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BRIEF COMMUNICATION

EFFECT OF FLOW OBSTRUCTIONS ON THE FLOW PATTERN TRANSITIONS IN HORIZONTAL TWO-PHASE FLOW

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INTRODUCTION

Flow patterns and flow pattern transitions are of considerable importance in the design of two-phase flow systems, as they can be significant in determining the pressure drop and heat transfer characteristics.

Flow patterns occurring in horizontal gas–liquid flow have been subject to extensive investigations. As most of the classifications were based on qualitative and subjective judgment of the observer, there were a multiple of names assigned to particular phase distributions in horizontal co-current flow. Also, many flow regime maps based on experimental data have been proposed by different investigators; amongst whom are Bergelin & Gazley (1949), Jenkins (1947), Alves (1954), Baker (1958), and Mandhane (1974).

Hubbard & Dukler (1966) suggest the following three basic flow pattern groups:

Separated continuous flows characterized by two phases flowing separately (e.g. stratified smooth, stratified wavy and annular flow).

Intermittent flows characterized by discontinuity of one of the phases (e.g. plug and slug flow).

Dispersed flows characterized by one phase being dispersed in the other phases (e.g. liquid deficient flow, bubbly flow).

The numerous flow patterns reported in the literature are basically combinations of these basic flow patterns.

The purpose of this study is to investigate the effect of flow obstructions on the flow pattern transitions. The practical importance of the problem is related to the use of rod spacing devices in water cooled nuclear reactors. These spacing devices are expected to affect the flow distribution, enhance flow homogenization and frequently improve heat transfer.

EXPERIMENTAL APPARATUS AND PROCEDURES

The experimental work was carried out on a loop shown schematically in figure 1. The test section consists of a 25.4 mm ID, 3 m long horizontal plexiglass tube. The air (max. 0.2 kg/s) and water (max. 1.7 kg/s) flow through a honeycomb mixer and a 3 m long calming section before entering the test section.

The effect of flow obstruction was studied using the two different designs illustrated in figure 1; each of them resulted in a flow blockage of 25% of the channel area. The effect of both obstructions was analyzed for different flow regimes. Flow regime maps were constructed for non-obstructed flows and flows with obstructions. The flow maps were constructed based on visual observations. A strobe light was used to improve visualization.

The maps for the obstructed flow were based on visual observation of the flow regime at a

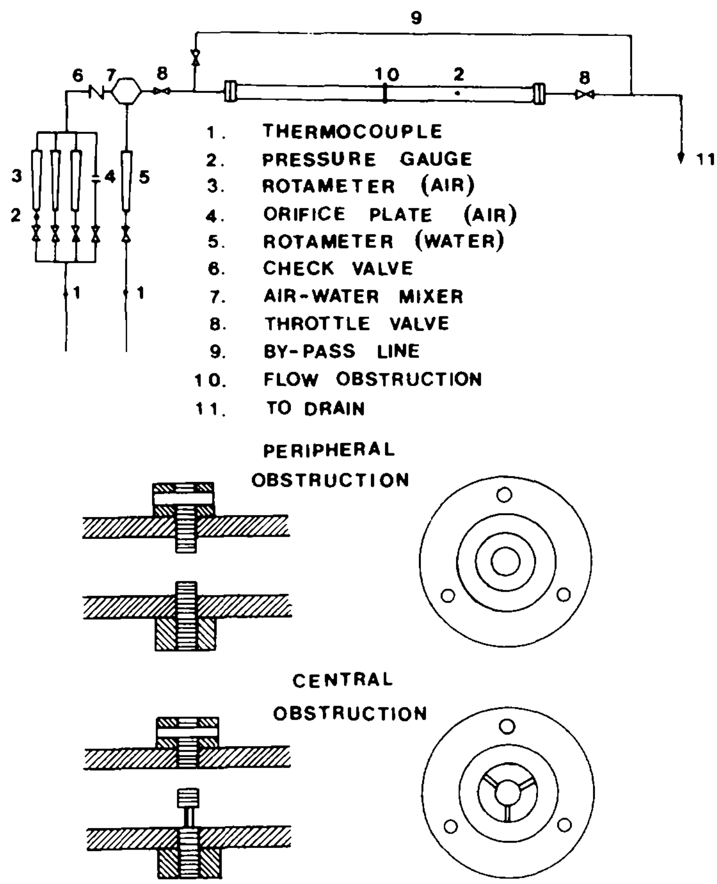

Figure 1. Schematic diagram of the loop and the obstructions.

section 300 mm downstream from the obstruction. The length affected by the flow obstruction was found to depend on the flow regime and was longer for the dispersed flow (30 L/D where L is the length of the channel and D is its diameter) and shorter for annular (15 L/D).

RESULTS AND DISCUSSION

Unobstructed channel results

Figure 2 illustrates the flow regime map of the unobstructed channel. The results are compared with Mandhane's (1974) map (empirical) and the map proposed by Taitel & Dukler (1976) (based on a physical model for flow regime transitions). Considering the differences between the existing flow regime maps the agreement is reasonable. The following discrepancies were noted: the transition between stratified smooth and stratified wavy to intermittent flow occurred at lower liquid velocities while the plug–slug transition occurred at higher gas velocities. Visual distinction between plug and slug flow is very subjective as they have the same general appearance, the difference being mainly in the size and shape of the plugs and slugs.

The slug to annular transition is in fairly good agreement with Mandhane's results except for higher liquid velocities. Note that the region characterized by Mandhane (1974) and the present work as slug flow is considered to be annular by Taitel & Dukler (1976). The discrepancy is due to the difficulty of observing or measuring the slug–annular transition especially for thin liquid films. Stratified smooth to stratified wavy and stratified wavy to annular transitions show good agreement with Mandhane's & Taitel–Dukler's map.

The major causes for the discrepancies between the maps are: (i) different experimental conditions (e.g. geometry, inlet), and (ii) subjective observer's judgment.

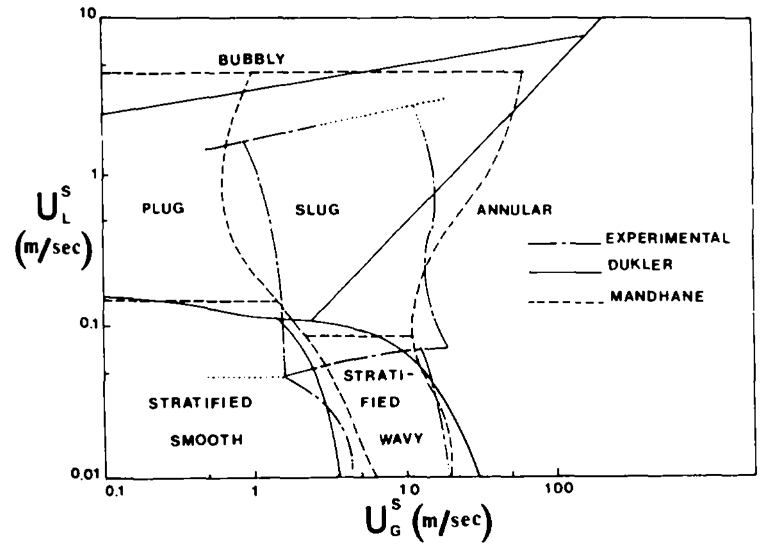

Figure 2. Flow pattern map in the unobstructed channel. Comparison with Mandhane's and Dukler's flow regime boundaries.

Obstructed channel results

Taitel & Dukler (1976) have analyzed the mechanism controlling the flow regime transition from stratified flow by considering the forces acting on a growing wave. As the gas flows over the wave, the pressure decreases due to the increased velocity generating an upward force. When the upward pressure force exceeds the gravity force conditions for wave growth are created. The obstructions decrease the area available for the gas flow, thus increasing the gas velocity. Hence, in general one expects (as was observed) that flow obstructions will cause the transition to occur at lower liquid and gas superficial velocities.

Figure 3 compares the flow regime maps in the unobstructed test section with maps for test sections with central and peripheral obstructions. The effect of the obstructions on each flow regime boundary is as follows:

Transition from stratified wavy to intermittent flow. The significant disturbance caused by the flow obstruction will result in larger waves which will eventually bridge the gas phase;

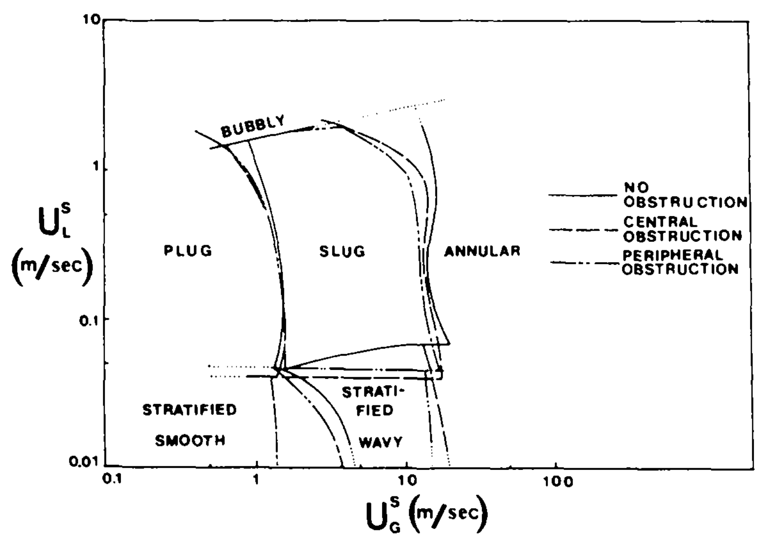

Figure 3. Comparison of the flow pattern transition boundaries; no obstruction, central obstruction and peripheral obstruction.

hence intermittent flow will occur for obstructed flow at lower liquid velocities. The observed stronger effect of the central obstruction is due to it intersecting the waves to a greater extent.

Transition from stratified wavy to annular flow. The effect of the peripheral obstruction is considerably greater than that of the central one. The reason is probably due to the low ratios of h_L/D* at which this transition occurs. The effect of the obstruction increases with decreasing liquid velocity (the ratio h_L/D decreases).

Transition from intermittent to annular flow. At low liquid velocities the effect of the flow obstructions is not significant. For higher liquid velocities, this effect becomes more important. The peripheral obstruction is more effective than the central one due to the presence of the slugs primarily in the upper part of the test section.

Transition from stratified smooth to stratified wavy flow. Taitel & Dukler (1976) suggest this transition occurs when the pressure and shear stress forces exerted by the gas flow on the wave is greater than the viscous dissipation in the waves. Flow obstructions locally increase the vapour velocities and hence the local pressure and shear forces. Thus a transition to stratified wavy flow is expected at a lower vapour velocity. This is corroborated by Figure 3. The central obstruction intersects the vapour to a greater extent, especially at low h_L/D ratios and hence is more effective in shifting the flow regime boundary to lower superficial vapour velocities. The central obstruction effect is considerably stronger than that of the peripheral one, because it intersects the liquid–gas interface to a greater extent.

CONCLUSIONS

Both central and peripheral flow obstructions affect the flow transitions. The central obstruction appears to have the strongest effect on the transition from stratified smooth to stratified wavy and from stratified wavy to intermittent flow. The peripheral obstruction has a stronger effect on the transition from intermittent to annular flow.

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*h_L/D represents the vertical liquid level measured from the bottom of the tube for smooth stratified flow. h_L is the liquid level.