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Analyzing temperature fluctuations to predict boiling regime

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ABSTRACT

Determination of forthcoming boiling regime is one of the challenging problems in diagnostics of industrial systems where rapid thermal transients exist. Taking into account intensive temperature oscillations met there, a conventional, boiling-curve based forecast becomes inaccurate. In the present paper we demonstrate the technique to cope temperature instabilities and predict the regime employing them. The method is validated against two experimental datasets, considering liquid nitrogen at 1–4 bars and water at normal conditions.

1. Introduction

A large-scale thermal system employed in, for example, nuclear, cryogenic or transport industry, may experience sudden transitions of boiling regime during operation. It becomes critically important to look ahead the process and understand when nucleate or film boiling occurs. There are two main diagnostic methods that are commonly utilized. The first is based on acoustic detection of early boiling events. Westwater et al. [1], in one of the earliest works on the desired problem, considered acoustic characteristics of boiling in methanol and successfully detected transition to film boiling, observing significant gradient of acoustic pressure level. In following contributions, for example, Aberle et al. [2] the acoustic measurement were employed to localize the boiling regions within the reactor core while Dorofeev and Volkova [3] succeeded to estimate kinetics of steam bubbles formation making use of mathematical treatment applied to sound logs. These techniques were however complicated for practical use since the measurements are often contaminated and need to maintain a distributed diagnostic system.

The second approach employs fluctuations of the heating surface temperature. The fluctuation history could be treated either statistically as in Lu et al. [4], or via the frequency response function [5–8], enabling prediction of boiling crisis and other related thermal phenomena. Deev et al. [5] and Skokov et al. [6] conducted experiments on subcooled boiling of water, tracking the process both in terms of the temperature fluctuations [5,6] and acoustically [5]. The experimental results demonstrate mutual correspondence of both techniques and their ability to map a transition of boiling regime. Pavlenko et al. [7] observed thermal oscillations during cavitation in an ultrasonic field, coming out with the conclusion that the formation of large-scale steam cavities was associated with the increase of the temperature oscillation frequency.

The present study reports experiments on boiling of two importantly different fluids and applies the later technique, based on the frequency response of temperature fluctuations. Here, applying Fourier transforms to the experimental temperature logs, we define a technical marker, capable to denote transition of the regime.

2. Measurements and treatment

The experimental set-up, presented schematically in Fig. 1, was consistent of a thermally insulated, pressurized volume of considered fluid, where a thin cylindrical heater was placed horizontally. The diameter of the heater, made of platinum, was 100 µm and the length below 35 mm. The heater was simultaneously used as a thermistor, while the heat generation was achieved in two different electric modes (DC) consequently stabilizing electrical current and voltage. At first, we used distilled water subcooled 0–30 K below saturation ($\theta = T_s - T_f$) at 1 bar. Secondly, liquid nitrogen was considered at pressures 1–4 bar. Two parameters were recorded during the experiments: surface heat flux coming from the heater $q(\tau)$ and superheat of the heating surface relative to the temperature of fluid $\Delta T(\tau) = T(\tau) - T_f$. The frequency of data acquisition was up to 100 kHz and a duration of typical sample was up to 100 s. The experimental system and experimental results are discussed in detail elsewhere [5,8].

Figs. 2 and 3 represent typical logs of superheat and surface heat

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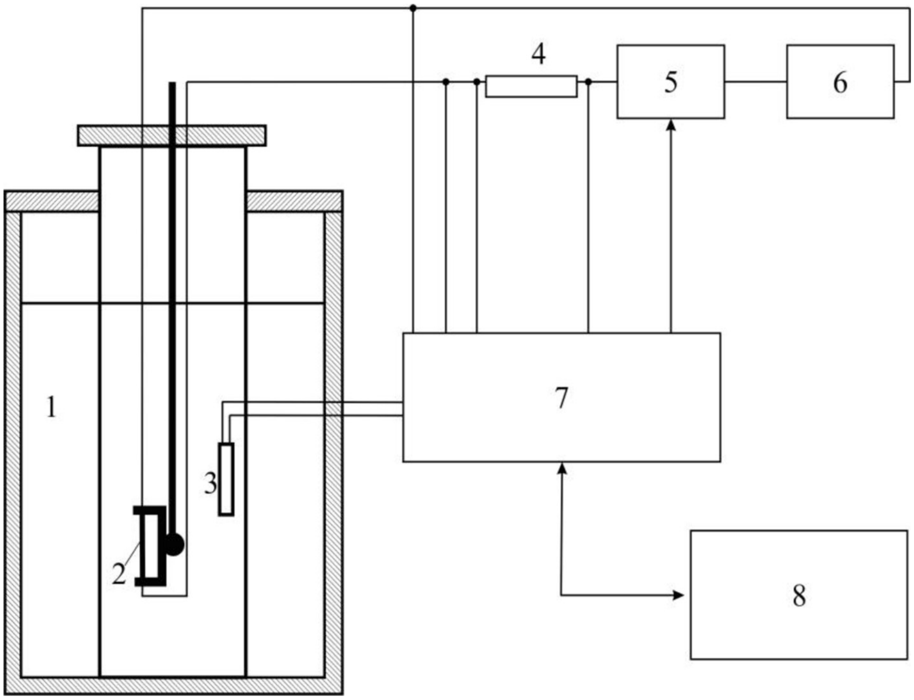

Fig. 1. Scheme of experimental system: 1 – cylindrical vessel; 2 – heater; 3 – thermometer; 4 – standard resistance; 5 – current load controller; 6 – power supply; 7 – device for experiments control and measurements; 8 – PC.

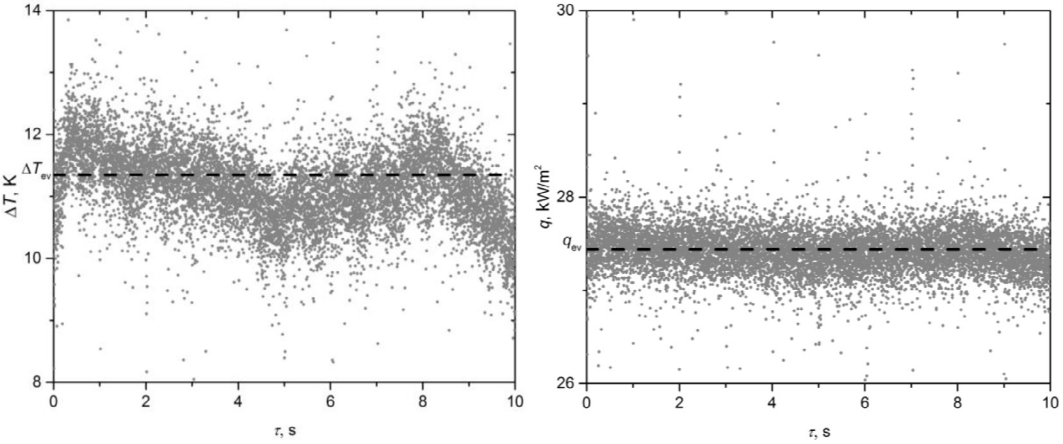

Fig. 2. Superheat (left) and heat flux (right) as a function of time in liquid nitrogen at 1 bar.

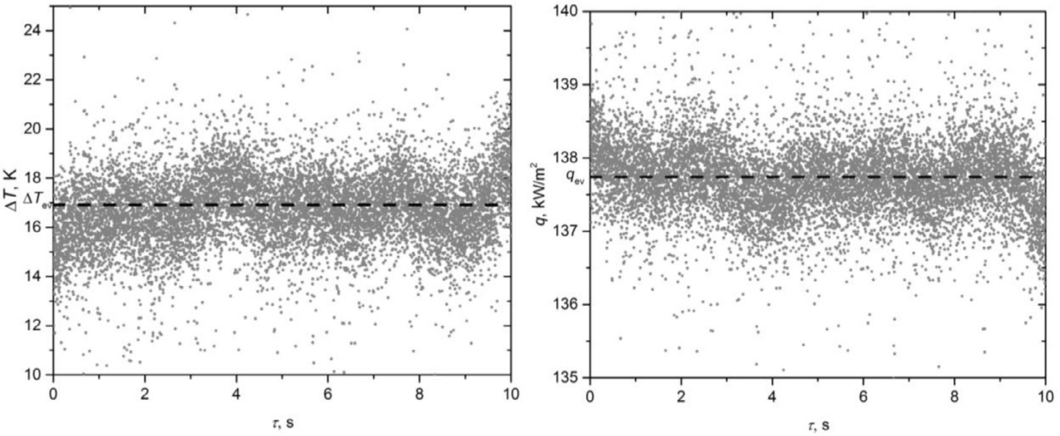

Fig. 3. Superheat (left) and heat flux (right) as a function of time in saturated water at 1 bar.