Study of Two Phase Flow Distribution and Its Influence in a Plate-fin Heat Exchanger

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In this paper, the experimental investigation on the effects of inlet flow rate and dryness on the two-phase flow distribution near entrance of plate-fin heat exchangers is presented. The results indicate that the liquid phase non-uniformity is more serious than that of gas and the flow non-uniformity in crosswise direction is more serious than that in ordinate direction. The effects of both gas Reynolds number and inlet flow dryness are also presented.

INTRODUCTION

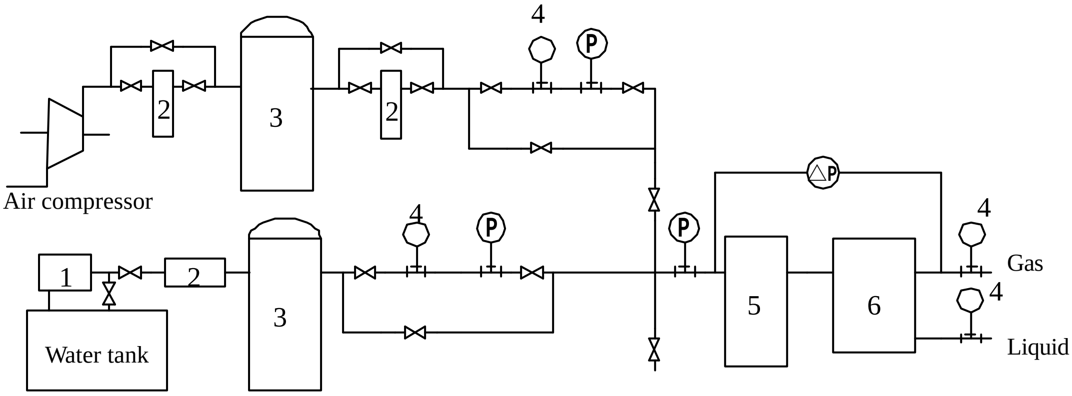
The maldistribution in the core of plate-fin heat exchanger caused by improper entrance configuration, such as poor design of header and distributor conformation, manufacturing tolerances, fouling, frosting of condensable impurities, especially in multi-phase flow, will lead to the performance deterioration of heat exchanger. For two-phase flow heat exchangers, especially for cryogenics heat exchangers working under little temperature difference, fluid flow distributing non-uniformly happens. A. C. Mueller[1] indicated that the types of two-phase maldistribution including (1) vapor quality difference in parallel circuits; (2) density-wave instability, which is a more complex phenomenon of oscillating flows and pressure drops. Wu Jianghong [2] theoretically analyzed the effect of two-phase maldistribution in plate-fin heat exchanger by setting up a model to numerically calculate the performance of distribution. P. Vlasogiannis [3] recorded construction of a flow regime map of air-water two-phase flow in a plate heat exchanger by a high-speed video camera. The experiment studies of realistic factors influencing two-phase maldistribution are fewer than that of single-phase [4,5]. In this paper, the experimental investigation on the effects of gas flow Re (i.e. inlet gas flow rate) and flow dryness in both crosswise direction (perpendicular to the inlet flow) and ordinate direction (parallel to the inlet flow) are presented.

EXPERIMENTAL SYSTEM

The experimental system is shown in Figure 1, which includes the fluid flow system and the data acquisition system. The fluid flow system is composed of air compressor, water tank, pump, stabilization tank, filter, test section, passage-switching device and separator. The data acquisition is composed of a series of pressure and pressure difference sensors (silicon crystal film), air turbine flow meter and liquid turbine flow meter, which are connected to a computer through a Keithley plug-in data acquisition board.

Single-phase and two-phase fluid flow distribution research can be taken in the experimental system. Water constitutes the liquid phase of the gas/liquid mixture and is provided by pumping from a water tank. Air is supplied by a screw air compressor and is mixed with the water in a joint, located on the pipe leading to the heat exchanger (see Figure 1).

Air and water flow rates are measured by a series of turbine meters and the accuracy of the measurement is less than 1%. The airflow rate recorded is corrected for deviations from standard conditions according the actual pressure and temperature. The test unit (see Figure 2), which is manufactured by Kaifeng Air Separation Group Company Limited, has the volume of 200× 250× 178 mm^3. The flow at cross-section is divided into 30 zones, and the flow distribution in each zone is assumed to be uniform. The arrangement of channels (zones) is shown in Figure 3.



1-Pump; 2-Filter; 3-Stabilization tank; 4-Flow meter; 5-Test section; 6-Separator

Figure 1 Schematic diagram of experimental system

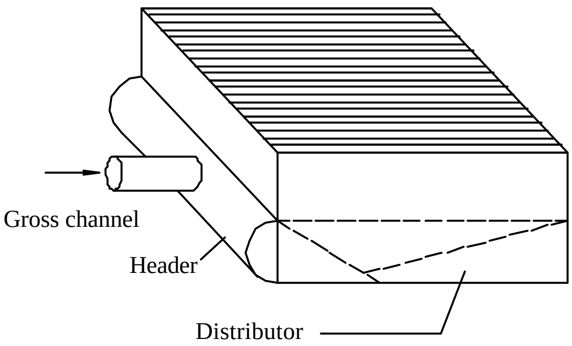


Figure 2 Schematic diagram of test section

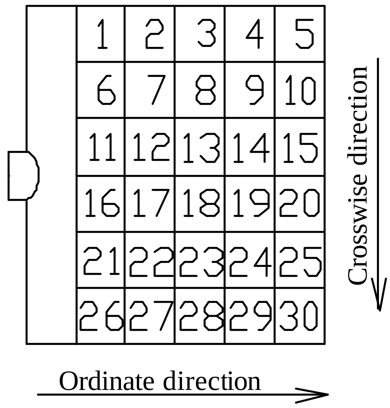


Figure 3 Channels arrangement and direction

DATA ANALYSIS AND DISCUSSION

All two-phase flow data are reported in terms of superficial air and water velocities V, which are defined from the respective volumetric flow rate, Q_G and Q_L, and the area S of zone shown in the Figure 3. In particular, the airflow rate is converted to standard state (1 atm and 25℃). Thus

$$V_G = \frac{Q_G}{S}, V_L = \frac{Q_L}{S} \tag{1}$$

For convenient investigation of the flow distribution in whole cross-section, the fluid flow is discomposed into those in crosswise and in ordinate direction (see Figure 3) as follows,

$$U_{j,i}' = (V_{j,5i-4} + V_{j,5i-3} + V_{j,5i-2} + V_{j,5i-1} + V_{j,5i})/5 \qquad \text{(i=1,2,3,4,5,6; j=G or L)} \tag{2}$$

$$U_{j,i}'' = (V_{j,i} + V_{j,i+5} + V_{j,i+10} + V_{j,i+15} + V_{j,i+20} + V_{j,i+25})/6 \qquad \text{(i=1,2,3,4,5; j=G or L)} \tag{3}$$

where U' and U'' are the average flow velocities in crosswise and in ordinate direction, respectively.

The dimensionless velocity deviation, q' and q'' indicates the flow uniformity in cross-section of the test unit as shown in eq. (4). The more the value is, the worse the flow distribution is.

$$q_i' = (U_i' - U_{ave})/U_{ave}, q_i'' = (U_i'' - U_{ave})/U_{ave} \tag{4}$$

where U_{ave} stands for average flow velocity of cross-section.

Single-phase flow distribution experiment

In this set of experiments the test section has been tested with air at different flow rates from 1.73～2.34 m^3/min. Figure 4 shows the relationship of velocity deviation vs. air flow Re. According to the figure, the single-phase flow maldistribution in both directions is an increasing function of inlet flow Re. The figure indicates that in both directions the velocity deviation is below ±0.3 and the deviation in ordinate direction is little greater than that in crosswise direction, which means that the velocity profile in ordinate direction is more non-uniform.

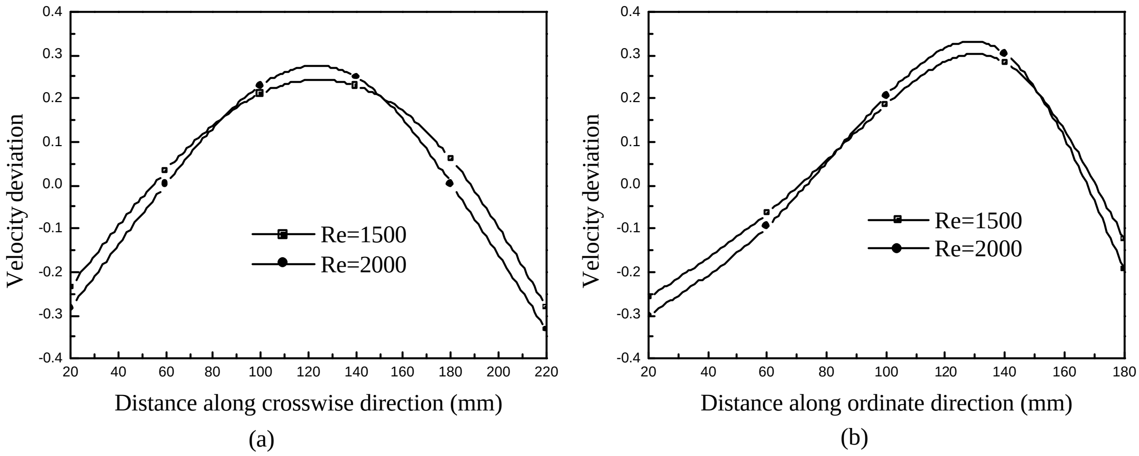


Figure 4 Velocity deviation in both crosswise and ordinate direction with different Re

Two-phase flow distribution experiment

In two-phase flow operation, we maintain the mass dryness of the flow at 18% by varying air and water flux synchronously to get the flow profiles in the cross-section with different gas Re. Then the Re of gas flow is kept constant at 2600, and we obtain the flow profiles in both directions with different fluid mass dryness by changing water flux.

Distribution of gas and liquid flow for different gas Re and for different fluid dryness is displayed in Figure 5 and Figure 6. According to the Figures, liquid phase non-uniformity, especially in crosswise direction (normal to gross channel), mainly represent the two-phase flow non-uniformity in the entrance of heat exchanger. Both gas and liquid components of the flow maldistribution increase with the increases of gas flow Re in Figure 5. And in Figure 6, the gas flow maldistribution decreases, especially in crosswise direction, with the inlet dryness increasing. However, the liquid flow maldistribution increases with the inlet dryness increasing, and it’s more obvious in ordinate direction.

Distribution of single-phase flow shown in Figure 4 with 100% dryness is much distinguishing with those of gas phase in two-phase flow shown in Figures 5 and 6. The gas phase velocity distributions in both crosswise and ordinate directions have more than one peaks, and moreover, the distributions in ordinate direction at different Re and those in crosswise with different dryness show various patterns, which are different with single-phase distribution. The figures also illustrate that single-phase gas flow distribution is more serious than gas phase distribution in mixture. The reason of this behavior can be explained as follows: the complex interaction between gas and liquid causes the change of flow pattern and liquid phase play major role in distribution of two-phase flow.

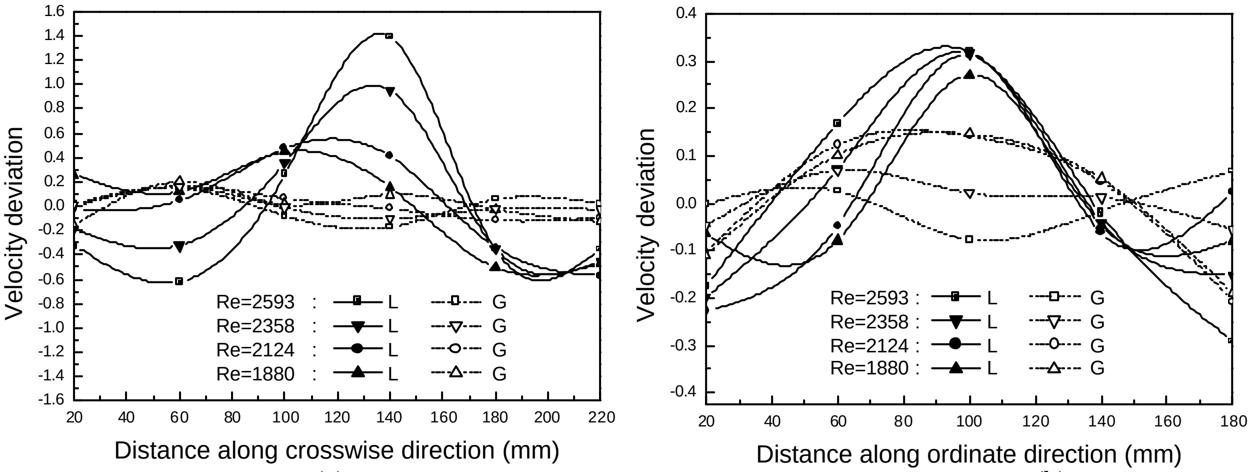
Figures 5 and 6 also illustrate that the variation of gas flow Re mostly affects the liquid flow profile in the crosswise direction and the dryness mostly affects that in ordinate direction.

CONCLUSIONS

The two-phase flow distribution at entrance of plate-fin heat exchangers is non-uniform for its configuration. The experimental results show that the liquid phase non-uniformity is more serious than that of gas and the flow maldistribution in the crosswise direction (perpendicular to the inlet flow) is more serious than that in ordinate direction. The velocity profile in crosswise direction plays a significant role in distribution of two-phase flow.

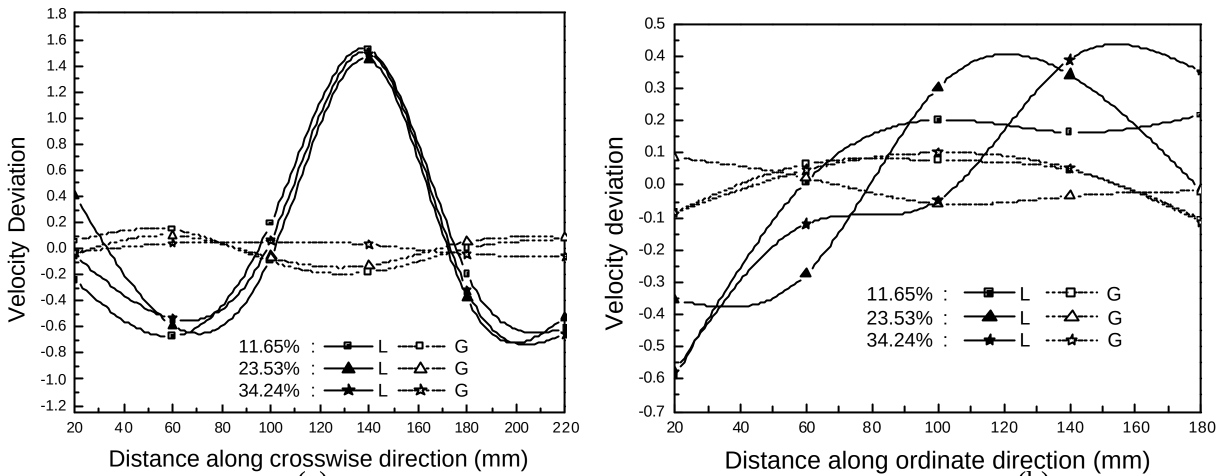
The flow maldistribution of both gas and liquid components will increase with the increase of gas flow Re. With the increase of inlet dryness, the gas flow maldistribution decreases but the liquid flow maldistribution increases simultaneously.

The variation of gas flow Re mostly affects the liquid flow profile in crosswise direction and the dryness mostly affects that in ordinate direction, which is significant for the improvement of two-phase flow non-uniformity at the entrance of plate-fin heat exchangers. It is known that header configuration and distributor conformation affect distribution in crosswise direction and ordinate direction, respectively.



(a) (b)

Figure 5 Velocity distribution in crosswise direction with different gas flow Re



(a) (b)

Figure 6 Velocity distribution in crosswise direction with different inlet dryness

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