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Effects of ultrasonic waves on the heat transfer enhancement in subcooled boiling

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ABSTRACT

This work represents an experimental basic research aimed to investigate the influence on the heat transfer rate of the ultrasounds, in free convection and in presence of liquid. In fact the ultrasonic waves induce, thanks to vibrations, turbulence on the dynamic field, and so an increase of the convection coefficient. The heater is a circular cylinder, immersed in distilled water, and warmed up by Joule effect. This study has carried on for 1 year at Energetics Department "L. Poggi". The effect was observed since 1960s: different authors had studied the cooling effect due to the ultrasonic waves at different heat transfer regimes, especially from a thin platinum wire to water. We have chosen to investigate the subcooled boiling regime, because this one is the best condition for the heat transfer enhancement, according to the scientific literature. We have carried out a wide experimental study, varying the different water subcooling degrees, the ultrasonic generator power, the ultrasound frequency and the placement of the heater inside the ultrasonic tank, in function of the range of the values of heat flux per unit surface needed dissipating. These values were supplied us by a possible practical application of the ultrasonic streaming: the cooling of 3D highly integrated electronic components. These packaging systems should have to provide all future devices, such as electronics, actuators, sensors and antenna. In fact, for these systems the thermal problem is a critical challenge, because they do not have to overtake critical temperature, after that they could damage irreversibly. Moreover, the traditional cooling systems used in electronic do not seem to be useful for them. On the contrary, the results obtained with ultrasounds, allow heat transfer coefficient enhancement of about 50% to be reached.

The purpose is to find out the set of optimal conditions, in order to apply successively all the results to a real packaging system.

1. Introduction

Since the 1960s the cooling effect due to acoustical waves was investigated. In 1965, Fand [1] observed the influence of the acoustical field on solid–liquid heat transfer process, involved in the water desalination. The frequency was set at 6.5 kHz (below ultrasound frequency) and the cavitation induced in the liquid was the most important mechanism in the heat transfer enhancement.

Successively, Li and Parker [2] carried on an experimental study about natural convection, from a thin platinum wire (0.2 mm in diameter) to water at room temperature, in presence of acoustical field (frequency at 20 kHz). They noticed the presence of a maximum heat transfer coefficient corresponding to a certain value of sound pressure, after that the heat transfer rate had started to decrease.

Park and Bergles [3], firstly, analyzed the ultrasound effects properly, in subcooling and pool boiling conditions, at the frequency of 55 kHz, using R-113 as working fluid and cylinders as test sections ($1.65\ \text{mm} \leqslant \text{O.D.} \leqslant 2.11\ \text{mm}$). The combined transducer output was 75 W. The highest heat transfer coefficient augmentation was reported for subcooled case, because of, in pool boiling case, the steam amount was too large and the ultrasonic energy quenched before to reach the heater surface.

More recently, Iida and Tsutsui [4] carried out a series of experiments to make clear systematically the effects of ultrasonic waves, at 28 kHz in frequency and 33.6 W in maximum power. The studies had been carried on in natural convection, nucleate boiling, and film boiling, from a heated 0.2 mm in diameter platinum wire to water or ethyl alcohol. No effects were observed in nucleate boiling of water, a small effect was attained in low heat flux nucleate boiling of ethyl alcohol. An increase of about 20% in the maximum heat flux, by applying ultrasonic waves, was observed in both liquids, in natural convection and film boiling heat transfer regimes. The minimum heat flux point (MHF) was raised at higher values of both the degree of superheat and the heat flux. Moreover, it might be noticed that the heat transfer coefficients, in presence of ultrasonic waves, were depended largely on the distance from the vibrating surface to the test position.

Kim et al. [5] tried to separate the effects induced by the cavitation and the ones due to the ultrasonic waves only. The frequency was set at 48 kHz, using FC-72 as working fluid.

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