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BRIEF COMMUNICATION

THERMAL HYSTERESIS OF FORCED CONVECTIVE BOILING

ABOLFAZL SALEHPOUR† and SHI-CHUNE YAO
Mechanical Engineering Department, Carnegie-Mellon University, Pittsburgh, PA 15213, U.S.A.

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INTRODUCTION

When an object is heated up in a transient process to film boiling and then cooled down through quenching, it is important to know whether the boiling curve of the transient heat up and cool down processes are identical. To identify the possible existence of thermal hysteresis in forced convective boiling, a temperature controlled transient experiment has to be performed.

Experiments were performed by various investigators to identify the difference between quenching data and the result of steady state pool boiling. Bergles & Thompson (1969) showed that under certain conditions there are significant differences between the boiling curve of quenched specimens and that of conventional steady state experiments. Peyayopanakul & Westwater (1978) developed the limits of the unsteady state quenching process. Based on this criterion quenching can be regarded as either quasi-steady or unsteady process.

On the other hand, heat flux controlled heat up experiments have been performed to investigate the transient effects on the critical heat flux (CHF). Due to the nature of the experiments, it has not been possible to explore the transient boiling behavior beyond the critical heat flux. Additionally, since most of the transient heat up experiments and the quenching experiments have been performed separately, comparison between these two types of boiling has not been established. Sakurai & Shiotsu (1978) were the first to use a computer controlled experiment to study the transient heat up followed by quasi-steady cool down in a pool. They observed the existence of thermal hysteresis near CHF. Since the rate of transient temperature rise in their experiments was only 2 K/s (which is a very slow transient), they did not observe any hysteresis in the regions away from CHF.

The objective of this brief communication is to report the typical data of temperature controlled boiling experiments in a vertical annular channel under forced convective condition for the thermal hysteresis of the transient heat up and the naturally cool down process. Detailed and complete information will be reported elsewhere at a later time.

EXPERIMENTAL WORK

High temperature liquid Tin has been suddenly poured into the test section (figure 1) to generate transient boiling of convective Freon-113 in the annular channel. The inner heating tube is made of 304 stainless steel (O.D. = 1.14 in., I.D. = 0.75 in.); the outer shroud is a pyrex tube (I.D. = 1.43 in.). The length over which visualization is performed is 15 in. The transient temperature of the SS tube at two interior points of the wall at different radial locations are measured with two thermocouples and recorded in a PDP-11/40 mini-computer at a rate of every 10 ms. Figure 1 shows the locations of the thermocouples. Nicrobraze-30, whose thermo-physical properties are close to that of the 304-SS, has been applied as the filler material to cover the thermocouple grooves. The data reduction program calculates temperature distribution between the thermocouples directly and calculate the surface temperature and heat flux by inverse conduction method (following D'Souza 1975).

†Present address: Heat Transfer Research Inc. 1000 S. Fremont Ave., Alhambra, CA 91802, U.S.A.

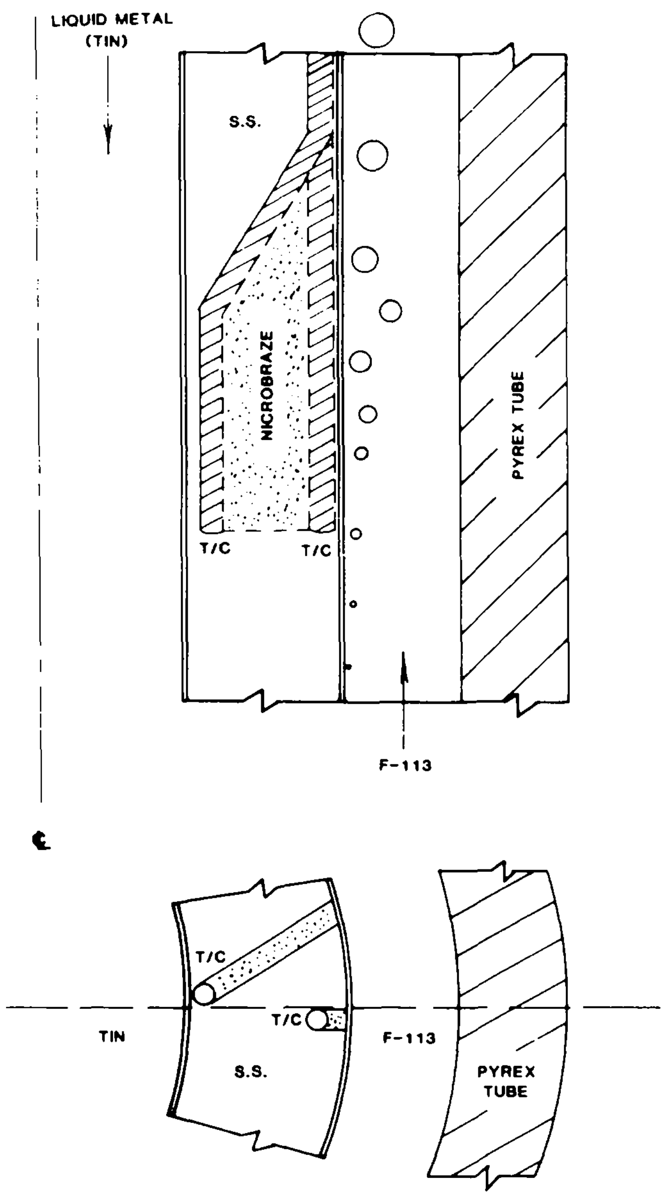

Figure 1. Details of thermocouple installation.

HYSTERESIS EFFECT

Figure 2 shows the hysteresis of boiling curves for a typical experiment whose conditions are: $P = 34.4$ KPa, $T_b = 73.9$°C, $G = 294.4$ Kg/(m^2-s) and $T_{\text{liq. metal}} = 589$°C (the solid curve). This curve shows both transient heat up and cool down processes. It is clear that difference exists between these two processes.

To check the repeatability, another test with similar conditions has been performed and the resulted boiling curve is also shown in figure 2 (the broken line). The estimated error is also indicated on this figure. The difference between the two curves is reasonably small. For comparison, the calculated steady state forced convection CHF (Coffield 1969) for the conditions of this typical test is also shown on figure 2.

The critical heat flux of the cool down process is found to be very close to the predicted steady state CHF. Similar observation has been reported in the quenching experiments of

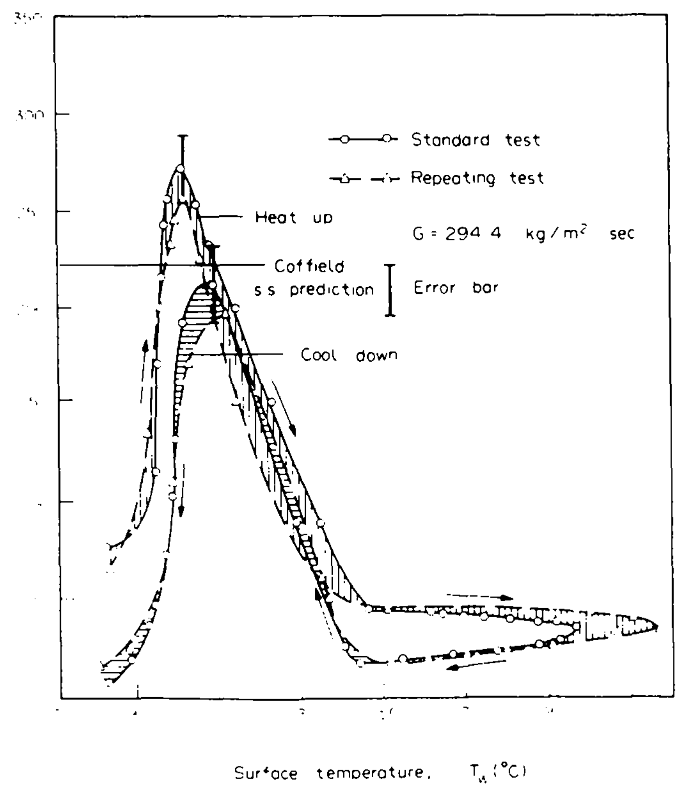

Figure 2. Typical and repeating boiling curves.

Peyayopanakul & Westwater (1978) for thick copper blocks. However, the CHF of the transient heat up process is clearly higher than the steady state CHF. This is consistent with the general observations of transient CHF studies performed by other investigators (e.g., Johnson *et al.* 1961).

Traditionally, the transition boiling is defined as the part of boiling curve with a negative slope. Figure 2 shows that the transient transition boiling of this experiment has two sub-

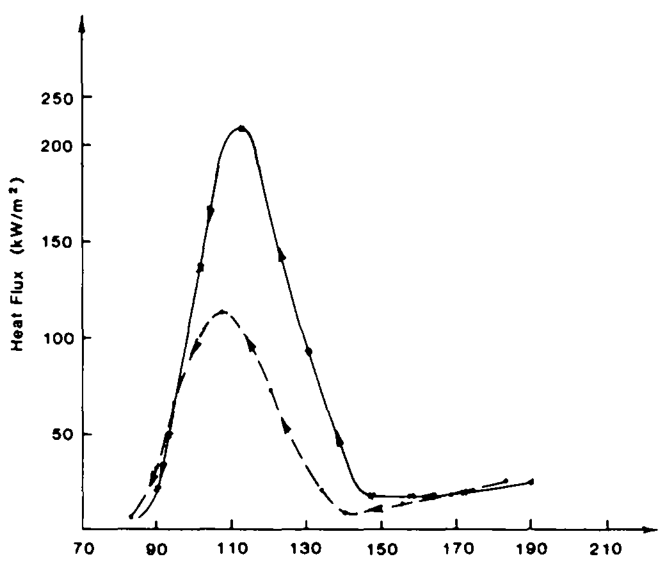

Figure 3. Comparison of quenching mechanisms.

regions. In the first sub-region (near the CHF) the heat flux drops rapidly as the surface temperature increases due to the rapid coverage of the heated surface by F-113 vapor which blocks the heat transfer. At the second sub-region (at higher surface superheat) the heated surface is already mostly covered by vapor. The additional heat transfer as compared with that of steady film boiling is possibly due to the agitation of the vapor and liquid as the remaining hydrodynamic effect of the boiling transient.

THE EFFECT OF QUENCHING MECHANISM

The heated section is quenched by the up flowing Freon-113. Due to the end effects to the cooling of the heated section, the quenching of the test section occurred at both upstream and downstream ends and propagated to downstream and upstream respectively.

Figure 3 shows the boiling curves obtained from the two quenching mechanisms. The solid line is the one when the quenching front travels toward downstream and the broken line is the one when the quenching front travels toward upstream. It is clearly seen that the CHF for the latter case is less than the first one. This indicates that the thermal hysteresis of boiling in a convective channel is also dependent upon the type of quenching mechanism.

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