Experimental Study of Silicon Oil Effect on Two-Phase Closed Thermosyphon

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1. Introduction

Two-phase closed thermosyphon (TPCT) is vertically oriented wickless heat pipe that has working fluid in the interior. The TPCT transports a large amount of heat from evaporator to condenser by phase change of working fluid, and the working fluid passively returns to evaporator by gravity. Due to these advantages of the TPCT, the TPCT is considered as method of PRHR (Passive Residual Heat Removal) system in nuclear system.

Parametric studies have done to investigate the heat transfer characteristics of the TPCT. Different working fluids such as water, ethanol, methanol and acetone were used at various filling ratios and at different operating temperatures to find maximum heat transport capabilities of TPCT [1]. Effect of heat transfer rate, filling ratio and aspect ratio were investigated [2]. Inclined angle effect was investigated at several filling ratios and working fluids [3].

Additive effect such as nanoparticle on the TPCT have done been investigated. Various additive were used for experiment with several weight percent: Ag [4], Al_2O_3 [5] and Laponite clay, CuO and Al_2O_3[6]. Most additives made better thermal performance of TPCT, but some additive made worse even through same additive. Many studies are interested in nanoparticle additive.

This study is interested in silicon oil effect on the TPCT. To carry out the experiment, experimental apparatus is designed and manufactured. In design process, the TPCT operation limit is considered [7]

This study is interested in silicon oil effect on the TPCT. Experiments were carried out at three oil weight percent with three input power. Effect of oil on the TPCT is evaluated by inner wall temperature distribution and thermal resistance.

2. Experiments

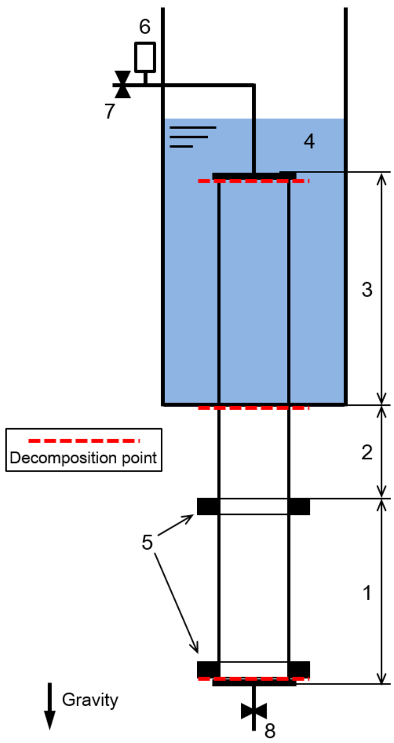
2.1 Experimental apparatus

To study effect of silicon oil, TPCT was designed (Fig. 1). The TPCT was made of stainless steel 304 with outer diameter of 42.7 mm and length of 1100 mm, and vertically installed. All the other geometric parameters of the TPCT are presented in Table 1. The heating method involved direct heating via the evaporator itself. The condenser part was cooled by cooling tank, and water of cooling tank finally reaches boiling temperature. Evaporator and adiabatic parts are insulated by insulation cotton to prevent heat loss. Pipe can be disassembled and its point is marked in Fig. 1.

Total twenty nine T-type thermocouples, which have ± 0.5 °C error, were used to measure the wall temperature, working fluid bulk temperature and steam temperature; several thermocouples are inserted into pipe to measure the bulk and steam temperature. The thermocouples location is described in Fig. 2. Pressure gage was installed at the top of the condenser part to measure the system operating pressure.

Table 1. Geometric parameters

Total length	1100 mm
Evaporator length	400 mm
Adiabatic length	200 mm
Condenser length	500 mm
Outer diameter	42.7 mm
Inner diameter	40.5 mm



1. Evaporator 2. Adiabatic part 3. Condenser
4. Cooling tank 5. Electrode 6. Pressure gage 7, 8. Ball valve

Fig. 1. Schematic diagram of experimental apparatus

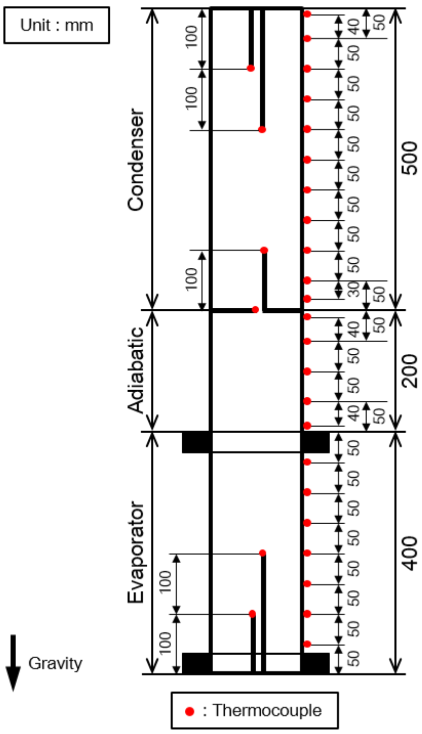


Fig. 2. Thermocouple location

2.2 Experimental condition and procedure

In this study, experiment was design to be in the allowable operational range of the TPCT. Thermosyphon dry out does not occur over 40 % filling ratio [8]. There is no major dependence between maximum operation power and filling ration [1]. All experiment of this study were done under 100 % filling ratio. Filling ratio is ratio of total evaporator volume to working fluid volume.

Water is suit for working fluid at high operation power [1]. In this study, DI water was used as basic working fluid, and the experiments were carried out at three input power: 5, 8, 11 kW.

To investigate the silicon oil effect on the TPCT, 100 cSt silicon oil were used for this study, and the silicon oil thermal properties are in Table 2. The experiments were carried out at three oil weight percent: 0.5, 2.0 and 5.0 w/o.

Table 2. Silicon oil thermal properties

	100 cSt oil
T_{flash}	> 326
ν (@ 20 °C)	100 cSt
ρ (@ 25 °C)	0.964
σ (@ 25 °C)	20.9
k (@ 50 °C)	0.155

Experiments were carried out, after cooling tank water reached boiling temperature, and all temperature were measured at steady state condition. Non-condensable gas was vented, during heating the cooling tank, by using pipe interior pressure.

After oil added experiment, pipe was cleaned up to eliminate oil. After cleanup, the TPCT was operated with pure water to check removal of oil.

3. Results

Fig 3, Fig. 4 and Fig. 5 show inner wall temperature distribution at 5, 8 and 11 kW respectively with pure water, 0.5 %, 2.0 % and 5.0% oil weight percent. Inner wall temperature was calculated by solving conduction equation with measured outer wall temperature.

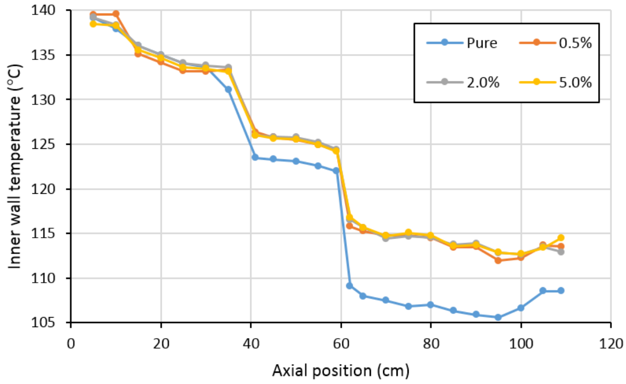


Fig. 3. Inner wall temperature distribution at 5 kW

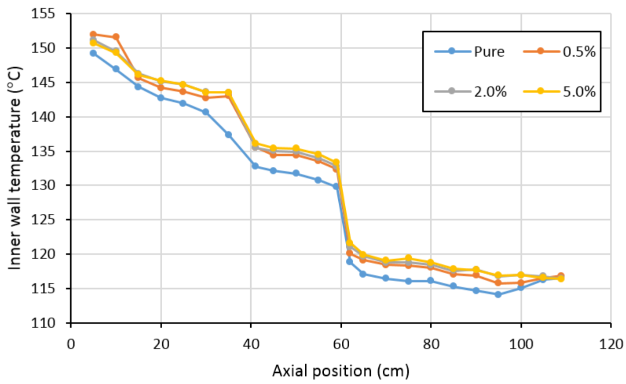


Fig. 4. Inner wall temperature distribution at 8 kW

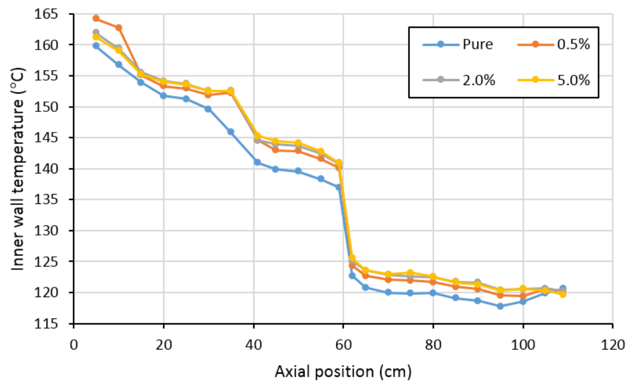


Fig. 5. Inner wall temperature distribution at 11 kW

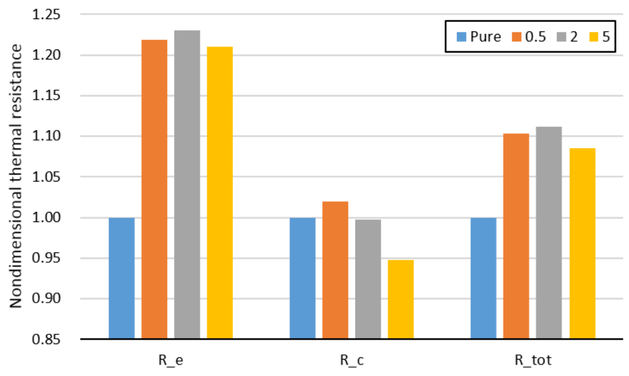


Fig. 6. Nondimensional thermal resistance at 5 kW

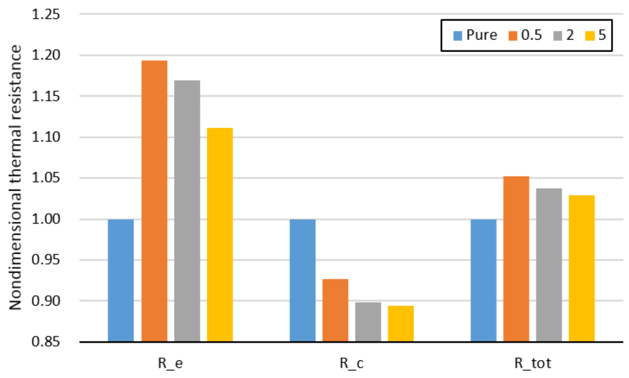


Fig. 7. Nondimensional thermal resistance at 8 kW

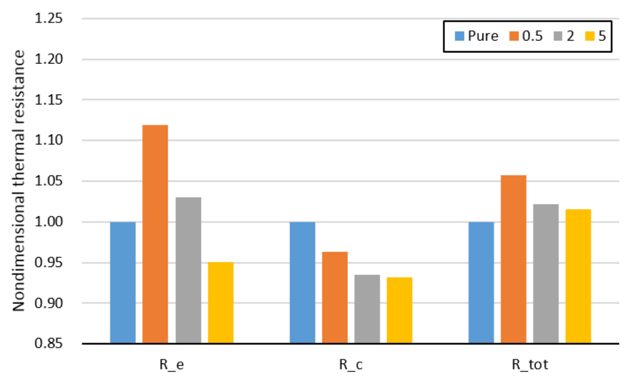


Fig. 8. Nondimensional thermal resistance at 11 kW

Fig. 6, Fig 7 and Fig. 8 show nondimensional thermal resistance at 5, 8 and 11 kW respectively with pure water, 0.5 %, 2.0 % and 5.0% oil weight percent. Each thermal resistance is calculated as follow:

$$R\_e = \frac{\overline{T_{eva}} - \overline{T_{bulk}}}{P} \quad (1)$$

$$R\_c = \frac{\overline{T_{steam}} - \overline{T_{cond}}}{P} \quad (2)$$

$$R\_tot = \frac{\overline{T_{eva}} - \overline{T_{cond}}}{P} \quad (3)$$

Nondimensional thermal resistance (η) is calculated as follow:

$$\eta = \frac{R\_oil}{R\_pure} \quad (4)$$

From Fig. 3 to Fig. 5, most wall temperature increased when oil was added to working fluid, but its increasing value was not dependent on oil weight percent.

From Fig. 6 to Fig. 8, the silicon oil reduced thermal performance of evaporator, but evaporator thermal performance was enhanced at high input power and high oil weight percent. On the other hand, the silicon oil enhanced condenser thermal performance except 0.5 w/o oil with 5 kW. These two effect of silicon oil on the TPCT competed with each other, therefore total thermal performance was reduced. Total thermal performance was reduced at all input power, and its magnitude decreased with input power. It means that silicon oil effect is minimized at high input power.

4. Conclusions

In this study, silicon oil effect on TPCT was investigated. The TPCT was operated with several oil weight percent and input power. From experiment, overall, the silicon oil reduced evaporator thermal performance, but enhanced condenser thermal performance. However, the TPCT total thermal performance was reduced by 100 cSt silicon oil.

Nomenclature

T_{flash}	Flashing temperature (°C)
$\overline{T_{eva}}$	Averaged evaporator inner wall temperature (°C)
$\overline{T_{cond}}$	Averaged condenser inner wall temperature (°C)
$\overline{T_{bulk}}$	Averaged working fluid bulk temperature (°C)
$\overline{T_{steam}}$	Averaged steam temperature (°C)
R_e	Evaporator thermal resistance (K/W)
R_c	Condenser thermal resistance (K/W)
R_tot	Total thermal resistance (K/W)
R_oil	Thermal resistance with oil (K/W)
R_pure	Thermal resistance with only water (K/W)
ν	Kinematic viscosity (cSt = 10^{-6} m^2/s)
ρ	Density (kg/m^3)
σ	Surface tension (10^{-3}N/m)
k	Thermal conductivity (W/m-K)
P	Input power (W)

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