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Heat Transfer Characteristics of a Miniature Two-Phase Closed Annular Thermosyphon

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이상(二相)의 초소형 열사이폰의 열전달 특성에 관한 연구

천원기* · 이영수**

ABSTRACT

An experimental study on the heat transfer performance of a miniature two-phase closed thermosyphon is described. Water, ethanol and methanol have been tested as the working fluids. A visualization regarding the motion of liquid with boiling, scattering of liquid drops and condensation of vapor has been made to clarify the heat transfer mechanism in the miniature thermosyphon. Out of many possible controlling variables, the effects of (a) the insert thickness (b) the ratio of heated-length to cooled-length and (c) the heat flux, were investigated.

Key words : Heat transfer, Experimental study, Miniature thermosyphon

I. Introduction

While the concept of the two-phase thermosyphon has been known for a long time, its use has been neglected - especially for low temperature operation - although large quantities of heat can be transferred easily from one place to another with small temperature difference. Serious interests in the thermosyphon first arose from the application of an open thermosyphon to the cooling of gas turbine rotor blades by Schmit(1) during the World War II. Research on the heat transfer in the two-phase closed thermosyphon was first performed by Cohen and Bayley(2) followed by Larkin(3), Lee and Mital(4), Strel'tsov(5), Savchenkov and Gorbis(6), Suematsu et. al(7), and Andros and Florschuetz(8).

A wealth of information on the heat transfer and the flow phenomena has been obtained thanks to these dedicated researchers. In 1984, Cotter(9) first introduced the concept of very small micro heat pipes incorporated into semiconductor devices to promote more uniform

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temperature distributions and improve thermal control. Micro heat pipes are of particular importance to the field of microeletronics. In addition, these small heat pipes may have applications in the aerospace field for cooling the leading wing edges of hypersonic aircraft wings or the medical field for the nonsurgical treatment of cancerous tissue through either high or low temperature.The object of the present paper is to make an experimental study into the performance of a miniature two-phase closed thermosyphon.

II. Experimental Apparatus and Procedure

In order to visualize the operation of microthermosyphon(miniature thermosyphon), experimental systems have been fabricated with glass. Fig. 1 shows a photograph of such systems.

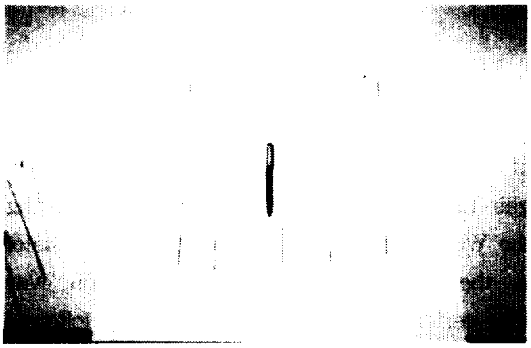

Fig. 1 A microthermosyphon made of glass

A series of test run and observations are made for the glass microthermosyphons(see Table 1) before stainless steel microthermosyphons are fabricated to further examine the operating characteristics. The total lengths of stainless steel tubes used were 300, 220 and 130mm. Each tube had a 2.3 and 1.5mm inside diameter and a 3.0 and 2.0 mm outside diameter. Insert wire diameters were 0.50 and 0.40 mm. Each tube of total length had the lengths shown in Table 2. The heat transfer loop consists of a miniature two-phase closed thermosyphon test tube, a electrical resistance heater assembly, a cooling jacket and associated instrumentation. A schematic diagram of the experimental devices is shown in Fig. 2.

Table 1 Miniature two-phase closed thermosyphon used for visualization

Glass outside dia. [mm]	Glass inside dia. [mm]	Total tube length [mm]	Insert tube dia. [mm]	Working fluid
5.0	3.4	300	1.5	distilled water, ethanol
4.0	2.4	300	1.0	distilled water, ethanol
3.0	1.8	300	0.6	distilled water, ethanol
2.0	1.0	150	0.4	distilled water, ethanol

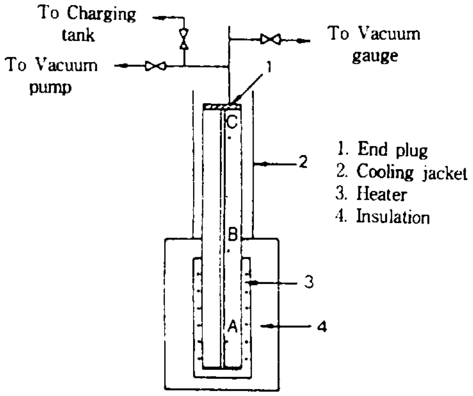

Fig. 2 A schematic diagram of the experimental apparatus

Table 2 Range of experimental variables

Case	Outside diameter	Inside diameter	Length	Inside wire diameter	Working fluid
1	3.0mm	2.3mm	300mm	0.5mm	methanol
2	2.0mm	1.5mm	220mm	0.4mm	methanol
3	2.0mm	1.5mm	130mm	0.4mm	methanol

A copper tube was soldered to the upper cap which provided connections to the vacuum pump, charging line of the working fluid, and pressure measuring instruments. A total of 3 chromel-alumel(K-type) thermocouples were used. The amount of the working fluid(ethanol) in the thermosyphon charged under vacuum of at least 10^{-5} torr was about 15% by volume.

The main requirement in the heat input section, here called the evaporator, was to have a heat input which could be measured accurately. The heater was kept in position with the help of 0.5 inch wide fiber glass tape and 0.5 inch dia. 'Atlas' asbestos rope insulations. The cooling system made of copper tubing of 3 mm inside dia. was wound around the condenser section of thermosyphon. The whole system was completely covered with very thick fiber glass insulation. The duration of each experiment was 2 hours. All data were collected and reduced using a HP 3052A data acquisition system which includes a HP micro-computer.

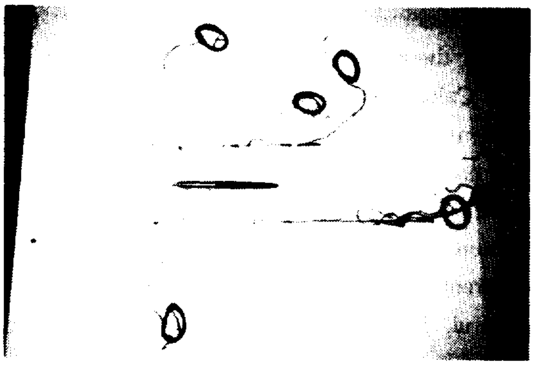

Fig. 3 A microthermosyphon made of stainless steel

For each exeperiment, measurements were made at 5 minutes intervals. Fig. 3 shows a photograph of the microthermosyphon fabricated in the present analysis.

III. Discussion of Results

A purely theoretical study of the miniature two-phase closed thermosyphon is not possible at present due to lack of information and the complexity of the condensation and boiling processes in a closed cavity. In the present study, the tube heat transfer coefficients(h) are defined by

$$Q = h_eA_e(T_e-T_a) = h_cA_c(T_a-T_c) = h_tA_e(T_e-T_c) \tag{1}$$

in which subscripts e, c, and a refer to the evaporator, condenser and adiabatic sections of the thermosyphon, respectively. Temperatures(T), Lengths(L) and Areas(A) are directly related to the heat transport rate. From Eq. (1), one obtains

$$1/h_t = 1/h_e + (1/h_c)(L_h/L_c) \tag{2}$$

to calculate the tube heat transfer coefficient h_t from Eq. (2).

The visualization results of the glass thermosyphon of 3.4mm ID with water have revealed the onset of dryout phenomena shortly after the commencement of its operation. However, the steady performance has been observed with the introduction of a stainless steel insert. When ethanol was used as the working fluid, no insert was required for its steady operation. This appears to be the consequence of larger surface tension in case of water.

In contrast, microthermosyphons with smaller diameters(ID) of 2.4mm, 1.8mm, and 1mm, the use of an insert deems essential even for the case of ethanol to maintain steady operating conditions without any dryout phenomena.

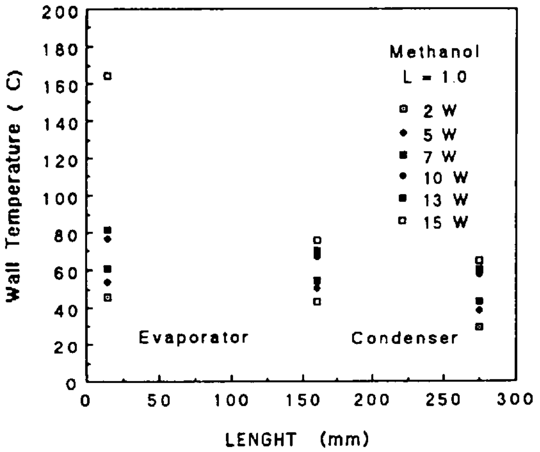

Fig. 4 Heat transfer variation

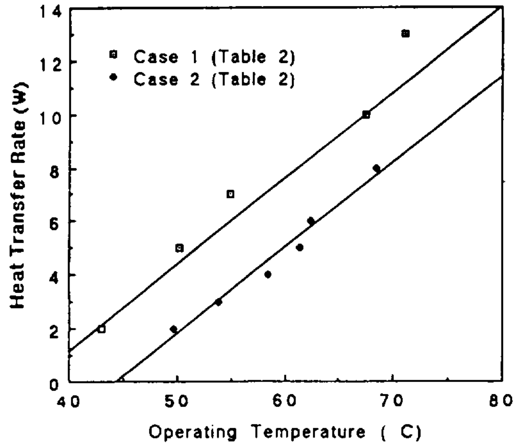

Fig. 5 Effect of thermosyphon tube length on overall heat transfer coefficient

Fig. 4 shows the performance of a microthermosyphon with a 0.5mm thick stainless steel insert. It is made with a stainless steel tube of 2.3mm ID and 300mm in total length(case 1). As illustrated, the wall temperature increases linearly in proportion to the heat input. This trend persisted in the other cases studied in the present investigation. The figure shown represents the case where dryout phenomena took place near 15W. Steady performance is observed up to a power level of 13W. Fig. 5 compares cases 1 and 2, where tests are performed to a maximum power of 13W and 8W, respectively.

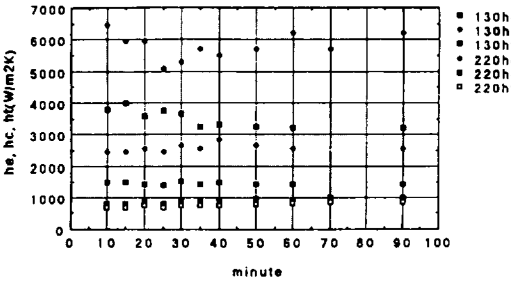

Fig. 6 Heat transfer results for different total lengths of 130mm and 220mm

3.1 Effect of thermosyphon tube length

Fig. 6 gives the result of an experimental investigation when different total lengths of 130mm and 220mm are used with an inner diameter of 1.5mm(cases 2,3). Heat transfer coefficients are calculated for the evaporator and condenser section as well as for the whole thermosyphon with a power input of 5W. Calculation shows larger values for the condenser section and for the whole thermosyphon as the total length decreases, while it gets smaller for the evaporator section. Identical results are obtained for different dimensions and heat inputs. In general, it appears shorter total lengths are desirable for steady operation and heat transport phonomena.

Fig. 7 represents the total heat transfer calculation under identical conditions as above when the power input is varied from 2W to 10W. As described in Fig. 6, a reduction in

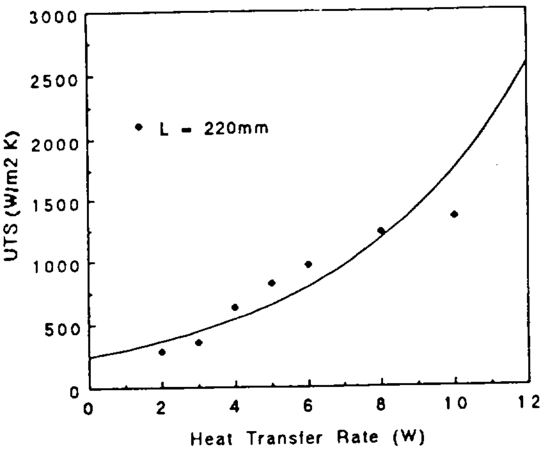

Fig. 7 Total heat transfer coefficient for the power input from 2W to 10W

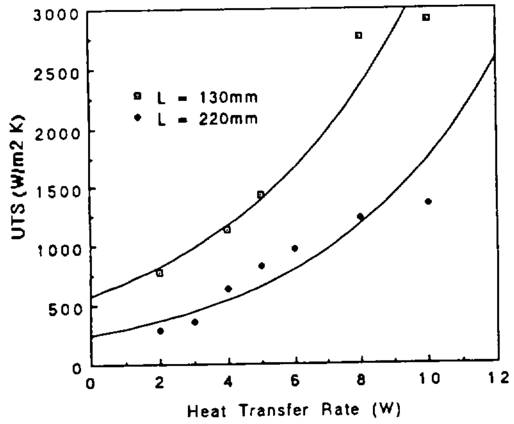

Fig. 8 Heat transfer calculation for different total lengths of 130mm and 200mm

total lengths deems effetive to augment heat transfer. Fig. 8 also compares the performance of microthermosyphons with different total lengths of 200mm and 130mm under identical conditions aforementioned. It shows a decrease in heat transfer as the aspect ratio(L/D) increases.

3.2 Effect of temperature distribution as a function of time .

Fig. 9 shows a temperature distribution for a microthermosyphon of 1.5mm ID and 220mm in total length at a power input of 8W (case 2). As time elapses, temperature rises at each point almost identically. This pattern of rise in temperature could be observed in other experiments as well. The total heat transfer coefficient has been maintained near a constant value of 1250 W/m^2K.

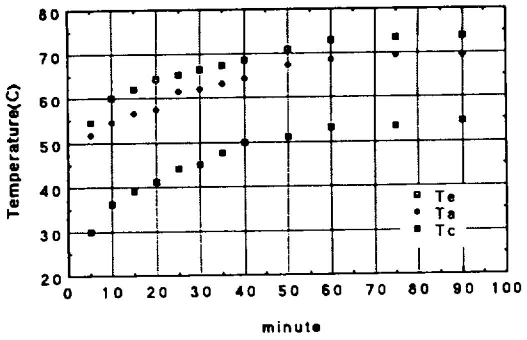

Fig. 9 Temperature distribution for a microthermosyphon of 1.5mm ID and 220mm in total length at a power input of 8W (case 2)

3.3 Effect of the ratio of heated-length to cooled-length, L+

Fig. 10 illustrates the result when the condenser section is reduced to 110mm and 85mm, respectively, under the same conditions as given in case 1. The total heat transfer coefficient increase with decrease in the heated-length to cooled length ratio, L+, as shown in Fig. 10. Lee and Mital reported similar effects in their study on a two-phase closed thermosyphon. A decrease in L^* means that the area of condensing region increased and that of the evaporator decreased. This can be related by the following equation which is from an energy balance for the whole tube,

$$q = q_c/L^{+}$$

(q: heat transport rate) (3)

where q_c is the condensation heat flux at a given operating condition. The increased condenser area seems to provide a more efficient system as a whole. However, there must be a limiting L+ below which the opposite trend will take place.

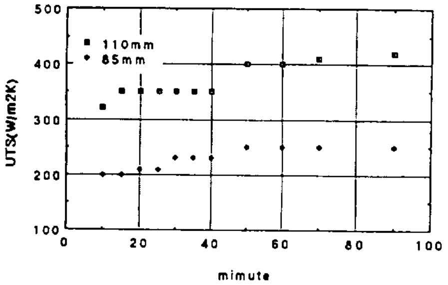

Fig. 10 Heat transfer results when the condenser length is reduced to 85mm

IV. Conclusion

In the present work, an experimental investigation has been carried out to study the heat transfer characteristics of a miniature two-phase closed thermosyphon. In order to visualize the operation of thermosyphons with small diameters on the order of a few millimeters, a number of microthermosyphons are fabricated with glass and observations are made on the motion of the working fluid. When the inner diameter of a thermosyphon reduces to about 3mm, the bubbles formed inside become motionless due to surface tension deactivating the thermosyphon cycle. It is almost impossible to properly operate a thermosyphon as its diameter becomes less than 3mm. The present study, however, has found that this predicament in the operation of a microthermosyphon could be resolved by introducing a wire insert which would promote the motion of bubbles-the thermosyphon action. This was vividly visualized in the glass microthermosyphon fabricated up to the order of 1mm ID. In practical terms, it is essential to introduce a wire insert in fabricating microthermosyphons whose inner diameters are less than 3mm. It has been also revealed that the size of a wire insert should be determined on the basis of working fluid properties.

V. 요 약

아주 작은(직경 수 mm) 밀폐형 써모싸이폰의 열전달 특성에 대하여 실험적 연구를 수행하였다. 물, 에탄올 그리고 메탄올 등이 작동유체로 사용되었으며, 써모싸이폰 내의 액상의 작동유체의 비등, 드랍의 분산, 그리고 증기의 응축등에 대한 현상을 관찰하기 위하여 가시화 실험을 수행하였다. 많은 작동변수중 본 논문에서는 삽입된 철사의 두께, 증발부와 응축부의 길이의 비 그리고 열유량에 대하여 그 영향을 살펴 보았다.

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