Int. J. Heat Mass Transfer. Vol. 10, pp. 553–554. Pergamon Press Ltd. 1967. Printed in Great Britain

SHORTER COMMUNICATION

CHARACTERISTICS OF ACTIVE NUCLEATION SITES IN POOL BOILING

YITZHAK HELED and ALUF ORELL
Chemical Engineering Department, Technion, Israel Institute of Technology, Haifa, Israel

(*Received* 1 *June* 1966 *and in revised form* 4 *October* 1966)

INTRODUCTION

It is now generally accepted that naturally occurring pits and cavities may serve as bubble nucleation sites during pool boiling. This view, however, is based mainly on theoretical considerations [1] and on a rather limited experimental evidence [2].

To date twelve pits and four scratches have positively been identified as active sites, photographed and measured [2]. The paucity of information on the nature, size and shape of natural nucleation centers is due mainly to the experimental difficulties involved in locating and identifying such sites.

The purpose of this communication is to describe a new experimental technique which greatly facilitates the identification and location of active sites and provides additional information about some important sites characteristics. The technique utilizes extremely thin scale deposits, formed on highly polished surfaces, for this purpose.

THE TECHNIQUE

It is a well-known fact that tap water, or distilled water containing specific soluble salts, form ring-shaped and circular deposits on the heat-transfer surface during nucleate boiling [3–6]. Since these deposits appear at the base of bubble columns they constitute a target area within which active nucleation sites should be sought.

Deposit spots, however, were never used for active sites location since two required conditions were not met up till now. First, the deposits must be thin enough to reveal the active pits in detail. Second, the surface density of the natural pits must be extremely low so as to limit the number of pits inside the deposit domain to one.

The described technique meets these requirements by using de-ionized water, containing minute quantities of solutes, which deposits extremely thin scale spots on highly polished surfaces.

APPARATUS AND PROCEDURE

Boiling took place on a flat horizontal surface of an electrically heated brass boiler. The vertical conducting section of the boiler was 2 in. in diameter, extending into a thin fin of $4\frac{5}{16}$ in dia. at its upper face. The heat-transfer surface was first polished to a high degree and then electroplated with either chrome or nickel finish. Extremely smooth and bright surfaces were obtained, having unusually low densities of pits relative to emery-polished surfaces. Thermocouples placed along the boiler axis supplied the necessary heat-transfer information.

Distilled and de-ionized water was boiled on the smooth, non-tarnishing surface of the boiler for several hours. At the end of each test the boiler was dismantled and its surface inspected by a metallographic microscope.

ACTIVE NUCLEATION SITES

A typical pattern of white circular deposit spots is shown in Fig. 1. Visual observations of the heat-transfer surface during boiling verified that the scale was deposited at the base of the growing bubbles. Identical disk-shaped spots were also found around four active artificial cavities drilled on this particular test surface (Fig. 1).

Microscopic observations of numerous scale spots revealed that they were generally so thin as to prevent masking the location of those natural pits that were located inside their domain. Many deposits formed concentrically around one single pit (Figs. 2 and 3), as they did around each and every one of the tested artificial cavities. Consequently, the symmetric position of these natural pits suggests that they were active nucleation centers. When occasionally several pits were detected inside a deposit, one would usually occupy its central region.

The size of the centrally located pits ranged from $5{\cdot}9 \times 10^{-4}$ to 2×10^{-3} in. Details of one of the large pits, measuring $1{\cdot}9 \times 10^{-3}$ in, are shown in Fig. 4. The theoretical size range predicted by Hsu [7] for a temperature difference of 18 degF and an assumed thermal boundary-layer thickness of 3000 μin is 2×10^{-4}–$1{\cdot}3 \times 10^{-3}$ in, in good agreement with the experimental results.

ACTIVE SITES CHARACTERISTICS

In addition to the identity of active sites the deposits provide also quantitative information as to their density and distribution pattern on the heat-transfer surface, as well as the maximum contact diameter of the bubbles.

The presence of the deposit spots on the heat-transfer surface after the cessation of boiling makes it an easy task to determine the active sites density for any given heat flux. It is thus possible to extend appreciably the density range usually determined by visual counting of bubble columns.

The surface in Fig. 1 contains 15700 sites/ft^2. As a comparison the highest reported site density on a flat metallic plate, based on visual counting during boiling, is 6050 sites/ft^2 [8].

High site densities, determined by an electroplating method, were also reported by Gaertner and Westwater [9]. Gaertner's elegant technique, however, is restricted to electroplating solutions only. The deposits technique proposed here is simpler and applicable to a variety of liquids containing trace additives.

The deposits method sheds also light on the spatial distribution of active sites on the heat-transfer surface. Figure 1 shows that in many instances two neighbouring deposits are so close as to touch, or even partially overlap, each other. Such a pattern precludes the possibility of simultaneous bubble growth at the two competing sites as this would result in physical interference and, eventually, coalescence of the bubbles. It is, therefore, suggested that once a site starts producing a bubble it deactivates the neighbouring site throughout the duration of the bubble growth period. Consequently, competing bubbles grow alternately.

The size of the circular deposits is a measure of the maximum contact diameter of bubbles prior to their detachment from the surface. The diameter of deposit spots formed around the measured active pits ranged from $2{\cdot}2 \times 10^{-2}$ to $4{\cdot}1 \times 10^{-2}$ in. This is within the reported size range of contact diameters of water bubbles detaching from a Chromel P surface [5]. The size range of the spots appearing in Fig. 1 is even wider, being approximately 3 to 1. Thus one cannot assume a constant maximum bubble contact diameter for a given liquid–surface combination.

The thickness of the scale spots is indicative of the bubble frequency at a given active site. The higher the frequency the larger the amount of scale deposited. The thickness of the various circular spots was estimated using the fine focusing device of the metallographic microscope. It ranged from 5 to 30 μ. Thus the observed difference in the deposit thickness points out that bubbles are formed at the various sites at a relatively wide frequency spectrum.

SCALE COMPOSITION

The chemical nature of the scale spots is definitely of interest since de-ionized water was used in all the experiments. Direct analysis of the scale was not possible due to the minute quantities involved and the difficulty in scraping it off the metallic surface intact.

There are several indications, however, that the scale is silica: (1) the 1 MΩ resistance of the de-ionized water used precludes the presence of depositable electrolytic solutes; (2) the presence of silica in the water was established by analysis, and (3) scale spots deposited from de-ionized water containing traces of silica have also been reported before [6].

CONCLUSIONS

Tagging active sites by the deposits formed around them during bubble growth gives an easy access to a large number of nucleation sites. Thus a way is opened to collection of vital information concerning active sites characteristics such as reported here.

REFERENCES

1. S. G. Bankoff, *Trans. Am. Soc. Mech. Engrs* **79**, 735 (1957).
2. H. B. Clark, P. S. Strenge and J. W. Westwater, *Chem. Engng Prog. Symp. Ser.* **55** (29), 103 (1959).
3. E. P. Partridge and A. H. White, *Ind. Engng Chem.* **21**, 834 (1929).
4. J. Freeborn and D. Lewis, *J. Mech. Engng. Sci.* **4**, 76 (1962).
5. N. B. Hospeti and R. B. Mesler, *A. I. Ch. E. Jl* **11**, 662 (1965).
6. D. J. Pulling and J. G. Collier, *Ind. Chemist.* **39**, 129 (1963).
7. Y. Y. Hsu, *J. Heat Transfer* **84**, 207 (1962).
8. R. F. Gaertner, *J. Heat Transfer* **87**, 17 (1965).
9. R. F. Gaertner and J. W. Westwater, *Chem. Engng Prog. Symp. Ser.* **56** (30), 39 (1960).

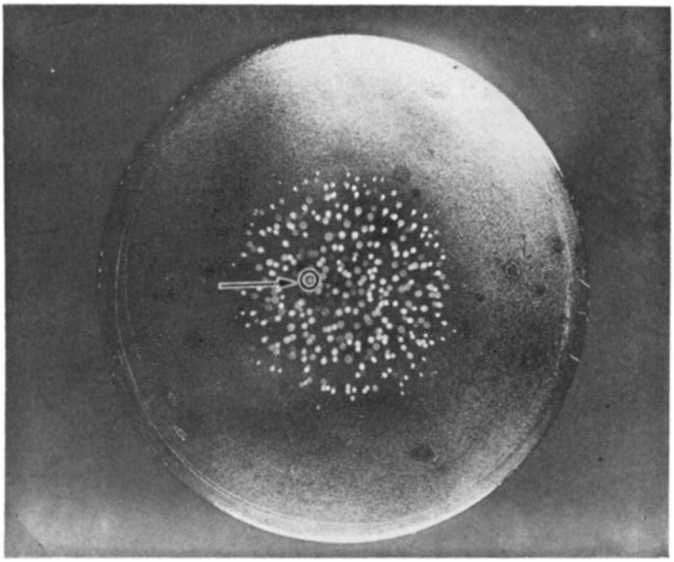

FIG. 1. Deposits pattern on a rough chrome-plated surface of $4\frac{5}{16}$ in dia. Gross heat flux: 78 000 Btu/h per ft^2.
Note the marked deposit around an artificial cylindrical pit.

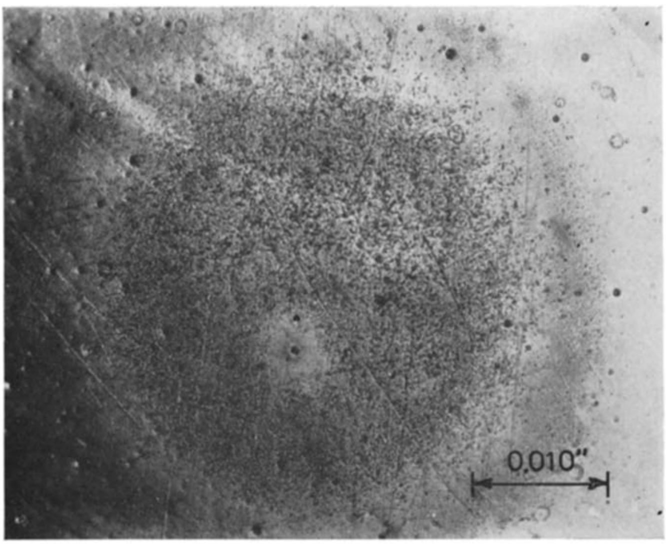

FIG. 2. Circular deposit around an active pit on a chrome-plated surface. Gross heat flux: 78 000 Btu/h per ft^2.

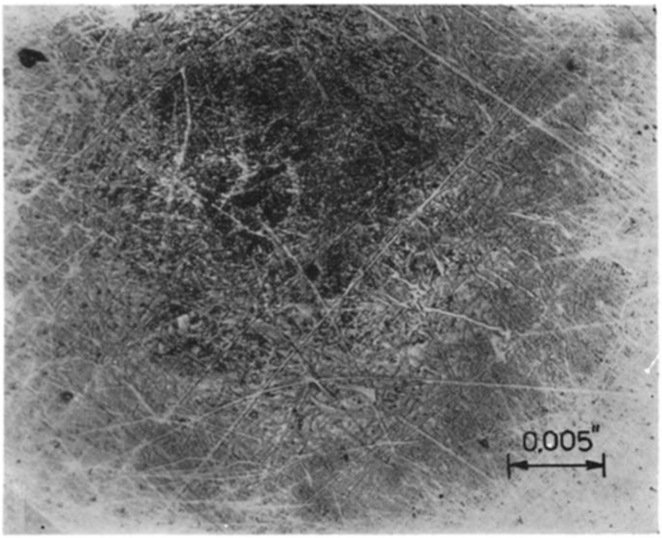

FIG. 3. A single circular deposit on a nickel-plated surface. Note the active pit in the center. Gross heat flux: 78 000 Btu/h per ft^2. $\Delta T =$ 18 °F.

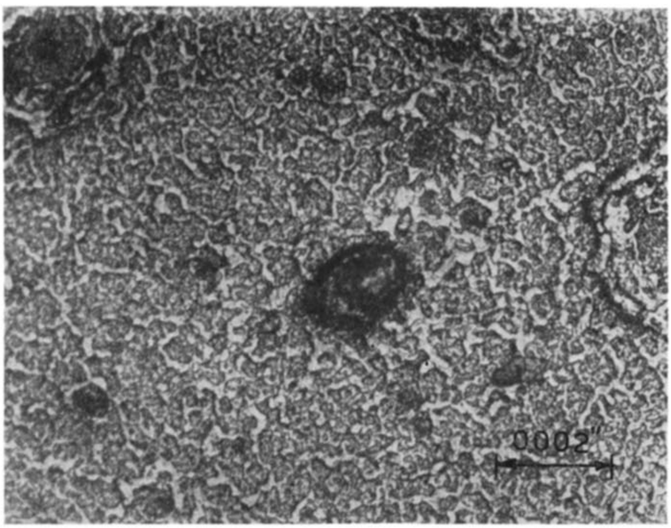

FIG. 4. Details of a large central pit and deposit on a nickel-plated surface. A second pit appears in the upper left corner.