# The influence of the near droplet neighbourhood on droplet evaporation

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## Introduction

In most industrial multi-phase simulations that also include phase change, Lagrangian models are used to keep track of the liquid phase and the evaporation process. One major assumption of these evaporation models is that they are based on the evaporation of a single isolated droplet. However, they do not account for interactions of neighbouring droplets. Hence, they are not well suited for the simulation of dense sprays, where the distance between droplets is rather small. According to [1], the interaction of evaporating droplets starts when the non-dimensional droplet distance

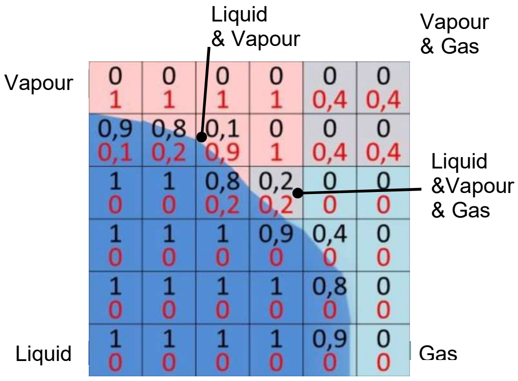
$$\boldsymbol{\beta} = \frac{\boldsymbol{L}}{\boldsymbol{D}} \tag{1}$$

is smaller than 8. Here, $L$ refers to the distance of the droplet centres, and $D$refers to the droplet diameter.

Using the method of Direct Numerical Simulation (DNS), a numerical study of two neighbouring evaporating droplets is performed. The temperature and vapour profiles in the near droplet neighbourhood are analysed. The results are compared to the screening factor calculations from the analytical model by [2]. The overall goal is to improve the understanding of the influencing parameters for a simple approximation that can then be used in Lagrangian models.

## Numerical method

The simulations were carried out using the in-house code Free Surface 3D (FS3D) [3], a multiphase DNS tool developed at the ITLR. The code solves the incompressible Navier-Stokes equations using the volume of fluid (VOF) method [4] to account for multiple phases. The convective transport is determined by the piecewise linear interface calculation (PLIC) method [5].



| | | | | | |
|---|---|---|---|---|---|
| 0<br>1 | 0<br>1 | 0<br>1 | 0<br>1 | 0<br>0,4 | 0<br>0,4 |
| 0,9<br>0,1 | 0,8<br>0,2 | 0,1<br>0,9 | 0<br>1 | 0<br>0,4 | 0<br>0,4 |
| 1<br>0 | 1<br>0 | 0,8<br>0,2 | 0,2<br>0,2 | 0<br>0 | 0<br>0 |
| 1<br>0 | 1<br>0 | 1<br>0 | 0,9<br>0 | 0,4<br>0 | 0<br>0 |
| 1<br>0 | 1<br>0 | 1<br>0 | 1<br>0 | 0,8<br>0 | 0<br>0 |
| 1<br>0 | 1<br>0 | 1<br>0 | 1<br>0 | 0,9<br>0 | 0<br>0 |

**Figure 1.** Schematic of scalar fields of both VOF-variables $f_1$ (black) and $f_2$ (red)

In order to account for phase change processes, an additional VOF variable, $f_2$, is introduced for the volume fraction of vapour (see Figure 1). As a consequence, we now solve a second transport equation

$$\frac{\partial f_2}{\partial t} + \nabla \cdot \left(f_2 \boldsymbol{u}_{gp}\right) = \nabla \cdot \left(\mathcal{D}_{12} \nabla f_2\right) + \frac{\dot{m}_v'''}{\rho_v}, \tag{2}$$

which includes a source term for the evaporating mass as well as a diffusion term. The source term is also accounted for in the transport equation of the liquid phase. However, diffusion of gas or vapour into the liquid phase is neglected.

## Results and Discussion

A water droplet tandem at temperature of $293\,\mathrm{K}$ is simulated with a non-dimensional distance of $\beta = 2$. The surrounding gas properties are set to those of air and no external flow field is induced. Figure 2 shows the contour plots of both the vapour volume fraction (left) and temperature distribution (right) on a centre slice through the domain.

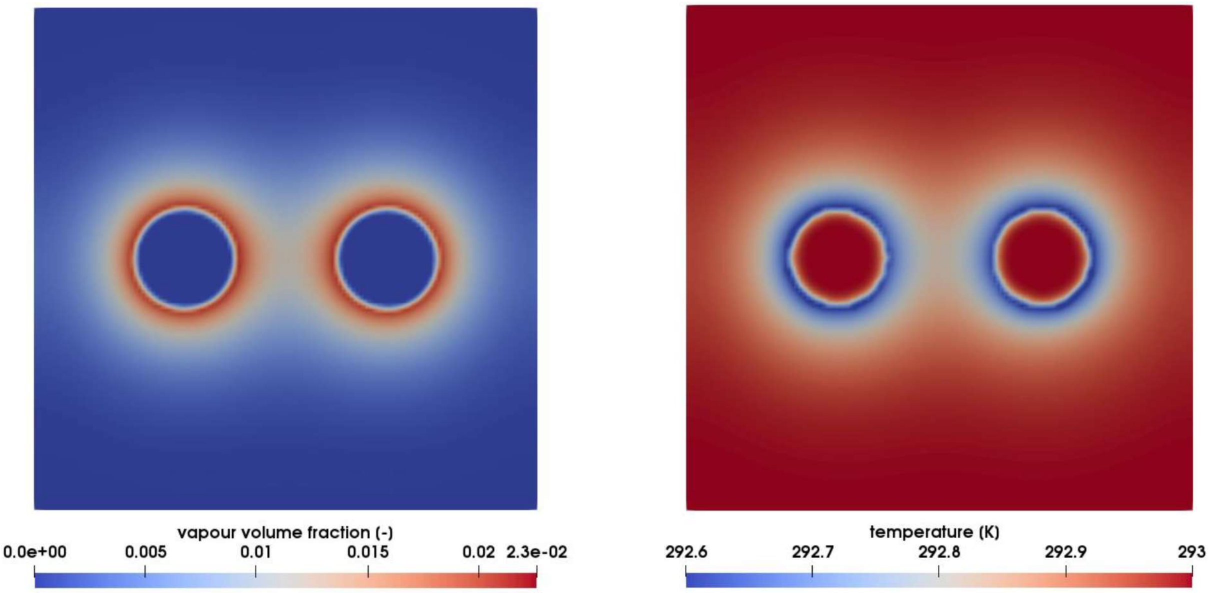


**Figure 2.** Contour plots of vapour volume fraction (left) and temperature (right)

Both droplets have the same size of $D = 6 \times 10^{-4}\,\mathrm{m}$. The computational domain has a size of $5D \times 5D \times 5D$ with a resolution of $128 \times 128 \times 128$ cells. Figure 2 displays the expected symmetry of the problem. Even though the simulation is started in isotherm conditions (with the surrounding gas being also at $293\,\mathrm{K}$), a temperature decrease at the droplet surface can be seen. This is due to the latent heat of evaporation which is required for the phase change. This can be further observed in Figure 3, showing the distribution along the centre line.

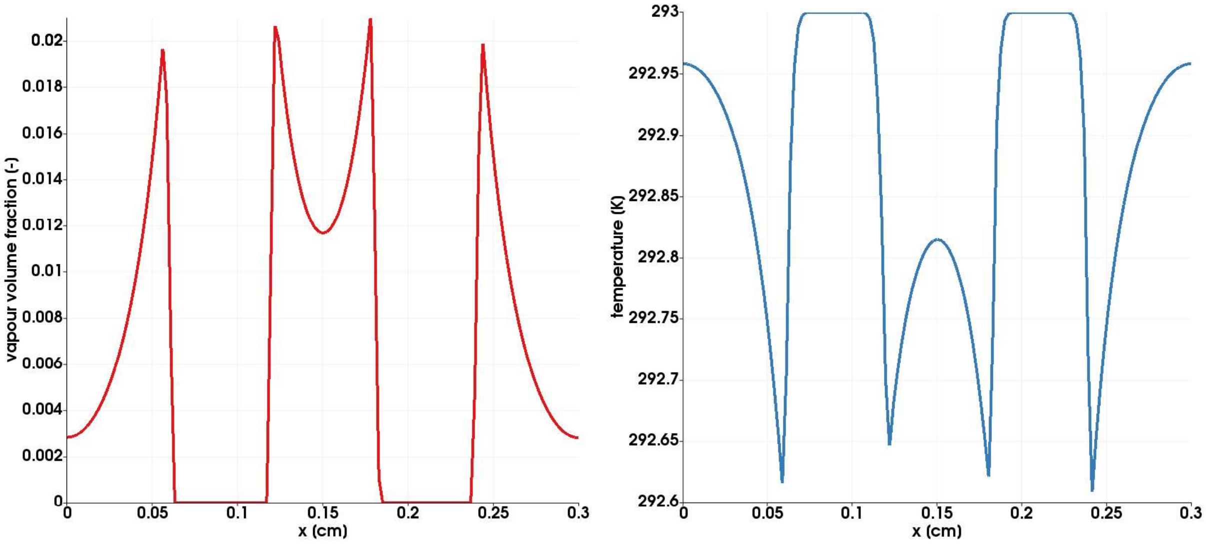


**Figure 3**. Distribution of vapour volume fraction (left) and temperature (right) along centre line

The existence of the second droplet has an evident influence on both the vapour and the temperature profile. First, the total evaporation rate decreases compared to that of two single, isolated droplets. Vapour accumulates between the droplets and does not diffuse to the surroundings. Therefore, the gradient of the vapour volume fraction decreases and with it also the evaporation rate. Second, the gas phase between the two droplets cools down, which causes a further decrease in the evaporation rate.

Finally, the numerical results of the evaporating droplet tandem are compared to an analytical solution [2] using a so called screening factor, which compares the total evaporation rate of the tandem to the sum of the evaporation rates of two isolated droplets and is defined as

$$\boldsymbol{\phi} = \frac{\boldsymbol{m}_{ev,1}+\boldsymbol{m}_{ev,2}}{\boldsymbol{m}_{ev,is,1}+\boldsymbol{m}_{ev,is,2}}. \qquad (3)$$

The analytical approach holds a value of $\phi_{analytical} = 80.48\,\%$ while the DNS results in a value of $\phi_{DNS} = 92.98\,\%$. Even though these values are in the same range, further investigations will show why the simulations show a much weaker influence of the neighbouring droplet. Additionally, a parameter study on the distance, temperature level, and initial vapour mass fraction will be conducted.

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**Nomenclature**

| | | |
|---|---|---|
| $\beta$ | [-] | nondimensional droplet distance |
| $D$ | [m] | droplet diameter |
| $\mathcal{D}_{12}$ | [m$^2$ s$^{-1}$] | binary diffusion coefficient |
| $f_i$ | [-] | volume fraction ($i$ = 1: liquid, $i$ = 2: vapour) |
| $L$ | [m] | distance between droplet centres |
| $\dot{m}_{\mathrm{v}}'''$ | [m$^3$ kg$^{-1}$] | volumetric mass source term |
| $\rho_v$ | [kg m$^{-3}$] | vapour density |
| $u_{gp}$ | [m s$^{-2}$] | gas phase velocity |
| $\phi$ | [-] | nondimensional screening factor |
| DNS | | Direct Numerical Simulation |
| FS3D | | Free Surface 3D |
| PLIC | | Piecewise Linear Interface Calculation |
| VOF | | Volume of Fluid |

**References**

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