EXPERIMENTAL INVESTIGATION OF FLOW CONDENSATION IN 'V' SHAPED MINICHANNEL

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Abstract

The measurement of the condensation heat transfer coefficient inside micro and minichannel is still elusive due to the difficulty in getting accurate result. investigation was carried in a single 'V' shaped channel having hydraulic diameter of 2mm. the experiment was carried using steam as an refrigerant and water as an coolant. The test was performed by varying mass flux and vapor quality. The paper concludes that there is a significant effect of mass flux and vapor quality. As the mass flux and vapor quality increases there is an increase in the heat transfer coefficient and pressure drop.

Keywords: *Condensation, Heat transfer coefficient, Minichannel, 'V' Shape*

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1. INTRODUCTION

Micro channel and minichannel are increasingly being used to achieve high heat transfer rates with compact heat exchangers. Condensation inside small hydraulic diameter channels finds applications in heat pipes and compact heat exchangers for electronic equipment, in automotive condensers, and in refrigeration applications. The adoption of minichannel also promotes the reduction of the refrigerant charge, which is favorable to the use of toxic or flammable refrigerants. Micro channel and Minichannel phase change may differ from the conventional channels due to differences in the relative influence of gravity, shear stress and surface tension. Kandlikar and Grande is classifies the channel are greater than 3mm are conventional channel, 200µm to 3mm are minichannel, 10µm to 200µm are micro channel, 1µm to 10µm are transitional micro channel, 0.1µm to 1µm are transitional nano-channel, less than 0.1µm are nano-channel.

There are a few previous studies on the condensation heat transfer of refrigerants in small diameter tubes. Zhongyu Guo & N.K. Anand,[1] carried out experiments on condensation heat transfer of R-410A in a rectangular Channel. The test section was 3m long horizontal rectangular brass (63% Cu, 37% Zn by mass) tube 12.7 mm wide and 25.4 mm height. The results showed average condensation heat transfer coefficient decreases with a decrease in vapor quality due to the relative content of liquid phase increases with increasing condensation.M.K. Dobson & J.C. Chato [2] conducted experimental investigation of condensation using zeotropic refrigerants over the wide range of mass flux in horizontal tubes. The test showed heat transfer coefficient increases with increasing in the mass flux and quality in annular flow due to increased shear stress and thinner liquid film than in other flow regimes. J.R. Baird et al.,[3] investigated local condensation heat transfer rates in fine passages for HCFC-123 in a 1.95 mm tube, with wall heat flux 60 kWm-2 at 290 kPa. The results showed that significant effect of mass flux on the heat transfer coefficient. The heat transfer coefficients increases with increasing mass flux. Yi-Yie Yan and Tsing-Fa Lin [4] performed experimentation on condensation heat transfer and pressure drop of refrigerant R-134a in a small pipe. The result showed, condensation heat transfer coefficient rises significantly with the mean vapor quality for lower saturation temperature. S.N. Sapali and Pradeep A.Patil [5] conducted two phase heat transfer coefficients and pressure drops of R-404A for different condensing temperatures in a smooth (8.56 mm ID) and micro-fin tube (8.96 mm ID) are experimentally investigated. The experiment were conducted at average saturated condensing temperatures ranging from 35°C to 60°C. The mass fluxes are ranges from 90 and 800 kg m-2s-1. The experimentally obtained results from both smooth and micro-fin tubes showed the average heat transfer coefficients and pressure drop increases with mass flux but decreases with increasing condensing temperature. Ravigururajan[6] studied the impact of channel geometry on two phase flow heat transfer characteristics of refrigerant R-124 in micro channel heat kexchanger. Chen Fang et al.,[7] studied the influence of film thickness and cross-sectional geometry on hydrophilic micro channel condensation. The investigation result showed, a smaller channel yields higher condensation heat transfer efficiency than a larger channel. Baird et al.,[3] conducted an experimental investigation on condensation of HCFC-123 and R11 in tubes with diameters of 0.92 and 1.95 mm for a range of mass velocities (70–600kgm-2s-1), heat fluxes (15–110 kWm-2) and pressures (1.2-4.1bar). Wu et al., [8] carried an experimental investigation on heat transfer and flow friction during steam condensation in trapezoidal silicon micro channels with diameters of 77.5, 93.0, and 128.5□m. experimental results showed that the condensation Nusselt number increases with an increase in the Re, Co (condensation number), and □h/□. Cavallini et al. [9] measured the heat transfer coefficient for condensation of R134a and R410a inside multi-port minichannel having a hydraulic diameter of 1.4 mm. The heat transfer coefficient was found as high as 16,000Wm-2K -1. The result showed that, condensation heat transfer will be enhanced with decreasing hydraulic diameter. The experimental investigation was carried out in a single 'V' shaped channel in order to determine and find the effect of experimental flow condensation heat transfer coefficient and pressure drop.

2. FABRICATION OF MINICHANNEL TEST SECTION

Aluminium bar of cross sections (150mm X 50mm) is fabricated for triangular minichannel of hydraulic diameter 2mm and length of 96mm with single channel were cut on the rectangular block as shown in Fig-1.

Fig -1: Shows the refrigerant and coolant side of channel cross section

The top of the mini channel was covered with the cover plate. Two cover plates(Acrylic glass) are provided with the two drilled holes of the inlet and outlet for the working fluid and coolant. The channel and cover plate are joined and tightened by using bolt and nuts in order to reduce leakage of refrigerant and coolant side. The entire shape of the test specimen was machined by C.N.C milling machine.

Table 1: Specifications of the test specimen

Channel geometry			
Width	Depth	Hydraulic diameter	Length
3mm	1.5mm	2mm	96mm

3. EXPERIMENTAL SETUP

The experimentation involves two cycles, refrigerant cycle and coolant cycle. In the refrigerant cycle it consists of pump, digital pressure gauge, and thermocouples. In this refrigerant cycle, the two major components are arranged in series as shown in Fig-2..they are preheater and minichannel condenser.

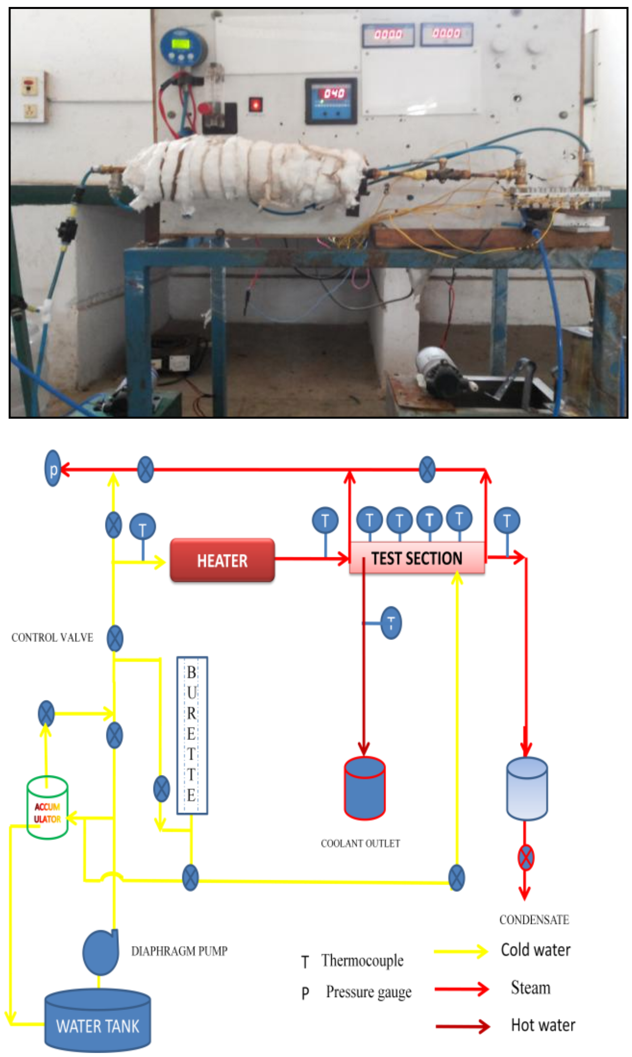

Fig -2: Experimental setup and flow diagram

This experimentation was conducted using steam as an refrigerant and water as an coolant in the condenser. The preheater is completely insulated with the glass wool. Fig-2 shows the test line assembled for the experimental investigation of flow condensation in minichannel. The booster pumps are used to circulate the refrigerant and coolant through the test line. The generated vapor is condensed in the test section. The five thermocouples are inserted between the refrigerant and the coolant side as shown in Fig-2. The intensive and extensive properties like temperature, pressure and flow rate are measured at various points during testing. The condensate from the condenser was measured.

4. OPERATING PARAMETERS

Table -1: Operating Conditions

Sl No	Saturation temperature(°C)	Saturation pressure(bar)	Mass flow rate of steam (g/s)	Mass flow rate of coolant (g/s)	Inlet vapor Quality (X_i)
1	100	1.0123	0.8	1	0.2
2			0.6		0.4
3			0.4		0.6
					0.8

5. DATA REDUCTION

The inlet vapor quality to the test section is determined by energy balance in the heat sink.

$$\dot{m}_s h_f + Q_a = \dot{m}_s (h_f + x_o h_{fg})$$

Where,
h_f is inlet enthalpy of the water in to the sink
h_{fg} is the latent heat of vaporization
Q_a= I*V is the heat to the heater

The experimental Heat transfer coefficient (h) is given by:

$$h = Q_c/(T_s - T_w)A$$

Where,
Q_c= heat removed by refrigerant in W
A= Area of surface in m^2 = (a* L) 2
a= Depth of the channel in m
L= Length of the channel in m

Heat absorbed by cooling water (Q_c) is given by:

$$Q_c = m_c c_p (T_{co} - T_{ci})$$

Where,
m_c= Mass flow rate of coolant in kg/s
C_p= specific heat of coolant in kj/kg °c
T_{co}= outlet temperature of coolant in °c
T_{ci}= Inlet temperature of coolant in °c

6. RESULT AND DISCUSSIONS

6.1 Effect of Wall Temperature along the Channel Length

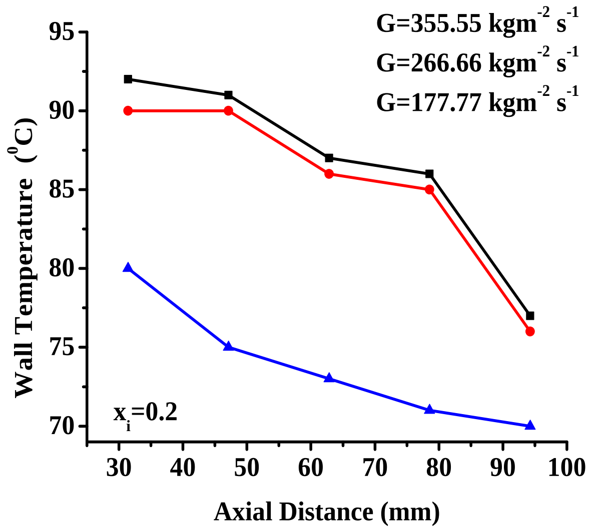

Fig-3 (a)

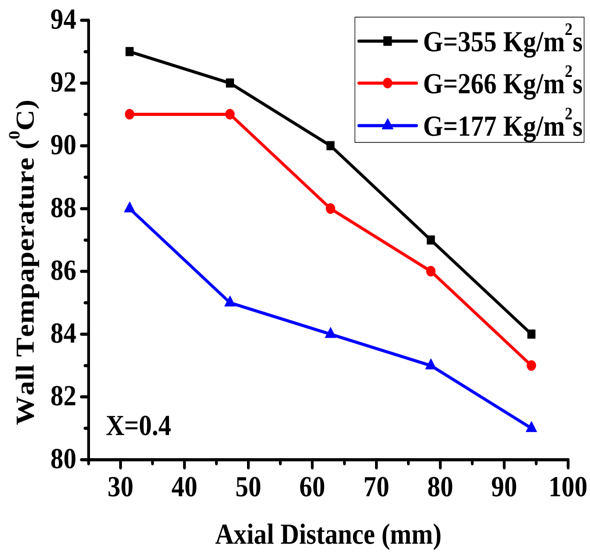

Fig-3 (b)

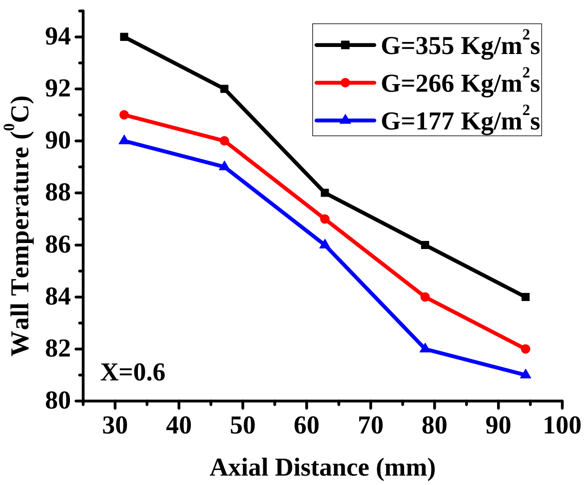

Fig-3 (c)

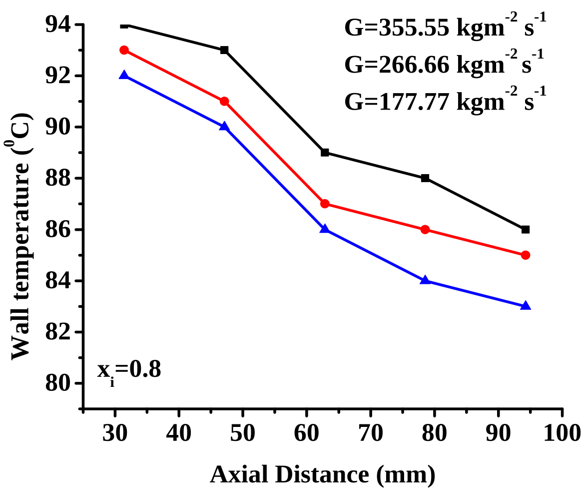

Fig-3 (d)

Fig-3 a,b,c,d:Shows the variation of wall temperature along the channel length for different inlet vapor quality

The Fig-3.a, b, c, d shows the variation of wall temperature along the length of the channel. From the initial observation of the result it is clearly indicates there is an decrease in the trend of the wall temperature along the length in addition to that it is evident from the figures the highest wall temperature was highest mass flux of 355.55kgm-2s-1. This trend was observed for all the vapor quality. This is due to the low temperature gradient on the coolant side and increase in the Reynolds number. This increase in the Reynolds number is due to increase in the mass velocity.

6.2 Effect of Mass Flux and Inlet Vapor Quality

From the Fig-4 observe that variation of heat transfer coefficient with mass flux and inlet vapor quality. In the annular flow, the condensation heat transfer coefficient increases with increasing mass flux and vapor quality due to an increase in shear stress at the wall and the thinning of the liquid film that decreases the thermal (conduction) resistance.

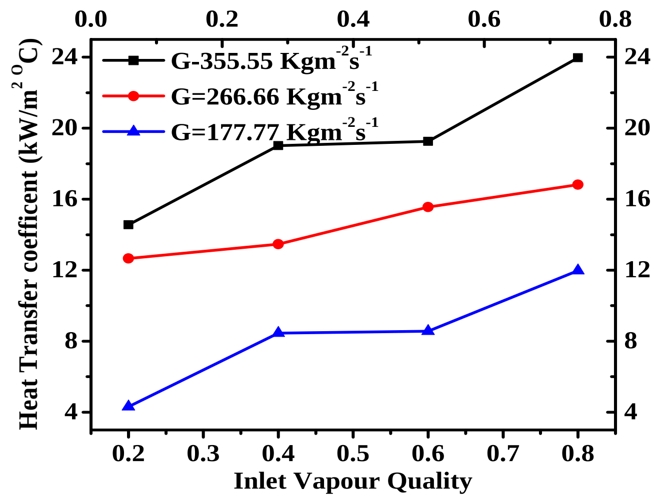

Fig-4: Shows variation of inlet vapor quality on heat transfer coefficient

6.3 Effect of Mass Flux on Pressure Drop

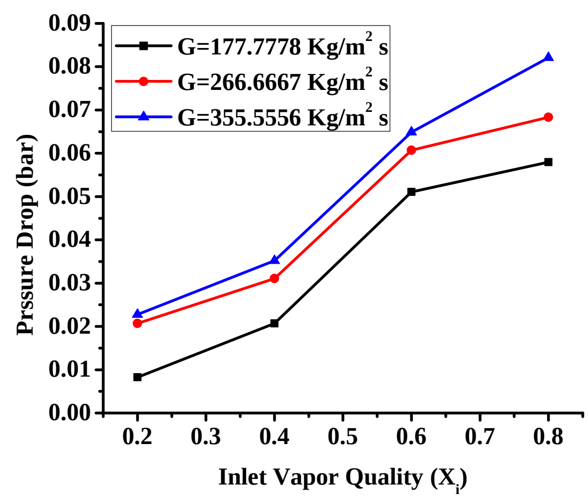

Fig-5: Effect of mass flux on pressure drop

The effect of mass flux on the pressure drop of condensation as shown in Fig-5. This graph(Fig-5) indicates the relationship between the pressure drop and the averaged inlet vapor quality at a fixed saturation temperature of 100 °C. The two phase pressure drop is obtained by subtracting pressure at the inlet and outlet manifold of the channel. It can be seen that pressure drop is increased with increasing vapor quality due to higher velocity of vapor flow causes more shear stress at the interface of the vapor and liquid film.

7. CONCLUSIONS

The triangular channel with hydraulic diameter of 2mm was tested. the tests was carried by varying mass flux of 177.77, 266.66 and 355.55 kg/m2s & vapor quality ranges from 0.2 to 0.8 at a fixed saturation temperature of 100°C.The result showed, as the mass flux and vapor quality increases there is an increase in condensation heat transfer coefficient and pressure drop.

NOMENCLATURE

m-Meter
w-Watt
T_{sat} - Saturation temperature
Re-Reynolds number
Co-Condensation number
D_h-Hydraulic diameter (m)
h_f - Inlet enthalpy of the water in to the sink(kJ/kg)
h_{fg} -Latent heat of vaporization(kJ/kg)
Q_a=I*V is the heat to the heater (w)
Q_c-Heat removed by refrigerant in (w)
A- Area of surface in ($m^{2)}$
a- Depth of the channel in (m)
L- Length of the channel in (m)
m_c- Mass flow rate of coolant in (kg/s)
C_p- Specific heat of coolant in (kJ/kg °c)
T_{co}-Outlet temperature of coolant in (°c)
T_{ci}-Inlet temperature of coolant in (°c)

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