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Effects of Microencapsulated Phase Change Material (MPCM) on Critical Heat Flux in Pool Boiling

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1. Introduction

Thermal power is limited by critical heat flux (CHF) in the nuclear power plant. And the in-vessel retention by external reactor vessel cooling (IVR-ERVC) is applied in some nuclear power plants; AP600, AP1000, Loviisa and APR1400. The heat removal capacity of IVR-ERVC is also restricted by CHF. So, it is essential to get CHF margin to improve an economics and a safety of the plant. There are some typical approaches to enhance CHF; vibrating the heater or fluid, coating with porous media on the heater surface, applying an electric field. The recent study related to the CHF is focus on using the nanofluid [1]. In this paper, the new approach was investigated by using the microencapsulated phase change material (MPCM).

MPCM is the particles whose diameter is from 0.1μm to 1000μm. The MPCM consists of the core material and the shell material [2, 3]. The core material can be solid, liquid, gas or even the mixture. The solid paraffin is the best candidate as the core material due to its stable chemical and thermal properties. And the shell material is generally synthesized polymer of about several micrometers in thickness. The most interesting feature of the MPCM is that the latent heat associated with the solid-liquid phase change is related to the heat transfer. When the MPCM is dispersed into the carrier fluid, a kind of suspension named as microencapsulated phase change slurry (MPCS) is formed. The study on the MPCS was conducted in field of both the heat transfer fluids and energy storage media. It is inspired by the fact that the latent heat can serve distribution to the additional CHF margin. The purpose of this work is to confirm whether or not the CHF is enhanced.

2. Description of experiment

2.1 Preparation of test samples

MPCM is already commercially available in the market. The used MPCM is RT 31 from Rubitherm Technologies GmbH company. The thermal property of the MPCM core material is shown in Table I. The shell material is melamine-formaldehyde resin. In this work, R-123 refrigerant is used as base fluid to use the latent heat of fusion of core material. Its boiling point is slightly lower than the melting point of the core material. The concentration of the test fluid is from 10^{-3} vol% to 10^{-1} vol%. This is to check the concentration effect of MPCM in R-123. The cases of uncoated heater and heater coated with the MPCM were used to distinguish the coating effect which has influence on CHF. The dispersion status of the MPCM is shown in Fig 1. Although there is different density between the MPCM and R-123, the sable dispersion status was maintained by Brownian motion. The alumina nanofluid and the mixture blending with alumina nanofluid and the MPCM are tested on CHF at 0.01v%.

Fig 1. Dispersion status of MPCM in R-123 (0.01v%)

2.2 Experimental procedure

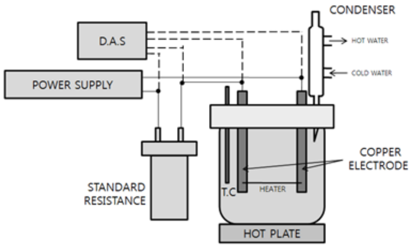


Fig. 2. Schematic diagram of the test facility

A schematic diagram of the experimental apparatus is shown in Fig. 2. The heating method on test section is joule heating. The experimental facility consists of rectangle vessel (100mm × 50mm × 120mm), copper electrodes, Teflon cover, reflux condenser, power supply, data acquisition device, hot plate and standard resistor. The concentration of test fluid is maintained by the Teflon cover and the reflux condenser. Obtaining the voltage data from the data acquisition device which is connected to the upper part of electrodes and standard resistor is saved and analyzed. The material of heating wire is nickel-chrome (80/20).

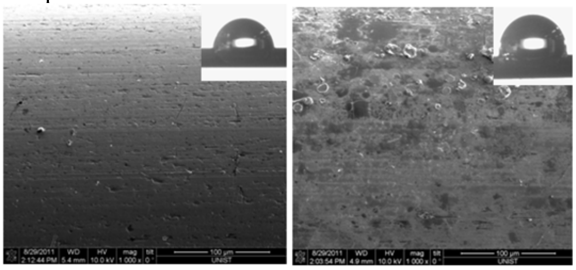
Before the experiments, the state of fluid was maintained at saturated temperature. Heating time remains the same during increasing the equal heat flux. The heat flux was calculated by obtained data in data acquisition system.

Table I. Thermal properties of MPCM

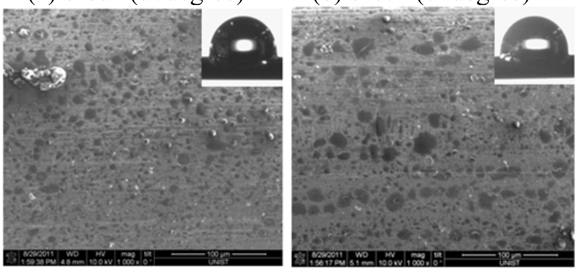
Name Formula	Melting Temperature (℃)	Latent Heat (kJ/kg)	Thermal Conductivity (W/mK)	Density (kg/m3) solid/liquid
n-nonadecane $C_{19}H_{40}$	30.4	182	0.2	890/770

3. Results and discussion

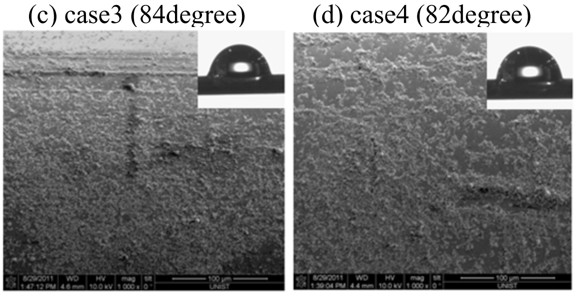
The results of this work are shown in Table II. When some materials are added in R-123, CHF was enhanced. The main reason is the change of heater surface characteristics caused by the deposition layer formed naturally during the boiling. Fig 3 shows the static contact angle and the geometry of the heater surface after CHF phenomenon occurred. The shell material of the MPCM is made of polymer which has hydrophobic characteristic. It is contributing to increase the static contact angle. And CHF value of the case 3, 4 is same. On the other hand, one of the case 2 is relatively low. As the heat transfer mechanism shows in Fig 4, it means that the latent heat serves distribution to the additional CHF margin. It is more obvious in comparison with the case 5 and 6.



(a) case1 (78degree) (b) case2 (82degree)



(c) case3 (84degree) (d) case4 (82degree)



(e) case3 (67degree) (f) case4 (75degree)

Fig 3. Static contact angle and SEM images of the heater surface

Fig 5 shows the effect of the concentration of the MPCM on CHF. It is reasonable that increasing the concentration increased the CHF continuously. The influence of the MPCM was strong at the high concentration because the number of particles effecting on CHF is increased exponentially.

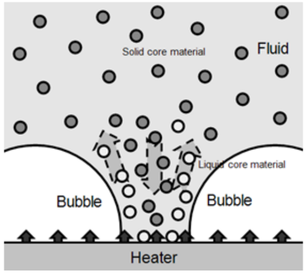


Fig 4. Concept of heat transfer mechanism with the MPCM

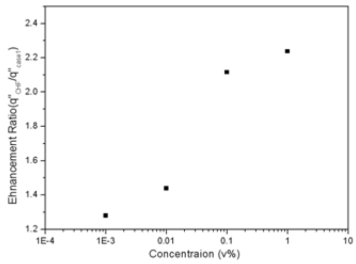


Fig 5. Effect of the concentration on CHF

4. Conclusions

In this paper, CHF tests were conducted to confirm whether or not the additional CHF margin is obtained when the MPCM was added in the base fluid. Over 20% of the CHF enhancement occurred by adding the MPCM. When the concentration of the MCPM is high, the additional margin was increased exponentially. There results of study will contribute to ensure the additional safety margin easily when applying to the present study related to CHF enhancement together like the case 6.

REFERENCES

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[2] Chen, B., Wang, X., Zeng, R., Zhang, Y., Niu, J., Li, Y., and Di, H., 2008, "An experimental study of convective heat transfer with microencapsulated phase change material suspension: Laminar flow in a circular tube under constant heat flux," Experimental Thermal and Fluid Science, 32(8), pp. 1638-1646.

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Table II. Result of CHF in various condition.

Case	Dispersed materials in R-123	MPCM Coating on the heater	Concentration (v%)	CHF enhanced rate CHF/CHF_{case1}
1	X	X	0	1
2	X	O	0.01	1.24
3	MPCM	X	0.01	1.44
4	MPCM	O	0.01	1.41
5	Al_2O_3	X	0.01	1.71
6	Al_2O_3+MPCM	X	0.01	1.94