# Experimental Study of the Naphtaline Heaɿ Pipe

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## 1. INTRODUCTION

The heat pipe has been widely applied for cooling, heating and soaking in various fields of industry including plastic injection machine. Most of heat pipes used in these applications operate at low temperatures below 200 C, and the working fluid of them are mainly water, Freon or ethanole. Industrial needs for the heat pipes which are operable at medium and high temperature ranges over 200 C are increasing in order to recover waste heat from high temperature furnaces or to cool aluminum diecasting molds.

Dowtherm A and mercury can be used as the working fluid of the heat pipe in the medium temperature range. The former is operable between 150 and 400 C, and the latter is usable in the range of 200 to 500 C but is not practical due to its cost and poisonous character. Naphtaline is attractive working fluid due to its cost and easiness of handling for medium temperature range.

In this paper, the heat transfer characteristics, the fabrication method and also the life test result of the heat pipes using naphtaline as the working fluid are reported.

## 2. SPECIFICATIONS OF THE HEAT PIPE

Table 1 shows the specifications of the heat pipe tested. This is made of SUS 304 Stainless Steel tube of 25.5 mm in outside diameter, 1.5 mm in thickness and 1 m in length. Two layers of SUS 304 net of 50 mesh are used as wick. Naphtaline of 90 g which corresponds to about 20% of the inside volume of the heat pipe is filled. High grade naphtaline is supplied through Shin Nihon Seitesu Kagaku Ind. Co., Ltd., the physical properties of which are shown in Table 2, together with those of Dowtherm A. The latent heat and the surface tension at the baoiling point of it are

Table 1. Dimensions of the heat pipe tested

| | Material | Dimensions |
|---|---|---|
| Container | SUS 304 | 25.4 mmD×1.5 mmt×1 mL |
| Wick | SUS 304 | 50 mesh×2 layers |
| Working fluid | Naphtaline | 90 g |

* Suzuki Metal Industry Co., Ltd.

Table 2. Physical properties of Dowtherm A and Naphtalin

| Properties | Unit | Dowtherm A | Naphtaline |
|---|---|---|---|
| Molecular weight | | 166.0 | 128.2 |
| Boiling point | C | 257.7 | 218.0 |
| Specific heat | Cal/gC | 0.524 | 0.424 |
| Critical temperature | C | 497 | 475 |
| Critical pressure | atm | 31.2 | 40.0 |
| Thermal conductivity | Kcal/mC | 0.104 | |
| Burning point | C | 115 | 78.9 |
| Specific density | kg/m3 | 860 | 858 |
| Kinematic viscosity | cS | 0.294 | 0.1837 |
| Surface tension | g/m | 1.561 | 1.947 |
| Latent heat | Cal/g | 70 | 79.9 |

higher than those of Dowtehrm A and the kinematic viscosity is lower, which sugest that it is suitable for the working fluid of heat pipes.

## 3. Experimental Method

The experimental setup is schematicall) shown in Fig. 1. Electric sheath heater is used for heating and the heat input is determined from the voltage and the current of it. The evaporator section length is adjusted by changing the width of the sheat heater, which was 15 or 30 cm. Water jacket is used for cooling and the condenser section length is kept constant of 20 cm. Hot water of about 60 C is use as cooling water. When the naphtaline heat pipe is operating at the condenser temperature lower than 60 C and the heat input is turned off, all the working fluid freezes at the condenser section, because that the naphtaline is solid at room temperature. Later when the heat input is turned on again, dry-out occures particularly in case of the horizontal mode. Hot water at over 60 C is used in order to avoid this. The inlet and the outlet water temperatures and the flow rate are measured and the heat transfer rate of the heat pipe, $Q$, is determined by them. In order to minimize the

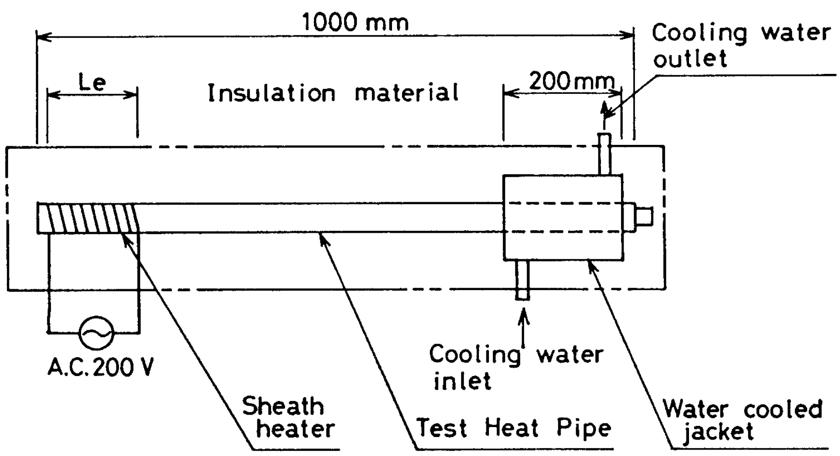


Fig. 1. Schematic diagram of the experiment.

direct rediation loss to ambient, the entire system was covered by insulating material.

Under a specified heating and cooling condition, the temperature distributions are monitored, and when the final steady state is achieved, the data are taken. The same procedure is repeated while the sheath heater length, the cooling water flow rates and the setting angle of the heat pipe are changed to determine the heat transfer characteristics of the heat pipe.

## 4. Experimental Results and Discussions

### 1) Heat Transfer Characteristics

Figs. 2 thru 4 show the temperature distributions of the naphtalin heat pipes tested. Fig. 2 is in the vertical mode, in which the liquid tends to accumulate in the evapo-

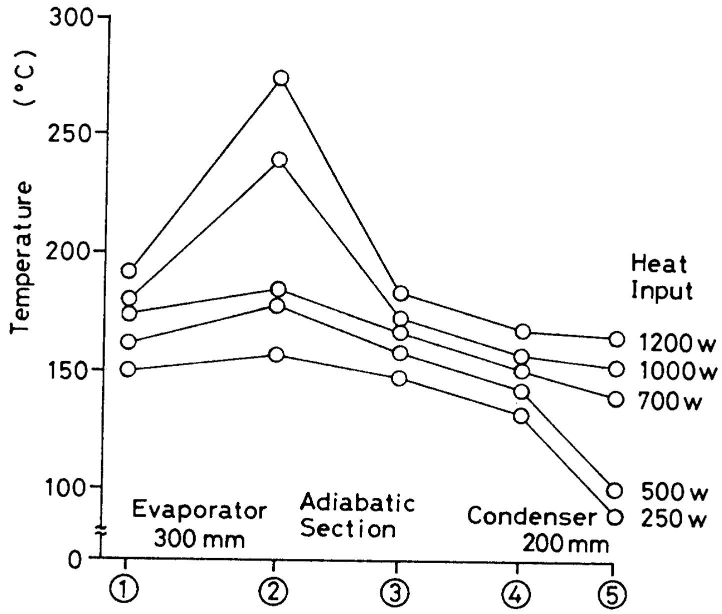


Fig. 2. Temperature distribution in vertical mode.

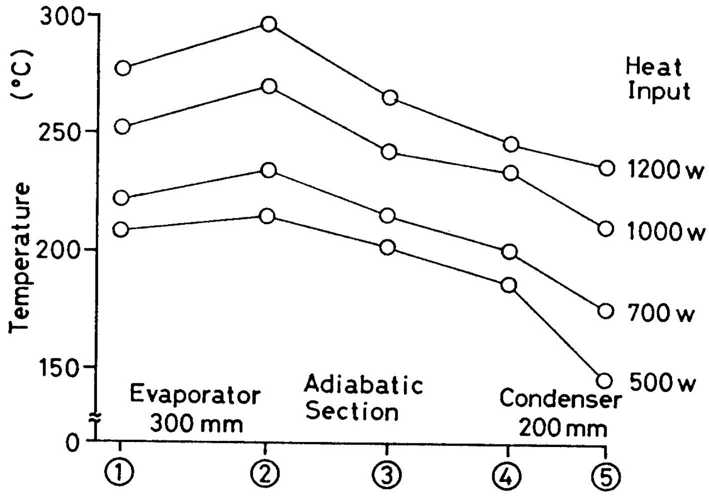


Fig. 3. Temperature distribution in horizontal mode.

rator causing irregular temperature distribution. Fig. 3 shows the relatively smooth temperature distributions at the horizontal mode. Fig. 4 is also at the horizontal mode with the shortened heater. The influence of the noncondensable gas is found in the condenser end when the evaporator temperature is about 150 C. When the the temperature rises to 180 to 200 C, this effect disappears. Therefore, the lowest

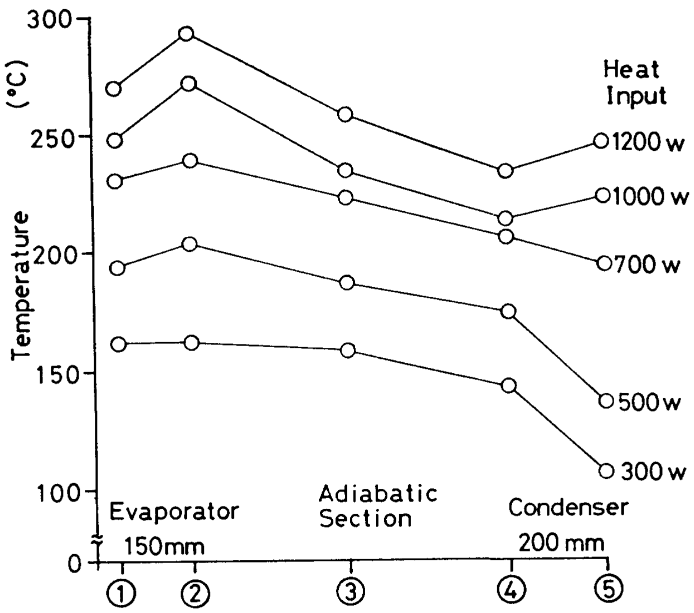


Fig. 4. Temperature distribution in horizontal mode with shortened heater.

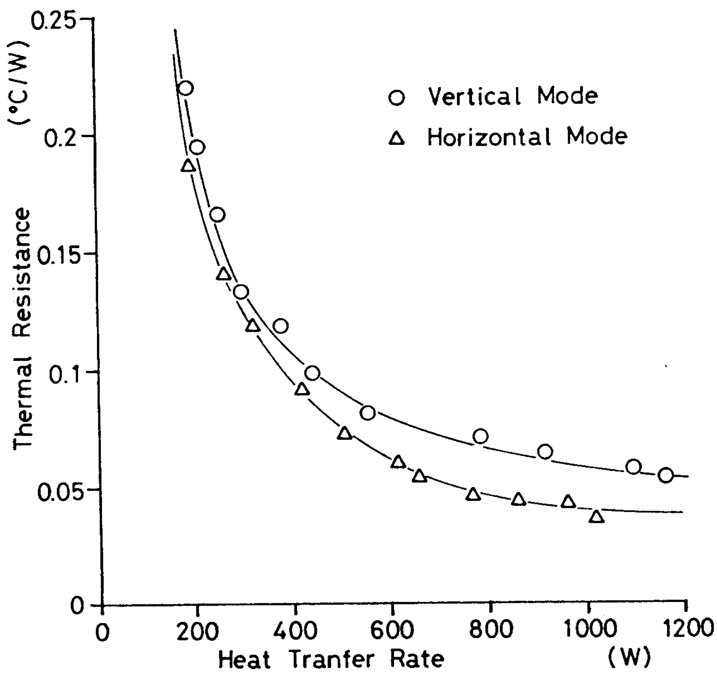


Fig. 5. Thermal resistance.

operating temperature of this heat pipe is to be set at 150 C. Although the testing facility can measure only up to about 300 C, it is conjectured that this heat pipe is operable up to the critical temperature of 475 C of naphtaline.

Fig. 5 shows the relation between the heat transfer rate and the thermal resistance, $R$, $R=(Te—Tc)/Q$, where $Te$ and $Tc$ are the temperatures of the evaporator and

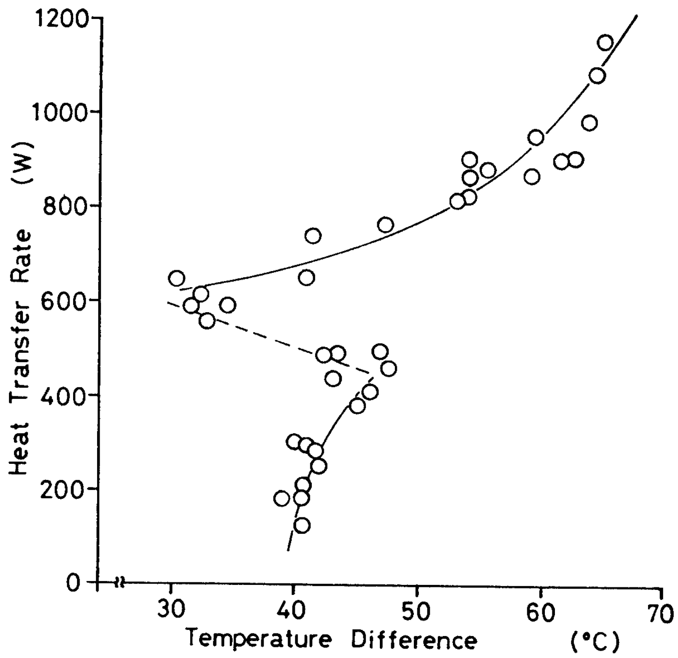


Fig. 6. Heat transfer rate in vertical mode.

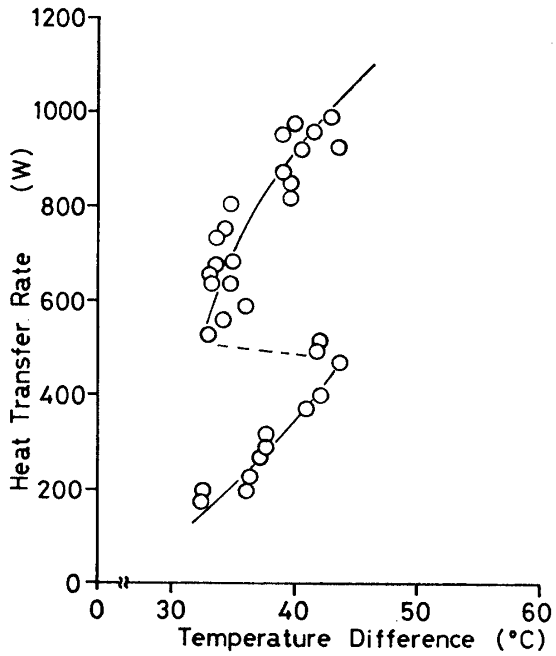


Fig. 7. Heat transfer rate in horizontal mode.

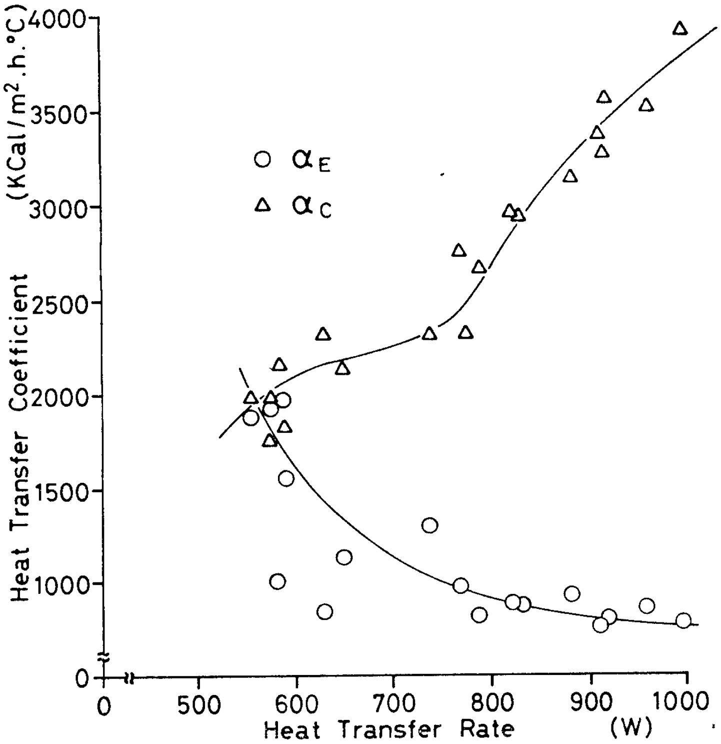


Fig. 8. Heat transfer coefficient in vertical mode.

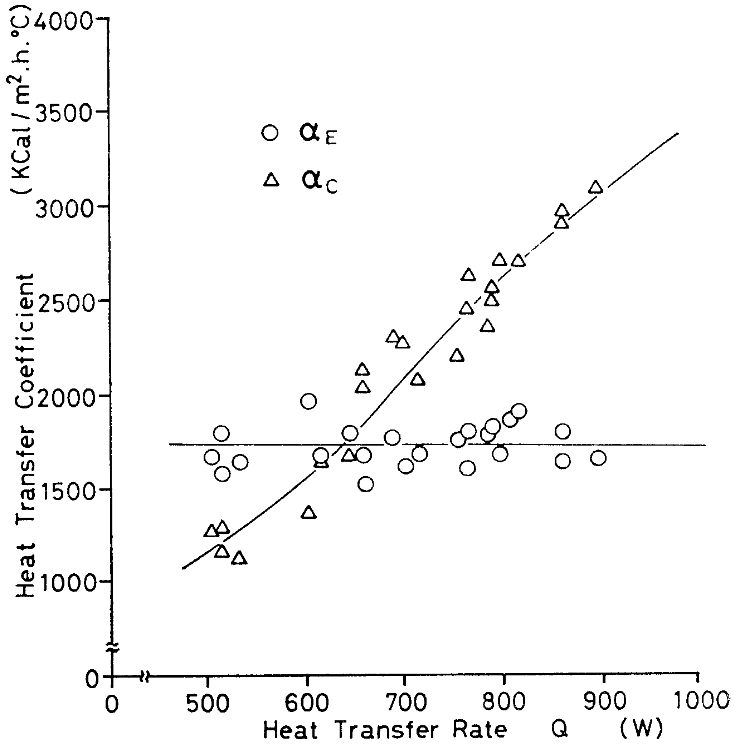


Fig. 9. Heat transfer coefficient in horizontal mode.

the condenser, respectively. The thermal resistance in the vertical mode is slightly higher than in the horizontal mode, which may due to the liquid pool at the evaporator end. The thermal resistance measured shows monotonically decreasing trend over the tested range, which suggests that this heat pipe still has some allowance to reach the maximum heat transfer capacity.

The heat transfer rates are plotted against the temperature difference of the evaporator and the condenser in Figs. 6 and 7. Initially, the heat transfer rate increases with increase of the temperature difference, and at a certain level of the heat transfer rate of about 500 W, which corresponds to the heat transfer rate of 10 W cm on the evaporator surface, it sudenly decreases. Then it begins to increase again. This is the condition where the flooding occures in the heat pipe.

The heat transfer coefficients of the evaporator section, *De,* and of the condenser section, *Dc,* are plotted against the heat transfer rates in Fig. 8 and 9, which correspond to the vertical mode and the horizontal mode, respectively, where $De = Q/Ae^*(Te\text{-}Ta)$, $Dc = Q/Ac^*(Ta\text{-}Tc)$, $Ta$ is the temperature of the adiabatic section and $Ae$ and $Ac$ are the surface area of the evaporator and the condenser, respectively. The values of *Dc* gradually increase with increase of the heat transfer rate regardless of the vertical or horizontal modes. Those of *De* in the horizontal mode remain almost constant, but in the vertical mode much irregularity is seen, probably due to the liquid pool in the evaporator.

2) Life Test

Life test is performed in order to check the life of naphtaline and its compatibility with SUS 304. The heat pipe used has the same dimensions as that used in the previous test, and the temperature measuring points are increased in order to detect the gas generation. The evaporator is 30 cm long and heated by the sheath heater. The condenser is 50 cm long and cooled by natural air convection. The heating rate is 780 W and on-off controlled so as to keep the evaporator temperature at 420 C. The thermal resistance is derived from the mean temperature difference of the evaporator and the condenser divided by the heat transfer rate.

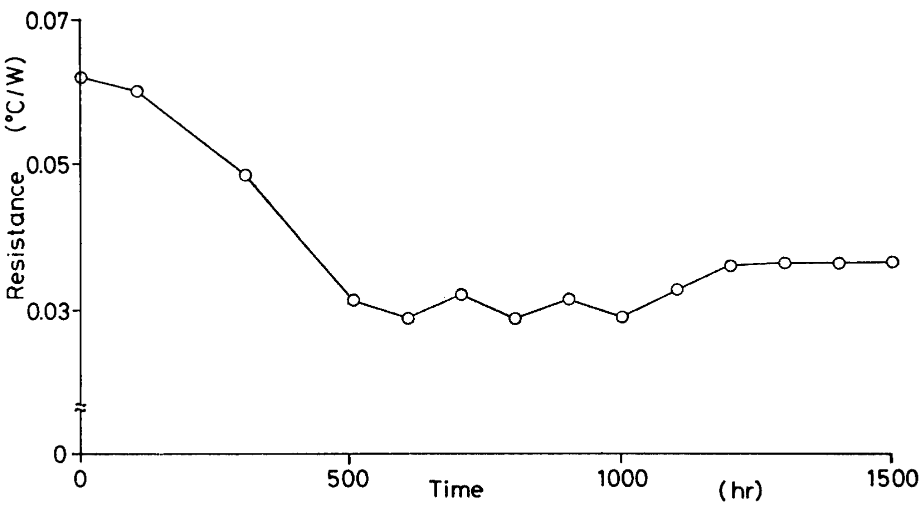


Fig. 10. Variation of thermal resistance during life test.

Fig. 10 shows 1500 hour test result, which shows that the thermal resistance up to 500 hours is relatively high. This is probably because wetting between the working fluid and the wick improves gradually. Generation of noncondensable gas or deterioration of the working fluid is not detected at al after 1500 hour life test. This test is still continuing at the present moment.

## 5. CONCLUSIONS

It is concluded that naphtaline has adequate physical properties as the working fluid of heat pipes in the medium temperature range and the heat transfer characteristics of the heat pipe using it are good. Its operating range is 150 to 475 C, which covers the range of Dowtherm A. The testing facility used could not check up to the maximum heat transfer capacity, though, it is conjectured, judging from the data measured and the literatures provided, that the heat transfer coefficient up to 10 W cm at the evaporator section may be possible. Since naphtaline is solid at room temperature, it crystalizes on the condenser part when excessively cooled. Therefore special precautions are required in its application to common water-cooled aluminum diecast or low temperature pre-heaters.

Further study on the heat transfer characteristics at higher temperature up to the maximum heat transfer capacity is in progress, and the life test has been still continuing. Also several application tests of the naphtaline heat pipe has been undertaken at the same time.

## REFERENCES

[*1*] JIS K 2436–1978 Naphthaline, anthracene and carbazole.

[*2*] "Selection of operating liquids for medium temperature heat pipe", Suzuki and Koizumi, Technical reports edited by Japan Society of Mechanical Engineers (SectionB).

[*3*] Catalog (Chemical Products) issued by Shin Nippon Seitetsu Kagaku Ind. Co., Ltd.

[*4*] "Heat Transfer Engineering", Revision No. 3, Japan Society of Mechanical Engineers.