The effect of co-current gas velocity on heat transfer of the pulse spray

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Abstract
This report represents the results of experimental investigation of the effect of gas and droplet phase parameters of the pulse spray on heat transfer with a surface under the conditions of evaporation cooling.

Introduction

It is shown experimentally that artificial perturbations, introduced into the flow, intensify heat transfer between the jet and heated surface [1 – 3]. Application of controlled sources of the gas-droplet flows in the cooling systems seems to be far-reaching from the point of improvement of heat transfer efficiency. Such systems allows assignment of parameters for the gas-droplet flow depending on heat loading of the heat exchanger at the expense of a change in duration, frequency and the supply point of the liquid flow component to the heat exchanger surface, what provides the optimal conditions for heat transfer.

Set-up and Methods of Measurements

The experimental set-up consists of the heat exchanger with the original digital calorimeter and pulse spray source [1]. The heat exchanger is made of high heat-conducting copper with the plane dimensions of 140 × 140 mm and thickness of 25 mm. The air-droplet flow is formed by the pulse spray source from 16 sprayers (matrix of 4 × 4) and 25 air nozzles (matrix of 5 × 5). The gas phase is stationary and it is uniformly distributed over the spray cross-section. The liquid sprayer is a disperser of four nozzles with the diameter of 125 μm with a solenoid valve. The time of sprayer opening $T_{\mathrm{front}} < 0.0002$ s was changed from 1 ms to 10 ms with frequency of valve opening from 1 to 50 Hz. The instantaneous flow through the sprayers and droplet velocity were registered by the pressure change at the inlet (Pl = 0.05 ÷ 0.6 MPa). The velocity of spray phases was changed: air velocity changed from 0 to 25 $\mathrm{m \cdot s^{-1}}$; water velocity changed from 1 to 20 $\mathrm{m \cdot s^{-1}}$. The distance between the injector and heat exchanger in these experiments was fixed and equaled L = 0.23 m. The temperature of heat exchanger surface was kept 70 °C constantly. Heat transfer was measured under the atmospheric conditions at the pressure of 0.1 MPa and medium temperature T_0 = 20 °C. The temperatures of air and liquid components of the spray were: 7 °C ÷ 13 °C for liquid and 20 °C ÷ 22 °C for air.

Results and Discussion

The effect of frequency and duration of spray supply pulse on the heat transfer coefficient is shown in Fig. 1 for the constant velocity of the co-current air flow (8 $\mathrm{m \cdot s^{-1}}$) and the ratio of mean mass phase velocities 0 – 0.01.

The heat transfer coefficient, average over the heat exchanger surface, was determined as $H = \frac{Q_T}{F_T(T_w - T_s)}$, where Q_{T} is heat energy supplied to the heat exchanger; F_{T} is its area, and T_{w} and T_{s} are the temperatures of the heat exchanger surface and liquid, fed to the sprayers.

At frequency of valve opening of 1 Hz for durations of 2 and 10 ms (the curves of other cases are between them) the heat transfer coefficients differ by the factor of 1.5. In both cases the conditions of evaporating heat transfer occur on the surface, when liquid droplets of spray evaporate before the arrival of the next portion of liquid With a rise of frequency the curves of heat transfer coefficient approach asymptotically their maximum. But for the case of 10-ms valve opening the evaporation conditions on the heat exchanger surface turn to the conditions of film cooling. While for the 2-ms opening the cooling conditions stay evaporating. In this case the optimum of cooling efficiency is achieved, when the amount of liquid, precipitated on the surface, is enough to complete the evaporation process by the arrival of the next liquid portion.

Dependences of heat transfer coefficients on the flow rate of liquid coolant are shown in Fig. 2. Experimental data diverge significantly depending on pulse duration, and the maximal heat transfer coefficients for shorter pulses are achieved at lower irrigation volumes. At repetition frequency, when the “head” of the next pulse reaches the “tail” of previous pulse the cooling conditions convert into the conditions of irrigation by continuous gas-droplet flow. Hence, application of short pulses of liquid supply is more efficient from the point of heat transfer intensification. At this the value of maximum depends weakly on the irrigation rate.

Dependences of heat transfer coefficient on the air flow velocity are shown in Fig. 3. It is obvious that the heat transfer coefficient increases significantly (by the factor of ~1.5) for the chosen parameters of liquid valve

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opening because of the co-current flow supply. At this heat transfer in the single-phase flow is (10 – 20)% of the total value at air supply into the spray.

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References

[1] Nazarov A.D., Terekhov V.I, Serov A.F. and K.A. Sharov K.A. *An Experimental Study of Pulsed-Spray Impingement Evaporative Cooling* // 7th International Symposium on Heat Transfer, (ISHT 08), October 26-29, 2008. Beijing, China.
[2] Pavlova A. A., Otani K. and Amitay M. *Active control of sprays using a single synthetic jet actuator* // Int. J. Heat and Fluid Flow. 2008. Vol. 29. P. 131 – 148.
[3] Panao M.R.O., Moreira A.L.N. *Intermittent spray cooling: A new technology for controlling surface temperature* // Int. J. Heat and Fluid Flow. 2009. V.30. P.117-130.

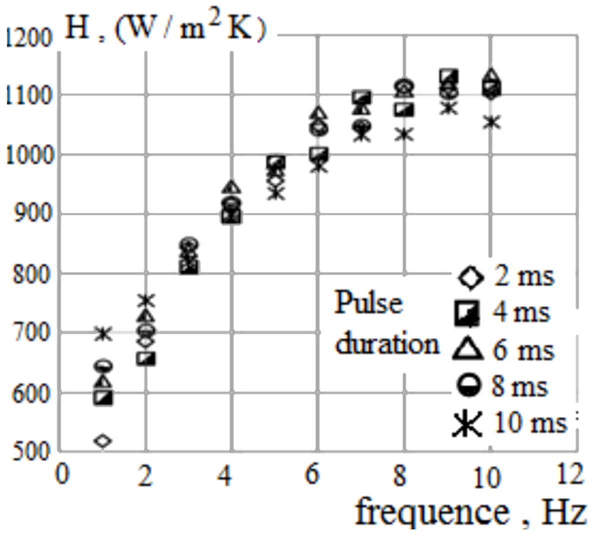

Figure 1. Heat transfer coefficient vs. frequency and duration of spray

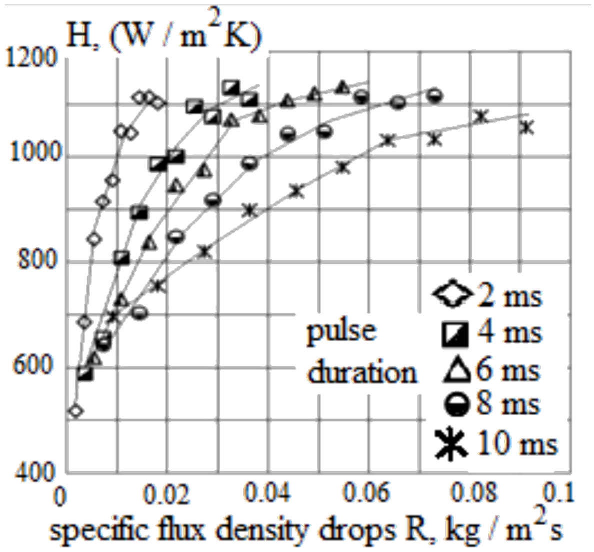

Figure 2. The effect of irrigation rate and pulse duration on the heat transfer coefficient

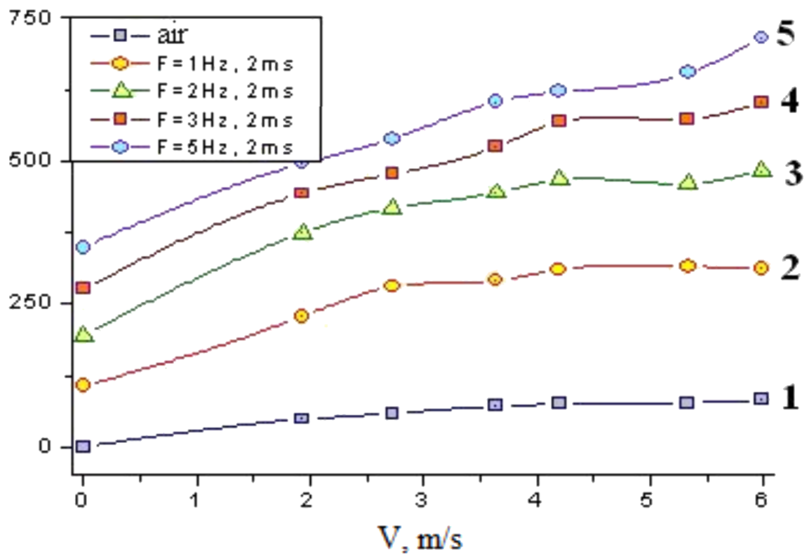

Figure 3. Heat transfer coefficient vs. air flow velocity