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Two-phase flow distribution of air–water annular flow in a parallel flow heat exchanger

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Abstract

The air and water flow distribution are experimentally studied for a round header – flat tube geometry simulating a parallel flow heat exchanger. The number of branch flat tube is 30. The effects of tube outlet direction, tube protrusion depth as well as mass flux, and quality are investigated. The flow at the header inlet is identified as annular. For the downward flow configuration, the water flow distribution is significantly affected by the tube protrusion depth. For flush-mounted configuration, most of the water flows through frontal part of the header. As the protrusion depth increases, more water is forced to the rear part of the header. The effect of mass flux or quality is qualitatively the same as that of the protrusion depth. Increase of the mass flux or quality forces the water to rear part of the header. For the upward flow configuration, however, most of the water flows through rear part of the header. The protrusion depth, mass flux, or quality does not significantly alter the flow pattern. Possible explanations are provided based on the flow visualization results. Negligible difference on the water flow distribution was observed between the parallel and the reverse flow configuration.

Keywords: Flow distribution; Parallel flow heat exchanger; Air–water flow; Two-phase; Protrusion

1. Introduction

Brazed aluminum heat exchangers consist of flat tubes of 1–2 mm hydraulic diameter on the refrigerant-side, and louver fins on the air-side. They are seriously considered as evaporators of residential air conditioners due to the superior thermal performance as compared with conventional fin-tube heat exchangers. To manage the excessive tube-side pressure drop by small channel size, a number of tubes are grouped to one pass using a header (parallel flow configuration). To use the parallel flow heat exchanger as a refrigerant evaporator, it is very important to evenly distribute the two-phase refrigerant (especially the liquid) into the tubes. Otherwise, the thermal performance is significantly deteriorated. According to Bullard (2002), the performance reduction by flow mal-distribution could be as large as 30%. For evaporator usage, the flat tubes are installed vertically (with headers in horizontal position) to facilitate the air-side condensate drainage.

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There are several options on the refrigerant-side design. Fig. 1 illustrates the four possible refrigerant circuits. The refrigerant may be supplied to the top header (downward flow), or they may be supplied to the bottom header (upward flow). The inlet and the exit may be located at the same side of the heat exchanger (reverse flow), or they may be located at the opposite side of the heat exchanger (parallel flow). The tube protrusion depth into the header will also affect the flow distribution. Webb and Chung (2004), Hrnjak (2004) provide recent reviews on this subject.

Watanabe et al. (1995) conducted a flow distribution study for a round header (20 mm ID) – four round tube (6 mm ID) upward flow configuration using R-11. The mass flux (based on the header cross sectional area) was varied from 40 to 120 kg/m^2 s, and the inlet quality was varied up to 0.4. The flow in the header inlet was mostly stratified. The flow distribution was highly dependent on the mass flux and the quality. Tompkins et al. (2002) tested a rectangular header – fifteen flat tube downward flow configuration using air–water. The mass flux was varied from 50 to 400 kg/m^2 s, and the quality was varied up to 0.4. The flow in the header inlet was stratified at low mass fluxes, and it was annular at high mass fluxes. The flow distribution was highly dependent on the mass flux and the quality. Better distribution was obtained at a lower mass flux (stratified flow regime). Vist and Pettersen (2004) investigated a round header (8 mm and 16 mm ID) – ten round tube (4 mm ID) configuration using R-134a. Both upward and downward flow were tested. The mass flux (based on the branch tube) was varied from 124 to 836 kg/m^2 s, and the quality was varied up to 0.5. The flow in the header inlet was mostly intermittent with some annular at high mass fluxes. For the downward flow configuration, most of the liquid flowed through frontal part of the header. For the upward configuration, on the contrary, most of the liquid flowed at the rear part of the header. The liquid distribution improved as the vapor quality decreased. The mass flux had negligible effect on the flow distribution. Lee and Lee (2004) investigated the effect of the tube protrusion depth for a vertical rectangular header (24 by 24 mm) – five horizontal rectangular branch tube configuration using air–water. The flow in the header inlet was annular. The flow distribution was highly dependent on the protrusion depth. As the protrusion depth increased, more water flowed through the downstream part of the header. Cho et al. (2003) investigated the effect of the header orientation (vertical and horizontal) and the refrigerant inlet pipe direction (inline, cross, parallel) for a round header – fifteen flat tube configuration using R-22. The mass flux was fixed at 60 kg/m^2 s, and the quality was varied up to 0.3. For the vertical header configuration, most of the liquid flowed through the frontal part of the header, and the effect of the inlet pipe direction was not significant. For a horizontal header, the flow distribution was highly dependent on the inlet pipe direction, and better distribution was obtained for the parallel or the cross flow configuration. Rong et al. (1995), Bernoux et al. (2001) provide flow distribution data for a plate heat exchanger geometry.

The literature survey reveals that the two-phase flow distribution in a header – branch tube configuration is very complex. Many parameters, both geometric and flow, affect the results, and definitely more data are needed on this subject. Especially, the effects of the tube outlet direction or the protrusion depth for a horizontal header configuration have not been investigated. In this study, the air–water flow distribution in a parallel flow heat exchanger comprised of horizontal round header (inner diameter, $D = 17$ mm) and 30 vertical flat tubes (hydraulic diameter, $D_h = 1.32$ mm) was experimentally investigated. The mass flux (based on header cross section) and the quality were varied for $70 \leqslant G \leqslant 130$ kg/m^2 s and $0.2 \leqslant x \leqslant 0.6$. The flow in the header inlet was annular. The effects of the flow direction (upward or downward), tube outlet direction

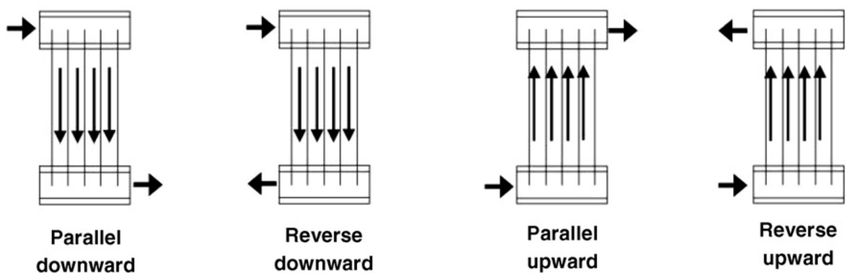

Fig. 1. Four different methods of flow distribution.