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Phase split in parallel vertical channels in presence of a variable depth protrusion header

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ABSTRACT

The air and water flow distribution are experimentally studied in a test section simulating a heat exchanger composed by a round header and 16 parallel upward channels. The effects of the tube protrusion depth as well as the gas and liquid superficial velocities are investigated and the results are compared with previous data. A new fitting solution to be inserted in the header has been developed based on previous findings by the Authors. The fitting geometry belongs to the family of the protruding pipes but the protruding depth has been varied along the header in order to cope with expected liquid and gas mass flow rates in the parallel channels. The flow at the header inlet is intermittent and annular and water and air have been employed as two phase mixture. The new header fitting demonstrated to yield meaningful improvements in phase distribution in terms of either dimensionless liquid and gas flow ratios or standard deviation of phase flow ratio (the overall performance parameter STD^2 here presented decreased by 64%) when compared to the previous configurations.

1. Introduction

Two-phase flow distribution phenomena in multiple header–tube junctions has been a matter of interest for many years because they can be encountered in a wide range of industrial equipment such as contactors, reactors, mixers, burners, heat exchangers, extrusion dies and textile-spinning chimneys. Plate heat exchangers in particular are employed in a wide range of engineering applications not only with single-phase flows but also as evaporators and condensers. Typical examples include refrigerating cycles and heat pumps in which the use of compact heat exchangers results in compactness, reduced weight and limited refrigerant charge.

Because of phase separation, it is very difficult to obtain uniform two-phase flow distribution in the branch tubes. The performance of parallel plate heat exchangers is strongly influenced by the degree of flow rate uniformity in the parallel channels since the heat transfer is strictly related at various level to the flow quality at the individual channel. In this sense usually the even distribution of the liquid phase is the design goal to be achieved in any parallel channel heat exchanger where a two phase mixture is introduced at the header inlet.

There is no general way to predict the distribution of the two phase mixtures at the header-channel junctions. In fact many variables act together such as the following geometric factors:

– hydraulic diameter of the manifold (of square and circular cross section);
– orientation of the manifold (horizontal and vertical) and orientation of heat exchanger tubes connected to the manifold (with upward flow or downward flow);
– intrusion depth of the channels into the header wall;
– length of the inlet pipe of the manifold;
– presence of nozzle or other restrictions at the inlet of the manifold.

From the operating point of view the following variables play a fundamental role:

– total mass flow to the manifold;
– inlet mass vapour fraction (inlet mass quality);
– heat load on the branches;
– exit condition at downstream manifold.

Most studies on two-phase distribution in compact heat exchangers have been based on experiments. Present paper literature survey is summarised in Table 1, which includes the description of test section geometry, experimental conditions, fluid type

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Table 1
Experimental studies on flow distribution in header/tube configuration.

Ref.	Fluids	Header/Tube configuration	Channel flow direction (tubes)	Diameter (mm)/area ratios	Operating conditions	Protrusion depth
Horiki and Osakabe [1]	Air/water	HH square cross-section Four vertical round pipes Protruding type header	Vertical Upward	Header $A = L^2 = 40 \times 40$ Pipe $d = 10$ $h = 0, 10, 20, 30$ $A_{branches}/A_{header} = 0.196$	$V_{sg} = 0–0.08$ m/s $V_{sl} = 0.054–0.10$ m/s	$0.0 \leqslant h/L \geqslant 0.75$
Lee and Lee [2]	Air/water	VH square cross section Six horizontal rectangular channels Protruding type header	Horizontal	Header $A = L^2 = 24 \times 24$ 6 channels 22×1.8 $A_{channels}/A_{header} = 0.4126$ Intrusion depth $h = 0, 3, 6, 12$	$x = 0.2–0.5$ $G = 54–134$ kg/m^2 s $V_{sg} = 6.43–39.9$ m/s $V_{sl} = 0.0276–0.109$ m/s	$0.0 \leqslant h/L \geqslant 0.5$
Bowers et al. [3]	R134a	HH circular Protruded flat pipes (15 micro-channels) Different protrusion schemes (not uniform)	Vertical downward	$D = 20$, $d_H = 1.54$	$x = 0.1–0.35$ $G = 50–120$ kg/m^{2}s at header	
Kim and Sin [4]	Air/water	HH circular Vertical flat (micro-channels) tubes Protruding type header	Vertical upward and downward	$D = 17.30$ flat tubes Each (micro-channel) tube has 8 rectangular ports $d_H = 1.32$ $A_{branches}/A_{header} = 0.18$	$x = 0.2–0.6$ $G = 70–130$ kg/m^2 s $V_{sg} = 8–45$ m/s $V_{sl} = 0.03–0.11$ m/s	$0.0 \leqslant h/D \geqslant 0.5$
Lee [5]	Air/water	VH Single or multiple side branches (T-junctions, Lee and Lee [2])	Horizontal	$D/d = 7.2$ $A_{head}/A_{tube} = 0.4, 1.6$ Square header 24×24	$x = 0.2–0.5$ $G = 54–134$ kg/m^{2}s $V_{sg} = 6.43–39.9$ m/s $V_{sl} = 0.0276–0.109$ m/s	
Koyama et al. [6]	R134 (21 °C)	HH 6 downward minichannel-branches Protrusions	Vertical downward	Header $D = 9$, 6 branches: each branch 6×0.85 i.d. $A_{branches}/A_{header} = 0.32$	$x = 0,1–0.4$ $G = 130$ kg/m^2 s $V_{sg} = 0.44–1.77$ m/s $V_{sl} = 0.064–0.096$ m/s	$0.0 \leqslant h/D \geqslant 0.5$
Kim and Han [7]	Air/water	HH circular Vertical flat (microchannels) tubes Protruding type header	Vertical upward and downward	$D = 17.10$ flat tubes Each tube 8 rectangular ports $d_h = 1.32$ $A_{branches}/A_{header} = 0.54$	$x = 0.2–0.6$ $G = 70–200$ kg/m^2 s	$h = 0.5$ D
Kim et al. [8]	R-134a	HH circular Vertical minichannel tube	Vertical upward and downward	$D/d = 12.9$ $A_H/A_T = 1.9$	$G = 70–130$ kg/m^2 s $x = 0.2–0.6$	$h/D = 0.5$
Liang et al. [9]	Air/water	HH circular 2 Nozzles connected with 2 side arms Swirl vane	Vertical upward arm and horizontal arm	Header $D = 40$ Each nozzle 8 mm, expansions angle 21°	$V_{sg} = 7.5–20$ m/s $V_{sl} = 0.018–0.16$ m/s	
Ben Saad et al. [10]	Air/water	Horizontal distributor; 2 phase injection configurations; vertical test section	Vertical upward-	Vertical test section: $1 \times 1 \times 7.13$	$V_{sg} = 0.9–8.8$ m/s $V_{sl} = 0.35–0.8$ m/s	
Hu et al. [12]	R410A	Plate evaporator with distributor	Vertical upward and downward	$N_{cha} = 24–37$ $D_{in,dist} = 14–28$ $D_h = 3.18$	$x = 0.204–0.241$ $\dot{m} = 0.095–0.335$ kg/s	
Barreto et al. [13]	Air/water	VH mixer, later splitted between 3 conducts Vertical flat (microchannels) tubes	Vertical upward	7 microchannels $d = 1.2$	$V_{sg} = 0.15–41.70$ m/s $V_{sl} = 0.005–0.3$ m/s	
Fossa et al. [14]	Air/water	HH circular Vertical flat tubes Protruding type header	Vertical upward	$D = 26$, $d_f = 5$ $A_{branches}/A_{header} = 0.592$	$V_{sg} = 1.5–16.5$ m/s $V_{sl} = 0.20–1.20$ m/s	$h/D = 0, 0.5, 0.75, 0.9$

G: mass flux (kg/m^2 s), x: mass quality (–); $\dot{m}$: total mass flow rate of refrigerant (kg/s); V_{sl}: liquid superficial velocity (m/s); V_{sg}: gas superficial velocity (m/s); HH: horizontal header; VH: vertical header.