Int. J. Heat Mass Transfer. Vol. 28, No. 12, pp. 2331–2342, 1985
Printed in Great Britain

0017–9310/85 $3.00 + 0.00


# Some aspects of the interaction among nucleation sites during saturated nucleate boiling

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(*Received* 4 *March* 1985 *and in final form* 1 *July* 1985)

**Abstract**—The results of an original experimental investigation of the interaction between nucleation phenomena occurring at adjacent nucleation sites during saturated boiling of dichloromethane are presented and compared with the results of Chekanov's investigation [*Teplofiz. Vysok. Temp.* **15**, 121–128 (1977)]. The interaction was found to be positive for distances between nucleation sites less than or equal to the mean bubble departure diameter in that bubble formation at one site tended to promote bubble formation at adjacent sites and negative for distances between sites greater than the mean bubble departure diameter in that bubble formation at one site tended to inhibit bubble formation at adjacent sites. No interaction was detected for distances between nucleation sites greater than three mean bubble departure diameters.

## INTRODUCTION

NUCLEATE boiling has been utilized extensively in industry because it is one of the most efficient mechanisms of heat transfer, particularly in high energy density systems such as those found in nuclear reactor power plants. The reason that nucleate boiling is capable of transferring quantities of energy many times greater than those transferred by convection or conduction comes undoubtedly from the nucleation and formation of the bubbles which are associated with this phenomenon. Previous research has been devoted to estimating the role of the bubbles in nucleate boiling and the prediction of the rate of heat transfer including the effects of bubble emission. As a result of this, many of the boiling parameters (growth time, waiting time, departure diameter, etc.) can be predicted assuming there is no interaction between the emission of bubbles at adjacent nucleation sites.

Only lately has research been conducted addressing aspects of the mechanics of groups of individual bubbles with emphasis on the interactions of the emission phenomenon as its focus. Work performed in recent times has shown that bubble emission is not an isolated process and that bubble emission at an active nucleation site may either promote activity at an adjacent site or may inhibit it. Although researchers do not agree on how these actions take place, the interaction of the bubble emission process at adjacent sites undoubtedly has a role in determining the actual nucleation site density. It is this line of research that the present investigation continues in order to reappraise earlier findings.

## PREVIOUS CONTRIBUTIONS

Notwithstanding the fact that most of the important boiling parameters are widely recognized and their role reasonably well understood, none of the existing theoretical models is capable of satisfactorily predicting the rate of heat transfer during nucleate boiling. One possible explanation of this may come from the fact that none of the models takes into the account interaction of the nucleation phenomena at adjacent sites.

The first suggestion of the interaction of the bubble emission phenomena occurring at an adjacent site was provided by Eddington and Kenning [1]. In their experiment, which is reported in ref. [2], a method of determining the bubble population data by studying bubble nucleation from supersaturated gas solutions was explored. Gas nucleation results showed that there were many more cavities on the surface which satisfied the site activation relationship:

$$r_c = 2\sigma T_{sat}/\rho_v h_{fg}(T_w - T_{sat}) \qquad (1)$$

than were actually activated during boiling. Many of these inactive sites failed to survive the prepressurization process in the gas rig, but some sites did survive this step and yet still failed to activate during boiling. The failure of apparently stable sites to nucleate was attributed to 'thermal interference' from already active sites, but no direct evidence of it was produced.

Eddington and Kenning also examined the sites which did not survive prepressurization and did activate during boiling. It was found that 76% of the sites had been covered by departing bubbles from an adjacent site just previous to bubble emission. This observation was said to support the explanation that 'site seeding' had occurred under the bubbles before departure by dryout of the microlayer as shown schematically in Fig. 1. Here two sites are shown, site A, which is active and is producing bubbles (STEP 1), and site B, which is free of any vapour residue and is not producing any bubbles. In (STEP 2) the growing bubble forms a microlayer, which evaporates (STEP 3) and the dry spot completely covers site B. When the bubble forming at site A departs, it leaves a residue of vapour (STEP 4) in site B which now is able to nucleate bubbles (STEP 5). If the geometry of site B were favourable, it

**NOMENCLATURE**

| | | | |
|---|---|---|---|
| $D_b$ | departure radius | Greek symbols | |
| $h_{fg}$ | latent heat | $\theta$ | time between appearance of successive bubbles |
| $p$ | pressure | $\lambda$ | reciprocal of average time without correlation |
| $q''$ | heat flux | $\nu$ | shape parameter |
| $R$ | radius of bubble | $\rho_v$ | vapour density |
| $r_c$ | radius of cavity | $\sigma$ | surface tension |
| $S$ | separation distance | $\tau$ | time |
| $T_{sat}$ | saturation temperature | $\bar{\tau}$ | average time. |
| $T_w$ | wall temperature. | | |

would trap some vapour during the departure of the bubble formed at it and so it would be able to continue nucleating.

The bubble flux density distribution on a heating surface may also be used as an indirect source of information about the nucleation process. Several years ago, Sultan and Judd [3] studied the spatial distribution of active sites and bubble flux density during boiling of water at atmospheric pressure on a copper surface at different levels of heat flux and subcooling. Their results demonstrated a random (Poisson) distribution of active sites on the heating surface irrespective of heat flux or subcooling although the number of active sites per unit area was related to the heat flux, in agreement with the results of an experiment reported by Gaertner. In ref. [4] he wrote that 'patchwise boiling' observed by many researchers in the light of the random distribution of active sites is not real, but is an illusion of clustering. However, this conclusion disagrees with the Sultan and Judd [3] finding that the bubble flux density actually is non-uniformly distributed over the heating surface, which suggests that the formation of bubbles at various locations on the surface is interrelated in some way.

Judd and Lavdas [5] examined high speed motion picture films of dichloromethane boiling on a transparent glass surface and provided direct evidence of the nature of the interactions occurring during the nucleation process. They observed two sequences of events, one leading to deactivation of an active nucleation site by the departure of a bubble formed at an adjacent site, which interferred with bubble nucleation as the 'thermal interference' postulated by Eddington and Kenning was supposed to have done and the other suggesting activation of an inactive site by the formation of a large bubble at an adjacent site which created a nucleus at the inactive site after it had been covered by the dry spot, which is accordant with Eddington and Kenning's description of 'site seeding'.

In ref. [6], Kenning and Del Valle M. presented a surface quenching model for boiling heat transfer which included an estimate of the degree of overlap of

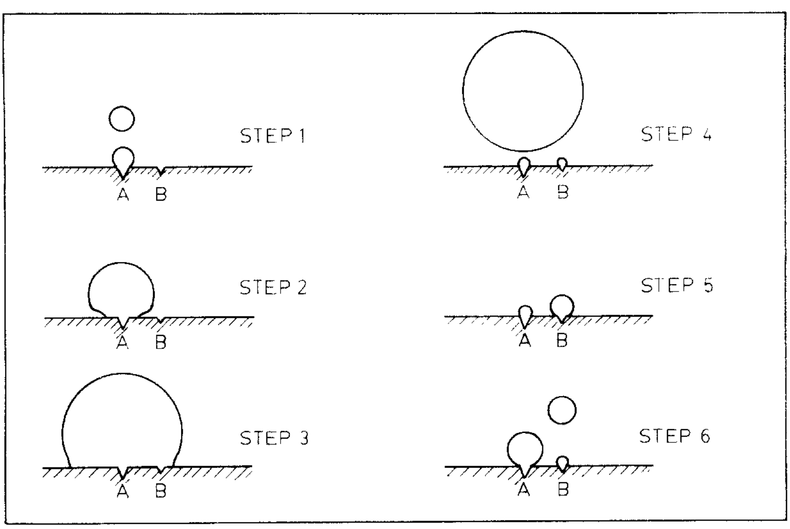


FIG. 1. Schematic representation of 'seeding' by dryout of a microlayer.

nucleation sites to produce a random distribution of nucleation sites modified by short range interference between them. Their experiments showed that the probability of nucleation within one bubble departure diameter of another site was much smaller than that predicted by a random distribution. Similar behaviour was observed by Del Valle M. [7] in high heat flux flow boiling of water at large subcooling. This behaviour was said to be indicative of interaction between the sites.

The interaction of active sites in nucleate boiling was the subject of Chekanov's research [8]. He conducted an experiment during which two artificial sites were produced in water boiling at atmospheric pressure on a thin permalloy foil. Two pointed heaters were positioned under the foil, one of which could be moved relative to the other. Movement of the heater over the lower side of foil altered the boiling condition on the upper surface in the way that heat was produced at the point of contact of the pointed heater with the permalloy foil. In the vicinity of the point on the surface of the foil, a nucleation site would be activated. The separation distance between the active sites $S$ was measured and the time $\tau$ elapsed between the start of bubble growth at one nucleation centre and the subsequent start of bubble growth at the other nucleation centre was obtained by analysis of photomultiplier signals corresponding to the formation of the bubbles at the adjacent nucleation sites.

Chekanov made an assumption based upon the theory of pulse processes that when pulses interact, the form of the distribution of the time between them is the gamma distribution:

$$p(\tau) = [\lambda^{\nu}\tau^{\nu-1}/\Gamma(\nu)]\,\mathrm{e}^{-\lambda\tau} \tag{2}$$

where $p(\tau)$ is the probability of an event in which the pulse associated with the bubble formed at one of the adjacent sites is formed in a time interval $(\tau, \tau+\mathrm{d}\tau)$ from the time of formation of the bubble at the other site, $\lambda$ is the reciprocal of the average time $\bar{\tau}$ and $\nu$ is the shape parameter. For non-interacting sites the distribution of time interval between the formation of a bubble at one nucleation site and the subsequent formation of a bubble at another will be exponential ($\nu = 1$). Using the method of moments, the shape parameter $\nu$ was calculated for different distances between the centres and was found to follow the trend depicted in Fig. 2. For separation distances more than three times the departure diameter, values of $\nu$ were found to be less than unity while for separation distances less than three times the departure diameter the shape parameter $\nu$ was greater than one. Chekanov claimed that for $\nu < 1$ the interaction between the sites was 'attractive' (a bubble formed at one site enhanced the formation of a bubble at the adjacent site), while for $\nu > 1$, the interaction between the sites was 'repulsive' (the formation of a bubble at one centre inhibited the formation of a bubble at the other site). Chekanov postulated that the bubbles affect one another by acoustic action and hydrodynamic mixing but gave no further explanation of the interaction mechanism.

The considerations presented above show clearly that researchers are cognizant of site interaction, although they do not agree about the nature of the interaction and its significance. The existence of site interaction suggests that the nucleation of bubbles at a particular active site is related to (and probably governed by) the pattern of bubble emissions of all of its neighbours within a localized region. This means that bubble formation is not an isolated event as commonly assumed and implies the necessity of a new approach to the formulation of heat transfer models requiring more experimental and theoretical study. The investigation reported herein is done to advance our understanding of the nucleation phenomenon.

## EXPERIMENTAL APPARATUS

An existing experimental facility at McMaster University used by Voutsinos and Judd [9] to investigate the microlayer evaporation phenomenon was redesigned to meet the special needs of the present

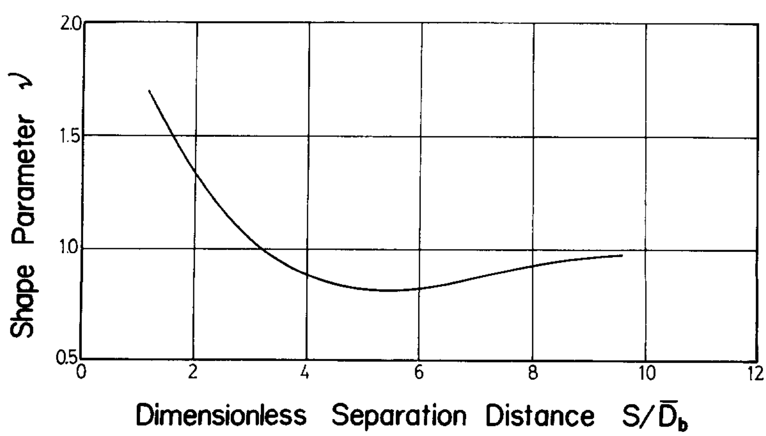


FIG. 2. Chekanov's results for saturated boiling water on permalloy.

investigation, of which the need to locate the active nucleation sites and to produce signals corresponding to the nucleation of bubbles was most important.

The basic component of the test assembly was a stainless-steel vacuum-tight vessel (Fig. 3) which contained a transparent glass surface. Dichloromethane was caused to boil on the glass surface which was coated, according to the manufacturer's specifications, with a half wavelength of He–Ne laser light thickness of stannic oxide that conducted electric current and permitted heat to be generated. The heat transfer surface had dimensions of 50 by 33 mm and it was assumed that heat was generated uniformly over it. The validity of this assumption was confirmed by measurements done by Judd and reported in ref. [10]. The lower part of the heat transfer surface which was coated with a one-quarter wavelength thickness of anti-reflective coating for He–Ne laser light was exposed to the air. More details about the heat transfer surface can be found in ref. [11].

In order to decrease the number of active sites and to increase the size of the bubbles as well as to enable operation at lower surface temperature thereby avoiding damage to the heat transfer surface, the pressure in the vessel was maintained lower than atmospheric pressure by means of an Edwards rotary vacuum pump. Adjustment of the pressure was accomplished with an atmospheric bleed valve and the pressure was continuously monitored by a mercury manometer and adjusted as required.

The measurement of the various temperatures was accomplished with chromel–constantan thermocouples. Three were used to measure the bulk liquid temperature and one was used to measure the heat transfer surface temperature. Each thermocouple measuring the bulk liquid temperature was suspended from the cover plate of the test vessel, while the one measuring the heater surface temperature was epoxied to the lower side. The signals from the thermocouples were measured either by a high precision Guideline potentiometer or a Minneapolis Honeywell recorder.

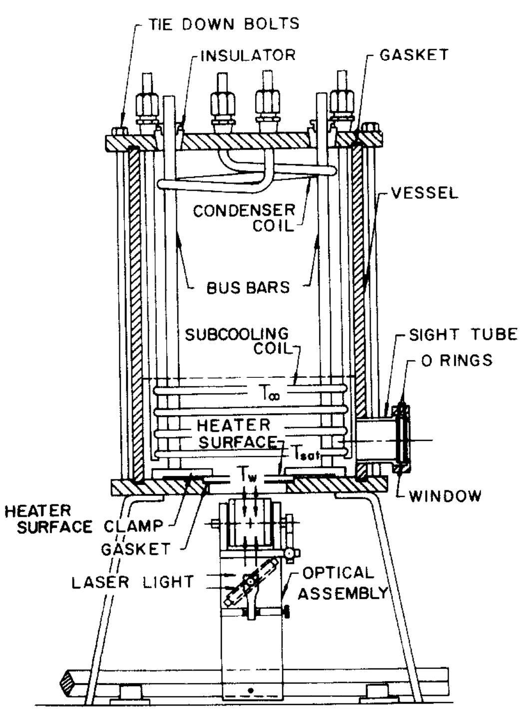


FIG. 3. Boiling vessel configuration.

The stannic oxide coating on the glass surface was provided with electric power by a Kepco power supply. This unit was capable of independently setting and controlling the upper limit on voltage as well as current, which was important in preventing overheating of the heat transfer surface.

The source of illumination used in the present investigation was a Spectraphysics He–Ne laser (model 125A, $\lambda = 0.6328$ $\mu$m) which was capable of producing a 50 mW beam of coherent light approx. 2 mm in diameter after which a collimator expanded the beam to a diameter of about 20 mm. A drawing of the test assembly is shown in Fig. 4.

For the purpose of the present investigation, a special two channel photo-optical nucleation site locating apparatus was designed and constructed. The ability to independently identify two closely related active nucleation sites on the heat transfer surface was the most important function that the apparatus had to fulfil and in order to achieve this goal, an optical solution was chosen. The transparent glass heat transfer surface was illuminated from below and a small part of the light was reflected back to the locating apparatus, which produced a magnified image of it. When a bubble formed at a particular site, it strongly reflected the laser light, thus producing a flash at the image plane. A location where light flashes occurred continuously indicated the position of an active nucleation site. Splitting of the reflected beam with a semi-transparent prism enabled two images of the heat transfer surface to be produced, thus enabling the closely related active nucleation sites to be identified and examined independently. By locating a viewfinder at the centre of the flashing light and recording the coordinates, the active nucleation site could be completely identified. By placing a phototransistor at the same location, the variation in light intensity corresponding to the formation of the bubbles could be examined.

The measurement of the time elapsed between the start of bubble growth at one nucleation site and subsequent start of bubble growth at an adjacent nucleation site was critical in this study. Thus the apparatus had to be able to determine the start of bubble growth and to produce a signal corresponding to growth and departure of a bubble independently for any two nucleation sites. This was achieved by replacing the viewfinders with phototransistors at the image planes which transformed the light reflected by the bubbles being formed to corresponding electric signals. The signals could be recorded or further processed in order to obtain the needed information.

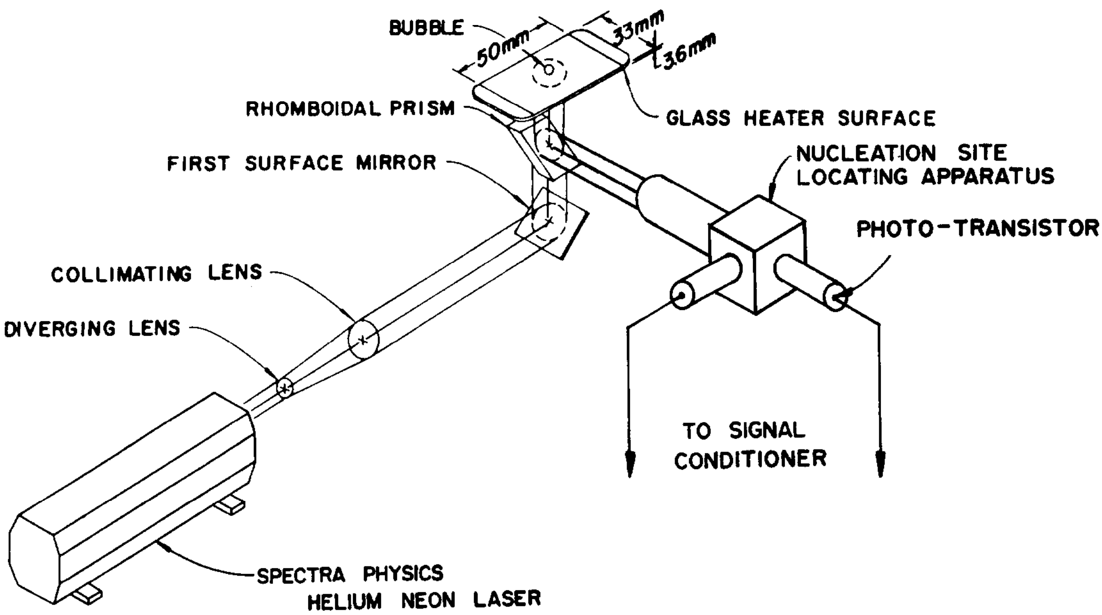


FIG. 4. Test assembly schematic arrangement.

A schematic drawing in Fig. 5 illustrates the operating principle of the nucleation site locating apparatus. The light reflected by a bubble forming on the surface was focused by a double convex lens ($f = 88$ mm). By means of the split prism, two images of the bubble were formed, one in plane P1, the other in plane P2 and the images could be observed with the two viewfinders. Two scanning mechanisms, one located in each of the image planes, were capable of positioning the viewfinders at the chosen nucleation site and determining the coordinates. The nucleation site locating apparatus could be moved along an aluminum rail, thus enabling change of magnification. In order to adjust the focus to the change in the magnification, the double-convex lens had to be moved along the supporting tube in which it was mounted.

Although boiling took place at reduced pressure, the frequency of bubble formation was so high (of the order of 20 Hz), that a DECLAB 11/03 laboratory computer had to be used to collect the data. A user-oriented software package (DECUS 11-320) was purchased in order to make data acquisition possible. The package, entitled Post and Inter Spike Interval Analysis was created for the PDP-11 computer with an RT-11 V02C operating system fitted with a LPS-11 Laboratory Peripheral System and a VT55 display terminal. The package contained two programs: ISH and PISH, which in order to be made operational had to be adapted to the existing hardware and software. The modifications to the programs were made by Judd [12] and mostly concerned the way that the clock counter interrupts generated by the signals from the Schmitt

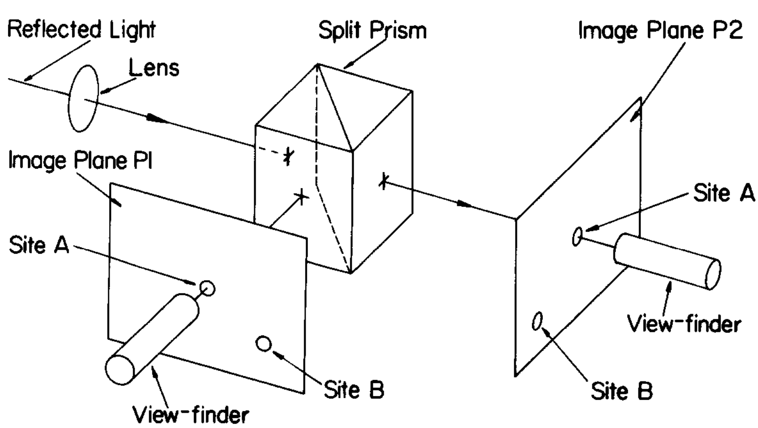


FIG. 5. Schematic representation of the locating apparatus.

triggers in the computer's programmable real-time clock were processed.

These programs which were provided on a floppy diskette with both source and object files, were able to acquire, display and store intervals between single spikes in real time. ISH counted and ordered absolute intervals between spikes, while PISH collected spike intervals after synchronizing pulses, as has been illustrated schematically in Fig. 6. Program PISH was of particular interest in this experimental investigation.

In order to gain some confidence in the ability of PISH to measure accurately interspike intervals, the software had to be calibrated. A Phillips signal generator was used to generate square waves at different frequencies which comprised the input for both Schmitt triggers. ST1 was set to fire at the positive crossing of the wave, while ST2 was set to fire at the negative crossing of the wave. These Schmitt trigger settings permitted the half-period of the wave to be measured for comparison with the result determined from the frequency setting. The calibration results indicated very good accuracy for the measurement of time intervals equal to or greater than 10 ms.

## SIGNAL PROCESSING

A modern data acquisition system (digital laboratory computer and appropriate software) was required to gather and store the data. Voltage signals from the two phototransistors, after being magnified by a signal conditioner designed and constructed by the technicians of the Department of Mechanical Engineering, were directed to the two Schmitt triggers (Fig. 7). The setting of the threshold levels of the Schmitt triggers was very important for the accuracy of the elapsed time measurement because of the necessity of minimizing spurious interrupts. For this reason the level of both Schmitt triggers was set as close to the base signal levels corresponding to boiling inactivity as possible and both were set to trigger on voltage rising (positive slope).

Program PISH collected the data (values of time elapsed between start of bubble growth at one nucleation site and the subsequent start of bubble growth at an adjacent site), in the form of histograms created during data collection in real time. To make sure that sufficient data was being acquired, at the beginning of each test an event counter would be set to 10,000 events and if stability of the histogram (no further apparent change in shape) were observed before 10,000 events had occurred, the event counter would be changed to a lower value, ordinarily between 3000 and 5000. However, in some cases 8000 events were required. When data acquisition was terminated, PISH would store the histogram if instructed to do so. Each of the stored histograms could be recalled later for further graphic and statistical analysis.

When the phenomena corresponding to bubbles growing at adjacent nucleation sites interact, one of the forms of the distribution of the time between them is the gamma distribution. In order to fit the data (histograms of the time elapsed between start of bubble growth at one nucleation site and subsequent start of bubble growth at an adjacent one) with the gamma distribution, a program GAMFIT was created. This program was able to access a specified histogram, calculate its probability density function and plot it in the form of vertical bars. Then the program was able to generate a gamma distribution and plot it in the form of points

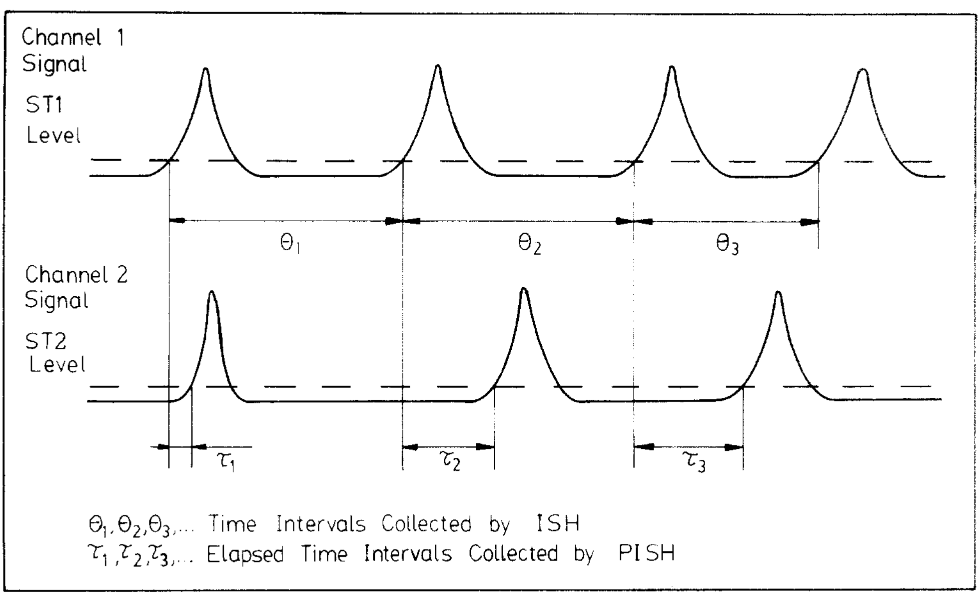


FIG. 6. Schematic explanation of the operation of programs ISH and PISH.

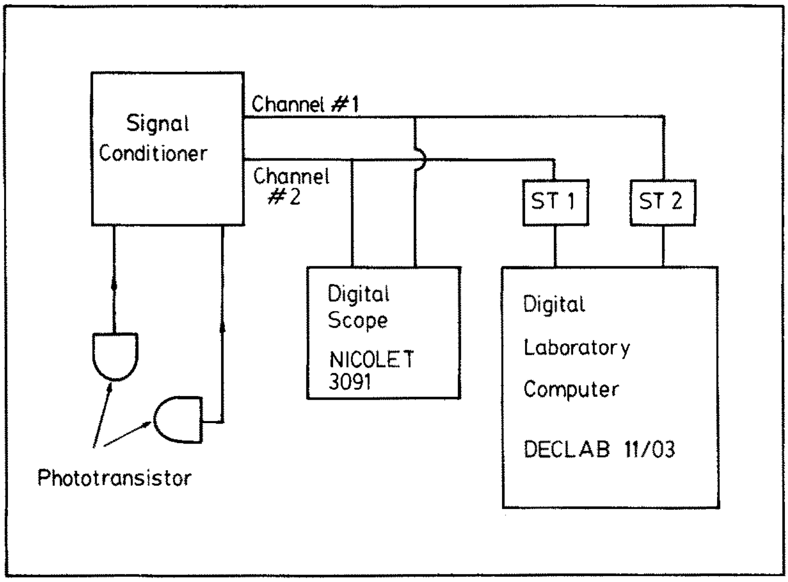


FIG. 7. Schematic representation of signal processing system.

superimposed on the original graph. Two parameters which determine the gamma distribution (mean value $\bar{\tau}$ and shape coefficient $\nu$) were needed as input for GAMFIT and had to be guessed at the beginning of a fitting session. Then, after both probability density function and gamma distribution had been plotted (superimposed upon each other), subjective evaluation of the goodness of fit was required. Adjustment of the mean value and shape coefficient took place until the fit was deemed to be satisfactory. This curve fitting technique was employed because of the appearance of spurious data which in some cases were very significant, leading to formation of a peak near the origin of the histogram. This peak, which occurred when the separation distance between the sites was very small (less than the bubble departure diameter) was due to the generation of signals in both channels of the locating apparatus by the same bubble. These signals caused the Schmitt triggers to fire one after another in a very short period of time (of the order of 5–10 ms or less) which then resulted in the formation of peaks in the histogram very close to the origin. These peaks had to be discounted while fitting the data with the gamma distribution and an interactive procedure in which the user determined the goodness of fit by inspection seemed the best way to do it.

Further details of the apparatus and procedures used in this investigation may be found in Calka [13].

## EXPERIMENTAL INVESTIGATION

Three series of tests were conducted for three different heat fluxes, all under saturated nucleate boiling conditions. In Table 1, values of heat flux, system pressure, bulk liquid temperature and saturation temperature are listed.

Table 1. Test conditions

| | Series I | Series II | Series III |
|---|---|---|---|
| Heat flux, $q''$ (kW m$^{-2}$) | 44.2 | 55.3 | 89.8 |
| Pressure, $p$ (mmHg) | 303 | 287 | 275 |
| Bulk temperature, $T_\infty$ (°C) | 15.6 | 14.8 | 13.8 |
| Saturation temperature, $T_{sat}$ (°C) | 15.8 | 14.6 | 13.9 |
| Wall temperature, $T_w$ (°C) | 45.5 | 46.2 | 48.3 |

The boiling of dichloromethane took place on a glass surface at naturally occurring nucleation sites. Prior to boiling, the condenser feed water valve was opened and the system was cooled down. The laser power supply was switched on and the vacuum pump was started. When the pressure in the vessel dropped to the desired value, the heat transfer surface power supply was turned on, thus starting the boiling at the required heat flux. At the same time the signal conditioner, digital oscilloscope and computer were also turned on. After an hour of preliminary boiling, the viewfinders of the nucleation site locating apparatus were positioned at chosen nucleation sites and then the phototransistors were substituted in their places, thus starting the generation of voltage signals. After setting both Schmitt trigger levels, program PISH was started and data collection was begun. When no more apparent change in the shape of a histogram was observed, the histogram was stored and the viewfinder corresponding to channel No. 2 was moved to the centre of another active nucleation site. The data collection process was restarted and another histogram was created. This procedure took place until the viewfinder corresponding to channel No. 2 had examined all of the active nucleation sites within the field of view. Then the viewfinder corresponding to channel No. 1 of the nucleation site locating apparatus was positioned at the centre of another active nucleation site where it remained until all of the other active nucleation sites were examined by the viewfinder corresponding to channel No. 2. In this way, the active nucleation site at channel No. 1 and all its neighbours were investigated, one pair of active sites at a time. When all pairs had been so examined, the heat flux was changed and after steady state was re-established, the whole procedure was repeated again.

## RESULTS

The first part of the investigation concentrated on the identification and location of the active nucleation sites on the heat transfer surface. As a result of this procedure, a map of the boiling surface within the field of view of the locating apparatus with all of active nucleation sites superimposed was produced. A total of 24 active sites was located and a map of the boiling heat transfer surface is presented in Fig. 8. This map shows the active nucleation site distribution within the area of 12.7 by 6.35 mm, the area of the view of the locating apparatus when the optics were adjusted to give 1.8 times magnification.

Figure 9 represents two histograms for the same heat flux (89.8 kW $m^{-2}$), but different pairs of nucleation sites (1–12 and 1–17), which have separation distances equal to 1.29 and 7.93 mm, respectively. Inspection of these histograms indicates a fundamental difference in the shape. The histogram for pair 1–12 has a shape which first increases and then decreases with increasing elapsed time, while the shape of the histogram for pair 1–17 decreases continuously similar to an exponential distribution.

Program GAMFIT was used to fit the data with the gamma distribution. Some examples of the fitting process are presented in Fig. 10. This figure presents the histograms seen in Fig. 9 with the gamma distribution superimposed. It is seen that the fitting in each case is good which demonstrates the appropriateness of using the gamma distribution in this investigation.

The values of the shape parameter obtained from the fitting procedure corresponding to each histogram were plotted against non-dimensional separation distance $S/\bar{D}_b$ as presented in Fig. 11. Values of departure diameter $\bar{D}_b$ obtained from previous photographic studies in the same boiling vessel with the same fluid presented by Judd and Hwang [14] were interpolated for the three heat fluxes used in the present investigation and then extrapolated to the lower pressure (about 40 kPa). Photographic studies done later using high speed photography confirmed the values of $\bar{D}_b$ obtained by the interpolating/extrapolating procedure. However, there were too few data in the films to yield reliable values and so it was considered prudent to use the results of the earlier study. Inspection of the graph presented in Fig. 11 reveals that there is a unique relationship between shape parameter $\nu$ and non-dimensional separation distance $S/\bar{D}_b$. One can distinguish three separate zones in the values of the shape parameter. The first zone corresponds to $S/\bar{D}_b < 1$ where $\nu$ is greater than one, the second zone corresponds to $1 \leqslant S/\bar{D}_b \leqslant 3$ where $\nu$ is less than one and the third zone corresponds to $S/\bar{D}_b > 3$ where values of $\nu$ asymptotically approach unity.

Analysis of the high speed motion pictures of dichloromethane boiling on the glass surface taken after the completion of the present investigation showed that bubble radius sometimes grew as large as the average departure diameter or even more ($R > \bar{D}_b$). In these instances, it was possible for sites located at a distance up to the departure diameter ($S/\bar{D}_b \leqslant 1$) from an active nucleation site to be 'seeded' upon bubble departure as was reported by Kenning [2] and Judd and Lavdas [5] and this was seen to occur in the high speed films. Subsequently, bubbles would form at the

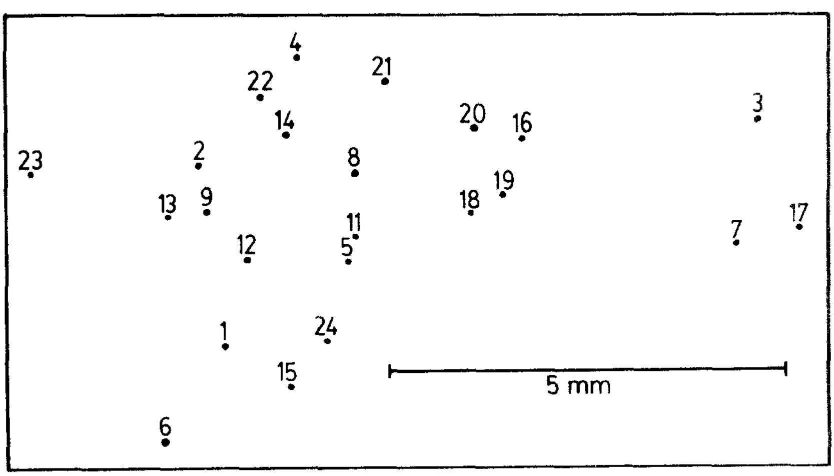


FIG. 8. Active site distribution.

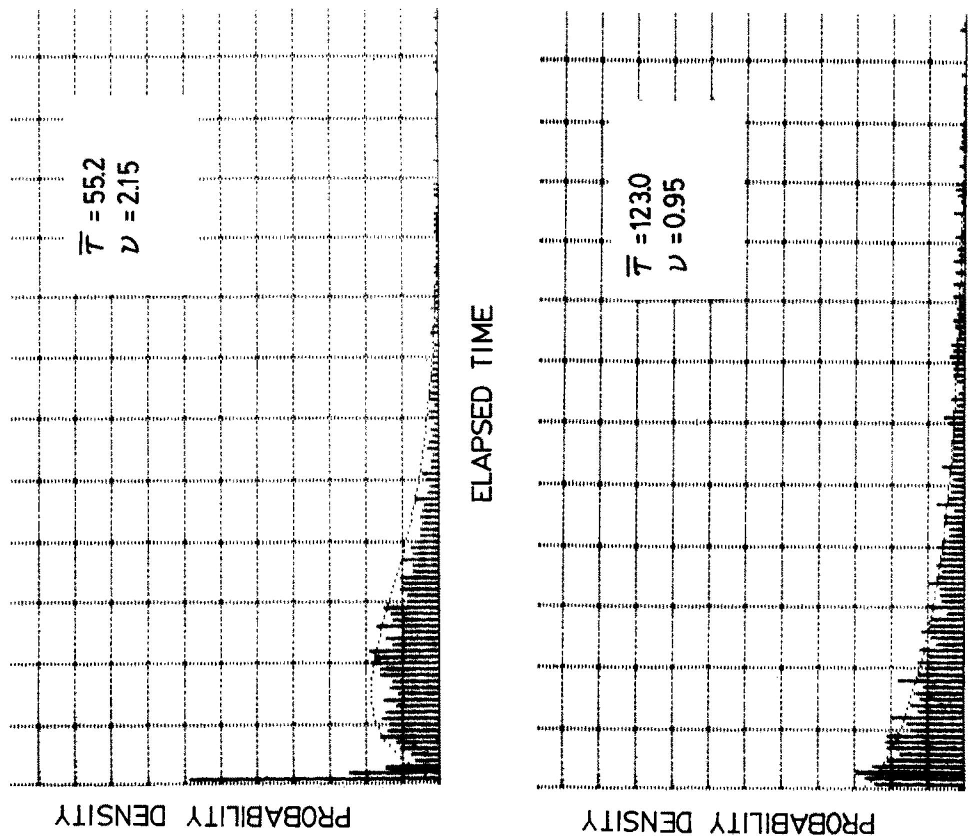


FIG. 10. Histograms fitted with the gamma distribution derived from program GAMFIT.

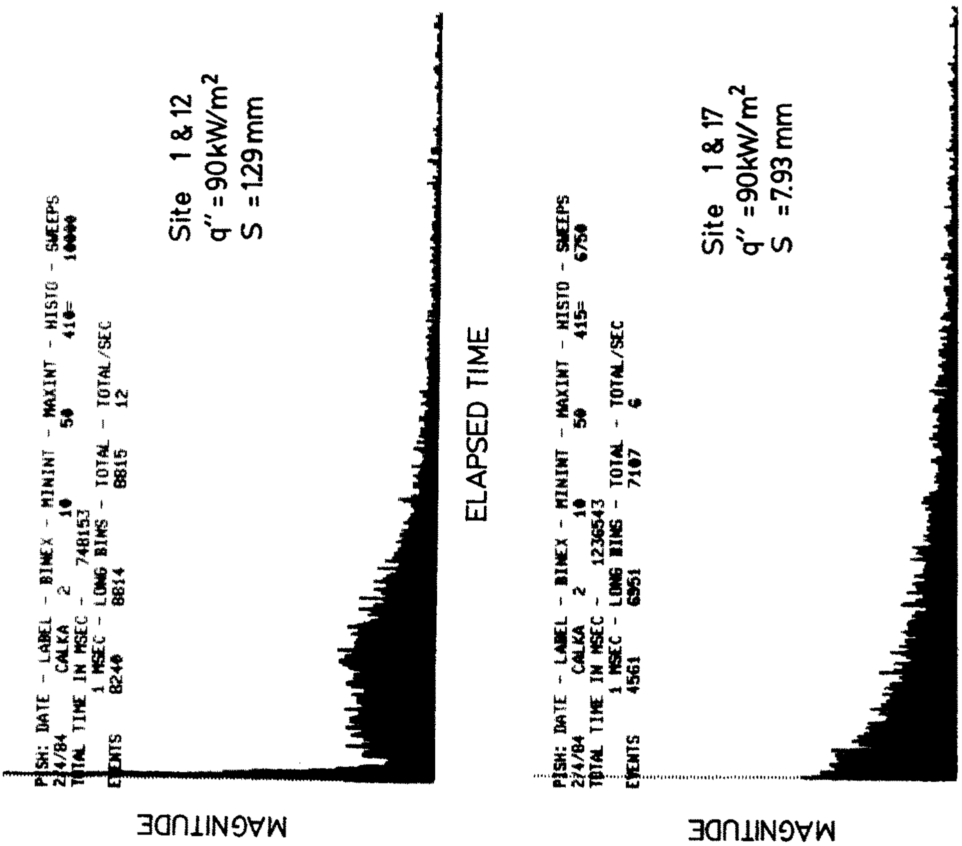


FIG. 9. Examples of the histograms derived from program PISH.

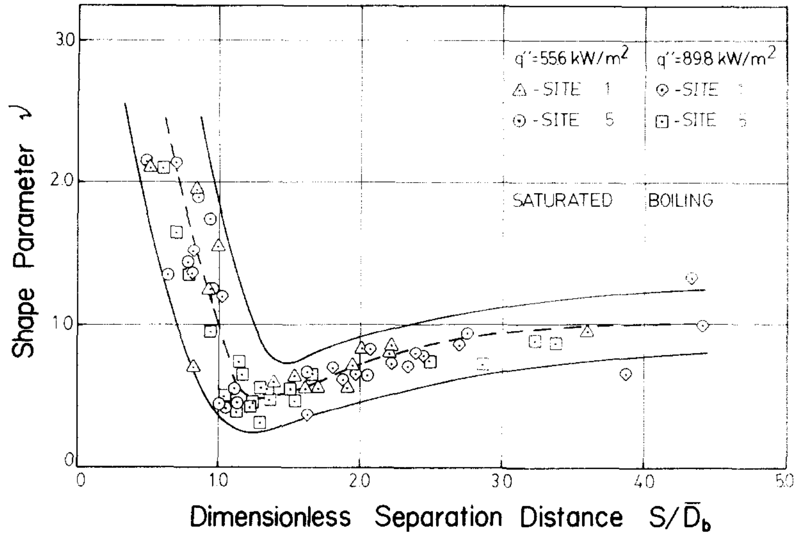


FIG. 11. Shape parameter vs dimensionless separation distance.

seeded sites and sites which would otherwise be inactive would be temporarily activated and emit bubbles. These observations lead to the conclusion that sites are activated within $1/2 \leqslant S/\bar{D}_b \leqslant 1$ by the 'seeding' mechanism, which has a promoting character. For the same range of separation distance, the values of the shape parameter are greater than one, and thereby it can be inferred that the occurrence of $\nu > 1$ corresponds to the promotion of activity at the surrounding sites.

Judd and Lavdas [5] showed that bubbles formed at one active nucleation site are sometimes able to deactivate surrounding sites. The mechanism of deactivation is not well understood and was not observed in this investigation. Although there is no plausible explanation at this time, in the authors' opinion, it would appear that the occurrence of $\nu < 1$ corresponds to the inhibition of activity at the surrounding sites. When the sites are far enough apart ($S/\bar{D}_b > 3$), values of $\nu$ approach unity for which the gamma distribution degenerates to an exponential distribution meaning that there is no interaction between the sites at all.

In Fig. 12, the results of the present investigation (the curve representing shape parameter as a function of non-dimensional separation distance) and that of Chekanov [8] are superimposed. Although the general shape of both curves is very similar, Chekanov's curve is shifted to the right. The reason for this difference is unknown but one possible explanation may come from the fact that Chekanov did not actually fit his data with the gamma distribution but calculated the shape parameter of the gamma distribution using the method of moments. Different fluid–surface combinations were used in the two investigations and since the 'site seeding' phenomenon depends on the surface tension which is

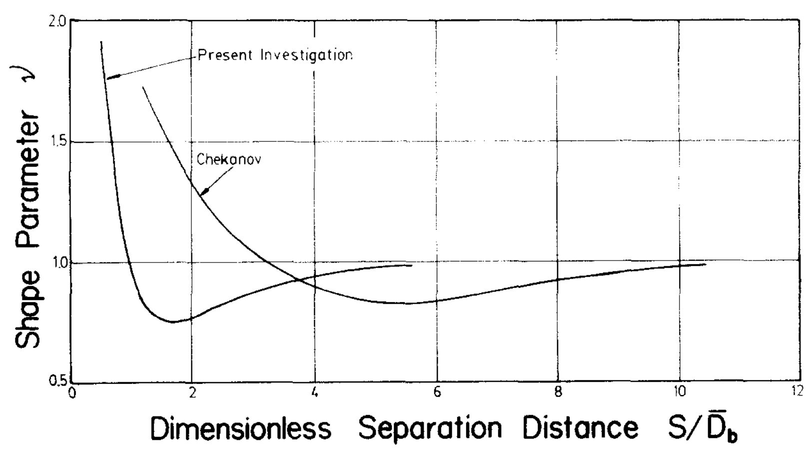


FIG. 12. Comparison between Chekanov's results and present investigation.

different for the different fluid–surface combinations, this may be another possible explanation of the difference between Chekanov's results and those presented herein. Chekanov's interpretation of the curve disagrees with that of the present investigation as given above in the sense that for separation distances $S/\bar{D}_b$ less than unity, interaction between the nucleation phenomenon at adjacent sites has a promoting character (the formation of bubbles at one nucleation site enhances the formation of bubbles at the neighbouring site which otherwise would be inactive) and not 'repulsion' as Chekanov claimed. Furthermore, based upon the results of the present investigation, it is believed that Chekanov is also wrong regarding the interpretation of the curve for separation distances $1 \leqslant S/\bar{D}_b \leqslant 3$ which according to the authors corresponds to inhibition of the activity at the adjacent sites and not 'attraction' as Chekanov claimed.

## CONCLUDING REMARKS

The investigation presented herein demonstrates that the nucleation sites are not acting independently as is commonly thought but interact and thus influence the nucleation phenomenon at one another. The time interval between bubble initiation at adjacent sites was measured and the distribution of the time interval was found to be represented by the gamma distribution.

A unique relationship was found to exist between the shape parameter of the gamma distribution and the non-dimensional separation distance between the sites which demonstrated that separation distance between adjacent sites governs the nature of the interaction which occurs between them. Further research through investigation of the relationship between the size and distribution of nucleation sites on one part and the elapsed time interval on the other, should lead to the prediction of the average frequency of bubble occurrence which would incorporate interaction among the nucleation phenomenon.

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## QUELQUES ASPECTS DE L'INTERACTION PARMI LES SITES DE NUCLEATION PENDANT L'EBULLITION NUCLEEE SATUREE

**Résumé**—Les résultats d'une expérimentation originale sur l'interaction entre phénomènes de nucléation se produisant à des sites de nucléation adjacents pendant l'ébullition saturée du dichlorométhane sont présentés et comparés aux résultats de Chekanov [*Teplofiz. Visok. Temp.* **15**, 121–28 (1977)]. L'interaction est positive pour des distances entre sites de nucléation inférieures ou égales au diamètre moyen des bulles au départ car la formation d'une bulle favorise aux sites adjacents, et négative pour des distances entre sites supérieures car la formation d'une bulle freine celles des bulles sur les sites voisins. Aucune interaction n'est détectée pour des distances entre sites supérieures à trois fois le diamètre moyen des bulles à a séparation.

## EINIGE GESICHTSPUNKTE ZUR WECHSELWIRKUNG ZWISCHEN DEN KEIMSTELLEN BEIM BLASENSIEDEN IM SÄTTIGUNGSZUSTAND

**Zusammenfassung**—Die Ergebnisse einer ursprünglich experimentellen Untersuchung der Wechselwirkung zwischen Blasenbildungsphänomenen, die an benachbarten Keimstellen beim Sieden von Dichlormethan im Sättigungszustand auftraten, werden vorgestellt und mit den Ergebnissen von Chekanov's Untersuchungen [*Teplofiz. Visok. Temp.* **15**, 121–128 (1977)] verglichen. Die Wechselwirkung war positiv für Abstände zwischen den Keimstellen, die kleiner oder gleich dem mittleren Blasenabreißdurchmesser sind; dabei unterstützt die Blasenbildung an einer Stelle die Blasenbildung an den benachbarten Stellen. Sie war negativ, wenn die Abstände zwischen den Keimstellen größer als der mittlere Blasenabreißdurchmesser ist; dabei behindert die Blasenbildung an einer Stelle die Blasenbildung an benachbarten Stellen. Keine Wechselwirkung wurde bei Keimstellenabständen entdeckt, die größer als drei mittlere Blasenabreißdurchmesser waren.

## НЕКОТОРЫЕ АСПЕКТЫ ВЗАИМОДЕЙСТВИЯ МЕЖДУ ТОЧКАМИ ЗАРОЖДЕНИЯ ПУЗЫРЬКОВ ПРИ НАСЫЩЕННОМ ПУЗЫРЬКОВОМ КИПЕНИИ

**Аннотация**—Представлены результаты оригинального экспериментального изучения взаимодействия процессов зародышеобразования в близких точках зарождения пузырьков в процессе насыщенного пузырькового кипения дихлорметана. Полученные результаты сравниваются с данными Чеканова [*ТВТ* **15**, 121–128 (1977)]. Найдено, что для расстояний между точками возникновения пузырьков, меньших или равных среднему диаметру отрыва пузырька, взаимодействие положительно, и образование пузырька в данной точке приводит к возникновению пузырьков в прилегающих точках, а для расстояний между пузырьками, больших, чем средний диаметр отрыва пузырька—отрицательным, и зародышеобразование в данной точке стремится подавить зарождение пузырьков в примыкающих. Для расстояний между точками зародышеобразования больших, чем три средних диаметра отрыва, взаимодействий не обнаружено.