Characteristics of Braided Wire Wick Heat Pipe for Heat Pipe Cooled Reactor

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1. Introduction

A heat pipe cooled reactor has been proposed as a type of micro reactor. It is considered to be superior for extraterrestrial bases and remote area. One of the major advantages of heat pipe cooled reactor is that heat is simply removed by heat pipes which have high thermal conductivity. The efforts for installation and maintenance of heat pipes are minimum comparing with that of conventional coolant such as water, helium and etc.

Straight heat pipes are simple and cost effective but room is limited for the space purpose. Bendable heat pipes is good to maximize space utilization. Design and manufacturing of bendable heat pipes is a challenge for a heat pipe cooled reactor in space bases. The selection of wick material is a key for the manufacturing. Sintered metal powder and screen mesh are widely used for high temperature application. Sintered metal powder heat pipes showed crack when it was bended. Screen wick heat pipes showed reduction in vapor flow passage and capillary force [1].

Braided wire wick structure is possible option to manufacture bendable heat pipes. Braided wire wick is soft and strong. It has a good elasticity.

Zhou et al. studied thermal performance of spiral woven mesh heat pipe and characteristic parameters [2]. Tang et al. studied capillary force of copper fiber wick [3]. These kind of woven wicks including braided wire wick are not standardized in terms of characteristics.

In the present study, characteristics of stainless steel braided wire wick are studied via analysis and experiments.

2. Material and methods

This section describes braided wire wick, analysis, and experimental apparatus.

2.1. Braided wire wick

Material of braided wire is stainless steel 304. There are two different wicks. One is braided using stainless steel wire with a diameter of 250 ㎛. The braided wire a forms tube shape with a dimeter of 18 ㎜. Another is braided using wire with 200 ㎛ and it forms 14 mm tube.

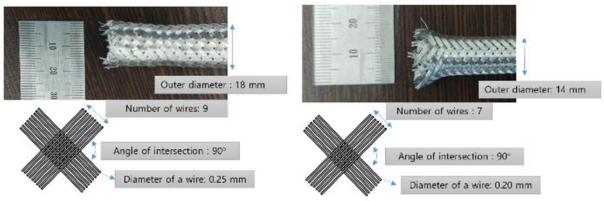

Fig. 1 shapes of braided wire wicks

2.2. Analysis

The porosity is defined as the ratio of the volume of the steel wires to the total volume of the wick.

$$\varepsilon = 1 - \frac{V_{wire}}{V_{wick}} \qquad (1)$$

The wick is elastic. The thickness and the length of the wick is deformed when the wick is inserted in the heat pipe tube. Therefore, the volume of the wick is determined after inserting the wicks into the tube.
A semi-empirical correlation for tightly wrapped wicks was suggested using a modified Blake-Kozeny equation [4].

$$\mathrm{K} = \frac{d_{wire}^2 \varepsilon^3}{122(1-\varepsilon)^2} \qquad (2)$$

Capillary rise can be expressed as follow:

$$\Delta \mathrm{p_{cap}} = \frac{\mu\varepsilon}{K} \mathrm{h} \frac{d\mathrm{h}}{dt} + \rho g \mathrm{h} \qquad (3)$$

where h is a height of liquid front, a capillary height, at time t and dh/dt is a capillary rise rate.
The capillary force can be calculated as

$$\Delta \mathrm{p_{cap}} = \frac{2\sigma}{r_{eff}} \qquad (4)$$

where σ is the surface tension of the working fluid and r_{eff} is the effective pore radius.
Effective pore radius can be calculated in the steady-state capillary rise experiment by

$$r_{eff} = \frac{2\sigma}{\Delta \mathrm{p_{cap}}} = \frac{2\sigma}{\rho g \mathrm{h}} \qquad (5)$$

The relation between capillary force and capillary rise can be expressed as:

$$\frac{\mu\varepsilon}{K} \mathrm{h}_1 \frac{d\mathrm{h}_1}{dt_1} + \rho g \mathrm{h}_1 = \frac{\mu\varepsilon}{K} \mathrm{h}_2 \frac{d\mathrm{h}_2}{dt_2} + \rho g \mathrm{h}_2 \qquad (6)$$

Capillary rise rate, *dh/dt*, at time t_1 and t_2 are assumed to be equal if t_1 and t_2 are close.
Therefore, permeability can be experimentally obtained:

$$K = \frac{\mu\varepsilon}{\rho g}\frac{h_1}{(h_2-h_1)}\frac{dh}{dt} \qquad (7)$$

2.3. Experimental apparatus

Two different wicks were inserted into transparent acrylic tubes. The inner diameters of each acrylic tube are 18 ㎜ and 13 ㎜, respectively.

Fig. 2

The internal diameters of the wicks were measured by vernier calipers.

3. Results

3.1. Analysis of previous study

Tang et al.'s experimental results was analyzed [3]. Capillary rise experiments were conducted with braided copper wire wicks, which are flattened. The permeability was analyzed from the experimental results using equation (7) and the permeability was calculated using equation (2). The results were summarized in Table I. Analyzed and calculated permeability shows good agreement in terms of order of magnitude.

Table I: Comparison of permeability

Material	Copper wire
Wire diameter	50 μm
Wick porosity	0.736
Flattened thickness	0.24 ㎜
Working fluid	Ethanol
Temperature	300 K
Permeability by Eq. (7)	3.33×10^{-10}
Permeability by Eq. (2)	1.17×10^{-10}

3.2. Measurement of wick parameters

The measured dimensional parameters of the braided wire wicks are summarized in Table II.

Table II Dimensional parameters of the braided wire wicks

Sample code	BW01	BW02
Radius of wire (μm)	200	250
Initial outer diameter (㎜)	14	18
Outer diameter (㎜)	12.8	18.3
Inner diameter (㎜)	10.6	16.0
Wick thickness (㎜)	1.1	1.2
Wick length (㎜)	979	987
Wick mass (g)	60.95	118.1
Volume of wire (㎣)	7686	14888
Total volume of wick (㎣)	39459	61764
Porosity	0.805	0.759
Calculated permeability	4.51×10^{-10}	3.85×10^{-10}

Sample BW01 was shrunk in radial direction when it was inserted. That means it was extended in axial direction. The porosity of BW01 was higher than that of BW02.

4. Conclusions and future work

4.1. Conclusions

The permeability correlation for the wire wick was calculated with Equation (2). Tang et al.'s experimental result was analyzed and permeability was calculated with Equation (7). Both calculated permeabilities show good agreement in terms of order of magnitude.

The braided wire wicks were inserted into the simulant acrylic tubes. The dimensional parameters of the wick was measured. Porosity and permeability were calculated.

4.1. Future work

Capillary rise experiment with sample BW01 and BW02 will be conducted. Permeability will be calculated with Equation (7) and it will be compared with value from the correlation

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