Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(4) (2018) 1-3
DOI:

Experimental Investigation and Visualization of Flow Boiling Heat Transfer in a Vertical Tube Containing Metal Porous Medium

M. Kashi , A. Ramezani , M. Nazari*, M. M. Shah Mardan

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

ABSTRACT: In this study, flow boiling heat transfer in a vertical copper tube with internal diameter of 16 mm under constant heat flux conditions and at atmospheric pressure is experimentally investigated by using water as working fluid. All two-phase experiments are within the Slug flow regime which are visualized by a glass tube placed at the end of the laboratory bed and a high-speed camera. Heat transfer parameters such as Nusselt number and convection heat transfer coefficients are measured in different mass flow rates and heat fluxes. The results of the experiments are compared with the experimental data for the two-phase flow and the amount of deviation of the results from the proposed relationships is reported. Also, the effects of porous material, heat flux and mass flux on heat transfer parameters are investigated. It was also found that, despite the use of metal foam, the slug flow pattern remains in the porous tube.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Two-phase heat transfer
Flow boiling
Metal foam
Vertical flow
Visualization

1- Introduction

Heat transfer enhancement has always been one of the favorite subjects of engineers. Two-phase flow boiling in vertically and horizontally channels are important topics in heat transfer and the phase change regimes play an important role in the rate of heat transfer. A promising method to enhance the heat transfer mechanism is the use of high porosity metal foams with a high surface-to-volume ratio leading to a high heat transfer area in a small volume. Thus the design and production of dense heat exchangers will be possible as well as the improvement of the heat transfer coefficient [1]. In recent decades, many experiments have been carried out on channels containing metal foams. Diani et al. [2] and Mancin et al. [3] studied the phase change of R134a, R1234yf, R1234ze (E) fluids in a channel containing metal foam with a pore-density of 5 (Pores Per Inch (PPI)). Heat transfer in this experiment was improved by about 4.8 times with low mass flux, low heat flux, and high vapor quality conditions.

Bamorovat Abadi et al. [4] have visualized the flow boiling and heat transfer inside the small tubes filled with metal foam. In order to compare, these experiments were carried out for a non-foam tube, and the results showed that the presence of foam increased the heat transfer coefficient by about 2 to 3 times.

Since considering that in the flow boiling, the effects of metal foam on the thermal performance of the vertical tubes as well as the pattern of two-phase flow in metal foams has not been considered accurately and sufficiently. For this reason, the main focus of this study is to investigate the importance of using metal foams in the flow boiling within the vertical tube and the flow pattern visualization.

Table 1. Properties of the copper metal foams

Porosity	PPI	diameter	Installation Method
85%	5	16 mm	Press-fitting

2- Methodology

In this experiment, an open circuit laboratory bed was used. The schematic diagram of the laboratory bed is shown in Fig. 1. In this experiment, all tubes are made of copper tube with an internal diameter of 16 mm and an external diameter of 19 mm and the tube length of the test section is 55 cm, also a copper foam were used to investigate the effect of porous material on the improvement of heat transfer, the characteristics of copper foams had given in Table 1.

Also uncertainty for the heat transfer coefficient in this experiment based on the proposed Moffat method [5] is ±3.9%. In the flow boiling discussions, the experimental heat transfer coefficient is calculated from Eq. (1):

$$h = \frac{q_E}{T_{w,i} - T_{sat}} \tag{1}$$

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

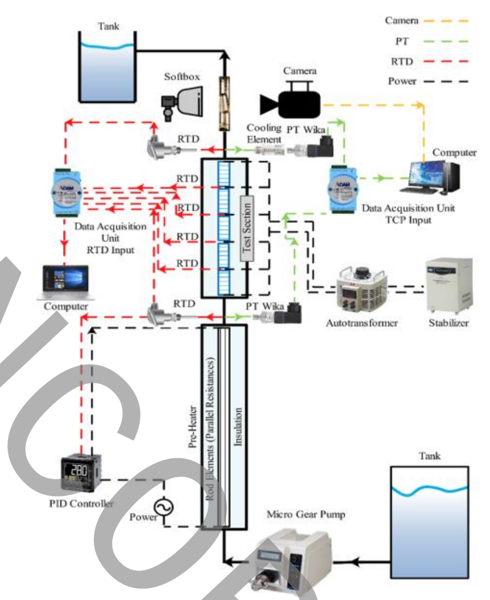

Fig. 1. Diagram of experimental setup

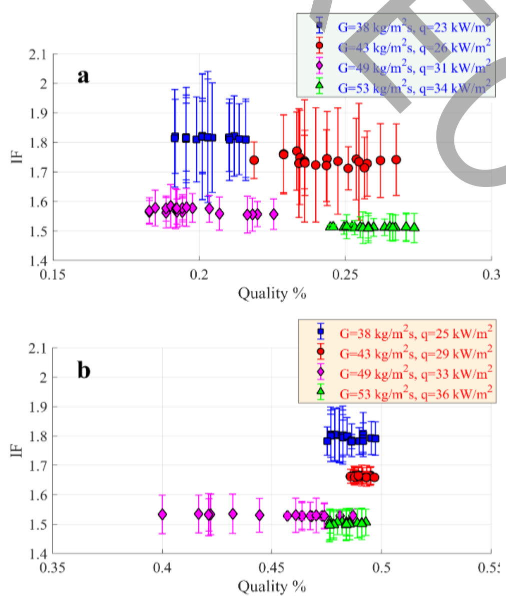

Fig. 2. Improvement factor (IF) for metal foam, a) the beginning of the slug flow, b) the end of the slug flow

where T_{sat} is the saturation temperature at the output pressure of the test section and for $T_{(w,i)}$ assumed:

$$T_{w,i} = T_{w,o} - \frac{q_E D_i}{4k}\left[\frac{(\eta)^2 - 2\ln(\eta) - 1}{1-(\eta)^2}\right] \tag{2}$$

And the parameter η as:

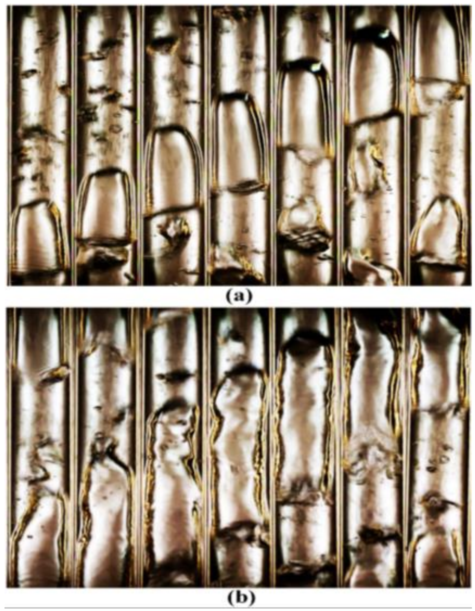

Fig. 3. Slug flow patterns of water in empty tube for G=43 kg/m2.s, a) the beginning of the slug flow-q=26 kW/m2, b) the end of the slug flow-q=269 kW/m2

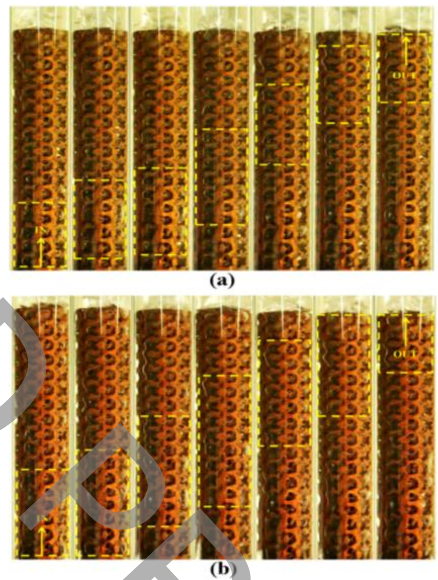

Fig. 4. Slug flow patterns of water in metal foam tube for G=43 kg/m2.s, a) the beginning of the slug flow-q=26 kW/m2, b) the end of the slug flow-q=29 kW/m2

$$\eta = D_i / D_o \tag{3}$$

Eq. (4) is also used to calculate the quality:

$$x = \frac{1}{i_{lv}}\left[\frac{Q_E}{\dot{m}} - c_p(T_{sat} - T_{in})\right] \tag{4}$$

In Eq. (4), the latent heat of evaporation is based on the temperature and pressure at the output of the test section. The Improvement factor is an important factor in the heat transfer and application of metal foam because it indicates the performance of metal foam:

3- Results and Discussion

The experimental results in two-phase mode are compared with proposed relation of Chen [6]; The mean absolute deviation of the test data from the Chen correlation [6] for the beginning and the end of the slug flow was 14.6% and 33.2%, respectively. Also Fig. 2 show the improvement factor of the metal foam versus vapor quality for both beginning and the end of slug flow regime. As shown in Figs. 2-a and 2-b, the metal foam improves the heat transfer coefficient from 1.5 to 1.8 times.

Also with visualization, it can be said that despite the use of metal foam in this test, the flow pattern remains slug, and metal foam did not change the flow regime.

4- Conclusions

In this experiment, it can be seen that copper foam effect on wall temperature reduction is noticeable, which, due to the constant heat flux condition, improves heat transfer in copper foam tubes and it was stated that the heat transfer coefficient in a tube with a metal foam improved from 1.5 to 1.8 times. In terms of the flow pattern, it can be said that the Slug regime remains when using metal foam, although slight changes due to foam structure have been created.

References

[1] L. Tadrist, M. Miscevic, O. Rahli, F. Topin, About the use of fibrous materials in compact heat exchangers, Experimental thermal and fluid science, 28(2-3) (2004) 193-199.

[2] A. Diani, S. Mancin, L. Doretti, L. Rossetto, Low-GWP refrigerants flow boiling heat transfer in a 5 PPI copper foam, International Journal of Multiphase Flow, 76 (2015) 111-121.

[3] S. Mancin, A. Diani, L. Doretti, L. Rossetto, R134a and R1234ze (E) liquid and flow boiling heat transfer in a high porosity copper foam, International Journal of Heat and Mass Transfer, 74 (2014) 77-87.

[4] G.B. Abadi, C. Moon, K.C. Kim, Flow boiling visualization and heat transfer in metal-foam-filled mini tubes–Part I: flow pattern map and experimental data, International Journal of Heat and Mass Transfer, 98 (2016) 857-867.

[5] R.J. Moffat, Using uncertainty analysis in the planning of an experiment, Journal of Fluids Engineering, 107(2) (1985) 173-178.

[6] J.C. Chen, Correlation for boiling heat transfer to saturated fluids in convective flow, Industrial & engineering chemistry process design and development, 5(3) (1966) 322-329.