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BOILING INVESTIGATION ON A SURFACE WITH THE ARTIFICIAL NUCLEATION SITES

VĀRĪŠANĀS PROCESU PĒTĪŠANA UZ VIRSMĀM AR MĀKSLĪGAJIEM TVAIKA FĀZES VEIDOŠANĀS CENTRIEM

Yuri Alfredovich Kuzma-Kichta, *Prof., Dr.sc.ing*
Moscow Power-Engineering Institute (Technical University), Department of Thermophysics
Address: Moscow, Krasnokazarmennaja str, 14, 111250, Russia;
Phone +7(495) 362 7674
E-mail: kuzma@itf.mpei.ac.ru

Sergey Afonin, *Postgraduate student*
Moscow Power-Engineering Institute (Technical University), Department of Thermophysics
Address: Moscow, Krasnokazarmennaja str, 14, 111250, Russia;
Phone +7(495) 362 7674
E-Mail: syafonin@mail.ru

Franz Durst, *Prof, Dr.sc.ing, Dr.h.sc.*
Fridrich-Alexander Universität Erlangen-Nürnberg, Institute of Fluid Mechanics
Address: Erlangen, Cauer str. 4, D-91058, Germany
Phone: +49/(0)9131/85-29500
E-Mail: franz.durst@lstm.uni-erlangen.de

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Introduction

The studying of boiling process is interested in connection with wide application in the engineering. The development of micro-processing technologies has made possible manufacturing of artificial cavities on a solid surface.

It allows to investigate boiling characteristics for a surface with single and the several nucleation sites. *M.Shoji* with co-authors [1-4] have spent experiences as with single and the several nucleation sites and have shown, that depth of a cavity has strong influence on boiling.

The research of boiling characteristics has represented in the works [5-6] spent on MPEI Engineering thermophysic`s department under the guidance of professor Kuzma-Kichta Yu.A. The method, based on use of a continuous low-power laser beam, is developed. The data on departure diameter, separation frequency, rising velocity of vapor bubbles, steam quality near a wall have been obtained at water and water - Na_2SO_4 solution`s boiling at atmospheric pressure. In [6] the processing method of the big data files is developed for the basic boiling characteristics and for the first time rising velocity of vapor bubbles are measured at water solution`s boiling.

The present work was executed in Friedrich - Alexander University in Erlangen (Germany) on department of fluid mechanics at support of professor`s Klaus Riedle fund. The research of water boiling on a surface with the single artificial nucleation sites is carried out with use of a digital videocamera. In work were measured separation frequency and departure diameter of vapor bubbles.

Research technique

The research technique is based on use of digital video camera Mocam 500 Mikrotron with the maximum speed of 520 frames/s. The origin, growth and a departure of a vapor bubble at single cavity on a heated surface is recorded in film. When finished recordings, shots were transferred to the personal computer and remained in the form of the single drawings making sequence for a certain experience. The objective F2.5/18 - 108 mm was used at reception of pictures. The surface with the artificial cavity made on it was located in a vessel with water.

The time intervals, which are passing between vapor bubbles departure from a surface are fixed for definition of bubble separation frequency and their quantity during experiment. The observation have shown, that a waiting time is equal zero.

The growth time was defined as follows:

$$\tau = \frac{n}{v}, \tag{1}$$

where n – frame quantity, v – camera speed.

The separation frequency of vapor bubbles was accepted to equal a return size of growth time.

The program *ImageJ* has been used for definition departure diameter of steam bubbles. The bubbles were compared with the ruler that is placed in each removed of shot for seals definition.

The most probable departure diameter of a vapor bubble was calculated from expression:

$$\bar{d} = \frac{1}{N}\sum_{i=1}^{N} d_i \tag{2}$$

The average quadratic deviation were defined from a parity:

$$\sigma_d = \sqrt{d^*} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^2\right]^{1/2} \tag{3}$$

The excess factor was defined from a parity:

$$E_d = \frac{\frac{1}{N}\sum_{i=1}^{N}(d_i - \bar{d})^4}{(d^*)^2} \tag{4}$$

The asymmetry factor was defined from a parity:

$$A_d = \frac{\frac{1}{N}\sum_{i=1}^{N}(d_i - \bar{d})^3}{(d^*)^{3/2}} \qquad (5)$$

Experimental setup

Two working surfaces are used with the single cylindrical cavities located on them in diameters - 100 up to 200 microns, and depth - 80 microns. The surfaces had electrical resistance10 Ω and the following sizes: one surface had the sizes: 15 mm x 50 mm and the cavity on it has been made in diameter 100 microns. The other surface, with the sizes 8 mm x 2.7 mm had a cavity in diameter 200 microns. On Figure 1 is presented one of the investigated surfaces. The thermocouple with which help the wall temperature was defined is visible in the front of unit.

Water boiling is investigated in the conditions of free convection at atmospheric pressure.

In experiments temperatures of a liquid and a heated up wall were defined. The wall temperature was defined by means of a standard thermo element. The program of video camera's management allows to change shooting speed and parameters of received images.

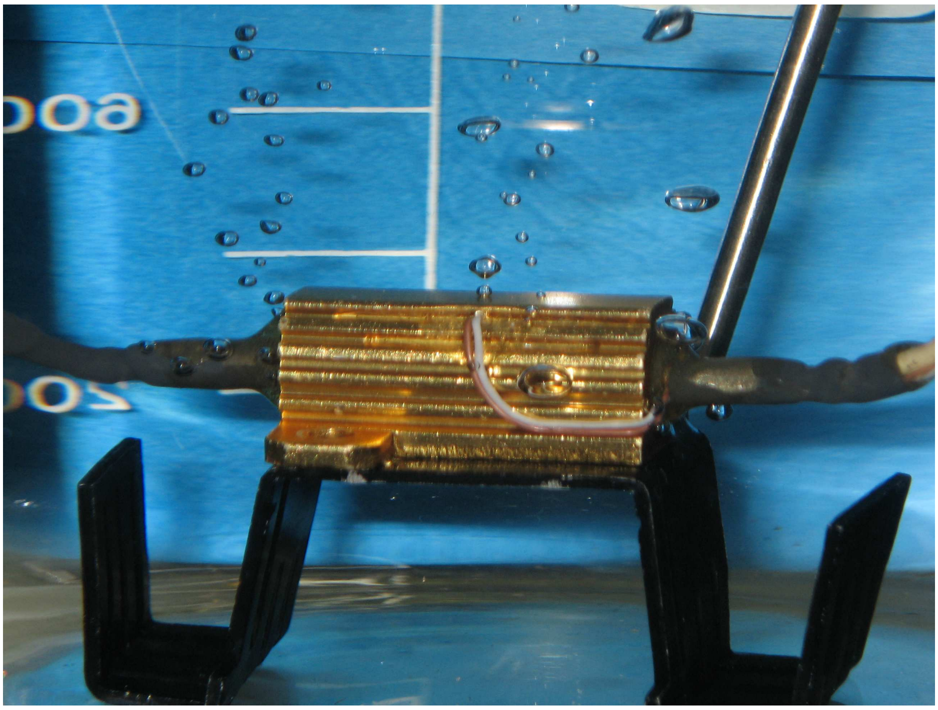

Fig.1. The surface with the artificial nucleation site with diameter 200 microns

Experimental data

Water boiling was researched both at saturated, both subcooled conditions. The subcooling of water to saturation temperature made ΔT_w=2-4 K.
On Fig. 2 are presented the frame shots received at carrying out of recording in one of experiments.

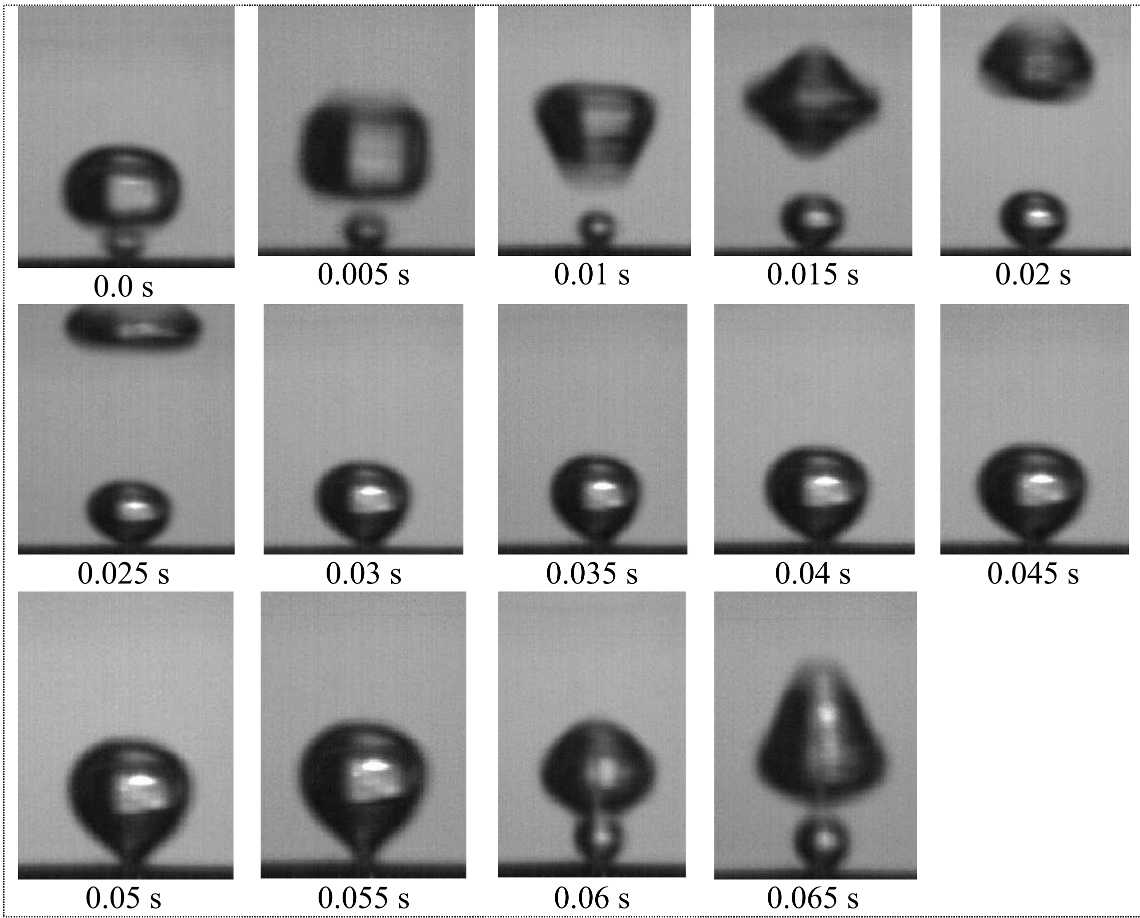

Fig. 2. Bubble growth on a surface with the artificial nucleation site (D=200 microns), ΔT_w=2 K, q=100 *kW/m*^{2}

On the finished shooting were defined departure diameter and departure frequency of vapor bubbles. An analysis of recordings allows to made observations: the first - when the steam bubble appears on a surface, the second - before origin of a new steam bubble (Fig. 2, time from 0 to 0.055 s). As result of shootings, it is possible to draw a conclusion, that the waiting time of a vapor bubble is small in comparison with growth time (it makes some percents).
The following dependence is constructed for the definition of a minimum quantity of vapor bubbles necessary for reliable separation frequency and departure diameter of a vapor bubble. On Fig. 3 is presented the dependence of the most probable separation frequency of vapor bubbles on quantity of processed vapor bubbles.

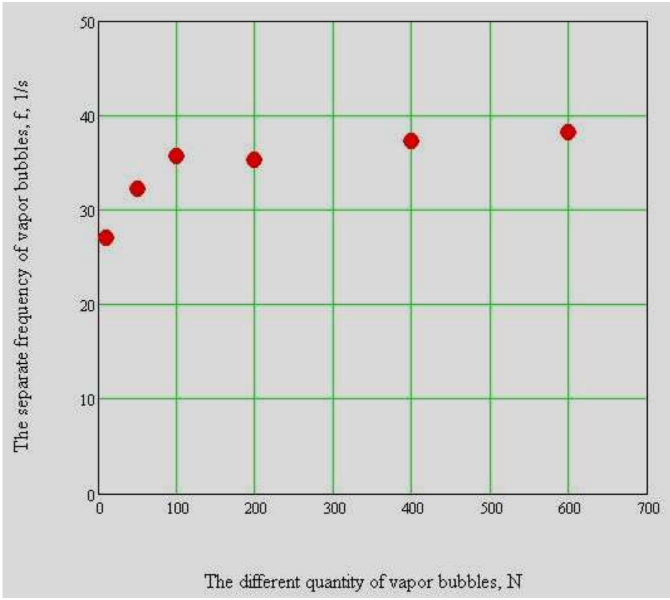

Fig. 3. The separation frequency received at processing of various vapor bubbles quantity

From the schedule on Fig. 3 it is visible, that the quantity of the processed bubbles should be not less than 100 for reliable most probable separation frequency. The dependences, to be presented on Fig. 4 are constructed through data about growth of a vapor bubble radius versus time. The results of calculation under *D.A.Labuntsov* and *V.V. Jagov* equations [8] and *M.A.Mikheyev* [9] are shown also on the Fig 4.

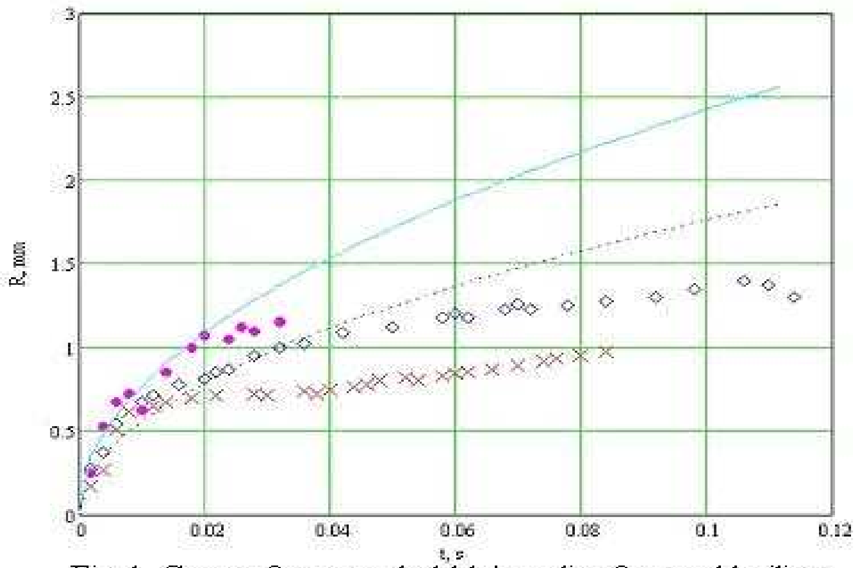

Fig.4. Grow of a vapor bubble's radius for pool boiling. Water, p=0.1 MPa.

× × 1 - Experemental data for a cavity D=100 µm

◇ ◇ 2 - Experemental data for a cavity D=200 µm

••• 3 - Experemental data for a cavity D=200 µm

4 - Equation of D.A. Labuntsov-V.V. Jagov [8]

5 - Equation of M.A. Micheev [7]

The curves 1 and 2 are received at subcooling ΔT_{sub}=2 K, the curve 3 is received under condition of saturation.

Since time t=0.02, the growth rate of a vapor bubble is less for a surface with the single artificial nucleation site, then according to calculated dependences for boiling on usual surfaces. The noted divergence is less in case of a bigger diameter's cavity. It is discovered, that the growth speed of vapor bubble is lower in the investigated conditions, than at boiling on a usual surface.

The vapor bubbles' separation frequencies and departure diameter's distributions are constructed for definition of the most probable sizes. On Fig. 5 the separation frequency distributions of a vapor bubble are presented at ΔT_w=2 K and various heat fluxes for a cylindrical cavity, with diameter 200 microns. The related number of the bubbles, which the bubbles' number with certain frequency to the total bubbles' number fixed in experiment is equal, is marked on a vertical axis.

The decreasing a maximum and its displacement are observed towards the big frequencies with increasing the heat flux.

On Fig. 6 the distribution of the vapor bubbles' departure diameters is presented at boiling on the surface with a 200 microns diameter cavity.

The decreasing a maximum and its displacement are observed towards smaller diameters with growth of heat flux. However, this displacement is not so great as on distribution of frequencies.

The decreasing departure diameter and increasing separate frequency of vapor bubbles are observed with increasing heat flux.

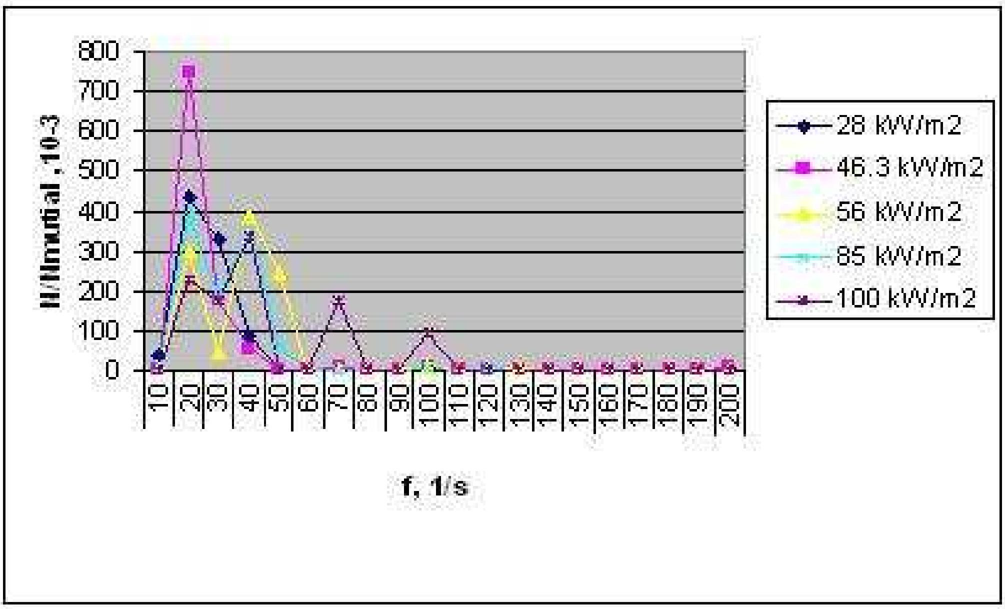

Fig.5. The vapor bubbles' separation frequency distribution for a cavity 200 microns at different heat fluxes, ΔT_w=2 K

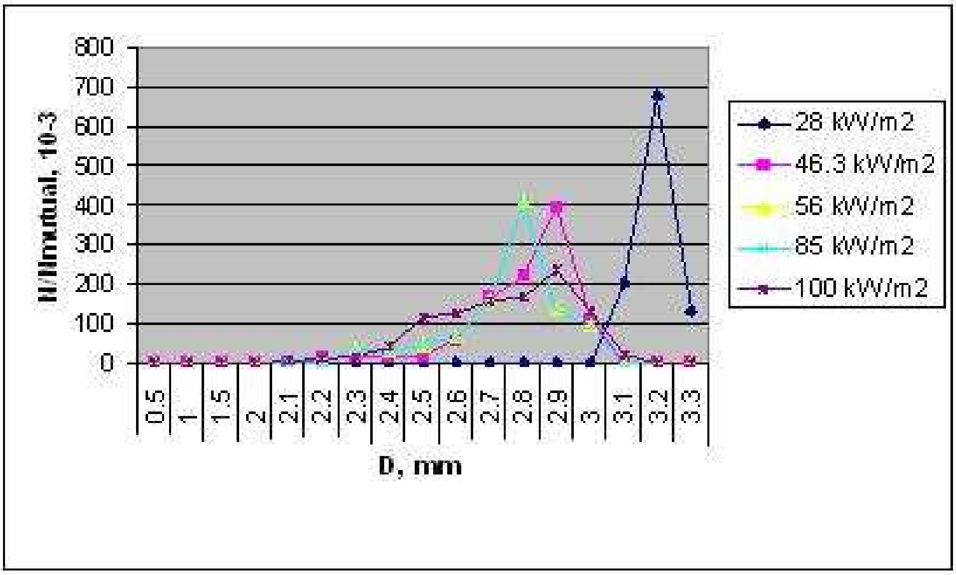

Fig.6. The vapor bubbles' departure diameters' distribution, for cavity diameter 200 microns, at different heat fluxes, ΔT_w=2 K

On Fig. 7 the dependence of asymmetry factors is presented at different heat fluxes. The growth of asymmetry factor is observed on departure diameters' distributions with the increasing heat flux. The asymmetry factor of vapor bubbles' separation frequency distributions passes through a maximum at heat flux q=56 *kW/m*^{2}.

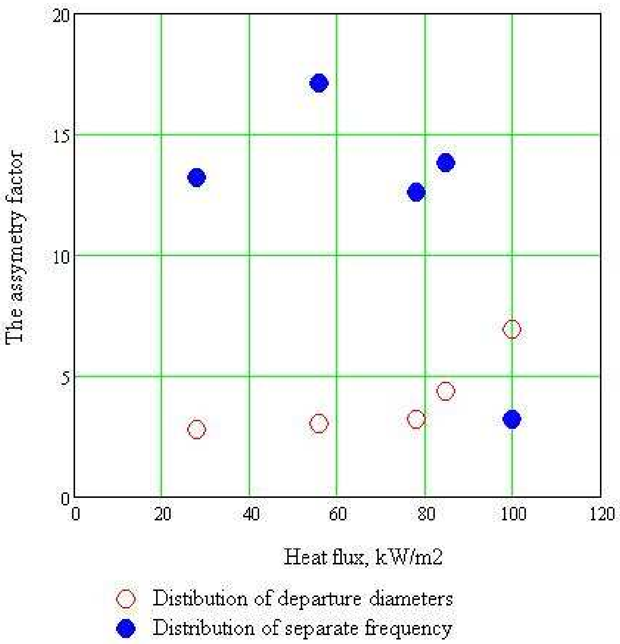

Fig.7. Dependences of asymmetry factors at different heat fluxes. Cavity 200 microns, ΔT_w=2 K

On Fig. 8 the dependence of most probable separation frequency is presented at different heat fluxes, ΔT_w=2 K. The increase of vapor bubbles' separation frequency is observed with increasing the heat flux. On Fig. 8 the data [3] are shown also for a cavity with diameter 10 microns. It can be seen: the curve *f(q)* displaced in the side of the smaller heat fluxes with decreasing cavity diameter.

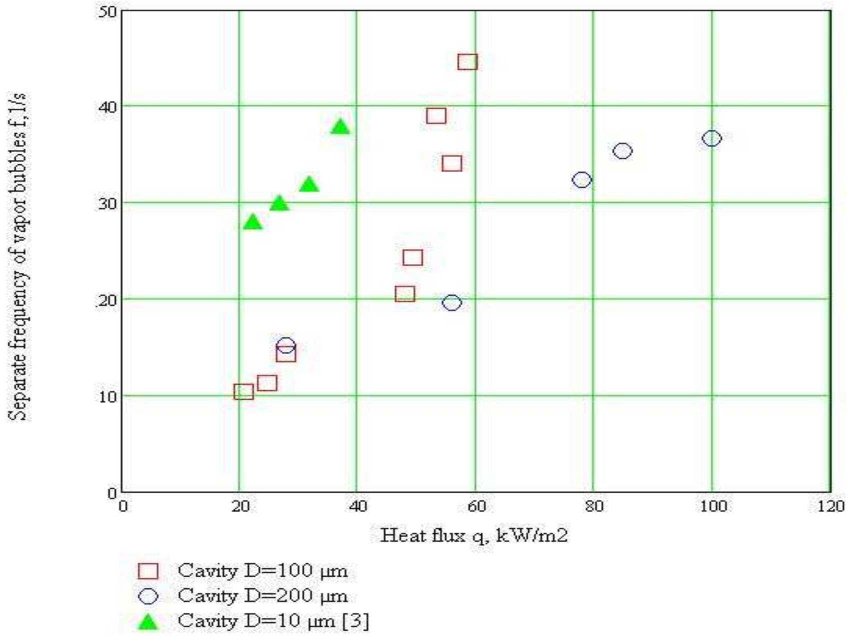

Fig. 8. Dependence of vapor bubbles' separation frequency at different heat flux, ΔT_w=2 K

On Fig. 9 skilled data of the present work are compared with the results received in works [6,7] and calculation under the equation of *V.V. Jagov*. Apparently, departure diameters of vapor bubbles do not depend in case of boiling on a surface with a single cavity practically at heat flux. The departure diameter of a vapor bubble is increasing with growth of cavity's diameter.

Boiling on usual surfaces gives other dependence *R (q)*. The data (○) are obtained in case of narrow beam and data (+) – in case of wide beam.

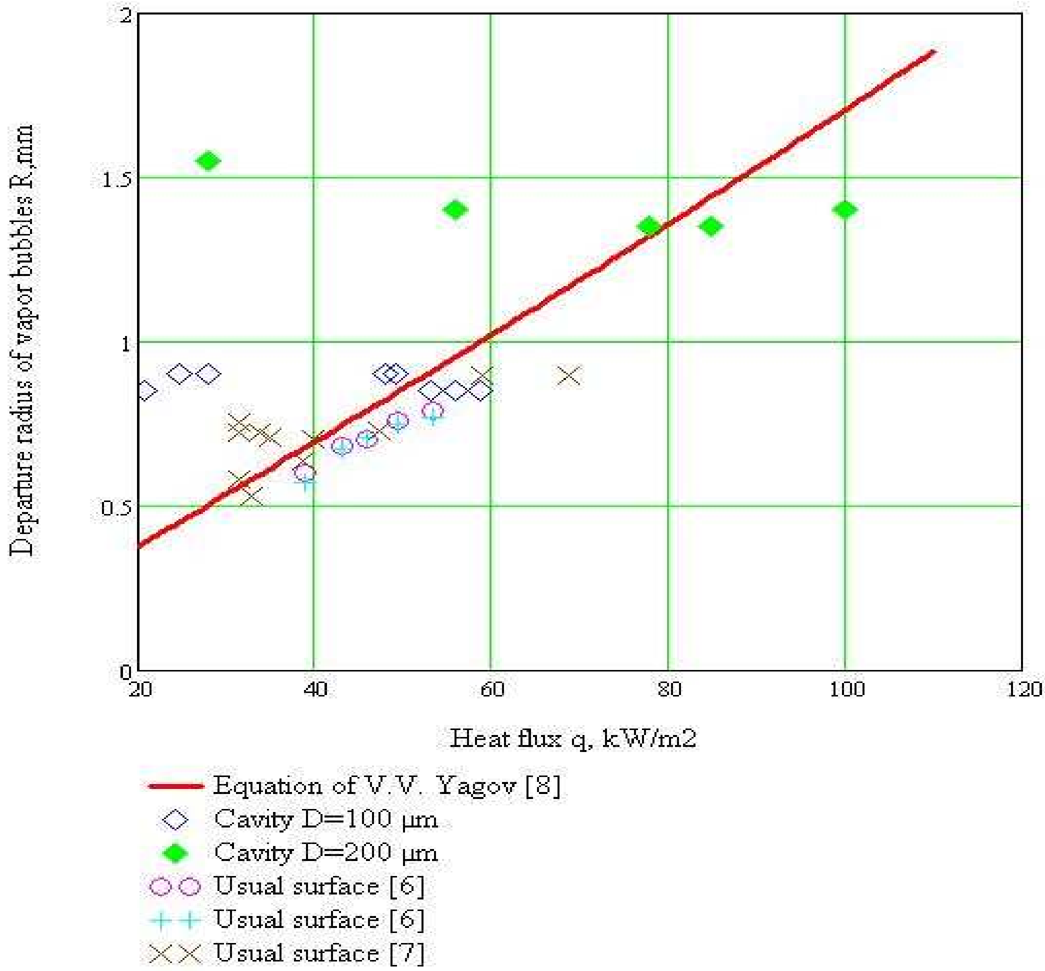

Fig. 9. Dependence vapor bubbles' departure radius on heat flux, ΔT_W=2 K

On Fig. 10 the dependence of dimensionless complex $\frac{f * d^2}{a}$ is presented as the function of Jacob's number:

$$F(Ja) = Ja \cdot \left(1 + \left(\gamma^2 / \beta_2\right) Ja + \left(\gamma / \beta_2\right)\left[2\beta_2 Ja + \left(\gamma Ja\right)^2\right]^{0.5}\right), \quad (6)$$

$$\gamma = 0.3, \beta_2 = 6$$

where: a – thermal diffusivity,

$$Ja = \frac{\rho' c_p}{\rho'' h_{lg}} \Delta T$$

.

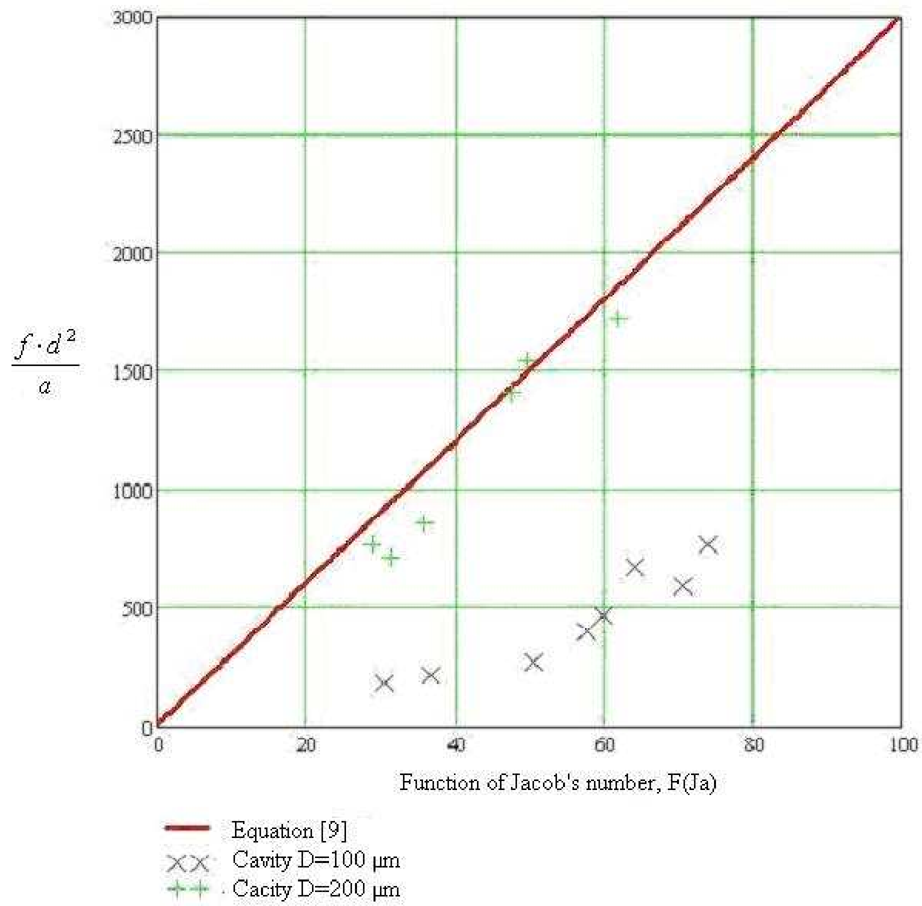

Fig. 10. Dependence of dimensionless complex $\frac{f * d^2}{a}$ on function of the Jacob's number, $\Delta T_{ж}$=2 K

On Fig. 10. Calculation on equation [9] is shown by a line:

$$\frac{fd^2}{a} = 48 \cdot \varepsilon_\tau \cdot F(Ja), \quad \varepsilon_\tau = 0.625 \tag{7}$$

It is visible on Fig. 10, that skilled data for a cavity in diameter 200 microns are co-ordinated with dependence for usual surface [9] whereas data for a cavity 100 micron lays lower.

Conclusions

The experimental data on vapor bubble's growth has been got on a surface with an artificial nucleation site for pool boiling water at atmospheric pressure. It is estimated, that the growth speed of vapor bubble is lower in the investigated conditions, than at boiling on an usual surfaces.
The distribution of separate frequency and departure radius are constructed at different heat fluxes.
It is discovered, that the decreasing a maximum and its displacement is occurred in side of bigger separate frequencies with increasing of heat flux. The drop of

maximum and its displacement is discovered on a distribution of departure diameters in side of smaller departure diameters with increasing of heat flux.
The most probably values departure diameters and separate frequencies are founded on a surface with a single artificial cavity. The dependences of vapor bubbles' departure diameters and separate frequencies are determinate on heat flux.
It is discovered, that the decreasing departure diameter and increasing separate frequency of vapor bubbles are observed with increasing heat flux.
The comparision has been undertaken of the separate frequency for a cavities of the different diameters with the famous experimental data for a surface with the artificial nucleation site.

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Afoņins S., Kuzma-Kičta Yu.A., Dursts F. Vārīšanās procesu pētīšana uz virsmām ar mākslīgajiem tvaika fāzes veidošanās centriem

Darbā veikti eksperimentāli šķidrumu vārīšanās procesu pētījumi uz virsmām ar mākslīgiem tvaika fāzes veidošanās centriem. Analizējot jaunāko pētījumu rezultātus un salīdzinot tos ar klasiskajiem darbiem (Labuncovs D.A, Jagovs V.V., Mihejevs M.A.), pierādīta dotā darba tematikas aktualitāte un perspektivitāte. Ar ātrdarbīgas fotokameras palīdzību iegūti dati par tvaika burbulīšu atraušanās no sildvirsmas diametru un frekvenci. Darba rezultātā iegūtas sakarības par burbulīšu atraušanās rādiusa un frekvences atkarību no siltuma slodzes. Tāpat iegūti dati par tvaika burbulīšu augšanas ātrumu šķidruma tilpumā uz sildvirsmām ar speciālu apstrādi. Veikts iegūto eksperimentālo datu salīdzinājums ar agrāk zināmajiem pētījumiem virsmām ar mākslīgajiem tvaika fāzes veidošanās centriem.

Afonin S., Kuzma-Kichta Yu.A., Durst F. Boiling investigation on a surface with the artificial nucleation sites

Results of an experimental investigation of liquid`s pool boiling at atmospheric pressure on solid heating surfaces with an artificial vapour nucleation sites are represented in the given report. An anlysis of latest investigations and classical works (D.A.Labuntsov V.V. Jagov, M.A.Mikheyev) confirms actuality and perspectivity of given thematic. Data regarding frequency and diameter of vapour bubble departure from surface are obtained by high speed photography. Relationships of departure conditions versus heat flux density on surfaces with artificial nucleation sites are elaborated. Comparision of obtained data with similar previous known experimental investigation`s results is carried out.

Афонин С., Кузма-Кичта Ю.А., Дурст Ф. Исследование кипения на поверхности с искусственным центром парообразования

В работе проведено экспериментальное исследование кипения на поверхности с искусственным центром парообразования в большом объеме при атмосферном давлении. Анализом результатов современных исследований и сравнением их с классическими работами (Д.А.Лабунцов, В.В.Ягов,М.А.Михеев) дозана актуальность и перспективность данной тематики. С помощью высокоскоростной видеокамеры получены данные по частоте отрыва и отрывному диаметру паровых пузырей. Результатами работы являются распределения и зависимости отрывного радиуса и частоты отрыва паровых пузырей от тепловой нагрузки. Также получены данные по росту парового пузыря при кипении в большом объеме на поверхности с искусственным углублением. Проведены сравнения опытных данных по частотам отрыва с известными данными для поверхности с искусственным центром парообразования.