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EXPERIMENTAL INVESTIGATION OF AIR- WATER TWO PHASE FLOW REGIME IN VERTICAL MINI PIPE

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ABSTRACT

In this study the flow patterns of air- water two phase flows have been investigated experimentally in a vertical mini pipe. The flow regimes observed by 1200 fps high speed video recorder in the pipe with diameters of 2, 3 and 4 mm having the length of 27, 31 and 25cm, respectively. The comprehensive visualization of air water two phase flow in a vertical mini pipe has been performed to realize the physics of such two phase flow. Different flow patterns of air–water flow were observed simultaneously in the mini pipe at different values of air and water flow rates. Consequently the flow pattern map proposed for flow in mini- pipe in terms of superficial velocities of liquid and gas phases. The resulted flow pattern map is compared with those of other researchers in the existing literatures.

INTRODUCTION

Gas- liquid two phase flow in micro structures has an enormous role in several industrial and medical applications such as micro heat exchangers, Lab-on-chips, bio-MEMS and micro cooling electronics. Physical perception of micro flows is critical in order to optimize and develop the design of such devices. Two-phase flows in mini and micro scales have recently attracted scientists attention as a result of its wide usage in advanced science and technology; namely micro-electro-mechanical systems (MEMS), chemical engineering, bioengineering, medical devises, micro cooling systems, micro structures in the computers, etc. The literature survey on this issue has been categorized into adiabatic and phase change works which has been summarized in the following.

Adiabatic works

The works of Suo and Griffith [1] were among the first studies made in the field of flow patterns in microchannels. They detected three different flow patterns, namely bubbly/slug, slug and annular flow in their studies using channels with the width of range 0.514–0.795 mm. Sadatomi et al. [2] proposed flow regime maps in vertical rectangular channel and indicated that channel geometries have little influence in noncircular channels with the large hydraulic diameter greater than 10 mm. Xu et al. [3] investigated concurrent vertical two phase flow in vertical rectangular channel with narrow gap experimentally. They reported that with the decrease of the channel gap, the transition from one flow regime to another occurs at smaller gas flow rates. Also they developed a new criterion to predict the transition from annular flow. Hestroni et al. [4] performed experiments for air–water and steam–water flow in parallel triangular micro-channels and developed a practical modeling approach for two-phase micro-channel heat sinks and considered the discrepancy between flow patterns of air–water and steam–water flow in parallel micro-channels. Fukagata et al. [5] simulated an air-water two phase flow in 20μm ID tube numerically with a focus upon the flow and heat transfer characteristics in the bubble train flows. He and Kasagi [6] simulated numerically adiabatic air water slug flow in micro tube. They focused on the pressure drop characteristics and its modeling. Also they found that the total pressure drop of a slug flow can be decomposed into the frictional pressure drop and pressure drop over the bubble itself. Carlson et al. [7] investigated characteristics of multiphase dynamics, especially two-phase gas-liquid flow by means of advanced numerical simulations. They compared two Computational Multi–Fluid Dynamics (CMFD) codes, Fluent and TransAT, and reported a prediction of recirculating flow in the bubbly flow case by TransAT, meanwhile significant recirculation not observed in the solution with Fluent. Saison and wongwises [8] performed series of experiments in a horizontal circular micro channel with inner diameter of 0.15 mm. They presented a flow pattern map in terms of the phase superficial velocities. They proposed a new pressure drop correlation for practical application.

Phase change works

The pool boiling heat transfer in vertical narrow annular with closed bottoms was observed through the transparent quartz shroud by Yao and Chang [9] and the stages of evolving the boiling phenomena with increase of heat flux were reported. Some researchers observed three basic flow patterns by them namely; bubbly, slug and annular flow in the mini pipe and channel. For example, Damianides and Westwater [10] performed experiments with 1 mm tube, Mertz et al. [11] and Kasza et al. [12] studied on the flow visualization of water nucleation in the single rectangular channel of 2.5 mm by 6 mm, and Lin et al. [13] used a single round tube of 2.1 mm inside diameter for their experiments and compared the flow transitions with those predicted by Bernea et al. [14], Sheng and Palm [15] did their experiments with 1–4 mm diameter tubes. Cornwell and Kew [16] found three different flow patterns for R-113 namely isolated bubbles, confined bubbles, and slug/annular flow in rectangular channels with the cross sectional area of 1.2- 0.9 mm and 3.5- 1.1 mm. Ory et al., [17] considered the effects of capillary, inertia, friction and gravity forces on the velocity distribution and temperature field along a single capillary two-phase flow in a heated micro-channel. A research dealing with gas–liquid two-phase flow in micro-channels in situations where the fluid inertia was significant in comparison with surface tension was reviewed by Ghiaasiaan and Abdel-Khalik [18]. Jiang et al. [19] studied boiling of water in triangular micro- channels with width of 50 and 100 µm. They observed the individual bubbles at low heat fluxes and an abrupt change in the flow pattern to an unstable slug flow with increasing heat flux. Chedester and Ghiaasiaan [20] addressed the hydrodynamically controlled onset of significant void (OSV) in heated microtubes. A simple semi- empirical correlation for the radius of departing bubbles at the OSV point was derived by them to show the accuracy of their hypothesis. Some experimental studies have been reported on gas liquid two phase flow in mini and micro conduit by kandlikar [21], Lee and Mudawar [22] and Serizawa et al. [23]. The three zone boiling heat transfer model was developed by Thome et al. [24]. Revellin and Thome [25] used an optical measurement method for two phase characteristics of R-134a and R-245fa in 0.5 mm and 0.8 mm diameter channels to determine the frequency of bubbles existing in microevaporator. They detected four flow patterns namely, bubbly, slug, semi- annular and annular flow which their transitions were not well compatible with macroscale map of refrigerants nor microscale map of air-water flows. Sobierska et al. [26] experimentally investigated the water boiling phenomena in a vertical rectangular microchannel with the hydraulic diameter of 0.48 mm. They observed three main flow patterns namely; bubbly, slug and annular flow.

Because of the effects of surface tension, the two phase flows in mini and micro scale have different behavior in comparison with macro scale. The aim of the present work is to visualize flow regimes in air–water two phase flows and propose a flow regime map for such flow in vertical mini pipes. The neural network technique is implemented to recognize and predict gas liquid two phase flow pattern in mini tube with diameters of 2, 3 and 4 mm. Also the image processing method can be used to calculate the void fraction and bubble velocity in the pipe.

EXPERIMENTAL SETUP

This study is carried out by the experimental apparatus which is schematically shown in Fig. 1. The air and water are used as the gas and liquid phases in the experiments. The water flow rates are regulated by the needle valves and are measured by the calibrated rotameter. Air and water are mixed together in the mixer which is made of acrylic glass and placed at the bottom of the riser pipe. The compressed air is fed by the compressor via air injector which is schematically depicted in Fig. 2. The water flows from the center hole of the mixer with diameter of 2 mm while air is injected into the holes around the center with 1 mm diameters. The air flow rates are set by the regulator and continuously are measured by the calibrated Gas rotameter. The overall height and inside diameter of the riser pipe are summarized in Table 1. In order to have the capability of visual observation of the two phase flow patterns, the riser pipe was made of a transparent glass. The water was flowed upward with air trough the riser and separated in the separation tank at the top of the riser and the air was disgorged to the atmosphere. Different flow regime images were captured by the digital high speed camera with the frame rate of 1200 fps [F1-CASIO,]. The superficial air and water velocity are 0.5-10 m/s and 0.05-1 m/s, respectively.

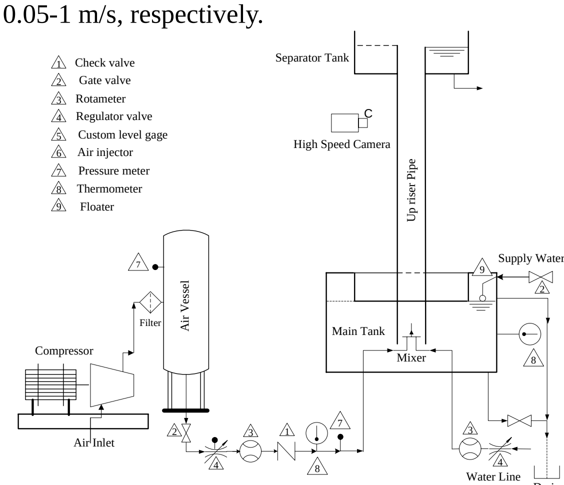


Fig. 1 schematic of test apparatuses

Table 1: length and diameters of main pipe

Pipe length	27cm	31cm	25cm
Pipe diameter	2 mm	3mm	4mm

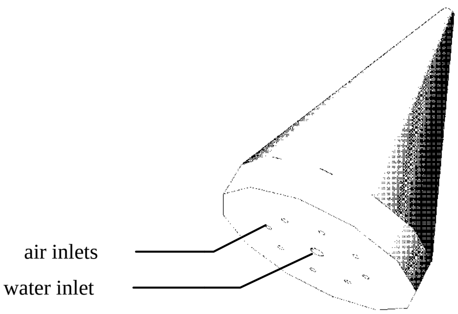


Fig. 2 schematic of air and water mixer

EXPERIMENTAL RESULT

Image processing

Some image processing techniques [27] must be performed in order to extract feature from the images of two-phase flow. Each picture was a 8bits RGB (red, green and blue) color format. It was converted from RGB to grey scale mode. The output image has 256 grey levels, from 0 (black) to 255 (white). It is difficult to extract the bubbles directly from an original digital image, therefore, some preprocessing procedures must be done to reduce noises and improve the quality of images. An image-subtracted algorithm was used to reduce the background noise by subtracting the background image from each dynamic image. In order to smooth the image border, a median filter was also used. A sliding window (3×3) was used in this process, and the median gray level of the pixels in the window is calculated, then the gray level of the pixel located at the center of the window was replaced by the median. The result of these processes is shown in Fig. 3.

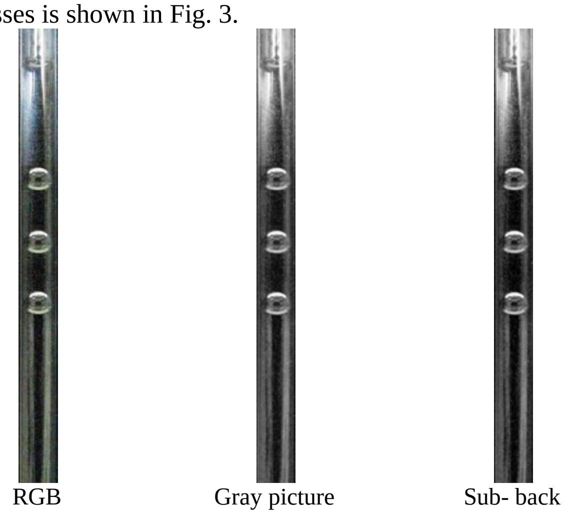


Fig. 3 a. RGB picture, b. gray picture, c. subtracting and median process of flow in the pipe (3mm diameter)

Inverting Binary Image

The images were converted from grayscale to binary mode by threshold segmentation, and an iteration algorithm was used to calculate the optimizing threshold as follows:

a: Calculate the minimum Z_l and maximum Z_k of gray level in the image, and define the initial value of threshold as:

$$T^0 = (Z_k + Z_l)/2 \tag{1}$$

b: Segment the image into two parts namely object and background according to the initial value of threshold T^k, and calculate the average value Z_O and Z_B of the two parts as:

$$Z_O = \sum_{Z(i,j)<T^K} \frac{Z(i,j)}{N_O} \tag{2}$$

$$Z_B = \sum_{Z(i,j)>T^K} \frac{Z(i,j)}{N_B} \tag{3}$$

where, $Z(i,j)$ is the gray level of the pixel (i,j) in the image, N_O is the number of the pixels which $Z(i,j)$ is less than T^K, and N_B is the number of the pixels which $Z(i,j)$ is more than T^K.

c: Calculate the new threshold as:

$$T^K = (Z_O + Z_B)/2 \tag{4}$$

If $T^K = T^{K+1}$, then end, else $K \ll= K + 1$, and turn to step 2. The binary image is shown in Fig. 4.

Fig. 4 binary image of two phase flow in mini pipe

Image Morphology Processing

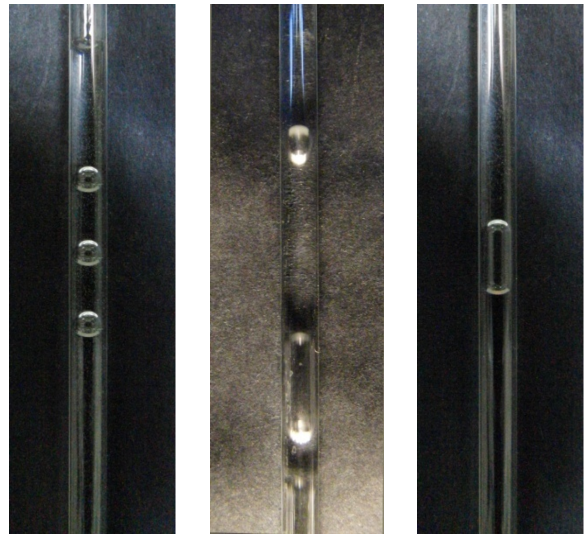
Finally, some morphological functions (such as dilation, erosion, opening and closing operation, etc) were applied to modify the shape of bubbles. Dilation adds pixels to the boundaries of the objects in an image, while erosion removes pixels on the object boundaries. The definition of a morphological opening of an image is erosion followed by dilation, using the same structuring element for both operations. The related operation, morphological closing of an image, is the reverse; it consists of dilation followed by erosion with the same structuring element. Both do not significantly alter the area or shape of objects. Opening operation removes small objects and smoothes boundaries. Borders removed by erosion are restored by dilation, but small objects that were absorbed during erosion do not reappear after dilation. Closing operation was used to fill tiny holes and smoothes boundaries. Objects were expanded by dilation and then reduced by erosion, so borders were smoothed and holes were filled. After all these operation, the result of image processing is shown in Fig. 5. Bubble images of two-phase flow were clear by the above image processing, and it prepared bubbles for the quantitative analysis such as measuring the area, perimeter and diameter.

Fig. 5 final image of two phase flow in the mini pipe

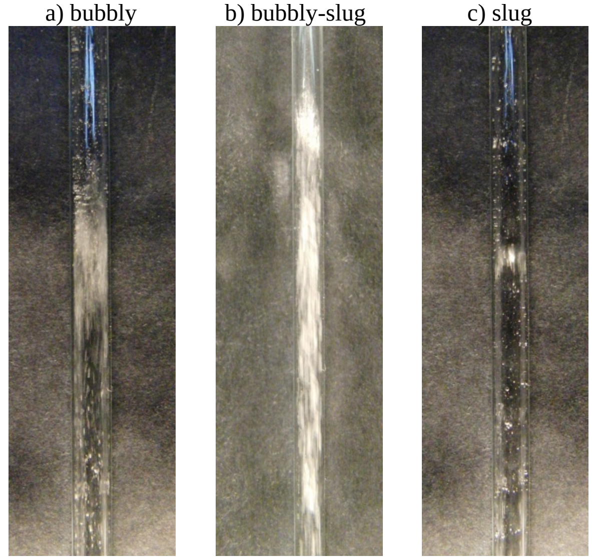
Velocity and void fraction of air bubbles can be determined by image analysis technique.

Flow pattern map

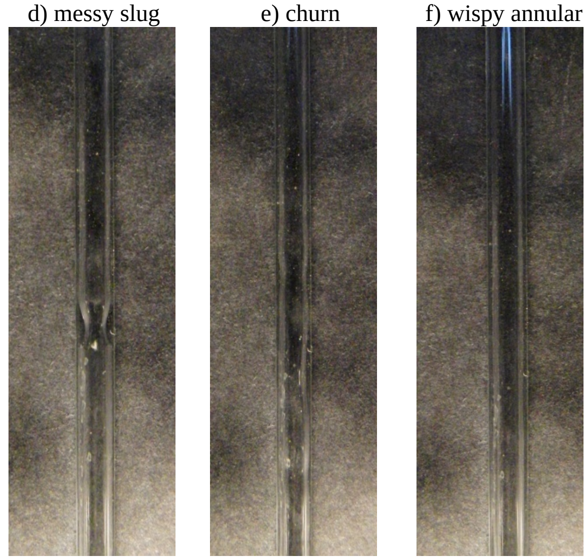
In the experimental procedure while varying gas or liquid mass flow rate, 10 sec film was recorded from the flow regime in speed of 1200 fps. The recorded film was replayed in slow motion speed for recognition of flow regimes. Each film converted to the separate frames in a picture format via Adobe Premiere software. Achieved pictures were used as inputs of image processing techniques. The final binary pictures were used for the mentioned post processing procedure such as; flow regime detection, void fraction and bubble velocity calculation, etc. Figure 6 shows the typical flow regimes which were observed in the vertical co- current air- water two phase flow in the 3 mm mini pipe. Four basic flow patterns, namely bubbly, slug, churn and annular accompanied by its transitions are illustrated in these figures. The visualization shows that air water two phase flows in mini pipe do not have three dimensional behaviors especially in bubbly and slug flows. Figures 7-9 show the flow pattern map for vertical round tube with inner diameters of 2, 3 and 4 mm, respectively. The proposed maps are in terms of superficial velocities of phases and the four main flow patterns are depicted in these maps. In Fig. 10 the achieved flow pattern for the pipe with 2 mm ID was compared by the work of Ide et al. [28]. The solid line shows the work of Ide et al. They divided the flow pattern map into the four main regions namely, dispersed bubble flow, intermittent flow, churn flow and annular flow.



a) bubbly b) bubbly-slug c) slug



d) messy slug e) churn f) wispy annular



g) ring h) wavy annular i) annular

Fig. 6 the photos of flow pattern in vertical pipe with 2 mm diameter

The comparison shows that the bubbly and annular flows in the present work are not in well accordance with Ide ones. In the present work the dispersed bubble was not seen because the injector of air bubbles had not very thin holes. As a result the created bubbles mostly have diameters in range of pipe diameter. Also the comparison of flow patterns shows that the slug, messy slug and semi annular flow in the proposed map are accordance with the intermittent flow of Ide.

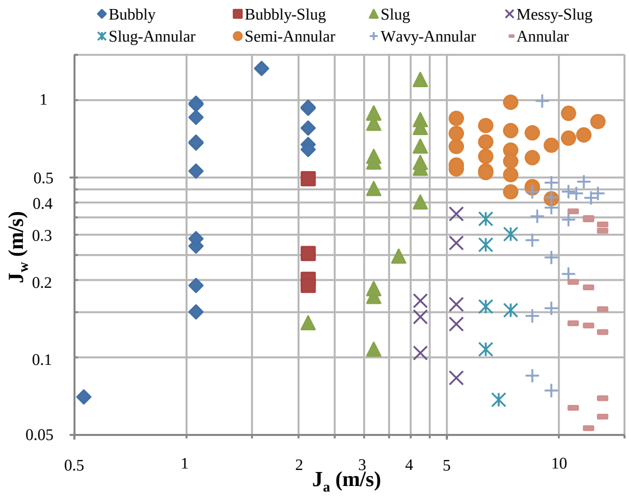


Fig. 7 flow pattern for 2mm inner diameter

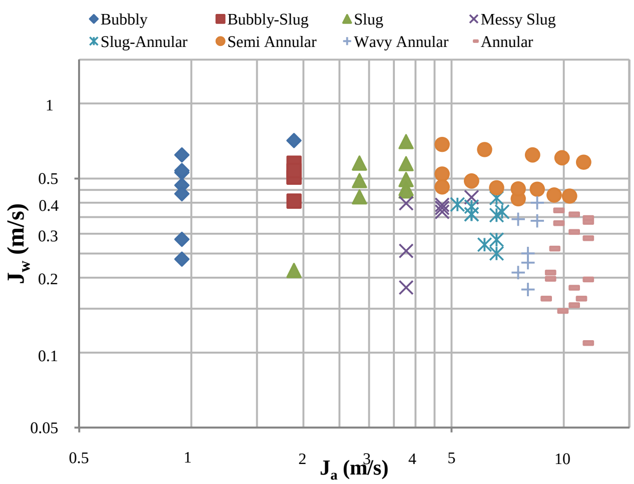


Fig. 8 flow pattern for 3mm inner diameter

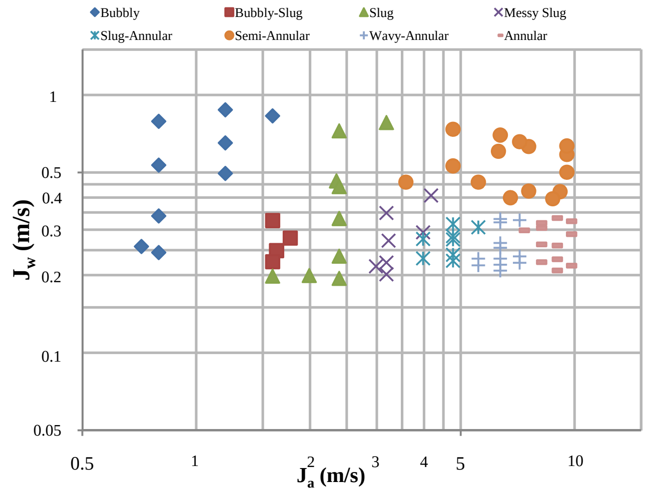


Fig. 9 flow pattern for 4mm inner diameter

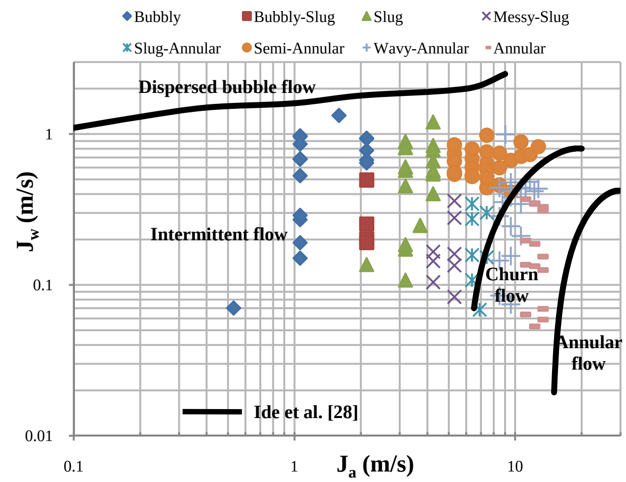


Fig. 10 comparison between the achieved flow patterns with the work of Ide et al. [28] for pipe with diameter of 2 mm

In the present study a noticeable difference between the flow pattern maps for vertical pipe with various diameters of 2, 3 and 4mm is not seen. Combination of these three flow pattern results in new flow pattern map which is illustrated in Fig. 11. The solid lines in the figures show the transition region of the flow patterns. This Figure shows the achieved flow map for mini pipe with diameters in the range of 2-4 mm.

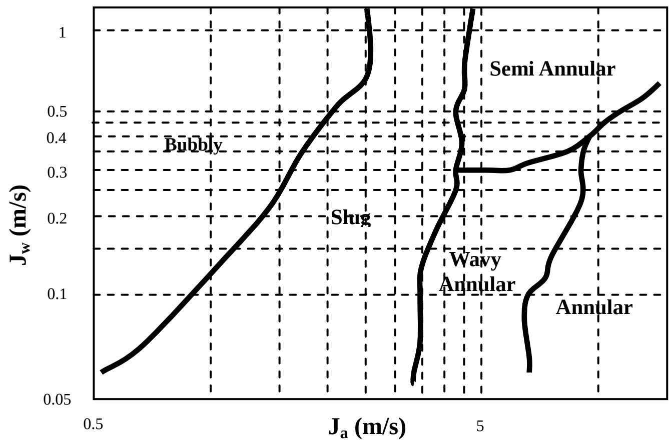


Fig. 11 proposed two phase vertical upward flow pattern map

CONCLUSION

In this paper air- water two phase flow regimes pattern were investigated experimentally for mini pipe with diameters of 2, 3 and 4 mm. the obtained flow pattern reveals that there is not any noticeable difference between two phase upward flow pattern in this range of diameters. A new flow pattern map was achieved for vertical mini pipe due to comparison of flow pattern of these three diameters of the pipe. The proposed map was compared with works of Ide et al. the comparison shows that the flow patterns of slug, messy slug and semi annular in the present work are compatible with intermittent flow pattern of Ide et al. But in the present study the annular flow is seen in lower superficial air velocity than the works of Ide et al. Also in this paper an image processing techniques was used for detection of flow patterns from the pictures which were derived from the films that were recorded with high speed camcorder.

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