A mathematical model for heating and evaporation of a multi-component liquid film

Sergei S. Sazhin, **Oyuna Rybdylova, Cyril Crua**

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Plan

Motivation

Basic equations

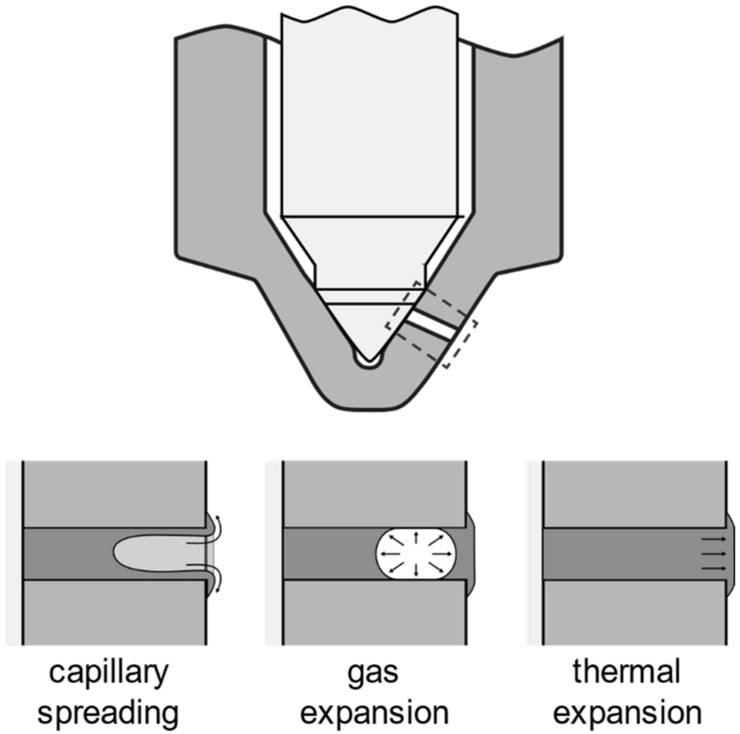
Results

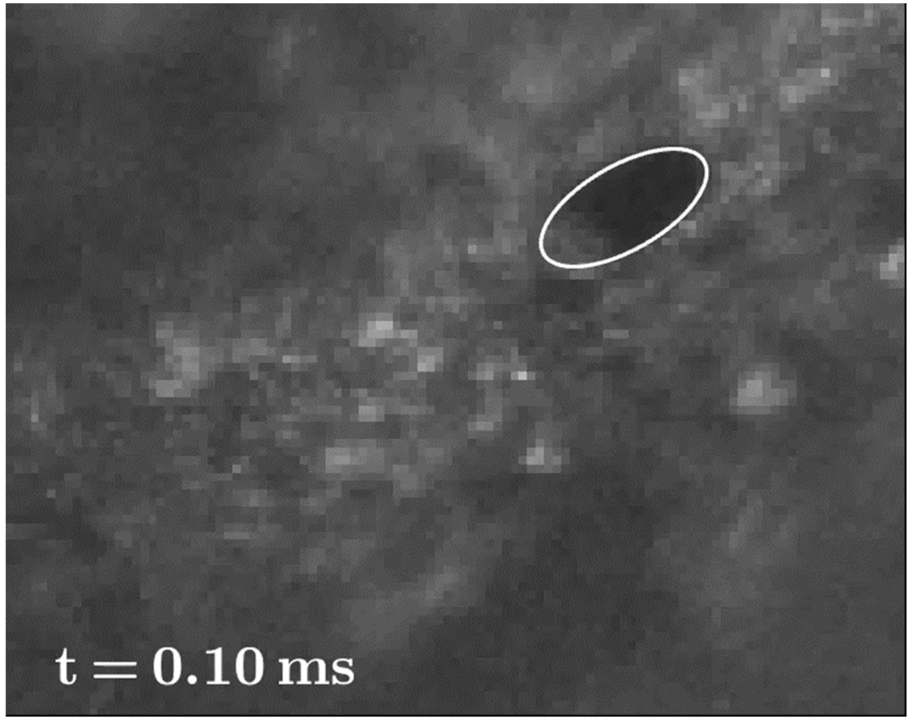
Conclusions

Related developments

Motivation

Quantitative analysis of nozzle surface films fuel for diesel injectors (Turner et al. (2017) ILASS-Europe, http://doi.org/CGMC; this slide was provided by C Crua)





Injection angle: 30° bTDC, injection pressure: 500 bar

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Basic equations

$$\frac{\partial T}{\partial t} = \kappa_1 \frac{\partial^2 T}{\partial x^2},$$

Following [16], we assume that the liquid temperature at the wall is equal to the constant wall temperature: $T(x=0,t) = T_w$ (Dirichlet boundary condition).

Following [16], the boundary condition at the surface of the liquid film ($x = \delta_0$) is presented as:

$$h(T_{\mathrm{eff}} - T_s) = k_l \frac{\partial T}{\partial x}\bigg|_{x=\delta_0-0},$$

where

$$T_{\mathrm{eff}} = T_g + \frac{\rho_l L \dot{\delta}_{0e}}{h},$$

[16] S. Liye, Z. Weizheng, Z. Tien, Q. Zhaoju, A new approach to transient evaporating film heating modeling based on analytical temperature profiles for internal combustion engines, Int. J. Heat Mass Transfer 81 (2015) 465–469,

Basic equations

$$T(X,t) = T_{\mathrm{w}} + \frac{Xh_0}{1+h_0}(T_{\mathrm{eff}} - T_{\mathrm{w}}) + \sum_{n=1}^{\infty} \exp\left[-\kappa_{\delta 0}\lambda_n^2 t\right]\left[q_n + f_n h_0 (T_{\mathrm{eff}} - T_{\mathrm{w}})\right]\sin(\lambda_n X),$$

where $X = x/\delta_0, h_0 = h\delta_0/k_1, \kappa_{\delta 0} = k_1/(c_1\rho_1\delta_0^2)$,

$$q_n = \frac{1}{||v_n||^2}\int_0^1 (T_0(X) - T_{\mathrm{w}})\sin(\lambda_n X)\mathrm{d}X,$$

$$f_n = \frac{1}{||v_n||^2}\int_0^1 f(X)\sin(\lambda_n X)\mathrm{d}X = -\frac{\sin\lambda_n}{||v_n||^2\lambda_n^2},$$

$f(X) = -X/(1+h_0)$, $\quad ||v_n||^2 = \frac{1}{2}\left(1 - \frac{\sin 2\lambda_n}{2\lambda_n}\right) = \frac{1}{2}\left(1 + \frac{h_0}{h_0^2+\lambda_n^2}\right)$, λ_n are non-trivial solutions to the equation

$\lambda\cos\lambda + h_0\sin\lambda = 0.$

Basic equations

$$\dot{m}_{\mathrm{f}} = h_{\mathrm{m}}(\rho_{\mathrm{vs}} - \rho_{\mathrm{va}})$$

Once the value of h has been estimated, the value of the mass transfer coefficient is estimated using the Chilton-Colburn analogy as [23]:

$$h_{\mathrm{m}} = \frac{h}{\rho_{\mathrm{g}} c_{p\mathrm{g}}} Le^{-2/3},$$

Basic equations

$$\frac{\partial Y_{1,i}}{\partial t} = D_1 \frac{\partial^2 Y_{1,i}}{\partial x^2}$$

$$D_1 \left.\frac{\partial Y_{1,i}}{\partial x}\right|_{x=\delta_0-0} = |\dot{\delta}_{0e}|\left(Y_{1,i}\big|_{x=\delta_0} - \epsilon_i\right),$$

$$\left.\frac{\partial Y_{1,i}}{\partial x}\right|_{x=0} = 0,$$

$$\epsilon_i = \frac{Y_{\mathrm{vs},i}}{\sum_{i=1}^{i=N} Y_{\mathrm{vs},i}} = \frac{\rho_{\mathrm{vs},i}}{\sum_{i=1}^{i=N} \rho_{\mathrm{vs},i}}$$

Basic equations

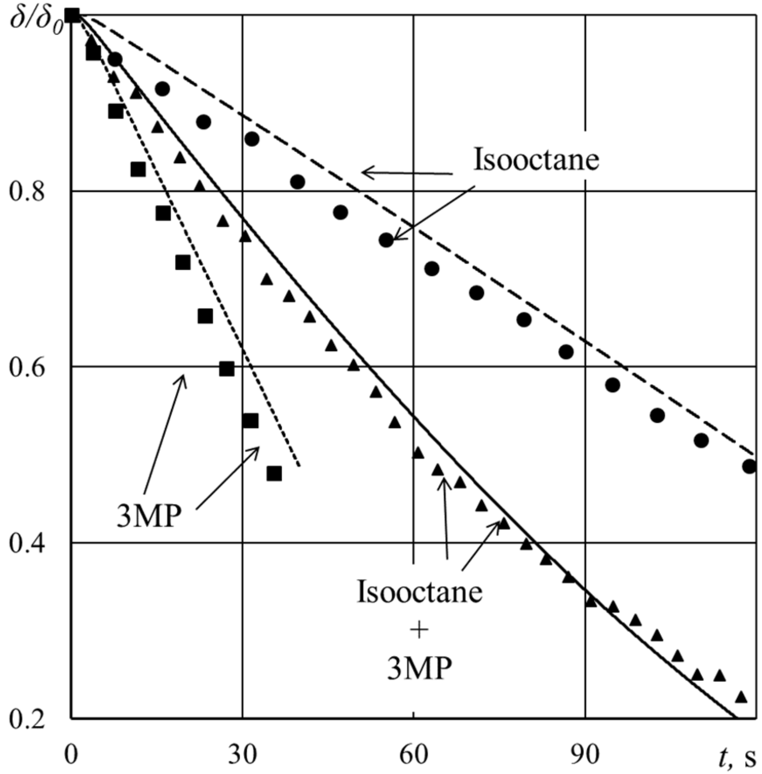
$$Y_{1,i}(t,x) = q_{Y0} \exp\left[D_1 \left(\frac{\lambda_0}{\delta_0}\right)^2 t\right] \cosh\left(\lambda_0 \frac{x}{\delta_0}\right) + \sum_{n=1}^{\infty} q_{Yn} \exp\left[-D_1 \left(\frac{\lambda_n}{\delta_0}\right)^2 t\right] \cos\left(\lambda_n \frac{x}{\delta_0}\right) + \epsilon_i.$$

$$p_{\mathrm{vs},i} = X_{\mathrm{ls},i} p^*_{\mathrm{v},i},$$

$$\Delta\delta_0 = -\Delta t \frac{|\dot{m}_{\mathrm{fi}}|}{\rho(\overline{T}_0)} + \left[\frac{\rho(\overline{T}_0)}{\rho(\overline{T}_1)} - 1\right] \delta_0$$

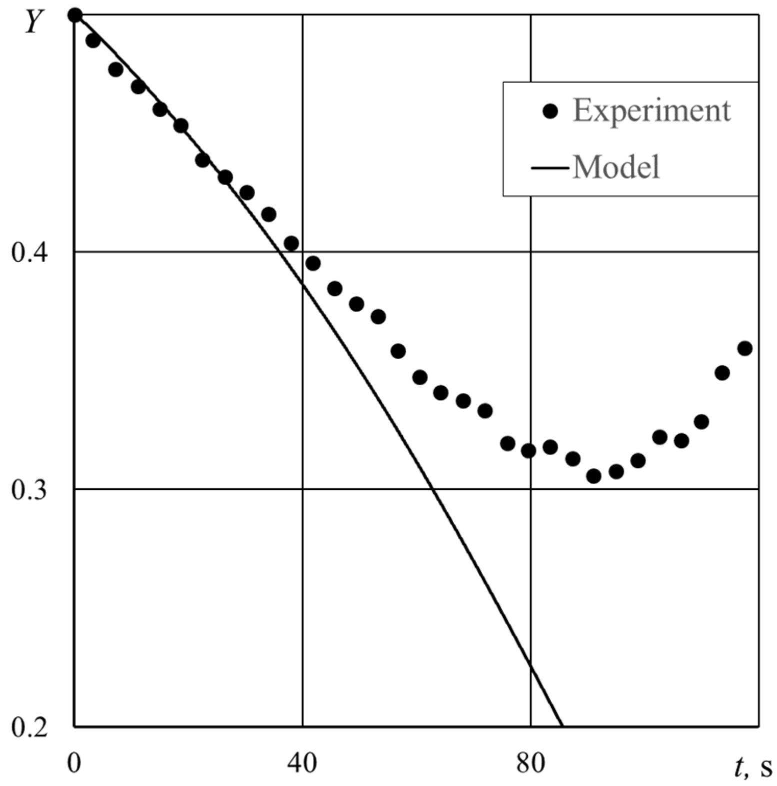
Results

Results



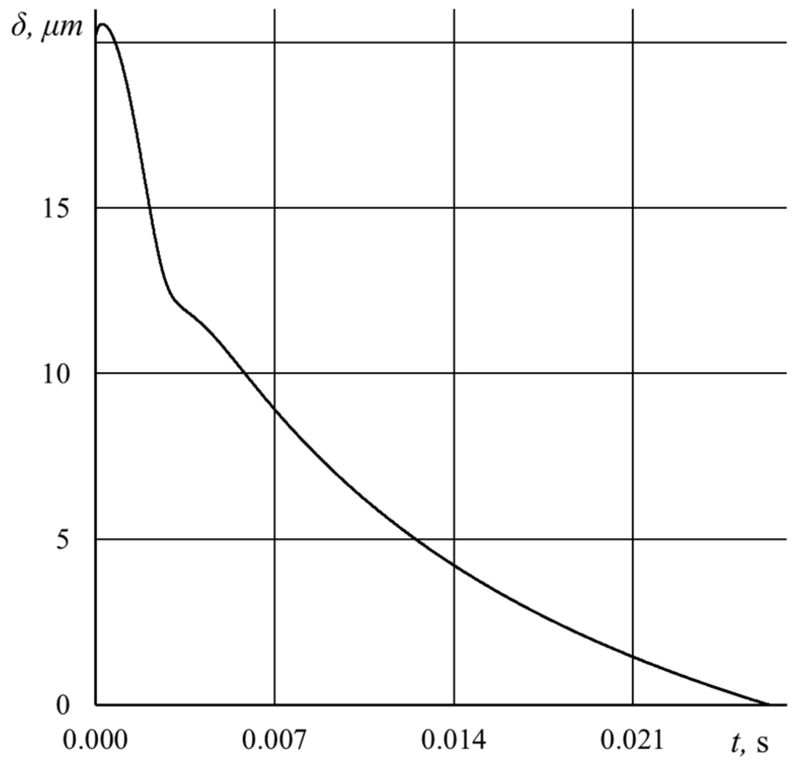
Time evolution of the normalised film thickness. Circles, triangles and squares show the values found by Kelly-Zion (2006); solid and dashed curves show the corresponding predictions of the model. Three cases were considered: pure isooctane, pure 3MP, and a 50%/50% mixture of isooctane and 3MP

Results



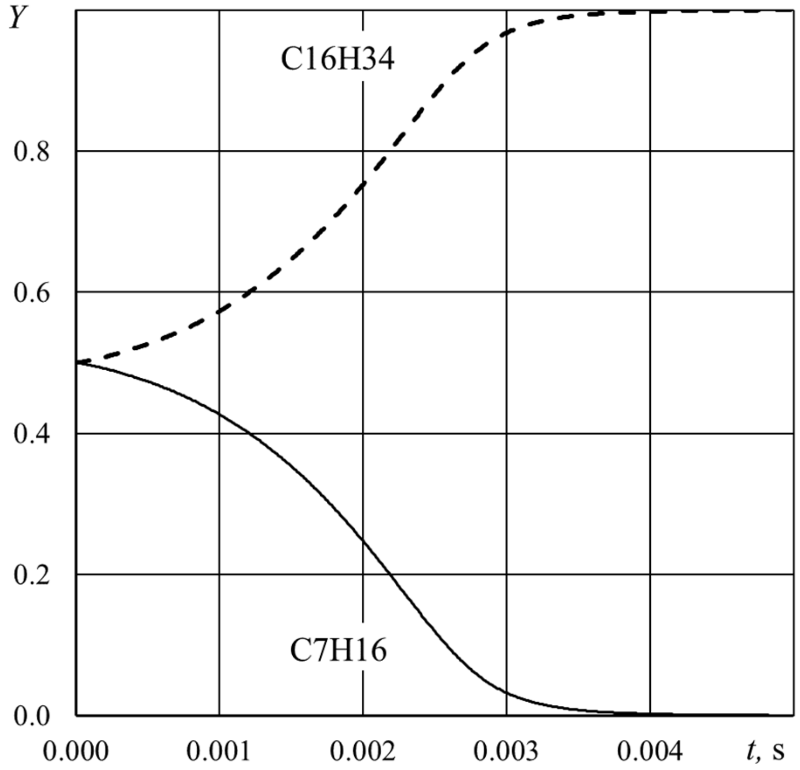
Time evolution of the average mass fraction of 3MP in the case of evaporation of a 3MP and iso-octane mixture film. Solid curve shows the prediction of the model, while dots show experimental data

Results



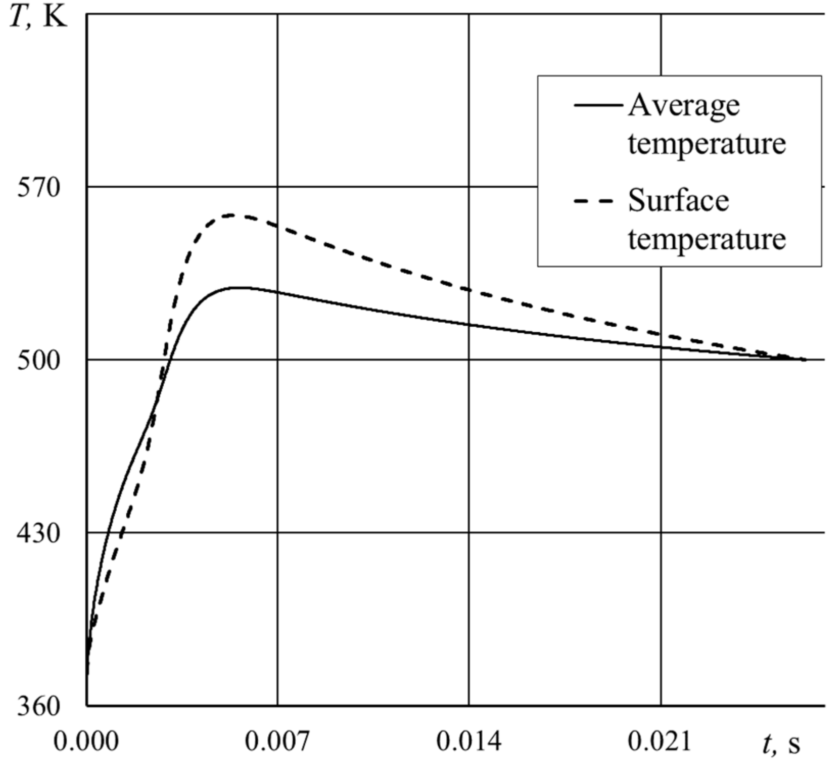
Time evolution of the thickness of the 50%/50% heptane and hexadecane film

Results



Time evolution of average mass fractions of C7H16 and C16H34

Results



Time evolution of surface and average film temperatures

Conclusions

A new model for heating and evaporation of a multi-component liquid film, based on the analytical solutions to the heat transfer and species diffusion equations inside the film, is suggested. The Dirichlet boundary condition is used at the wall and the Robin boundary condition is used at the film surface for the heat transfer equation. For the species diffusion equations, the Neumann boundary conditions are used at the wall, and Robin boundary conditions are used at the film surface. The convective heat transfer coefficient is assumed to be constant and the convective mass transfer coefficient is inferred from the Chilton-Colburn analogy. The model is validated using the previously published experimental data for heating and evaporation of a film composed of mixtures of isooctane/3-methylpentane (3MP). Also, it is applied to the analysis of heating and evaporation of a film composed of a 50%/50% mixture of heptane and hexadecane in Diesel engine-like conditions.

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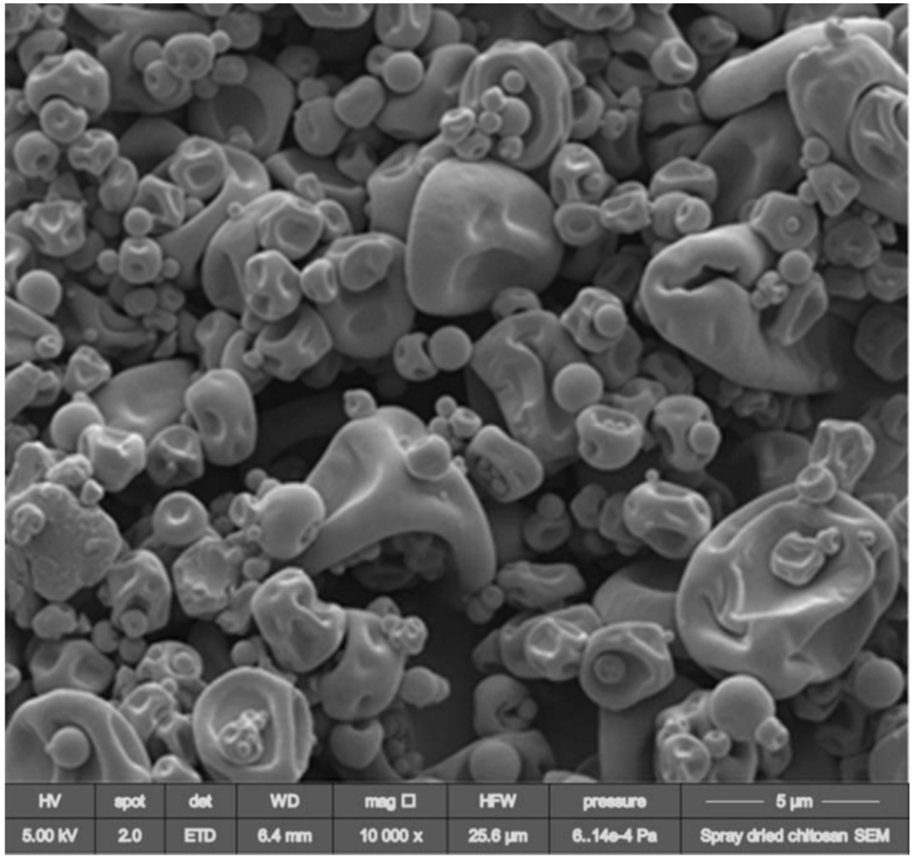
Related developments

Droplet drying

Background


HV
spot
det
WD
mag
HFW
pressure
5 µm
5.00 kV
2.0
ETD
6.4 mm
10 000 x
25.6 µm
6..14e-4 Pa
Spray dried chitosan SEM

Problem formulation

$Y_{p0} = 0.004$, $Y_{w0} = 0.996$

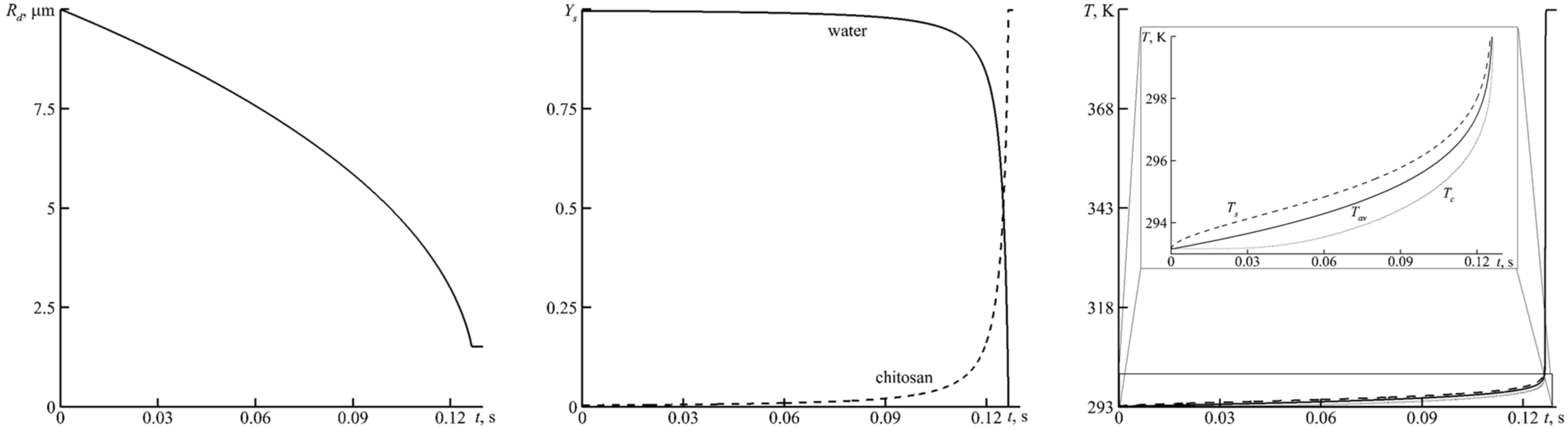
$T_{d0} = 20$ °C, $T_a = 120$ °C

$d_0 = 20$ μm

Chitosan properties:

density 1300 kg/m^3, $c_p = 1674.7$ J/(kg K), $k = 0.25$ W/(m K)^2, $M = 120\,000$ g/mole

Results



Radius, average mass fractions, temperature evolutions
Evaporation time 0.127 s, dry remainder radius 1.51 µm (6% error).

A new model for a drying droplet

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THE FULLY LAGRANGIAN APPROACH TO THE ANALYSIS OF PARTICLE/DROPLET DYNAMICS: IMPLEMENTATION INTO ANSYS FLUENT AND APPLICATION TO GASOLINE SPRAYS

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A model for confined vortex rings with elliptical-core vorticity distribution

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Order reduction in models of spray ignition and combustion

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