UNIQUENESS OF THE ELEMENTARY PHYSICS DRIVING HETEROGENEOUS NUCLEATE BOILING AND FLASHING

NIKOLAY IVANOV KOLEV
Framatome ANP
P.O. Box 3220, D-91058, Erlangen, Germany
E-mail : Nikolay.Kolev@framatome-anp.com

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Boiling and flashing are driven by the same physics for nucleation, bubble growth, departure etc. An adequate model of boiling has to describe the flashing too. The subject of this paper is to prove this uniqueness of the elementary physics driving the both processes.

KEYWORDS : Nucleate Boiling, Flashing, Heterogeneous Nucleation, Boiling Crisis, Bubbles

1. INTRODUCTION

What is different between flow-boiling and flow flashing? In the case of boiling the surface is hotter then the bulk and the thermal energy transfer happen from the wall to the bulk. In the case of adiabatic flashing, the bulk is hotter then the saturated wall boundary layer and the thermal-energy-transfer is inversed.

What is common between flow-boiling and flow flashing? In both cases nucleation in technical systems is experimentally observed at the wall and the bubble growth and departure generate boundary layer turbulence that is the main heat transfer driving mechanism. Therefore both phenomena are driven by the same physics! An adequate representation of the one phenomenon has to describe the other too. The subject of this paper is to prove this *uniqueness* of the elementary physics driving the both processes.

Adequate description of boiling requires adequate description of the nucleation activation process, the bubble growth and departure, the frequency of departure and the mechanism of the bubble generated wall turbulence that controls the heat transfer at the wall. Good models for nucleate boiling are those that give good comparison with experimental data for each of the above mentioned elementary processes and this for the *right* reason. The splitting of the boiling process on sub-process is not only helpful for understanding the boiling physics, it provides also the appropriate information required for modeling the boiling and flashing processes in the computational multiphase fluid dynamics (CMFD).

Let us have a close look on the data and the appropriate models describing them.

2. ACTIVATION OF NUCLEATION SITES

After long years discussing why at polished surfaces the nucleate boiling data spread with 200% as shown in Fig. 1 the answer seems to be finally found.

This is because the spreading of the data for the corresponding active nucleation sites, see Fig. 2, due to differences mainly in the wetting angle as shown in Fig. 4. No theory predicts well this behavior as shown in Fig. 3.

Qualitative reasoning was given by the Russian scientists in 1958 [1] but there are *Wang and Dhir* [48] who correlated their own measurements, Fig. 4, to provide finally well establish basis to the next step of the description of nucleate boiling.

3. BUBBLE DEPARTURE DIAMETER

During heterogeneous nucleation of saturated water at walls the bubble departs the polished wall with a size D_{1d} depending on the superheat as presented in Fig. 5.

Reviewing the literature in 1994 regarding availability of theoretical models for description of the bubble departure diameter as a function of the local parameters, resulted in the picture seeing in Fig. 5. Surprisingly I find out that the phenomenon was not satisfactory described by any of the existing theories. Especially the observation by *Gardner* [12] reported 39 years ago, that the increasing superheat leads after reaching a maximum to decrease of the bubble departure size, as seen from Fig. 5, was not understood. I found the explanation of the phenomenon observed by Gardner in the mutual bubble interaction during their explo-

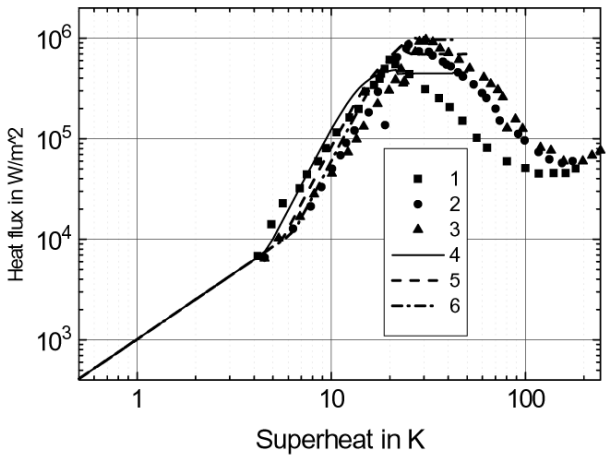

Fig. 1. Heat flux as a function of superheat. Saturated water at 0.1 MPa. 1) Gaertner [13] 1965, 4/0 polished copper, 2) Kurihara and Myers [30] 1960, 4/0 polished copper, 3) Yamagata et al. [50] 1955, fine polished brass, 4) Sultan and Judd [41] 1978, diamond grid 600 polished copper, 5) Wiebe [49] 1970, diamond 600 polished copper, 6) Gaertner and Westwater [11] 1960, 4/0 polished copper, 20 p.c. nickel salt-water solution, 7) Borishanskii et al. [3] 1961, steel, 5 to 8 p.c. error, 8) Jakob and Fritz [16] 1931, polished steel, 9) Jakob and Linke [18] 1932, polished steel, 10) Cornwell and Brown [7] 1978, 4/0 polished cooper, 11) Vachon et al. [45] 1968, emery grid 600 polished 304 stainless steel, 12) Nishikawa et al. [35] 1984, emery grid No.0/10 polished copper, 13) Rallis and Jawurek [37] 1964, nickel wire, 14) Wang and Dhir [48] nuclead and transition boiling. Contact angle 90 *deg*, 15) Wang and Dhir [48] nuclead and transition boiling. Contact angle 18 *deg*, 16) Wang and Dhir [48] nuclead and transition boiling. Contact angle 35 *deg*, 17) Wang and Dhir [48] nuclead and transition boiling. Contact angle 35 *deg*. Liaw data.

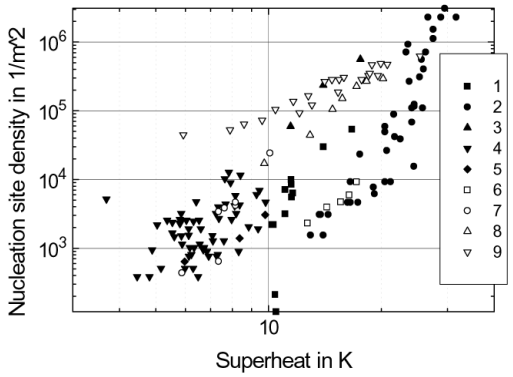

Fig. 2. Active Nucleation Site Density as a Function of Superheat. Saturated Water at 0.1 MPa. 1) Gaertner [13] 1965, 4/0 Polished Copper, 2) Gaertner and Westwater [11] 1960, 4/0 Polished Copper, 20 p.c. Nickel Salt-water Solution, 3) Sultan and Judd [41] 1978, Diamond Grid 600 Polished Copper, 4) Yamagata et al. [50] 1955, Fine Polished Brass, 5) Jakob and Linke [18] 1932, Polished Steel, 6) Cornwell and Brown [7] 1978, 4/0 Polished Cooper, 7) Kurihara and Myers [30] 1960, 4/0 Polished Copper, 8) Rallis and Jawurek [37] 1964, Nickel Wire, 9) Faggani et al. [8] 1981, Polished 316 Steel Horizontal Cylinder

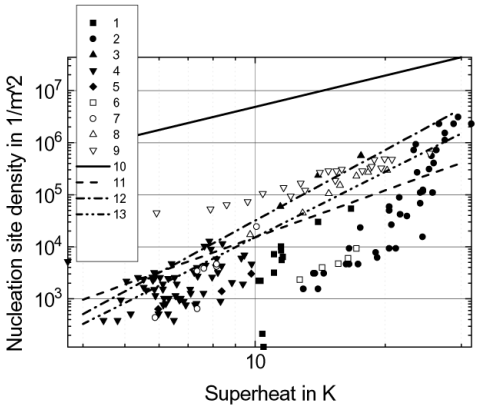

Fig. 3. Active nucleation site density as a function of superheat. Saturated water at 0.1 *MPa*. 1) to 9) Data from Fig. 16.2. Prediction with correlations proposed by 10) Avdeev et al. [2], 11) Johov [21], 12) Cornel and Brown [7] and 13) Kocamustafaogullari and Ishii [27]

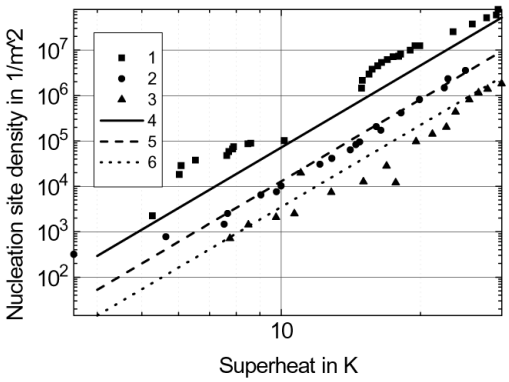

Fig. 4. Active nucleation site density as a function of superheat. Saturated water at 0.1 *MPa*. Wang and Dhir [48] data for three different static contact angles 1) 90, 2) 35 and 3) 18 deg. Prediction of the same data with their correlation 4), 5), and 6), respectively. Larger static contact angle results of larger active nucleation site density by the same superheating.

sive growth and departure. The time averaged wall shear stress turns to be different from zero. The new model developed by me [25] takes into account this force and delivered acceptable agreement with the experimental data as shown in Fig. 6. This model has the following form

$$\left(D_{1d} / D_{1d,nc}\right)^3 + \left(D_{1d} / D_{1d,fc}\right)^2 = 1 \qquad (1)$$

Here $D_{1d,nc}$ is the bubble departure diameter for natural circulation and $D_{1d,fc}$ is the bubble departure diameter for predominant forced convection. For more details see the references [25, Ch. 15 in 60, p.421]. This model is for the time being the only one that adequately describes this phe-

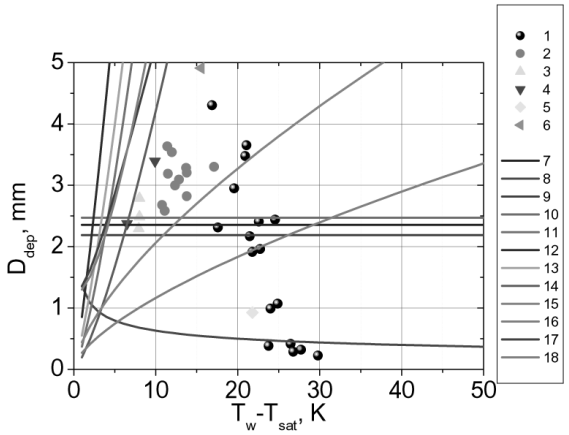

Fig. 5. Bubble departure diameter as a function of superheating. Saturated water pool boiling at 0.1 MPa pressure. Data: 1 Gaertner and Westwater [11], 2 Gaertner [12], 3 Tolubinsky and Ostrovsky [43], 4 Siegel and Keshok [40], 5 van Stralen et al. [73], 6 Roll and Mayers [71]. Theories: 7 Fritz [10], 8 van Krevelen and Hoftijzer [68], 9 Kocamostafaogullari and Ishii [27], 10 Cole and Rohsenow [6], 11 Moalem et al. [70], 12 Klausner et al. n = 1/2 [63], 13 Klausner et al. n = 1/3 [63], 14 Ruckenstein [77], 15 Voloshko and Vurgaft [78], 16 Golorin et al [79], 17 Kutateladze, and Gogonin [80], 18 Jensen and Memmnel [81]

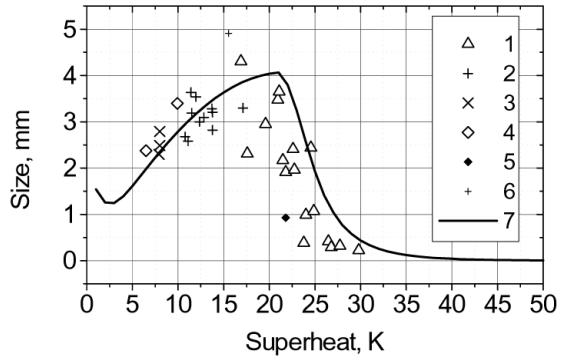

Fig. 6. Bubble departure diameter as a function of superheating. Saturated water pool boiling at 0.1 MPa pressure. Data 1: Gaertner and Westwater [11], 2 Gaertner [12], 3 Tolubinski and Ostrovsky [43], 4 Siegel and Keshok [40], 5 van Stralen et al. [73], 6 Roll and Mayers [71], 7 IVA5 model with bubble interactions

nomenon. The model describes well the available data also for forced convection as presented in Fig. 7. Data for low- and high pressures are also very good reproduced as demonstrated on Fig. 8.

4. MECHANISM OF NUCLEATE BOILING

As already mentioned, the experimentally observed spreading of about 200 % of the heat flux as a function of

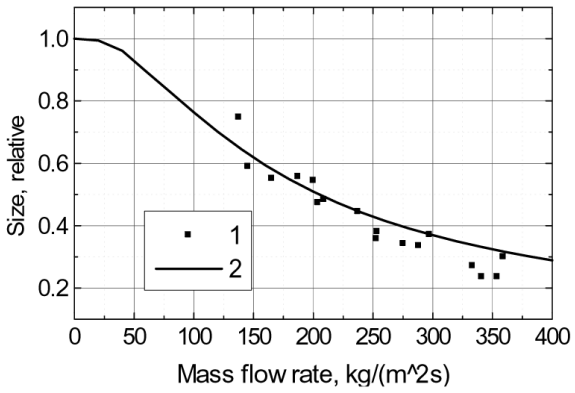

Fig. 7. Bubble departure diameter as function of mass flow rate. Saturated water flow boiling at 0.1 *MPa* pressure. D_{hy} = 0.019 *m*, T_w - T_2 = 15 *K*. 1 Data of Koumoutsos et al. [67], 2 IVA5 model without bubble interaction

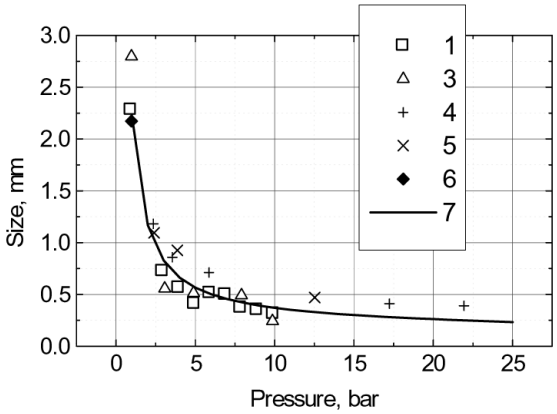

Fig. 8. Bubble departure diameter as a function of pressure. Saturated water pool boiling, superheat = 7.2 *K*. Data of Tolubinsky and Ostrovsky: 1 Permalloy, 2 brass, 3 copper. Data of Semeria: 4 wire D = 0.8*mm*, 5 plate. 6 Model IVA with bubble interaction

the wall superheating for polished surfaces as shown in Fig. 1, was not explained quantitatively until 1995.

I realized that the turbulence controlled by the bubble growth and departure is the most important heat transfer mechanism. My new theory provided new peace of information for description of the nucleate boiling. The form of the model provides the heat flux at the wall

$$\dot{q}''_{w2,nb} = \frac{c_1 c\left[5\times10^{-27}(1-\cos\varphi)\right]^{1/4}}{\left[\ell'_2\left(1+c_2\Delta\tau_{1w}/\Delta\tau_{1d}\right)\right]^{1/2}} \times\left[\frac{\rho''\Delta h}{4\sigma T'(p)}\right]^{3/2}\frac{\lambda'\rho' c'_p}{\rho'\Delta h}\left(T_w-T_2\right)^{7/2}, \quad (2)$$

as a function of the fluid properties, inclination angle, wall turbulence length scale, the time scales controlling the fluctuations, and the difference between the liquid and wall temperature. For more details – see Ch. 16 in [60], p. 439. The new model description is based on the boundary layer turbulence induced by the bubble growth and departure, as mentioned above, together with an relationship for the nucleation site density as a function of the superheating experimentally obtained by *Wang* and *Dhir* [48], provided the following surprising predictive capability: Not only the data spreading was quantitatively described by the differences in the wetting angle, but the new boiling model provided *inherent* prediction of the departure from the nucleate boiling (DNB) with increasing wall superheat that was not available from any other existing nucleate boiling model up to that time. I have reported this result for a first time in 1995 [26]. Having the information provided by Eqs. (1) and (2) it is easy to compute the mass and energy source terms in the conservation equations as well as the source term for the bubble number density as shown in [93].

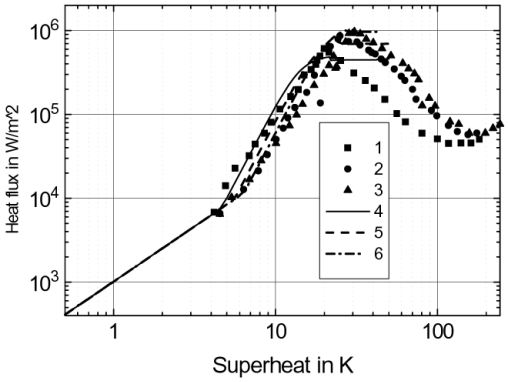

Fig. 9. Heat flux as a function of superheat. Saturated water at 0.1 *MPa*. Comparison of the prediction of the new theory with the experimental data by Wang and Dhir for three different static contact angles: 1) Exp.- 90 *deg*; 2) Exp.-35 *deg*; and 3) Exp.-18 *deg*, 4) Kolev-90 *deg*; 5) Kolev-35 *deg*; and 6) Kolev-18 *deg*. The larger the static contact angle the smaller the critical heat flux.

5. HETEROGENEOUS NUCLEATION – FLASHING

If the above described mechanisms of bubble formation, departure and energy transfer between the heated wall and the bulk flow are *universal* mechanisms, they have to work also at an adiabatic wall in case of expanding superheating liquid being in spontaneous evaporation.

The common feature of the nucleate boiling and of the spontaneous evaporation of superheated liquid that happens at the wall (heterogeneous nucleation) is that the energy transfer between the wall and the bulk flow happens in the same way. That is the reason why I have applied

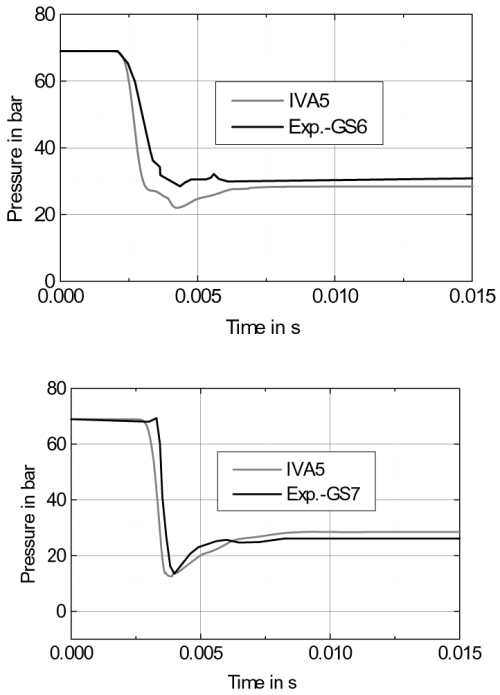

Fig. 10. Pressure at 0.072 and 0.914 m from the dead end of pipe as a function of time. Comparison IVA prediction with experimental data by Edwards and O'Brien. Pipe diameter 0.0732 m, length 4.096 m

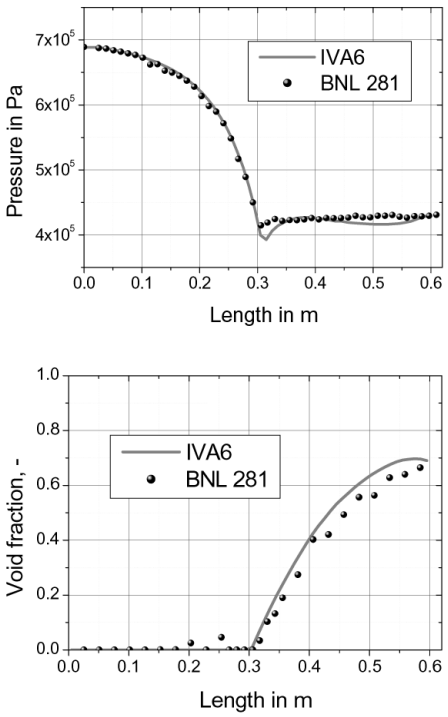

Fig. 11. Comparison of IVA prediction with BNL experimental data for pressure distributions and area averaged void fractions for Runs 281 - 283. p_{in} = 688 *kPa*, T_{in} = 148.8°*C*, G_{in} = 5730 *kg*/(m^2s), p_{out} = 431 *kPa*, p_c = 452 *kPa*, T_c = 148.8°*C*, G_{com} = 5533 *kg*/(m^2s)

the same theory without any changes for description of a spontaneous evaporation of superheated liquids in [93]. The good prediction of the experimental observation collected by *Edwards* and *O'Brien* (blow down of superheated water in a pipe – see Fig. 10) [90], of the experimental observation by *Abuaf* et al (flashing water flows in convergent-divergent nozzles) [87] – see Fig. 11 was a very interesting and original conformation of the universal character of this phenomena. The computer code used in this computation is IVA – see Appendix 1 for some details.

If the bubble departure diameter for nucleate boiling at hot wall or for flashing of superheated liquid is known, and if the energy transfer between the wall and the bulk of the flow is known, so a set of constitutive source terms are easily computed like the particle number generated per unit flow volume and unit time, the evaporation mass source, the associated energy and mass transfer etc – see [93].

6. IS THE METHOD EXTENDABLE TO OTHER PARAMETERS?

Yes. It is. We give here an example of extension the theory of bubble departure to sub-cooled liquids.

Ünal [82] proposed in 1976 to consider the sub-cooled boiling bubble growth as superposition of evaporation feed by the conduction from the wall and partial condensation at the bubble top. Using the imagination of *Zuber* [54] that the superheated micro-layer is created before the explosion of the nucleus and neglecting the nucleation diameter as a small compared to any later bubble size after the origination we can write the following equation for the growth of the bubble mass

$$\frac{d}{d\tau}\left(\rho''\frac{\pi}{6}D_1^3\right)=\frac{\pi D_1^2}{\Delta h}\left[-\dot{q}_2''^{1\sigma}-c_1\left(h_{2,w=0}^{1\sigma}+h_{2,w\neq 0}^{1\sigma}\right)\left(T'-T_2\right)\right], \quad (3)$$

which for constant vapor density results in

$$\frac{dR_1}{d\tau}=-\frac{\dot{q}_2''^{1\sigma}}{\rho''\Delta h}-c_1\left(h_{2,w=0}^{1\sigma}+h_{2,w\neq 0}^{1\sigma}\right)\frac{\left(T'-T_2\right)}{\rho''\Delta h}. \quad (4)$$

For bubble growth at a wall the expression obtained by Labuntzov et al. [51] in 1964 can be used

$$-\frac{\dot{q}_2''^{1\sigma}}{\rho''\Delta h}=\frac{B_{\sup}}{2\sqrt{\tau}}, \quad (5)$$

where

$$B_{\sup}=2.5\sqrt{2a_2\beta Ja_{2w}}\,, \quad (6)$$

$Ja_{2w}=\frac{\rho_2 c_{c2}\left(T_w-T'\right)}{\rho''\Delta h}$, and $\beta\approx 6$. We assume that the disc with a cross section $\pi D_1^2/4$ receive the evaporation mass flow rate corresponding to $q_2''^{1\sigma}$. The constant c_1 reflects the part of the bubble surface πD_1^2 contacting the sub-cooled liquid e.g. $c_1 = 1/2$. The condensation is assumed to be driven by a superposition of molecular heat conduction

$$h_{2,w=0}^{1\sigma}\frac{\left(T'-T_2\right)}{\rho''\Delta h}=Ja_{2,sub}\sqrt{\frac{1}{\pi}\frac{a_2}{\tau}}\,, \quad (7)$$

$$Ja_{2,sub}=\frac{\rho_2 c_{p2}\left(T'-T_2\right)}{\rho''\Delta h}, \quad (8)$$

Forschluetz and *Chao* [84] (1965), and eddies renewal due to turbulence

$$\frac{h_{2,w\neq 0}^{1\sigma}D_h}{\lambda_2}=0.228\,\mathrm{Re}_2^{0.8}\,\mathrm{Pr}_2^{1/2}\left(\Phi_{20}^2/\alpha_2\right)^{1/4}, \quad (9)$$

Avdeev [53]. Replacing the heat flux components in the mass conservation equation results in

$$\frac{dR_1}{d\tau}=\frac{B}{2\sqrt{\tau}}-A\,, \quad (10)$$

where

$$B=B_{\sup}-\sqrt{\frac{a_2}{\pi}}Ja_{2,sub}\,, \quad (11)$$

$$A=0.228\frac{1}{2}\frac{a_2}{D_h}Ja_{2,sub}\,\mathrm{Re}_2^{0.8}\,\mathrm{Pr}_2^{1/2}\left(\Phi_{20}^2/\alpha_2\right)^{1/4}. \quad (12)$$

Note that there is a driving mechanism for a bubble growth in sub-cooled liquid only if

$$2.5\sqrt{2\beta\pi Ja_{2w}}>Ja_{2,sub}\,. \quad (13)$$

The radius of the bubble as a function of time is then

$$R_1\approx R_{1c}+B\sqrt{\tau}-A\tau\,. \quad (14)$$

The radius possesses a maximum

$$R_{1\mathrm{m}}\approx R_{1c}+\frac{1}{4}\frac{B^2}{A} \quad (15)$$

at

$$\tau_{1m}=\frac{1}{4}\left(\frac{B}{A}\right)^2. \quad (16)$$

If the maximum of the diameter is smaller then the bubble departure diameter the bubble will stay at the sur-

face, else the bubble will depart with the bubble departure diameter. The bubble growth equation can be rewritten in dimensionless form as proposed by *Zuber* [86] in 1961

$$\frac{R_1 - R_{1c}}{R_{1m} - R_{1c}} = 2\sqrt{\frac{\tau}{\tau_{1m}}} - \frac{\tau}{\tau_{1m}} . \qquad (17)$$

Note that the form of the equation is as obtained by Zuber but not the contents of the different terms. As expected for a given radius there are two solutions for the time

$$\frac{\tau}{\tau_{1m}} = \left(1 \pm \sqrt{1 - \frac{R_1 - R_{1c}}{R_{1m} - R_{1c}}}\right)^2 . \qquad (18)$$

The center of mass velocity corresponding to this bub-ble growth mechanism is then

$$V_{1cm} = \frac{dR_1}{d\tau} = \frac{R_{1m} - R_{1c}}{\tau_{1m}} \left[\left(\frac{\tau}{\tau_{1m}}\right)^{-1/2} - 1\right]. \qquad (19)$$

The temporal bubble acceleration is

$$\frac{\partial V_{1cm}}{\partial \tau} = -\frac{1}{2}\frac{R_{1m} - R_{1c}}{\tau_{1m}^2}\left(\frac{\tau}{\tau_{1m}}\right)^{-3/2} . \qquad (20)$$

The total bubble acceleration is

$$\frac{\partial V_{1cm}}{\partial \tau} + V_{1cm}\frac{V_{1cm}}{R_1 - R_{1c}}$$

$$= \frac{R_{1m} - R_{1c}}{\tau_{1m}^2}\left\{\frac{R_{1m} - R_{1c}}{R_1 - R_{1c}}\left[\left(\frac{\tau}{\tau_{1m}}\right)^{-1/2} - 1\right]^2 - \frac{1}{2}\left(\frac{\tau}{\tau_{1m}}\right)^{-3/2}\right\}. \qquad (21)$$

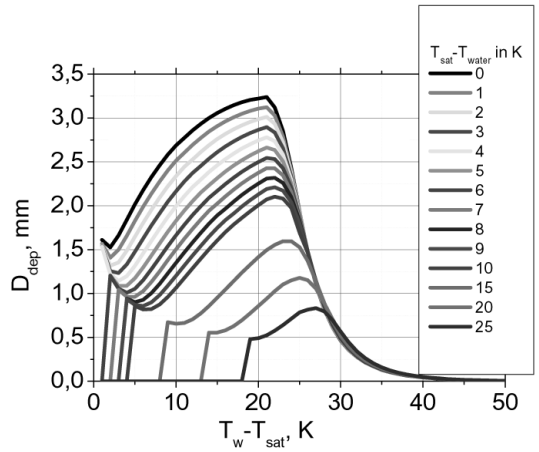

Fig. 12. Bubble departure diameter at horizontal surface without flow as function of the wall superheating at 1bar. Parameter – water sub-cooling. Stagnant liquid

Neglecting the virtual mass force we apply now the momentum balance equations as described in [60] by using the already described mechanism of the bubble growth and collapse. The result for horizontal plane at 1 bar pressure and varying sub-cooling is presented in Fig. 12. For zero sub-cooling we reproduce well the experimental data as already discussed in the pervious section. For increasing sub-cooling the bubble departure diameter decreases. The zero-values are artificially set to indicate in the graph that in the particular combination of superheating and sub-cooling there are no conditions for bubble departure at all.

7. CONCLUSIONS

The new method for description of the energy transfer between the wall and the bulk successfully explained the spreading of the data and provided several interesting features one of them being predicting of boiling crisis without empirical correlation for boiling crisis. The method turns to operate properly for bubble production on heated and non-heated surfaces, which confirmed the universal character of the basic physics used for the model development. The method is extendable for other situation. To encourage colleagues to make further steps in this direction an example is given of extension of the method to predict the bubble departure diameter in sub cooled flow boiling.

The model was implemented into the IVA computer code series (see Appendix 1 for brief description) and is being in use for many practical applications.

NOMENCLATURE

Latin

a_2	liquid thermal diffusivity, m^2/s
a'	saturation liquid thermal diffusivity, m^2/s
B^2	$= 2R_1 dR_1/d\tau$, m^2/s
c_{p2}	specific heat of liquid, $J/(kgK)$
D	total differential, *dimensionless*
D_1	bubble diameter, m
D_{1c}	critical diameter, m
D_{1d}	bubble departure diameter, m
$D_{2,inf}$	$= 2R_{2,inf}$, average center to center spacing, m
$D_{1d,fc}$	bubble departure diameter for strongly predominant forced convection, $V_{21d} \gg \bar{\bar{V}}_2'$, m
$D_{1d,nc}$	bubble departure diameter for natural circulation, $V_{21d} \gg \bar{\bar{V}}_2'$, m
f_{1w}	bubble departure frequency, $1/s$
f_{1w}^t	boundary layer turbulence fluctuation frequency, $1/s$
G	mass flow rate, $kg/(m^2 s)$
g	gravitational acceleration, m/s^2
h'	saturated liquid specific enthalpy, $J/(kgK)$
h''	saturated steam specific enthalpy, $J/(kgK)$
Δh	$= h'' - h'$, J/kg
Ja	$= \rho_2 c_{p2}[T_2 - T'(p)]/(\rho_1 \Delta h)$, Jacob *number*, *dimensionless*

Ja' = $\rho' c'_p [T_2 - T'(p)]/(\rho'' \Delta h)$, *Jacob* number, dimensionless
n''_{1w} active nucleation site density, $1/m^2$
p pressure, Pa
p_c critical pressure, Pa
p' saturated pressure, Pa
Pr_2 = $\eta_2/(p_2 a_2)$, Prandtl number, dimensionless
$q''_{w2,nc}$ heat flux from the wall into the liquid during natural convection without boiling, W/m^2
$q''_{w2,nb}$ heat flux from the wall into the liquid during pool boiling, W/m^2
R_1 bubble radius, m
$R_{2,inf}$ = $D_{2,inf}/2$, half of the average center-to-center spacing, m
$T'(p)$ saturation temperature at system pressure p, K
T_2 liquid temperature, K
T_w wall temperature, K
V_{1cm} center-of-mass bubble velocity at the moment of detachment, m/s
V_{21d} tangential velocity in the boundary layer of thickness D_{1d}, m/s
u_2 liquid velocity in the region between R_1 and $R_{1,inf}$, m/s
$\bar{V}_2'$ volume-averaged fluctuation velocity, m/s
$\bar{\bar{V}}_2'$ time- and volume-averaged fluctuation velocity over, $\Delta\tau_w + \Delta\tau_d$, m/s

Greek

β_2 $= -\frac{1}{\rho_2}\left(\frac{\partial \rho_2}{\partial T_2}\right)_p$ thermal expansion coefficient, $1/K$
$\delta_{2.\min}$ minimum of the thermal boundary layer thickness, m
$\Delta\rho_{21}$ = $\rho_2 - \rho_1$, kg/m^3
$\Delta\tau_d$ time needed from the origination of a bubble with critical size to the bubble departure from the wall, s
$\Delta\tau_w$ delay time, s
∂ partial differential, *dimensionless*
η_2 dynamic viscosity of liquid, $kg/(ms)$
λ_2 thermal conductivity of liquid, $W/(mK)$
λ_{RT} $= \left(\frac{\sigma}{g\Delta\rho_{21}}\right)^{1/2}$ *Rayleigh - Taylor* instability wavelength, m
ν_2 cinematic viscosity of liquid, m^2/s
φ angle between the flow direction and the upwards-directed vertical, $-\mathbf{n}_g$, rad
φ static contact angle between "liquid drop" and the wall, rad
ρ_1 gas density, kg/m^3
ρ_2 liquid density, kg/m^3
ρ'' saturated steam density, kg/m^3
ρ' saturated liquid density, kg/m^3
σ surface tension, N/m
τ_{2w} $= \frac{\xi}{8} G^2/\rho$ shear stress, N/m^2
τ time, s
θ_0 angle between the bubble axis and the wall, rad

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Appendix 1: Brief description of the computer code IVA

IVA_5M is a computer code for computational simul-ation of multi-phase flows. The flow is described by means of three velocity fields. Each of the fields consists of several chemical components. The first field presents gas mixtures of up to 13 real gasses in addition to water vapor. The water-vapor properties are valid up to 2000bar pressure and 6000K temperature. The thermal dissociation of the vapor is taken into account. The gasses may be air, nitrogen, helium, oxygen, carbon dioxide, methane, carbon oxide, hydrogen, ethane, propane, n-Butane, sulfur dioxide and argon in arbitrary combination.

The number and the kind of the appearing components have to be specified as a part of the input. The components are allowed to move by turbulent or molecular diffusion inside the gas field in addition to the macro-scale movement in the space of the gas field.

The second and the third velocity fields consist of liquid water and inert components of different species. In the limi-ting case of absence of water in one of these fields or in both of them the inert components are allowed to be a ma-terial being either in molten state, or in solid-liquid equili-brium state, or in liquid state. One of the following inert materials may be chosen: uranium dioxide, nuclear reactor corium (mixture consisting of 76% UO_2, 24% ZrO_2), zirconium, zirconium dioxide, stainless steel, aluminum dioxide, silicon dioxide, iron oxide, molybdenum, alumi-num and boron oxide. If water is present in the fields 2 or 3 the inert component inside this field is solid being in thermal equilibrium with the water (having the temperature of the water) and is allowed to move by turbulent or mole-cular diffusion inside the corresponding fields in addition to the macro-scale movement in the space. An example of such situation is boron oxide and water mixture used frequently in the nuclear reactor technology.

Each of the three velocity field posses its own velocity and temperature. Thus, the flow is in a complete thermo-dynamic and mechanic non-equilibrium with all consequen-ces for interfacial heat, mass and momentum transfer.

The fields are allowed to be continuous or disperse. The transition of the fields between continuum and dispersion as well as the local size of the dispersions is modeled by means of dynamic fragmentation and coalescence model-ing.

The geometry of the space within the flow is simulated, is described either in Cartesian or cylindrical coordinates. Other modern capability of the code is the description of multi-phase flows in multiple interconnected blocks with boundary fitted orthogonal grids.

In addition pipe networks are simulated consisting of arbitrary number of pipes and components like, pumps, valves etc. The pipe network can be connected with the three dimensional space.

Local surface permeabilities in the three main directions and local volumetric porosities are defined as a function of time as for the 3D space. The same is valid also for the pipe network.

Inside the blocks different kind of structure types can be simulated: Heat-transmitting 1D-structures and heat-conducting 3D-structures. The heat conducting 3D-struc-tures my have internal heat sources prescribed by the user. The structures are connected to the 3D flow in the space or between the pipes by complete heat transfer mechanism including all known heat transfer regimes to single, two- and multi-phase flows. Special kind of structure like a nuclear reactor core can also be defined and simulated.

The numerical method used for integration of the system of the resulting partial differential equations is: first order donor-cell discretization for the convective terms, second order central differencing for the diffusion terms, first order time discretization, implicit. The method is characterized by a strong coupling between the velocity fields obtained by analytical reduction of the algebraic problem to a pressure equation and successive substitutions.

The code has powerful visualization systems, SONJA, for input processing, post-processing, on-line visualization and move production.

IVA_5M is written in the modern FORTRAN 95 lang-uage and is running in all modern computers and platforms having this compiler. SONJA is written on C and works on platforms having this compiler and OpenGL. These may be either UNIX workstations or PC's under LINUX.

Most of the aspects of the code are peer reviewed in many international journals. The basics of the method and the validation procedure are carefully documented in [59, 60].