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Drop distributions and numerical simulation of dropwise condensation heat transfer

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Abstract

The random fractal model is firstly put forward to simulate the drop size and spatial distribution in dropwise condensation. The boundary conditions of heat conduction through the condensing wall surface are then established using the heat transfer model through a single drop proposed by J.W. Rose. A numerical method towards the directed simulation of dropwise condensation heat transfer is presented. The model considered the effect of the nonuniformity of surface heat transfer thermal conductivity of the condenser material on dropwise condensation. Numerical computations are conducted for dropwise condensation heat transfer of water on the copper wall on a very wide range of pressure. The numerical simulation results agreed well with the bulk of existing experimental data and the precision is higher than the model proposed by Rose. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Dropwise condensation; Heat transfer; Fractal; Numerical simulation

1. Introduction

Dropwise condensation has attracted considerable interest owing to its heat transfer coefficient much larger in order of magnitude than that of filmwise condensation. Considerable progress has been made to calculate the heat transfer through a single drop of a given size. However, the size and spatial distribution of drops must also be known to calculate the average heat transfer for the entire surface. The nonuniformity of surface heat transfer and the effect of thermal conductivity of the condensing wall material on dropwise condensation still need to be studied.

Gose, Mucciardi and Baer [1], Tanasawa and Tachibana [2] have attempted to model the growth and coalescence by computer simulation for the entire range of sizes on a fixed area, but the computer facility at that time limit their investigations to artificially low site densities in the order of 10^4 sites per cm^2. Their calculated heat transfer coefficients were lower in order of magnitude than experimental observed values. Glicksman and Hunt [3] divide the dropwise condensation cycle into a number of stages, starting with values of nucleation site density up to $10^8/cm^2$, but they also omit the effects of nonuniform conduction.

The description of drop size and spatial distribution is the key to simulating dropwise condensation heat transfer. Although many research works on drop size distributions of dropwise condensation had been conducted early and a general drop size-distributions function is obtained [4–9]. The drop spatial-distributions on dropwise condensations are less well understood till now. Drop spatial-distributions has become the main obstacle to the direct numerical simulation of dropwise condensation heat transfer. It is the aim of the present work to put forward the random fractal model describing the drop size and spatial distributions. The boundary condition of heat conduction equation of condensing wall is obtained from the model of heat transfer through a single drop proposed by Rose. The numerical simulations of dropwise condensation over a wide range of pressures are performed thereby.

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Nomenclature

A	area
A_k	area of elementary cell of generation k
$A(r)$	the fraction of total area covered by all drops having radius in the interval r, r_m
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
h	heat transfer coefficient
h_c	heat transfer coefficient of drop
h_n	heat transfer coefficient of forced convection
h_{fg}	latent heat of vaporization
k_s	thermal conductivity of condenser material
k_l	thermal conductivity of drop
k_v	thermal conductivity of vapor
l	length
n	drop size distributions exponent
N_k	area of elementary cell of generation k
$\bar{N}(r)$	number of drop with radius larger than r
Nu	Nusselt number
P	the fraction of available area
Pr	Prandtl number
q	mean heat flux
r	drop radius
r_{min}	minimum drop radius
r_{max}	maximum drop radius
$\hat{r}_{max}$	instantaneous maximum drop radius
R	gas constant
Re	Reynolds number
T	temperature
T_v	vapor temperature
T_0	temperature on the bottom surface of condenser
T_s	saturated temperature
ΔT	subcooling
u	vapor velocity

Greek symbols

σ	surface tension
ρ_l	liquid density
ρ_v	vapor density
a	thermal diffusivity (m^2/s)
τ	time
τ_0	drop sweeping period
v	kinematic viscosity

2. Drop size and spatial distributions

2.1. The general drop size distributions function

The fraction of total area covered by all drops, $A(r)$, having radius in the interval (r, r_m) can be written as

$$A(r) = 1 - (r/r_m)^n. \tag{1}$$

This form is supported by the experimental results of different researchers, such as Graham and Griffith [5], Tanaka [6], Tanasawa and Ochiai [7] with the distribution exponent, n, lying in the range (0.313–0.350). So we assume n to be a constant and take a value about 1/3. Then if $\bar{N}(r)$ is defined as the number density of the drops which have radius larger than r,

$$-\frac{\mathrm{d}(\bar{N}(r))}{\mathrm{d}r} = -\frac{1}{\pi r^2}\frac{\mathrm{d}A}{\mathrm{d}r} = \frac{n}{\pi r_m^3 (r/r_m)^{n-3}}. \tag{2}$$

Drops size distribution can be well described by Eq. (2). The dimensionless drops size distribution can be obtained as

$$\lg\left[-r_m^3\frac{\mathrm{d}\bar{N}(r)}{\mathrm{d}r}\right] = -(3-n)\lg(r/r_m) + \lg\left(\frac{n}{\pi}\right). \tag{3}$$

Thus the experimental results of different researchers could fall on the same line in plots of $\lg[-r_m^3\frac{\mathrm{d}\bar{N}(r)}{\mathrm{d}r}]$ versus $\lg(r/r_m]$. The drops size distribution measured by Graham and Griffith [5], Tanaka [6], Tanasawa and Ochial [7] are plotted together in Fig. 1, from which the drops size distribution can be well described by Eq. (3) in the drops size range covering three orders of magnitude.

Rose and Glicksman [8] have attempted to describe the drop size distributions using a sequence events' model and derived a modified function of the drop size distributions being the approximately the same as Eq. (3) with distribution exponent $n = 0.382$. Tanaka [9] expressed the stochastic process of drop growth due to

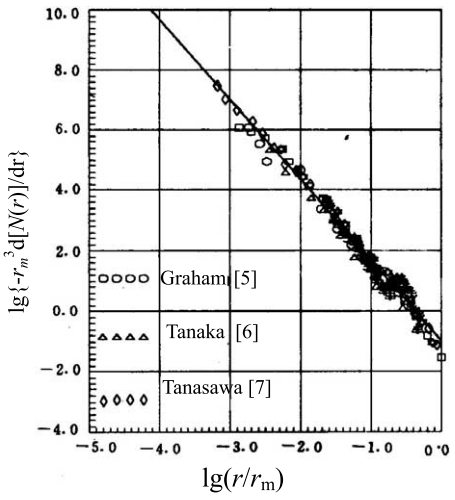

Fig. 1. Experimental results of drops size distribution.

both condensation and coalescence with a set of integral–differential equations [10], and a transient distribution of drop belonging to the same generation was obtained firstly, and then, the averaged drop size distributions were obtained. The averaged drop size distributions agreed also very well with that of Eq. (3), and the value of the distribution exponent n was show as 0.320.

As mentioned above, a surprisingly good agreement exists between theories and measurements, especially in the theoretical works, the fluctuation and the inhomogeneity of condensing surface temperature are not take into consideration. So, Le Fevre [11] guessed that the drop size distributions might be decided simply geometrically, independent of the heat transfer process [11]. In fact, dropwise condensation consists of the transient process occurring repeatedly on the condensing surface. We find that the photographs of dropwise condensation taken at different instant or in different scale are similar and a whole photograph can be obtained by enlarging properly a local photograph. These features indicated that dropwise condensation appears with self-similarity which is one of the most important feature of fractal. In addition, drop spatial distribution also possesses randomicity. So, a random fractal model is presented here to describes drop size and spatial distribution.

2.2. Proposed random fractal model of drop distribution

Referred to Fig. 2(a), a square with unit length were divided into m^2 small squares, in which $P \times m^2$ small squares were randomly selected as the first generation of elementary cells ($P < 1$). In order to construct the second generation of elementary cells, the side length were reduced to $1/(2m)$, thus the unit length square can be divided into $4m^2$ small squares with the side length of $1/(2m)$. Then in these small squares, some small squares were randomly selected as the second generation of elementary cells. The fraction of 'available area' covered by the generation of elementary cells must also be P. The fraction of available area is defined as the ratio of the area covered by every generation of elementary cells to the area not covered by older generations. By repeating the above process, more generations of elementary cells with smaller side length can be constructed. If these small squares were replaced by inscribed circles, we can obtain the lifelike picture of drop distributions on dropwise condensing surface. For comparison, a condensing photograph from [10] is also given in Fig. 2(b).

Generally, the total area of elementary cells of generation k is given by

$$N_k A_k = \left(1 - \sum_{i=1}^{k-1} N_i A_i\right) \cdot P, \tag{4}$$

where N_k and A_k are amount and area of elementary cells of generation k, respectively.

From Eq. (4), we obtain

$$N_k A_k = (1 - P) \cdot N_{k-1} A_{k-1}. \tag{5}$$

The amount of elementary cells of generation k is then given by

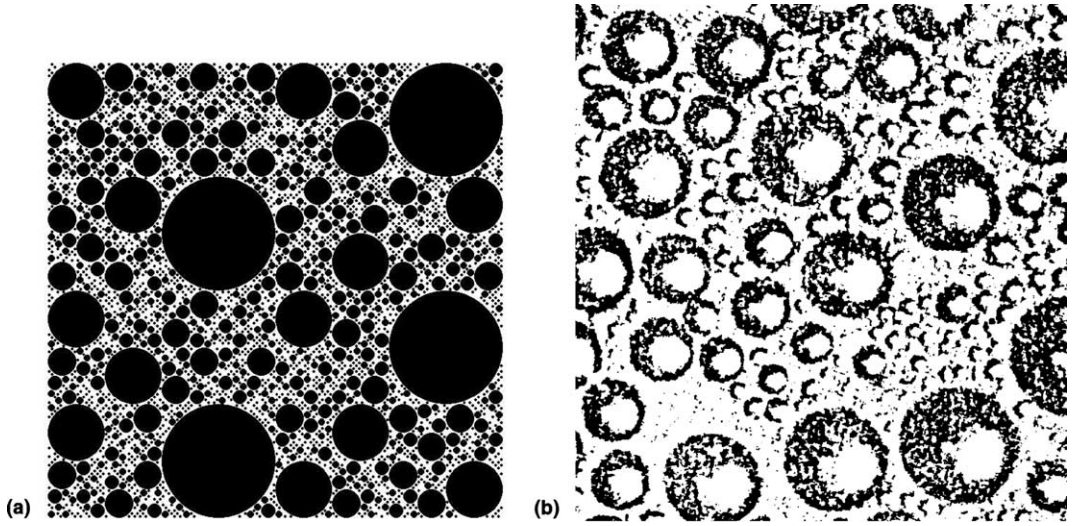

Fig. 2. Comparison of drop distribution between random fractal model and photography. (a) Drop distribution constructed by using the random fractal model. (b) Close-up photography of condensing surface [10].

$$N_k = N_1 Z_1^2 (1-P)^{k-1} \cdot Z_k^{-2} = P(1-P)^{k-1} Z_k^{-2}, \tag{6}$$

where Z_k is the side length of elementary cells of generation k.

From the method of elementary cells, we have

$$k - 1 = \frac{\lg(Z_k/Z_1)}{\lg 2} \tag{7}$$

and

$$\Delta Z_k = Z_k - Z_{k-1} = Z_k - 2Z_k = -Z_k. \tag{8}$$

Denoting $\bar{N}_k = \sum_{i=1}^{k} N_i$, then

$$\bar{N}_k = \bar{N}_k - \bar{N}_{k-1} = N_k. \tag{9}$$

In addition

$$\frac{\mathrm{d}\bar{N}_k}{\mathrm{d}Z_k} = \lim \frac{\Delta \bar{N}_k}{\Delta Z_k}. \tag{10}$$

Thus we can obtain the size distribution of elementary cells as

$$\lg\left(-Z_1^3 \frac{\mathrm{d}\bar{N}_k}{\mathrm{d}Z_k}\right) = -\left[3 + \frac{\lg(1-P)}{\lg 2}\right] \lg \frac{Z_k}{Z_1} + \lg P. \tag{11}$$

Comparing Eqs. (11) and (3), we find that the distribution exponent can be written as

$$N = -[\lg(1-P)/\lg 2]. \tag{12}$$

In fact, the ratio, γ, of the side length of any generation of elementary cells to the next generation is arbitrary constant. If the drop size distributions is rededuced and γ replaced 2 as the ratio of the side length between any two neighboring generations of elementary cells, then Eqs. (11) and (12) become

$$\lg\left(-Z_1^3 \frac{\mathrm{d}\bar{N}_k}{\mathrm{d}Z_k}\right) = -\left[3 + \frac{\lg(1-P)}{\lg \gamma}\right] \lg \frac{Z_k}{Z_1} + \lg \frac{P}{\gamma - 1}, \tag{13}$$

$$n = -[\lg(1-P)/\lg \gamma]. \tag{14}$$

2.3. Determination of P by using renormalization group method

Larger drop is formed by coalescence between neighboring smaller drops. The fact enlightens us that the fraction P of available area can be obtained by using renormalization group method. P can also be actually considered as the probability of finding drop in a grid. For the four neighboring grids, the drops can coalesce in all the situations except having only a drop and two neighboring diagonal drops, as illustrated in Fig. 3. Thus the probability of finding drop in the grid with the double size can be determined by

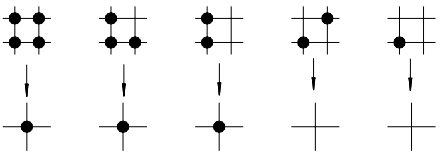

Fig. 3. Sketch of renormalization.

$$P' = P^4 + 4P^3(1-P) + 4P^2(1-P)^2. \tag{15}$$

According to the constructing process of the random fractal model, $P' = P$ can be obtained, that is, P is the stationary point of the followed equation

$$P = P^4 + 4P^3(1-P) + 4P^2(1-P)^2. \tag{16}$$

Four roots of Eq. (16) are: $P_1 = (-3 - \sqrt{21})/6$, $P_2 = 0$, $P_3 = (-3 + \sqrt{21})/6$, $P_4 = 1$. Among the four roots, only $P_3 = 0.2638$ meets the condition $0 < P < 1$. Compensation factor $\pi/4$, which is the ratio of area of inscribed circle to that of square is introduced to eliminate the error which is brought by the replacement of small squares by inscribed circles. Thus drop distribution exponent can be obtained from Eq. (12)

$$n = -[\lg(1 - P\pi/4)]/\lg 2 = 0.3349. \tag{17}$$

The value of n is very close to the experimental result, 1/3. By computer simulation, Rose and Glicksman [8] find the value of P lies in 0.5–0.6 and for $P = 0.5$, 0.55 and 0.6, the corresponding values for γ are 4.4643, 5.2910 and 6.3291, respectively. Substituting these values into Eq. (14), the corresponding values of distribution exponents are 0.3334, 0.3395 and 0.3454, respectively. The results are also very close to the experimental results and the above results obtained by using renormalizing group method. In addition, the value of the second item in the right of Eq. (3) is $\lg(n/\pi) = -0.9743$. substituting these above-mentioned values of P and γ obtained by Rose and Glicksman into the second item in the right of Eq. (14), the corresponding values of the second item are −0.9458, −0.9973 and −1.0536, respectively. On the other hand, Substituting $P = 0.2638$, $\gamma = 2$, into the second item in the right of Eq. (14), the corresponding values of the second item is −0.579. It can be found that $P = 0.55$ and $\gamma = 5.29$ can obtain the best agreement with the existing experimental results. So $P = 0.55$ and $\gamma = 5.29$ were taken in the following numerical simulation.

The random fractal model provides a method of constructing drop size and spatial distribution and obtains the geometric boundary condition of dropwise condensation heat transfer. This established the base for the following numerical simulation.

3. Mathematical model of dropwise condensation heat transfer

3.1. Basic equations

Fig. 4 shows the considered cell, which consists of the drops and the part of the condensing wall. The governing equation for energy conservation to describe the process is

$$\frac{\partial T}{\partial \tau} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right). \tag{18}$$

In fact, dropwise condensation consists of transient processes, i.e., the primary drops are formed at nucleation sites, and then coalescence occurs between the drops' growth of neighboring drops. A new generation of drops is formed at the sites exposed by coalescence, and so on until a falling drop sweeps from condensing surface. Because the time response of the condensing surface temperature variable is quite rapid, and the average heat transfer coefficients of dropwise condensation can be calculated using the simplified steady-state conduction equation as: $(\partial T/\partial \tau) = 0$ in Eq. (18), or

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0. \tag{19}$$

As for comparison, typical results with unsteady-state model are also given to obtain the temperature variation with time for specified condensing surface.

3.2. Heat transfer through a single condensate drop

For a hemispherical drop with uniform base temperature, Rose [10] evaluated the combined thermal resistance arising from conduction in the drop and interfacial mass transfer at the vapor–liquid interface to obtain the mean heat transfer coefficient through a hemisphere drop as

$$h_c = \frac{4k_l}{\pi r}\left(1 - \frac{r_{\min}}{r}\right)\ln\left[1 + v\left(1.09 + \frac{\pi/2 - 1.09}{v/5.7 - 1}\right)\right], \tag{20}$$

where r is drop radius,

$$v = \alpha_i r/k_l, \tag{21}$$

α_i is the vapor–liquid interfacial heat transfer coefficient which may be estimated from kinetic theory, or

$$\alpha_i = \frac{n-1}{n+1}\frac{\rho_v h_{fg}^2}{T_v}\sqrt{\frac{2\pi}{RT_v}}, \tag{22}$$

and minimum drop radius $r_{\min}$ can be calculated from

$$r_{\min} = \frac{2\sigma T_v}{\rho_l h_{fg}\Delta T}. \tag{23}$$

3.3. Heat transfer through bare surface

In order to prevent the buildup of enriched noncondensable gas, steam must flow along the condensing surface. So heat transfer through the bare surface can be considered as the forced convection heat transfer flowing along a flat plate, for which the mean heat transfer coefficient is predicted as usual from well-known relations

$$\begin{aligned} Nu &= 0.664 Re^{1/2} Pr^{1/3}, \quad Re < 5\times 10^5 \\ Nu &= (0.037 Re_l^{0.8} - 871) Pr^{1/3}, \quad Re \geqslant 5\times 10^5 \end{aligned} \tag{24}$$

where $Nu = h_f l/k_v; Re = ul/v$. l is the characteristic length of condensing surface, i.e., the vapor flow path along the surface.

4. The numerical simulation method

Since the heat conduction equation for the condensing wall cannot be solved analytically, a numerical method has to be used. A finite difference method

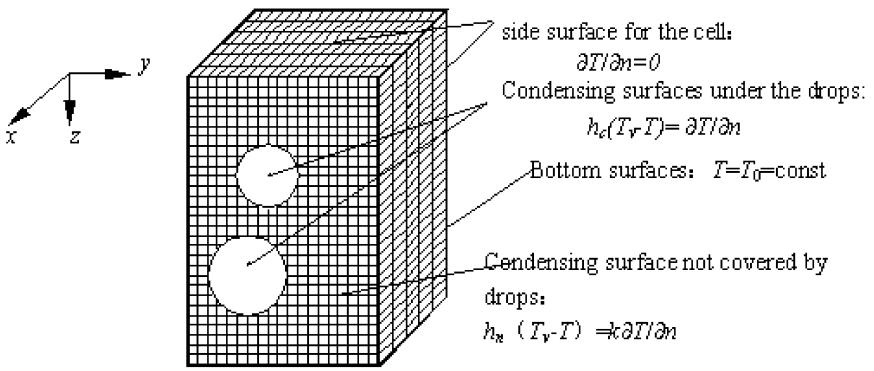

Fig. 4. Condensing cell and boundary conditions.

(FDM) is chosen to simulate dropwise condensation heat transfer.

4.1. Finite difference equation

Eq. (18) is discretized using the method of control volume approach as shown in Fig. 5, the integral form of Eq. (18) is established as

$$\begin{aligned}\int_s^n \int_w^e \int_b^m \int_t^{t+\Delta t} \rho c_p \frac{\partial(T)}{\partial t}\,\mathrm{d}t\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z &= \int_t^{t+\Delta t} \int_b^m \int_s^n \int_w^e \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}t \\ &+ \int_t^{t+\Delta t} \int_b^m \int_w^e \int_s^n \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)\mathrm{d}y\,\mathrm{d}x\,\mathrm{d}z\,\mathrm{d}t \\ &+ \int_t^{t+\Delta t} \int_w^e \int_s^n \int_b^m \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial Z}\right)\mathrm{d}z\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}t. \quad (25)\end{aligned}$$

It can be discretized using the finite-volume mesh so that as

$$\begin{aligned}a_P T_P &= a_E T_E + a_W T_W + a_N T_N + a_S T_S + a_M T_M \\ &+ a_B T_B + a_p^0 T_p^0, \quad (26)\end{aligned}$$

where

$$a_E = \frac{\Delta y \Delta z}{(\delta x)_e}, \quad a_W = \frac{\Delta y \Delta z}{(\delta x)_w}, \quad a_N = \frac{\Delta x \Delta z}{(\delta y)_n},$$

$$a_S = \frac{\Delta x \Delta z}{(\delta y)_s}, \quad a_M = \frac{\Delta y \Delta x}{(\delta z)_m}, \quad a_B = \frac{\Delta y \Delta x}{(\delta z)_b},$$

$$a_P^0 = \frac{\Delta x \Delta y \Delta z}{\alpha \Delta t},$$

$$a_P = a_E + a_W + a_N + a_S + a_M + a_B + a_P^0.$$

The discretization of Eq. (19) can be similarly obtained

$$\begin{aligned}a_P T_P &= a_E T_E + a_W T_W + a_N T_N + a_S T_S + a_M T_M \\ &+ a_B T_B, \quad (27)\end{aligned}$$

where $a_P = a_E + a_W + a_N + a_S + a_M + a_B$.

4.2. Treatment of boundary conditions

Fig. 6 shows the control volume of boundary point. For the four side surfaces of condensing wall, the discretization of boundary condition may be written as

$$T_W = T_P. \quad (28)$$

For the condensing surface, the discretization of boundary condition may be written as

$$T_B = \frac{hT_f + (k_B/(\delta z)_b)T_P}{[h + (k_B/(\delta z)_b)]}, \quad (29)$$

where h is heat transfer coefficient from condensing surface to vapor within the control unit.

The heat transfer coefficient h is different for the different boundary points due to different drop size, the major difficulty for the present numerical simulation is that a very wide range of drop size (10^{-2}–10^3 μm) exists on the condensing surface, extending from the primary drop to the largest departing drop. If the grids are generated according to the diameter of the minimum drop, there would be $10^5 \times 10^5 \times 10^5$ grids in 1 cm^3 condensing wall, and the calculation is out of the question for the limitation of the computer capacity and speed. As shown in Fig. 7, the present simulation used two kinds of grid system: a fine grid system with the same side length as the diameter of primary drop being used to construct drop distributions, then, a coarse grid system is used to calculate the temperature distribution and average heat transfer coefficient of dropwise condensation. An area-weighted average heat transfer coefficient of drops is considered to be the heat transfer coefficient of the grid point, thus,

$$h = \left(\sum_{i=1}^{n} h_i A_i + h_f A_f\right)/A_k, \quad (30)$$

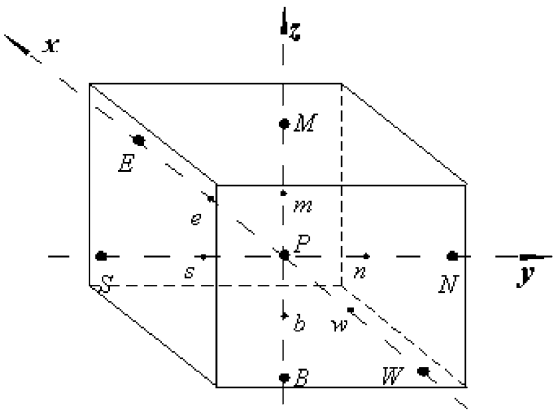

Fig. 5. Three-dimensional control volume.

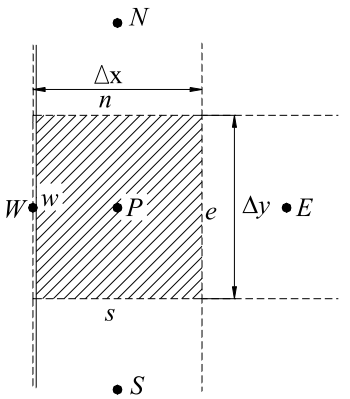

Fig. 6. The control volume of boundary points.

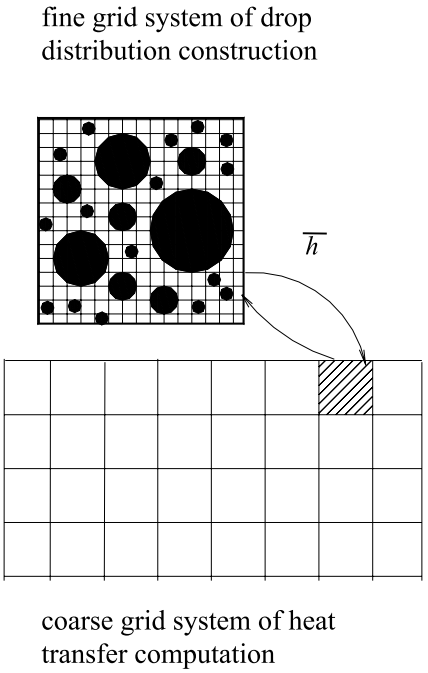

Fig. 7. Sketch of two kinds of grid systems.

where h_i, A_i are the heat transfer coefficient and area covered by drop i, respectively, h_f, A_f are heat transfer and area of bare surface, respectively, A_k is the total area of the boundary control unit.

4.3. Determining of instantaneous effective maximum drop diameter

For the transient numerical simulation, drop instantaneous effective maximum diameter is necessary which can be calculated by

$$\frac{\hat{r}_{\max}}{r_{\max}} = 1.53\left(\frac{\tau}{\tau_0}\right)^{1/1.3}, \tag{31}$$

where $\tau_0 = 1.1 \times 10^6/q$.

4.4. The average heat flux and the average subcooling of condensing surface

The mean heat flux, q, through the entire condensing surface may be calculated by

$$q = \frac{1}{A}\sum_{j=1}^{nx}\sum_{k=1}^{ny} h_{jk}(T_v - T_{jk0})A_{jk}, \tag{32}$$

where A is the total area of condensing surface, h_{jk} is the heat transfer coefficient through the j, kth control point, T_{jk0} is the temperature of the j, kth boundary control point, A_{jk} is the area at the j, kth boundary control unit.

The average subcooling ΔT is calculated as

$$\Delta T = \frac{1}{A}\sum_{j=1}^{nx}\sum_{k=1}^{ny}(T_v - T_{jk0})A_{jk}. \tag{33}$$

4.5. Grid independence study

In order to study the grid independence, dropwise condensation heat transfer coefficients of three groups of typical input parameters (Table 1) are calculated at four different mesh spacings, i.e., $20 \times 20 \times 20$, $40 \times 40 \times 40$, $50 \times 50 \times 50$, $80 \times 80 \times 80$ grids, respectively. The computing results are plotted in Fig. 8. From Fig. 8, we find that heat transfer coefficients decrease with the grid size between the $20 \times 20 \times 20$ mesh and $40 \times 40 \times 40$ mesh, and approximately no significant difference between the $40 \times 40 \times 40$ mesh and $80 \times 80 \times 80$ mesh. This leads to the selection of $40 \times 40 \times 40$ mesh as the appropriate grids number within the $8 \times 8 \times 12$ mm domain.

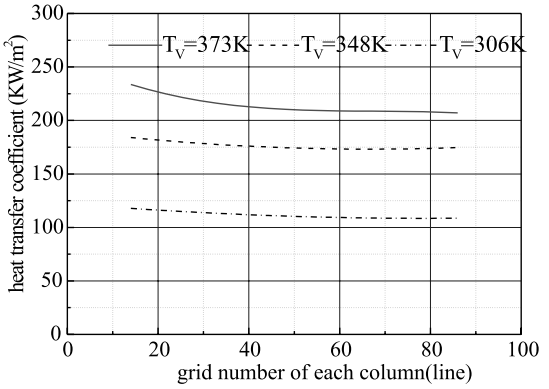

Fig. 8. Effect of grid size on the heat transfer coefficients.

Table 1
Basic input parameters

Serial number	Computing domain (mm)	Maximum drop diameter (mm)	Saturation temperature (K)	Temperature of the bottom surface of condensing wall (K)
1	$8 \times 8 \times 12$	2	374	355
2	$8 \times 8 \times 12$	1.8	348	337
3	$8 \times 8 \times 12$	1.5	304	296

5. Numerical simulation results with discussion

A VC6.0 program was used to carry out the simulation. It was run on a 64 MB RAM, 300 MHz computer. The computing domain is $8 \times 8 \times 12$ mm and the drop size range is 10^{-2}–2×10^{3} microns. It took fourteen hours to compute heat flux and temperature subcooling for unsteady-state numerical sim-

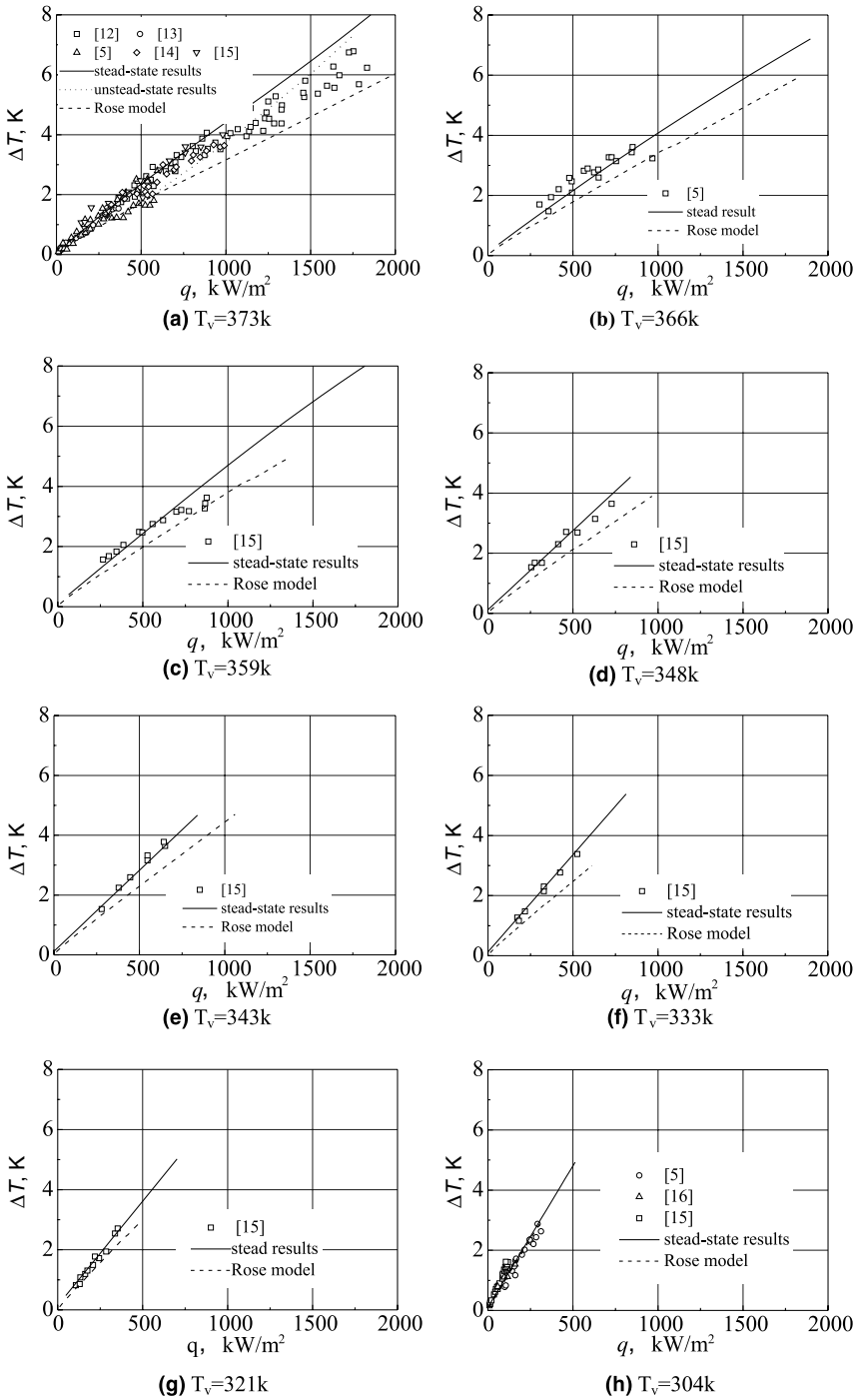

Fig. 9. Comparison of experiment and theory of dropwise condensation heat transfer.

ulation and 15 min for steady-state numerical simulation.

In order to verify the proposed model of dropwise condensation heat transfer, the simulation results for vapor dropwise condensation heat transfers of the copper surface at different pressures from 0.05 to 1.02 bars are compared with the existing experimental results [5,12–16] as shown in Fig. 9. The results calculated using Rose model [10] are also given in Fig. 9. The predictions with the proposed model agree quite well with the bulk of existing experimental data and the precision is higher than that of Rose model [10].

Fig. 10 shows the temperature spatial distribution on the condensing surface at a given instant, from which the temperature on the condensing surface covered by the smaller drop will be higher than that of the surface covered by larger drop. Such a nonuniformity of surface temperature indicates that drop spatial distributions are ununiform. Rose did not consider the influence of drops

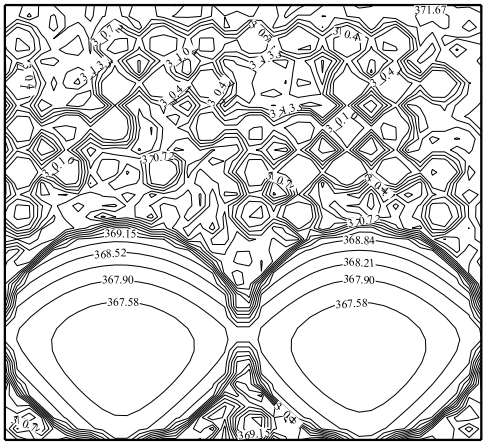

Fig. 10. Temperature spatial distribution on the condensing surface.

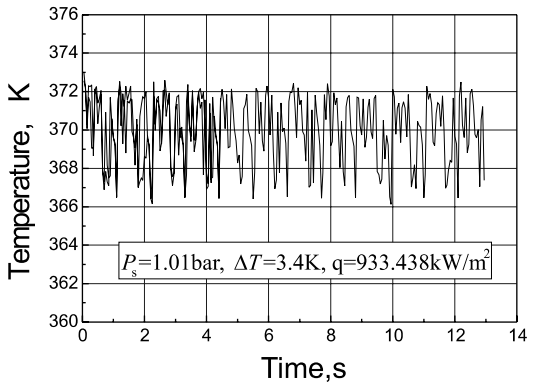

Fig. 11. Temperature variations of copper surface.

spatial distributions on heat transfer of dropwise condensation, and therefore, the predicted results with his model will be in lower higher precision.

The variation of surface temperature can be illustrated by typical unsteady-state numerical simulation. As from Fig. 11, the condensing surface temperature of the condensing surface varies periodically, the transient dropwise condensation occurs repeatedly on the tracks left by the departing drops. This confirms that heat-transfer of a drop would be influenced by the neighbor drops.

6. Conclusion

The conclusions can be drawn as follows:

1. Dropwise condensation is a typical fractal growth process. A random fractal model is proposed to construct the drops size and spatial distribution. This established a base to the direct numerical simulation of dropwise condensation heat transfer.
2. The proposed model considers the randomicity of drops distribution and the nonuniformity of the surface heat flux, and thus overcomes the limitation of Rose model [10].
3. The agreement of theoretical results with the bulk of existing experimental data at a very wide range of pressures, ranging from 0.05 to 1.02 bar, verifies the reliability and universality of the present numerical simulation.

Further study is needed to simulate the dropwise condensation heat transfer on different material surface and study the effect of the thermal conductivity of the condenser material on dropwise condensation heat transfer.

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