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The Characteristics of Two-Phase Flow Distribution in a Bottom Dividing Header

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Abstract : In this paper an experimental study was investigated for two-phase flow distribution in compact heat exchanger header. A test section was consisted of the horizontal bottom dividing header(ϕ: 5 mm, L: 80 mm) and 10 upward circular mini channels (ϕ: 1.5 mm, L: 850 mm) using an acrylic tube. Three different types of tube intrusion depth were tested for the mass flux and inlet mass quality ranges of 50 - 200 kg/m^2s and 0.1 - 0.3, respectively. Air and water were used as the test fluids. The distribution of vapor and liquid is obtained by measurement of the total mass flow rate and the calculation of the quality. Two-phase flow pattern was observed, and pressure drop of each channel was measured. By adjusting the intrusion depth of each channel an uniform liquid flow distribution through the each channel was able to solve the mal-distribution problem.

Key words : Two-phase flow distribution, Bottom dividing header, Mini channel, Intrusion depth

1. Introduction

Mal-distributions of the two-phase flow in compact heat exchanger reduce the thermal and hydraulic performance. Because two-phase flow is separated in the header, the vapor and the liquid are distributed unequally into the channels. In evaporators, proper distribution is essential to avoid dry-out of liquid phase. However, two-phase flow structure in compact heat exchangers is very complex. Therefore, optimal design of the header is the most important problem, especially in case of the problem about unequal distribution. Furthermore, the improvement of phase distribution requires a good understanding of physical phenomena.

Kim[1] reported the two-phase distribution in a horizontal circular header connected to four parallel vertical tubes.

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Recently, Lee and Lee[2] performed an experimental work about header-channel junctions of compact heat exchanger. Three different intrusion depths were tested for the mass flux and the mass quality ranges of 54~134 kg/m^2s and 0. 2~0.5, respectively. Air and water were used as test fluids. Their result showed that a uniform liquid - flow distribution through the parallel channels could be achieved simply by adjusting the intrusion depth.

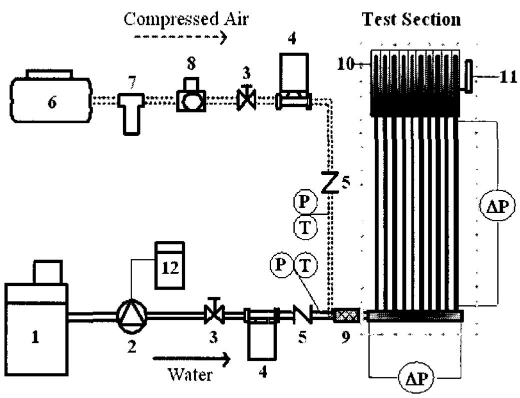
Vist and Pettersen[3] used circular header as horizontal inlet manifolds (ϕ: 8mm, L: 16mm) with 10 parallel vertical tubes. Experimental investigation was performed for operating factors (mass flux: 199~331 kg/m^2s, vapor fraction: 0.11~0.50, heat load on the branches: 50 ~650W) and geometrical factors (diameter of the manifold, orientation of the manifolds), and R-132a was used as refrigerant.

Bernoux et al.[4] performed an experimental investigation about the effect of mass flux (100~290 kg/m^2s) and mass quality (0.1~0.8). Their results were shown that the vapor distribution is excellent at high mass quality, but it deteriorates strongly when mass quality decreases. Inversely, the liquid distribution is very uneven at high quality while it is much better at low quality, although not very good.

Therefore, in this study, to provide a design data for compact heat exchanger header, experimental study was conducted about the effect of the intrusion depth and geometry of the channels. Particularly the effect of inlet flow conditions and header design on the performance of the multi channel evaporator, the information of flow pattern in small diameter tubes and pressure drop of two-phase flow in header were investigated.

2. Experimental Apparatus and Method

The schemaict diagram of the experimental apparatus is shown in Fig. 1. They were built to measure the two-phase flow distribution under different operating conditions. The test section was consisted of a horizontal tube header, ten vertical channels and air / liquid separators. Air and water were used as the test fluids.



1. Water bath 7. Air filter
2. Gear pump 8. Pressure regulator
3. Valve 9. Air / water mixer
4. Mass flow mete 10. Air / water separator
5. Check valve 11. Air flow meter
6. Compressed air storage tank 12. Inverter

Fig. 1 Schematic diagram of the experimental apparatus.

Air was supplied from a compressed air storage tank at temperature (287~290 K) and flew through a pressure regulator & mass flow meter to air/water mixer.

Water was pumped from the constant temperature water bath at 288~289 K by water pump through mass flow meter to mixer. Both air and water mass flow rate were measured by using calibrated mass flow meter (Model: Oval-DO25S, Range: 0~3 kg/min, accuracy: 0.2 %). The mixer was made of cylindrical chamber with inside diameter 8 mm and length 100 mm, and it was filled with copper mesh filter of 144 pores per square centimeter, which provide strong agitation and complete mixing of air/water. The air/water mixture then flows through the test section, header and channels, to an air/water separator.

The flow rate of water and air for each channels was measured at air/water separator by using the weighing (Model: OHAUS-TP2KS, range: 0~2,000 g, accuracy: ± 0.1 g) for mass of water and air flow meter (Model : Dwyer-RMB, range: 0~2.5 l/min, accuracy: 4%). Pressure drop tests at header and channels were performed using differential pressure gauge (Model: Druck PMP 4170, Range: 0~700 mbar, accuracy: ± 0.04 %).

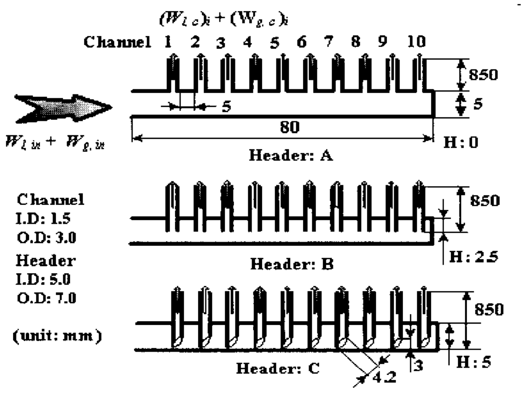


Fig. 2 Configuration of three type headers used in this study.

Fig. 2 shows the configuration of three type manifolds used in this study. The header is horizontal circular tube (ϕ: 5 mm L: 80 mm) and the branch tubes are ten vertical channels(ϕ: 1.5 mm L: 850 mm). Those were made of transparent acrylic tube for flow visualization.

Three different intrusion depths (H = 0, 2.5 and 5 mm) were tested. To describe the practical operational conditions of evaporators, experiments were performed at the following conditions. At the header, inlet mass flux and mass quality ranges of air/water mixtures were 50~200 kg/m^2s and 0.1~0.3, respectively.

Definition of the terms are as follows. In the presentation of the two-phase distribution measurements, the mass flow ratio in channel i is presented in a normalized manner:

$$\text{Flow ratio}(\%) = W^*_{k,i} = \frac{W^*_{k,i}}{\sum_{j=1}^{10} W_{k,j}/10} \times 100 \quad (1)$$

where $k=l$ (liquid), or $k=g$ (gas).

The two-phase Reynolds number is defined as:

$$\mathrm{Re}_{TP} = \frac{G \cdot D}{\mu_{TP}} \quad (2)$$

$$\frac{1}{\mu_{TP}} = \frac{x}{\mu_g} - \frac{1-x}{\mu_l} \quad (3)$$

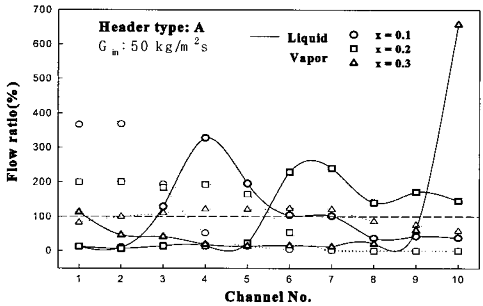
where D is the inner diameter of header tube.

Various definitions have been given for the two-phase viscosity μ_{TP}, the most commonly used being that of McAdams[5] et al.

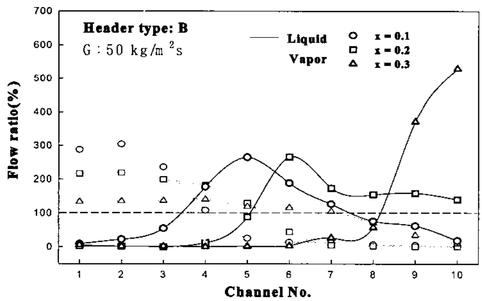
3. Results and Discussion

3.1 The effect of mass quality on flow distribution

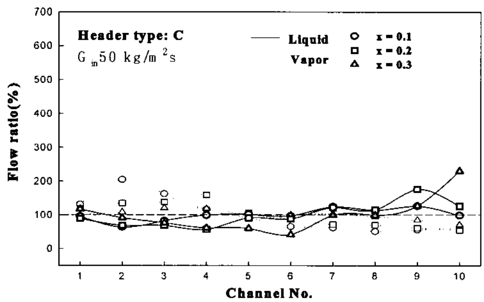
To investigate the influence of inlet mass quality on two-phase distribution in the header, the range of inlet mass quality was 0.1~0.3, and inlet mass flux was fixed at 50 kg/m^{2}s.



(a) Header type: A



(b) Header type: B

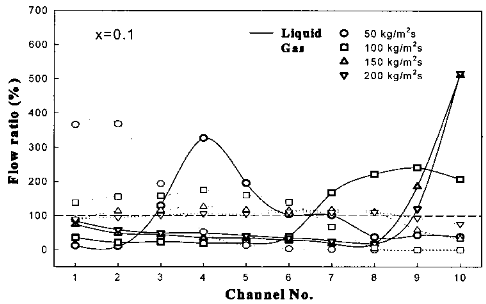


(c) Header type: C

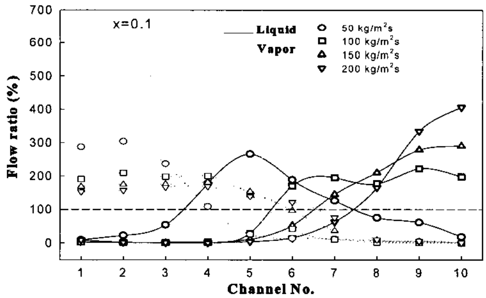
Fig. 3 Influence of inlet mass quality in phase distribution

Fig. 3 shows liquid and vapor distribution as a function of inlet mass quality to the header. At low mass quality, x = 0.1, most of the vapor were fed to channel 1~3 and most of the liquid were fed to channel 3~8, respectively. For higher inlet mass quality, the vapor flow distribution was improved, while the liquid flow distribution was worse.

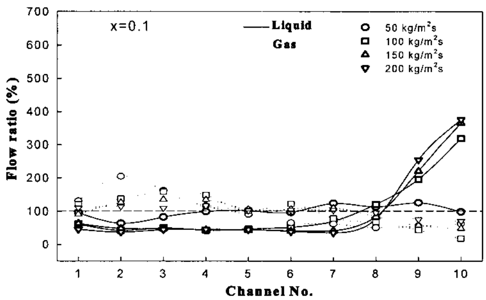
3.2 The effect of mass flux on flow distribution



(a) Header type: A

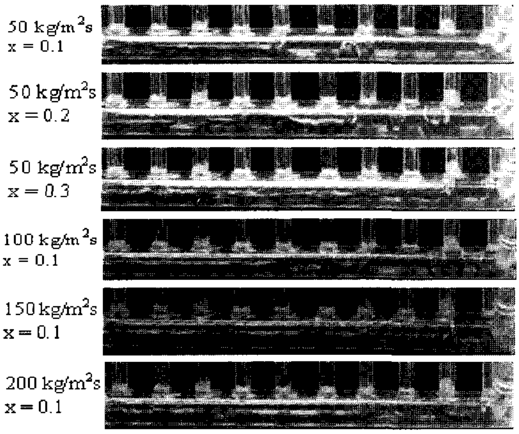


(b) Header type: B

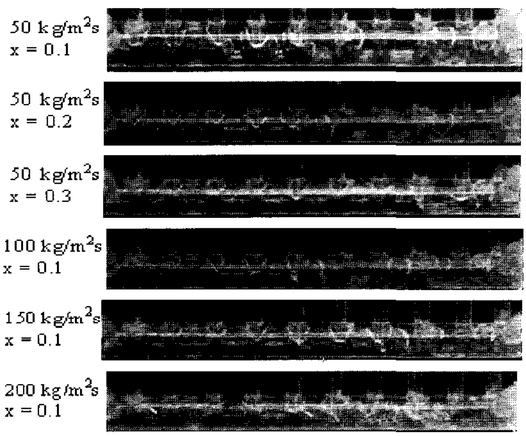


(c) Header type: C

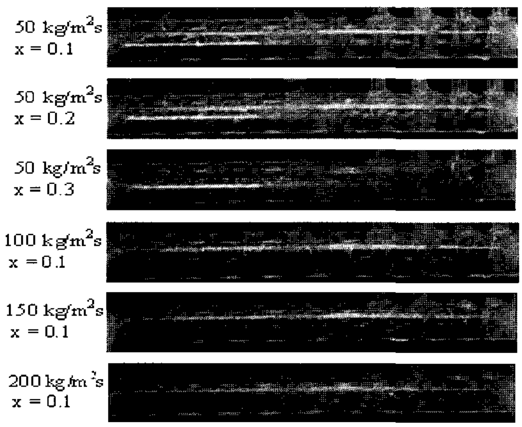
Fig. 4 Influence of inlet mass flux in phase distribution



(a) Header type : A



(b) Header type : B



(c) Header type : C

Fig. 5 Influence of inlet mass quality and mass flux on flow structure in header.

Fig. 4 presents the effect of the mass flux on two-phase distribution for three different type headers. The inlet mass flux was varying from 50 to 200 kg/m^{2}s, and mass quality was kept constant at x = 0.1.

At low mass flux, G = 50 kg/m^{2}s, most of the vapor were fed to channel 1~3, and most of the liquid were fed to channel 3~7 in the header A and B, while distributed well in the header C. However, according to increasing the inlet mass flux at header inlet, distribution of the liquid flow was deteriorated (overfed to channels 7~10 in the header A and B, channels 9~10 in the header C), while the vapor flow distribution was improved.

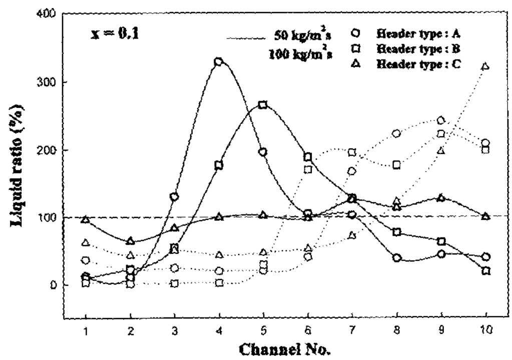
3.3 Flow patterns in the header

Fig. 5 shows the two-phase flow patterns in the three type's header according to increasing mass quality and mass flux. For the header type A, flow patterns were observed as slug, stratified and wavy flow. Water and air were fully separated. In case of these flow patterns, the momentum and inertia of the upper air were smaller than those of the lower part's water.

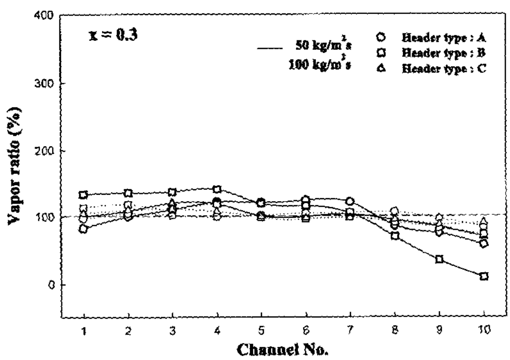
Therefore most of the air was fed to the near inlet part channel, in contrast to the water. For the header type B, a projecting part of channel, which was inserted into the header, promoted local circulations and acted as a mixer. Owing to the effect of the projecting part, the mal- distribution of water and air decreased when compared with the header type A. For the header type C, local circulation and vortex of the mixtures more increased among the projecting part of each channel. The two-phase flow for inside header was mixed almost homogeneously, and the distribution was more improved when compare with the header type A and B.

3.4 The effect of intrusion depths on flow distribution

Fig.6 (a) (b) shows the characteristics of liquid and vapor phase distribution for three type's header at mass quality x = 0.1 & 0.3, mass flux G = 50 & 200 kg/m^{2}s. More amount of liquid was fed tomiddle part or end part of the header, for type A and B. However, a mal-distribution of liquid-phase flow considerably decreased under the influence of an increasing intrusion depth, especially the header type C. The tendency of the vapor phase's mal-distribution was less than liquid phase distribution among the three type's header, though vapor phase was most well distributed in the header type C. The deeper inserted channels into the header reinforced promotion or hindrances of flow into the other channels.



(a) x = 0.1



(b) x= 0.3

Fig. 6 Influence of intrusion depth in phase distribution

3.5 Pressure drops of the header and channels.

Fig. 7 shows the pressure drop characteristics of three type's header for various Re_{TP} at the header inlet. For the header type A, pressure drop was almost equal, but it was proportionally increased in the header B and C. This is the reason why the channel inserted into the header acted like resistance of a two-phase flow.

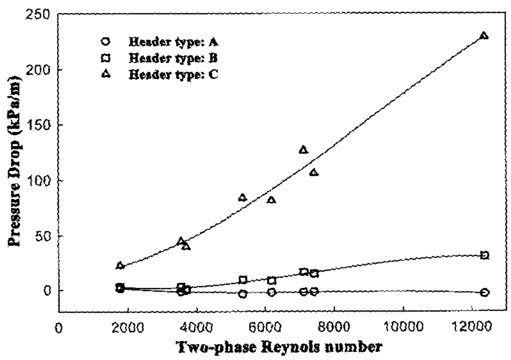


Fig. 7 Pressure drop at headers

Fig. 8 shows the pressure drop characteristics at each channel for header type C, mass quality of header inlet varied from 0.1 to 0.3, and inlet mass flux was kept at G = 100 kg/m^2s. Because of the pressure drop of header, the pressure drop of the fore part's channel was a little bit higher than that of the end part's channel. However, their pressure drop is almost equal, when consider the pressure drop effect at header. This is the main reason for the uniform two-phase distribution. In other words, equal pressure drop at each channel is a principal of uniform phase distribution.

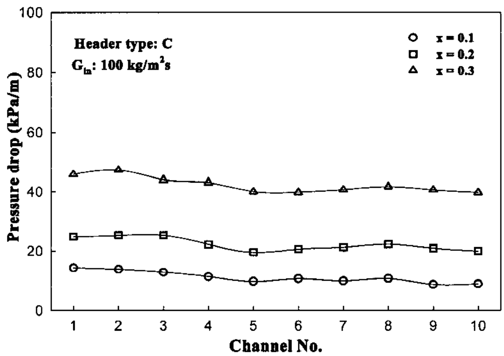


Fig. 8 Pressure drop at channels of header type C.

4. Conclusion

An experimental investigation of two-phase distribution characteristics in three type headers was conducted using horizontal circular header and small vertical channels. The major object of this paper was to investigate the influence of mass quality & mass flux, the channel's intrusion depth & shape and pressure drops of the header & channels on two-phase flow distribution phenomena.

1. For liquid phase distribution was improved when the low inlet mass quality and mass flux, but vapor distribution was contrary to the tendency of liquid phase distribution.
2. The channels, which were inserted into the inside header, promoted the local recirculation and mixing of two-phase flow. Therefore, the mal-distribution was decreased for the header type B & C. Especially, for the header type C, the channels inserted into the header bottom with end cutting angle 45°, remarkably improved the problem of mal-distribution.
3. The pressure drop of header type B and C was higher than header type A, since the inserted channels acted like a hindrances. Also, the pressure drop at channels increased according to the increasing of header inlet mass quality and mass flux.
4. For the header type C, the pressure drop of the each channel was almost equal. Therefore, two-phase flow was distributed almost equally.

Nomenclature

ϕ : inner diameter, (mm)
G : mass flux, (kg/m^2s)
H : intrusion depth, (mm)
L : Length, (mm)
μ : viscosity, (kg/ms)
W : mass flow rate, (kg/s)
W^* : mass flow ratio, (%)
x : mass quality, $W_g/(W_g + W_l)$

Subscripts

c : channel
g : gas
in : inlet

i : channel number
l : liquid
TP : two-phase

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