Investigating Bubble Expansion in Pool Boiling Under Influence of Magnetic Field in Microgravity Conditions

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Abstract: - Pool boiling of a paramagnetic liquid was created under microgravity conditions to study bubble characteristics and boiling behavior under the influence of a magnetic field. Parabolic path of an aircraft was used to create microgravity conditions for a period of 20-30 seconds. Two tanks, one with a permanent magnet attached at the bottom were used to create the field. Magnetic field strength was measured along vertical axis of the tank to study the influence on the bubbles. $MnCl_2$ dissolved in distilled water was used as the paramagnetic liquid. Pool boiling process was captured using three different video cameras and those video clips were used to obtain still frames with a constant frame rate of 0.4 seconds. Color images were converted to gray scale to determine exact bubble perimeter and location. *MatLab Image Processing Tool Box* was used to analyze the still images. Bubble diameter was measured and radius and area of the bubble was calculated and graphed respect to the frame number. This project was funded by West Virginia University Mechanical and Aerospace Engineering Department and NASA-WV Space Grant Consortium.

Key-Words: - Pool boiling, Microgravity, Paramagnetic liquid, Heat transfer, Bubble characteristics

1 Introduction

At a given temperature and pressure, boiling and heat transfer are different under the microgravity conditions compared to the Earth gravity conditions. A continuous pool boiling experiment was conducted in order to observe the boiling phenomena and bubble characteristics under influence of a magnetic field in microgravity environment. The field conditions were achieved by using two cylindrical tanks with heating pads and a circular magnet attached to the bottom of one of the tanks. $MnCl_2$ was dissolved in distilled water and used as the paramagnetic liquid. The tank without the magnet served as a reference to observe effect on the bubbles being generated during pool boiling as a result of heat transfer. Convection served as the mode of heat transfer from heating pads to the liquid. Temperature control was obtained by varying the voltage and thus the current supplied to the heating pads. Temperatuere of the superheated paramagnetic liquid was 73.6 ºC.

In order for the bubbles to generate and escape from heating pad, the paramagnetic liquid should reach superheated temperature. Generally, for the bubble size to expand and grow, liquid temperature has to be greater than the temperature of the vapor inside the bubble. It was possible to see sudden bubble growth phenomenon that occurs during the microgravity time period. Also the rate of change of bubble radius under microgravity was comparatively at a higher level than normal gravity conditions. This whole process was captured in video and the clips were used to study the characteristics and behavior of the bubbles.

2 Methodology

In order to simulate the microgravity conditions, an aircraft was used to fly in a parabolic path that created microgravity conditions within a short time period of 20-30 seconds. Pool boiling process was conducted throughout the flight time and three video cameras were used in three different angles to video capture the entire process. Later those video clips were used to study pool boiling behavior and bubble characteristics by capturing still frames at a constant rate of 0.4 seconds. Cylindrical shaped permanent magnet was attached to the bottom of the one of tanks and the other tank was left as a reference to observe the effect of the magnetic field on bubble. Magnetic field strength of the circular shaped magnet along the vertical axis of the tank was measured and graphed. It is demonstrate in the figure.1

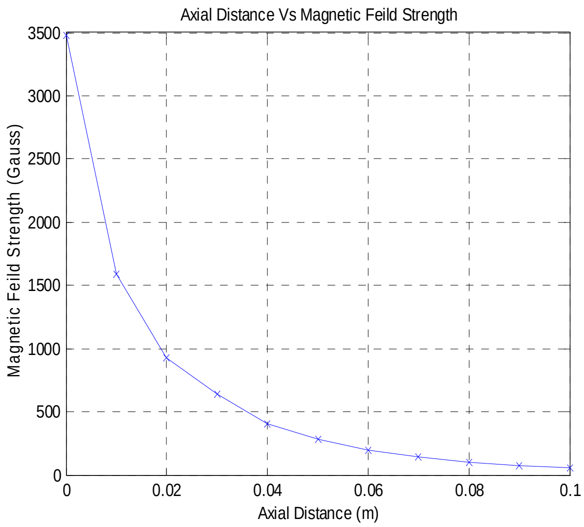

Fig. 1 Measured magnetic field strength

After that, field strength relevant to the position and bubble size were compared to evaluate the magnetic field influence on the bubbles. Two bubbles were chosen at the same height from the bottom of each tank. Average radius for each bubble was calculated based on vertical and horizontal diameter measurements.

2.1 Image processing technique

In order to observe the boiling behavior and bubble characteristics, a careful study of video clips had to be done. Using Power Director advanced video editing software, image frames were captured with a constant frame rate of 0.4 seconds. *MatLab Image Processing Tool Box* was used to analyze the images. Image resolutions of 550 X 380 pixels were taken and imported to *MatLab*. In order to determine the exact location and perimeter of bubbles the color images were then converted to gray scale images.

As it shown in Figure.2, left hand side represents a colored image segment taken from tank with magnetic field and the right hand side represents without the magnetic field.

Fig.2 Colored images segments.

Gray scale images relevant to Figure.3 are shown below. Consecutively left hand side represents an image segment taken from tank with magnetic field and the right hand side represents without the magnetic field.

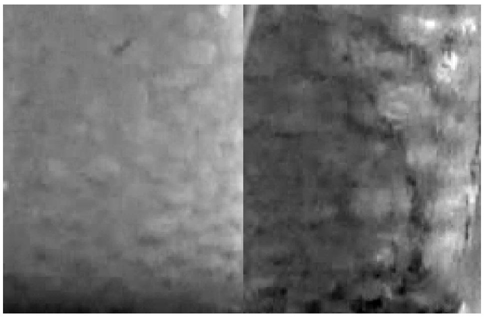

Fig.3 Converted Gray scale images.

3 Results

Horizontal and vertical radius of the bubble with respect to frame number under magnetic field influence is shown in figure.4 below.

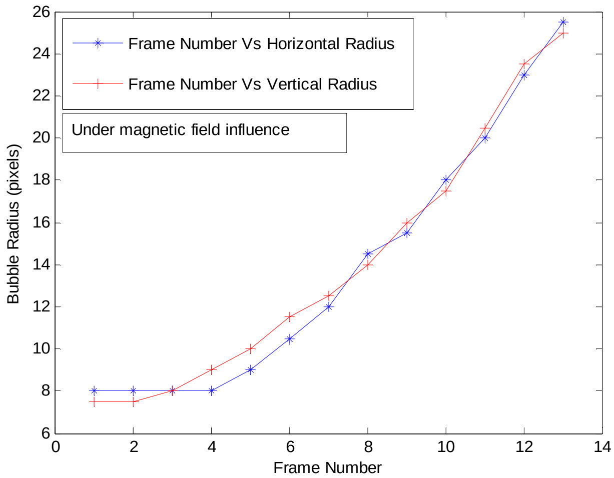

Fig.4 Horizontal and Vertical radius of the bubble Vs Frame number under magnetic field.

The Horizontal and Vertical radius of the bubbles with respect to frame numbers without the magnetic field influence are shown in figure.5 below.

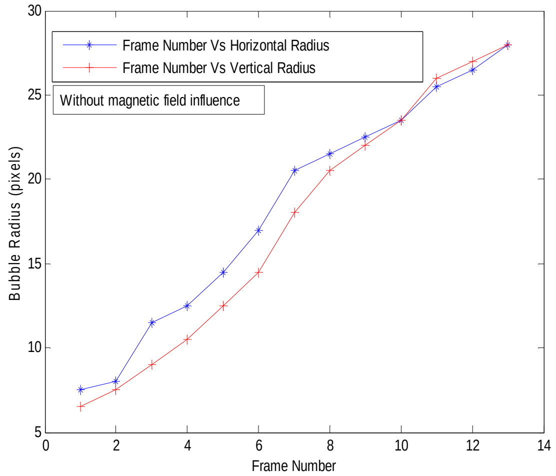

Fig.5 Horizontal and Vertical radius of the bubble Vs Frame number (without magnetic field).

As is demonstrated in figures 4 and 5, horizontal and vertical radii of the bubbles under the influence of magnetic field are very close to each other. In other words, under the magnetic field influence, bubbles generated by pool boiling under microgravity conditions are more circular in shape. On the other hand, bubbles without the magnetic field influence tend to have higher horizontal than the vertical radius.
Average radius was used to calculate area of the bubble. Figure.6 demonstrates the variation in between the two fields with respect to frame number.

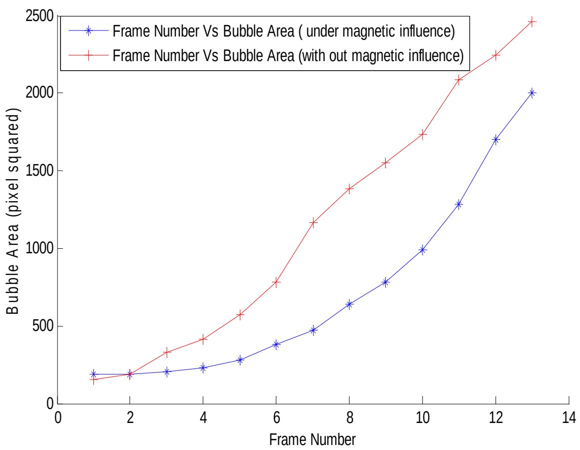

Fig.6 Frame Number Vs Bubble Area.

4 Conclusion

Pool boiling was done in two cylindrical shaped tanks filled with paramagnetic liquid with and without magnetic field influence under the microgravity conditions. Boiling and bubble behavior was video captured and video clips were used to create constant frame rate images. Colored images were cropped to the desired segments and converted to gray scale images to determine exact bubble location and boundaries. One bubble was chosen from each tank at the same height. Horizontal and vertical diameters were measured and average radius and area of the bubbles was calculated. The variation was demonstrated in a graph respect to the frame numbers. Comparative analysis of the two tanks shows that magnetic field has influenced the size of the bubble under pool boiling conditions.

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