesel fuel investigated in Ref. [3].

by droplets are weak functions of n, the calculations for all fuels will be based on the plot shown in Fig. 4.

3. Absorption and extinction coefficients

Calculations of thermal radiation transfer, using the transport approximation, are based on spectral absorption coefficient a_λ and spectral transport extinction coefficient e_λ^{tr} [21,31]. The relation between them and the absorption and transport extinction efficiency factors of single spherical droplets (Q_a and Q_{tr}) can be presented as (cf. Ref. [21])

$$\{a_\lambda, e_\lambda^{tr}\} = 0.75 f_v \frac{\{\bar{Q}_a, \bar{Q}_{tr}\}}{r_{32}}, \tag{4}$$

where

$$\{\bar{Q}_a, \bar{Q}_{tr}\} = \frac{1}{r_{20}} \int_0^\infty \{Q_a, Q_{tr}\} r^2 F(r) dr,$$

$$r_{ij} = \int_0^\infty r^i F(r) dr / \int_0^\infty r^j F(r) dr, \tag{5}$$

r is the droplet radii, $F(r)$ is the normalised distribution function of droplets by radii ($\int_0^\infty F(r) dr = 1$), f_v is the volume fraction of droplets. In the case of monodisperse spray Eq. (4) can be used without bars over Q_a and Q_{tr}.

Absorption and scattering of thermal radiation by droplets can be calculated using the Mie theory. According to this theory, Q_a and Q_{tr} depend on droplet diffraction (size) parameter $x = 2\pi r/\lambda$ and complex index of refraction of the fuel $m = n - i\kappa$ [21,24]. These calculations are rather complicated, especially for large droplets ($x \gg 1$). This stimulated attempts to develop simplified models specifically focused on the range of parameters typical for diesel fuel droplets [3,18]. The following approximations for Q_a and the transport efficiency factor of scattering $Q_s^{tr} = Q_{tr} - Q_a$ have been suggested [18]

$$Q_a = \frac{4n}{(n+1)^2} [1 - \exp(-4\kappa x)], \tag{6}$$

$$Q_s^{tr} = \begin{cases} C\zeta & \text{when } \zeta \le 1, \\ C/\zeta^\gamma & \text{when } \zeta > 1 \end{cases}, \tag{7}$$

where

$$C = 1.5 n(n-1) \exp(-15\kappa), \qquad \gamma = 1.4 - \exp(-80\kappa),$$

$$\zeta = 0.4(n-1)x.$$

These equations give slightly better approximations for Q_a and Q_s^{tr} when compared with those used in Ref. [3]. Eq. (6) is valid in the geometrical optics limit ($x \gg 1$) and small index of absorption ($\kappa \ll 1$). It has been shown, however, that it can be applicable even in the case when these conditions are not satisfied. Approximation (7) have been obtained from curve fitting of the corresponding Mie calculations. Simplicity of Eqs. (6) and (7) is expected to

lead to considerable simplification of the analysis of sprays based on Eqs. (4) and (5).

Note that the radiation power absorbed by a single droplet can be calculated as

$$P = \pi r^2 \int_0^\infty Q_a I_\lambda^0 \, d\lambda, \tag{8}$$

where

$$I_\lambda^0 = \int I_\lambda \, d\Omega$$

is the local spectral energy density of thermal radiation, I_λ is the radiation intensity at a given point, $d\Omega$ is the solid angle near the direction Ω.

Approximation (6) can be poor for large κ. This equation predicts that Q_a is always less than 1, while Mie theory predicts that $Q_a > 1$ for some combinations of parameters [21,24]. It will be demonstrated, however, that the spectral range when this approximation is poor is narrow. Hence, this equation is not expected to lead to substantial errors in the calculation of thermal radiation heat transfer.

The range of applicability of Eqs. (6) and (7) for modelling of absorption and scattering of thermal radiation by diesel fuel droplets is investigated in Section 4.

4. Results of calculations

Results of Mie calculations of the efficiency factor of absorption Q_a and transport efficiency factor of extinction Q_{tr} are shown in Fig. 5 for different types of fuel. These calculations have been performed using the algorithm described in Ref. [21]. As can be seen from Fig. 5(a), the dependence of both parameters Q_a and Q_{tr} on the type of fuel is relatively weak for $r = 10 \, \mu$m. The influence of the type of fuel on the values of Q_a and Q_{tr} becomes more noticeable for larger droplets with $r = 50 \, \mu$m, especially in the ranges of semi-transparency (Fig. 5(b)). It is expected that this difference in the values of Q_a and Q_{tr} will influence the integral characteristics of thermal radiation in diesel engine combustion chambers.

Results of Mie calculations and calculations based on approximate formulae (6) and (7) for single spherical droplets of various radii are shown in Fig. 6. As can be seen from this figure, the agreement between Mie calculations of Q_a and the calculations of Q_a based on Eq. (6) is reasonably good for all droplet radii over the whole spectrum. Noticeable difference between the values of Q_a is observed only in the vicinity of the absorption peak at $\lambda = 3.5 \, \mu$m. This difference is clearly seen for small droplets when Mie calculations predict the values of Q_a in the range 1.1–1.3. The approximation of Q_{tr} by Eq. (7) is also satisfactory except for large droplets in the visible range. At these wavelengths, the values of Q_{tr} predicted by Eq. (7) are smaller than those predicted by Mie calculations. The above-mentioned deviation of the predictions of Eqs. (6)
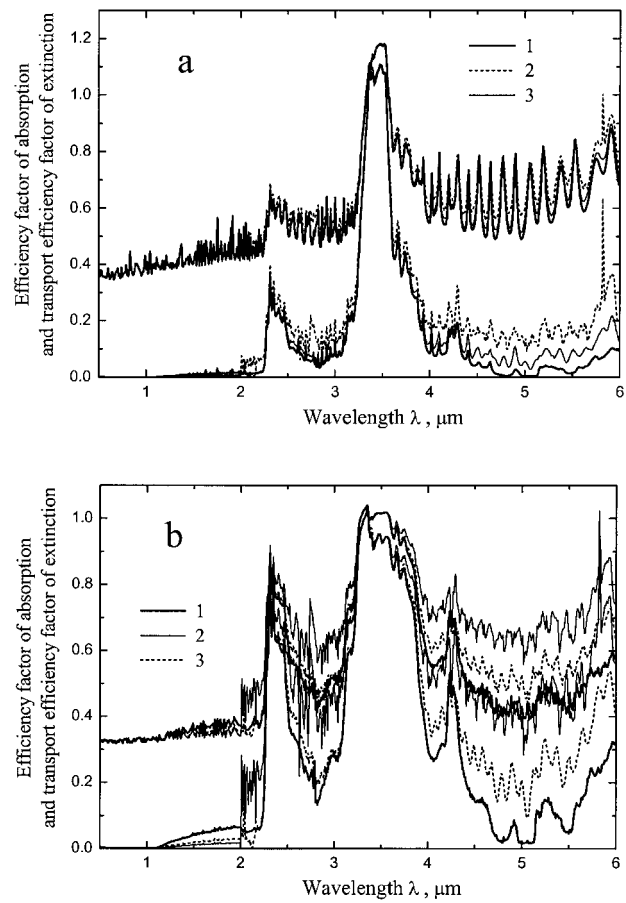

Fig. 5. Results of Mie calculations of the efficiency factor of absorption Q_a (lower curves) and transport efficiency factor of extinction Q_{tr} (upper curves) of individual spherical droplets with $r = 10 \, \mu$m (a) and $r = 50 \, \mu$m (b): diesel fuel investigated in Ref. [3] (1); yellow diesel fuel unboiled (2); pink diesel fuel unboiled (3).

and (7) from the Mie calculations are not expected to be important for practical applications. This justifies the application of these equations for calculation of the values of Q_a and Q_{tr}.

Comparing the values of Q_a and Q_{tr} shown in Figs. 5 and 6 one can see that radiation scattering is more dominant than absorption for most part of spectral range, except in relatively narrow absorption bands. This indicates the importance of taking into account the scattering of thermal radiation by fuel droplets in heat transfer calculations in diesel engines.

The scattering of thermal radiation by fuel droplets in diesel engines can lead to considerable reduction of the radiative flux to the cylinder head. The shielding effect of thermal radiation by scattering droplets is expected to be particularly important in the ranges of semi-transparency ($\lambda < 2 \, \mu$m, λ close to 2.8 and $5 \, \mu$m). As can be seen in Fig. 6, absorption of thermal radiation is negligibly small compared with scattering in these ranges. In this case the effect of shielding can be approximated as (cf. Equation
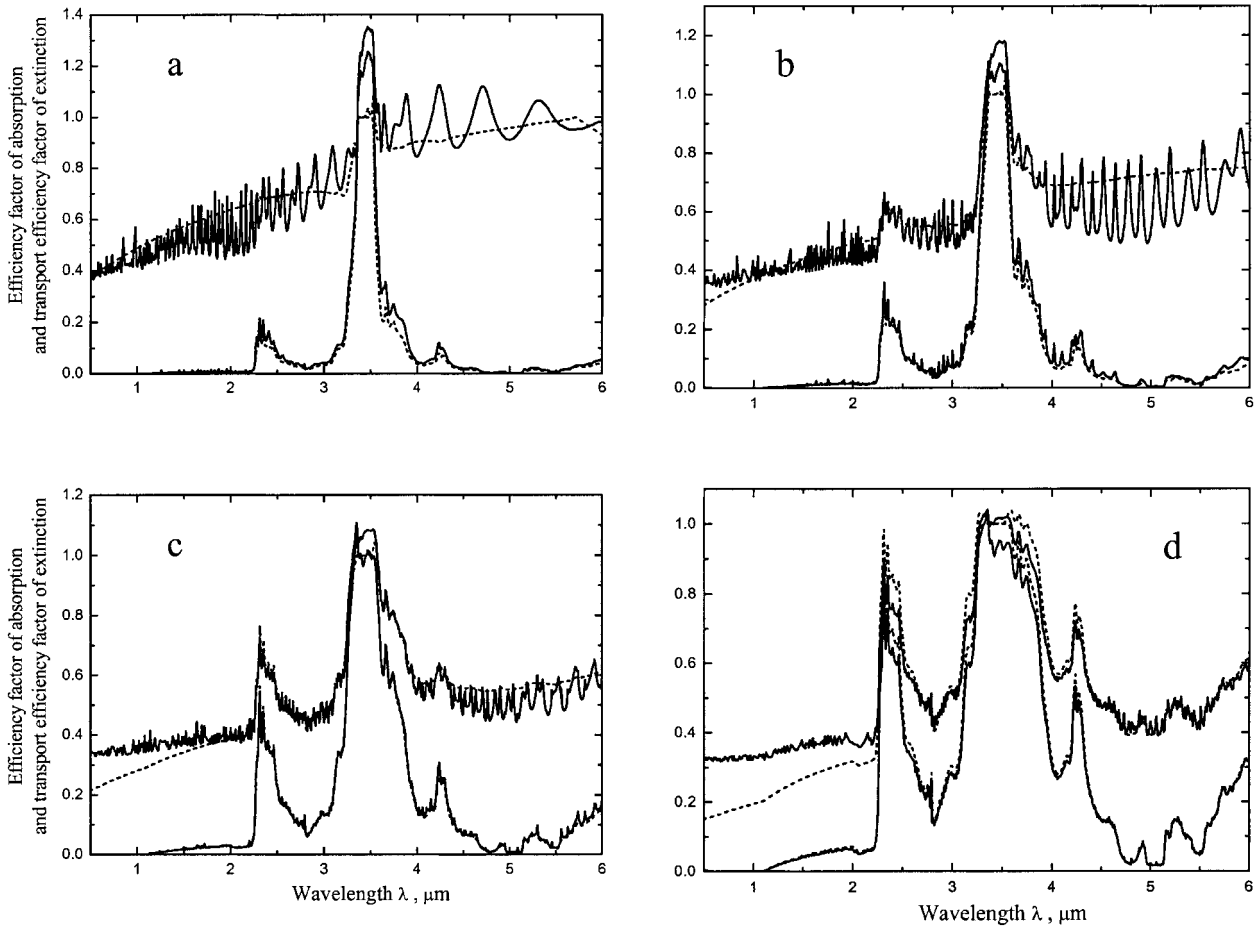
Fig. 6. Results of Mie calculations (solid curves) and calculations based on approximate formulae (6) and (7) (dashed curves) of the efficiency factor of absorption Q_a (lower curves) and transport efficiency factor of extinction Q_{tr} (upper curves) of individual spherical droplets with $r = 5$ μm (a), $r = 10$ μm (b), $r = 20$ μm (c) and $r = 50$ μm (d); all curves are calculated for diesel fuel investigated in Ref. [3].

(1.65) in Ref. [21])

$$q_\lambda = \frac{q_\lambda^0}{1 + 0.75\tau_\lambda}, \qquad (9)$$

where q_λ and q_λ^0 are spectral fluxes reaching the wall with and without taking into account the effect of scattering, $\tau_\lambda = e_\lambda^{tr}\Delta$ is the optical thickness of the droplet layer of geometrical thickness Δ. When deriving Eq. (9) it was assumed that the wall is cold and black, as is reasonable in modelling diesel engines.

In the case of monodisperse spray, the combination of Eqs. (4) and (9) gives:

$$\bar{q}_\lambda = \frac{q_\lambda}{q_\lambda^0} = \frac{1}{1 + 0.5625(Q_{tr}/r)f_v\Delta} \qquad (10)$$

Taking $r = 10$ μm, $f_v = 0.002$, $\Delta = 10$ mm, and $Q_{tr} = 0.4$ (Fig. 6(b)) we obtain $\bar{q}_\lambda = 0.69$. This means that ignoring the effect of scattering would lead to overestimation of q_λ by more than 30%.

To investigate the effects of polydisperse spray on the average values of Q_a and Q_{tr} ($\bar{Q}_a$ and $\bar{Q}_{tr}$) the Gamma distribution for $F(r)$ has been taken [18]

$$F(r) = \frac{A^{B+1}}{\Gamma(B+1)}r^B \exp(-Ar), \qquad (11)$$

where B was assumed equal to 2 in our calculations.

Eq. (11) seems to be an adequate approximation of the actually observed distribution of droplets by radii [28–30].

Plots of $\bar{Q}_a$ and $\bar{Q}_{tr}$ for $A = 0.25$ and 0.5 μm^{-1} are shown in Fig. 7. In the same figure, the results of calculations for a single droplet with $r = r_{32}$ are also shown. The latter result is obviously applicable to a monodisperse spray with low concentration of droplets. The closeness of the curves for polydisperse and monodisperse sprays for both $\bar{Q}_a$ and $\bar{Q}_{tr}$ shows that the monodisperse approximation is applicable for the analysis of infrared radiative properties of realistic polydisperse diesel fuel sprays. Note that substitution of Eq. (11) into the expression for r_{ij} gives $r_{32} = (B + 3)/A$. This gives $r_{32} = 10$ μm for $A = 0.5$ μm^{-1}, and $r_{32} = 20$ μm for $A = 0.25$ μm^{-1}.
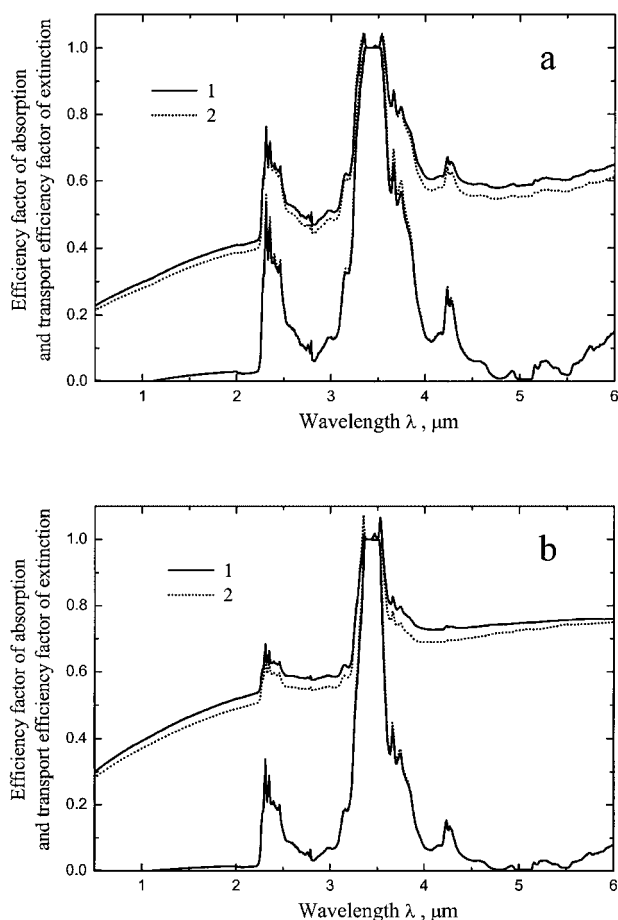
Fig. 7. Results of calculations based on approximate formulae (6) and (7) (dashed curves) of the average efficiency factor of absorption $\bar{Q}_a$ (lower curves) and average transport efficiency factor of extinction $\bar{Q}_{tr}$ (upper curves), based on Eq. (5) and assuming the Gamma distribution of droplets by radii (solid curves); the same calculations but for single droplets with radii equal to r_{32} (dashed curves); calculation have been performed for the following parameters of the Gamma distribution: $A = 0.25\ \mu m^{-1}$ (a) and $A = 0.5\ \mu m^{-1}$ (b).

5. Conclusions

Absorption spectra of several types of diesel fuel have been studied experimentally. The measurements have been performed for diesel fuel used in cars (yellow) and diesel fuel used in off road equipment in which dye has been added for legislative purposes (pink). Similar measurements have been repeated for these diesel fuels after they undergo a simulation of ageing process by prolonged boiling. The difference in absorption between different diesel fuels is shown to be noticeable, especially in the regions well away from absorption peaks. The peaks of absorption practically coincide for all types of diesel fuels. At the same time, the indices of absorption of 'pure' substances heptane and decane are less than those of diesel fuels in the whole spectral range under consideration. The absorption of the boiled diesel fuel in the ultraviolet–near-infrared range is noticeably larger than that of the unboiled fuels.

Index of refraction of these fuels is calculated using subtractive Kramers–Krönig analysis. The dependence of the predicted values of this index on the type of fuel is shown to be weak and can be safely ignored in the calculations of absorption and scattering of thermal radiation by fuel droplets.

Absorption and scattering of radiation by diesel fuel droplets is calculated using the Mie theory and a simplified approach, based on analytical approximations of absorption and scattering efficiency factors. The calculations have been performed in the range $0.5 < \lambda < 6\ \mu m$, which is particularly important for radiation heat transfer in diesel engines. Droplet radii have been taken in the range $5 < r < 50\ \mu m$. It has been shown that the influence of the type of fuel on the values of the absorption efficiency factor Q_a and transport extinction efficiency factor Q_{tr} is strong in the ranges of semi-transparency. Except near the absorption peaks, the scattering of radiation dominates over absorption. This indicates the importance of taking into account the scattering of radiation by fuel droplets in radiation heat transfer calculations in diesel engines.

The agreement between Mie calculations of Q_a and the calculations of Q_a based on Eq. (6) is reasonably good for all droplet radii over the whole spectrum. The approximation of Q_{tr} by Eq. (7) is also satisfactory except for large droplets in the visible range. The above-mentioned deviations of the predicted accuracy of Eqs. (6) and (7) from the Mie calculations are not expected to be important for applications in diesel engines.

A comparison of calculations for polydisperse and monodisperse sprays has shown that the monodisperse approximation with droplet radii equal to r_{32} is applicable for the analysis of infrared radiative properties of realistic polydisperse diesel fuel sprays.

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