Chapter 2
Laminar Mist Flows Over a Flat Plate with Evaporation

The experimental and numerical study of laminar two-phase boundary layer with evaporating liquid droplets performed in relatively small number of works (Bhatti and Savery 1975; Heyt and Larsen 1970; Hishida et al. 1980, 1982; Osiptsov and Shapiro 1989, 1993; Osiptsov and Korotkov 1998; Pakhomov and Terekhov 2012; Terekhov and Pakhomov 2002; Terekhov et al. 2000; Trela 1981). Nevertheless investigation of such flows is a topical problem for various short channels that are widely used in different heat transfer equipment.

Below there is a brief review of works devoted to investigation of hydrodynamics and heat and mass transfer in the laminar two-phase flows at the absence and or presence of evaporation on the surface of the particles.

Possibly the first numerical and experimental chapter in which studied the laminar boundary layer on dry isothermal surface at the gas-droplets flow process was performed in the work (Heyt and Larsen 1970). The system of differential equations in the approximation of the boundary layer includes the equation of continuity, impulse, energy and diffusion with the source members. The effect of droplets evaporation on the boundary layer structure, wall friction and heat transfer for the case of low droplets mass fraction of small particles ($M_{L1} < 0.05$) with high velocity of evaporation has been examined. It was shown that with the increase of water droplets mass concentration the increase of heat transfer is significant, whereas the friction growth on the wall is minor. Theoretical dependences for heat transfer and friction on the wall in the laminar gas-droplets flows have been obtained.

The chapter (Bhatti and Savery 1975) refers to the theory of the two-phase boundary layer on the plate at which the droplets penetrate into the boundary layer and evaporate without deposition on the plate surface. The equations of the droplets motion taking into account the drag forces, the lift force and the gravity have been obtained. With use of the theory is possible to calculate the upper and the lower limits of the particles size penetration in the boundary layer and evaporating time there without the surface wetting. Significant influence of the droplets diameter and their mass fraction on evaporation is shown. The increase of the dispersed phase content leads to the augmentation of the heat transfer between two-phase flow and the wall. Influence of the droplets initial diameter increase is

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more complex: initial increase of the particles dimensions intensifies heat transfer and further with the growth of the droplets size heat transfer decreases.

The most detailed experimental studies of heat and mass transfer in the gas-drop flow streamlining the plane plate is the series of works of Hishida et al. (Hishida et al. 1980, 1982). In these works the heat transfer from the vertical flat plate to the laminar mist flow was studied. The average size of particles was $d_1 = 35$ μm. The other parameters of the two-phase flow: mass concentration of water M_{L1} = 0–0.023, the wall temperature is $t_W = 50$–80 °C, the initial temperature of air is $t_1 = 15$–20 °C and the Reynolds number built along the longitudinal coordinate and the velocity of the unperturbed flow is $\mathrm{Re}_x = U_1 x/\nu = (2.4–9.5) \times 10^4$.

Numerical study of dynamics and heat/mass transfer in a gas-droplet turbulent boundary layer on a vertical flat plate was carried out in the chapter (Pakhomov and Terekhov 2012). A large number of factors which affect the heat and mass transfer and the structure of thermal and concentration fields in a turbulent boundary layer is analyzed. It is shown that the increase in droplet concentration results in the intensification of heat transfer, as compared with the single-phase air flow.

A model for predicting heat and mass transfer in a laminar gas–vapor-droplets mist flow on a flat isothermal flat is developed in the chapter (Terekhov and Pakhomov 2002). Using this model, a numerical study is performed to examine the effect of thermal and flow parameters, e.g., Reynolds number, flow velocity, temperature ratio, concentration of the liquid phase, and drop size, on the profiles of velocity, temperature, composition of the two-phase mixture, and heat transfer intensification ratio. It is shown that, as the concentration of the liquid phase in the free flow increases, the rate of heat transfer between the plate surface and the vapor–gas mixture increases dramatically, whereas the wall friction increases insignificantly.

With the use of LDA measurements it was determined that the distribution of particles across the boundary layer is uniform and their velocity insignificantly exceeds the velocity of the air flow. The self-similarity velocity distribution in the two-phase flow does not depend on the mass flow rate ratio of water and air, wall temperature and velocity of the external flow and approximately agrees with the Blasius law (1955) for the laminar one-phase flow. In the wall region of the boundary layer the value of droplets velocity is somewhat higher than the Blasius profile. Authors of chapters (Hishida et al. 1980, 1982) explain this fact by the droplets inertia. The measurements have shown that sliding between the phases is practically absent in the considered range of the droplets sizes, the exception is only in the vicinity of the wall where the droplets insignificantly excel the gas phase. The averaged sliding of the phases according to the data of LDA was in the range of 0.03–0.07 m/s.

Authors derived that heat transfer intensification ratio at constant Reynolds number and the wall temperature was linearly depends on water mass flow rate ratio. It has been proved that intensification of heat transfer occurs for the account of the latent heat of liquid drops evaporation in the boundary layer. The value of heat transfer intensification is substantially affected by the value of the wall temperature. With the increase of the amount of water liquid the temperature of the air-vapor mixture and of the wall decreases and the length of evaporation area increases.

In the literature there are practically no data on the flow structure and influence of the droplets initial size on the heat transfer between the mist flow and the wall. The main aim of this work is to study the effect of the dispersed phase on the flow, structure of the boundary layer and heat transfer rate at thermal and gas dynamics parameters variation.

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