Experimental Nucleate Pool Boiling on a Horizontal Plate in Saturated Water

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Introduction

Nucleate pool boiling is an effective phenomenon of heat transfer. It is composed of many complicated boiling mechanism. This fact makes it has a very high heat transfer coefficient. Therefore the nucleate boiling is applied in many industries, such as nuclear plant system, and electronic components cooling.

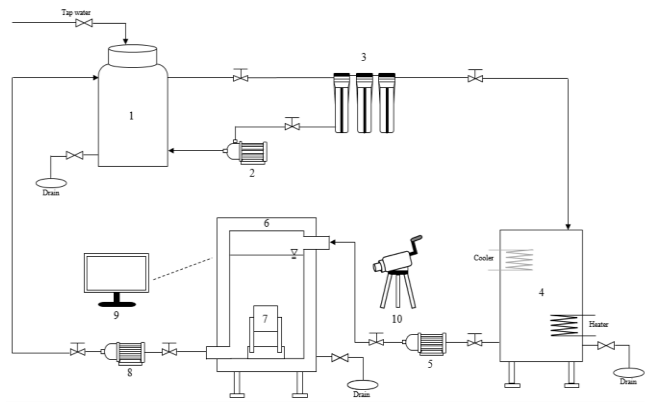
In the past decades, many researchers worked toward understanding the behavior of nucleate pool boiling. Gaertner [1] used the horizontal plate of platinum and copper to study. The results showed the nucleate pool boiling can be divided into two major region called discrete bubble region and vapor mushroom region. In addition, a region called first transition region is existing between this two regions, and second transition region is existing from the vapor mushroom region to the point of critical heat flux. Manikandaprabu et al. [2] used the horizontal plate of stainless steel to experiment. They saw the similar results as mentioned above.

The purpose of the present study is to investigate the nucleate pool boiling, and the photography obtained by high speed camera will be discussed to receive valuable information about bubble behavior in nucleate boiling region.

Experiment Apparatus and Procedure

Experiment Loop and Test Facility

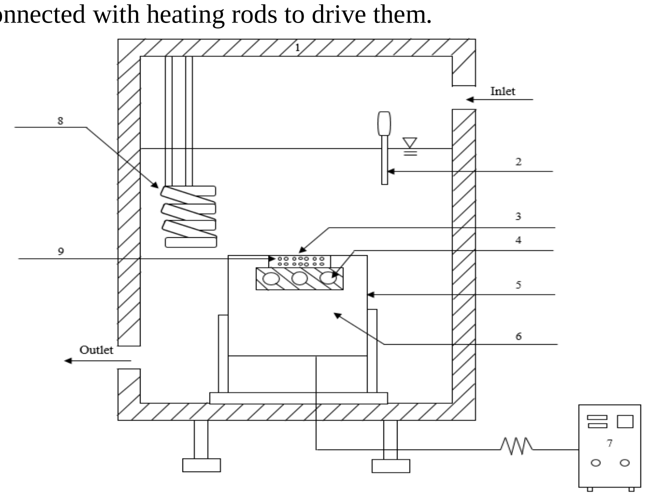
The schematically of experiment loop is illustrated in Fig.1. This loop comprises four experimental system. According to each feature of region, they can be divided into four system named filter system, preheated system, heating system, and data acquisition system. In the filter system, the tap water is circularly cleaned by circulation pump to remove the impurities. Thus, we can obtain the high quality of experimental water. In the preheated system, a preheating tank is used to heat the water, because a saturated temperature of inlet water is required. In the data acquisition system, the temperature and bubble dynamic will be recorded by data logger and high speed camera, respectively.



No	Name	No	Name
1	Water storage tank	6	Test section
2	Circulation pump	7	Heating block
3	Filter	8	Outlet pump
4	Preheating tank	9	Data logger
6	Inlet pump	10	High speed camera

Fig. 1 Schematic diagram of experiment loop

Fig.2 shows the cross section of heating system that it consist of test section, preheater, heating block, and power supply. The test section is a vessel made of stainless steel. The dimensions of vessel is $543 \times 500 \times 765$ mm. It has two quartz windows for visual section in the front and back. The preheater is used to maintain the bulk temperature at saturated in the test section. A DC power supply is connected with heating rods to drive them.



No	Name	No	Name
1	Test section	6	Insulation material
2	Thermocouple(Tc)	7	Power supply
3	Heating surface	8	Preheater
4	Heating rod	9	Thermocouples(T1-T16)
5	Heating block		

Fig.2 Schematic diagram of heating system

The heating block is made of copper that its thermal conductivity is 391 W/m-K. The details of heating block assembly are shown in Fig.3(a) and (b). As shown in Fig.3(a), three heating rod are embedded in the copper to supply the power of 190W, and sixteen K-type thermocouples are evenly embedded in two layers. The red dots indicate the locations of thermocouples in Fig.3(a). Their vertical distances from the heating surface at each layer are 1.8 mm and 2.6 mm, respectively. The heating surface is rectangular that its dimensions is 40×20 mm. Fig.3(b) shows the exterior dimensions of heating block, the dashed lines indicate the thermal insulation material which used to wrap the cooper to avoid the heat loss.

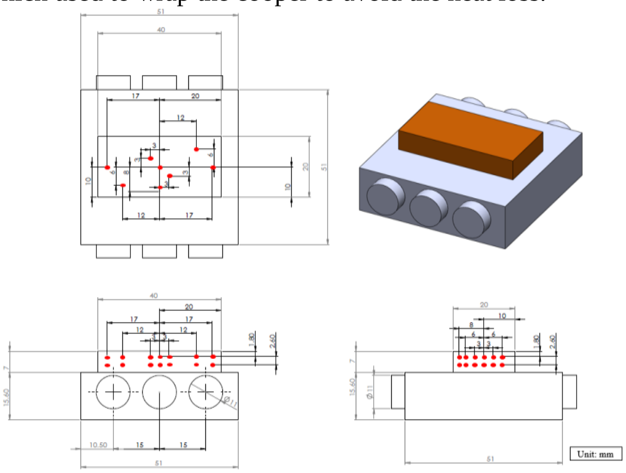


Fig. 3(a) Drawing of internal heating block

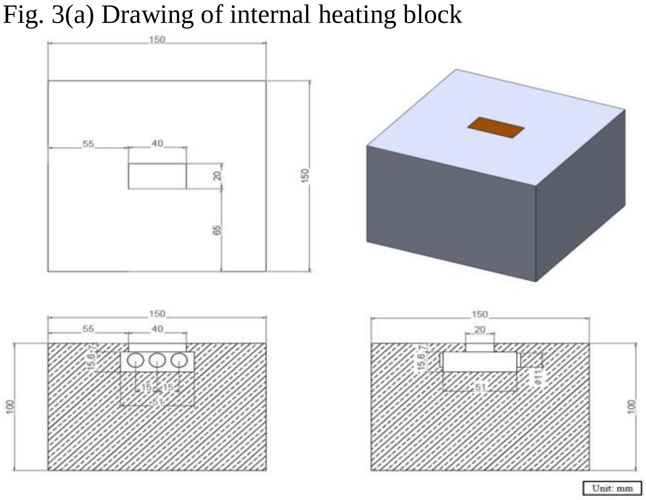


Fig. 3(b) Drawing of external heating block

Experimental Procedure

The experimental produce is designed to standardize the operating process in this experiment. The process is listed in the following steps:

1. Turn on the main switch of instrument power.
2. The water cleaned is injected into preheating tank to heat until it is saturated.
3. The saturated water is injected into test section to experiment of pool boiling.
4. Turn on the data logger and camera to recode the temperature and images, respectively.
5. Turn off the main switch of instrument power when the experiment is the end.

Results and Conclusions

The boiling curve of the present experiment is shown in Fig.4. The figure shows the onset nucleate boiling called ONB and the range of each region.

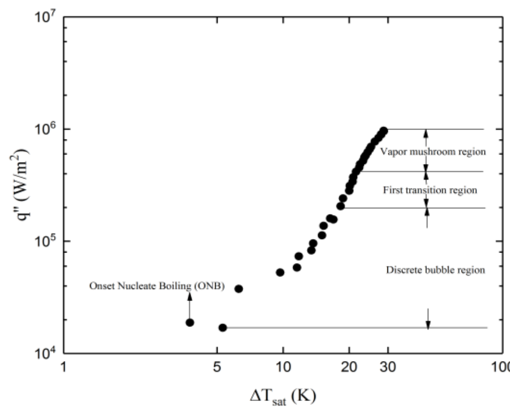


Fig. 4 Experimental data of nucleate pool boiling on a horizontal plate

The onset nucleate boiling is shown in Fig.5. At this time, the surface start to generate bubbles, however, it condensed immediately, because the wall superheated is too low to let bubbles departure. The discrete bubble region is shown in Fig.6(a) and (b). In this region, the quantity of bubble and the bubble size are getting more and bigger, receptivity. The Fig.7 is occurred in the first transition region where the bubbles start to coalesce with near bubbles. The Fig.8 shows the vapor mushroom region. Precisely as its name, the shape of bubbles are like mushroom in this region. From the view of boiling curve in Fig.4, there is an inflection point where $\Delta T_{sat} = 21.47(K)$ and $q'' = 4.17 \times 10^5 (W/m^2)$. At the beginning of this point, the bubbles enter the vapor mushroom region.

Fig. 5 Onset nucleate boiling ($\Delta T_{sat} = 21.47K$, $q" = 1.7 \times 10^{4} W / m^{2}$)

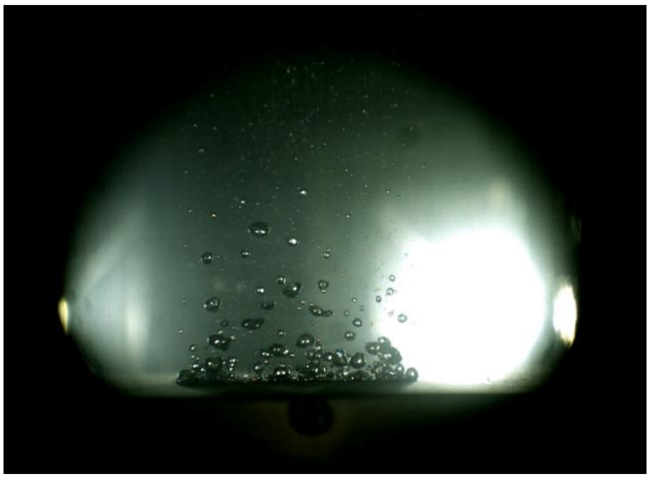


Fig.6(a) Discrete bubble region($\Delta T_{sat} = 15K$, $q" = 1.12 \times 10^{5} W / m^{2}$)

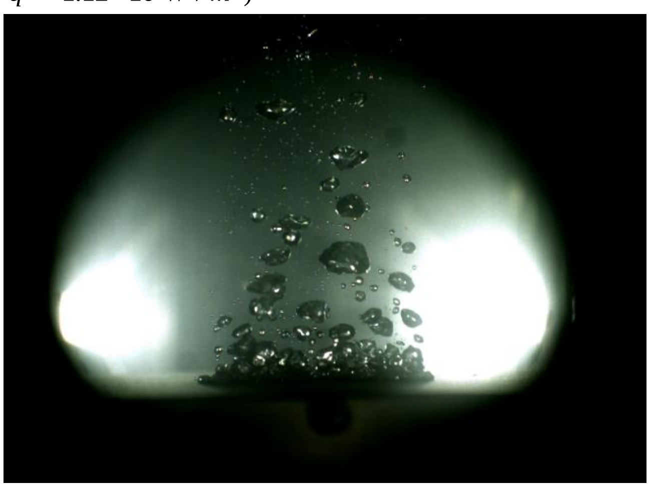


Fig.6(b) Discrete bubble region($\Delta T_{sat} = 18.3K$, $q" = 2.05 \times 10^{5} W / m^{2}$)

Fig.7 First transition region ($\Delta T_{sat} = 20K$, $q" = 2.82 \times 10^{5} W / m^{2}$)

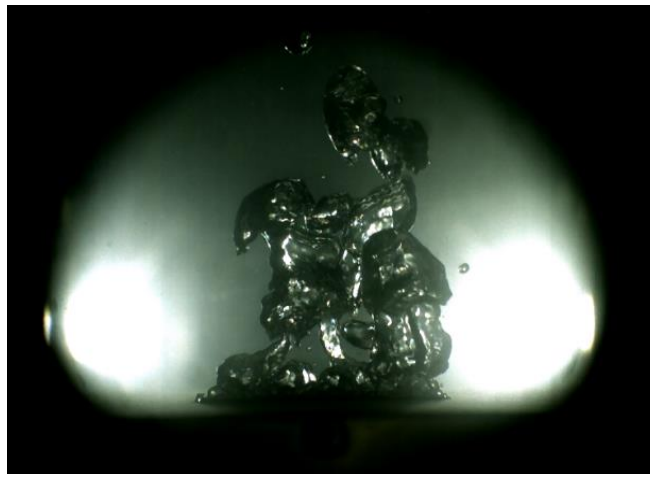


Fig.8 Vapor mushroom region ($\Delta T_{sat} = 24.28K$, $q" = 6.2 \times 10^{5} W / m^{2}$)

Future Work

The characteristics of nucleate pool boiling vary with the heater conditions, such as orientation and size. Therefore, more experiment about different orientation will be investigate in the near future. Furthermore, some of parameters play an important role in the bubble behavior, such as nucleation site density, bubble departure diameter, and bubble departure frequency. These parameter will be also study.

Nomenclature

$q"$ =Heat flux

ΔT_{sat} =Wall superheated

T_c=Bulk temperature

$T_{1\sim16}$=Inside temperature

References

[1] R. F. Gaertner, "Photographic study of nucleate pool boiling on a horizontal surface," *Journal of Heat Transfer,* vol. 87, no. 1, pp. 17-27, 1965.

[2] B. Manikandaprabu, S. Mohankumar, and R. Kathiravan, "Pool boiling of water over a stainless steel flat plate heater," *International Journal of Instrumentation, Control and Automation,* vol. 1, pp. 2231-1890, 2012.