Characterstics of Top Heat Mode Thermosyphons
(Part II: An Improved Model)

By

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Summary: Thermosyphon works only on bottom heat mode and heat pipe equipped with wick can lift the returning working fluid about one meter at the best in gravitational field. If the thermosyphon has no directional restriction, it is very available and it can be used for wider purpose and area.

A lot of suggestion has been proposed concerning top heat mode thermosyphons, however, a few report has been presented on the experimental research. The top heat mode thermosyphon equipped with liquid lifting pipe heated at its bottom is one influential solution for recirculation of the working fluid.

1. NOMENCLATURE

Notation
A : heating surface $[m^2]$
d : inside diameter of pipe [m/s]
g : acceleration by gravity [mm]
H : initial liquid level in the lifting pipe [mm]
h : lifting height [m]
K : overall heat transfer coefficient $[W/m^2K]$
L : latent heat [J/kg]
l : length [m]
m : flow rate [kg/s]
Q : quantity of heat [W]
T : temperature [K]
η : efficiency [-]

Subscripts
ad : adiabatic section
c : condensing section
e : evaporating section
i : inner
o : outer
s : lifting pipe of liquid
v : vapour
w : water
0~10 : position of temperature measured

1. INTRODUCTION

Recentry, the following requests are arising:

(1) Accumulate the solar energy into the soil and regenerate it for space heating

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purpose as a trial of natural energy utilization.

(2) Regenerate the waste heat which is recovered at the elevated level for heating of combustion air at the ground level.

Above mentioned requests can be achived economically if we can apply the heat pipe principle which has no directional restriction of working fluid recirculation in the gravitational field. Such thermosyphon can be used for wider purpose and area not only above mentioned request.

One solution for this purpose is top heat mode thermosyphone utilizing small boiling phenomena for liquid returning in the lifting pipe. The experimental research for above mentioned thermosyphon has been continued by us about two years and the target of our research in the first year step was settled to observe the behavior of inside working fluid and to find out the conditions of its stable operation. Accordingly, the test apparatus made of heat-resisting glass was equipped with lifting pipe having a throttle and heating coil at its bottom, and also equipped with a wick between upper trap and evaporating section to transport liquid.

The purposes of our research on the second year step are as follows:

(1) To improve the constructions of the lifting pipe and the evaporating section to progress the heat transport ability and the liquid lifting efficiency.

(2) To discuss the factor which affect on the condition of stable liquid recirculation.

(3) To search the relation between heat input in the lifting pipe and heat transporting ability of the whole thermosyphon.

(4) To calculate the overall heat transfer coefficients in the evaporating, condensing section, and the heat transport efficiency.

2. EXPERIMENTAL APPARATUS

The Improved experimental apparatus used in this research and the details of evaporating section are shown in Fig. 1, and Fig. 2 respectively.

The equipment is composed of evaporating, condensing section, liquid lifting pipe and connecting pipe among them. They are all made of heat-resisting glass to observe the behavior of the working liquid from outside. To heat the liquid pool in evaporator, nickel-chrome electric heating wire of 0.29mm OD [electric resistance: 7.77Ω/m, total resistance 8.5Ω] is attached to the outside surface of it's bottom by an adhesive tape. The dimention of adiavatic and condensing section is 2.05mm thickness, 25mmOD, and 815mm total length. Cooling jacket (2.05mm thickness, 60mmOD, 270mm total length) and deaerator 2.05mm thickness, 12mmOD and 110mm total length, are attached to condensing section as one body.

Distilled water was enclosed as the working fluid and the temperature of each point (0)~(10) shown in Fig. 1 were measured by copper-constantan thermoconples. The improvements of the equipment of the present research compared with the previous year step one are as follows.

(1) By direct heating system in evaporator as mentioned above, heat conductive resistance of wick is eliminated. By putting into consideration of receiving solar

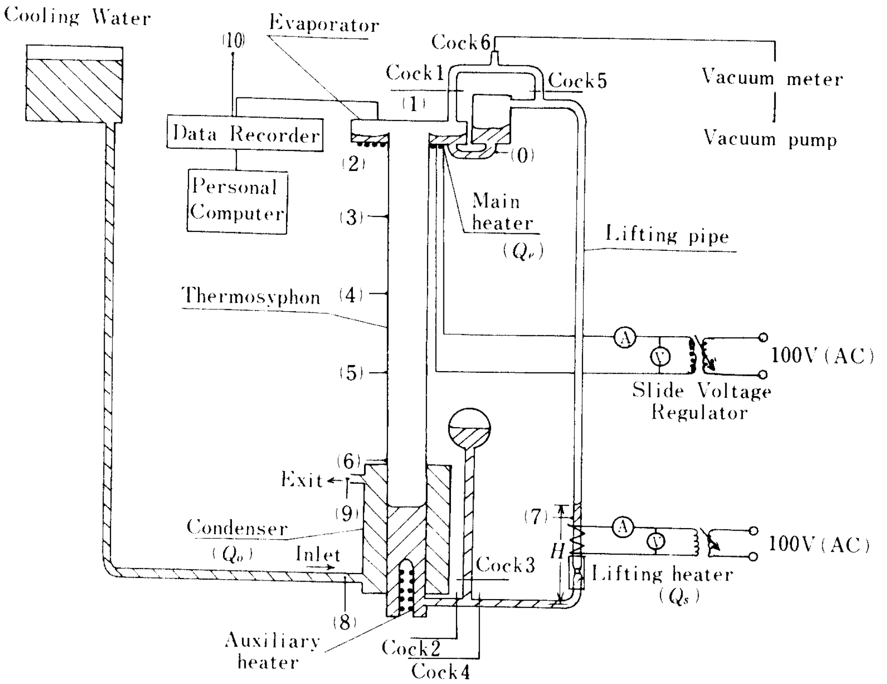


Fig. 1. Experimental Apparatus.

energy in near future, horizontal, flat and extended heating surface is prepared to obtain large collecting ability.

(2) By utilizing syphon system between the upper trap and the evaporating section to transport the liquid instead of wick as the 1st year step, the limitation of liquid transporting ability by wick was eliminated.

(3) Small ball and covering copper mesh were put on the throttle in the liquid lifting pipe as a check valve to eliminate downward energy loss at the bumping of liquid. Two kinds of type of liquid lifting pipe as shown in Table 1 were examined in the present study.

3. EXPERIMENTAL RESULT AND DISCUSSION

3–1 Patterns of liquid lifting

In case of existence of ball as a check valve in the lifting pipe, liquid lifting patterns are divided into three types as follows,

(1) Pattern 1:

After gradual rising of liquid temperature by lifting heater, the bumping occured at a certain temperature of liquid and the liquid was lifted to the upper trap. Lifting quantity of liquid by one bumping is generally constant and lifting intervals are periodical in this case.

(2) Pattern 2:

The pattern occurs in the case when stored liquid quantity is little above the check valve, and liquid block can not be lifted to the upper trap in one bumping.

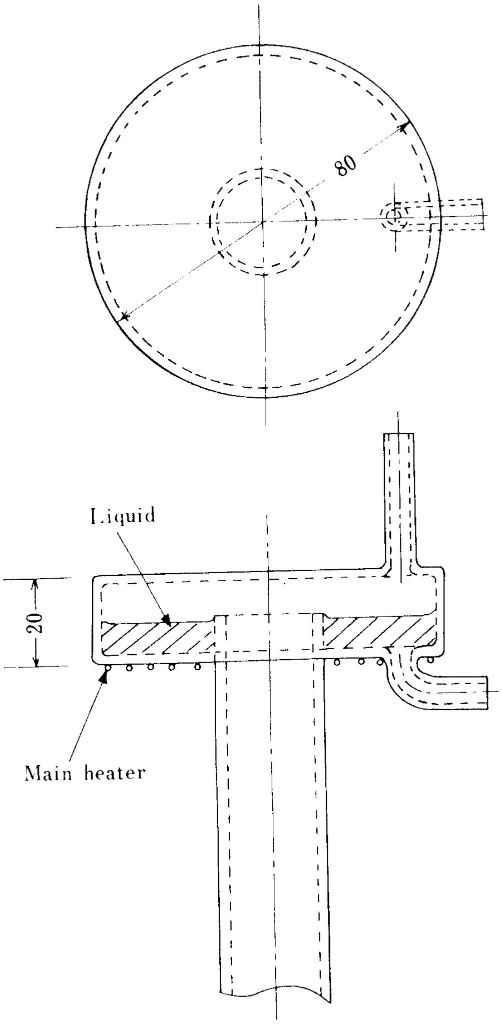


Fig. 2. Evaporator.

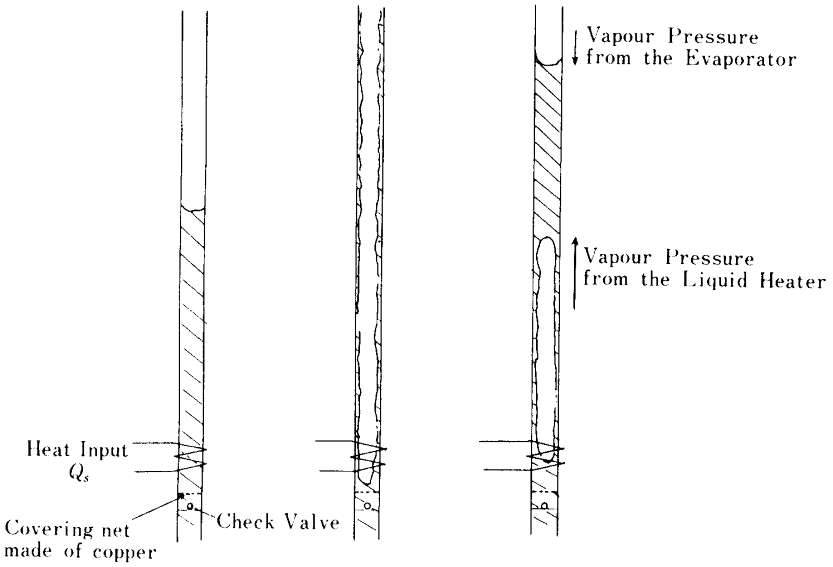
Table 1. Type and Specification of Lifting Pipe

Type	Outer Dia. (mm)	Inner Dia. (mm)	Total Length (mm)	Material of Ball and Dia. (mm)	Electric Resistance of Lift Heat (Ω)
Type 3–1	6	3.5	970	2.5mm Steel Ball	2.6
Type 3–2	7	4.5	970	3.3mm Glass Ball	4.6

After repeating several bumping, liquid columns were formed in the lifting pipe as in Fig. 3 and transported slowly to the upper trap by pressure difference between the lifting heater and the evaporating section.

(3) Pattern 3:

The liquid column formed in intermediate height between heater and upper trap in pattern 2 was shooted up suddenly to the upper trap. This phenomenon was seemed to cause by bumping of water which is flowed down from the water column and heated at the bottom heater.



Fi. 3. Liquid Lifting pattern.

The stable liquid lifting is continued mainly by pattern 1 and pattern 2. The pattern 3 occures in the case of small quantity of accumlated liquid or excessively high heat input of heater (it occures just before).

3–2 Region of stable operation

The region of stable transport of liquid in each type of lifting pipe is shown in Fig. 4.

The white circular marks in Fig. 4 show the reeation between Qs (heat input in lifting pipe) and Qe (heat input in evaporating section) in the case of stable transport of fluid. The cross marks show the data of dry out generation, and the range below the dotted line means stable working region.

The following results can be understood from Fig. 4.

(1) Liquid lifting ability is rapidly decreased at low value of Qs.

(2) Contrarily, in the region in which the Qs is bigger than the certain valve written in (1), stable transport of liquid can be attained untill the value of Qe which is approximately till fifteen times of Qs.

(3) The maximum quantity of heat transport can be attained at H=200~220mm (liquid level in the lifting pipe) in the case of 3.5mm inner diameter, and at H=180mm in the case of 4.5mm inner diameter.

The following improved results also can be observed by inserting the check value.

(1) Stable liquid lifting can be started in each following Qs value at the first step research.

for 3.5mm inner diameter	more than 7W
for 4.5mm inner diameter	more than 11W

However, the stable operation can be confirmed in smaller value of Qs in the improved equipment as follows,

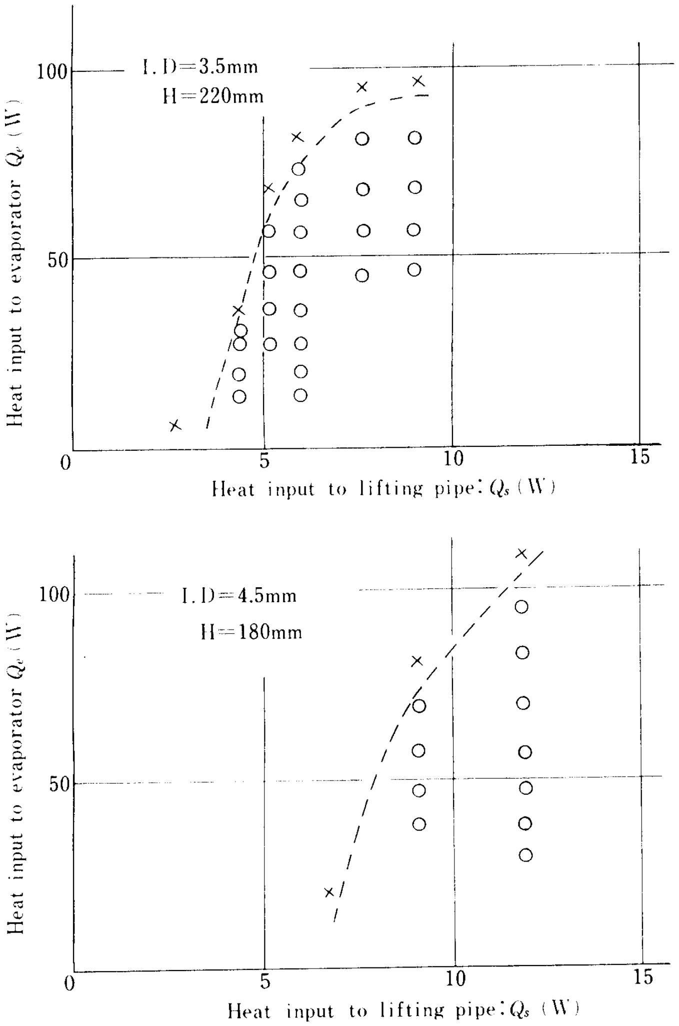


Fig. 4. Region of stable liquid recirculation.

for 3.5mm inner diameter, more than 3W
for 4.5mm inner diameter, more than 9W

(2) Up and down alternating movement of working liquid surface in the condenser was disappeared in the present research. The downward energy loss occured at liquid bumping in the previous one is realized to vanish in this study.
(3) Approximately fifteen times value of Qe to Qs can be acquired. In the previous study, the value of Qe/Qs was four to six.

3–3 Liquid lifting efficiency

The liquid lifting efficiency is calculated as follows.
The mass flow rate is given by

$$m = Qo/L \quad [kg/s] \qquad (1)$$

where

m = recirculating liquid quantity [kg/s]
Qo = heat transport quantity [W]
L = latent heat [J/kg]

The liquid lifting work from the level of the heater to the upper trap is presented as follows.

$$P = m \cdot h \cdot g \qquad [\mathrm{kg \cdot m^2/s}] \tag{2}$$

where

h = lifting height [m]

Accordingly, the liquid lifting efficiency is shown by Eq. (3)

$$\eta_o = \frac{P}{Qs} = \frac{Qo \cdot g}{L \cdot Qs} \tag{3}$$

where

Qs = heat input of the lifting pipe

The each liquid lifting efficiency is shown in Table 2 in both cases when lifting pipe has a throttle only and equipped with check value additionaly.

We can understand by Table 2 that liquid lifting efficiency has improved about two to three times in comparison with the case in the previous study, however, the absolute values of then are still low.

3–4 Overall heat transfer coefficients in the evaporating and condensing section

Being used heat-resisting glass as the materials of evaporating and condensing section, thermocouples could not be attached to the inside surface of glass wall. Therefore, the heat transfer coefficient on inside tube wall could not be measured.

Contrarily, measuring of vapour temperature, outside wall temperature in the

Table 2. Liquid Lifting Pipe

	Inner Dia. of Lifting Pipe (mm)	Qo (W)	Qs (W)	η_o (%)
Throttle only	3.5	80.0	26.0	0.0012
	4.5	105.0	25.0	0.0016
Throttle and check Valve	3.5	66.3	7.7	0.0033
	4.5	72.4	11.8	0.0022

evaporating section, and mean cooling water temperature in the condensing section were possible.

The heat transports in the evaporating and condensing section can be calculated (as forms of overall heat transfer coefficient) by utilizing above mentioned values. The overall heat transfer coefficients of both are presented as Eqs. (4) and (5)

$$Ke = \frac{Qo+Qad}{Ae(Teo-Tv)} \tag{4}$$

$$Kc = \frac{Qo}{Ac(Tv-Tw)} \tag{5}$$

where

Qo = heat output from the condensing section [W]

Qad = heat release from the adiabatic section [W]

Teo = outside surface temperature of evaporator [K]

Tv = vapour temperature [K]

Tw = mean cooling water temperature in the condenser [K]

Ae, Ac = heat transfer surfaces of the evaporating and condensing section [m^2]

The overall heat transfer coefficients Ke and Kc in the evaporator and condenser as the functions of Tv are shown in Fig. 5.

The following discriptions concerning Ke and Ke will be understood by Fig. 5.

(1) Evaporating section

a. The elevated value of Ke can be maintained for high vapour temperature range (for high heat input) in comparison with the case of previous study, because the evaporating limitation by wick has eliminated (direct heating from the bottom and pool boiling were applied in the present study). The decrement of Ke with increasing vapour temperature is similar tendency as in the report of the previous study. This is because that the value of Qad/Qo increases with the rising of vapour temperature.

b. The meam value of overall heat transfer coefficients are approximately from 500W/m^2K to 600W/m^2K, and the values are reasonable for low heat conductive material (heat-resisting glass) of evaporator.

(2) Condensing section

a. The heat output from the condenser Qo does not include heat release to atomsphere from the wall, and Kc maintains even and stable value over the whole rang of vapour tamperature Tv accordingly.

b. The mean value of the heat output from the condenser Qo is from 150W/m^2K to 180W/m^2K, and the value is approximately same as in the former report.

3–5 Efficiency of heat transport

The heat output in the condenser Qo can be calculated by Eq. (6), where ΔT is

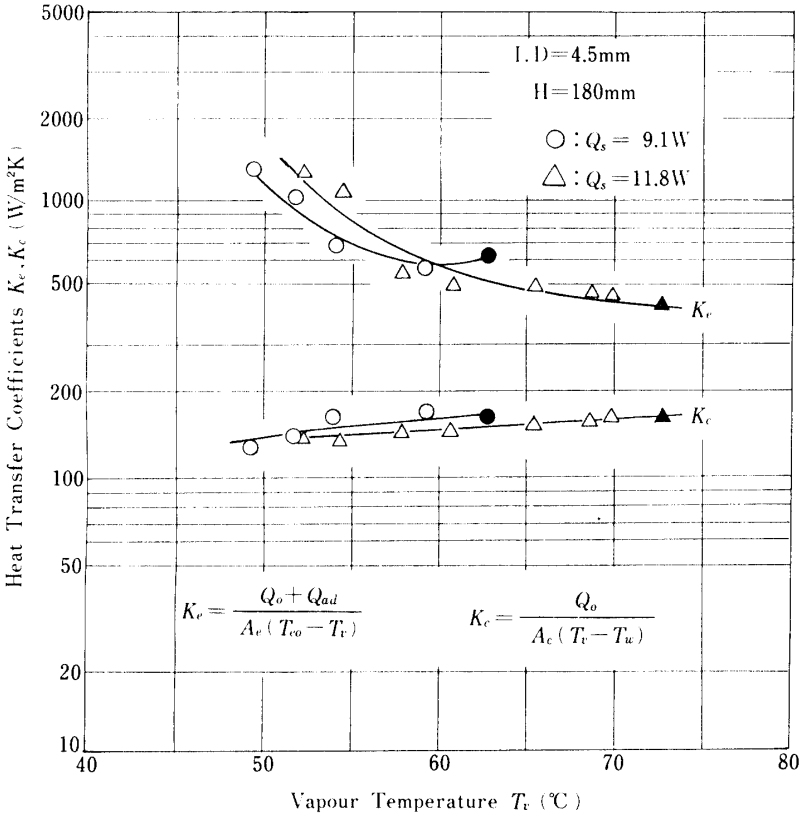


Fig. 5. Overall heat transfer coefficients of the evaporator and condenser.

temperature difference between inlet and outlet of condenser [K] and m is the flow rate of cooling water [kg/s]

$$Qo = 4180 \cdot \Delta T \cdot m \quad [W] \tag{6}$$

The efficiency of heat transport η_h is defined by Eq. (7)

$$\eta_h = \frac{Qo}{Qe + Qs} \tag{7}$$

The values of η_h as a function of Tv are shown in Fig. 6.

The construction of the evaporator is different from the one in the previous study as mentioned before, and the heat loss of the evaporating section is seemed widely to depend upon the construction of the evaporator. Therefore we can explain as follows.
(1) The heat loss of evaporting section is understood comparably low in compairison with the case in the previous study because of following reasons:
a) The heat transfer coefficient of water side is larger (pool boiling vs vaporizing through wick as mentioned before), and the wall temperature is lower for the same vapour temperature Tv than of the previous one.
b) As the heat convection rate from vertical surface, the construction in the previous study, to the atomosphere is larger than that of horizontal reverse surfase (the

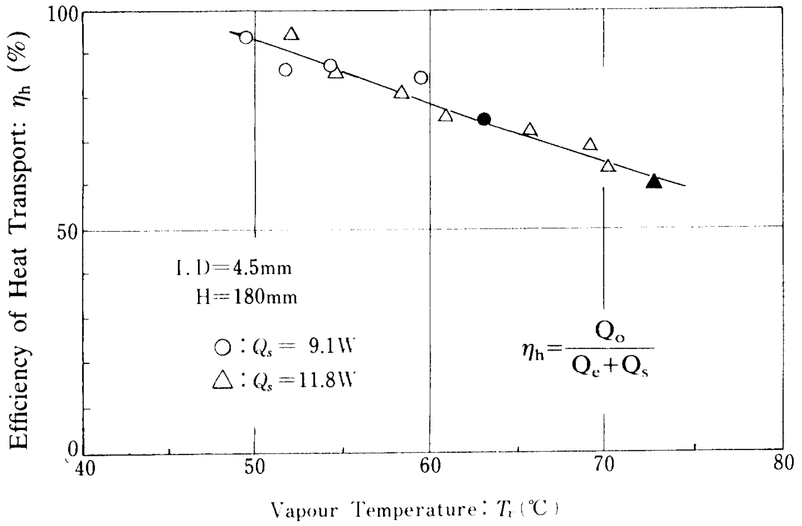


Fig. 6. Efficiency of heat transports.

construction in the present study) to the atomosphere.

c) Furthermore, the heating surface in this study is reduced to 63% of the previous one.

(2) The liquid lifting efficiency is considered to affect on the heat transporting efficiency, specially, in the region of low vapour temperature Tv, namely, low heat input to the evaporator Qe. Accordingly, the heat transporting efficiency in the region of low vapour temperature in this study can be increased as shown in Fig. 6, because of the improved liquid lifting efficiency.

(3) The tendency of the decreasing heat transporting efficiency η_h with increasing vapour temperature Tv is same as the value of Ke in Fig. 5. The tendency will be caused by saturating tendency of Qe with increasing value of Qs as shown in Fig. 4.

(4) According the large heat conductive resistance of heat-resisting glass, the heat loss of the evaporator is far more than the adiabatic section for the fixed Qo. The total heat loss is understood larger in compairison with the case of metal pipes. The mean value 60 to 70% of heat transporting efficiency in Fig. 6 is then considered reasonable by the above reasons.

4. CONCLUSIONS

The results of experimental research in the second step are concluded as follows.

(1) The improved ability of the liquid lifting pipe was confirmed by inserting check value in compairison with the former case (equipped with throttle only and without the check value).

(2) The inside diameter, intial liquid level and heat input to the liquid lifting pipe affect on the pattern and period of liquid lifting. The ability of the liquid lifting pipe is varied by above factor correspondingly.

(3) The liquid lifting efficiency has been improved from two to three times more than

that of the previous study, and the efficiency of heat transport is increased accordingly.

(4) Approximately fifteen times of heat transporting quantity can be attained to the value of heat input to liquid lifting pipe.

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