Investigation the effect of powder type

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Investigation the Effect of Powder Type on the Capillary Pumping Performance and Wettability

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Abstract. This study examined the effects of powder types on capillary pumping performance and wettability of wick samples. The raw material used are molecular sieve and copper powder with grain size of 80-100 microns and 177-200 microns respectively. Wick samples were produced by sintering with two shapes of powder grain comprised spherical and irregular shapes. Tests were carried out to determine the microstructure of the sample, capillary pumping amount and wettability. The test results showed that the grain type and grain size of powder could affect the roughness of the samples, of which, consequently, could also influence their wettability and capillary pumping amount. Proposed grain size and shape of the molecular sieve and copper powder are potential to be considered as wick alternatives for heat pipe application.

Keywords: capillary pumping amount, wettability, molecular sieve and copper powder

1. INTRODUCTION

Wick is a critical component of heat pipe that circulates the working fluid from the condenser to the evaporator. Wick provides the capillary pressure for driving the working fluid to circulate in the heat pipe. Wick with its capillary pressure can work as driving pump to make fluid circulation. Capillary pumping performance has important effect on the heat transfer capacity of heat pipe [1].

Generally, sintered powder is used as a wick in heat pipe technology. Sintered porous structures have attracted considerable attention over the last few decades because of their special properties, such as good permeability, high porosity and fine pore size.

Currently, wick is made of metal such as copper, stainless steel, metal alloy such as Cu-Ni, Al-Ti-Mg. Metal is easily oxidized and often caused corrosion problems. The oxidation in the heat pipe caused the loss of hydrophilicity and this condition will affect the heat pipe thermal performance, force capillarity and working fluid boiling process.

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Introduction Sintered porous wicks have been regarded as a promising candidate for high heat flux applications due to its high capillary pressure and effective thermal conductivity [2].

The morphologies of the powders, including powder size and powder type, would influence the capillary performance. The larger powder size and irregular type were better for liquid rise. Meanwhile, nanostructures on the powder surface played a dominant role in forming the hydrophilic surface on the copper powders, which could achieve the higher capillary height and rising velocity of working fluid for the wick. The pores have opposite effect on the capillary pressure. There exists a dilemma in the wick between the vapor release and liquid suction. While the capillary pumping of wick is not adequate for the required liquid to the evaporator, there will be dry-out phenomenon in the evaporator. The lower the contact angle is, the higher the capillary force can be presented as:

$$\Delta P_c = \frac{2\sigma \cos\theta}{r} \tag{1}$$

where θ is the contact angle and r is the pore radius.

It can be deduced that the large pores in the irregular sample may be easy to be filled by the capillary flow. Larger powder size leads to better vapor transport and evaporation, but beyond a certain point the large pores can cause weakened structure [3, 4]. Wettability of a solid surface is an important to boiling heat transfer. A hydrophilic surface helps to enhance the boiling heat transfer coefficient and the critical heat flux (CHF). Wettability indicates the degree of wetting when a solid and liquid interact. To characterize the surface wettability, two different types of contact angles are applied. One is static contact angle and the other is dynamic contact angle. Small contact angles (<90°) correspond to high wettability, while large contact angles (>90°) correspond to low wettability. The contact angle is defined as the angle formed by the intersection of the liquid-solid interface and the liquid-vapor interface [5, 6]. When the surface tension of solid (γS) is greater than the solid-liquid interfacial tension (γSL), the contact angle becomes smaller than 90 degrees and the surface is wettable. When the balance is opposite, the surface repels the liquid [7-10].

In this study, the effect of molecular sieve powder types on capillary pumping performance and wettability of wick samples are presented. Proposed wick materials are made from molecular sieve powder with a sintering process, then they are observed for the microstructure, capillary pumping performance and wettability.

2. EXPRIMENTAL DETAIL

2.1 Fabrication of wick sample

In this study the raw material used for making wick samples are molecular sieve and copper powder. Molecular sieve and copper powder are spherical in shape but different in grain size, the molecular sieve is 1.6-2.5 mm and copper powder is 80-100 µm and 177-200 µm. In order to optimized, molecular sieve must be mashed and sieved into 80-100 µm and 177-200 µm grain size. This process makes the grain size homogenous but the shape of the molecular sieve granules becomes irregular. List of sample and characteristic are summarized in Table 1. The molecular sieve powder and hybrid molecular sieve-copper powder were inserted into copper pipe with 65-mm long and 8.58-mm diameter then sintering was carried out. Sintering process was controlled in the furnace at a temperature of 950 °C for 60 minutes and wick sample shown in Figure 1.

TABLE 1. LIST OF SAMPLE AND CHARACTERISTIC

No.	Sample code	Material base	Powder size (µm)	Powder type	Wick dimension, length x dia. (mm x mm)
1	M1	Molecular sieve	80 - 100	Irregular	65 x 8.58
2	HM1C1	75%Molecular sieve-25% Cu	80 - 100	Spherical & irregular	65 x 8.58
3	HM1C2	50%Molecular sieve-50% Cu	80 - 100	Spherical & irregular	65 x 8.58
4	HM1C3	25%Molecular sieve-75% Cu	80 - 100	Spherical & irregular	65 x 8.58
5	M2	Molecular sieve	177 - 200	Irregular	65 x 8.58
6	HM2C1	75%Molecular sieve-25% Cu	177 - 200	Spherical & irregular	65 x 8.58
7	HM2C2	50%Molecular sieve-50% Cu	177 - 200	Spherical & irregular	65 x 8.58
8	HM2C3	25%Molecular sieve-75% Cu	177 - 200	Spherical & irregular	65 x 8.58

FIGURE 1. Wick sample

2.2 Characterize of wick sample

The pore shape, pore size and pore distribution of the wick sample observed by scanning electron microscope (SEM). From Figure 2 the shape and distribution of pores formed between molecular sieves is irregular. Whereas the shape of pores possessed by molecular sieves are almost homogeneous and evenly distributed.

The porosity of wick sample calculated by Archimedes' method, which measures the weight of the dry sample and the weight of the saturated sample filled with working fluid, such as following formula:

$$\varepsilon = \frac{W_{st}-W_{dy}}{W_{dy}} \ x \ 100\% \quad (2)$$

where ε is the porosity, W_{st} is the weight of the saturated sample and W_{dy} is the weight of the dry sample.

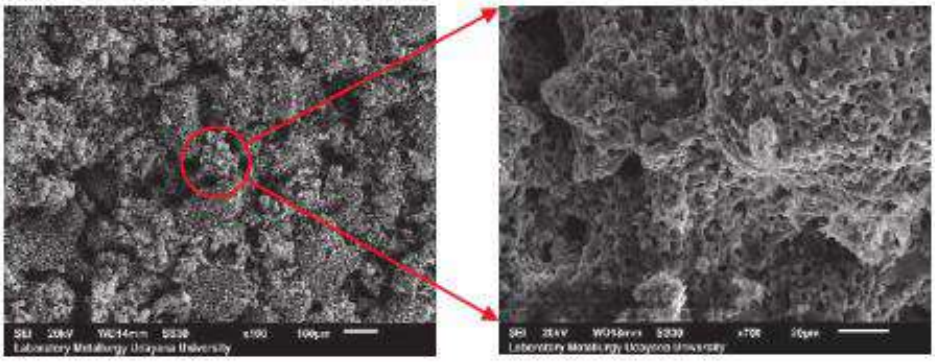

FIGURE 2. SEM images of wick sample

2.3 Capillary Pumping Amount

In this study, to evaluate the capillary performance of the wick sample is using capillary pumping amount method proposed by Li et al [11]. Capillary pumping amount measure the mass of working fluid transported along the wick sample using analytical balance and then record by computer.

The experimental setup of the capillary pumping amount is shown in Figure 3. The fluid reservoir is placed on the analytic balance and the wick sample holder is positioned beside the analytic balance to hold the wick sample so that only the wick surface touches the working fluid. The capillary effect moves the working fluid along the wick sample. The amount of working fluid in the reservoir will decrease and this reduction recorded by the analytical balance and computer.

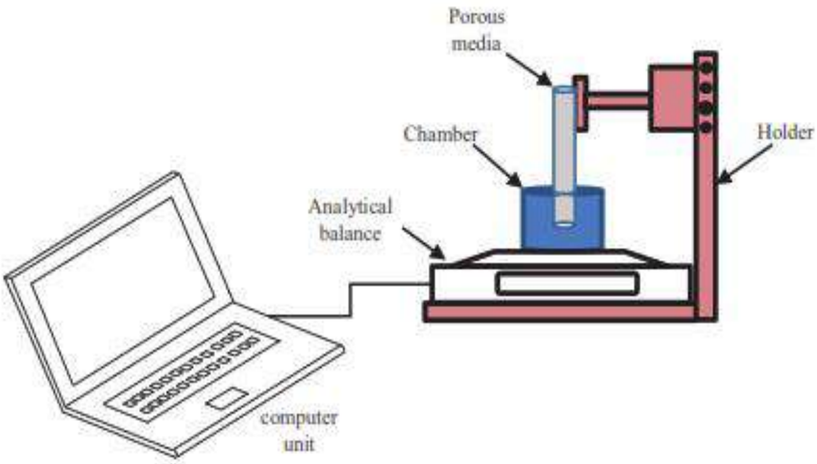

FIGURE 3. Experimental setup of capillary pumping amount

2.4 Contact Angle

In addition to this capillary pumping amount, the wettability of wick sample was also evaluated with contact angle (CA) measurements. The contact angle measurement equipment, shown in Figure 4, consists of camera, sample stage, light and syringe. The camera, sample stage and light should be aligned to ensure accurate CA measurement. To improve image quality, the light is placed opposite the camera. The syringe is mounted above the wick sample for producing the sessile drop.

The contact angle measurement begins with flattening and cleaning the surface of the sample, preparing the camera and lights, then water is dripped very carefully on the surface of the sample using a syringe. The image of the droplet is captured and analyzed to determine the CA. Tests were carried out 8 times for each sample.

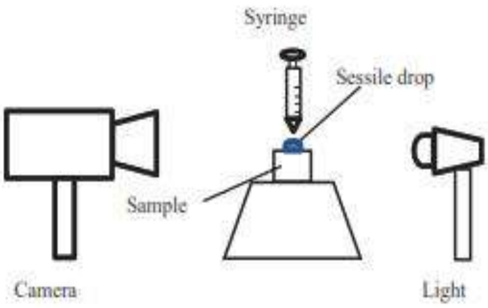

FIGURE 4. Schematic of contact angle measurement equipment

3. RESULT AND DISCUSSION

3.1 Effect of Powder Type and Powder Size on Porosity

Table 1 details the wick base material with grain sizes 80-100 µm and 177-200 µm. The table also shows grain shape spherical, irregular shape or the mixture of both spherical and irregular shape. The porosity of each wick sample can be seen in Table 2 and Figure 5.

TABLE 2. POROSITY OF THE SAMPLE

No.	Sample code	Powder size (µm)	Powder type	Porosity (ε)
1	M1	80 - 100	Irregular	0.855
2	HM1C1	80 - 100	Spherical & irregular	0.349
3	HM1C2	80 - 100	Spherical & irregular	0.234
4	HM1C3	80 - 100	Spherical & irregular	0.320
5	M2	177 - 200	Irregular	0.619
6	HM2C1	177 - 200	Spherical & irregular	0.574
7	HM2C2	177 - 200	Spherical & irregular	0.388
8	HM2C3	177 - 200	Spherical & irregular	0.215

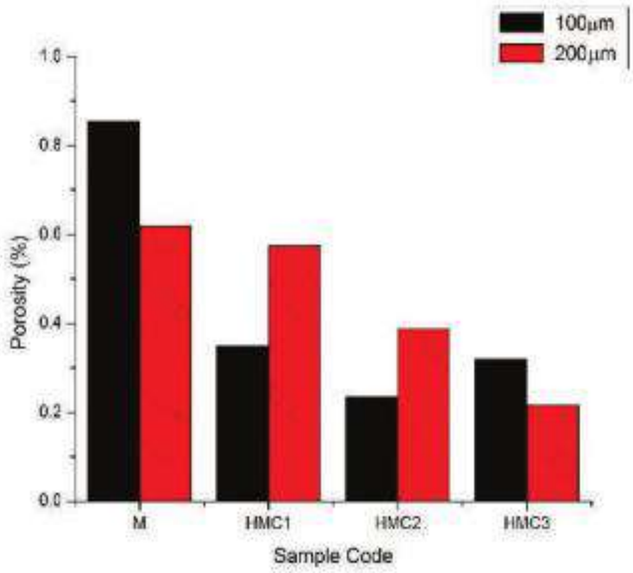

FIGURE 5. Porosity of the wick sample

Wick with molecular sieve material produces greater porosity than wick with hybrid material. Molecular sieve grain size of 80-100 µm produces greater wick porosity than 177-200 µm grain size. This is due to molecular sieve itself a pore material with alot of pores to be added with pores formed between grains. Therefore, the wick molecular sieve porosity is 80-100 µm greater than 177-200 µm. While in hybrid wicks, copper granules cover the pores of molecular sieve and lead to reduce wick porosity.

3.2 Capillary Pumping Amount of Wick Sample

Capillary pumping amount is one of parameter to determine the capillary pumping performance of porous wick. The capillary pumping performance of porous wick has important effect on heat transfer capacity of heat pipe. In this experiment the influence of powder type on the capillary pumping amount is shown in Table 3 and Figure 6.

The grain size of 80-100 μm, results the highest capillary pumping amount that is 1.4 grams, achieved by the HM1C3 wick sample, then sequentially wick samples of M1, HM1C2 and HM1C1. At 177-200 μm grain size the highest capillary pumping amount is 1.3 grams achieved by the HM2C2 wick sample, and then HM2C1, M2 and HM2C3. 80-100 μm grain size result capillary pumping amount higher than 177-200 μm grain size.

TABLE 3. CAPILLARY PUMPING AMOUNT OF THE SAMPLE

No.	Sample code	Porosity (%)	CPA (gr/s)
1	M1	0.855	1.029
2	HM1C1	0.349	0.547
3	HM1C2	0.234	0.595
4	HM1C3	0.320	1.428
5	M2	0.619	1.069
6	HM2C1	0.574	1.234
7	HM2C2	0.388	1.317
8	HM2C3	0.215	0.616

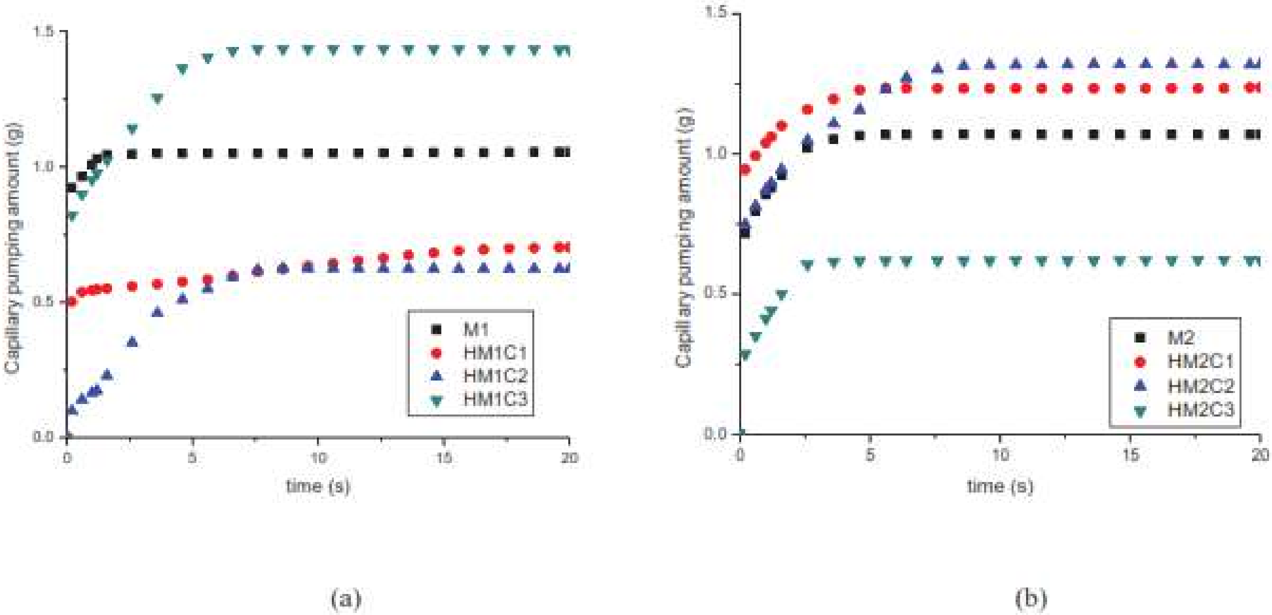

FIGURE 6. Effect of powder type on the capillary pumping amount (a) 80-100μm, (b) 177-200μm

Uniform powder shape at grain size of 80-100 μm results in a higher capillary pumping amount than irregularly powder shape. This is evidenced by the highest capillary pumping amount of HM1C3 which have composition of 75% copper in spherical and 25% molecular sieve in irregular shape. Then the capillary pumping amount of M1 is smaller than HM1C3, M1 is 100% molecular sieve in irregular powder shape. Spherical copper powder in HM1C3 has a composition of 75% resulting pores that function as liquid flow channels. The pores formed between irregular molecular sieve powder will form a channel slightly inhibiting fluid flow, but the pore structure possessed by molecular sieves still functions as a liquid flow channel, so pumping capillaries does not decrease significantly. The working fluid will require a longer time to pass through the irregular pore.

At 177-200 µm grain size, HM2C2 samples which have a composition of 50% molecular irregular sieves and 50% spherical copper resulting in the highest capillary pumping amount. Grain size of powder increase, the capillary pumping amount can be enhanced effectively, accordance to the Hui Li[3] statement. Nevertheless, the capillary pumping amount of HM2C2 is lower than HM1C3, this occurs because the pores formed between spherical copper powder in HM1C3 result better flow channels.

3.3 Wettability of Wick Sample

Capillary pumping performance is influenced by wettability. Wettability can transport fluid and reduce critical heat loads during operation of heat pipes. Wettability of wick sample examined by measure the contact angle of fluid dripped on solid surface. Samples with different grain shape and size were tested for contact angles, repeated for 8 times. A measurements of contact angle shown in Table 4 and Figure 7.

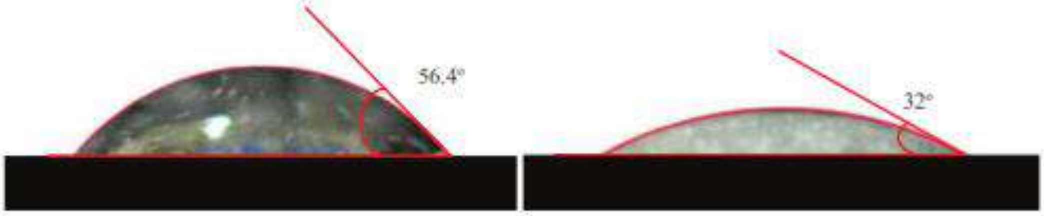

FIGURE 7. Contact angle measurement

TABLE 4. CONTACT ANGLE OF THE SAMPLE

No.	Sample code	CA (°)
1	M1	32.0
2	HM1C1	44.4
3	HM1C2	52.1
4	HM1C3	54.7
5	M2	56.4
6	HM2C1	39.4
7	HM2C2	39.4
8	HM2C3	46.1

Table 4 and Figure 7 show the result of the contact angle for all wick samples lower than 90°. This means the sample is a hydrophilic material with favorable surface wetting. When the contact angle lower than 90° and surface tension of solid (γ_S) is greater than the solid-liquid interfacial tension (γ_{SL}), the capillary pressure exist and the fluid can flow.

The effect of contact angle on capillary pumping amount is shown in Figure 8. The increase of contact angle induces a decrease in capillary pumping amount. HM1C3 results the highest capillary pumping amount of 1.428 gram/second. Then the capillary pumping amount greater than 1 gram/second are respectively HM2C2, HM2C1, M2, and M1. While other samples, the capillary pumping amount below 1 gram/second include HM2C3, HM1C2 and

HM1C1. The capillary pumping amount greater than 1 gram/second is dominated by samples with 200 micron grains and contact angles ranging from 30° except HM1C3 and M2 with contact angles ranging from 50°.

Surface roughness can influence the capillary pumping amount. Surface roughness in this study is indicated by grain size. Powder with grain size of 177-200 μm results coarser surface. Shown by HM2C2, HM2C1 and M2 samples, the increase of contact angles will decrease the capillary pumping amount. The rough surface of the sample and molecular channel of molecular sieve results in a small contact angle. Whereas smoother surfaces and molecular sieve channels will produce a greater contact angle.

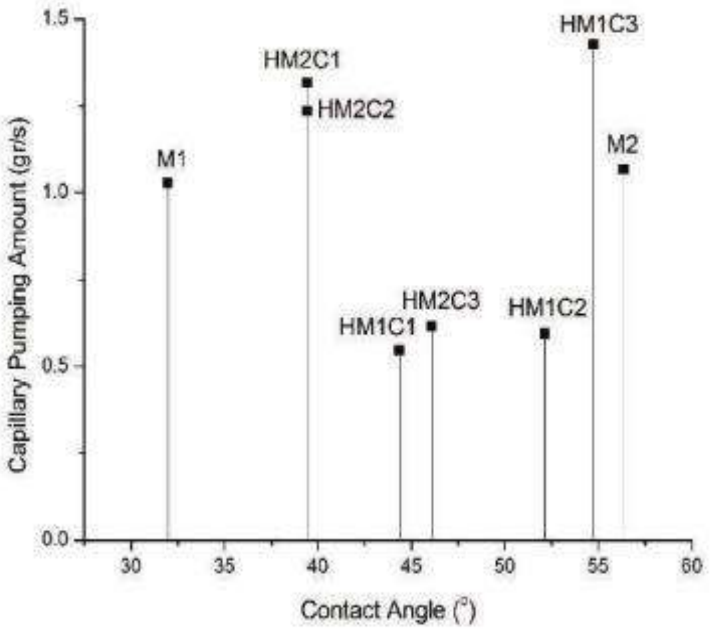

FIGURE 8. Effect of contact angle on capillary pumping amount

4. CONCLUSION

Powder types based on its grain sizes and grain shapes of wick raw materials has been investigated. The investigated grain sizes were divided into sizes: 88-100 μm and 177-200 μm. The powder shapes are divided into irregular and spherical shapes. It was found that the grain type and size of the powder could affect the roughness of the samples and consequently, could also influence their wettability and capillary pumping amount. The highest capillary pumping amount can be achieved on the hybrid material, mixture of spherical and irregular shapes, size 88-100 μm of composition 75% spherical copper and 25% molecular sieve. For hybrid material of grain size 177-200 μm, the highest capillary pumping amount can be achieved when the mixture of the powder has a composition of 50% molecular irregular sieves and 50% spherical copper. It can be concluded that proposed grain size and shape of the mixture between molecular sieve and copper powder are potential to be considered as wick alternatives for heat pipe application.

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