Initial water temperature influence on the thermal state of evaporating droplets

G. Miliauskas, S. Šinkūnas, K. Norvaišienė, K. Šinkūnas
Kaunas University of Technology, K. Donelaičio 20, Kaunas, 44239, Lithuania, E-mail: gimil@ktu.lt

Nomenclature

a – thermal diffusivity, m^2/s; B – Spalding transfer number; c_p – mass specific heat, J/(kg K); c_0 – speed of electromagnetic radiation propagation in vacuum, m/s; D – mass diffusivity, m^2/s; h – Planck's constant, J s; Fo – Fourier number; g – evaporation velocity, kg/s; I_ω – spectral intensity of radiation, W/(m ster); $I_{\omega 0}$ – spectral intensity of blackbody radiation, W/(m ster); k – conduction; $k+r$ – conduction and radiation; k_0 – Boltzmann's constant, J/K; L – latent heat of evaporation, J/kg; m – vapour mass flux, kg/(m^{2}s); n – number of the term in infinite sum; n_ω – spectral index of refraction; $n_{\omega k}$ – spectral complex refractive index; Nu – Nusselt number; p – pressure, Pa; P – symbol of free parameter in heat-mass transfer; q – heat flux, W/m^2; r– radial coordinate, m; $r_{\omega,\beta}$ – reflectivity; R_μ – universal gas constant J/(kmol K); t – free selected time, s; s – free direction coordinate, m; T – temperature, K; $\beta, \gamma, \varphi, \psi$ – angles in figure 1, rad; η – nondimensional radial coordinate; λ – thermal conductivity, W/(m K); κ_ω – spectral index of absorption; μ – molecular mass, kg/kmol; ρ – density, kg/m^3; τ – time, s; ω – wave number, m^{-1}; χ_ω – spectral absorption coefficient, m^{-1}.

Subscripts: C – droplet centre; co – condensation; e – equilibrium evaporation; f – phase change; g – gas; i – time index in a digital scheme; it – number of iteration; I– control time; j – index of radial coordinate; J – droplet surface; k – conduction; l – liquid; m – mass average; r – radiation; rs – radiation source; R – droplet surface; v – vapor; vg – gas-vapor mixture; ω – spectral; 0 – initial state; ∞ – far from a droplet.

Superscripts: $+$ – external side of a droplet surface; $-$ – internal side of a droplet surface.

1. Introduction

Sprayed liquid technology is widely used in modern industry and understanding of liquid fuel and water droplet evaporation is important when designing technological processes. Rapid evaporation of liquid droplets allows a more efficient burning of fuel. Disperse water injection is an effective way to control the rate of thermal processes. A wide range of liquid spray technology application and variety of droplet evaporation conditions influences the continuing interest in the research of droplet heat and mass transfer. Applied research methods are discussed in detail [1]. In modern studies there is an objective to take into account dynamics of combined heat and mass transfer process and their interaction in more detail. One of the factors which influence the interaction of transfer processes is radiation absorption of semi transparent droplets. The effect can be evaluated via the spectral radiation modeling

[2-10]. The models are described in detail in [1, 2] and their analysis is outside the scope of this paper. Among spectral radiation models there are models based on geometrical optics theory. This theory is not valid for small-size droplets (diameter-to-wavelength) [2] but is used to determine local radiant flux in droplets. This is important when evaluating the interaction of combined heat transfer processes in the droplet. Additionally, heat and mass transfer processes are influenced by the droplet Stefan hydrodynamic flow. This effect traditionally is evaluated using Spalding parametric functions [11, 12]. The analytical droplet evaporation models based on Stefan's logarithmic formulas for vapour flux are presented in [13-15]. When modeling small droplet evaporation the effect of Knudsen layer needs to be accounted [1, 16, 17]. The important parameters for droplets evaporation process is the temperature of sprayed liquid, droplet dispersity, and partial vapour pressure in the gas and gas temperature. Conditions of heat and mass transfer between droplets and its surroundings are important also. The influence of individual factors to heat and mass transfer processes can be assessed using benchmarking method beginning with the simple droplet models and then considering more complex cases. The choice of the basic parameters for benchmarking is essential. It can be any heat and mass transfer parameter P_k of conductively heated droplets. Function $P_k(Fo)$ is independent on droplet dispersity [18] when initial water temperature for all conductively heated evaporating droplets is the same and the gas temperature and the vapour pressure in the gas is determined.

This paper evaluates the initial temperature effect to the droplet thermal state during evaporation process.

2. Research method

Droplets are assumed spherically; influence of Knudsen layer for evaporation is neglected. The change of droplet volume is determined by vapour flux on the droplet surface [13] and heated liquid expansion:

$$\left. \begin{aligned} &\frac{1}{3R^2}\frac{\partial\left(\rho R^3\right)}{\partial\tau} = -m_v^+; \\ &m_v^+ = \frac{D_{vg}\mu_v}{T_R R_\mu R}\Big[p_{v,R} - p_{v,\infty} + \\ &+ \frac{\mu_v}{\mu_g}\left(p\,ln\frac{p-p_{v,\infty}}{p-p_{v,R}} + p_{v,\infty} - p_{v,R}\right)\Big]. \end{aligned} \right\} \quad (1)$$

For Eq. (1) the temperature function $T_R\left(\tau\right)$ is re-

quired and it is estimated on the base of energy balance on the evaporating droplet surface (Fig. 1, a):

$$\left.\begin{array}{l} \vec{q}_{\Sigma}^{+} + \vec{q}_{\Sigma}^{-} + \vec{q}_{f}^{+} = 0; \quad q_{\Sigma}^{+} = q_{r}^{+} + q_{k}^{+}; \\[2mm] q_{k}^{+} = \dfrac{\lambda_{vg}}{R}\left(T_{g} - T_{R}\right)\dfrac{ln\left(1+B\right)}{B}; \\[2mm] B = \dfrac{c_{p,vg}\left(T_{g} - T_{R}\right)}{L}\left(1+\dfrac{q_{k}^{-}}{q_{k}^{+}}\right); \\[2mm] q_{\Sigma}^{-} = q_{r}^{-} + q_{k}^{-}; \quad q_{k}^{-} = -\lambda\dfrac{\partial T}{\partial r}\Big|_{r=R^{-}}; \quad q_{f}^{+} = m_{v}^{+}L. \end{array}\right\} \quad (2)$$

$$|R^{+}| \equiv |R^{-}| \equiv |R|$$

a

b

Fig. 1 The model of combined heating of evaporating water droplet (a) and validation (b): (1-6) combined heating; (7, 8) conductive heating; (1, 2) experiment [19]; (3, 4) numerical research [2]; (5-8) present model [20]. T_g, K: (1, 3, 5, 7) 981, (2, 4, 6, 8) 1133

Temperature gradient in the droplet is determined by function of unsteady temperature field $T(r, \tau)$ which in case of combined heat transfer by conduction and radiation is described by energy equation:

$$\frac{\partial\left(\rho c_{p}T\right)}{\partial \tau} = \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\left(\lambda\frac{\partial T}{\partial r} - q_r\right)\right]; \quad \frac{\partial T}{\partial r}\Big|_{r=0} = 0. \quad (3)$$

Eq. (3) is solved analytically. It is assumed that function of radiation flux in the droplet $q_r(r, \tau)$ is known and boundary conditions are valid:

$$\left.\begin{array}{l} T\left(r, \tau \equiv 0\right) = T_0\left(r\right); \quad R\left(\tau \equiv 0\right) = R_0; \\[2mm] T\left(R, \tau\right) = T_R\left(\tau\right) \equiv f_{T_R}\left(\tau\right); \quad R\left(\tau\right) \equiv f_R\left(\tau\right). \end{array}\right\} \quad (4)$$

The system equations (3, 4) using function $f_T\left(r, \tau\right) = r\left[T\left(r, \tau\right) - T_R\left(\tau\right)\right]$ is substituted with the infinite series of integrals assuming that the droplet initially is isothermal and liquid physical properties dependence on the temperature is neglected [21].

When the droplet initially is non-isothermal in equation (5) such initial state is evaluated according [22]. The variability of physical properties in warming liquid droplet is evaluated according [23].

$$T\left(r, \tau\right) = T_R\left(\tau\right) + \frac{2}{r}\sum_{n=1}^{\infty}\sin\frac{n\pi r}{R} \times$$

$$\times\int_0^{\tau}\left[\begin{array}{l}\left(-1\right)^n\dfrac{R}{n\pi}\dfrac{dT_R}{d\tau_*} + \\[3mm] + \dfrac{1}{R\rho c_p}\displaystyle\int_0^R q_r\left(n\pi\eta\,\cos n\pi\eta - \sin n\pi\eta\right)dr\end{array}\right] \times$$

$$\times\exp\left[-a\left(\frac{n\pi}{R}\right)^2\left(\tau - \tau_*\right)\right]d\tau_*. \quad (5)$$

The radiation flux in the semitransparent droplet is defined by the system of integral-differential equations:

$$\left.\begin{array}{l} q_r = 2\pi\displaystyle\int_0^{\infty}\int_0^{\pi} I_{\omega}\sin\phi\cos\phi\,d\phi\,d\omega; \quad \dfrac{dI_{\omega}}{ds} = \chi_{\omega}\left(n_{\omega}^2 I_{\omega 0} - I_{\omega}\right); \\[3mm] \chi_{\omega} = \dfrac{4\pi\kappa_{\omega}}{\omega^{-1}}; \quad I_{\omega 0} = \dfrac{2c_0^2\omega^3 h}{\exp\left(c_0\omega h / k_0 T\right) - 1}; \\[3mm] ds = \dfrac{\pm r\,dr}{\left(r^2 - R^2\sin^2\beta\right)^{1/2}}; \quad n_{\omega\kappa} = n_{\omega} - i\kappa_{\omega}, \end{array}\right\} \quad (6)$$

here: "–" stands for $0 < s < R\cos\beta$ (Fig. 1, a). It is assumed that function of temperature field in the droplet $T(r)$ is known and boundary condition $I_{\omega}(r \equiv R) = I_{\omega,R}$ is valid. Using radiation heat flux distribution in a cylindrically symmetric no isothermal gas with temperature-dependent absorption coefficient methodology presented in [24] the system of Eq. (7) for spherical semi transparent volume is transformed to integral equation [9]:

$$q_r\left(r\right) = 2\pi\int_0^{\infty}\int_0^{\pi/2}\left[\begin{array}{l}\displaystyle\int_{r\sin\gamma}^r n_{\omega}^2 I_{\omega,0}\exp\left(-\theta_{r_*}^r\right)d\theta_r^{r_*} - I_{\omega,R}\exp\left(-\theta_r^R\right) + I_{\omega,R}\exp\left(-\theta_{r\sin\gamma}^R - \theta_{r\sin\gamma}^r\right) - \\[3mm] -\displaystyle\int_r^R n_{\omega}^2 I_{\omega,0}\exp\left(-\theta_r^{r_*}\right)d\theta_r^{r_*} + \int_{r\sin\gamma}^R n_{\omega}^2 I_{\omega,0}\exp\left(-\theta_{r\sin\gamma}^r - \theta_{r\sin\gamma}^{r_*}\right)d\theta_r^{r_*}.\end{array}\right] \quad (7)$$

The angles in the droplet (Fig. 1, a): $r\sin\gamma = R\sin\beta$; $\gamma = \pi - \varphi$. For $r = R$, $\gamma = \beta$ and the spectral intensity of radiation on droplet inner surface are defined by equation [25]:

$$I_{\omega,R} = \left[1 - r_{\omega,\beta}\, exp\left(-2\theta_{R\sin\gamma}^{R}\right)\right]^{-1}\left\{\left(1 - r_{\omega,\beta}\right)n_{\omega}^{2}I_{\omega 0}\left(T_{g}\right) + r_{\omega,\beta}\int\limits_{R\sin\gamma}^{R}n_{\omega}^{2}I_{\omega 0}\left(r\right)\left[exp\left(-\theta_{R\sin\gamma}^{R} - \theta_{r_{*}\sin\gamma}^{r_{*}}\right) + exp\left(-\theta_{r_{*}}^{R}\right)\right]d\theta_{R}^{r_{*}}\right\}. \quad (8)$$

Optical thicknesses representing symbols used in Eqs. (7) and (8) are described as [26]:

$$\theta_{r_{1}}^{r_{2}} \equiv \int\limits_{r_{1}}^{r_{2}}\chi_{\omega}dr_{*}\,/\,\sqrt{1 - \left(r\,/\,r_{*}\right)^{2}\sin^{2}\gamma}\,, \quad (9)$$

where r_{1} and r_{2} are θ integral limits in Eqs. (7) and (8). The system of Eqs. (1), (2), (5), (7) and (8) is solved numerically. At first we assume droplet heating time t. This time is divided into number of I-1 time intervals $\Delta\tau_{i}$. The no dimensional coordinate η for interval from 0 to 1 is divided into number of J-1 intervals $\Delta\eta_{j}$. For such operations conditions are valid:

$$\left.\begin{array}{l}\sum\limits_{i=1}^{I-1}\Delta\tau_{i} = \sum\limits_{i=1}^{I-1}\left(\tau_{i+1} - \tau_{i}\right) \equiv t;\\[2mm]\sum\limits_{j=1}^{J-1}\Delta\eta_{i} = \sum\limits_{i=1}^{I-1}\left(\eta_{i+1} - \eta_{i}\right) \equiv 1.\end{array}\right\} \quad (10)$$

The droplet surface temperature $T_{R,i}$ for time moment τ_{i} is defined numerically solving the system of Eq. (2) by steepest descent iterative method. Imbalance of heat fluxes on the droplet surface is achieved no more as 0.01%. Radiation fluxes $q_{r,i,j,it}$ in droplet concentric sections determined by coordinate η_{j} are calculated according Eqs. (7) and (8). In such calculations we must evaluate $T_{i,j,it-1}$ temperatures in the droplet. In radiation spectrum the finite interval $\omega_{1} \div \omega_{2}$ is selected. It is divided linear to NM-1 intervals $\Delta\omega_{nm} = \omega_{nm+1} - \omega_{nm}$. Integrals in Eq. (7) are solved numerically for wave number using rectangular method and for γ angle using Gauss method with 7 point scheme. Integrals in Eqs. (7) and (8) for radial coordinate r are replaced by finite sum of integrals for selected $\Delta r_{j} = r_{j+1} - r_{j}$ intervals. Integrals of exponential functions are solved analytically and integrals of optical thicknesses are replaced by finite sums of algebraic terms. For example:

$$\theta_{r\sin\gamma}^{r_{j}} \equiv \theta_{r\sin\gamma}^{r_{j0}} + \theta_{r_{j0}}^{r_{j}} = \chi_{j}\sqrt{r_{j0}^{2} + r^{2}\sin^{2}\gamma}\,+$$
$$+\sum\limits_{jj=1}^{j-1}\chi_{jj}\left(\sqrt{r_{jj+1}^{2} + r^{2}\sin^{2}\gamma} - \sqrt{r_{jj}^{2} + r^{2}\sin^{2}\gamma}\right), \quad (11)$$

here $r_{j0-1} < r\sin\gamma \leq r_{j0}$ and $j_{0} \geq 2$. Spectral coefficients of light reflection $r_{\omega,\beta}$ on the droplet surface are calculated according [27]. The Brewster angle effect is evaluated assuming $r_{\omega,\beta} = 1$ when $\beta > arcsin\left(1/n_{\omega\kappa}\right)$. The spectral optical properties for water are found according [27, 28] recommendations. The temperature field $T_{i,j,it}$ in droplet is calculated numerically solving Eq. (5) when $q_{r,i,j,it}$ is determined. In infinite sum the finite number of N terms is evaluated. Integrals in Eq. (5) are solved numerically using rectangular method. Stability of digital scheme in iterative

cycle for time moment τ_{i} requires to keep constant droplet radius $R_{i,it} \equiv R_{i-1}$. At the end of iterative cycle the radius of droplet R_{i} is calculated solving the system of Eq. (1). The above calculations are provided after every time step. Numerical investigation is ended when estimated time t is reached or when the diameter of evaporating droplet diminished to 10 microns.

3. Results and discussion

Evaporation of water droplets heated by conduction and radiation source with temperature $T_{rs} = T_{g}$ is modelled by above discussed iterative digital scheme for $NM = 151$, $J = 81$, $N = 101$, $I < 201$. The comparison of equilibrium evaporation results obtained using digital scheme presented in this work with experimental results [19] and theoretical research [2] in case of heating by conduction and radiation of water droplets is presented in Fig. 1, b. For equilibrium evaporation $q_{f}^{+} \cong q_{\Sigma}^{+}$ is assumed.

In our research water with initial temperature 293 K which is lower than equilibrium evaporating droplets temperature is named sub cooled. In opposite case, water with initial temperature 363 K is named sub heated. The initial water temperature is significant to the thermal state of the evaporating droplet (Fig. 2). If spayed water is sub cooled then droplets heat until reaching equilibrium evaporation temperature via unsteady evaporation process. If sprayed water is sub heated, then droplets cool down until the equilibrium evaporation temperature is reached. Droplet thermal state dynamics is defined by heat transfer peculiarities between droplets and surrounding. The peculiarities are well highlighted by dynamics of the evaporating droplet surface and centre temperatures.

Functions $\bar{T}_{\eta,k}\left(Fo\right)$ are individual to every cross-section and locate between characteristic functions $\bar{T}_{\eta=0,k}\left(Fo\right)$ and $\bar{T}_{\eta=1,k}\left(Fo\right)$. The set of functions $\bar{T}_{\eta,k}\left(Fo\right)$ determines thermal state change during unsteady evaporation regime for conductively heated water droplets. At the end of unsteady evaporation regime the curves get close to each other $\bar{T}_{\eta,k}\left(Fo \rightarrow Fo_{e,k}\right) \rightarrow 1$ and their merge represents the beginning of equilibrium evaporation. The thermal state of no isothermal droplet determines mass average temperature $T_{m}\left(Fo\right)$. The curves $\bar{T}_{R,k}\left(Fo\right)$, $\bar{T}_{C,k}\left(Fo\right)$ and $\bar{T}_{m,k}\left(Fo\right)$ are characteristic. Functions $\bar{T}_{\eta,k}\left(Fo\right)$ are defining temperature change in cross-sections of the droplet defined by coordinate $\eta \equiv r\,/\,R\left(Fo\right)$. Those cross-sections are symmetric in respect of the droplet centre. It is obvious that thermal state of conductively heated droplets does not change during equilibrium evaporation regime (Fig. 3): $\bar{T}_{m,k}\left(Fo \geq Fo_{e,k}\right) \equiv 1$ and $T_{m,k}\left(Fo \geq Fo_{e,k}\right) \equiv T_{e,k}$.
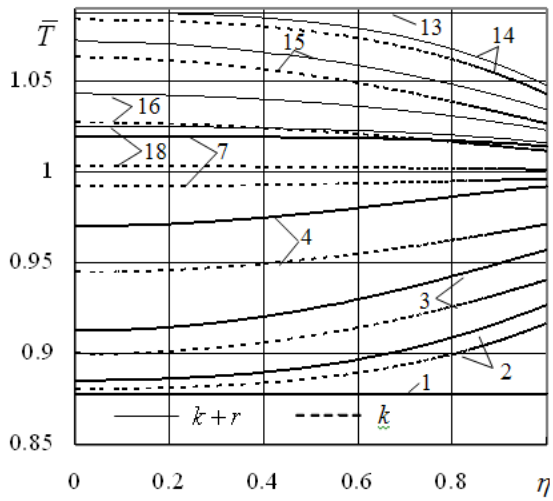
a
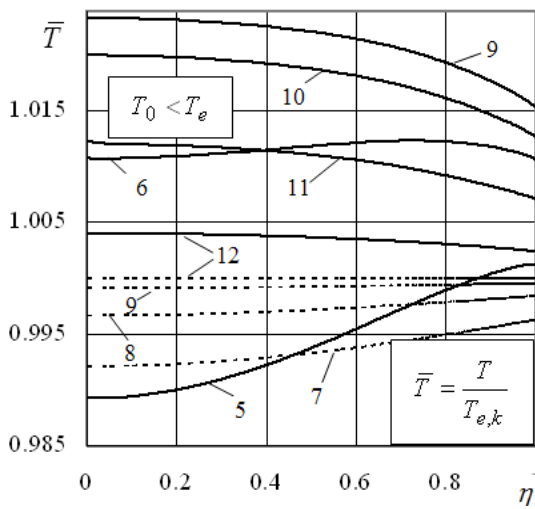
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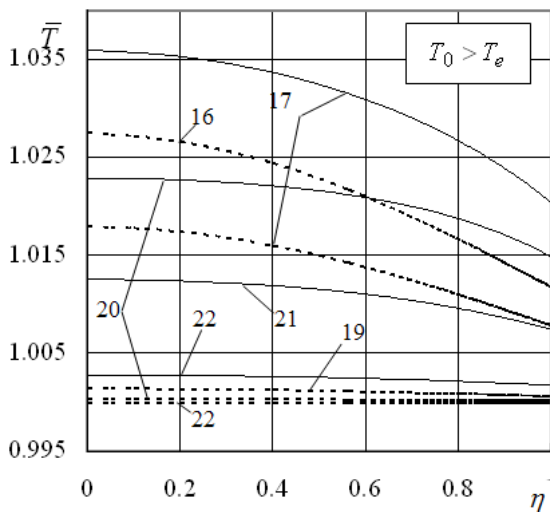
c

Fig. 2 Effect of water temperature on the droplet thermal state T_0, K: (*1-12*) 293, (*13-22*) 363; *Fo*: (*1, 13*) 0, (*2, 14*) 0.094, (*3, 15*) 0.188, (*4, 16*) 0.375, (*5, 17*) 0.469, (*6*) 0.656, (*7, 18*) 0.844, (*8, 19*) 0.938, (*9, 20*) 1.313, (*10*) 2.906, (*11,21*) 5.156, (*12*) 6.281, (*22*) 6.656; T_g = 973 K; $T_{e,k}$ = 333.7 K; R_0 = 200×10^{-6}m
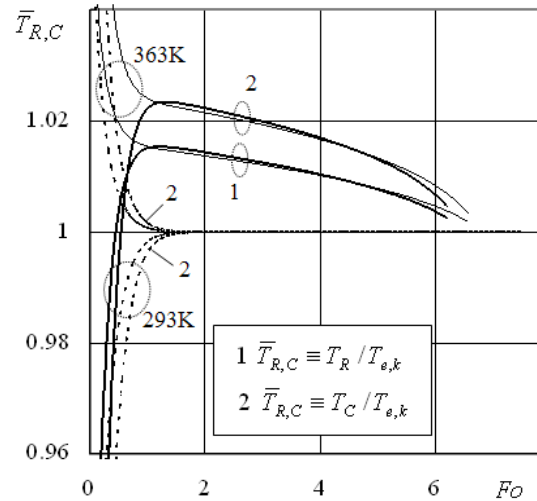

Fig. 3 Effect of radiation on the droplet surface and centre temperatures. T_g = 973 K; R_0 = 200×10^{-6}m

Radiation absorbed by semi transparent droplets essentially changes their thermal state (Fig. 4, a). This shows that during combined heating functions $\overline{T}_{\eta,k+r}(Fo)$ for different size droplets are individual during the evaporation process. Peculiarities of the droplet surface and centre temperatures change determine non isothermality of combined heated droplets (Fig. 4, b). Radiation absorbed by droplets accelerates their heating if initial water temperature is lower than equilibrium evaporation temperature (Fig. 2, a, b), but slows droplets cooling process if the initial water temperature is higher than equilibrium evaporation temperature (Fig. 2, a, c). Therefore, in the case of the same surroundings temperature the droplet mass average temperature is always higher in combined heating case than for conductively heated droplets independently of the sprayed water temperature (Fig. 4, a).

Radiation absorbed by droplets changes the droplet thermal state and influences evaporation process (Fig. 5). Absorbed radiation flux in water droplets mainly depends on surroundings temperature and droplets dispersity.

The radiation absorption by smaller droplets is lower (Fig. 5, b). During unsteady evaporation the reduction of $q_{r,R}$ is slight, but it enhances during equilibrium evaporation (Fig. 5, a). This is caused by the rapid reduction of droplet radius during the last stage of evaporation. In combined heating case the droplet evaporation is faster than for conductive heating. This effect for superheated water droplets is more significant. It is also seen that sub heated water droplets heated conductively evaporate faster than sub cooled droplets in combined heating case (Fig. 5, a). The higher sped of evaporation is determined by participating of liquid internal energy in evaporation process of cooling droplets. During evaporation process local radiation flux in the droplet changes significantly (Fig. 5, b). For larger droplets radiation absorption in droplet surface sub layer is intensive. With decreasing of evaporating droplets radiation flux absorption decreases (Fig. 5, a) also becomes more even in droplet until becomes approximately linear in the final evaporation period (Fig. 5, b).
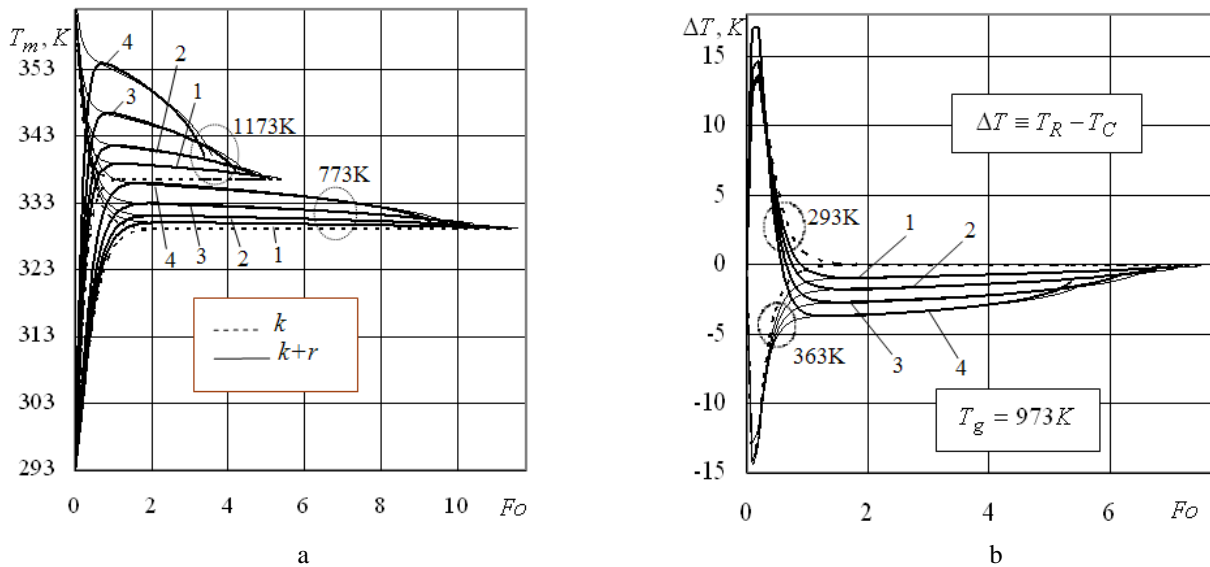
Fig. 4 Effect of radiation on the droplet mass averaged temperature (*a*) and on non isothermality (*b*). $R_0 \times 10^6$, m: (*1*) 50, (*2*) 100, (*3*) 200, (*4*) 400
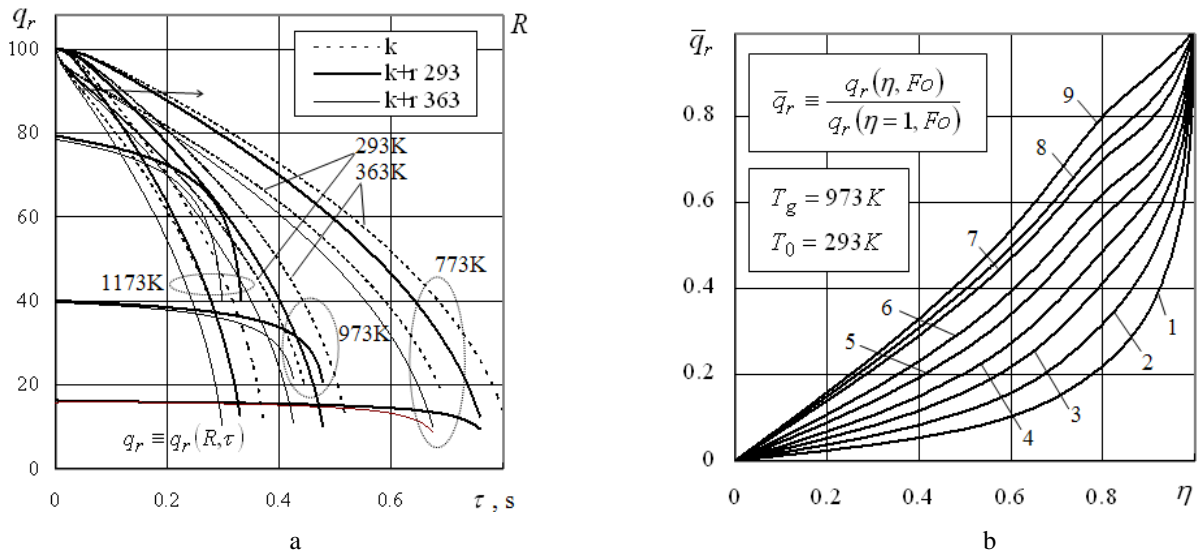

Fig. 5 Absorbed radiation flux in the evaporating droplet (*a*) and the local radiation flux relationship (*b*). *Fo*: (*1*) 0, (*2*) 2.72, (*3*) 4.03, (*4*) 4.6, (*5*) 4.97, (*6*) 5.16, (*7*) 5.34, (*8*) 5.39, (*9*) 5.42; $R_0 \times 10^6$, m: (*1*) 400, (*2*) 275.5, (*3*) 187.5, (*4*) 139.4, (*5*) 99.3, (*6*) 74.2, (*7*) 40.5, (*8*) 27.2, (*9*) 14.9; $q_r(\eta = 1, Fo)$, kW/m^2: (*1*) 43.79, (*2*) 43.05, (*3*) 42.13, (*4*) 41.19, (*5*) 39.77, (*6*) 38.2, (*7*) 33.72, (*8*) 30.05, (*9*) 24.2

The non-linear character of curves $\bar{q}_r$ can be explained by the effects of light reflection at the inner surface of a droplet, which enhances when optical thickness of semi transparent droplet reduces. The initial water temperature determines peculiarities of heat fluxes change on the droplet surface (Fig. 6).

Function of radiation heat flux $q_{r,R}(Fo)$ for sub cooled and sub heated droplets differs only quantitatively. Comparison of heat flux functions $q_k^+(Fo)$, $q_k^-(Fo)$ and $q_f^+(Fo)$ for sub cooled and sub heated water in unsteady evaporation process differs quantitatively and qualitatively. For conduction heat flux q_k^- such difference is very obvious. Value of q_k^- for sub heated water droplets during unsteady evaporation reduces to radiation heat flux value $q_{r,R}$.

For the sub cooled water droplets value q_k^- during unsteady evaporation initially reduces to zero, but later enhances up to value $q_{r,R}$. Evaporation heat flux q_f^+ of sub cooled water droplets continuously increases during evaporation process. For sub heated water droplets value q_f^+ initially reduces intensively until minimal value and later continuously increases during evaporation process. During the equilibrium evaporation regime the influence of sprayed water temperature is only quantitative.

Radiation flux absorbed in the droplet changes dynamics of droplet thermal state (Fig. 7). During equilibrium evaporation regime (Fig. 7, a) and during unsteady evaporation regime (Fig. 7, b) the thermal state change of droplet significantly differs. During equilibrium evaporation the droplet thermal state peculiarities are depended on droplet heating way, whereas during unsteady evaporation

the thermal state dynamics additionally is affected by sprayed water temperature. For sub heated water droplets the temperature decreases most rapidly when droplets are heated by conduction and for sub cooled water droplets the temperature increases faster when droplets are heated in combined way (Fig. 7, b). During unsteady evaporation the temperature change rate of droplet surface sub layers continuously reduces, but for the droplet centre layers temperature change rate initially enhances until reaches maximum, and then continuously reduces. At the end of unsteady evaporation regime: $d\overline{T}_R / dFo \rightarrow 0$, $d\overline{T}_C / dFo \rightarrow 0$ and $d\overline{T}_m / dFo \rightarrow 0$.

The thermal state of droplets heated by conduction does not change during equilibrium evaporation: $d\overline{T}_{m,k}\left(Fo \geq Fo_{e,k}\right) / dFo \equiv 0$. The temperature of droplets in the case of combined heating during equilibrium evaporation is decreasing (Fig. 4).
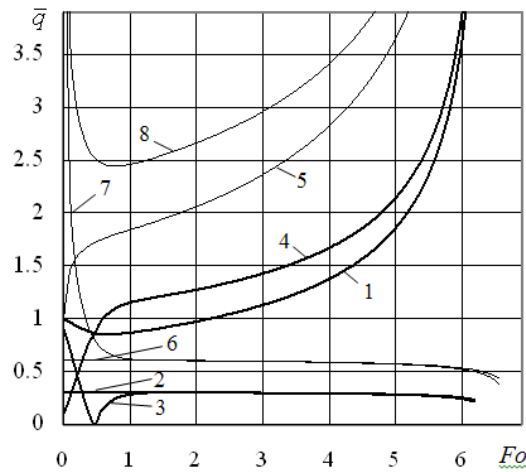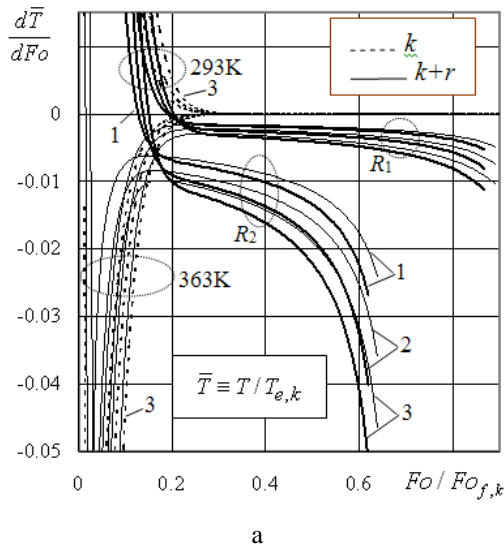
Fig. 6 The effect of water temperature on heat fluxes at the surface of the evaporating droplet. T_0, K: (1-4) 293, (5-8) 363; $\overline{q}$: (1, 5) $q_k^+ / q_{k,0}^+$, (2, 6) $q_{r,R} / q_{k,0}^+$, (3, 7) $q_k^- / q_{k,0}^+$, (4, 8) $q_f^- / q_{k,0}^+$; $T_g = 973$ K; $R_0 = 200 \times 10^{-6}$ m

a

b
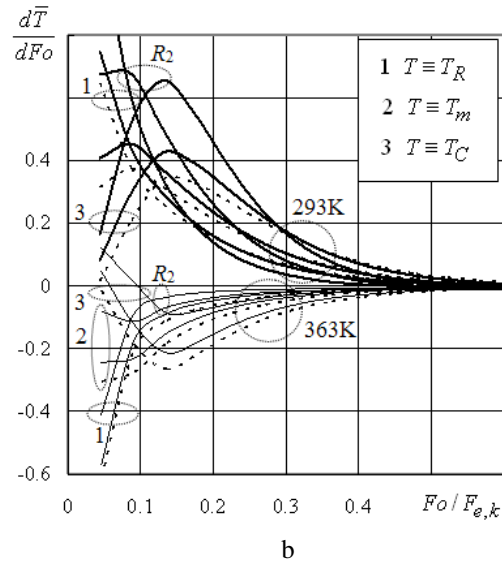
Fig 7 Radiation influence on the droplet thermal state change rate: (*a*) for droplet lifetime; (*b*) for droplet unsteady evaporation regime. $T_g = 1173$ K; $R_1 = 10^{-4}$ m; $R_2 = 10^{-4}$ m; $T_{e,k} = 336.6$ K

4. Conclusions

Sprayed water temperature has a significant influence on droplets thermal state change and on unsteady evaporation process. The influence of water initial temperature is convenient to determine using a parameter based on the ratio of water initial temperature and droplet equilibrium evaporation temperature $\overline{T}_0 \equiv T_0 / T_{m,e}$. For sub cooled water the value of parameter $\overline{T}_0 < 1$ and droplets during unsteady evaporation warms up to temperature $T_{m,e}$. For sub heated water the value of parameter $\overline{T}_0 > 1$ and droplets during unsteady evaporation cools down to temperature $T_{m,e}$. The influence of initial water temperature for droplets evaporation process is negligible when parameter $\overline{T}_0 \approx 1$. The influence of radiation flux absorbed by sub cooled and sub heated water droplets for their thermal state change is different.

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VANDENS PRADINĖS TEMPERATŪROS ĮTAKA
GARUOJANČIŲ LAŠELIŲ TERMINEI BŪSENAI

R e z i u m ė

Straipsnyje pateiktas vandens lašelių šilimo ir ga-
ravimo sausame ore modeliavimas esant skirtingai pradinei
jų temperatūrai. Įvertinta oro temperatūrą turinčio juodo
kūno spektrinio spinduliavimo įtaka sudėtiniam šilumos
plitimui pusskaidriame lašelyje. Išpurškiamo vandens pra-
dinės temperatūros įtaka yra esminė. Vandens pradinės
temperatūros įtaka lašelio šilumos ir masės mainams nesta-
cionariųjų fazinių virsmų režime įvertinama vandens pra-
dinės temperatūros ir lašelio pusiausviro garavimo tempe-
ratūros santykiu.

G. Miliauskas, S. Šinkūnas, K. Norvaišienė, K. Šinkūnas

INITIAL WATER TEMPERATURE INFLUENCE ON
THE THERMAL STATE EVAPORATING DROPLETS

S u m m a r y

The paper discusses modelling of water droplet
heating and evaporation in dry air at different initial tem-
perature. The effect of black body spectral radiation of air
temperature to combined heat transfer in the semitranspar-
ent droplet has been evaluated. The effect of sprayed water
temperature has been highlighted. Influence of water initial
temperature to droplet heat and mass transfer during un-
steady evaporation regime was evaluated by ratio of water
initial and droplet equilibrium evaporation temperatures.