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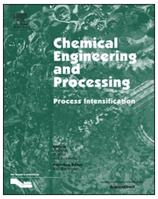

Short communication

A note on adiabatic two-phase flow maldistribution in a set of horizontal parallel minichannels with I-type and Z-type configurations

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ABSTRACT

Two-phase flow from a conventional size flow header that gets split into a set of parallel minichannels finds numerous practical applications in situations where a high heat dissipation rate per unit volume is demanded. Distribution of the two phases into parallel minichannels determines the thermo-hydraulic performance of the entire cooling system. In the present study, trends of time-averaged void fraction and pressure drop are analyzed for a horizontal set of parallel minichannels, with air-water adiabatic two-phase flow in the plug and slug regimes, in I-type and Z-type configurations, by changing significant parameters like header diameter, channel diameter, and number of channels. Results show that the trends of void fraction and pressure drop on either side of the inlet/outlet flow header for an I-type configuration resemble those for a U-type configuration. For both I-type and Z-type configurations, time-averaged void fraction and pressure drop show a more uniform trend when the two-phase flow is in the slug regime. Flow split is found to depend heavily on the geometry and the flow regimes rather than on the pressure drop.

1. Introduction

The idea of distributing the two-phase flow from an inlet header into a set of parallel minichannels to achieve high heat dissipation rate per unit volume is commonly used in many compact cooling devices due to their size and weight constraints. Many factors affect the splitting of the two phases into each of these parallel minichannels, which has a direct consequence on the thermo-fluidic performance of the system. As per Kulkarni et al. [1], unequal distribution, sometimes referred to as maldistribution, can cause as high as a 30% reduction in the cooling performance. Choi et al. [2] studied the two-phase flow distribution in evaporators with parallel channels and showed that maldistribution caused a similar reduction in the performance of the evaporator.

Dario et al. [3] provided a comprehensive review of the impact of different parameters on the two-phase distribution in such parallel minichannels under various scenarios. According to them, geometric parameters, flow regimes, and fluid properties are found to have a great significance in deciding the flow split in the individual minichannels for almost all the flow regimes except for the mist regime. In the mist regime, the distribution seems to be even and insensitive to changes in such parameters. Marchitto et al. [4] also pointed out that the distribution of the phases in parallel channels is a strong function of the flow regime in the header. Another extensive review of research on two-phase flow distribution in divided tubes and parallel channels was presented by Lee [5].

Dang et al. [6] carried out air-water two-phase flow experiments and compared the flow distribution in cross-linked channel plates having multi-parallel mini-channels with the header in the horizontal position. The effect of the entrance, surface tension and inertia are considered as the possible causes of maldistribution.

Kim and Go [7] performed experiments using R-134a refrigerant to see the two-phase distribution in the parallel minichannels of a heat exchanger in an I-type configuration with different orientations. In an I-type configuration, the inlet and the outlet flow headers are located exactly opposite to each other and the flow splits symmetrically to either side of the test section. For the horizontal orientation, they found that the gas flow ratio in the channels follow a trend that peaks for the channel(s) closest to the inlet header and decreases as we move to the channel farthest from the inlet header. Furthermore, the orientation of the heat exchanger was found to have an adverse effect on the distribution of the phases (refrigerant), with the best distribution observed at the horizontal position.

Kim and Sin [8] and Kim and Han [9] performed adiabatic air-water experiments in annular flow regime to examine the flow maldistribution in a set of vertical parallel channels that are normal to the inlet and

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Nomenclature

d	diameter (m)
n	number of parallel channels
Q	volumetric flow rate (L/h)

Subscripts

l	liquid
g	gas
c	channel
h	header

outlet headers. Similarly, Cho and Cho [10] examined the effect of header inlet location on flow distribution into a round shape header with fifteen tubes for upflow using both vertical and horizontal headers.

Madanan et al. [11] investigated the effects of various geometric parameters and flow regimes on the two-phase flow splitting in a set of horizontal parallel minichannels for a U-type configuration, where both the inlet and the outlet headers are on the same side. The possibility of using a separated flow model for predicting the mass split of the individual phases in the parallel minichannels was found to be inadequate.

Dario et al. [3] also advised to not rely completely on the empirical correlations in predicting the pressure drop or the mass split within each of the parallel minichannels (or microchannels) as they are still preliminary and inadequate to completely reflect the real complexity of the two-phase flow inside the inlet header. Furthermore, it was recommended to use inserts, such as an expansion orifice or a splashing grid (proposed by Ahmad et al. [12]), to achieve a better phase distribution while dealing with the two-phase flow in the parallel minichannels.

Webb and Chung [13] provided an extensive review on two-phase flow distribution in air-cooled heat exchangers and suggested possible reasons and fixes for the maldistribution. From their work, it can be noted that although horizontal header and horizontal parallel tubes/channels case is one of the significant situations in terms of applications, experimental investigations dealing with this particular orientation are too scarce to draw any conclusions.

In the present study, the effect of geometric parameters such as the channel diameter, the header diameter, the number of channels, and the flow regimes (slug and plug) are analyzed for air-water two-phase flow distribution from a horizontal inlet header into a set of horizontal parallel minichannels with I-type and Z-type configurations. The time-averaged void fraction and the pressure drop across each of the channels are used as dependent variables in deciding the effect of the investigated parameters. Since flow boiling is very complex, flow patterns have been investigated through adiabatic two-phase flow experiments as the first step towards understanding two phase flows with accompanying phase change.

2. Experiment

2.1. Experimental setup

Fig. 1 is a schematic representation of the experimental setup used for the study. A gravity-driven water flow system from a large overhead tank is employed to minimize any possible fluctuations in the water flow rate. A reciprocating compressor produces the necessary air flow, with a controlled air pressure of 1.5 bar. Flow control valves are used to control the air and water flow rates. Combined flow from this T-junction is allowed to pass through a constant diameter channel of sufficient length to ensure desirable mixing and produce the required two-phase flow regime, as observed optically, before entering the test section. For further details of the experimental setup and test section, one may refer to Madanan et al. [11].

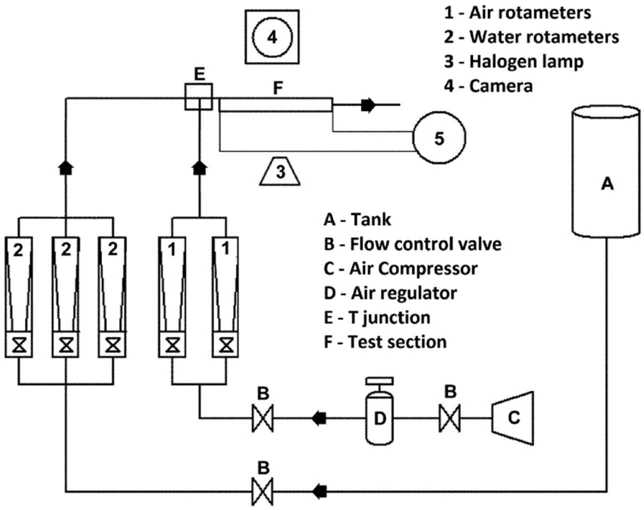

Fig. 1. Schematic of the experimental setup (Madanan et al. [11]).

Two air rotameters, with ranges 11–110 L/h and 25–250 L/h, and 3 water rotameters, with ranges 0.163–1.63 L/h, 1.13–11.3 L/h, and 6–60 L/h, are used for flow monitoring. A PYROTECH made capacitance type differential pressure transducer, with a range of 0–10 kPa, is used for measuring the pressure drop across the individual channels. For the visualization, a uniform light intensity is achieved with the help of a 1000 W halogen lamp and ground glass diffusers. Canon EOS 550D digital camera with EFS 18–55 mm f/3.5–5.6 IS kit lens is used for the visualization studies at 30 fps with an image sensitivity of 800 ISO.

2.2. Methodology

Leak-testing is performed and any trapped air pockets are removed before the experiments are started. The experimental conditions are maintained for a sufficiently long time, till a steady-state is achieved, prior to the data acquisition and visualization. Pressure drop measurements are made with the help of appropriately positioned pressure taps across each of the channels. The digital images, obtained from the flow visualization, are processed using ImageJ™ software and the time-averaged void fractions are estimated for each of the channels. First of all, the magnification factor associated with the image was estimated by using the known channel diameter value and the measured diameter value from the image. The magnification factor was used to estimate the actual slug/plug lengths from the image. The ratio of the sum of slug/plug lengths and the total channel length is calculated and reported as void fraction (or gas hold-up) since the cross-sectional area is invariant here.

For estimating the time-averaged measurements, an averaging window of ~3 minutes is chosen. This is several times the characteristic time (~1/10th), which is computed by taking the ratio of an average slug length to the ideal superficial air velocity in a channel. The measurements are repeated at least 3 times to confirm the repeatability of the time-averaged void fraction and pressure drop values.

This experimental procedure is repeated for a set of experiments designed using Taguchi's orthogonal array method. The channel