Spatial distribution modeling of droplets during water dropwise condensation on textured surfaces

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MOTS CLES
Spatial distribution, Poisson process, dropwise condensation, textured surface, topography

INTRODUCTION

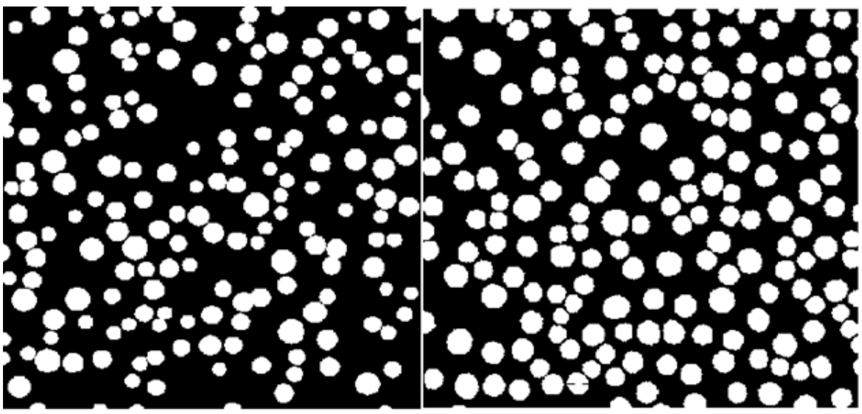
The aim of this study is to simulate water droplets spatial distribution on flat and textured surfaces in order to control droplets nucleation and growth by manipulating surface morphology. This process has a great importance in analyzing and manufacturing of condensers, heat exchangers and other steam operating devices [1]. Two main mechanisms for droplet growth are generally considered in dropwise condensation models, water absorption from gas phase and coalescence [2]. It can be said that water absorption is a slow continuous growth mechanism for all types of droplets, contrary to the effect of coalescence which is a faster growth process. In the current study, the process of dropwise condensation was modeled using a computer program considering both absorption and coalescence. Then the results of this model were compared to experimental results using Ripley function method.

Computer simulation

We used an algorithm starting with 1500 random points with size of 1µm, containing an iterating process in which, droplets grow at each time step according to equation 1 [3].

$$r_{new} = [(r_{old})^2 + G]^{1/2}, \quad G = 4.15\frac{K\Delta T}{H\rho} \qquad (1)$$

where K is water thermal conductivity, ΔT is temperature difference between substrate and water, H is heat of condensation and ρ is water density. At each step the probability of coalescence was checked by calculating the distance between each pair of points and if the distance was less than the sum of the two drops radii, these coalesced and formed a bigger drop (see Figure 1). The radius of the resulting droplet was calculated based on its volume and its centroid was in the center of mass of the two coalescing drops.Figure 1 shows the distribution of droplets from model and experiments. It can be seen that there is a good agreement between the two pictures. In both figures the droplets are dispersed randomly and cover about 80% of the surface.



a)Droplets distribution from model b)Droplets distribution from experiments

Figure 1: Results of model and experiment for droplets distribution on a flat surface.

Data validation

The validation of the model was done by comparing the simulation with experimental data. For this reason, the dropwise condensation experiments were observed on a plaque of Polycarbonate, with a resolution of 2.2 Megapixels (2028x1088) grayscale 8-bit, and a magnification allowing to have 0.87 microns / pixel.

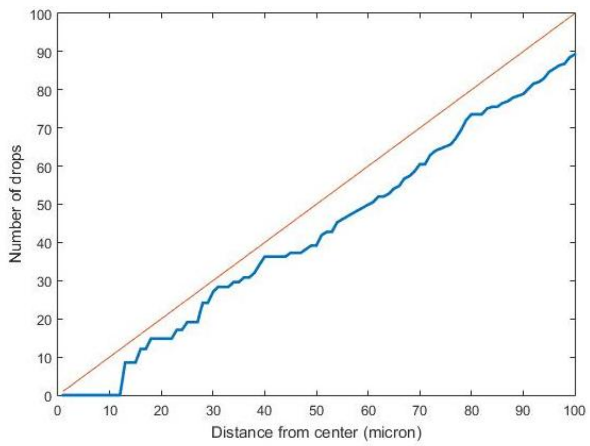
The Ripley function was used for comparison [4]. It basically evaluates the mean number of drops within a specific distance from each drop center. As an element of comparison, the Ripley function of a Poisson Point Process (considered as a completely random process) is the straight line of equation x=y. In the case of clustering or dispersion the graph will deviate from this line.

Ripley function $\hat{K}$ (x) can be calculated according to equation below.

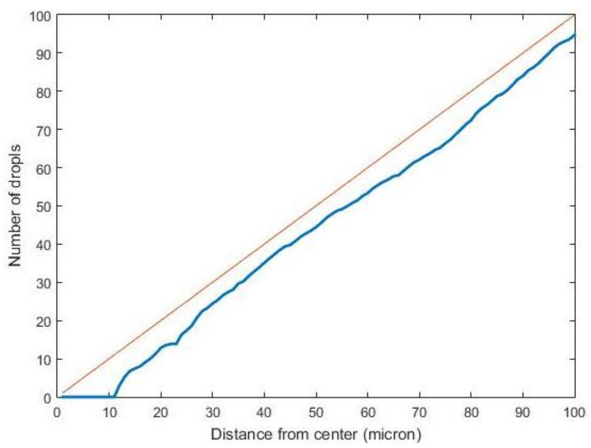
$$\hat{K}(x) = \hat{\lambda}^{-1} \sum_i \sum_{j \neq i} w(l_i, l_j)^{-1} \frac{I(d_{ij} < x)}{N} \qquad (2)$$

where$d_{ij}$is the distance between the ith and jth points, and generally I(X) is the indicator function with the value of 1 if Xis true and 0 otherwise. However, since the boundaries of the study area are usually arbitrary, edge effectsarise because points outside the boundary are not counted in the numerator, even if they are within distance t of a point in the study area. The weight function, $w(l_i, l_j)$, provides the edge correction. It has the value of 1 when the circle centered at $l_i$and passing through the point l_j(i.e. with a radius of d_{ij}) is completely inside the study area. If part of the circle falls outside the study area (i.e. if $d_{ij}$is larger than the distance from lto at least one boundary), then $w(l_i, l_j)$is the proportion of the circumference of that circle that falls in the study area.

Figure 2 shows the Ripley function of results of model and experimental data. The straight orange line indicates Poisson point process. As it can be seen in these two graphs there is a gap around 10 µm between each two drops center. This means that each two droplets cannot become very close to each other without coalescing. The rest of graphs are asymptotic to the Poisson Ripley function. This shows that Poisson process can predict properly the experimental results except for small radii.



a)Ripley function of droplets distribution from model



b)Ripley function of droplets distribution from experiments

Figure 2: Ripley function of results of model and experimental data.

CONCLUSION

In this study a model based on Poisson Point Process was used to describe droplet spatial distribution in dropwise condensation. The comparison of the results that was predicted by model and experimental data shows that there is a good agreement between droplet spatial distribution and Poisson point process before sliding of big droplets, except for small radii. To handle this problem, a hard-core process model can be used for modeling the spatial distribution of droplets during dropwise condensation.

The main perspective of this project is to study the spatial distribution models of nucleation in relation with the geometrical and physical properties of textured surfaces.

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