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THE EFFECT OF ORIFICES ON THE LIQUID DISTRIBUTION IN ANNULAR TWO-PHASE FLOW

K. W. McQuillan and P. B. Whalley
Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, England

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Abstract—The effect of using orifices to disrupt the water film in air–water annular two-phase flow has been studied experimentally in a vertical tube by measuring the wall film flowrate at various distances upstream and downstream of several different sizes of orifice. The orifices cause a temporary reduction in the downstream water film flowrate, which returns to its equilibrium value further downstream. The experimental results have been used, together with those of other investigators, to compare the effects of orifices to those of swirl tapes, and further to compare the processes of entrainment and deposition within annular two-phase flow.

1. INTRODUCTION

In annular gas–liquid two-phase flow the liquid flows partly as a film along the channel walls and partly as droplets entrained within the gas core. If the annular flow occurs as a result of the fluid being heated as it flows along a tube the critical heat flux will depend strongly on the proportion of the liquid which flows as a film along the tube walls. In many industrial situations the surface film is periodically disturbed by intrusions into the flow, for example spacer grids supporting nuclear fuel rods. Several investigators have carried out experiments to measure the effect of such intrusions on the critical heat flux. These experiments have been with particular reference to the nuclear industry. Katsaounis *et al.* (1977, 1978) and Smolin & Polyakov (1978) found that the presence of grids usually has the effect of increasing the critical heat flux. Glastonbury & Ralph (1978) examined the effect of grids on the water film thickness, and found that mean film thickness is decreased downstream of the grid spacer, but that the minimum film thickness is unchanged. More fundamental experiments on the effect of obstacles have been performed by Sekoguchi *et al.* (1978a, b) and Shiralkar & Lahey (1973). Both found that obstacles cause a dramatic reduction in the film thickness in the vicinity of the obstacle. The present work examines the effect of orifice plates on the liquid film flowrate. The variation of liquid film flowrate with distance downstream of the orifice is measured for several sizes of orifice and various combinations of air and water flowrates.

McQuillan & Whalley (1983) give the full tabulated results from these experiments, and also give more graphs than is possible here.

2. APPARATUS

The experiments were carried out in a vertical perspex tube of 32 mm inside diameter. The general layout of the apparatus is shown in figure 1. Metered air and water were supplied to the bottom of the tube, the water being introduced through a short length of porous wall made of sintered bronze. Annular flow was produced with a central core of air and a water film flowing up the walls of the tube. The water film had large disturbance waves on its surface.

The water film flowrate was measured by allowing the pressure in the tube to force the liquid film through a second sinter section situated 6 m above the first. Two sinter lengths were used to remove the film. One was 76.2 mm long and the other was 25.4 mm long. The 76.2 mm sinter section was used for most measurements, but the 25.4 mm sinter

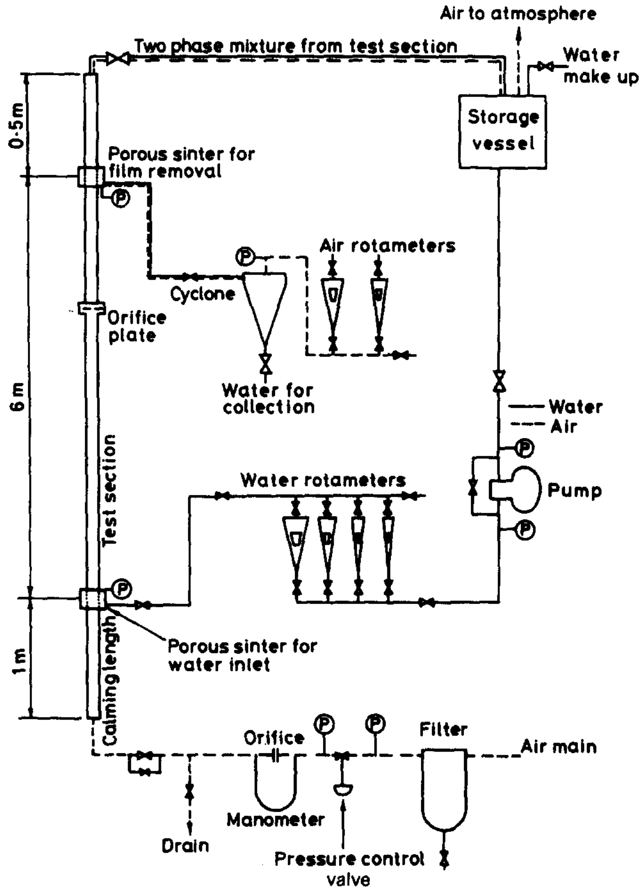

Figure 1. General layout of the apparatus.

section was used to enable more sensitive examination of the film flow close to the orifice. In all cases the position of the mid point of the sinter was used to indicate the exact position at which the film flowrate was measured. In the present work the two different sinters were used to measure nominally identical flows, and the values given by the 25.4 mm long sinter were adjusted accordingly. Further details of the adjustment are given by McQuillan & Whalley (1983). The rates at which air and water were removed by the sinter section could be measured after the two phases had been separated in a cyclone. The air flowrate was measured by a gas-meter or a rotameter and the water flowrate by timed collection of the flow. The water flowrate was found to be almost independent of the air flowrate except at very low air flowrates. Results derived by assuming the constant value of the water flowrate at higher air flowrates to be the water film flowrate have been shown to be consistent with other methods, see Hewitt (1978).

Seven different brass orifice plates were used to obstruct the flow in the tube. The orifices were 2.5 mm thick and their inside diameters ranged from 32 mm to 22 mm. They were located in recesses machined into the flanges of the perspex test section, as shown in figure 2. Different lengths of test section enabled the orifice plates to be positioned at any chosen position upstream or downstream of the film removal section. The water inlet and removal sinters were a fixed distance of 6 m apart, and therefore it was not possible to alter the distance between the orifice and the film removal sinter without moving the orifice relative to the water inlet sinter. This is not important for small changes in the position of the orifice, but for large changes in position (up to 2.4 m in the present work) the likely change in the distribution of the phases at the orifice must be considered. To

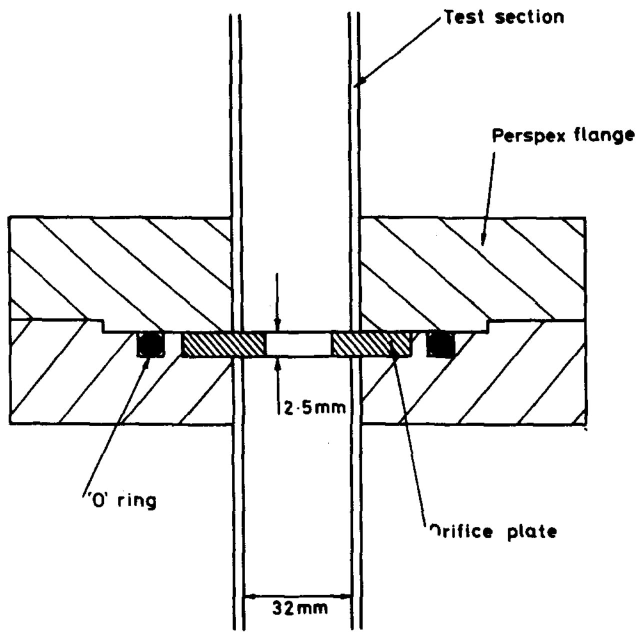

Figure 2. Section through perspex flange showing the location of the orifice plate.

assess the magnitude of this difference in phase distribution the film flowrate was measured at distances of 3.5 m and 6 m from the water inlet sinter.

In separate tests, high speed cine photographs (4000 frames per second) were taken of the flow. Two views were used, both with the camera axis at right angles to the tube axis. The first showed the flow for a distance of 190 mm downstream of the orifice, and the second showed 100 mm upstream and 500 mm downstream of the orifice. The flowrates used for the photographic runs were 53.5 g/s of air and 25.2 g/s of water, and the orifice plate used had an inside diameter of 28 mm.

All the experiments were conducted with a pressure of 1.5 bar at the film removal point, and at normal room temperature.

3. RESULTS

Film flowrate measurements were taken for eight combinations of air and water flowrates, and for eleven positions of the orifice within the tube. The orifice of inside diameter 32 mm presented no obstruction to the flow, and its use enabled two checks to be made.

Firstly, the measured values of the film flowrate were found to be consistent with those of Azzopardi & Whalley (1980). The measured film flowrate decreases with distance downstream of the inlet sinter, but the magnitude of the decrease is small between the two extreme positions of the orifice. This is consistent with the results of Gill & Hewitt (1968) which show a decrease in film flowrate of 14% in moving from 3.5 m to 6 m downstream of the inlet.

Secondly, the effect of sinter length on measured film flowrate could be determined. In agreement with Singh *et al.* (1969), the results show that, particularly for high water film flowrates, the longer sinter records higher values. Singh *et al.* consider that this is due to the inability of the short sinter lengths to decelerate completely and extract all the water in the waves on the surface of the water film, and also because of the extra deposition of droplets over the length of the longer sinters. In the present work all of the water film flow measurements taken with the 25.4 mm sinter are adjusted to give results directly comparable with the 76.2 mm sinter, see McQuillan & Whalley (1983).

Results for the effect of the orifice diameter on film flowrate are given graphically in figures 3–7. Figures 3–5 show the effect of orifice size on measured water film flowrates for different positions of the orifice plate relative to the flow removal sinter. Figures 6 and 7 show how the measured water film flowrate varies with distance downstream of an orifice. Only the readings obtained with the 76.2 mm sinter are used in figures 6 and 7. The distances given in figures 6 and 7 correspond to the distance between the orifice plate and the mid point of the flow removal sinter.

To the naked eye the orifice plates seemed to produce two effects. Periodic fast moving bursts of entrainment could be observed downstream of the orifice, and the disturbance waves were not visible on the liquid film immediately downstream of the orifice, but reformed further downstream. The cine film verified these observations. Frame by frame analysis of the film shows that for the orifice and flow conditions chosen, the disturbance waves begin to reform approximately 0.05 m downstream of the orifice. The wave velocity was found to be 2.8 m/s or 6% of the gas core velocity. The velocity of the bursts of entrainment caused by the orifice was 45 m/s or 93% of the gas core velocity. The velocity of the gas core was calculated at the orifice assuming that the whole of the tube cross section was occupied by gas. The cine film also revealed that each wave hitting the orifice caused the almost simultaneous production of a large burst of entrained liquid droplets and a reforming wave downstream of the orifice

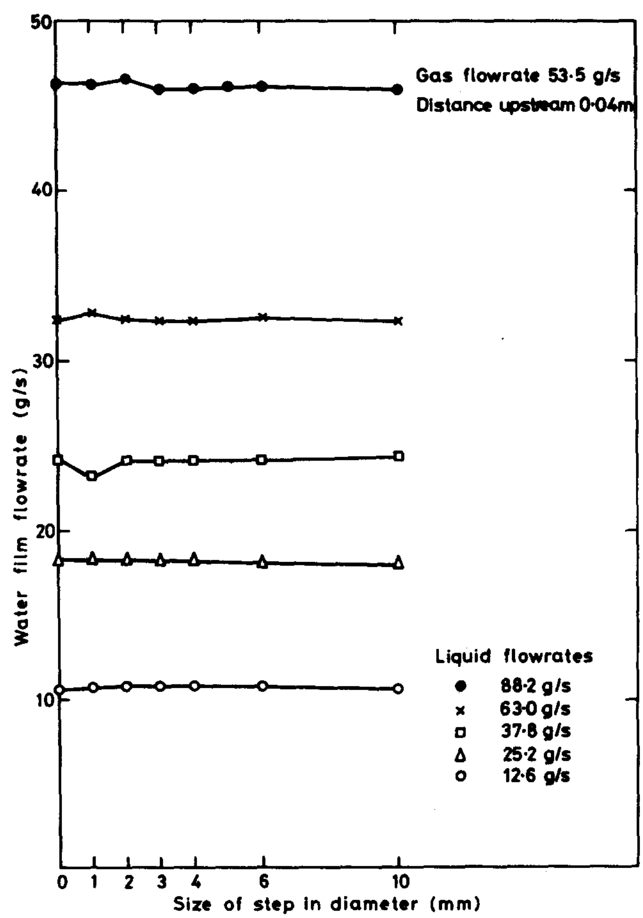

Figure 3. Effect of orifice size on the film flowrate measured 0.04 m upstream of the orifice.

4. DISCUSSION

4.1 *The effect of orifice plates on the water film flowrates*

Figure 3 shows the influence of orifice plates on the upstream flow. No effect is noticeable here, but a few results did show that at high water film flowrates there is a slight increase in the water film flowrate as the size of the obstruction increases. The hypothesis that this effect is due to deposition of droplets on the water film flowing over the orifice can be discarded by calculation of the effect that such deposition would cause. The effect could, however, be due to the orifice plate in some way assisting the removal of roll waves immediately upstream of it. Figures 4 and 5 show the effect of the orifice on the downstream water film flowrate. These graphs, and others, show that the reduction in film flowrate at any given distance downstream increases with total water flowrate, air flowrate and the size of the flow obstruction. In all cases the main reduction in the water film flowrate occurs for orifices presenting reductions in the diameter of between 2 mm and 6 mm. It is also noticeable that the orifice presenting a reduction of 1 mm in the diameter has only a small effect on the measured film flowrate. Hewitt & Nicholls (1969) found that for a limited range of flow conditions the average disturbance wave height would be approximately five times the mean film thickness. The average wave heights calculated with this assumption, using values of the mean film thickness calculated for identical flows by Fryer & Whalley (1982) are in the range 0.6–1.6 mm. It is therefore likely that the waves are able to negotiate small obstructions whilst to some extent remaining attached to the

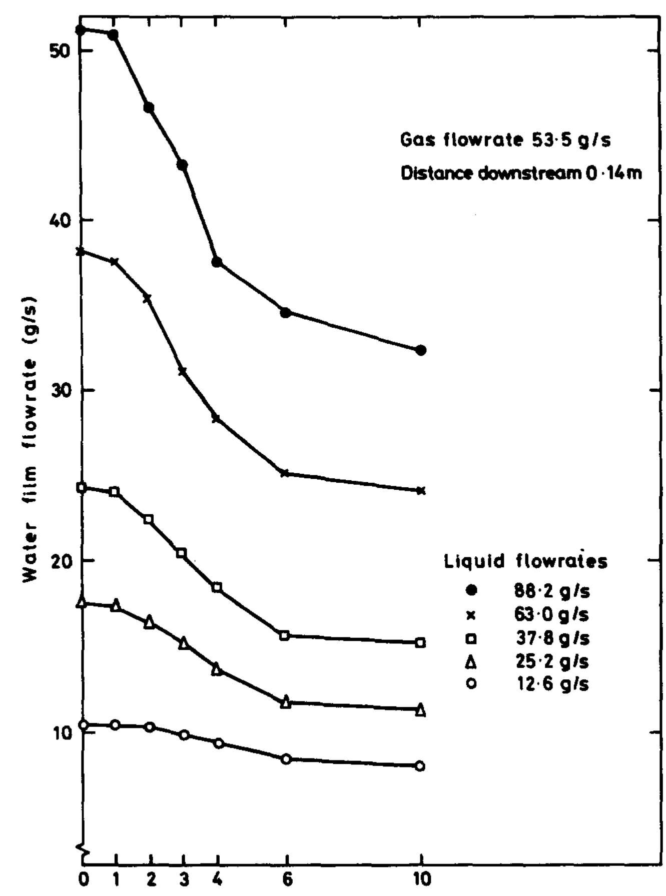

Figure 4. Effect of orifice size on the film flowrate measured 0.14 m downstream of the orifice.

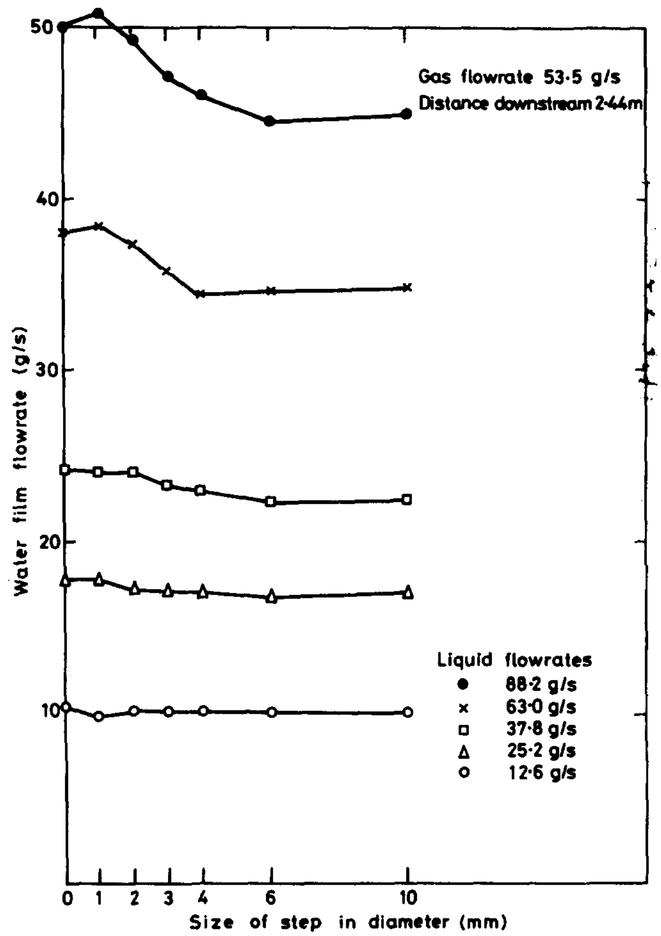

Figure 5. Effect of orifice size on the film flowrate measured 2.44 m downstream of the orifice

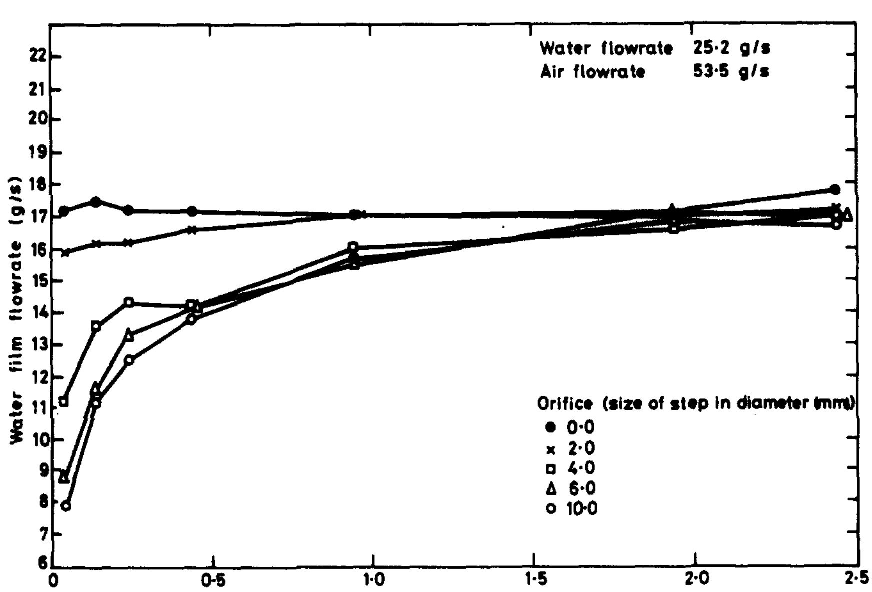

Figure 6. Variation of film flowrate with distance downstream of the orifice.

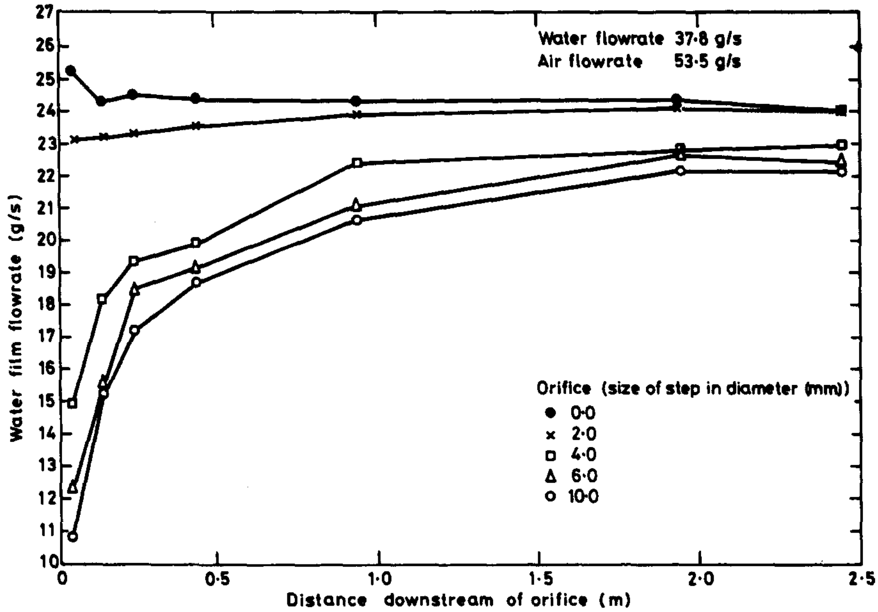

Figure 7. Variation of film flowrate with distance downstream of the orifice.

liquid film. Thus film flows with a large average wave size should be more slowly affected than film flows with a small average wave size as the size of the obstruction is increased. The detailed results in general support this hypothesis. Because step changes in diameter of less than 1 mm have little effect on the water film flowrate, it is unlikely that the steps which occur at flanges in perspex tube due to the slightly non circular cross section and variable wall thickness will have any noticeable effect on the measured flow parameters, unless these changes in diameter are greater than 1 mm.

4.2 *Comparison of the effects of orifice plates and swirl tapes*

Figures 6 and 7 show how the measured water film flowrate varies with position downstream of an orifice plate. Fryer & Whalley (1982) performed a series of experiments at the same conditions as the present experiments. They investigated the effect of a swirl tape on the water film flowrate. Their results show that the swirl tape causes a large amount of the entrained liquid droplets to be centrifuged onto the liquid film, resulting in an increase in the water film flowrate downstream of the swirl tape. Further downstream the water film flowrate returns to its value upstream of the swirl tape. Comparison with the present results shows that the return to equilibrium occurs after a greater distance downstream for the swirl tape than for the orifice plate. A similar situation occurs when, as in Gill & Hewitt (1968), comparison is made between water flow injected into a gas flow via a porous wall sinter, in which equilibrium is attained by net entrainment, and centre jet axial injection, in which equilibrium is attained by net deposition. The results of Gill & Hewitt (1968) also show that the entrained liquid fraction rises towards the equilibrium value more slowly than it falls towards the equilibrium value.

4.3 *The effect of orifice plates on critical heat flux*

All the experimental results indicate that there is a reduction in the water film flowrate just downstream of an orifice plate obstruction, and that further downstream the water film flow gradually returns to its equilibrium value. The results further indicate that the amount by which the water film flowrate is reduced is small for step obstructions in the diameter of less than 1 mm, but then increases noticeably with step size. There is very little effect upstream of the orifice plate.

Comparison of the above results with those of Sekoguchi *et al.* (1978a, b) for film thickness in the vicinity of an orifice plate obstruction reveals that downstream of the obstruction the reduction in film flowrate is accompanied by a decrease in the film thickness. Sekoguchi *et al.* also find that the water film thickness is reduced upstream of the orifice.

The implications of the results in the present work are that the presence of orifice type flow obstructions in a vertical tube in which there is annular flow will cause a reduction in the critical heat flux. The point at which dryout occurs is likely to be immediately downstream of the orifice plate. The discussion in section 4.2 would indicate that the combined effects of swirl and flow obstruction would be likely to cause a net increase in the water film flowrate, thereby increasing the critical heat flux for the tube. This is in agreement with findings of several investigations into the effect of grid spacers combined with swirl tape.

5. CONCLUSIONS

Water film flowrates have been measured in annular air–water two-phase flow at various distances upstream and downstream of orifice plate obstructions of different open area ratios. The experimental results demonstrate that the orifice plate has little effect on the upstream water film flowrate, but that immediately downstream of the orifice the water flows almost entirely as entrained droplets. The return to equilibrium occurs over a shorter distance for this deposition process than for the entrainment process which follows swirl tape disturbances as discussed by Fryer & Whalley (1982).

The implications of the results are that the reduction in film flowrate due to orifice plate obstructions would be likely to cause a decrease in the critical heat flux for a tube containing such an obstruction.

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