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SHORTER COMMUNICATIONS

THE MEASUREMENT OF GROWING BUBBLES ON A HEATED SURFACE USING A COMPUTERISED IMAGE ANALYSIS SYSTEM

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INTRODUCTION

IN THE study of boiling heat transfer, high speed cine films are often taken of vapour bubbles growing from cavities on a heated surface. The cine films are analyzed to provide data on bubble growth dynamics. Because the growth of successive bubbles from a cavity is statistical in nature [1], a large sample of measurements is necessary.

Until now, the vapour bubbles have been measured manually using various projection methods. Since manual measurement is quite time consuming, sample sizes reported in the literature are often too small for statistical analysis. Normally only the bubble's height and diameter are measured from which the bubble's volume is determined assuming an ellipsoidal shape. More accurate manual measurements have been made where ten diametral measurements at ten heights up the bubble were taken. Here the total volume is determined by summing the volume of each slice, which are frustrums of a cone (assuming symmetry about the vertical axis), and multiplying by a factor to adjust for sphericity. A comparison of the two methods for 24 departing bubbles, shows that the simple, two measurement method overpredicts by an average of 16%. Thus, a more accurate and less time consuming method is needed.

To fulfill the needs of accurate bubble dimensions and fast measurement a computer programme has been developed to control a film analysis machine which is used to analyze the film. The programme records the cine film frame number, measures the magnification factor, measures the complete profile of the bubble, and determines the volume, major diameter, and neck diameter of the bubble. The beginning and end of the waiting time and the growth time of the bubble are also noted. All these values are stored in a computer file. This programme was developed for use on the PEPR film-scanner system [2] constructed by the Image Analysis Group, Nuclear Physics Department, Oxford University.

PATTERN RECOGNITION

The PEPR (Precision Encoding and Pattern Recognition) machine consists of a high accuracy flying spot cathode ray tube, a film transport mechanism, and an interactive operation station.

The spot generated on the cathode ray tube face is imaged onto the film and moved around under programme control. The light transmitted by the film is picked up by a photomultiplier. The signal is processed by electronics and ends up as a data element in the programme. For 16 mm film the spot can be driven around a 4096×4096 grid at 6.4 μm intervals. A short local sweep in x and y at a grid point gives the instrument a measuring accuracy of 1.2 μm. The phase boundary accuracy is dependent on the quality of photography and is in the present case estimated to be about $\pm 3\%$ of the diametral measurement.

The interactive station consists of a television screen showing the raw image (as the bubble looks on film), a graphics screen to prompt the operator (showing the outline of the determined profile), and a tracking cross-hair pointer synchronized to both screens and controlled manually. The operator responds to requests for the location of the wire, the frame of bubble departure, etc. by pressing buttons on a control panel or typing commands at a teletype.

The film transport mechanism accepts 16, 35 and 50 mm reels of film which are moved backwards or forwards under programme control to position the film for measurement.

TYPES OF BUBBLE MEASUREMENT

Three different shapes of bubbles growing from a heated surface can be processed with the programme (see Fig. 1). Spherically shaped bubbles attached to the surface with a thin neck are measured by one routine where the base of the bubble is determined by searching for the minimum diameter from the bubble profile (Fig. 1a). The programme checks the profile and accepts only spherically shaped bubbles. The profile below the neck is the bubble's shadow

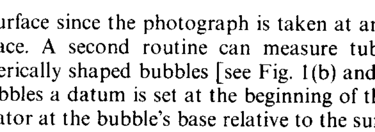

FIG. 1. (a) Spherical shaped bubble with neck; (b) tubular shaped bubble; (c) hemispherical shaped bubble (without shadow).

on the surface since the photograph is taken at an angle to the surface. A second routine can measure tubular and hemispherically shaped bubbles [see Fig. 1(b) and (c)]. For these bubbles a datum is set at the beginning of the film by the operator at the bubble's base relative to the surface. The routine locates and measures the bubble profile whatever its shape relative to this datum in subsequent frames. Note that on the cine film the bubble is light and the background (i.e. liquid) is dark.

PROCEDURES

The actual sequence of measurements of a bubble is as follows:

1. A contrast threshold between light and dark areas is set by the operator.

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2. The system scans the bubble along lines parallel to the heated surface between two set vertical datum limits (see Fig. 2). Data is returned as X, Y coordinates at points where the contrast of the boundary crosses the set threshold.

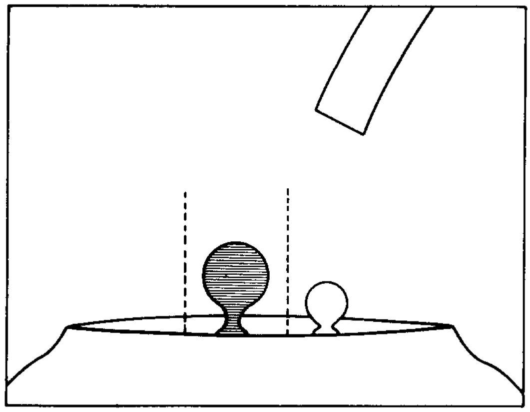

FIG. 2. Horizontal chords partitioning a bubble between the two dashed datum limits.

3. The length of each bubble chord is measured by the system, accurate to within $\pm 1.2\,\mu m$, the actual length being threshold dependent. Each chord is a fixed incremental height above the previous one such that a departing bubble is sliced into about 25 chords depending on its height. The chords are 6–7 μm apart at the plane of the film.

4. The bubble profile measurements from the films proceed for one boiling site at an overall rate of about 800 frames/h (not to be confused with the filming speed of 1000–4000 frames/s).

The operation of the system is as follows:

1. The 16mm cine film is drawn from one reel onto another past the flying spot scanner.

2. The images on the frame are scanned by the projected image of the spot under programme control. When required, a magnified image of a frame can be viewed on a television screen.

3. The operator designates the bubble site of interest with a cross-hair pointer on the television screen and specifies its identification number.

4. The operator again uses the cross-hair to locate four points on the wire which is in the focal plane of the bubble (shown in the upper right hand corner of Fig. 2). These four

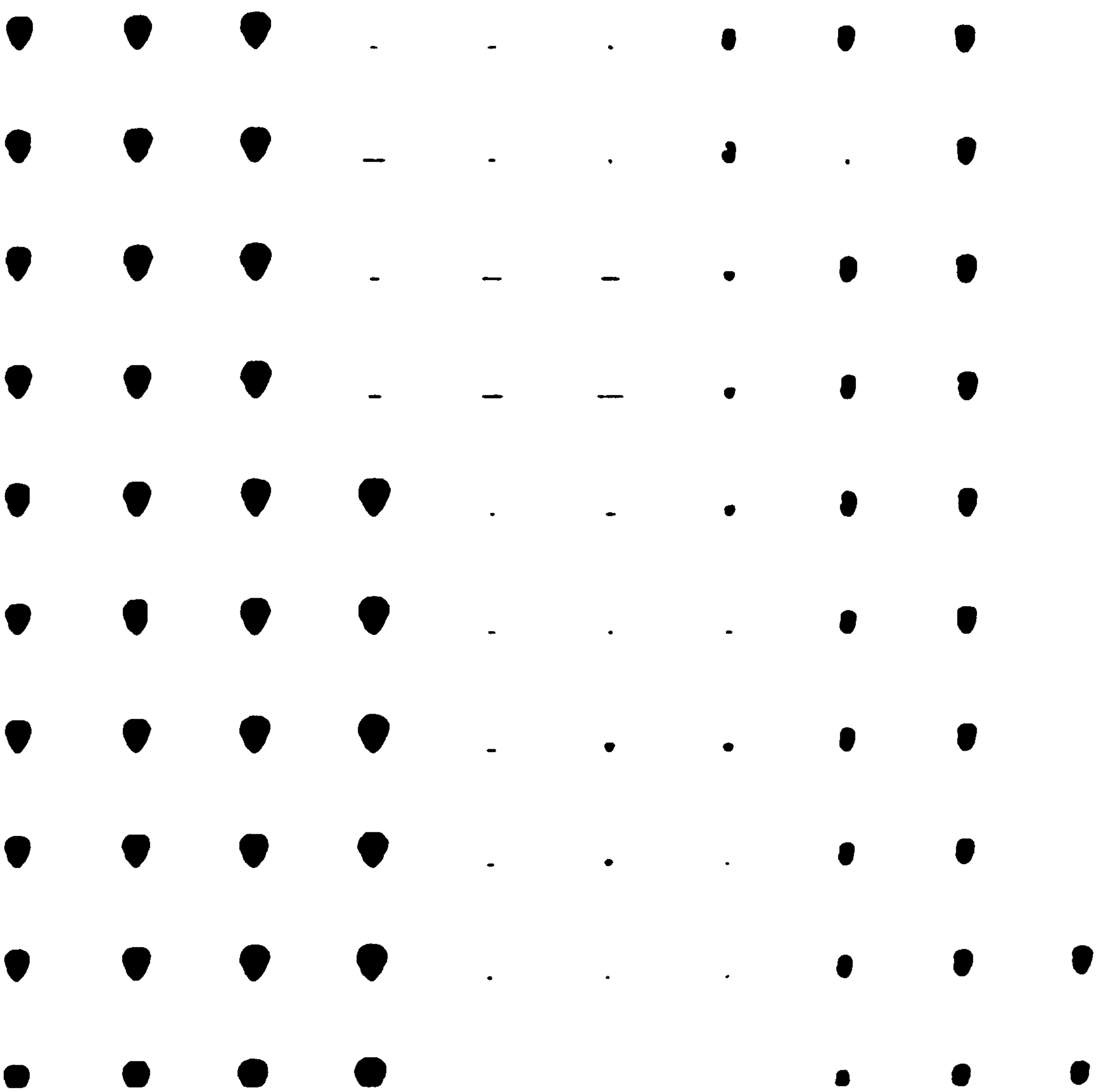

FIG. 3. Sequence of a scanned spherical shaped bubble. Note that a fraction of the top is lost and that the dashed line marks the interface between cycles.

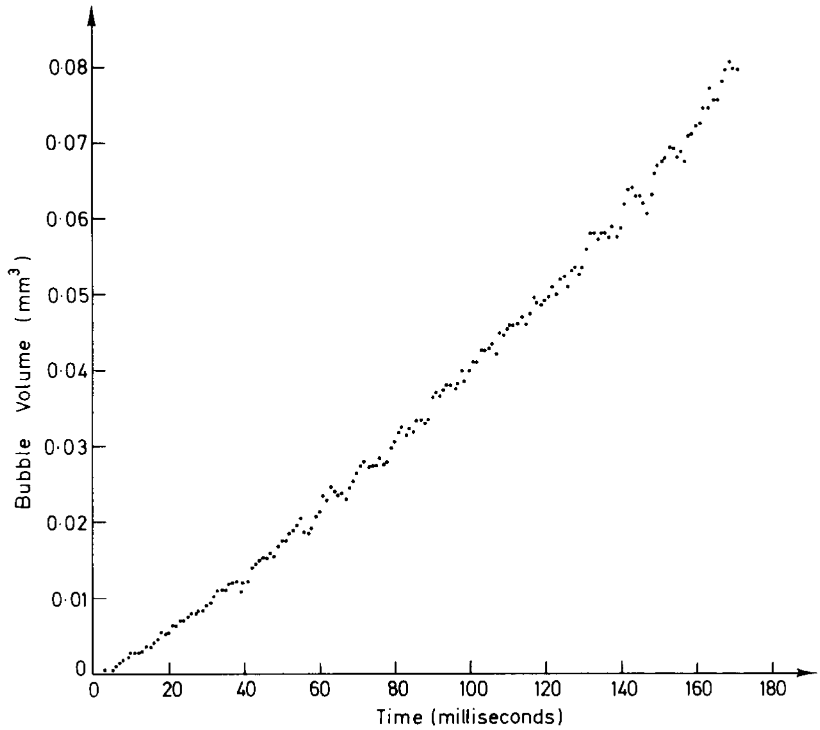

FIG. 4. Bubble growth curve in liquid nitrogen.

points are used to calculate the diameter of the image of the wire to establish the magnification factor.

4a. The operator selects the threshold giving the best looking representation of the bubble image.

5. Next the operator views successive frames until the initial frame of growth is found and designates it as such to the computer.

6. Now the system proceeds on its own locating and measuring the bubble on each successive frame.

7. The operator can set a break point which forces the programme to ask the operator to check whether the bubble has really departed from the surface. The frame of departure is noted to the computer. The operator under programme guidance proceeds to the initial frame of the next bubble growing at the site and so on.

EXAMPLES

In Fig. 3 a typical sequence of scanned bubble images for the growth of a spherically shaped bubble is shown. It shows the last half of a bubble growth cycle, the waiting period where no bubble is present, and the initial growth of the successive bubble (the time sequence is read from bottom to top, left to right). The bubble images are produced on a computer printing device using the x and y coordinates of the bubble profile. The departing bubble has an actual diameter of 0.7 mm. The time interval between each image is 1 ms.

Figure 4 shows the resulting curve of bubble volume vs time for a spherically shaped bubble in liquid nitrogen. The scatter of the data points is about $\pm 2.5\%$. Hence, the equivalent radius of the bubble has a scatter of less than 1%

ACCURACY

Bubble departure diameters for 20 departing bubbles have been measured by both the computer system and by the manual ten diametral measurement technique. These values agree to within about $\pm 5\%$, thus better than the two measurement method. There is only a small error of several percent involved in setting the contrast threshold for locating the bubble interface. If the filming quality is poor (i.e. the bubble interface is fuzzy and not well defined), then the diametral measurements are very sensitive to the contrast setting. Hence, in this case the accuracy would be poor. Naturally, films such as these should not be measured by any method since the exact interface is undefinable. On the other hand, if the photography is of good standard (i.e. the bubble is in good focus, unobstructed by other bubbles, and the bubble outline is sharp and clear with sufficient contrast), then the PEPR system will give results of good accuracy. Thus, the accuracy is primarily dependent on the film quality rather than on the computerised image analysis system.

CONCLUSIONS

In conclusion, this method of analysis is ideal for obtaining large amounts of accurate data with relative ease. The online interactive nature of the system enables frame to frame tracking of the bubble growth to proceed largely automatically, calling in the operator infrequently to aid the programme.

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