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Flow Distribution and Pressure Drop in Micro-channel Manifolds

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ABSTRACT

The primary objective of this project is to establish an understanding of the flow field in a manifold distributing two-phase refrigerant flow into a series of micro-channels. Preliminary studies have been performed using two-phase flow of air and water. Fifteen aluminum microchannel tubes are set in a linear array in an experimental header distribution system. Air distribution, water distribution, and pressure profiles are obtained along the length of the header. Physical models are then employed to predict distribution.

INTRODUCTION

Successful implementation of micro-channel tubes in evaporators requires controlled distribution of refrigerant to the micro-channel tubes. The reasons for maldistribution of refrigerant flow may be due to manifold design or to a natural preference of the flow field. Maldistribution effects may be spatial, temporal, or a combination. An example of one type of maldistribution is seen in Figure 1. Here, an inlet two phase flow divides unevenly (darker shade is liquid, lighter is vapor) due to momentum and geometry effects. Flow visualization combined with experiments in a micro-channel heat exchanger are used to determine flow field parameters important for controlling refrigerant flow.

BACKGROUND

Much study has been given to the experimentation and modeling of two phase flow in header systems. Kim, Choi, and Cho [1995] performed studies using trapezoidal, triangular, and rectangular header geometries to study the effects of area ratio on distribution. Penmatcha, Ashton, and Shoham [1996] examined stratified wavy flow at a T-junction with an angularly displaced (downward and upward) header inlet arm. Saba and Lahey [1984]
developed an empirical model to predict phase distribution of two-phase flow downstream of a header conduit. Çabuk and Modi\textsuperscript{4} [1989] noted that uniform header flow is necessary to maximize heat transfer with an acceptable loss in pressure for the constraints of system geometry. Bajura\textsuperscript{5} [1971] proposed that lateral flow distribution is related to header geometry and not fluid properties and derived a single phase lateral distribution model. Previous research indicates some general trends that are applicable to the present system. Ballyk, Shoukri, and Chan\textsuperscript{6} [1988] studied dividing steam-water annular flow in a T-junction. Pressure recovery was observed to occur downstream of the inlet as total phase separation was approached. Axial momentum associated with branching flow is insignificant. For lower branch flow rates, phase separation depends on total inlet quality. Fei, et al.\textsuperscript{7} found that maldistribution in flat-plate heat exchangers reduces effectiveness and creates uneven air temperature profiles.

**EXPERIMENTAL SETUP**

A manifold test section has been designed and constructed. Initial tests use air and water; however, the test section has been designed to withstand refrigerant (R134a) level pressures. Subsequent tests will employ R134a. The header consists of a 28cm by 56cm (11-inch by 22-inch) PVC top plate. Five pressure tap ports are machined into the top plate to provide for static pressure measurements directly within the flow. The bottom plate is either AL 2024 or PVC. A PVC spacer plate is located between the top and bottom plates and is available in sizes of 3.75mm, 6.35mm, and 12.7mm (1/8”, ¼”, and ½”). Changing the spacer plate allows for a change in the manifold cross-sectional area. Altering this area, in turn, allows for variations in the mass flux. Four mass flux cases have been investigated: 50, 150, 250, and 400 kg/m\textsuperscript{2}s.

A typical microchannel tube can be seen in Figure 2. The microchannel tubes used in this experiment consist of 6 ports with a hydraulic diameter of 1.586mm (0.06”). The ports are housed in a rectangle as seen below. The length of the tube is approximately 31.75cm (12.5”).

![Figure 2. Typical microchannel tube. The width shown is \( \approx 19.05 \text{mm} \) \( (0.75”\) ](image)

A two-phase flow regime is developed by mixing water and air at a tee-junction upstream of the header. The desired two-phase flow quality is set by using a pressure transducer (scale factor 64.5 Pa/mV, ±3% linearity) to regulate air flow, and a liquid flow
meter (±0.2GPH for less than 7 GPH, ±2 GPH for flows above 7 GPH) to regulate water flow (0 to 0.0041 L/s or 0 to 40 GPH). A suitable length of pipe before the test section allows for the establishment of flow regimes. Upon entering the header the flow distributes among fifteen aluminum micro-channel tubes and flows into separator tanks, which allow for air and water mass flow rate determination over a timed interval. Local static pressures are determined by using a system of five valves and a differential pressure transducer (677 Pa/mV, ±3% linearity). The transducer signals were read via a digital multimeter (±0.01mV). The actual header is seen in Figure 3. A schematic of the system is presented in Figure 4.

![Figure 3. Actual header used in experiments.](image1)

![Figure 4. Header and experimental setup.](image2)

**EXPERIMENTAL PROCEDURE**

Experiments are performed according to a matrix of ideal mass fluxes of 50, 150, 250, and 400 kg/(m²-s) and two-phase qualities of 0, 0.1, 0.2, 0.3, and 0.4. The data indicates the actual mass flux and quality that was achieved. For each mass flux and quality, the inlet conditions (top, bottom, left, or right) and header channel area (determined by spacer plate)
can be changed. For each test case, the micro-channel air volumetric flow rate is determined by a gas rotameter (±0.5L/min). For liquid, the volume of water is weighed on a balance (±0.1g) and the time interval is obtained via a quartz stopwatch (±0.25s reaction time). Through propagation of error, each data point is subject to 5.1% variance. Atmospheric pressure is first read, and then each local pressure differential with respect to this reading is obtained, resulting in local static pressures P1, P2, P3, P4, and P5. For comparison, single phase air (quality = 1.0) and single phase water (quality = 0.0) data have also been obtained. De-aerated water is fed into the test manifold by a 0.12kW (1/6HP), 60Hz submersible pump for the single phase liquid data.

RESULTS

Figures 5, 6, and 7 provide a representative sample of distribution data for the 12.7mm (0.5”) spacer plate. Figure 5 shows the liquid distribution data. Some key conclusions may be immediately drawn. Lower mass fluxes demonstrate a greater degree of uniformity throughout the distribution header. At lower flow rates, the flow in the manifold is a stratified–wavy configuration. For increasing flux, maldistribution becomes more apparent. Liquid flows are high in the microchannel tubes at the beginning and end of the header. Note that there is little difference in the liquid flow distribution when the quality is changed for a given flux. At high mass fluxes, annular flow occurs in the manifold. The liquid film on the bottom of the header enters the first microchannel tubes, while the remaining liquid film around the periphery of the header tube bypasses the microchannel tubes. The film reaches the end of the header tube where it begins to flow into the microchannel tubes at the end of the header. Figure 6 shows the air distribution for the same case. This representative data follows the general trend that the air mass flow rate increases as the water mass flow rate decreases along the header length. The air velocity is higher than the liquid. It is not the case that the liquid has a higher momentum which propels it past the tubes; rather, the water film is moved along the header wall past the tubes by the vapor drag on the liquid film. Figure 7 shows the pressure measurements for the same case as in Figure 5. The plot shows that pressure losses in the manifold are relatively small but pressure slightly increases in the direction of flow.

Figures 8, 9, and 10 represent single phase air (quality = 1.0) and water (quality = 0.0) data. A systematic variation occurs in the single phase distribution. Regardless of inlet condition, the discharge flow rate slightly increases along the header. A general flow field effect may be present that is independent of tube variation effects. This behavior was first predicted by Bajura [1971] and is substantiated in this experiment. Further insight can be gained when this single phase data is viewed in light of the pressure profile presented in Figure 10. Note the slight regain in pressure. This behavior was also analytically formulated by Bajura and is substantiated in this experiment. For completeness, a single phase lateral distribution model was developed based on Bajura [1971]. Example distribution predictions are provided in Figures 11 and 12.

*In figures, the mass flux, $G$, is in kg/m²s. In addition, mass flow is in g/s.*
Figure 5. Water Distribution Data: 12.7mm Short Inlet, Bottom, Two Phase Water

Figure 6. Air Distribution Data: 12.7mm Short Inlet, Bottom, Two Phase Air

Figure 7. Sample Pressure Data relative to atmospheric pressure: 12.7mm Short Inlet, Bottom, Two Phase Pressure
Figure 8. Sample Single Phase Water Data: 12.7mm Single Phase Water, Down. Inlet flow of 1.74L/s (1380GPH).

Figure 9. Air Data: 12.7mm Short Inlet, Bottom, Single Phase Air

Figure 10. Pressure Data: 12.7mm Short Inlet, Bottom, Single Phase Air Pressure
Figure 11. Single Phase Data with Bajura Prediction: 12.7mm Short Inlet, Bottom, Single Phase Air, Down with Bajura Single Phase Model

Figure 12. Single Phase Water Distribution with Bajura Prediction: 12.7mm Single Phase Water, Down with Bajura Single Phase Model

Future Study
Two-phase flow distribution is seen as a precursor toward understanding micro-channel header distribution using refrigerants. Preparations are underway to adapt the present header to a pre-existing refrigerant loop.

While preparations continue, the full spectrum of possibilities for two-phase water air-water distribution has not been exhausted. The header will be oriented for other manifold configurations. Also, the spacing between the micro-channel tubes will be altered. Efforts will continue to analyze the flow results and to compare two-phase results to single-phase reference cases. A flow distribution simulation model is currently being developed for the single phase fluid cases.
CONCLUSIONS

Distribution within the micro-channel header is found to depend largely upon the flow regime within the header. With increasing flux and quality, an annular film forms along the top and sides of the header channel. The annular flow field causes significant non-uniformities in liquid and vapor distribution among the microchannel tubes. At lower mass fluxes, a stratified flow develops and the flow distribution is more uniform. The air distribution seems to follow the opposite trend as the water distribution; in general, for a relatively large micro-channel water flow rate, the air mass flow rate is relatively low. Increasing the channel area decreases the mass flux for a given mass flow rate. Slight differences in quality for a given mass flux yield approximately the same distributions.

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