Experiments on Influence of Gravity to Heat Transfer Efficiency in Micro Tube Condenser

Thanhtrung Dang, Kiencuong Giang, Minhhung Doan

Abstract - *This study experimentally investigated the influence of the gravity to the condensation heat transfer of steam in a micro tube condenser with the internal diameter of 0.8 mm. The design capacity of this condenser is 700 W. From the experimental results, the actual capacity of the condenser is the same with the design capacity. In the range of steam from 0.08 to 0.27 g/s, the heat transfer efficiency of the horizontal case is higher than that obtained from the vertical case. However, the difference is not strong. In this study, the maximum heat transfer rate in the horizontal condenser is 673.1 W and the maximum heat transfer coefficient of the horizontal case is 1601.9 W/m².K. This experiment added the results on the gravity, the heat transfer rate, and the heat transfer coefficient in the field of micro tube condensation.*

Keywords: *EXPERIMENT; GRAVITY; HEAT TRANSFER; CONDENSATION; MICRO TUBE*

I. INTRODUCTION

In recent years, the necessity for designing the effective heat exchangers has promoted researches in micro tube condensation by scientists. Regarding to two-phase flow in microchannels, Chen et al. [1] investigated two-phase flow patterns in four circular tubes with internal diameters of 1.10, 2.01, 2.88 and 4.26 mm. The experiments were conducted in vertical upward two-phase flow using R134a as the working fluid. The observed flow patterns include dispersed bubble, bubbly, confined bubble, slug, churn, annular and mist flow. Sur and Liu [2] studied adiabatic air water two-phase flow in circular microchannels with inner diameters of 100, 180 and 324 mm. Four basic flow patterns were identified, namely, the bubbly flow, slug flow, ring flow and annular flow. The two-phase flow regime maps were constructed and the transition boundaries between different flow regimes were identified. Experimental results on two-phase flow patterns inside circular mini-tubes using air–water mixtures were presented by Venkatesan et al. [3]. The different tube diameters used were 0.6, 1.2, 1.7, 2.6, and 3.4 mm. The two-phase flow was visualized through a high-speed CMOS camera and flow regime maps were presented for different tube diameters. The two-phase flow of liquid nitrogen in vertically upward micro-tubes of 0.531 and 1.042 mm diameters was done by Zhang and Fu [4]. The results

show that the flow patterns were mainly bubbly flow, slug flow, churn flow and annular flow. The confined bubble flow, mist flow, bubble condensation and flow oscillation were also observed.

Condensation heat transfer of steam on vertical micro-tubes was investigated by Wang et al. [5]. Experiments were carried out under various vapor pressures and velocities. Four tubes with different diameters, 0.608 mm, 0.793 mm, 1.032 mm, and 1.221 mm, were included. The results showed that the condensation heat transfer coefficient monotonously decreased, with the increase of vapor-to-surface temperature difference. Oh and Son [6] experimentally the studied condensation heat transfer coefficients of R-22, R-134a, and R-410A in a single circular micro tube. The test section is a smooth, horizontal copper tube with the inner diameter of 1.77 mm. The experiments were conducted at the mass flux of 450–1050 kg/m²s and the saturation temperature of 40°C. The test results showed that the condensation heat transfer coefficient of R-22 is almost a similar value to that of R-134a. Most of the existing correlations which were proposed in the large diameter tube failed to predict condensing heat transfer. The effects of fin height and fin angle on condensation heat transfer inside micro fin tubes were investigated by Al-Dadah and Naser [7]. One smooth and six micro fin tubes with outer diameters of 9.52 mm were used to condense R134a at 30°C and a mass flux range of 157 –347 kg/m²s. Experimental results showed that micro fin tubes had distinct performance advantages over the smooth tube. Liu et al. [8] studied condensation heat transfer process of R245fa with 4.38mm-horizontal tube. The results showed that the change of the heat transfer coefficient for R245fa is normally same in the different condensation temperature. The peak of the heat transfer coefficient exists with increasing the large mass flow conditions and the heat transfer coefficient increases with increasing the small mass flow conditions.

The condensation heat transfer characteristics for R744 flowing in a horizontal smooth tube with the inner diameter of 4.95 mm were experimentally investigated by Son and Oh [9]. The experimental results showed that the mass flux and saturation temperature have a strong effect on the condensation heat transfer coefficients of R744. Kaew-On et al. [10] investigated the condensation heat transfer characteristics of R134a flowing in a circular tube with the inner diameter of 3.51 mm and three flattened copper tubes. The tested tube configurations were as follows: a circular tube with the inner diameter of 3.51 mm; flattened tube with the aspect ratio of 0.72 (FT1); flattened tube with the aspect ratio of 3.49 (FT2); and flattened tube with the aspect ratio of 7.02 (FT3). The results revealed that the condensation heat transfer coefficient increased with increasing mass flux, heat flux, and vapor quality. The heat transfer coefficients of

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the flattened tubes were higher than that of the circular tube, around 5–10%, 10–50%, and 200–400% for FT1, FT2, and FT3, respectively. The effects of viscous dissipation on micro-tube fluid flow and heat transfer were investigated for three different fluids by Lelea et al. [11]. The laminar fluid flow regime was analyzed; the influence of the viscous heating on Nu and Po was analyzed and compared with Br=0. Du and Zhao [12] theoretically analyzed the film condensation heat transfer in a vertical micro tube with a thin metal wire welded on its inner surface. The influences of the contact angle (between the condensed liquid and the channel wall), the wire diameter, and the heat transfer characteristics were examined. In this study, an increase of the wire diameter was enhanced the heat transfer coefficient in the channel.

From literature reviews above, influence of the gravity to the condensation heat transfer efficiency of steam in micro tube condenser have not been carried out by experimental method. So it is essential to experimentally investigate the condensation of steam in micro tube condenser. In the following sections, the two cases (horizontal and vertical cases) will be discussed. The air velocity will be fixed at constant value and the mass flow rate of steam will be changed.

II. EXPERIMENTAL SET UP

Figure 1 shows the schematic of the test loop. The core component of the system is a micro tube condenser, where steam was completely condensed to liquid by rejecting heat to cooling air. In the mini boiler, steam was produced and routed through the buffer tank that ensures the steam is the saturated state (dry vapor). Then, the steam continued to move to the test section in which the condensation process occurs. In this test loop, an air-cooled condenser was used with the fan power of 40W. A mini boiler with heating capacity of 9 kW was used in this system. Each T_i is the temperature value at each position of the test loop. The pressure drop was obtained from the differential pressure transismits. The micro tube condenser uses 28 tubes and 252 fins. The design capacity of this condenser is about 700 W. The dimensions of the micro tube condenser are shown in Fig. 2.
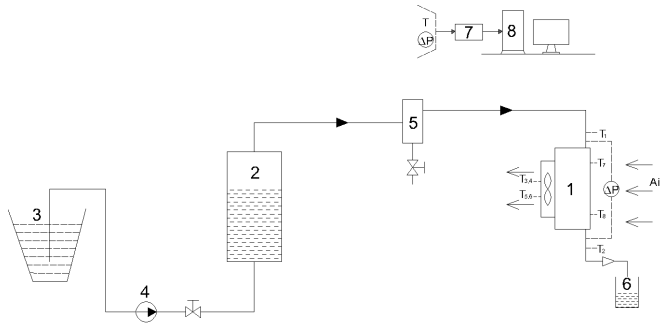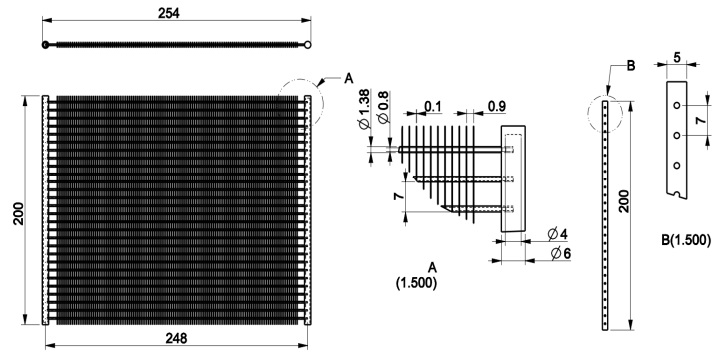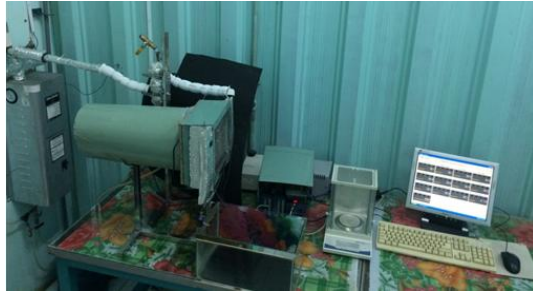

Fig 2. *Dimensions of micro tube condenser*

The apparatuses were used for the experiments such as thermal camera, thermocouples, pressure sensor, anemometer, electronic scale, etc. At measurement points of the system, the temperature and pressure values were recorded each 60 seconds. The mass flow rate of steam was recorded each 60 seconds by electronic scale. Their accuracies and ranges are listed in Table 1. Fig. 3 shows photos of the experimental system.

TABLE 1. *Uncertainty data for measured parameters*

Parameter	Uncertainty
Temperature	± 0.1 °C
Pressure	± 0.025% FS
Mass flow rate	± 0.0015 g
Anemometer	± 0.1 m/s

Fig 1. *Schematic of the test loop. (1) − Micro tube condenser; (2) − Electric mini boiler; (3) − Water tank; (4) − Mini pump; (5) − Buffer tank; (6) − Tank; (7) − MX100 acquisition unit; (8) − Computer.*

a)

b)

Fig 3. *a) The test loop, b) Micro tube condenser.*

III. METHODOLOGY

To calculate and analyze the condensation in micro tubes, the governing equations were given as below [13]. The heat transfer rate is expressed by

$$Q = \rho_a V_a (C_{p,out} T_{a,out} - C_{p,in} T_{a,in}) \quad (1)$$

Where Q is the heat transfer rate (W).

ρ_a is the density of the cooling air (kg/m^3).

V_a is the volumetric flow rate of the cooling air (m^3/s)

C_p is the specific heat of the cooling air (kJ/kg.K).

$T_{a,out}$ is the average outlet temperature of the cooling air (K)

$T_{a,in}$ is the average inlet temperature of the cooling air (K)

The overall heat transfer coefficient k can be obtained by

$$k = \frac{Q}{A \Delta t_{lm}} \quad (2)$$

Where k is the overall heat transfer coefficient (W/m^2.K).

A is the heat transfer area (m^2).

ΔT_{lm} is the logarithmic mean temperature difference (K).

The log mean temperature difference is calculated by

$$\Delta T_{lm} = \frac{\Delta T_{max} - \Delta T_{min}}{\ln \dfrac{\Delta T_{max}}{\Delta T_{min}}} \quad (3)$$

IV. RESULTS AND DISCUSSION

Experimental data obtained from the micro tube condenser were under a constant room temperature condition of 30°C. For the experimental system, the air velocity was fixed at 1.1 m/s; the mass flow rate of steam was varying from 0.08 to 0.27 g/s. The experimental data were recorded by the MX100 acquisition system, as shown in Fig. 4.

Statistics [Data-0.278713.mxs]					
Parameter	**Min**	**Max**	**P-P**	**Mean**	**RMS**
Steam Inlet [^{o}C]	102	102.2	0.2	102.1	102.1
Water Outlet [^{o}C]	30.7	30.9	0.2	30.7	30.7
Air Outlet 1[^{o}C]	35.9	37	1.1	36.6	36.6
Air Outlet 2 [^{o}C]	34.1	35	0.9	34.6	34.6
Air Outlet 3 [^{o}C]	46.6	49	2.4	48.4	48.4
Air Outlet 4 [^{o}C]	47.9	51.4	3.5	49.8	49.8
Air Inlet 1 [^{o}C]	30.9	31.7	0.8	31.3	31.3
Air Inlet 2 [^{o}C]	30.6	31.4	0.8	30.8	30.8

Fig 4. *Data obtained from the MX100 recorder.*

In this study, influence of gravity was determined by two cases: (1) with horizontal position and (2) vertical position. Fig. 5 shows the experimental results regarding of the effect of the gravity on the differential temperature of cooling air in the micro tube condenser. For the horizontal case, the differential temperature of cooling air is higher than that obtained from the vertical case. It is observed that the differential temperature increases as raising the mass flow rate of steam. Besides, the change of differential temperature of cooling air between the two cases is not strong.
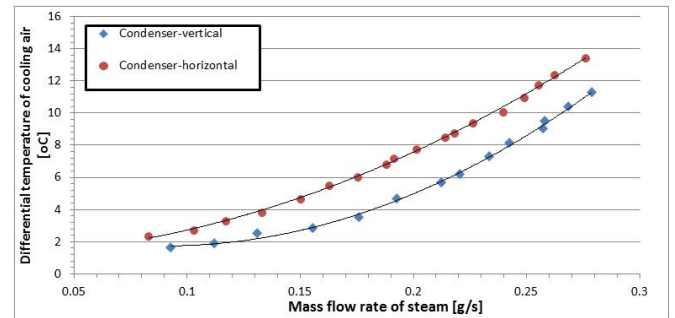

Fig 5. *Experimental results for the differential temperature and the mass flow rate.*

Fig. 6 shows the experimental results of the outlet temperature of cooling air and the mass flow rate of steam in the micro tube condenser. For the horizontal case, the average outlet temperature of cooling air is higher than the vertical one. It is observed that the difference of two outlet temperatures is stronger in the steam range from 0.15 to 0.25 g/s. This may be due to experimental errors as well as heat transfer efficiency.
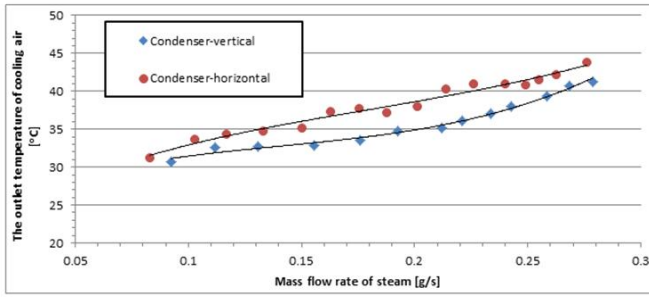
Fig 6. *Experimental results of the outlet temperature and mass flow rate of steam.*

The experimental results for effects of gravity on heat transfer rate of the micro tube condenser are shown in Fig. 7. When mass flow rate of steam varies from 0.08 to 0.25 g/s, the heat transfer rate rises also. The heat transfer rate of the horizontal case is higher than that obtained from the heat transfer rate of the vertical case. The maximum value of heat transfer rate in the horizontal condenser is 673.1 W while with the vertical condenser is 564.9 W. Comparing with the design capacity of this condenser, the actual capacity is the same. In addition, comparing with conventional condensers having the same capacity, the dimensions of this condenser is smaller.
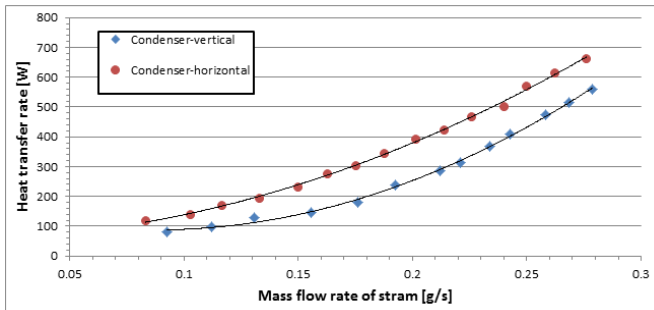

Fig 7. *Experimental results of the heat transfer rate and the mass flow rate of steam.*

Fig. 8 shows the experimental results of the heat transfer coefficient and the mass flow rate of steam. For the horizontal condenser, the heat transfer coefficient is higher than that obtained from the vertical condenser. The change of the heat transfer coefficient between the two cases increases with raising the mass flow rate of steam from 0.08 to 0.27 g/s. The maximum heat transfer coefficient of the horizontal case is 1601.9 W/m^2.K; the vertical case, 1142.5 W/m^2.K.
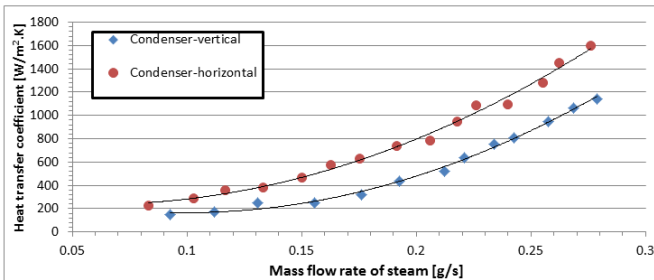

Fig 8. *Experimental results of the heat transfer coefficient and the mass flow rate.*

A photo about the temperature profile of micro tube condenser with the vertical case was taken by a thermal camera, as shown in Fig. 9. This photo was taken at the steam mass flow rate of 0.27 g/s. On the figure, the red color indicates for the hot air (contact with vapor) and the blue color indicates for the warm air (contact with condensed water). The results are in good agreement with the results from thermocouples. They are useful for comparing with other numerical methods. In summary, the results in this study are needed and important. They carried out new results in effects of the gravity on the heat transfer rate as well as the heat transfer coefficient in a micro tube condenser.
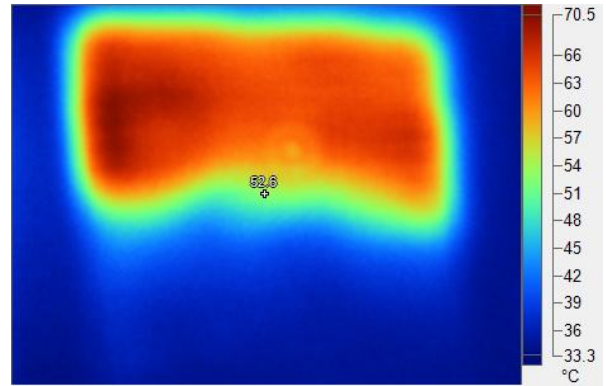

Fig 9. *A photo of the micro tube condenser.*

V. CONCLUSION

The influence of the gravity on the heat transfer efficiency in a micro tube condenser has been done by the experimental method. The design capacity of the condenser is about 700 W. With horizontal case, the actual capacity is the same with the design capacity. Comparing with the conventional condensers having the same capacity, the dimensions of micro tube condenser are smaller.

In this study, the heat transfer efficiency with the horizontal case is better than that obtained from the vertical case. In this study, the maximum value of heat transfer rate in the horizontal condenser is 673.1 W and the maximum heat transfer coefficient of the horizontal case is 1601.9 W/m^2.K. The results are useful for researches in micro tube condensation.

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