LIQUID SUBCOOLING INFLUENCE ON CRITICAL HEAT FLUX AT BOILING OF WATER ON POROUS TITANIUM SURFACES

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Abstract

Titanium materials have found application in many modern types of equipment as heat – exchanging surfaces, working at high thermal loads. In connection with this we received new data for subcooling critical heat flux (CHF) in pool boiling on porous surfaces of titanium materials. Comparing the CHF of the solid plate with that of the porous surface, we found that the CHF for a solid Ti plate was 40% higher. The experiments revealed a considerable influence of liquid subcooling on the CHF in the range of investigation. A simple empirical formula has been deduced to estimate the CHF on the porous surface with taking into account the subcooling of the liquid.

KEYWORDS

Liquid subcooling, CHF, porous titanium surface

INTRODUCTION

It is known that the materials of titanium are characterized by unique properties. They are often used at high temperatures and heat fluxes. Hence there is a necessity to investigate critical heat fluxes (CHF) at titanium porous strips. The pool boiling process took place at atmospheric pressure. Geometrical characteristics of the titanium porous strips under study were as follows: 85 mm in length, 3 mm in height, 0.46 mm and 1.38 mm in thickness.The porous strips were obtained from the plate of fine-dispersated powder of titanium by rolling. Average porosity of our strips was equal to 40%, roughness of solid strips came out to 10 micron. Average diameter of particles of these porous plates was equal to 8÷10 micron.

The special experimental device from stainless steel, shown in Fig. 1, has been developed for the investigation of CHF. The given temperatures in the boiling liquid have been reached by the thermostat 11, isolation 2 and electro-heater 10. Electrical heating of experimental plates of Ti was realized by means of transformer 9 and transformer rectifier 4, which moved rectified current directly to the experimental plate by the cable 3 and holder 5. The current from the transformer rectifier to experimental plate was supplied by the amperemeter. The current intensity and voltage were measured by the ammeter and voltmeter. Thus, heat flux in the porous titanium strip under investigation was determined on that basis.

The critical heat flux was fixed on the titanium strip overburning. The strip was placed vertically (Fig. 1, A). Bubbles developed on all surfaces. Visual observation showed more intensive boiling on porous surfaces, which is typical for them. At half value of CHF the porous strip was covered by continuous steam bubbles. For comparison the CHF on solid titanium strip of the same sizes was studied. The comparison of CHF on solid and porous strips has shown that CHF on solid strip was 40% higher.

The carried out experiments have shown considerable influence of liquid subcooling on CHF within the investigated range. A simple formula for CHF estimation on porous surface with liquid subcooling was obtained.

The temperature of the liquid was measured by thermocouple 7 and thermometer 8 with an accuracy of 0.1÷0.15°C. The approximate views of an interior porous strip were chaotic. It is obvious that the diameter of pores varies from place to place. The metal frame of the plate between the adjacent pores is also of different thickness.

Accordingly, the temperatures at such places are different. As a result, the appear of steam bubbles is change. Generated bubbles start to move within the pores and stimulate chaotic moment to the low-pressure regions, i.e. outside the pores. The pressure within the pores is higher than in liquid because

of the evaporation, and the moving force of bubbles is caused by the evaporation of the bubbles' surface layer. By the surface layer of a bubble is meant a border of contact of the bubble with the heating surface. The volume of pores around a steam bubble is limited, so that it cannot sufficiently expand. This causes the increase of pressure within the bubble. Due to this, the steam bubble starts to move outside the porous medium.

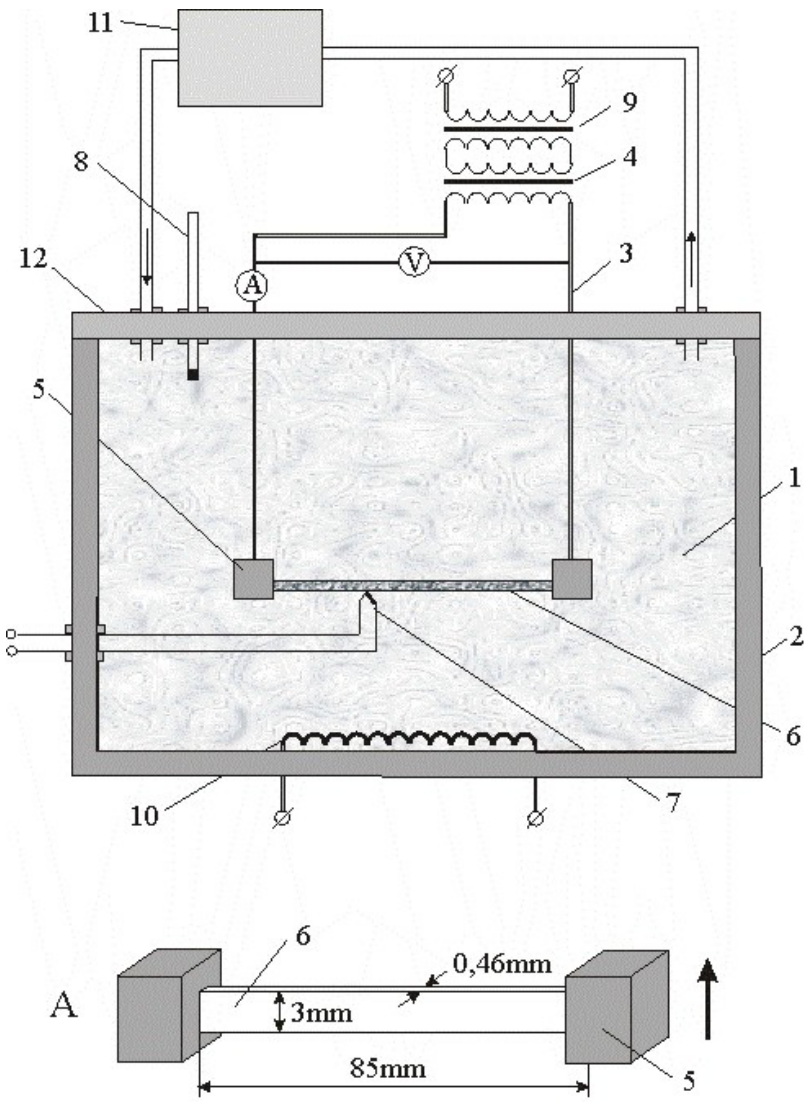

Fig. 1

1 – Boiling liquid, 2 – Stainless steel vessel, 3 – Current cable, 4 – Rectifier transformer, 5 – Porous plate holder, 6 – Porous plate, 7 – Thermocouple, 8 – Thermometer, 9 – Primary transformer, 10 – Heating element, 11 – Thermostat, 12 – Head

The bubble movement during the boiling process on a solid surface takes another form. Bubbles can easily go away from the heating surface and move upward. For the solid surface, the processes of nucleation, growth, separation and uprise of bubbles as well as interaction of pore and liquid medium can be described by stability criterion. This criterion of general importance was introduced at the end of XIX century by Lord Rayleigh [1]. He investigated two parallel flows of nonviscous liquid streams. It was assumed that a heavy liquid flows under a light liquid. This process is characterized by the hydrodynamic stability criterion. According to this theory, for the estimation of critical heat loads the following correlation [2, 3] are used:

$$k = q_k \big/ r\sqrt{\gamma''}\sqrt[4]{g\sigma\left(\gamma' - \gamma''\right)}. \tag{1}$$

The value k =14 is true during free convection boiling.

An investigation was carried out for titanium surfaces with liquid subcooling within the range from 0 to 50 degrees in water boiling at atmospheric pressure. The results of this experiment, i. e. the values of q_{sub} depending on subcooling temperature ΔT_{sub} of liquid, are shown in Fig. 2.

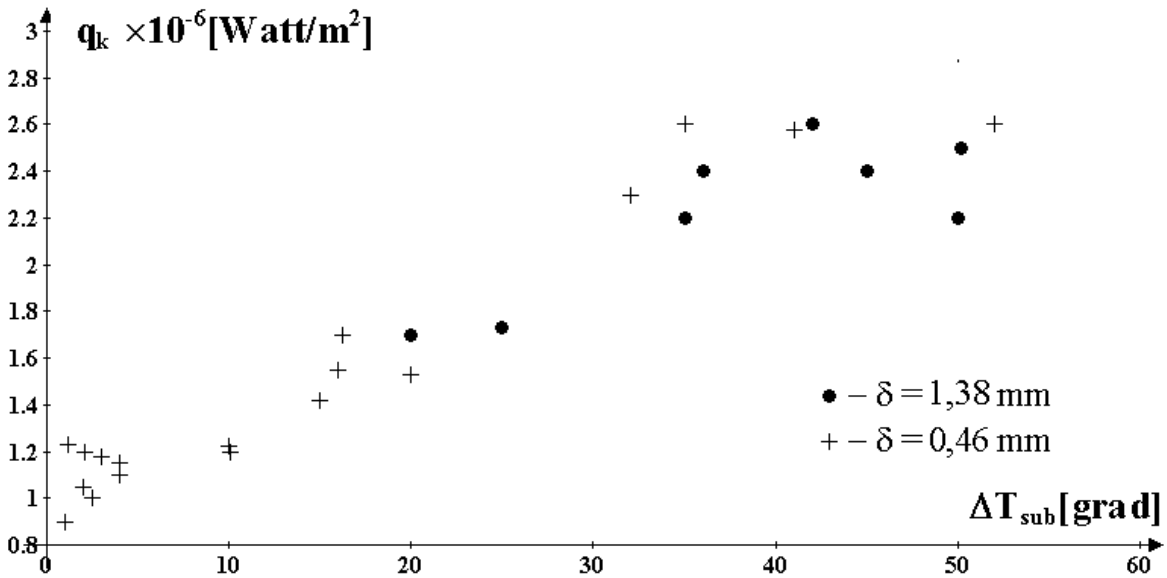

Fig. 2

As might be expected, CHF increases with ΔT_{sub}. It should be noted that CHF shown in Fig. 2 is the value of critical heat load of dry-out. It is possible to explain the mechanism of increasing CHF during subcooling process as follows: during subcooling of the liquid volume, the liquid at a temperature which is lower than the saturation temperature moves on the heating surface. At the beginning of the evaporation process, first of all it is necessary to raise the temperature on the heating surface up to the saturation temperature. This requires an additional heat load:

$$\Delta q = G \cdot C_p \left(T_s - T_e\right), \tag{2}$$

where G is the liquid mass that demands the additional heating, C_p is the heat capacity of liquid, T_s is the saturation temperature, T_e is the existing temperature in the liquid volume.

The influence of subcooling on CHF at boiling in big volumes on flat-type titanium porous surfaces can be calculated according to the following empiric formula (for porosity of 40%):

$$q_{k-sub} = 1{,}1 + 0{,}033 \cdot \Delta T_{sub} \left(MW\right).$$

It should be noted that the theoretical estimation of the CHF on porous heat transfer surfaces demands thorough additional study [4]. This is confirmed by the review of investigations of heat exchange on porous surfaces [5].

In summary it may be deduced that in the given paper new experimental data for CHF at boiling of subcooling water on porous titanium surfaces were obtained which are of practical importance for highly technologies.

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Nomenclature

C_p – Specific heat, J/(kg·K)

g – Gravitational acceleration, m^2/s

G – Liquid mass, kg

k – Coefficient of correlation

q_k – Critical heat flux, MW/m^2

q_{k-sub} – Subcooling critical heat flux, MW/m^2

q_{k-sat} – Saturation critical heat flux, MW/m^2

r – Latent specific heat of evaporation, J/kg

T_s – Saturation temperature, K

T_e – Existing temperature, K

ΔT_{sub} – Temperature of subcooling, K

δ – Thickness, mm

γ' – Specific mass of liquid, kg/m^3

γ'' – Specific mass of vapor, kg/m^3

σ – Surface tension, N/m

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