Flow Boiling Experiment for the Heat Transfer Enhancement using Nanoporous Coatings

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1. Introduction

Porous, microporous and nanoporous coatings (either metallic or ceramic) have been a heat transfer enhancement technique of great interest to many researchers in the world. Various geometric parameters have been considered to produce higher enhancements, out of which particle size, particle shape, coating thickness and porosity were the primary variables. Use of the nanoporous coated surfaces as a boiling enhancement method is to increase the number of small scale cavities on a surface.

Nanoporous coatings have superior wear and oxidation resistances. They have uniform pore size in the nanometer range and high particle surface area (high surface to volume ratio). Void surface area (pores) is also high compared to the bulk. Each void/pore is interconnected & assists the fluids flow. The nanoporous layers appreciably resist vapor escape, thereby enhances CHF. This enhancement is due to the lateral capillary assist to the liquid flow towards the phase-change interface. It reduces the liquid vapor counter flow resistance and hinders the development of localized dryout conditions. Capillary pumping in porous media generates the required liquid draw, and establishes the fluid flow artery

However, the effect of nanoporous coating on critical heat flux has not yet sufficiently investigated. Particularly, critical heat flux hardly studied at low mass flow rate and at low pressure with nanoporous coatigs. Most of the research has been done with pool boiling and effect of nanoporous surface coatings during flow boiling still needs to be explored. S.M. You et al, used Alumina (Al_2O_3) particles (0.3-3 μm) as the coating material and tested in FC-72 [1]. The deposited particles adhered to the surface due to Van der Walls molecular attraction forces. They reported significant reduction in incipient and nucleate boiling superheats (~50%) and an increase in CHF (~32%). O'Connor and S.M. You developed a boiling enhancement paint with silver flakes (3-10 μm). They showed an 80% reduction in nucleate boiling superheat and a 109% increase in CHF over the non-painted surfaces as shown in Figure 1. D. Schroeder-Richter conducted flow boiling experiment with plain and porous tubes at atmospheric pressure and determined some enhancement of heat transfer [2]. They explained the enhancement of heat transfer with different mass flow rates, mass fluxes and pressures.

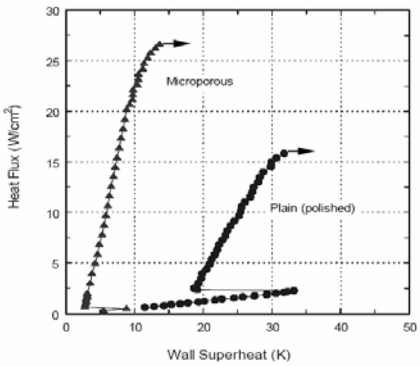

Figure 1: Comparative analysis of microporous coated and plain surfaces [1]

By manufacturing optimum cavity sizes on a heat surface, both the boiling site density and the nucleate boiling heat transfer can be efficiently increased. Srinivas Vemuri and Kwang J.Kim [4] performed the pool boiling heat transfer experiment from nanoporous surface immersed in a saturated FC-72 dielectric fluid at atmospheric pressure (101 kPa). The diameter of the Alumina (Al_2O_3) nanoporous surface was in the range of 50 to 250 nm. They compared the results of nanoporous surface with plain surface and obtained a decrease of 30% in the incipient superheat for the nanoporous surface, as shown in Figure 2.

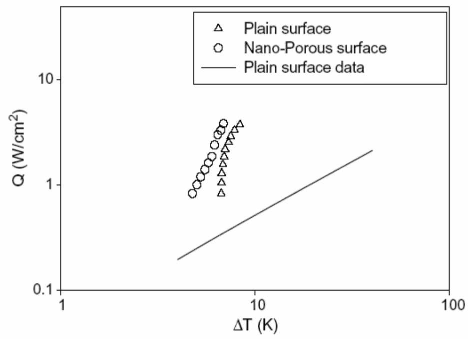

Figure 2: Comparative analysis of nanoporous coated and plain surfaces [3]

2. Experimental Apparatus and Procedure

Boiling heat transfer under planning will be performed at a high heat flux up to CHF at Korea Advanced Institute of Science and Technology. The experimental facilities consists of a closed water flow boiling loop, a test section, which is heated directly using an electrical DC power supply unit (maximum capacity of 64 kW). The schematic diagrams of test loop and tubular test section are shown in Figure 3 & 4. The experiments will be carried out at atmospheric pressure by venting to ambient. The main test loop consists of a condenser, surge tank (with overhead water reservoir), a centrifugal pump, turbine flow meter, a pre-heater (to control the inlet water temperature), needle valve (to provide throttling) and a test section.

The water will flow in the upward direction in the test section tube, which is coated from inner side. The dimensions of the cylindrical tube and vertical upward flow parameters are mentioned in Table 1. The test section is made of SS 304 round tube with nanoporous Alumina (Al_2O_3) particles coating of 100 nm. The nine Type-K thermocouples (outer diameter = 0.5 mm) are attached onto the outer surface of the test section to detect the wall temperature. The distance between each thermocouple is 90 mm. Copper electrodes are provided to connect heated length of tube with the DC power supply, to be heated by Joule heating.

	Parameters	
Geometry	*Vertical Cylindrical Tube*	
	Outer Diameter	10 mm
	Inner Diameter	8.5 mm
	Tube Thickness	1.5 mm
	Heated Length	850 mm
Flow	*Vertical Upward Flow*	
	Pressure	101 kPa (1 atm)
	Mass Flux	0 ~2000 kg/m^2 sec
	Inlet Subcooling	50 °C

Table 1: Test conditions for the flow boiling experiment

Thermocouples, pressure transducers, etc will be connected to HP 3852A data acquisition/control unit for data collection and processing. During the measurements, the heating power at the test section was carefully increased with time, until CHF was reached and the power to the test section was switched off as soon as one of the thermocouples fixed onto the tube perceived a rise in the wall temperature beyond a preset value due to exceeding the peak of removable heat flux. Heat flux is to be estimated from the voltage applied and the resistance in the heating element.

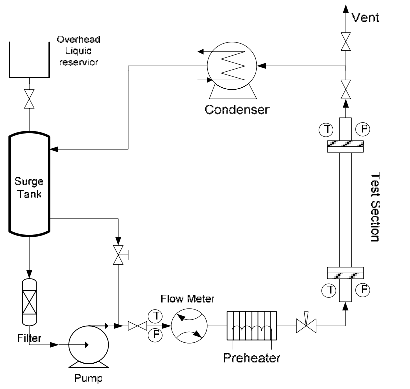

Figure 3: Schematic diagram of experimental test loop

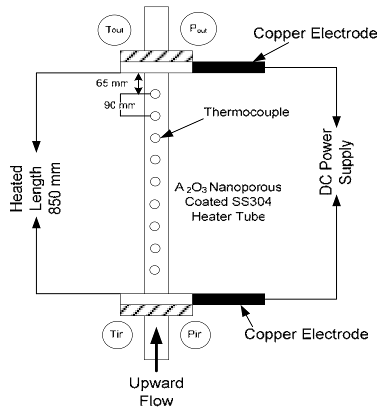

Figure 4: Schematic diagram of experimental test section

3. Conclusion

The present research is an experimental study of a novel technique of flow boiling heat transfer using nanoporous surfaces. The nanoporous alumina coating on SS 304 tube is planned and dimensional optimization work is completed. There are high chances of decrease in the incipient superheat for the nanoporous surfaces as compared to the plain surfaces. The experiments will be performed using different flow parameters

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