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PERFORMANCE CHARACTERISTICS OF AN ARTERY WATER HEAT PIPE WITH LARGE STEP HEAT INPUTS AND ADVERSE TILT ANGLES

Jong Hoon Jang
Dept. of Mechanical Engineering

<Abstract>

A water heat pipe which has an artery wick structure made by using sintered copper powder was tested to demonstrate the high heat transport capability. Three aluminum heater blocks were mounted longitudinally on the surface of the evaporator section to provide a maximum heat input of 4.8 kW. A maximum step heat input of 3.3 kW was applied to the evaporator. The experimental results show the artery wick structure performed well at both high and low temperatures. The water heat pipe transported 4.5 kW (9.03 W/cm^2) without dry-out at the evaporator. Axial temperature gradients between the evaporator and condenser sections during these tests were negligibly small. The heat pipe was tested with the adverse tilt angles up to 4 degrees to check gravity effect. Heat transport capability dropped significantly with the adverse tilt angles.

역기울기와 큰 열 입력 상태에서의 아터리 히트 파이프의 성능 특성

장종훈
기계공학과

<요 약>

본 논문에서는 구리 분말을 신터링하여 제작한 아터리 윅과 물을 작동 유체로 사용한 히트 파이프의 높은 열전달 능력을 시험하였다. 세개의 전기 히터가 히트 파이프의 증발

부의 표면에 길이 방향으로 설치되어 최대 4.8kW의 열을 히트 파이프에 가할 수 있었다. 최대 계층 열 입력 3.3kW가 증발부에 가하여졌다. 실험 결과는 본 히트 파이프에 사용된 아터리 윅이 고온과 저온에서 잘 작동되었음을 보여주었다. 즉 본 히트 파이프는 증발부에서의 dry-out 없이 4.5kW(9.03W/cm^2)의 열을 전달하였다. 히트 파이프의 증발부와 응축부 사이의 축 방향에서의 온도 차이는 무시할 정도로 매우 작았다. 중력이 히트 파이프에 미치는 영향을 연구하기 위하여 히트 파이프의 응축부가 증발부 보다 높은 상태로 4도까지 기울인 조건에서 시험하였으며, 이와 같은 조건에서는 히트 파이프의 열 전달 능력이 현저히 떨어졌다.

1. INTRODUCTION

Heat pipes effectively transport large amount of heat with small temperature gradients. Thus, water heat pipes are being considered to reject waste heat from a Nuclear Stirling Power Conversion System. However; heat pipes have several operating limits. The two limits of primary concern are the capillary and boiling limits. To avoid these limits an improved wick structure has been designed to increase heat transport capability.

Water heat pipes have been tested to study various phenomena and applications. For normal transient tests, Shlosinger(1) studied a technique to control humidity and temperature in a space suit by using a water heat pipe. McKinney(2) conducted experimental and analytical studies with small heat input over a temperature range of from 366 K to 450 K. Jang(3) tested a grooved water heat pipe to investigate dry-out and rewetting of wick structures. Reinarts(4) made visual observations of internal flow through glass top of a specially configured water heat pipe. All tests mentioned above used heat inputs of less than several hundred watts.

To increase heat transport capability of water heat pipes, Faghri and Thomas(5) built and tested a concentric annual heat pipe and Ponnappan et al.(6) tested a double-wall artery heat pipe. The concentric annual heat pipes transported a maximum heat load of 1.3 kW and a maximum operating temperature was 343 K. The double-wall artery heat pipe transported a maximum heat load of 1.8 kW at about 470 K.

This paper presents the experimental results of tests on a water heat pipe with a sintered copper powder artery wick structure. Large step heat inputs were applied to study transient performance of the heat pipe. Also, experiments were conducted to investigate operating temperature range of the water heat pipe and heat transport capability with adverse tilt angles.

2. EXPERIMENTAL SETUP

A water heat pipe which has a sintered copper powder artery wick structure was used for experimental study. The total length of the heat pipe is 0.9144 m and the lengths of the listed in Table 1.

A cross sectional view of the artery wick structure(7) is shown in Fig. 2. The wick structure is made of two different sizes of sintered copper powder and has one internal artery to provide for returning liquid. The coarse copper powder wick structure has a pore radius of 3.5 x 10^{-5} m and the permeability of 2.5 x 10^{-11} m^2. The fine copper powder wick structure has a pore radius of 1.0 x 10^{-5} m and a permeability of 1.87 x 10^{-12} m^2. The outer diameter and thickness of the wick are 0.03854 m and 0.00178 m, respectively. The diameter of the artery is 0.00472 m. Seventy five ml of water was used as the working fluid.

To measure the surface temperature of the heat pipe(8), a total of 16 chromel-alumel thermocouples were installed as shown in Fig. 1. Twelve thermocouples out of sixteen were placed at the evaporator. There were three peripheral thermocouples at each of the two axial locations and six peripheral thermocouples at the center of the evaporator to investigate temperature variation around the circumference. Thermocouples (Nos. 0 and 17) were mounted at the center of insulated surfaces of the evaporator and condenser end caps to measure temperature closest to the vapor temperature. Another two thermocouples were used to measure inlet and outlet temperatures of the coolant. All thermocouples were connected to a data logger. The data was stored on a personal computer by using communications software.

3. RESULTS AND DISCUSSIONS

The water heat pipe, initially at ambient temperature, was tested to demonstrate fast transient performance by applying large step heat input of 3.3 kW from heaters 1 and 2. Temperature along the heat pipe increased rapidly and then the heat pipe reached a steady state without dry-out of the wick as shown in Fig. 3. When an additional heat input of 1.6 kW from heater 3 was added, the heat pipe transported 4.5 kW heat out of 4.8 kW (1.17 kW/m^2) heat input. The temperature difference between both ends of the heat pipe was negligible. When heaters 1 and 2 were suddenly turned off, isothermal conditions were maintained at the evaporator and adiabatic sections. However, the temperature at the condenser end cap was about 7 K less than those at other locations. This temperature difference disappeared when heat input was increased. This may indicate that an excessive amount of water accumulated near the condenser end during the sudden reduction of heat input at the evaporator. The sintered copper wick structure with an artery provided good capillary pumping capability under transient conditions.

An operating temperature of above 500 K was attempted by reducing the coolant flow rate from 50 ml/s to 15 ml/s for the maximum heat input. At this temperature range, the physical properties of water related to heat pipe operation such as the surface tension, heat of vaporization, and density are much smaller than those at ambient temperature as shown in Fig. 4. Also, the vapor pressure increases rapidly. Thus, performance of water heat pipes decreases significantly. Test results and heat inputs as shown in Fig. 5 show that the heat pipe temperature reached about 510 K without dry-out at the evaporator. The temperature distribution along the heat pipe was uniform. This may indicate that the heat transport capability of this heat pipe could be higher than the maxi mum heat input.

Tests were conducted with an adverse tilt angle to investigate the effects of gravity. First, the evaporator end was elevated by 1.5 degree angle and then the step heat inputs were added to the evaporator as shown in Fig. 6. When the heat input was increased, temperatures at the evaporator and the evaporator end cap started to deviate from temperature at the adiabatic section. Then, with larger heat input the temperature at the evaporator rapidly increased while temperatures at the adiabatic and condenser sections were increased little. This indicates that the vaporization of the working fluid at the evaporator was not enough to cool the evaporator. When the elevation of the evaporator section was eliminated with the same heat input, the temperatures at the evaporator and the evaporator end cap were suddenly decreased to the temper ature at the adiabatic section. This means that the dry-out condition existed at the evaporator was disappeared when the heat pipe was leveled.

After the heat pipe reached the steady state, the evaporator section was elevated again by the same angle. The temper atures at the evaporator and evaporator end cap rose rapidly as before, indicating that part of the evaporator section was undergoing dry-out again. Fig. 6 shows similar temperature variations at the evaporator and evaporator end cap. From this one may conclude that the gravity field resulting from the elevation of the evaporator reduced performance of the heat pipe.

Fig. 7 shows the comparison of the heat transport capabilities of three heat pipes with adverse tilt angles. Each heat pipe has a unique configuration such as concentric wall(5), double-wall artery(6), and sintered powder artery. The test results of the heat pipe show that dry-out of the evaporator was not detected until adverse tilt angle reached about 0.8 degree angle. Thus, the maximum heat transport capability of the heat pipe could be much higher than 4.5 kW which was the largest amount with the present heating system. Also, Fig. 7 shows that the heat transport capabilities of all three heat pipes dropped signifi cantly with small change of the adverse tilt angles. This means that if the gravity field exists, the level of heat pipes is a very important factor to consider during the installation of heat pipes.

4. CONCLUDING REMARKS

A water heat pipe with an internal artery was tested to study heat transport capability and transient performance with large step heat inputs. The water heat pipe transported 4.5 kW (9.03 W/cm^2) without dry-out at the evaporator. Also, the artery wick structure performed well for the sudden heat input of 3.3 kW. A maximum operating temperature of 510 K was achieved for the water heat pipe. The effect of adverse tilt angles on the heat transport capability was significant and is a very important factor to consider in gravity field.

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Table 1. Water Heat Pipe Design Summary.

Heat Pipe Wall	
Material	Alloy 110 Copper
Total Length	0.9144 m
Evaporator	0.3842 m
Condenser	0.3874 m
Outer Diameter	0.04128 m
Inner Diameter	0.03854 m
Wall Thickness	0.00137 m
End Cap Thickness	0.00317 m
Wick Structure	
Type	One Inner Artery
Material	Sintered Copper Powder
Outer Diameter of Wick	0.03854 m
Thickness of Wick	0.00178 m
Diameter of Artery	0.00472 m
Working Fluid	
Water	75 ml
Total Weight of Heat Pipe	3.09 Kg
Heater Block	
Heater	"Firerod" Cartridge Heater
Electric Resistance	25 Ohms
Length	0.381 m
Diameter	0.0119 m
Heater Block Material	Aluminum
Size	0.381 x 0.03175 x 0.03175 m
Weight	0.964 Kg
Calorimeter	
Length	0.3874 m
Diameter	0.0508 m

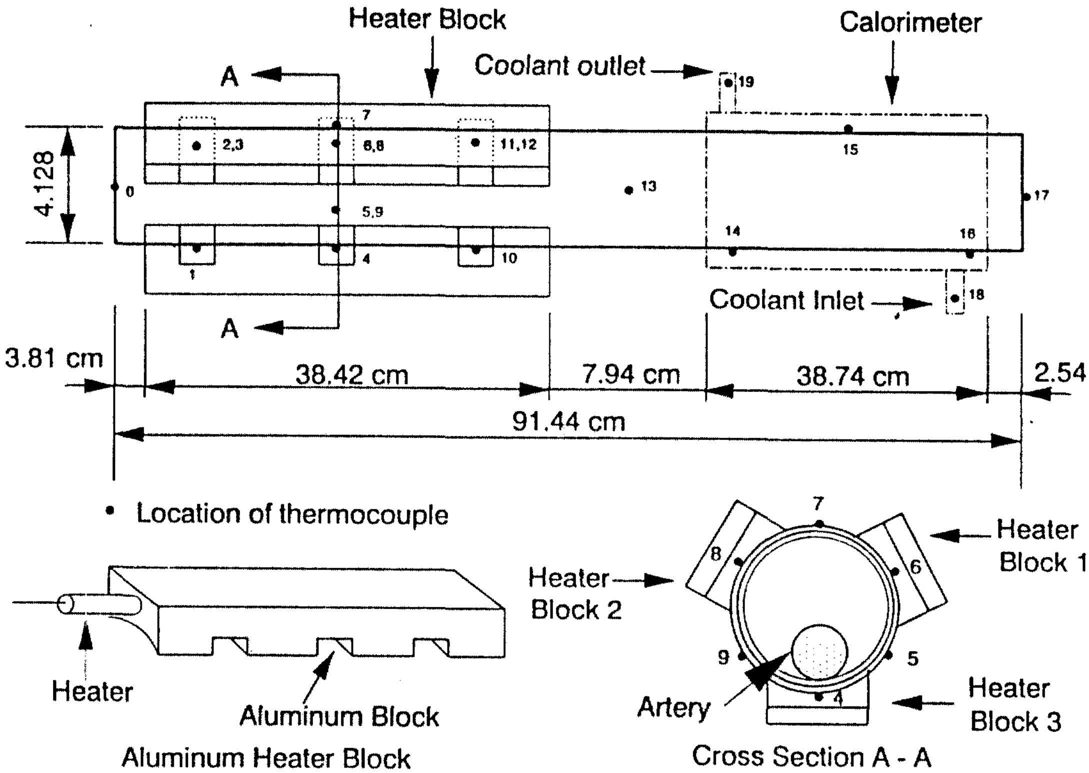

Figure 1. Schematic of the water heat pipe with an artery.

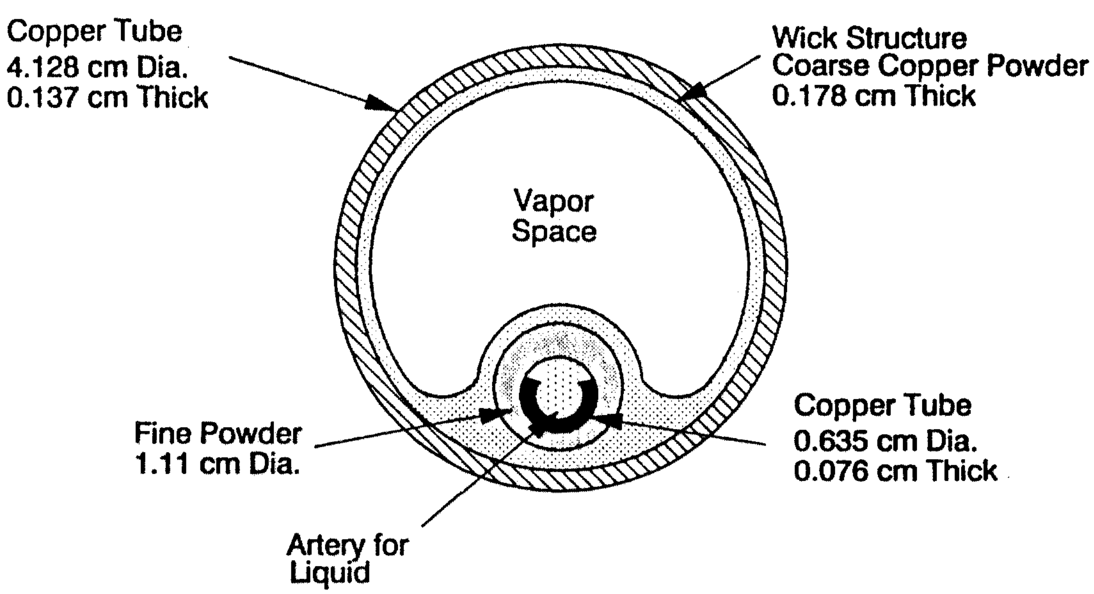

Figure 2. Cross section of the water heat pipe.

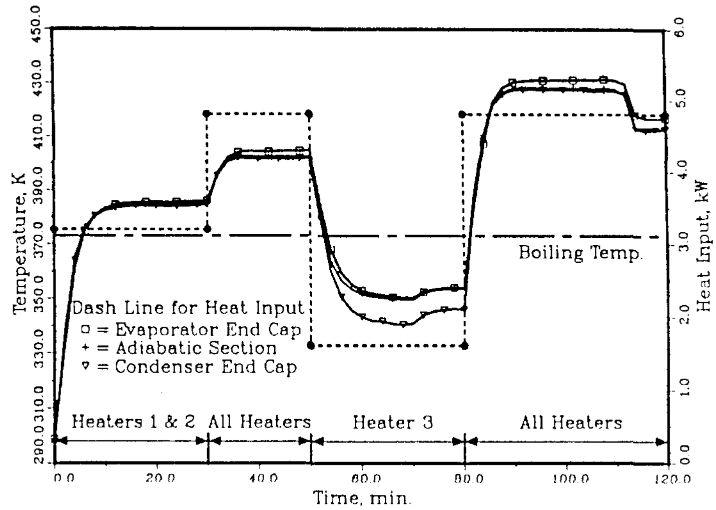

Figure 3. Transient temperature variations with large step heat inputs and different flow rates of coolant.

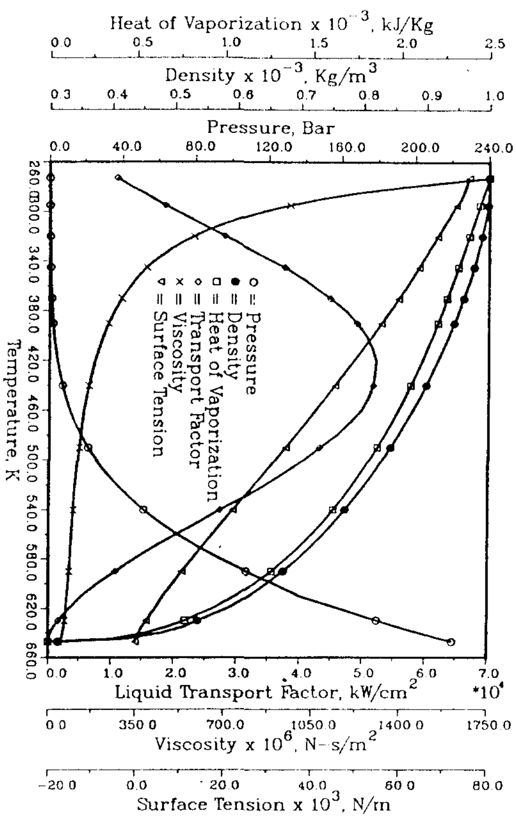

Figure 4. Physical properties of water.

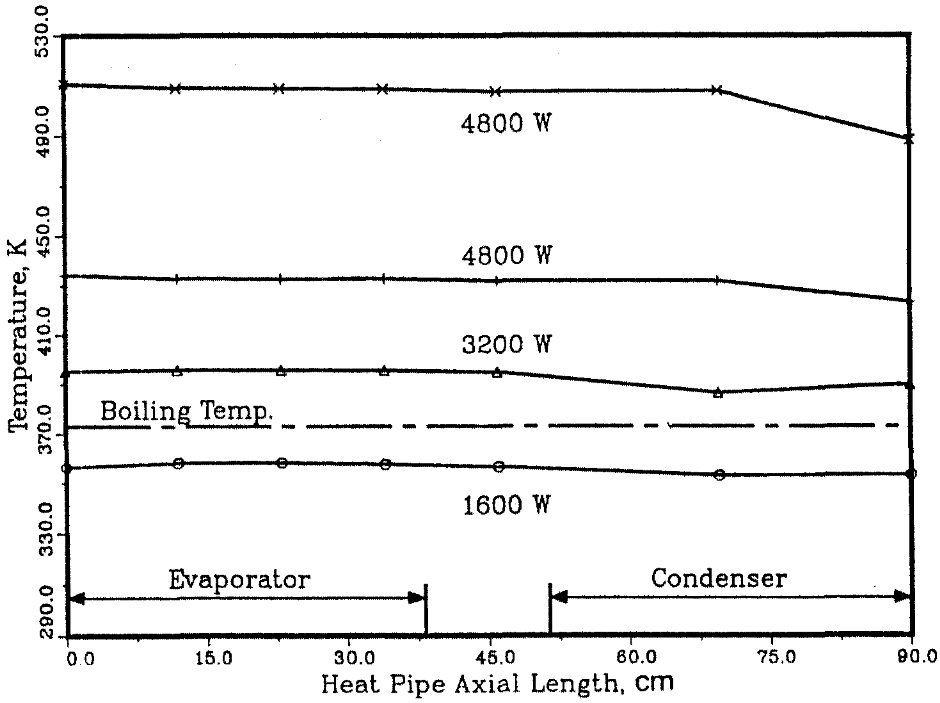

Figure 5. Steady state surface temperature distributions of the water heat pipe.

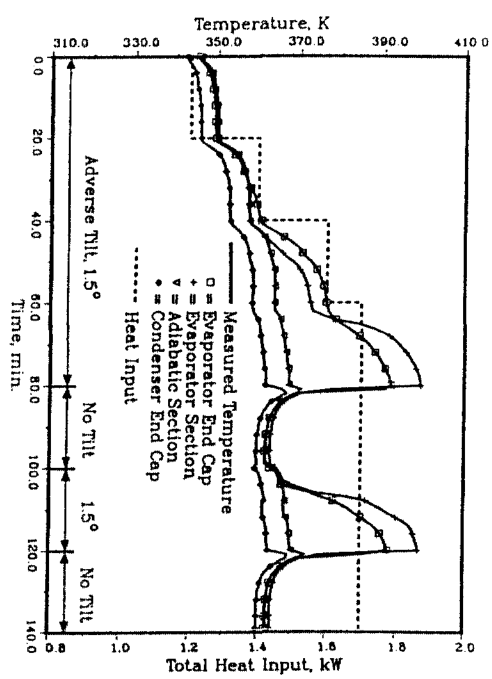

Figure 6. Dry-out and rewetting of a water heat pipe with variable heat load and tilting.

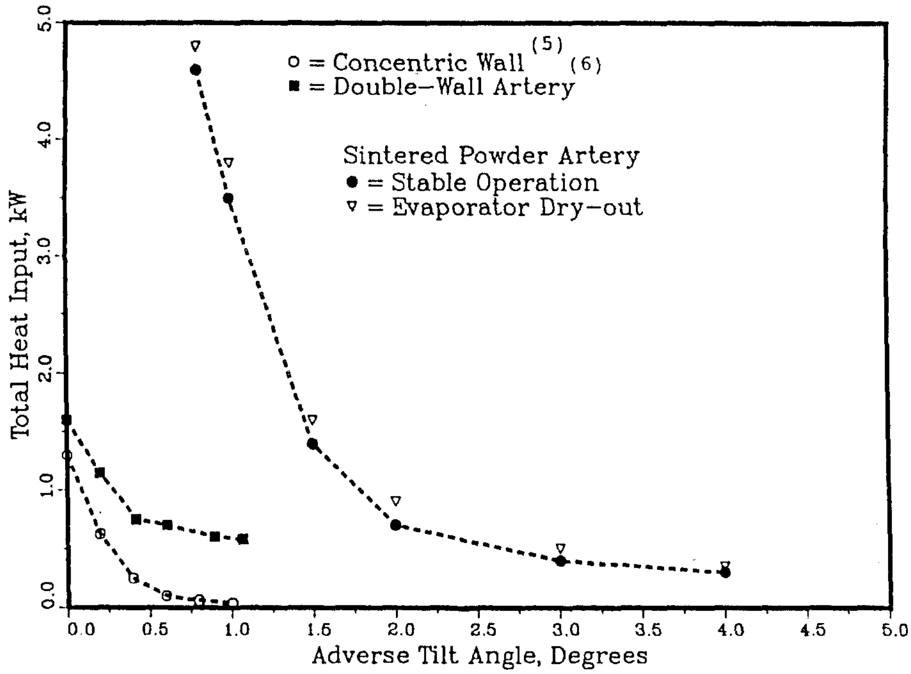

Figure 7. Comparison of performance of water heat pipes with adverse tilt angles