Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(7) (2021) 1029-1032
DOI: 10.22060/mej.2020.18545.6841

Measurement of subcooled flow boiling heat transfer coefficient in vertical annulus tube

M. Yarahmadi, M. M. Shahmardan, M. Nazari* , A. Asgharzadeh

Faculty of Mechanical Engineering , Shahrood University of Technology, Shahrood, Iran

ABSTRACT: The boiling heat transfer, especially the subcooled flow boiling, is one of the cooling systems being used in industries due to their high heat transfer coefficient. The subcooled flow boiling happens when the bulk flow temperature and the interface temperature are lower and higher, respectively than the saturated temperature corresponding to the flow pressure. In the current study, an experimental apparatus was constructed, and subcooled flow boiling in an annulus tube was investigated. The annulus tube is in the vertical direction, and the internal and external diameters are 50.7 and 70.6 mm. The operating pressure was 1 atm, and the working fluid was water. In this investigation, heat flux, mass flow rate and the inlet subcooling effectiveness on heat transfer coefficient are considered. The experiments were performed in the mass flow rate range of 0.012 kg/s to 0.0286 kg/s in which the flow consists of both forced convection and flow boiling. The results show that the heat transfer coefficient is highly dependent on heat flux in a direct relationship. The mass flow reduction causes heat transfer coefficient increments to 30% in subcooled boiling regions. The use of porous media also increases the subcooled flow boiling heat transfer coefficient up to 30%. The validation of empirical results has also been done with valid previous reports.

Review History:

Received: Jun. 05, 2020
Revised: Oct. 18, 2020
Accepted: Oct. 25, 2020
Available Online: Nov. 18, 2020

Keywords:

Heat transfer
Subcooled flow boiling
Experimental study
Vertical tube

1. INTRODUCTION

Boiling in vertical channels under natural or forced conditions has been a critical subject of interest. Boiling heat transfer is a key phenomenon in thermal control of most energy conversion systems and heat exchangers. Benefiting from boiling heat transfer, these systems are cooled. This field has been widely applied to the design of boilers, refrigeration apparatus, unclear reactors, evaporators, and much other major equipment in power plants and electronic and chemical industries that depend on fluid mechanics and heat transfer procedures occurring in flow boiling. The flow boiling includes saturated flow boiling and subcooled flow boiling. Subcooled flow boiling occurs when the bulk liquid temperature is lower and the wall temperature is higher than the saturation temperature of the fluid corresponds to flow's pressure [1]. It has been empirically proved that subcooled flow boiling outperforms saturated flow boiling in terms of heat transfer efficiency and Critical Heat Flux (CHF) performance [2, 3].

Hence, we concentrate on the subcooled flow boiling of water in the annulus tube at low mass fluxes.

2. EXPERIMENTAL SETUP

The present study has experimentally investigated the porous effect on subcooled flow boiling in a vertical annulus tube by providing an open-loop experimental setup. Hence, the test device comprised an ionized water tank, a preheater, test section, and measurement and control apparatus. Fig. 1(a, b) shows the schematic design and general view of the test device.

*Corresponding author's email: mnazari@shahroodut.ac.i

3. TEST SECTION

Fig. 2 depicts the test section and locations of sensors. The test section consists of a vertical annulus tube where its inner tube is heat-resistant and has an outer diameter of 50.7 mm, thickness of 1 mm, and length of 1.5 mm.

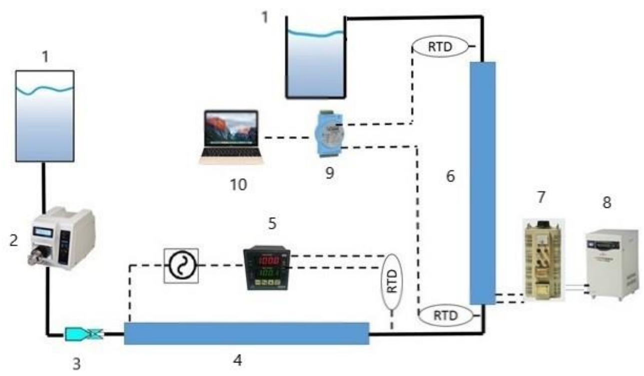
4. CALCULATIONS

The local heat transfer coefficient (h) is obtained by the following relation.

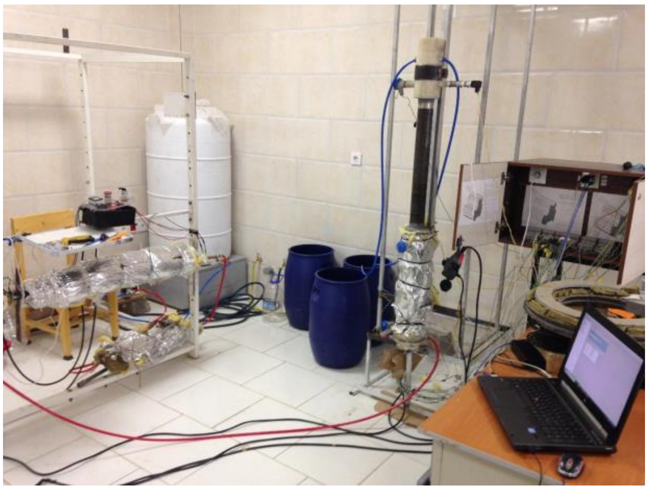
$$Q_{\mathrm{w}} = \frac{VI}{\pi D_{\mathrm{o}} L} \tag{1}$$

where, z represents the axial distance to the test section inlet, $\ddot{q}$ denotes the heat flux applied to fluid, $T_{\mathrm{w,o}}$ is the temperature of the tube outer surface which is found by:

$$T_{\mathrm{w,o}} = T_{\mathrm{w,i}} - \frac{qD_{\mathrm{i}}}{2K}[\ln \frac{D_{\mathrm{o}}}{D_{\mathrm{i}}}] \tag{2}$$



(a)



(b)

Fig. 1. a) Schematic design and b) general view of the test device

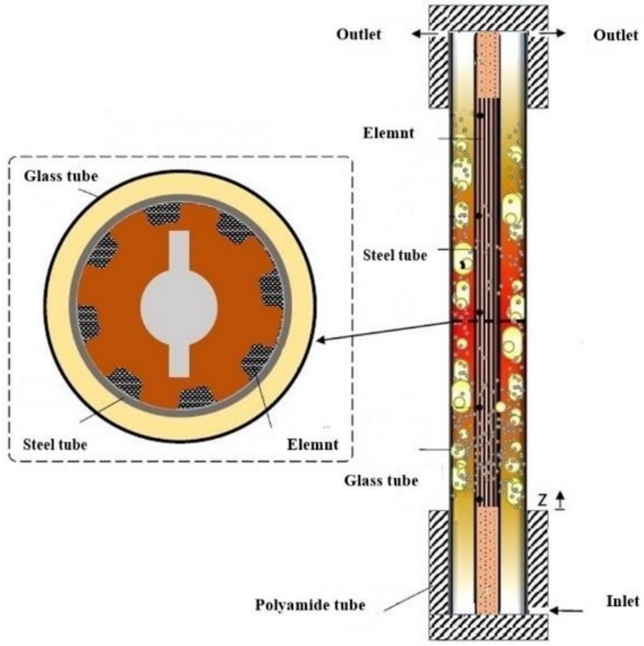


Fig. 2. Schematic design of test section

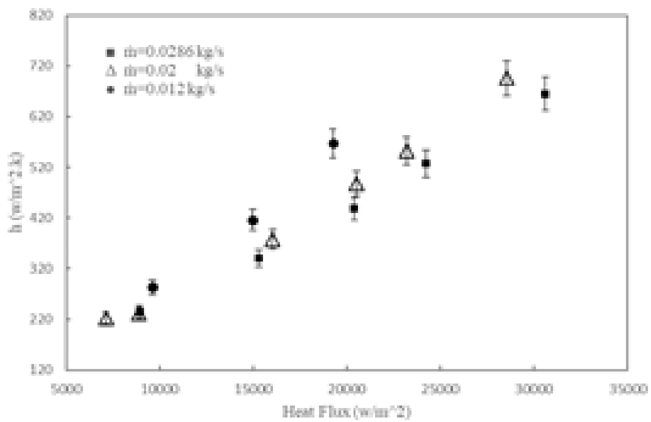


Fig. 3. Variations of heat transfer coefficient at the mass flow rate of 0.02 and 0.0286 kg/s under various heat fluxes in the vertical annulus tube at fixed axial positions of z = 45 cm

Here, T_b is fluid bulk temperature and obtained by the following equation:

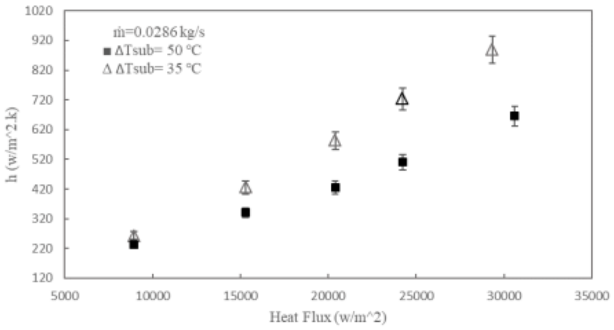
$$T_b = T_{in} - \frac{\ddot{q}\pi D_o}{\dot{m}C_p} z \quad (3)$$

T_{in} is the temperature of inlet fluid.
The heat flux received from the fluid is calculated by:

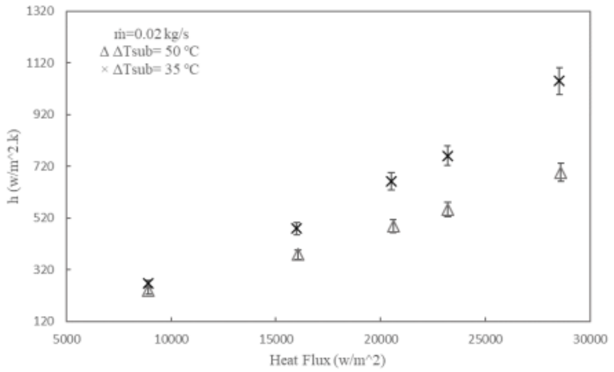
$$\ddot{q} = \frac{\dot{m}C_p}{\pi D_o L}(T_{out} - T_{in}) \quad (4)$$

5. RESULTS AND DISCUSSION

Fig. 3 shows the variation of the heat transfer coefficient on different mass flow rates in the vertical annulus tube at fixed axial positions of z = 45 cm and inlet subcooling of 50 °C. As can be observed the heat transfer coefficient is a function of mass flow rate for a certain amount of heat flux. In the subcooled boiling heat transfer zone, the wall temperature increased very slightly and stays almost constant. Hence, if mass flow rate reduces in this zone, the fluid bulk temperature is increased while wall temperature remains constant. So, the heat transfer coefficient will be increased accordingly.



(a)



(b)

Fig. 4. The effect of inlet subcooling on the heat transfer coefficient at the mass flow rates of a) 0.0286 kg/s and b) 0.02 kg/s in the vertical annulus tube at fixed axial positions of z = 45 cm

Fig. 4 presents the effects of inlet subcooling on the heat transfer coefficient at mass flow rates of 0.02 and 0.0286 kg/s in the vertical annulus tube at fixed axial positions of z= 45 cm. The obtained results indicate that the decreased inlet subcooling leads to increased coefficient of subcooled heat transfer. Particularly, at higher heat fluxes, the variation of subcooled heat transfer coefficients are evident. In the lower inlet subcooling, by increasing the nucleation site density and generating more bubbles, the intensity of liquid agitation increases and the liquid touch the heating surface easily that leads to higher values of heat transfer coefficient[4]. Figure 8 shows the more influence of inlet subcooling on the heat transfer coefficient in the subcooled flow boiling zone than single-phase convection.

6. CONCLUSIONS

This study experimental investigation the effect of parameters such as heat flux, mass flow rate ranging from 0.012 to 0.0286 kg/s and the inlet subcooling 35 and 50 °C, was assessed on heat transfer coefficient. The obtained results during all of the testing stages, the heat transfer process included forced convection and nucleate boiling mechanisms. The results revealed that increasing the heat flux leads to a higher subcooled flow boiling heat transfer coefficient. The heat transfer coefficient increases by reducing the mass flow rate within the subcooled flow boiling region. The experimental results show that the nickel porous affect the subcooled flow boiling performance. It was found that the use of 10 PPI nickel porous had enhanced the subcooled flow boiling heat transfer coefficient about 30 %.

REFERENCES

[1] G.J. Collier, J.R. Thome, Convective boiling and condensation, (1994): Clarendon Press.

[2] J. Lee, I. Mudawar, Critical heat flux for subcooled flow boiling in micro-channel heat sinks. International Journal of Heat and Mass Transfer, 52(13-14) (2009) 3341-3352.

[3] G. Wang, P. Cheng, Subcooled flow boiling and microbubble emission boiling phenomena in a partially heated microchannel, International Journal of Heat and Mass Transfer, 52(1-2) (2009) 79-91.

[4]] M.G. Kang, Effects of pool subcooling on boiling heat transfer in a vertical annulus with closed bottom. International journal of heat and mass transfer, 48(2) (2005) 255-263.

HOW TO CITE THIS ARTICLE

M. Yarahmadi, M.M. Shahmardan, M. Nazari, A. Asgharzadeh, Measurement of subcooled flow boiling heat transfer coefficient in vertical annulus tube, Amirkabir J. Mech Eng., 53(7) (2021) 1029-1032.

DOI: 10.22060/mej.2020.18545.6841