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Research Article

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The Effect of Cooling Water on Condensation of Microchannels

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Abstract-

In this paper, the influences of cooling water on the performance of square microchannel condenser were studied experimentally. There are 10 square microchannels with the hydraulic diameter of D_h = 500μm in the condenser. The experiments were carried out in both case of vertical microchannel condender and case of horizontal one. The ranges of parameters examined: mass flow rate of water and steam from 2 [g/s] to 3 [g/s] and from 0.02 [g/s] to 0.08 [g/s], respectively. When compared the data for vertical microchannels, the capacity and temperature fluctuation of cooling water for the horizontal microchannels are the same; however, the pressure drop of vertical microchannels is lower than horizontal microchanels and the performance index of vertical microchannels is higher than horizontal one. Besides, in the fixed conditions, the pressure drop of steam increases with the increasing of mass flow rate of water.

Keywords- square microchannels condenser, mass flow rate of water, vertical microchannels, horizontal microchannels, cooling water.

I. INTRODUCTION

Heat transfer and fluid flow phenomena of two phase flow in microchannels are interesting topics in recent years. Regarding to this fields, Sur and Liu [1] studied adiabatic air – water two-phase flow in circular microchannels. Four basic flow patterns (bubbly flow, slug flow, ring flow, and annular flow) were observed with inner diameters of 100, 180 and 324 μm. The effects of channel size and superficial phasic velocity on the two-phase flow pattern and pressure drop of air – water mixture were done experimentally. The results showed the flow pattern-based models which provide the best prediction of the two-phase pressure drop in the microchannels. Hasan et al. [2] studied in the effect of microchannel shapes on its performances for different channel cross-sections (circular, square, rectangular, iso-triangular and trapezoidal). The simulations (FVM-Finite Volume Method) showed that for the same volume of a heat exchanger, the circular channels give the best overall performance (thermal and hydraulic); however, the rectangular channels give lowest pressure drop. Mohammed et al. [3] investigated in the performances of differential channel shapes of microchannel heat sink - MCHS (Zigzag, step, straight, and wavy MCHS). They concluded that at the same cross-section of a MCHS, the heat transfer coefficient of the zigzag MCHS is the greatest. However, the zigzag MCHS has the highest value of pressure drop, friction factor, and wall shear stress. Chung and Kawaji [4] investigated in the effect of diameters on adiabatic two-phase flow characteristics in microchannels. The experiments were carried out with a mixture of nitrogen gas and water in circular channels with diameters of 530, 250, 100, and 50 μm. In this paper, the gas and liquid flow rates were varied, the images of the two-phase flow patterns captured. Besides, they also examined the data of two-phase friction pressure drop and void fraction. Park and Hrnjak [5] investigated in the effect of differential types of condensers on the performance of R410A for residential air conditioning systems (Microchannels condenser and round-tube condenser). The results showed that the COP of the system with the microchannel condenser was 13.1% higher than round-tube condenser. While, the refrigerant charge amount for the system with the microchannel condenser was 9.2% smaller than that with the round-tube condenser. Bhatkar et al. [6] studied in the performance of of R134a and R152a using aluminum microchannel condenser experimentally. The experiments were carried out for condensation temperature of 48°C while evaporation temperature varied from -10 to 15°C. The results showed that using refrigerant R152a is more efficiency than the of refrigerant R134a as following: discharge temperature of R152a was more than R134a by around 6 to 10°C, the compressor power consumed by R152a is slightly less than R134a from -10 to 15°C, the COP with refrigerant R152a was more than R134a for all evaporator temperatures, condenser capacity for R152a was higher than R134a, the two phase heat transfer coefficient of R152a was more than R134a. Hrnjak and Litch [7] studied in a prototype ammonia chiller with an air cooled condenser and a plate evaporator experimentally. The results showed that the microchannels (D_h = 0,7mm) charge is about 53% less than for the serpentine, the microchannel condenser charge per capacity ratio is around 76% less than for the macrochannel (D_h = 4,061mm) serpentine condenser. Choi et al. [8] investigated in the adiabatic two-phase flow in rectangular microchannels with different aspect ratios to study the effect of them on the flow pattern, pressure drop and void fraction. The experiments were carried out with the liquid water and nitrogen gas. The widths and heights of rectangular microchannels are: 490, 490, 322, and 143μm. The aspect ratios of the rectangular microchannels are: 0.92, 0.67, 0.47, and 0.19. Choi et al. [9] also investigated the adiabatic two-phase flow in rectangular microchannels with different aspect ratios. However, in this paper, they try to study the effect of them on bubble behaviors and pressure drop in single bubble. The results showed that the pressure drop in the single elongated bubble is proportional to the bubble velocity; the pressure drop in the single elongated bubble in the rectangular microchannel increased as the aspect ratio decreased. The effect of surface wetting properties on gas–liquid two-phase flow patterns in rectangular polymeric microchannels were studied by Huh et al. [10]. They observed seven flow regimes in microchannels with hydrophobic walls (stable stratified flow, wavy stratified flow, wiggly stratified flow, detached stratified flow, annular-droplet flow, spreading stratified-droplet flow and break-up), whereas only two flow patterns were identified in hydrophilic microchannels (annular-droplet flow and annular flow).

Dang and Doan [11] experimentally studied condensation heat transfer of microchannel heat exchangers. The condensation heat transfer coefficient in the microchannel heat exchangers decreases as increasing the inlet cooling water temperature. The results for two phases were in good agreement with the results for single phase. Doan and Dang [12] studied in the effect of channel lengths to the condensation in horizontal square microchannels (D_h = 500µm). The results showed the position of condensation in microchannel. Besides, the comparison of pressure drop and performance index for two cases with differential channel lengths was also conducted.

Subsequent to the above literature reviews, it is very important to clearly understand the effects of mass flow rate of cooling water on pressure drop, heat transfer behaviours and performance index for two phase flow microchannel condenser. For the present study, above problems will be investigated experimentally.

II. EXPERIMENTAL METHOD

Figure 1 shows the experimental setup of the system using a microchannel condenser. The steam from the mini boiler goes to microchannel condenser in order to release the heat for cooling water before becoming the hot water at the outside of microchannel condenser. The cooling water is conducted to the channels by the mini pump.

The four temperature sensors were used at the inlet and outlet to measure the temperatures of steam and water, 01 differential pressure sensor was used at the hot water side to measure the pressure drop. Besides, 01 temperature was used to define the ambient temperature during the experiments. The electric balance was used to measure the mass flow rate of water. All the data was handled by MX100 controller. The installed location and accuracies of apparatuses are listed in Table 1 and Table 2, respectively.

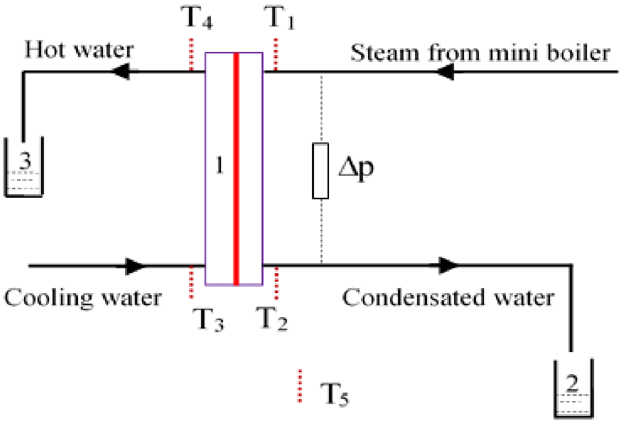


Fig. 1 Schematic of the test loop

1. Microchannel condenser, 2. Electronic balance,T. Thermocuples, Δp. Pressure different sensor

Table I. Sensor Positions

Sensors and equipments used for the experiments	Position	Measurement
Thermocouples: *T – type*	T_1	Inlet vapor temperature
	T_2	Condensing water temperature
	T_3	Inlet cooling water
	T_4	Outlet cooling water
	T_5	Ambient temperature
Pressure different transducer: *Model PMP4110, made by Duck*	Δp	Pressure drop
Micro Electronic balance: *Model TE-214S, made by Sartorious.*	2, 3	Mass flow rate of fluid

The square microchannel condenser has 10 microchannels the hydraulic diameter of D_h = 500µm. The distance between two microchannels is 500 µm. The cross section at the cooling water is 4.75mm^2. The thickness of the substrate is 700 µm. In a microchannel heat sink, all channels are connected to a manifold for both sides. The manifolds of the condenser have a rectangular cross-section with a width of 10 mm and a depth of 0.5 mm. The material used for the substrate of condenser is Aluminum, with the thermal conductivity of 237 W/(mK), density of 2,700 kg/m^3, and specific heat at constant pressure of 904 J/(kgK). To seal the microchannels, the layer of PMMA (Polymethyl methacrylate) was bonded on the both side of the substrate by specific gel and bolts. The PMMA has the thermal conductivity of 0.19 W/(mK) and density of 1,420 kg/ m^3. The Figure 2 shows the dimensions of the square microchannel condenser.

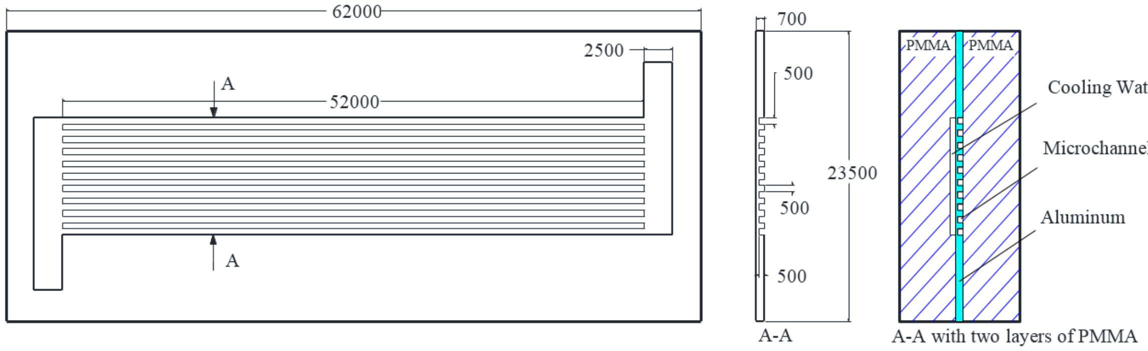


Fig. 2 Dimensions of the test section (μm)

Table 2. Uncertainty Data for Measured Parameters

Parameter	**Uncertainty**
Temperature	± 0.1 °C
Pressure	± 0.04% FS
Mass flow rate	± 0.0015 g
Channel height	± 7 μm
Channel width	± 10 μm
Channel length	± 70 μm

The experiments were carried out at the following conditions:
The ambient and cooling water temperatures are 32 and 29.5°C, respectively.
The mass flow rate of cooling water are 2 [g/s] and 3 [g/s]
The temperatures of steam from the mini boiler are 101 - 107°C with the ranging of mass flow rate of steam from 0.01[g/s] to 0.08[g/s].
The heat transfer rate is calculated by

$$Q_w = m_w.r + m_w(c_{wi}.T_{wi} - c_{wo}.T_{wo}) \qquad (1)$$

The Reynolds number is calculated by

$$\mathrm{Re} = \frac{\rho w D_h}{\mu} = \frac{2m}{\mu(W_c + D_c)} \qquad (2)$$

The pressure drop due to friction is determined by

$$\Delta p = 2 f \rho w^2 \frac{L}{D_h} = 2 f \,\mathrm{Re} \frac{L}{D_h^2} w \mu \qquad (3)$$

Where $D_h = \frac{4A_c}{F}$ the hydraulic diameter, w is is velocity, μ is dynamic viscosity, ρ is density, A_c is cross-sectional area, F is wetted perimeter, L is channel length, m is mass flow rate, w is water, c is specific, r is latent heat, and f is Fanning friction factor.
The performance index, ξ, is determined by

$$\xi = \frac{Q_w}{\Delta p} \qquad (4)$$

III. RESULTS AND DISCUSION

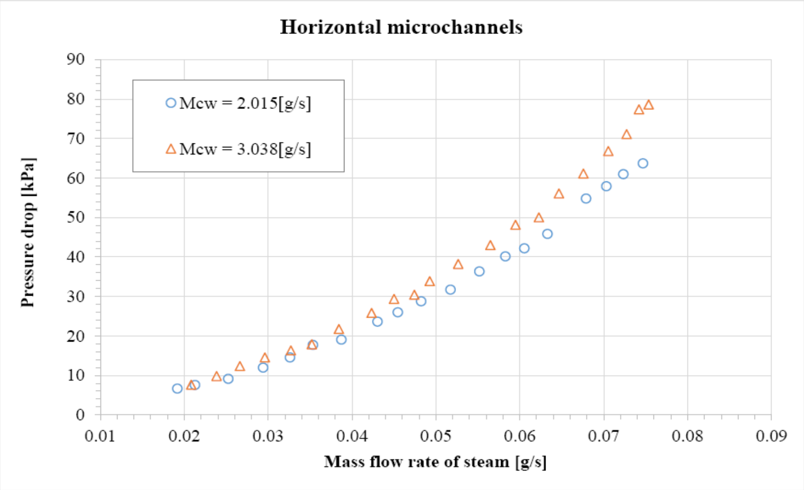


Fig. 3 Pressure drop vs. mass flow rate of steam

Figure 3 shows the pressure drop between the inlet and outlet with the mass flow rate of steam from 0.015 [g/s] to 0.075 [g/s] and mass flow rates of cooling water are 2 [g/s] and 3 [g/s]. It is indicated that the pressure drop increases with the increasing of mass flow rate of steam. It is due to steam having high density and velocity. Thus, as showed in equation (3), the pressure drop is in direct proportion with density and velocity of steam. Besides, the pressure drop also increases with the increasing of mass flow rate of cooling water because when increasing mass flow rate of cooling water, the condensed water from steam increases which increasing the friction factor (liquid has friction factor and dynamic viscosity higher than steam at the same mass flow rate).

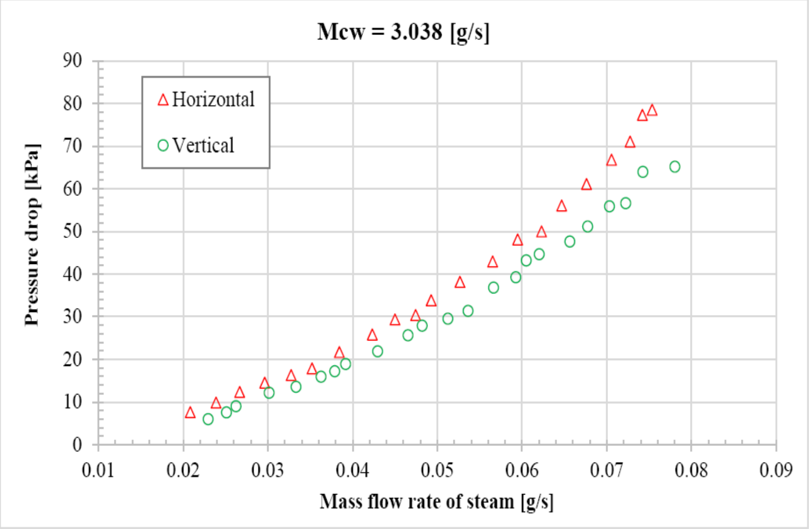
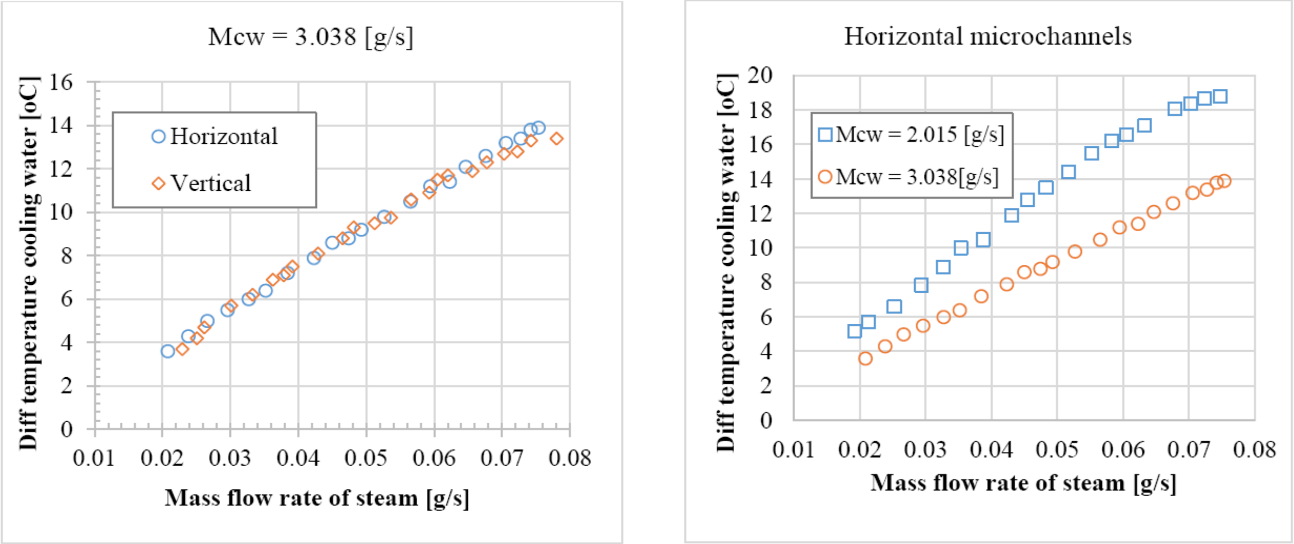


Fig. 4 The comparison of pressure drops in horizontal and vertical cases

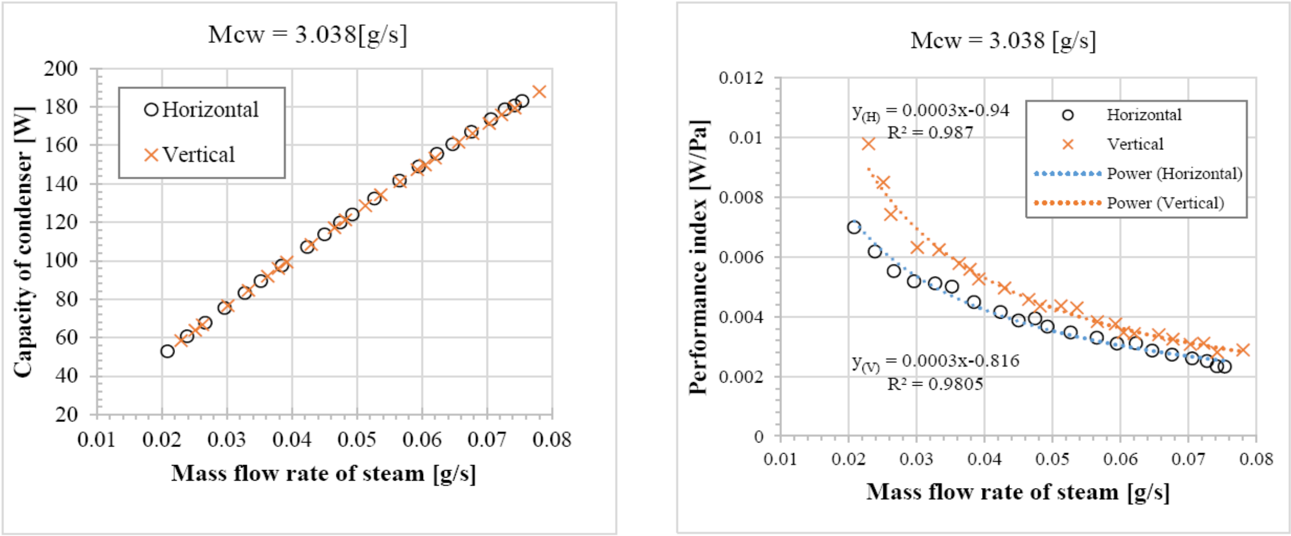
The figure 4 shows that in the same conditions, the pressure drop of horizontal microchannels is higher than vertical microchanels. So, it is clear to conclude that the pressure drop depends on the gravitational acceleration. This is explained that: in case of horizontal microchannels, the gravitational acceleration is perpendicular to water velocity; whereas, in the same direction in case of vertical microchannels, the state makes the hot water to leave condenser faster than the first case. On the other hand, in case of vertical microchannels, the volume of water is lower than the volume of steam comparing to the case of horizontal microchannels.



(a) (b)

Fig.5 The difference temperature vs. mass flow rate

The Fig. 5a shows the temperature fluctuation in both cases of vertical and horizontal microchannels. It is indicated that they are almost the same. The experiments were carried out at the mass flow rate of cooling water 3 [g/s], the inlet temperatures are ranged from 101 to 107°C. However, in the separated case, it is clearly indicated that the temperature fluctuation of cooling water strongly depends on its mass flow rate as shown in Fig. 5b (Horizontal case). Thus, the temperature of cooling water increases from 1°C to 5°C when the mass flow rate of cooling water decreases from 3 [g/s] to 2 [g/s], and it is direct proportion with mass flow rate of steam in a range of 0.015 [g/s] to 0.075 [g/s]. On the other hand, the capacity of condenser increases with increasing of mass flow rate of steam, leading to the increase of the heat transfer rate for the cooling water side, as shown in Figure 6a. The statement increases the differential temperature of the cooling water in case of decreasing the mass flow rate of cooling water.



(a) (b)

Fig. 6. Capacity and performance index

Figure 6 shows the capacity and the performance of condenser when increasing the mass flow rate of steam. Based on above parameters, the capacity is 40W - 190W. These data based on the enthalpy of inlet steam and enthalpy of outlet cooling water corresponding to these mass flow rates. As a result, the maximum thermal losses are determined, it is about 20W. The Figure 6a shows that the capacities for two cases (horizontal and vertical) are almost the same. However, the performance index of vertical case is higher than the horizontal one, as shown in Figure 6b.

IV. CONLUSIONS

An experimental study has been done on both cases of vertical and horizontal microchannel condensers to evaluate their performance. The dimensions of test specimen are D_h = 500µm with the length of 52mm. The mass flow rates of water and steam were ranging from 2 [g/s] to 3 [g/s] and from 0.02 [g/s] to 0.08 [g/s], respectively. Based on this study, there are some following conclusions:

- The pressure drop increases with increasing of mass flow rate of steam; whereas, the pressure drop decreases with decreasing of mass flow rate of cooling water; the maximum pressure drop gained 10kPa corresponding to the steam mass flow rate of 0.075 [g/s].
- The pressure drop of vertical microchannels is lower than horizontal microchanels; however, the performance index of vertical microchannels is always higher horizontal one.
- The temperature difference of cooling water is the same in both horizontal and vertical cases. Besides, the temperature difference is in inverse state with the mass flow rate of cooling water.
- In this study, the temperature increases from $1^{o}C$ to $5^{o}C$ when decreasing mass flow rate of 1 [g/s] for cooling water. The maximum capacity of microchannels condenser is 180W. The thermal losses in both cases are 20W.

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