行政院國家科學委員會專題研究計畫成果報告

振動與轉動對強化沸騰熱傳影響之研究

THE EFFECTS OF VIBRATION AND RECIPROCATING ON BOILING HEAT TRANSFER IN CYLINDRICAL CONTAINER

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主持人：周煥銘 崑山科技大學機械工程系
E-mail：hmchou@mail.ksut.edu.tw

Abstract

The performance of enhancing boiling heat transfer in cylindrical container was studied experimentally. The effects of the heat load, the grain size of the steel and plastic balls added in the container, the vibration frequency of the disk, and the reciprocation frequency of the cylindrical container on the characteristics of heat transfer were investigated in detail for water as working fluid. The experiment results show that the active methods can really improve the boiling heat transfer promisingly. That is, the heat transfer can be raised only by adding an appropriate amount of additives inside the heated container with vibration or reciprocating rotation, then the boiling heat transfer can be raised by 20%~65% without increasing the heating area.

中文摘要

本研究係以實驗方法研究振動與轉動對強化沸騰熱傳影響之研究，實驗模型是將加熱端加裝振動盤或轉盤，利用振動或轉動來強化沸騰熱傳，工作流體則為水。除了改變振動盤之振動頻率與轉盤之往復轉動頻率測試外，並將封入不同材料之顆粒於加熱端，以測試其對強化沸騰熱傳之影響。結果顯示：在本實驗中僅在加熱槽中加入適量之鋼珠與振動或轉動配合，不須增加加熱面積，即可提昇沸騰熱傳約 20%~65%**。**

Introduction

In general, from the point of view of whether the external power exerted on the system or not, it could be classified as active and passive methods for enhancing the heat transfer. The different roughness of the surfaces and the additives in the heated container, e.g., are the passive methods, while the vibration and rotation effects are classified as the active ones.

Due to the increased functional ability of electronics in processing information and the necessity of working in high speed, and also the progression of technology in making semiconductor volume circuit increases very fast, stimulate the volume of machine to be minimized. In addition, the prosperous growth of micro electromechanical system (MEMS) making the heating generation of manufacturing machine increases in the exponential relationship. Therefore, impelling the cooling technique must be upgraded to a more efficient heat transfer installation. For example, the natural convection innovates to the forced convection, or even the method of cooling off by boiling is used to get the enormous amount of heat transfer under a very small temperature difference.

To fully utilizing the property of boiling heat transfer, many investigations of boiling heat transfer have been carried out in the last 60 years, and many published experimental results in the field are reviewed in the reference [1]. In the recent years, the property of boiling heat transfer is still one of the important investigation topics [2-10]. The relevant applications and technology are booming immediately, such as heat pipe and thermosyphon loop are two of the important representative inventions [11-15].

The industry thinks highly of the heat pipe since its invention in 1942 due to its property of a huge amount of heat can be rapidly transferred in a very small temperature difference through the phase change of the working fluid. It is an important application in many situations such as the thermal preserving system, the cooling techniques in the electronic components, the cooling system of the nuclear reactors, the solar energy collector, the geothermal application and the heat exchanger for energy regeneration.

The published reports about the performance of enhancing boiling heat transfer are mainly considering a horizontal tube and its outer surface characteristics [3-9]. Most of them only investigated the effect of the surface property on the boiling heat transfer [16-18], while seldom were about vibration, rotation, and the different size of additives on the boiling phenomena. The combination effects of vibration, rotation with different size of additives on the boiling even have not ever been studied till now. In this work, an experimental method is used. The vibration and reciprocating rotation of the container with the different size of additives on the boiling heat transfer are investigated.

Experimental installation and method

The effects of the vibration and reciprocating rotation of the cylindrical container, and the different sizes of additives sealed in the container on the boiling phenomena were studied. The inner diameter of the cylindrical container is 165 mm, and the outer diameter is 167 mm. The apparatus shown in figure 1 was used in the experiments. The main unit consists of a temperature-preserving container, a heater, a condensing section, an insulated tube between the container and the condensing section, and a disk for vibration and reciprocating rotation. The control unit is composed of a temperature controller, a water level regulator and a frequency controller. The additive sizes are 3.18, 3.97, 4.76, 5.56, 6, 6.35, and 7.94 mm in diameter for the steel balls, and 6 mm in diameter for the plastic balls respectively. The vibration disk or the reciprocating rotation disk is attached in the bottom side of the heated container with the working fluid, i.e., the water. The temperature of the supply working fluid is kept at the saturated temperature by a temperature controller, and the water in the container is also kept at a constant level by the regulator in order to raise the accuracy of the experiments. The vibration and the reciprocating rotation motions are driven by an actuator, so that the control of the vibration and the reciprocating rotation frequencies is achieved.

When the experiment is proceeding, the working fluid is heated to vaporize into the vapor phase. Then the water vapor is conducted into the condensing section where the vapor can be rapidly condensed into the liquid phase. A measure cup just beneath the exit of the condensing section is used to collect the condensed liquid water, and calculate the heat transfer rate.

Results and discussion

The base data are obtained from the experiments without vibration, without reciprocating rotation and without the additives of metal balls in the working fluid. The target of this study is to research the effects of various parameters on the boiling heat transfer. The parameters include the size, the amount of the steel and plastic balls. In addition, the vibration frequency and the reciprocating frequency of the container are also the major research items in this study.

Figure 2 shows the results of the steel and plastic balls 6 mm in diameter under the same reciprocating rotation frequency of 0.5 Hz, various sizes and thermal load on the boiling heat transfer. One can find that the vapor production amount by adding steel balls is larger than that of by adding plastic balls. This is because that the thermal conductivity of steel is larger than that of plastic. During the initial stage, the amount of vapor production increases with increasing the quantity of the steel or plastic balls. However, when the amount of steel ball is reaching 600 grains, the amount of vapor production appears the maximum value, after then, it decreases. The similar result also happens in 700 grains of plastic balls. That is, the ultimate vapor production can be obtained for various added amounts of balls. Simultaneously, the results for different thermal load have the similar trend.

Figure 3 illustrates the amounts of plastic and steel balls of 6-mm diameter under different vibration frequency on boiling heat transfer. From this figure, one can find that the addition of plastic and steel balls can enhance the vapor production, and it also shows that the addition of steel balls can get more apparent result. In addition, whatever the plastic or the steel balls is, the amount of vapor production increases with increasing the addition of balls, and when the plastic balls reach 500 grains, or the steel balls reach 400 grains, the vapor production achieves a stable value respectively.

Figure 4 demonstrates the addition of steel balls with or without reciprocating rotation on the boiling heat transfer. From this figure, one can find that the best result can be obtained with the addition of steel balls and rotation effect, the gain of 20% is obtained. The second best is with the steel ball addition but without rotation. The noticeable result is that the condition of no steel ball addition with rotation is worse than that of no ball addition without rotation. This is because that the rotation causes the water level adjacent to the wall rising up and leads to the higher heat loss due to the increase of heat transfer area. Therefore, the condition of no additives with rotation causes a drawback on the boiling heat transfer if the wall of container is not insulated.

Figure 5 shows the effects of steel ball addition and vibration on the boiling heat transfer under 50-Hz vibration frequency. From this figure, one can find that the condition of steel ball addition with vibration leads to the best result, the second best is with steel ball addition but without vibration, and the worst result is obtained under the condition of no steel ball addition with vibration. So, the enhancement of vapor production can be obtained provided the steel balls are added whether the effect of vibration is added or not.

Figure 6 and figure 7 illustrate the effect of steel ball size on the boiling heat transfer with 0.5-Hz reciprocating frequency and 50-Hz vibration frequency respectively. In figure 6, one can find that the amount of vapor production increases with the size of the steel ball under the constant reciprocating frequency. Next in figure 7, in which the vibration frequency is kept at a constant value, during the initial stage, the amount of vapor production increases with the size of the additives. However, when the amount of vapor production reaches the maximum value, the ball diameter being 6.35 mm, then the decrease tendency appears. This is because that the steel balls are piled up to the second layer so that the heat transfer reduces due to the decrease of contact area between the balls and bottom of the container.

Figure 8 shows the effect of reciprocating frequency on the vapor production with and without additives. The additives are the 600 grains of steel balls with the size of 6 mm in diameter. It illustrates that the higher reciprocating frequency leads to the larger amount of vapor production. It also can be found that the evident enhancement of heat transfer by the addition of steel balls in this condition. The percentage of improvement due to reciprocating is proportional to the reciprocating frequency from 3% of 1/6 Hz to the 33.9% of 6/6 Hz.

Figure 9 demonstrates the effect of vibration frequency on the vapor production with and without additives. From this figure, the best result can be obtained at the vibration frequency of 50 Hz whether the steel balls are added or not, and the maximum vapor production rate is about 13.4 ml per minute. Furthermore, the result also shows that the boiling is enhanced obviously by the addition of steel balls. The best-improved percentage due to vibration is about 32%.

Conclusion

1. When the effect of vibration frequency is studied, the boiling heat transfer increases with the numbers of additives, and the stable values can be achieved. However, in the reciprocating case, after the best boiling heat transfer is obtained, then the vapor production reduces.
2. When the number of the added steel ball is kept at a constant value, the boiling heat transfer increases with the size of the steel balls.
3. In this study, the boiling heat transfer is improved as the reciprocating frequency increases. However, in the vibration condition, the best result is obtained at some frequency, after then, the boiling heat transfer reduces.
4. In this experiment, we only add the effects of vibration and reciprocating rotation, then the boiling transfer can be raised by 20%~65% without increasing the heating area.

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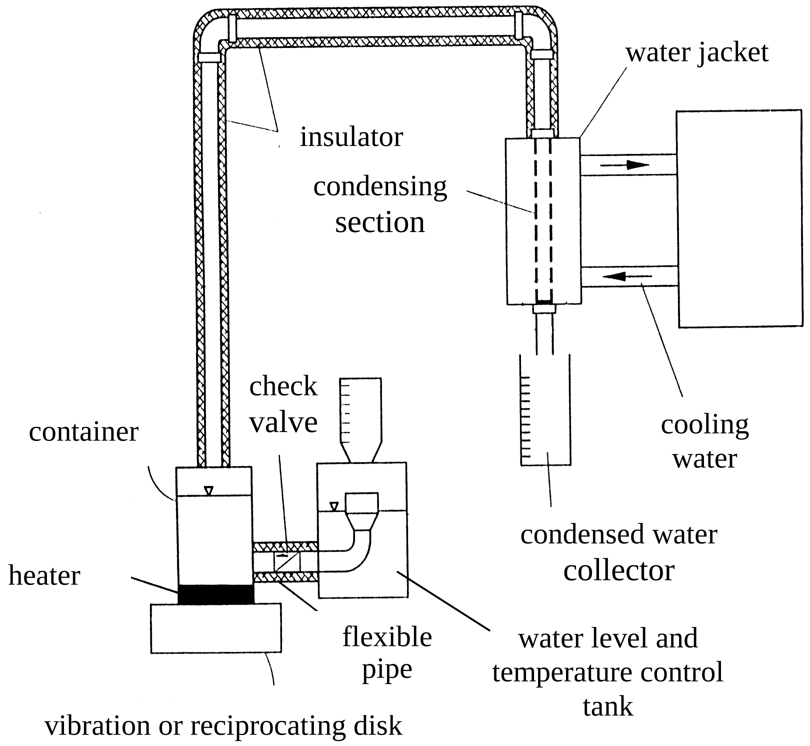

FIG. 1 Experimental apparatus

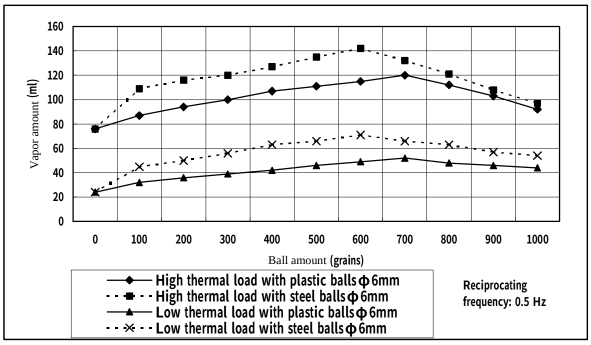

FIG. 2 Amount of additives on the boiling heat transfer for reciprocating case

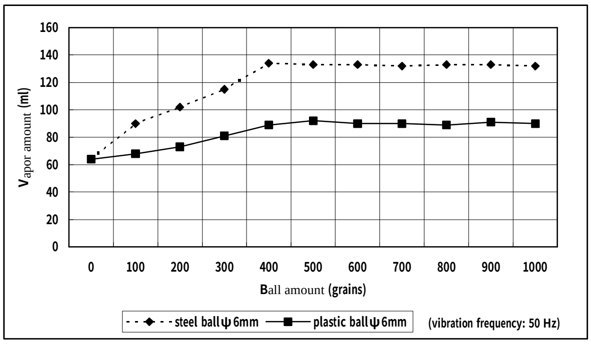

FIG. 3 Amount of additives on the boiling heat transfer for vibration case

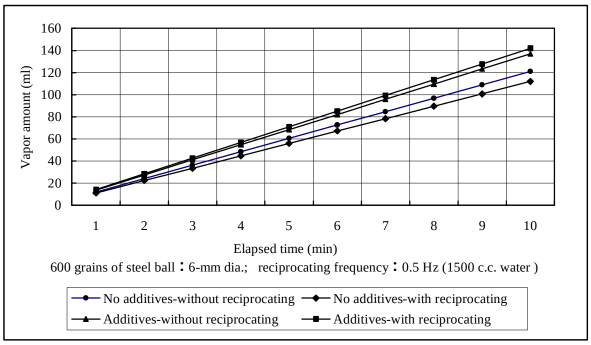

FIG. 4 The additive and reciprocating effects on the heat transfer

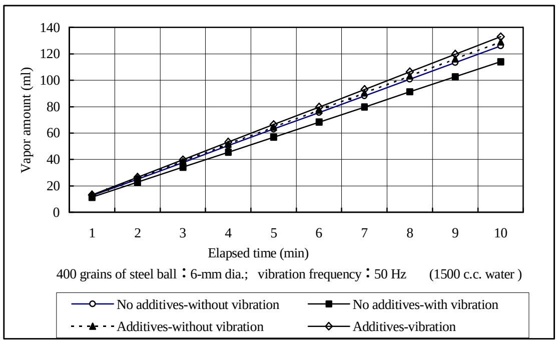

FIG. 5 The additive and vibration effects on the boiling heat transfer

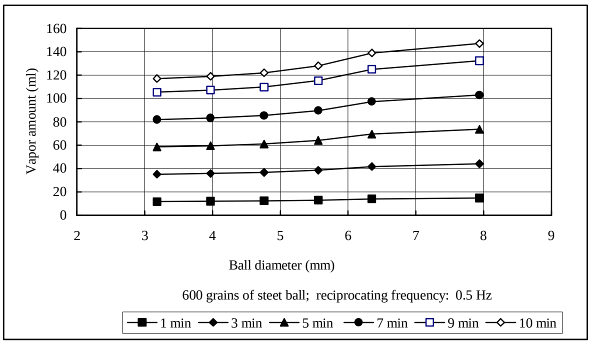

FIG. 6 Steel ball size with reciprocating on the boiling heat transfer

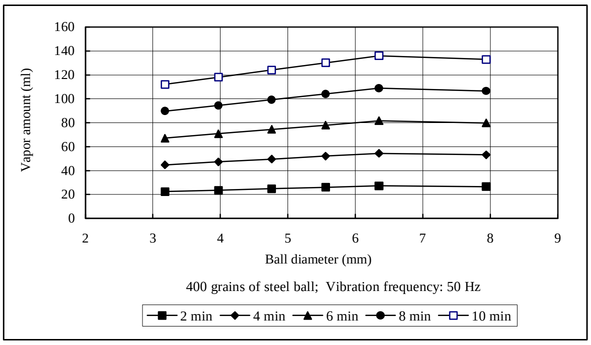

FIG. 7 Steel ball size with vibration on the boiling heat transfer

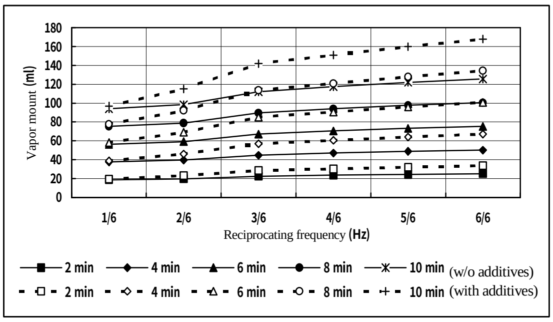

FIG. 8 The reciprocating frequency and additive on the boiling heat transfer

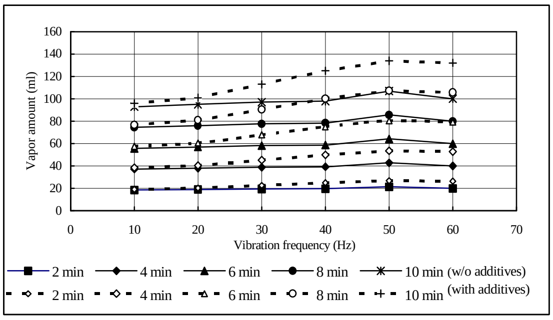

FIG. 9 The vibration frequency and additive on the boiling heat transfer