OBSERVATION AND MEASUREMENT OF THE VAPOR PHASE AND ITS FLOW VELOCITY IN A HEAT PIPE SYSTEM

Yosuke Hoshi, Ryo Ueno, Hitoshi Nakamura, Takashi Yamada, Naoki Ono

Graduate School of Engineering and Science, Shibaura Institute of Technology

md15068@shibaura-it.ac.jp

ABSTRACT The electric car is driven by LiB (Lithium ion Battery) power. The electric car has a merit of releasing no exhaust gas, however, the LiB has demerit of emitting much heat in hard driving. A study to solve this demerit is going on in our laboratory. The study is about controlling surface temperature of LiB by using heat pipes and PCM (Phase Change Material). The heat pipe is heat transportation device for cooling electronic equipment. The heat pipe transports heat by latent heat of inner fluid and its capillarity of Wick. The good performance of heat pipe is required for controlling surface temperature of LiB.

In this study, we produced a special heat pipe with copper board and acrylic board. This device holds the acrylic board between two pieces of the copper board. The O ring is sandwiched between the copper boards and acrylic board to vacuum the space inside. Pure water is added as working fluid in the device. We observed the vapor phase inside this heat pipe by high speed camera and measured flow velocity by PIV (Particle Image Velocimetry) technique. We used a ceramic heater and a Peltier unit for the heating and the cooling of the device. We injected tracer particles for measuring flow velocity by PIV technique. In addition, we measured surface temperature and internal pressure of this heat pipe.

As a result of velocity measurement by PIV technique, the vapor flow velocity was approximately 1-7mm/s. This velocity was slower than the velocity that we had expected. As the reason for the result, we thought that heat pipe became steady state and the difference of temperature between the heating and the cooling was small. Furthermore, internal pressure was increased by surface temperature rise. Temperature difference was increased by heater output increasing.

1. INTRODUCTION

In late years, electric cars has been remarkably developed, and its market is widely spreading. The electric car is driven by LiB power. However, the LiB has demerit of emitting much heat in high temperature (more than 80 degrees Celsius). Our laboratory has been doing R&D to solve this problem, and last year our laboratory proposed a method of controlling surface temperature of LiB by using combination of heat pipe and PCM. Fig.1 shows a concept of this method. We have to investigate basic characteristic of heat pipe to be applied in this method so that we develop a robust and highly-efficient heat pipe in future to be used in the system.

The heat pipe is a heat transportation device which can be used for cooling electronic equipment such as computer and smart phone. The concept of heat pipe is shown in Fig.2. The heat pipe consists of working fluid, container and Wick(grooves etc.). The heat pipe is activated by temperature difference. The working fluid is evaporated by heating at one side of heat pipe. Vapor is moved to another side (cooling side) by pressure difference. Vapor condenses at cooling side and becomes liquid again. The working fluid returns to heating side by capillarity of the Wick. The heat pipe transports heat by repeating this cycle.

In this study, we produced a special heat pipe. The inside of the heat pipe can be observed through transparent window. We observed vapor phase in this heat pipe, and measured flow velocity by PIV technique. Furthermore, we measured the internal pressure and surface temperature of special heat pipe. We investigated inside condition of special heat pipe.

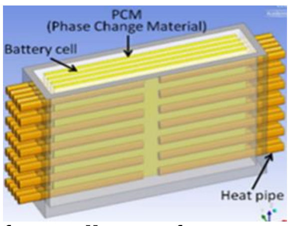

Fig.1 Method of controlling surface temperature of LiB

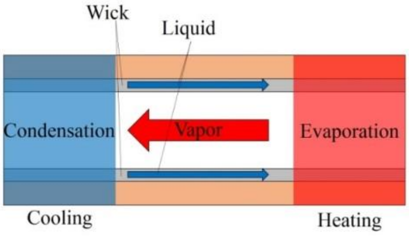

Fig.2 Concept of heat pipe

2. METHOD

2.1 Experimental Apparatus

We produced special heat pipe with copper board and acrylic board. Fig.3 shows the special heat pipe. This device holds the acrylic board between two pieces of the copper board. Some grooves are carved to two pieces of copper board. These grooves cause capillary force to transport working fluid to the heating side. The number of grooves per one piece of copper board is 23. The depth of grooves is 0.3 mm. The width of a groove is 0.3 mm. The length of a groove is 120 mm. Fig.4 shows an image of grooves which is taken with laser microscope. The inside of this device has to be a vacuum as in the inside of general heat pipe. The O ring is sandwiched between the copper boards and the acrylic board to keep internal low pressure of device. An acrylic board is inserted as the observation window. There are some screw holes on this part. The role of screw hole was to connect the pressure gage, the joint for vacuum pomp and tracer particles injection device with the apparatus.

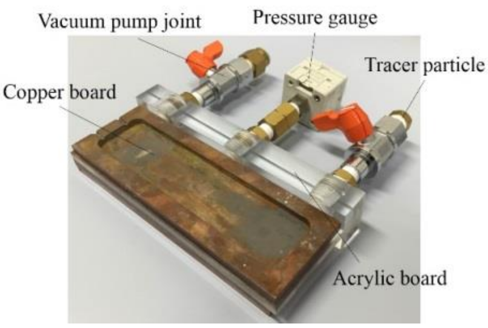

Fig.3 Experimental apparatus

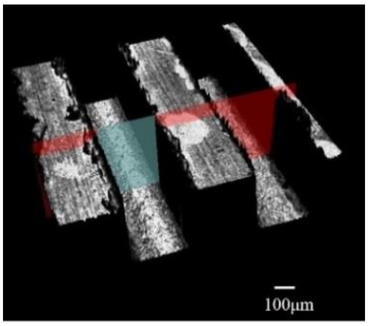

Fig.4 The image of the groove in the copper plate observed by laser-microscope (OLYMPUS LEXT-4000)

2.2 Method for Injecting Tracer Particles

There was a problem that internal pressure increases when injecting tracer particles, however we thought of a method of preventing internal pressure increasing. Fig.5 shows the injection method of tracer particle. Tracer particles were injected by difference of pressure between inside device and inside valve. The pressure inside device was kept to approximately 1000Pa before injecting, and it increased to approximately 5000Pa after injecting.

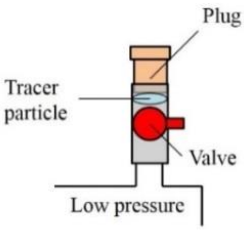

Fig.5 The injection method of the tracer particles in the experiment

2.3 Observation Method

Fig.6 shows the method of observation. Firstly, working fluid was enveloped in the device and the device was vacuumed to 1000Pa. One side of the device was heated by a ceramic heater. The surface temperature of ceramic heater was controlled by a volt transformer. Another side of the device was cooled by a Peltier unit. Fig.7 shows method of heating and cooling. In this way, temperature difference occurred and working fluid moved. After the working fluid moved, tracer particles (white alumina with less than 10μm of particle diameter) were injected and the device was irradiated with raiser beam for observation. The movie was taken by a high speed camera. The flow velocity of vapor was measured with the PIV technique. Furthermore, two thermocouples were put on surface of under copper board. Fig.8 shows the placement of two thermocouples. A pressure gauge was connected the device. In the case of measuring pressure of both of heating side and cooling side without observation, two pressure gauges were connected to each side.

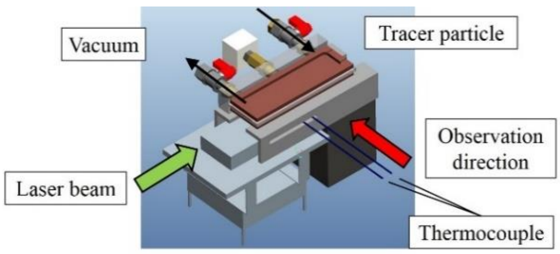

Fig.6 Observation method

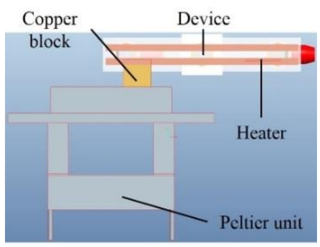

Fig.7 Heating and cooling method

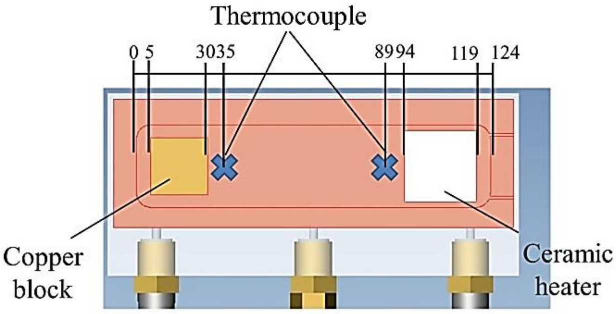

Fig.8 Placement of two thermocouples

3. RESULTS

3.1 Observation Result and PIV Technique

Fig.9 shows an image of a movie of the observation result. The pure water was enveloped in the device as working fluid. The volume of the pure water was 1.5 cc. Position of this image taken is at middle position between cooling part and heating part. Many points shining white were tracer particles. It is thought that the flow of particles show flow of vapor phase. This flow velocity was measured by PIV technique. The velocities of tracer particles were approximately 1 ~ 7 mm/s. The temperature at the time of taking movie was 37.9 degrees at heating side and 37.2 degrees at cooling side. Difference of temperature between heating and cooling was 0.7 degrees. The pressure difference between heating side and cooling side was 0.35 kPa then internal pressure of device was assumed to be the saturated steam pressure. If difference of temperature is larger than this result, flow velocity of tracer particle would be faster.

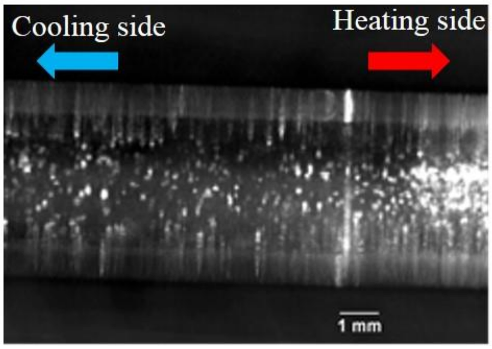

Fig.9 Observation result

3.2 Surface Temperature and Internal pressure

The pure water (1cc) was enveloped in the device, then surface temperature and internal pressure was measured. Table1 and Table2 show result of surface temperature and internal pressure at the heating side and the cooling side. Internal pressure increased by surface temperature increased. The internal pressure of each side was compared with saturated steam pressure at surface temperature.

At the heating side, internal pressure was larger than saturated steam pressure. Generally, the inside of the heat pipe is thought to be in saturation, however, the inside of this device was not in complete saturation.

At the cooling side, internal pressure was larger than saturated steam pressure and the inside of this device was not in complete saturation, either.

Table3 shows temperature difference and pressure difference between heating side and cooling side in each output of ceramic heater. The temperature difference was approximately 10 K and the pressure difference was 1~3 kPa. It is thought that this pressure difference was driving vapor flow inside the device.

Table1 Temperature and pressure at heating side

Output of heater in W	Surface temperature in K	Internal pressure in kPa	Saturated steam pressure in kPa
23	299.65	5.63	3.46
46	303.35	9.95	4.30
69	311.65	15.44	6.81
92	322.25	21.90	11.81
115	331.15	28.45	18.17
138	336.85	40.43	23.62

Table2 Temperature and pressure at cooling side

Output of heater in W	Surface temperature in K	Internal pressure in kPa	Saturated steam pressure in kPa
23	290.95	4.74	2.04
46	294.45	7.93	2.53
69	301.85	14.43	3.94
92	310.65	19.69	6.46
115	318.25	26.11	9.64
138	323.65	37.85	12.66

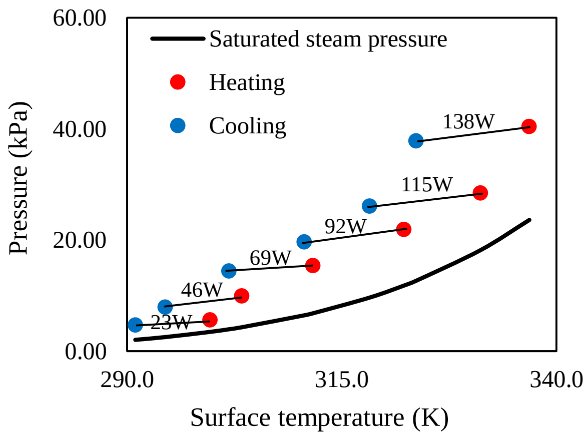

Fig.10 Comparison with the saturated steam pressure

Table3 Temperature difference and pressure difference

Output of heater in W	Temperature difference in K	Pressure difference in kPa
23	8.70	0.89
46	8.90	2.02
69	9.80	1.01
92	11.60	2.21
115	12.90	2.34
138	13.20	2.58

CONCLUSION

In this study, we developed a method of the injection of tracer particles in a special heat pipe for visualizing the vapor flow. We succeeded in observing vapor flow by using the injection system. The velocity of vapor flow was slow because the difference of pressure between heat side and cooling side was small.

Furthermore, we measured the surface temperature and the internal pressure of device. The internal pressure at both heating side and cooling side was successfully measured, and they increased as surface temperature increased. Temperature difference became larger as the output of ceramic heater was raised.

FUTURE PROSPECTS

We will prepare a special thermocouple and measure temperature inside of the device. In addition, we will investigate the performance difference of the heat pipe with changing volume of working fluid. In future, we will observe a state near dryout condition and explore an idea to restrict the onset of dryout.

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Yosuke Hoshi received B.E. (2015) degree in Dept. of Engineering Science and Mechanics from Shibaura Institute of Technology. He is a master course student at Shibaura Institute of Technology.

Ryo Ueno He is a bachelor course student at Shibaura Institute of Technology.

Hitoshi Nakamura received B.E. (2014) degree in Dept. of Engineering Science and Mechanics from Shibaura Institute of Technology. He is a master course student at Shibaura Institute of Technology.

Takashi Yamada received B.E. (2010), M.E. (2012) and PhD. (2015) degrees in Dept. of Engineering Science and Mechanics from Shibaura Institute of Technology.

Naoki Ono received B.S. (1985), M.S. (1987) and PhD. (2008) degrees in Dept. of Mechanical Engineering from the University of Tokyo. He is a professor at Dept. of Engineering Science and Mechanics at Shibaura Institute of Technology.