Proceedings of the 18th UK Heat Transfer Conference

9-11 September 2024, Birmingham

UKHTC2024-097

FLOW BEHAVIOUR AND WALL TEMPERATURE DISTRIBUTION OF LOW CONCENTRATION BUTANOL-WATER MIXTURE FLOW BOILING UNDER DIFFERENT FLOW ORIENTATION

Arif Widyatama[1,3*], Mandi Venter[2], Jaco Dirker[2], Daniel Orejon[1], Khellil Sefiane[1]

[1] Institute for Multiscale Thermofluids, School of Engineering, University of Edinburgh, King's Buildings, Mayfield Road, Edinburgh EH9 3JL, Scotland, United Kingdom

[2] Department of Mechanical and Aeronautical Engineering, Faculty of Engineering, Clean Energy Research Group, University of Pretoria, Lynnwood Road, Hatfield, 0028, Pretoria, South Africa

[3] Department of Mechanical and Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Jl. Grafika No.2, Yogyakarta, 55281, Indonesia

1. ABSTRACT

The aim of this study is to investigate the flow boiling characteristics of butanol water mixture under different flow orientations. Here, a 5% v/v butanol-water mixture was chosen as a working fluid. Next, a one-sided coated rectangular channel for an aspect ratio of 20 and with a hydraulic diameter of 571 µm was used as the test section under three different flow orientations (horizontal flow, vertical upward flow and vertical downward flow). The results show that flow orientation influences the characteristics of the flow pattern and the wall temperature distribution, with vertical downward flow being dominated by the vapour phase. This phenomenon in vertical downward flow will lead to the occurrence of dry out that increases the wall temperature along the channel.

2. INTRODUCTION

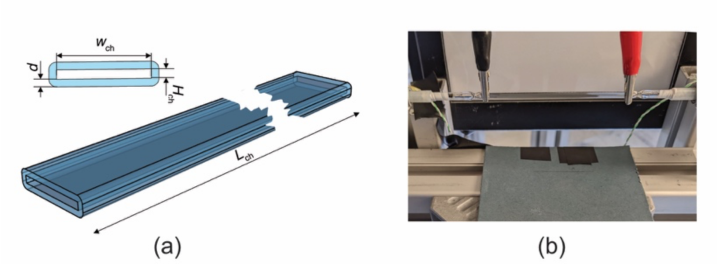
Numerous efforts have been made to improve the performance of flow boiling at the mini-/micro-scale. While the shape and the geometry of the mini- and/or micro-channels have been widely addressed, the utilisation of a binary mixture in flow boiling instead has received lesser attention. To this end, Sitar and Golobic [1] revealed that the addition of a small amount of butanol to pure water, forming a self-rewetting fluid, could enhance the flow boiling performance by forming an annular flow that postpones the dry out event. However, a more in depth study is needed to understand the flow boiling characteristics of the butanol-water mixture, especially at a low liquid flow rate. In addition, the effect of flow orientation is also rarely discussed. Hence, the current study will be focused on investigating the flow behaviour and wall temperature distribution of butanol water mixture under different flow orientations.

3. METHODOLOGY

The experiment was conducted in a flow boiling facility, and the details of the general set-up have been explained in our previous work [2]. Here, transparent heating was used to induce the flow boiling and accommodate visual observation. The test section was made of a borosilicate glass rectangular channel, as illustrated in Fig. 1. The channel features an aspect ratio of 20 (6 mm width (W_{ch}) and 0.3 mm depth (H_{ch}) and a heated length between 65 and 70 mm with the different dimensions illustrated in Fig. 1(a). Those dimensions equal a hydraulic diameter of 571 µm. The channel was externally coated with Tantalum for electric heating on one side, and it was connected with an electrical close circuit, as shown in Fig. 1 (b).

*Corresponding Author: a.widyatama@sms.ed.ac.uk

The wall temperature distribution was captured using a thermal camera, FLIR® A645. The frame rate was 25 fps, and the maximum resolution of the thermal image was 640 x 480 pixels. Furthermore, a Basler® acA800-510um camera was used to observe the liquid vapour interface during the flow boiling. It was set at 500 fps with an image resolution of 800 x 600 pixels. Equally important, the pressure and temperature in the outlet and inlet region were monitored using pressure transducers and thermocouples, respectively.



(a)

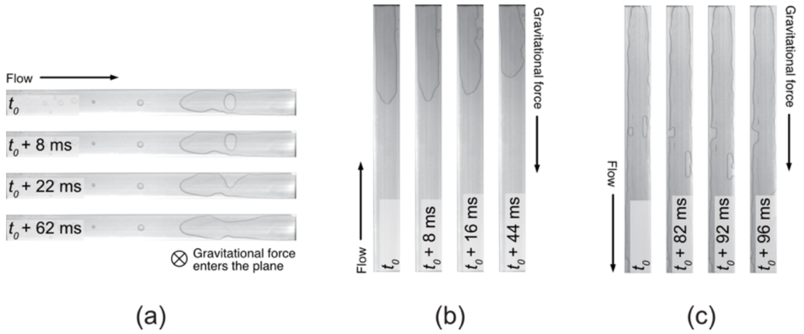
(b)

Fig. 1 a) the illustration of channel dimension b) coated microchannel that was installed to the system

The current study used a 5% v/v butanol-water mixture as the working fluid, and it can be considered a self-rewetting fluid. To represent the liquid low flow rate that became our focus of interest, a mass flux, *G,* of 15 kg m^{-2} s^{-1} was used. Next, the heat flux, *q,* varied from 16.69 kW m^{-2} to 50.08 kW m^{-2}. In addition, the test was adjusted into three flow configurations: horizontal flow, vertical upward flow, and vertical downward flow.

4. RESULTS

Fig. 2 shows an example of flow visualisation for the case of G = 15 kg m^{-2} s^{-1} under different flow orientations. In the horizontal cases (Fig. 2. (a), q = 25.95 kW m^{-2}), the vapour-dominant phase forms an elongated bubble tail that occupies the outlet region. Similarly, this phenomenon is also found in the vertical upward flow (Fig 2. (b), q = 25.45 kW m^{-2}). It is interesting to note that there is some liquid vapour interface movement due to bubble nucleation, growth, and coalescence process, as shown at $t = t_0 + 44$ ms in Fig 2. (b).



(a)

(b)

(c)

Fig. 2 flow visualisation of a) horizontal flow (q = 25.95 kW m^{-2}) b) vertical upward flow (q = 25.45 kW m^{-2}) c) vertical downward flow (q = 20.20 kW m^{-2})

Moving to the vertical downward flow (Fig. 2(c), q = 20.20 kW m^{-2}), a different phenomenon is observed. Here, the vapour phase dominates the channel. The low flow rate reduces the ability to provide rewetting for the channel and to push the vapour toward the outlet region. Consequently, this may trigger the dry-out easily. However, the occurrence of liquid bridging in the middle of the vapour phase can also indicate the presence of a thin liquid film between the vapour phase and the channel. Hence, additional analysis related to the wall temperature distribution should be conducted.

The wall temperature characteristics are shown in Fig. 3. Based on Fig. 3(a), the horizontal flow tends to be stable, as demonstrated by the rather stable temperatures at different intervals of time. In vertical upward flow, an intense fluctuation of the wall temperature is observed, as reported in Fig. 3(b). Fig 3(c) reveals that vertical downward flow experiences larger severe fluctuations. Compared to the vertical upward flow cases, the vertical downward flow produces irregular patterns, which are strongly influenced by the ability of the liquid to be in contact with the local heated wall. In terms of average wall temperature, it is evident that the vertical downward flow shows the highest average wall temperature among others near the outlet for $z/L > 0.9$. It is also interesting to note that although the flow visualisation of the horizontal and vertical upward flow tends to be similar, some different features of the wall temperature characteristics are found. For example, the inlet region of the vertical upward flow shows a slightly higher wall temperature, as shown in Fig. 3(d). It may be due to the flow fluctuation that can accelerate the liquid mixing in the inlet region.

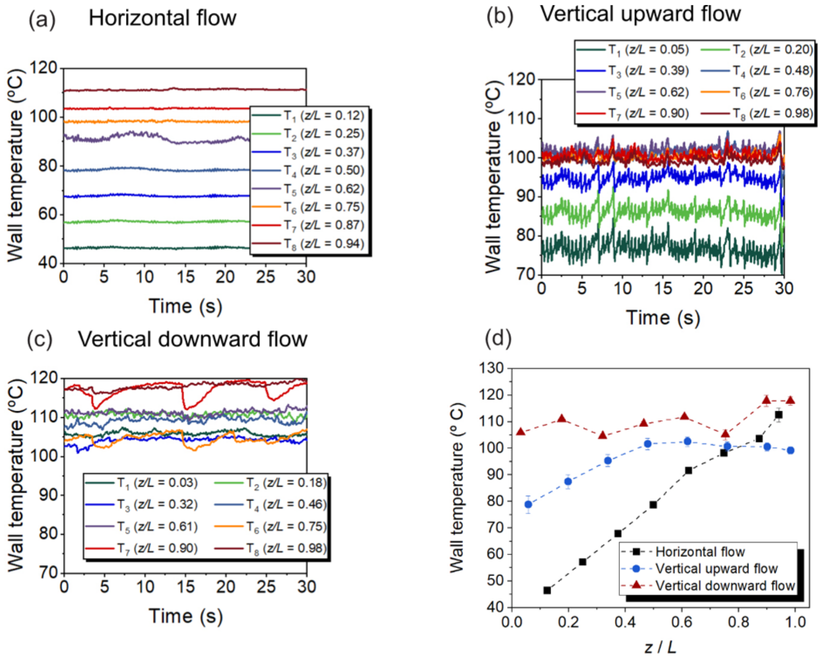


Fig. 3 Time series data of wall temperature for a) horizontal flow (q = 25.95 kW m^{-2}), b) vertical upward flow (q = 25.45 kW m^{-2}), and c) vertical downward flow (q = 20.20 kW m^{-2}). d) Average data of wall temperature under various flow configurations (G = 15 kg m^{-2} s^{-1})

5. CONCLUSIONS

The experimental study on the flow boiling characteristics of a 5% v/v butanol-water mixture in three different flow orientations was conducted. The preliminary results show that the flow orientation influences the characteristics of the flow pattern and the wall temperature distribution. While no major differences are found when comparing the cases of horizontal and vertical upward flow, when shifting our attention to vertical downward flow, such configuration is governed by the vapour phase, which will lead to the occurrence of dry out that increases the wall temperature along the channel.

REFERENCES

[1] A. Sitar, I. Golobic, Heat transfer enhancement of self-rewetting aqueous n-butanol solutions boiling in microchannels, *Int. J. of Heat and Mass Transfer,* 81 (2015), 198-206.

[2] A. Widyatama, M. Venter, D. Orejon, K. Sefiane, Experimental investigation of bubble dynamics and flow patterns during flow boiling in high aspect ratio microchannels with the effect of flow orientation, *Int J.* of Thermal Sciences, 189 (2023), 108238.