Technique for the measurements of the temperature profile near liquid-gas interface

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Abstract. The technique for the experiments with moving microthermocouple across the liquid-gas systems with interfaces is presented. The experimental setup, apparatus and automation technique for temperature profile measurements are described. The special software for automation, processing and synchronization of the experimental procedure and data is developed. The software allows one to control the progress of the experiment, such as evaluation of various equipment delays. The data can be collected and stored in an accessible and comprehensive form. The typical experimental values are automatically obtained. The use of program minimizes the human factor.

1 Introduction

Nowadays, data centers and mobile devices have many problems with thermal regulation [1]. The micro-sized two-phase cooling systems with phase transition are of a particular interest because of the high heat transfer coefficients [2]. The study of the heat and mass transfer in system with evaporation, boiling and condensation is required. Study of heat transfer in a two-layer system with liquid-gas interfaces is one of the topical scientific problems, for instance, in developing the technologies for heat pipe production and in investigation of dry spot formation [3]. The temperature jumps at in the Knudsen layer at phase transition are known for a long time in the kinetic theory, since the phase transitions occur under the non-equilibrium conditions [4,5]. An approach to the description of heat and mass transfer in the two-phase system, based on the Navier–Stokes equations with the temperature and pressure jumps boundary conditions, was suggested in [6]. However, the experimental data on the pressures and temperatures jumps at the interfaces is limited [7,8,9].

The experimental setup, apparatus and automation technique for temperature profile measurements in two-layer liquid-gas system are presented in this paper. The purpose of work is creation of the software for the automation of experimental process of the temperature field measurements across two-layer systems with a moving interface and heating elements. The data synchronizing with sufficient accuracy should be an important procedure of the software.

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2 Experimental setup and measurements technique

A photo of the experimental setup is presented in Figure 1. The main part is a round test cell with a local heater in the centre. Ultrapure water (MilliQ) is used as a working fluid, which evaporates into the atmosphere under normal conditions. The main measuring device is a self-made microthermocouples of type-E with a bead thickness of less than 4 microns. Also there are standard microthermocouple of type-K located in the heater and the air, which provide additional temperature control. Cold junctions of a microthermocouples are soldered to the copper wires and lowered into an electronic zero point with error of 0.001 °C (Fluke). Accuracy of all thermocouples is 0.02 °C. Calibration is performed using two references RTD (ETS 100). Microthermocouples receives data from the data collection terminal (NI TB-9214). Precise micropositioner (Zaber) with a minimum step size of about 50 nanometers moves the main microthermocouples fixed in a special holder. Special software determines the position of microthermocouple bead. The shadow technique is used to control the movements of the microthermocouple. The experiments are carried out for the different heating modes. The experimental setup is insulated by protective box. The data is processed in real time using a computer.

Figure 1. Photo of experimental setup.

3 Automation and synchronization

The experiment is as follows: microthermocouples moves to a position above the water and then a passes through the liquid-gas interface with constant speed. The experiment is controlled by specially developed on C++ software, which allows carrying out all experiments in the same operating condition. The program records the time and position of micropositioner, as well as the time and temperature values from the thermocouples data collection terminal. The comparison and correlation

of collected data with respect to time are made by software. A coordinate of the liquid-gas interface is defined in two ways: first method is by shadow technique visualization with CCD-camera in the moment of contact of the microthermocouple and liquid; second is by the definition by the temperature jump when microthermocouple passes through the liquid-gas interface.

Finally, as a result of the measurements and data processing by software we obtain a graph. The graph (Figure 2) presents the temperature profile (yellow line) across the liquid and gas layers, including interface, via microthermocouple position, where zero point is a position of liquid-gas interface. Green line in Figure 2 is a delay in data synchronization. The software collects, stores and processes the data from other thermocouples located in different parts of the experimental setup. Timing error is calculated as the difference between the times of signal acquisition module from microthermocouple and of micropositioner signal. Figure 2 shows the delay time not exceeding 35 ms, which is sufficient for the present experiment because the size of microthermocouple bead is an order of magnitude greater than the distance travelled by microthermocouples during this time.

Figure 2. Temperature profile and delay of measurements. Position 0 corresponds to the liquid-gas interface. Ambient temperature 25.2 °C, humidity 20.2 %, pressure 99 kPa, heating power is 18 mW. Speed of microthermocouple displacement is 5 $\mu\text{m/s}$. The microthermocouple signal reads every 0.5 seconds.

The position and coordinate of the heater surface, situated in bottom of cuvette, are determined once for all experiments. The determination of the heater coordinate allows automatically calculate the liquid layer thickness and hence mass flow rate of evaporated liquid. The temperature difference between readings of two steps of microthermocouple is calculated automatically by software and obtained, see Figure 3. The value of the maximum temperature jump of about 0.09 °C is obtained for the operating condition. The time of the temperature jump occurring from the experiment beginning is 176.8 s. The position of the maximum jump in the micropositioner coordinates is 18422.7 μm . The bottom position of micropositioner coordinates is 20621.5 μm . Hence, the liquid thickness of 2198.8 μm is obtained.

Figure 3. The absolute change in temperature after each read. Ambient temperature 25.2 °C, humidity 20.2 %, pressure 99 kPa, heating power is 18 mW. Speed of microthermocouple displacement is 5 $\mu\text{m/s}$. The microthermocouple signal reads every 0.5 seconds.

4 Conclusions

The technique for the experiments with moving microthermocouple across the liquid-gas systems with interfaces is described. The experimental setup, apparatus and automation technique for temperature profile measurements are developed.

The specially developed software allows one to control the progress of the experiment, such as evaluation of various equipment delays. It reduces the number of different options for some experiments. The software collects and stores comprehensive experimental data in an accessible and visual form. The typical experimental values are automatically obtained. The use of program minimizes the human factor.

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