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CHF Enhancement in the Flow Boiling R-134a by Adding Wire Nets to Inner Surfaces of a Round Tube

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1. Introduction

CHF is a significant safety criteria for engineering devices which have high heat flux surfaces like nuclear reactors or steam generators.

Many studies have been performed for enhancing CHF, finding CHF models, and predicting CHF for pool boiling and flow boiling. The usual way to enhance CHF is by controlling heated surface conditions. Attaching promoters, porous coatings, and artificial roughness such as micro and macro-roughness, finning vibroroling, and tunnel-and pore forming are examples.

In this paper, a CHF experiment was performed by inserting mesh inside of pipes using the flow boiling refrigerant R-134a. Three different kinds of meshes were used. The mesh structure provides many vapor columns during boiling, enhancing CHF. The effect of mesh aperture on CHF enhancement was examined.

2. Methods

The test loop experiment is shown in Fig. 1. The loop was composed of a condenser, pump, accumulator, pre-heater, chiller, and test section. The working fluid of the loop was R-134a(CF_3CH_2F). The wall temperature and pressure in the CHF experiment with R-134a was lower than those in an experiment with water, because the critical pressure and saturated temperature of R-134a was relatively lower than that of water, indicating that R-134a is safer and requiring less electric power.

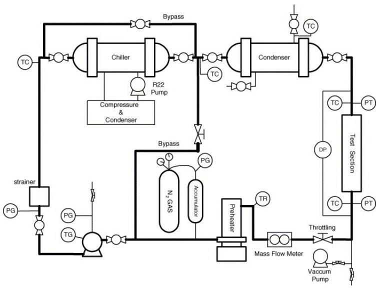


Fig 1. Schematic diagram of R-134a test loop

The test section is a circular tube (SUS304) installed vertically on the test loop. The test section was directly heated with a DC power supply, using power transformer with silicon controlled rectifiers. The heated length of the test section was 1m and the inside and outside diameters were 10.4mm and 12.7mm. The temperature of the liquid at the inlet and outlet of the test section was measured with in-stream T-type sheathed thermocouples. Nine K-type thermocouples were installed along the test section to measure the heated wall surface temperature. The lengths from the bottom end of the heated section to each thermocouple was 300mm, 600mm, 800mm, and 1000mm. Three thermocouples were installed 120 degrees apart at the last two locations to measure temperature change. The test section was connected to the flange, which was insulated from the test loop by Teflon.

Three kinds of mesh were used in this study. The original shape of mesh is shown in Fig. 2.1 The mesh apertures were 1.5mm, 2.0mm, 2.5mm. The wire diameter was 0.5mm. The shape of rolled mesh is shown in Fig 2.2.

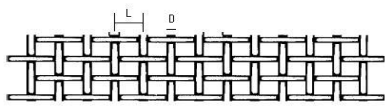


Fig 2.1 Mesh

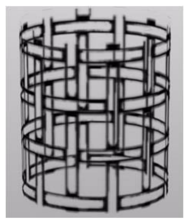


Fig 2.2 Rolled mesh

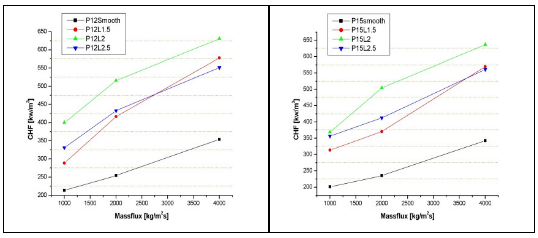
Experiments were performed at a pressure greater than 12bar, which is equivalent to 75 bar in water. Test matrix is listed in Table 1. The pressure ranged from 12 to 15 bar, the mass flux ranged from 1000kg/m^{2}s to 4000kg/m^{2}s, and the inlet subcooling was 40kJ/kg.

R-134a	
Pressure [bar]	12, 15
Mass flux[kg/m^{2}s]	1000, 2000, 4000
Inlet Subcooling [KJ/kg]	40
Mesh aperture[mm]	1.5, 2.0, 2.5

Table 1. Test matrix

3. Results and Discussion

At 12bar, CHF was enhanced by 35% (G=1000kg/m^2s, L=1.5mm) to 103% (G=2000kg/m^2s, L=2.0mm). At 15bar, CHF was enhanced by 56% (G=1000kg/m^2s, L=1.5mm) to 114%(G=2000kg/m^2s, L=2.0mm).



at 12bar　　　　at 15bar

Fig 3. Parametric trends of CHF with the mass flux

CHF was enhanced in R-134a flow boiling by using mesh structures. These effects were influenced by thermo-physical properties of surface and fluid and on the parameters of mesh structures.

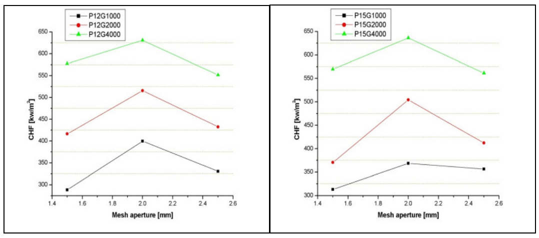
Nucleation site density is an important internal characteristic of nucleate boiling. A porous coating presents a lot of artificially made nucleation sites, which are first filled by gas and then by water vapor later in boiling process. [5]

The mesh structure is one of distinguished types of porous coating on heating surfaces. The points of contact of the wire of mesh with the heated surface are good for vapor nucleation. Each hole of meshes is regarded as a nucleation site for vapor growth. The holes provide an additional liquid supply to the heated surface due to capillary effects resulting in CHF increases in comparison to boiling on a smooth surface. The departure of the vapor bubble is also helped by forced convection of the whole loop . These effects in synergy enhance heat transfer rate between heating surface and flow, and finally enhance CHF.

Enhancement of CHF is largest at 2000kg/m^2s rather than 1000kg/m^2s and 4000kg/m^2s in view of Mass flux reliance of CHF enhancement. Flow can help the departure of bubbles, however the higher flow rate is not always better than lower one. A lower rate than optimized rate will be less helpful in departure of bubbles from holes of mesh. A higher rate than the optimized rate cannot be good for resupplying liquid into hole of mesh.

In a 15bar pressure condition, CHF enhancement is a bit larger than at a 12 bar pressure condition. This result tells higher pressure can be more effective for making higher pressure gradient between flow and nucleation site.

CHF enhancement trends with mesh aperture L are shown in Fig 4. CHF was greater for a mesh aperture of 2.0mm, rather than for 1.5mm, 2.5mm sizes.



at 12bar　　　　at 15bar

+

Fig 4. CHF enhancement dependent on mesh aperture

CHF enhancement is highest with a mesh aperture 2.0mm rather than 1.5mm, 2.5mm. Bubble growth is restricted by wire in a mesh hole, so a bubble departs from the hole more easily. Film boiling is restricted because the bubbles do not coalesce easily due to physical restriction of mesh wires. Thus, the optimal mesh size(2.0mm) for enhancing heat transfer rate and CHF can be regarded the size of a departing bubble from a surface. The relationship between mesh size and CHF enhancing should be examined by more experimentation.

4. Conclusion

In summary, the metallic wire mesh structure is a simple and cheap method to obtain porous coatings for flow boiling. Wire net coatings provide many additional nucleation sites and an additional capillary pressure gradient for liquid inflow into the region of intense evaporation in comparison to a smooth surface, enhancing CHF.

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