

# The dynamics of nucleate boiling of salt solutions at a high heat flux

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**Abstract.** In this paper, experimental results are obtained for the desorption of layers of aqueous salt solutions of LiBr and CaCl<sub>2</sub> at a temperature of nucleate boiling on a horizontal heating surface. The wall temperature is 130 °C. The required volume of the solution with a given mass concentration is placed on the working surface using the Thermo Scientific dispensers. After that, the desorption rate continuously decreases over time. A decrease in the wall temperature leads to a drop in the intensity of the bubbling boiling. The effect of gas convection during evaporation and thermal radiation is small in comparison with the heat of evaporation.

## 1 Introduction

Intensive cooling with rapid evaporation of liquid is used in practice in power plants and in chemical technologies in the presence of high heat fluxes. Experimental and theoretical complexity significantly increases in the presence of non-isothermal conditions. Evaporation of liquids was studied in [1-4], and non-isothermal desorption of saline solutions was considered in [5-7]. Evaporation of water-salt solutions of salts is accompanied by an increase in the concentration of salt in solution. An investigation of the kinetics of growth of crystalline hydrates was considered in [8]. The cooling rate of the heated wall depends both on the geometric parameters of the droplets (the effect of an angle, diameter) and on the wettability [9-10]. The presence of a structured wall leads to an increased heat transfer [11-12]. The lower is the thermal conductivity of the wall material (high thermal inertia), the larger is the wall cooling under the liquid layer. Multiple reduction of heat transfer can be associated with nucleate boiling suppression [13-16] at liquid film thickening and with a boiling crisis (local liquid separation from the wall by a vapor layer). The problems of fuel combustion and dissociation of gas hydrates are closely related to gas droplet flows [17-23]. Evaporation of gas-droplet flows are widely used in practice in technical apparatuses [24, 25]. Modern contactless methods for visualization of instantaneous velocity and temperature fields (PIV) and Planar Laser Induced Fluorescence (PLIF) serve to a deeper understanding of the effect of free convection when the rate of evaporation and heat transfer decrease [26, 27]. To date, there is little data on how the behavior of heat transfer coefficient in a thin layer of an aqueous solution of salt, when the

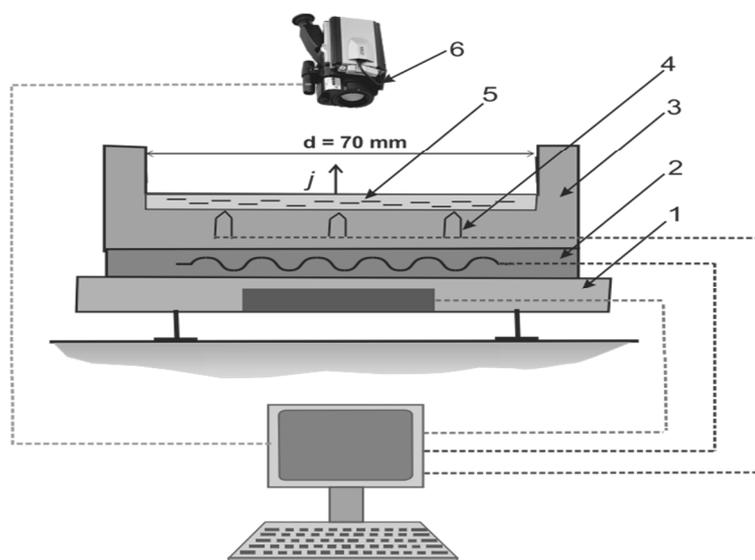
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evaporation of the layer occurs at high temperatures and in the presence of intense gas convection. The goal of the experimental work is to investigate the dynamics of the nucleate boiling of salt solution at high heat flux.

## 2 Experimental data

The experiments were carried out on a horizontal heated titanium wall (3) (Fig. 1). The ambient temperature was 22 °C, and the pressure was 1 atm. The diameter of the working surface was 70 mm, and the height was 50 mm. The wall temperature was 130 °C. The initial concentration of aqueous solutions of LiBr and CaCl<sub>2</sub> salts was 10 % and was determined by standard densitometers. The evaporation rate and concentration were determined using the gravimetric method (scales (1)). The thermal field of the layer ( $T_s$ ) was measured by a thermal imager (NEC R500) (6). The temperature of the heated wall ( $T_w$ ) was determined by means of thermocouples (4) located near the wall. The maximum error in measuring  $T_w$  did not exceed 1-2 °C. The initial height of the layers (5) in all the experiments was 3 mm. The distillate layer and aqueous salt solutions of the LiBr and CaCl<sub>2</sub> were formed at room temperature on the surface, using a Finnipipette Novus volumetric dispenser. The experiments were carried out until the boiling stopped.

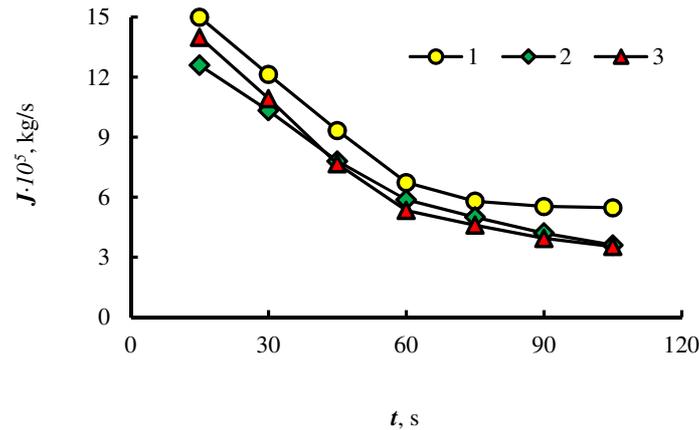


**Fig. 1.** The scheme of experimental setup: 1 – electronic balance; 2 – heater; 3 – metal working section; 4 – thermocouples; 5 – liquid; 6 – thermal imager.

The evaporation rate of the solution layer  $j$  was determined for narrow time intervals

$$j = \Delta m / \Delta t, \quad (1)$$

where the change in the drop mass  $\Delta m$  was determined experimentally,  $t$  is the time. Fig. 2 shows experimental data on evaporation rate  $j$  for distillate and for aqueous salt solutions: LiBr and CaCl<sub>2</sub>. During the first two seconds there is no boiling, as it takes time to heat the layer from room temperature to wall temperature. A significant drop of  $j$  and the bubble growth rate for the aqueous salt solution at nucleate boiling is associated with an increase in salt concentration, low thermal conductivity of the wall (titanium) and low thermal inertia.

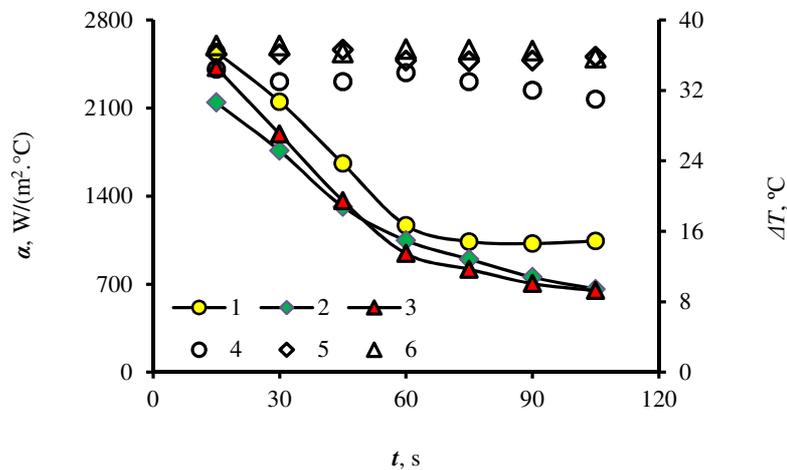


**Fig. 2.** The evaporation rate  $j$  for distillate and for aqueous salt solutions: 1 –  $H_2O$ ; 2 –  $H_2O/LiBr$ ; 3 –  $H_2O/CaCl_2$  ( $T_w=130\text{ }^\circ\text{C}$ , the initial salt concentration is 10 %, the initial thickness of the liquid layer is 3 mm).

The heat transfer coefficient  $\alpha$  for a liquid can be determined from expression (2),

$$\alpha = q_\Sigma / \Delta T \quad (2)$$

where the heat flux density  $q_\Sigma = q_w = q_h + q_e + q_c + q_r$ ,  $q_w$  is the heat flux density of the wall,  $q_h$  is the heat flux due the liquid heating,  $q_e$  is heat flux due to evaporation,  $q_c$  is the heat flux due to gas convection,  $q_r$  is the heat flux due to radiation, and  $\Delta T = T_w - T_s$ . The convection flux  $q_c = 380\text{ W/m}^2$  and the radiation flux  $q_r = 367\text{ W/m}^2$  vary slightly throughout the evaporation time interval. The effect of gas convection during evaporation and thermal radiation is small in comparison with evaporation heat. Fig. 3 shows the experimental data on the change in the heat transfer coefficient. The heat transfer coefficient  $\alpha$  for water is higher than for salt solutions by 15-30 %. Suppression of heat transfer for salts is associated with an increase in viscosity and surface tension with increasing salt concentration in solution. The maximal measurement error  $\alpha$  is within 14-17 %.



**Fig. 3.** Total heat flux  $q_\Sigma$  ( $W/m^2$ ) over time: 1 –  $H_2O$ ; 2 –  $H_2O/LiBr$ ; 3 –  $H_2O/CaCl_2$  and  $\Delta T = T_w - T_s$ : 4 –  $H_2O$ ; 5 –  $H_2O/LiBr$ ; 6 –  $H_2O/CaCl_2$ .

### 3 Conclusions

The dynamics of nucleate boiling of layers of aqueous salt solutions H<sub>2</sub>O/LiBr and H<sub>2</sub>O/CaCl<sub>2</sub> at high heat flux has been experimentally studied. The data and further research will serve to better understand the specific features of operation of high-temperature desorbers of new generation of absorption thermotransformers.

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