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General characteristics of two-phase flow distribution in a compact heat exchanger

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ABSTRACT

An experimental loop representing a compact plate heat exchanger was built up to study the two-phase distribution in the different header channels. The test section consists of a cylindrical horizontal header and eight rectangular channels in which the liquid and vapour flow rates are evaluated and the flow inside the header can be visualized. Several geometrical and functional parameters to study the two-phase distribution were tested using "HFE 7100" at a temperature close to 57 °C and a pressure close to 100 kPa. A flow pattern map in the header was built up using the different entry parameters on which a quantitative understanding of the two-phase distribution could be deduced.

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1. Introduction

Two-phase maldistribution reduces the thermal and hydraulic performance of compact heat exchangers with parallel flow circuits and may cause the apparition of dry-out zones in evaporators and high liquid loading zones in condensers. The maldistribution in parallel circuits is significantly related to the two-phase flow patterns in the header, as well as to several other factors as the non-uniform thermal loading of different sections of the heat exchanger, fouling, corrosion, etc.

Different authors have investigated the two-phase flow distribution in compact heat exchangers. Watanabe et al. [1] studied experimentally the distribution of R11 in an evaporator of four tubes manifold and they examined the load heat effect on flow distribution. Rong et al. [2] carried out an adiabatic experiment to study the distribution of air–water flow in a horizontal manifold of vertical channels with downward or upward orientation of a compact heat exchanger used for automotive air-conditioning. Moura [3] carried out both experimental study and numerical modeling on the two-phase flow distribution between two passes of a heat exchanger. Webb and Chung [4] examined the effect of the manifold geometry and the orientation of inlet and outlet channels on the distribution. Bernoux [5] investigated experimentally the effect of inlet mass flow rate and mass quality on the two-phase distribution of a compact plate heat exchanger. Fei [6] made some experiments detecting the importance of the expansion valve position on establishing the flow configuration before plate evaporators. Vist and Pettersen [7] used circular header as horizontal inlet manifolds (inner diameter: 8 and 16 mm) with 10 parallel vertical tubes. They investigated the two-phase flow distribution of R134a in round tube manifolds with 10 parallel tubes with operating conditions (mass flux: 199–331 kg/m^2 s, quality: 0.11–0.50). The results showed that vapour phase flow was mainly distributed into the tubes near the inlet, and the liquid was preferentially distributed to the last tubes of the heat exchanger. Lee and Lee [8] examined the distribution of two-phase annular flow at header channels junctions of a compact plate heat exchanger. They focused on the effect of the intrusion depth of the channels to improve the liquid phase distribution. Jiao and Baek [9] proposed an original concept of an evaporator design adding a complementary fluid cavity in the distributor. The experimental studies showed that the maldistribution is highly affected by the distributor configuration. Rao Bobbili et al. [10] developed a mathematical model to investigate the effect of maldistribution on the thermal performance as well as the exit vapour quality of a plate heat exchanger. All the above research mentioned described the uneven distribution of the two phases in the different heat exchanger channel without eliminating its causes.

In the present study, different structural and functional parameters that can influence the distribution are investigated to get a general understanding of the two-phase distribution in a compact plate heat exchanger. A general investigation of the different two-phase flow structures in the header explains the causes of maldistribution in different test conditions and helps in designing an optimized heat exchanger.

2. Experimental apparatus

2.1. Test section

The test section consists of a horizontal header (manifold) and eight parallel downward channels (Fig. 1). The test section with eight channels can be rotated around the manifold axis so that

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Nomenclature

C_p	specific heat at constant pressure (J/kg K)
G	mass velocity (kg/m^2 s)
h	enthalpy (J/kg)
$\dot{M}$	mass flux (kg/h)
P	pressure (Pa)
T	temperature (K)
x	mass quality
Greek symbols	
ΔT	variation in temperature (K)
Subscripts	
e	inlet
i	tube number
l	liquid
s	outlet
SI	test section inlet
v	vapour
evap	pre-evaporator

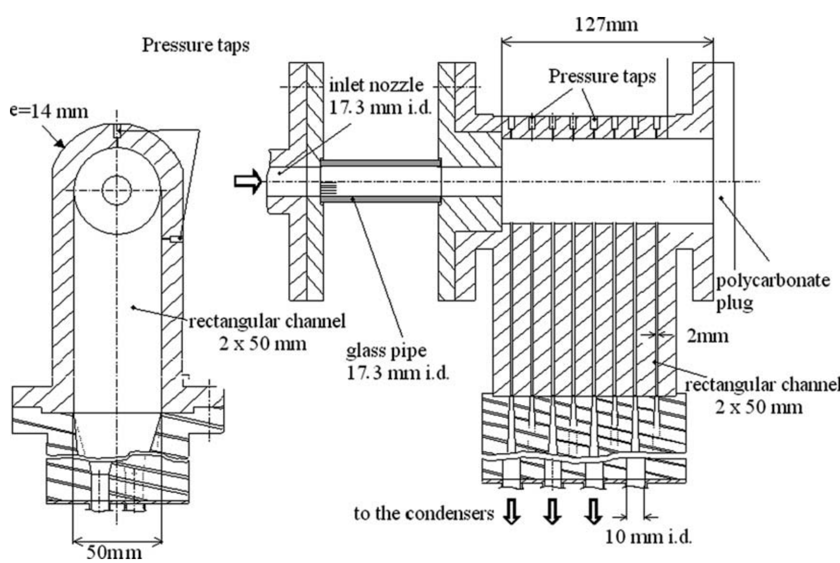

Fig. 1. Test section.

we can get horizontal flow, vertically upward or downward flow in the channels. The manifold is made of stainless steel. It is 127 mm long and its diameter is 50 mm. It is horizontally supplied by a 17.3-mm in diameter and 100-mm-long glass pipe to visualize the two-phase flow at the header inlet connected to a 1500-mm tube made of stainless steel of the same diameter. The long tube provides a steady-state flow at the header inlet. The end of the header is closed by a transparent polycarbonate plug. Each branch is 2 × 50 mm rectangular. The channels are regularly 10 mm spaced along the manifold.

The header diameter is reduced to 30 mm and then to 17.3 mm by introducing cylindrical devices in the main header of 30 and 17.3 mm, respectively, as inner diameters and an external diameter of 50 mm pierced at the channels level.

2.2. Flow loop and experimental procedure

The experimental loop, shown in Fig. 2 consists of four circuits: the main circuit (HFE 7100), a heating circuit of hot water (pre-evaporator), a cooling circuit of cold water with eight sub-circuits (eight condensers) and a sub-cooling circuit of cold water to assure the sub-cooling of HFE 7100 and thus to avoid the cavitation in the main circuit pump.

In the main circuit, the flow is driven by a variable speed gear pump which can facilitate the control on the flow rate. Nine heat exchangers are placed in the main loop of the experimental set-up: the pre-evaporator (upstream the test section) and the eight condensers (one downstream each channel). Four RTD (platinum temperature sensors) sensors are located at the inlet and the outlet of each heat exchanger (two on the HFE 7100 side and two on the heating–cooling water side). An absolute pressure transducer is used to measure the pressure evolution in different positions in the header and at the inlet manifold. Differential pressure transducers are used to study pressure difference in the eight channels. The HFE 7100 mass flow rate in the test section is controlled through a regulation valve upstream the pre-evaporator and is measured by a coriolis mass flow-meter. Other eight coriolis mass flow-meters are located downstream the eight condensers. The water flow rate is deduced from an electromagnetic volumetric flow-meter in the pre-evaporator circuit and a micro-oval volumetric flow-meter downstream each condenser.

The fluid "HFE 7100" is controlled to be in two-phase state at the entry of the test section with an operating saturation pressure close to the ambient pressure. The notation of the pre-evaporator or one of the eight condensers is schematized in Fig. 3. The mass quality is regulated by the pre-evaporator and is calculated at its outlet, and in a similar way in each of the eight channels, from an enthalpy balance neglecting the thermal losses as shown by the following equation:

$$x = \frac{\dot{M}_{\text{water}}\overline{C}_P\Delta T_{\text{water}} - \dot{M}_{\text{HFE}}\left[h_l^{\text{sat}}(T_{\text{sHFE}}) - h_l(T_{\text{eHFE}}, P_{\text{eHFE}})\right]}{\dot{M}\left[h_v^{\text{sat}}(T_{\text{sHFE}}) - h_l^{\text{sat}}(T_{\text{sHFE}})\right]} \quad (1)$$

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