A Numerical Analysis of Single & Multi-component Droplet Vaporization in Microgravity

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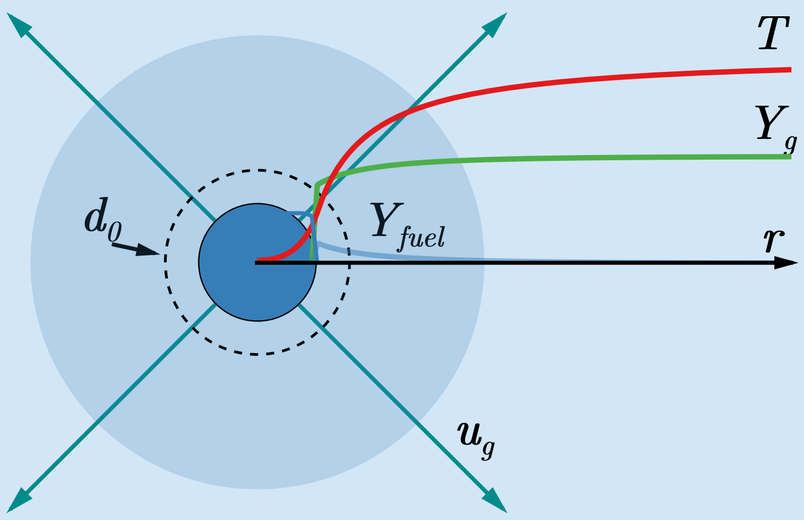
Abstract

As part of a wider effort devoted to increase the basic understanding of droplet combustion, in this work we are concerned with the analysis of the vaporization, without gravity, of an individual droplet in a hot and inert nitrogen environment. Our computational results of a simple-component droplets of n-heptane show a very good agreement with both experiments and other numerical simulations.

Also, in this work we considered the vaporization of bi-component droplets of n-dodecane or n-heptane and n-hexadecane. At low ambient temperatures below the boiling temperatures of both fuels, we found a two-stage vaporization in which the droplet temperature reaches a plateau before the less volatile fuel starts evaporating after the droplet runs out of the most volatile liquid.

On the other hand, at sufficiently high ambient temperature, the experiments found in the literature demonstrated the appearance of puffing, phenomena that cannot be captured in our 1D model. Nevertheless, our simple model turned out to be useful to provide an explanation of the experimental observation in cases when puffing is present.

Formulation



Conservation equations

$$\frac{\partial \rho_\beta}{\partial t} + \nabla \cdot (\rho_\beta u_\beta) = 0$$

$$\frac{\partial (\rho_\beta Y_{\beta,i})}{\partial t} + \nabla \cdot (\rho_\beta Y_{\beta,i} u_\beta) = -\nabla \cdot J_{\beta,i}, \quad i = 2, ..., N_\beta \qquad \beta = \begin{cases} \ell, & \text{if liquid} \\ \mathrm{g}, & \text{if gas} \end{cases}$$

$$\frac{\partial (\rho_\beta h_\beta)}{\partial t} + \nabla \cdot (\rho_\beta h_\beta u_\beta) = -\nabla \cdot \left(-k_\beta \nabla T + \sum_{i=1}^{N_\beta} J_{\beta,i} h_{\beta,i} \right)$$

Boundary conditions at the liquid-gas interface, $r = a(t)$

$$-\dot{m}''(Y_{\mathrm{g},i} - Y_{\ell,i})_{r=a} = -(J_{\mathrm{g},i} - J_{\ell,i})_{r=a}, \qquad i = 2, ..., N_\ell$$

$$(Y_{\mathrm{g},i})_{r=a} = \left(Y_{\ell,i} \frac{W_\ell}{W_\mathrm{g}} \right)_{r=a} \frac{p_{\mathrm{atm}}}{p_\infty} \gamma_i e^{\int_{T_{\mathrm{b},i}}^{T_s} \frac{\mathrm{L}_i(T)}{RT^2} dT}, \qquad i = 1, ..., N_\ell$$

$$-\dot{m}''(Y_{\mathrm{g},i})_{r=a} = -(J_{\mathrm{g},i})_{r=a}, \qquad i = N_\ell + 2, ..., N_\mathrm{g}$$

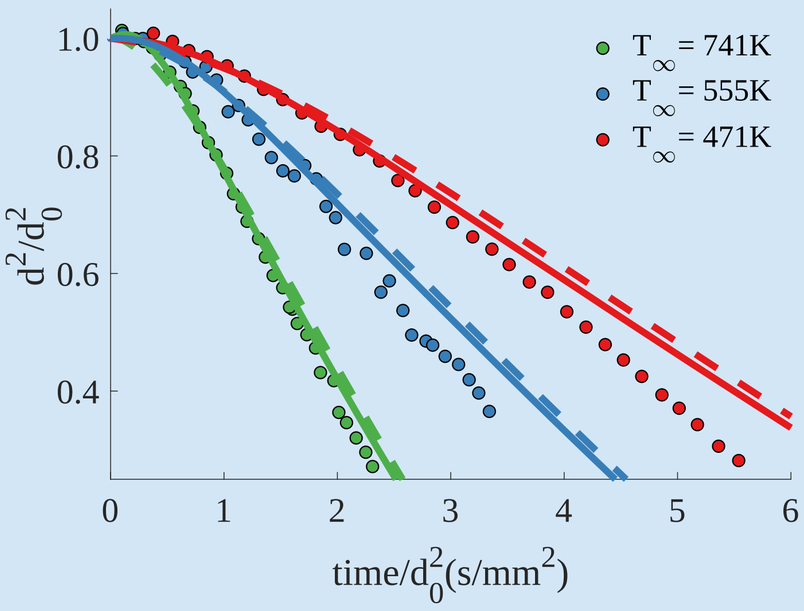
$$-\dot{m}'' \sum_{i=1}^{N_l} \left(Y_{\ell,i} \mathrm{L}_i(T) \right)_{r=a} = \left(k_\mathrm{g} \frac{\partial T}{\partial r} - k_\ell \frac{\partial T}{\partial r} \right)_{r=a} - \sum_{i=1}^{N_l} \left(J_{\ell,i} \mathrm{L}_i(T) \right)_{r=a} + \alpha_{\mathrm{eff}} \sigma (T_\infty^4 - T_s^4)$$

Results

1 Dimensional approach – – **Rapid Mixing approach ——**

Single-component droplets

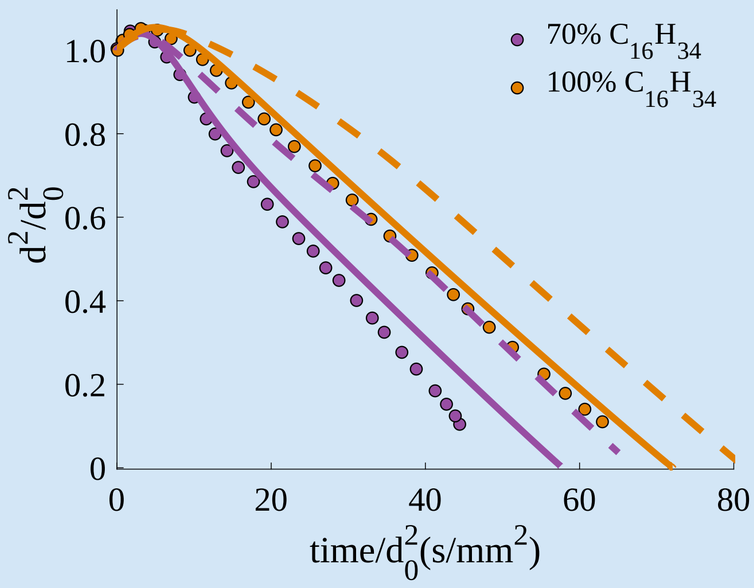
C_7H_{16} droplets evaporation



Multi-component droplets

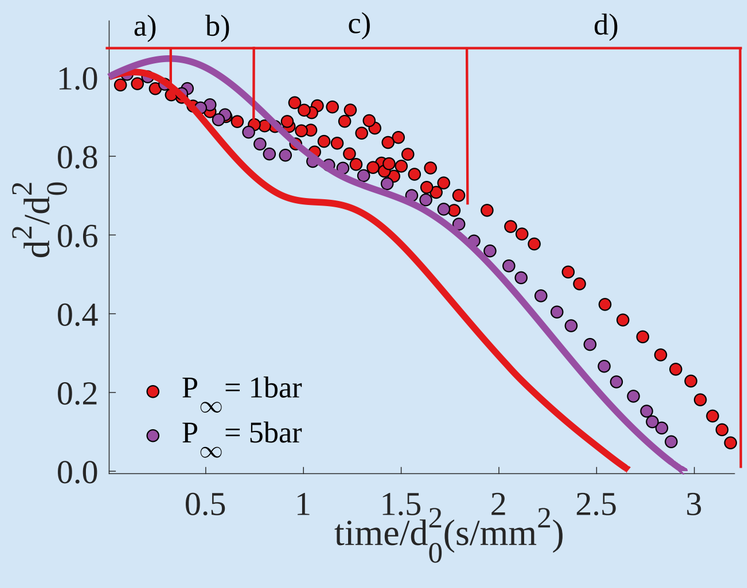
T_∞ **below boiling temperatures**

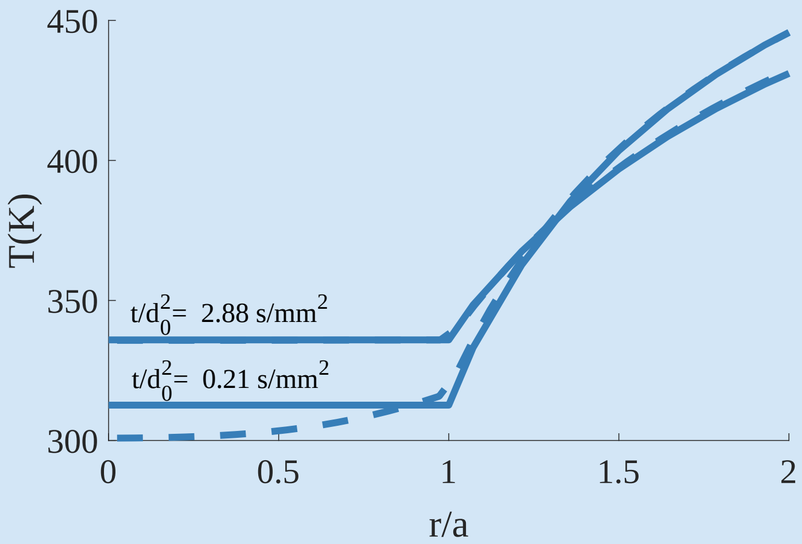
$C_{12}H_{26}$ & $C_{16}H_{34}$ mixture droplets evaporation

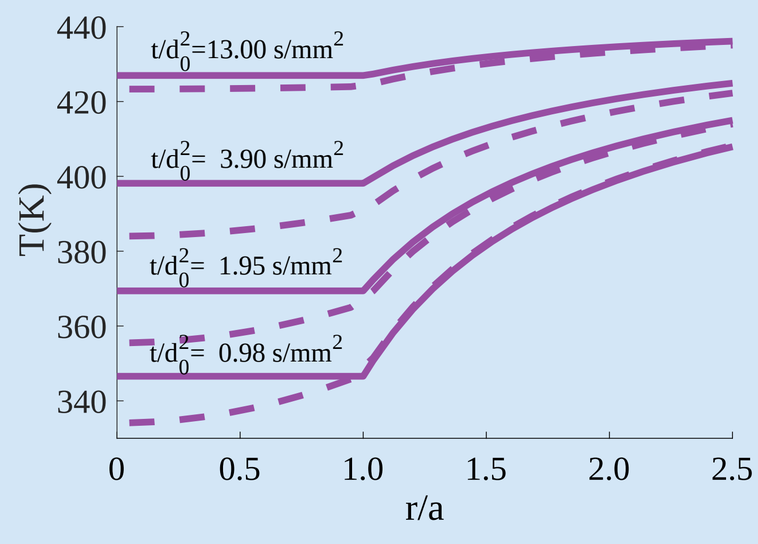


T_∞ **above boiling temperatures**

C_7H_{16} & $C_{16}H_{34}$ mixture droplets evaporation







a) Heat up

b) Bubble nucleation

c) Puffing phenomena

d) Vaporization of the less volatile component

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This work was supported by project ENE2015-65852-C2-1-R (MINECO/FEDER,UE)