Studies on Two-phase Flow Instability and Heat Transfer under Oscillatory Flow

Il Woong Park [a, b] *, Maria Fernandino [a], Carlos Alberto Dorao [a]
[a] *Norwegian University of Science and Technology, Norway*
[b] *Jeju National University*
**Corresponding author: ilwoongpark@gmail.com*

1. Introduction

Even though two-phase flow has been studied over the past decades, there are still open questions [1–5]. Especially, the mechanism of two-phase flow instabilities and effect on heat transfer has not been fully identified. In this paper, we introduce studies which were conducted with the experimental facility for two-phase flow at Norwegian University of Science and Technology [6–8]. Two research questions are considered as follows [6–8]:

1) Why the superimposed density wave oscillations occurs?

2) Does the oscillatory flow deteriorate under the two-phase condition?

Among two-phase flow instabilities, Pressure Drop Oscillations (PDO) and Density Wave Oscillations (DWO) are considered [1–5]. This is because they are mostly studied in the previous studies. Furthermore, an interaction between them has been considered as one of the remaining questions regarding two-phase flow instabilities.

For heat transfer, the heat transfer coefficient (HTC) is obtained for the case of oscillatory flow which is generated by controlling the pump. This is because self-induced instabilities such as PDO and DWO have difficulties to control the conditions such as amplitude and period of the oscillations.

2. Methods and Results

2.1 Experimental Facility

The experimental facility for two-phase flow instability test at Norwegian University of Science and Technology has been used for identifying the underlying mechanisms of two-phase flow as depicted in Figure 1 [6–10]. It consists of the main loop, a pump, a condenser, a conditioner, a heated pipe, two flow meters, two chillers, and an expansion tank. As working fluid, R134a is circulated by the pump. The heated pipe which is a test section (5mm of the inner diameter and 2035mm of length) is heated by the Joule effect. All the variables are logged with an NI data acquisition system at a frequency of 10 Hz. Detailed descriptions for the instruments are available in the references [11–14]. Details of the accuracy of temperatures (0.1K), a pressure (0.04%), and a heat flux (5%) can be found in the reference [8].

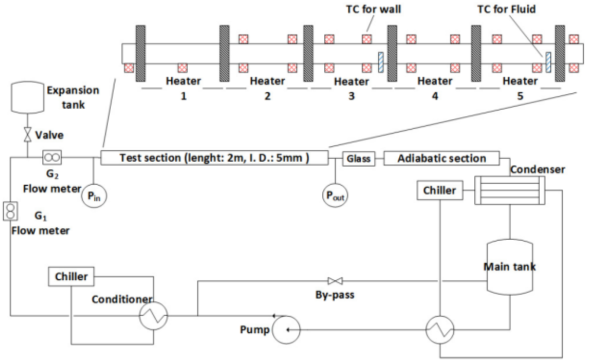

Fig. 1. Experimental Facility for two-phase flow [8].

2.2 Superimposed Density Wave Oscillations

It has been reported that superimposed DWO can occur when PDO exists [15–17]. There are only a few studies to identify the mechanism of superimposed DWO. The underlying mechanism of occurrence of superimposed DWO and amplified amplitude of it has been discussed by Park et al [6]. Especially, it is interesting that pure DWO can be amplified like superimposed DWO as described in Figure 2 [6].

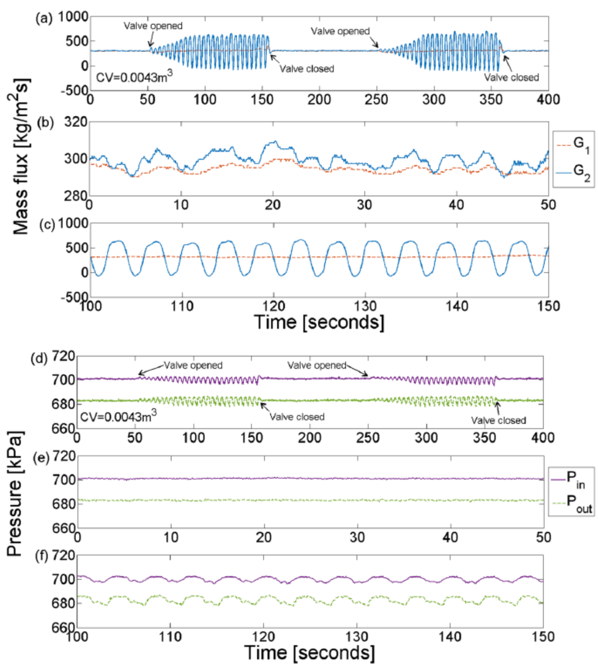

Figure 2. Effect of the control volume on DWO [6].

Figure 2a–2c present profile of the mass flux and 2d–2f show profile of pressure while the valve which can be observed in figure 1 and locate between the expansion tank and the test section opened and closed. The valve for opening the compressible volume was opened at 50 and 250 seconds and closed at 150 and 350 seconds. This is for showing the effect of compressible volume on pure density wave oscillation which has not been reported in the previous studies. In figure 2b and 2e, profiles of mass flux and pressure for the condition of the closed valve can be observed while the profiles of them can be observed for the condition of the existence of compressible volume are depicted in figure 2c and 2f.

Furthermore, level of the compressible volume has no effect on the amplified mass flux [6]. Results show that even though there is small fluctuations, it can be amplified more than 10 times.

2.3 Heat transfer under Flow Oscillations

In case of heat transfer performance, how much heat transfer can be deteriorated because of two-phase flow instability has not been fully quantified. In order to quantify that, research has been conducted by Park [8]. In the case of self-induced oscillations such as DWO and PDO, it is not easy to control the parameters of oscillations. Thus, controlled flow by controlling the pump in the sinusoidal profile of the pump speed was considered. Results show that the heat transfer coefficient can deteriorate when the amplitude of mass flux to mass flux for stationary condition and period are higher than the certain value as shown in Figure 3 and 4. For example in case of the outlet quality 0.4 in figure 3, it is possible to observe that there is no significant deterioration of heat transfer coefficient up to 0.48 of the ratio between the amplitude of mass flux to the mass flux for the stationary condition (*ΔG/G*) while the period of the oscillation is large up to 131 seconds. In case of outlet quality 0.8, as presented in figure 4, similar criteria for the mass flux can be observed at 0.18 of *ΔG/G*. It can be observed that deterioration of the heat transfer coefficient occurs lower *ΔG/G*. It was explained that the deterioration is attributed to dry-out in low mass flux conditions [8].

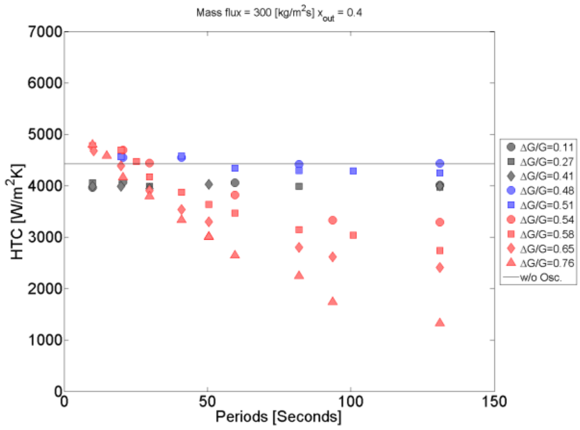

Figure 3. HTC under oscillatory flow in low quality.

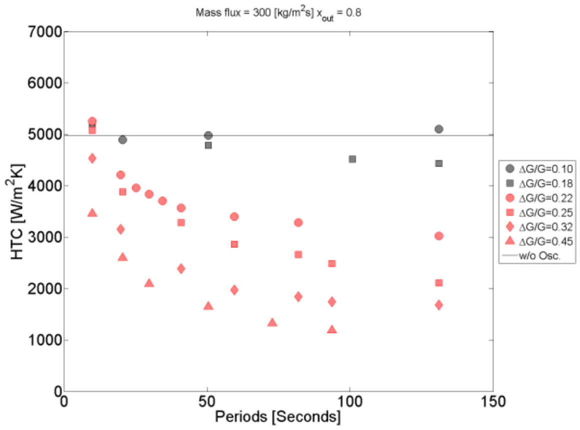

Figure 4. HTC under oscillatory flow in high quality.

3. Conclusions

Researches on heat transfer under two-phase flow, two-phase flow instability have been conducted at Norwegian University of Science and Technology. In these studies, fundamental aspects of two-phase flow have been focused. Especially, the mechanism of superimposed density wave oscillation and deterioration of heat transfer coefficient under the oscillatory flow has been identified. It should be noticed that there are still fundamental questions on two-phase flow.

REFERENCES

[1] Boure, JA, AE Bergles, and S_ L. Tong. "Review of two-phase flow instability." Nuclear Engineering and Design 25.2 (1973): 165-192.
[2] Tadrist, L. "Review on two-phase flow instabilities in narrow spaces." International Journal of Heat and Fluid Flow 28.1 (2007): 54-62.
[3] Prasad, V. Gonella Durga, Manmohan Pandey, and Manjeet S. Kalra. "Review of research on flow instabilities in natural circulation boiling systems." Progress in Nuclear Energy 49.6 (2007): 429-451.
[4] Kakac, S., and B. Bon. "A review of two-phase flow dynamic instabilities in tube boiling systems." International Journal of Heat and Mass Transfer 51.3 (2008): 399-433.

[5] Liang, Nan, et al. "Instability of refrigeration system–A review." Energy conversion and management 51.11 (2010): 2169-2178.
[6] Park, I. W., Fernandino, M., & Dorao, C. A. (2018). On the occurrence of superimposed density wave oscillations on pressure drop oscillations and the influence of a compressible volume. AIP Advances, 8(7), 075022.
[7] Park, I. W., Fernandino, M., & Dorao, C. A. (2018). Experimental study on the characteristics of the pressure drop oscillations and their interaction with the short-period oscillation in a horizontal tube. International Journal of Refrigeration.
[8] Park, I. W. (2018), Two-phase Flow Instabilities during Flow Boiling and Control of Wettability by Micro-structured Surfaces. Norwegian University of Science and Technology
[9] Dorao, C. A., Drewes, S., & Fernandino, M. (2018). Can the heat transfer coefficients for single-phase flow and for convective flow boiling be equivalent?. Applied Physics Letters, 112(6), 064101.
[10] Dorao, C. A., Fernandez, O. B., & Fernandino, M. (2017). Experimental Study of Horizontal Flow Boiling Heat Transfer of R134a at a Saturation Temperature of 18.6 C. Journal of Heat Transfer, 139(11), 111510.
[11] Chiapero, E. M., Doder, D., Fernandino, M., & Dorao, C. A. (2014). Experimental parametric study of the pressure drop characteristic curve in a horizontal boiling channel. Experimental Thermal and Fluid Science, 52, 318-327.
[12] Sørum, M., & Dorao, C. A. (2015). Experimental study of the heat transfer coefficient deterioration during Density Wave Oscillations. Chemical Engineering Science, 132, 178-185.
[13] Dorao, C. A. (2015). Effect of inlet pressure and temperature on density wave oscillations in a horizontal channel. Chemical engineering science, 134, 767-773.
[14] Dorao, C. A., Langeland, T., & Fernandino, M. (2017). Effect of heating profile on the characteristics of pressure drop oscillations. Chemical Engineering Science, 158, 453-461.
[15] Park, I. W., Fernandino, M., & Dorao, C. A. Effect of the Mass Flow Rate and the Subcooling Temperature on Pressure Drop Oscillations in a Horizontal Pipe.
[16] Çomaklı, Ö., Karslı, S., & Yılmaz, M. (2002). Experimental investigation of two phase flow instabilities in a horizontal in-tube boiling system. Energy Conversion and Management, 43(2), 249-268.
[17] Ding, Y., Kakac, S., & Chen, X. J. (1995). Dynamic instabilities of boiling two-phase flow in a single horizontal channel. Experimental Thermal and Fluid Science, 11(4), 327-342.