MODELING OF UNSTEADY “GAS–DROPLETS” SYSTEMS

Gintautas Miliauskas, Jonas Gylys, Stasys Sinkunas, Vaidotas Sabanas,
Department of Thermal and Nuclear Energy,
Kaunas University of Technology, Donelaicio 20, LT-3006 Kaunas, Lithuania

The state of a radiating two – phase “gas–droplets” system is modeled numerically. The interaction of the unsteady heat and mass transfer processes in semi-transparent droplets is examined by taking into account the spectral absorption of radiation. Systems of “gas–droplets”, produced by spraying semi-transparent liquid into a radiating environment, are widely used in thermal technologies: liquid fuel combustion chambers, water evaporators and scrubbers, and also in various thermal control and emergency systems. In order to increase the efficiency and reliability of energy equipment, it is necessary to optimize these technologies. Therefore it is useful to know the regularities of transfer processes, but very complicated thermal and hydrodynamic processes occur in systems of “gas–droplets”. The condensed phase of liquid is continually influenced by an external energy flux, the condensed phase is heated and phase transformations occur. In turn, the intensity of the transfer processes in the condensed phase influences the rate of state transformation of the carrying medium. Therefore the transfer processes in discrete and carrying media of the “gas–droplets” system are closely related.

It is quite expensive and complicated to research transfer processes in high-temperature two-phase “gas–droplets” systems experimentally and therefore the theoretical research is of high importance[1-2]. The level of present computing technique has significantly expanded the possibilities of theoretical investigations. Numerical research of the “gas–droplets” systems is complicated due to the fact that the transfer processes in the thermal technologies are distinctly unsteady; their interaction occurs under the intensive influence of selective radiation and phase transformations; boundary conditions of heat and mass transfer are changing all the time. Therefore, when modeling the unsteady state of “gas–droplets” systems it is necessary to evaluate the peculiarities of combined heat and mass transfer in separate droplets.

RESEARCH TECHNIQUE AND RESULTS

The rate of change of “gas – droplets” systems depends not only on the intensity of the energy and mass transfer processes in individual phases, but also on the interaction of the phases. Transfer processes have been modeled using an iterative method which is based on the complex "droplet problem”. The complex "droplet problem” covers the analysis of combined energy transfer in a semi-transparent droplet, and also the combined heating and evaporation of the droplet. The main point of such a problem is that the instantaneous temperature of the interphase contact surface is not known, but calculated during the iterative procedure, solving the system of equations of the energy fluxes on the interphase contact surface. The temperature of the interphase contact surface is determined when there is a balance of the energy fluxes taken to the surface and taken from the surface :

$$\vec{q}_{\Sigma}^{+} + \vec{q}_{\Sigma}^{-} + \vec{q}_{f}^{+} = 0\,. \tag{1}$$

In the case of combined heating, the total heat flux on the external side of the semi-transparent droplet surface depends on the radiant and convective heat fluxes $q_{\Sigma}^{+}(t) = q_{r}^{+}(t) + q_{c}^{+}(t)$. One part of the energy that is supplied to the droplet is used for its heating (q_h), another part is used for evaporating (q_f). The energy intensity q_h used for the heating of the droplet is determined by the total heat flux on the internal side of the droplet surface: $q_\Sigma^-(t)=q_r^-(t)+q_c^-(t)$. Since $q_h(t)=q_\Sigma^+(t)-q_f(t)$, the difference between total heat flux q_Σ^+ and q_Σ^- defines the intensity of energy used for the droplet evaporating q_f and determines the density mass flow liquid vapor on the droplet surface:

$$m(t)=\frac{q_f(t)}{L}=\frac{q_\Sigma^+(t)-q_\Sigma^-(t)}{L}. \qquad (2)$$

When a combined energy transfer process takes place in a semi-transparent droplet, the total heat flux can be calculated by summing up the components of the radiant and conductive fluxes:

$$q_\Sigma^-(t)=q_r^-(t)+q_c^-(t)=q_r^-(t)+k_e\lambda\left.\frac{\partial T(r,t)}{\partial r}\right|_{r=R^-}. \qquad (3)$$

In the case of radiant-conductive energy transfer, the unsteady temperature field in a spherically – symmetrical droplet is defined by the method[1] which evaluates the influence of radiation absorption peculiarities in a semi-transparent droplet and the rate the droplet's surface temperature change. As the local radiation flux in a droplet is calculated, such factors as the variations of spectral – optical characteristics of the semi-transparent liquid (during warming of a droplet) and the spectral – optical effects inside and outside the droplet are taken into account[1]. The influence of convection inside the droplet is evaluated by the effective conductivity parameter[3].

Temperature and concentration fields become distorted as a result of the interaction of the transfer processes. Therefore, the intensity of heat and mass fluxes in the case of combined transfer processes will change, compared with the case when the heat fluxes are acting independently (under the same conditions). It should be noted that radiation critically influences the interaction of the heat transfer processes in semi-transparent droplets, while Stefan flow influences the processes in their surroundings. The influence of radiation on the intensity of convection energy transfer in a gas is significantly lower than in a semi-transparent medium. The influence of the interaction of radiation and convection in a gas medium is neglected. Therefore, it is possible to calculate the intensity of the convection heating of an evaporating droplet using well-known empirical expressions for convection heat transfer in a non-evaporating sphere additional evaluating the influence of Stefan flow[1].

It is stated that the "gas – droplet" system is constructed by uniformly spraying the semi-transparent liquid into the flowing gas, spherically symmetrical droplets do not scatter and coalesce and the effects of viscous dissipation are negligible. The change velocity of gas enthalpy (h_g) for monodispersed two-phase flow passing through an adiabatic channel without an additional inner sources of energy depends on the intensity of heat transfer from the gas to the droplet (q_Σ^+) and the concentration of liquid droplets in the gas medium:

$$\frac{d(\rho_g h_g)}{dt}=-4\pi R^2 N q_\Sigma^+. \qquad (4)$$

In polydispersed flow, the parameters N and q_Σ^+ are individual for each group of different size droplets.

The discussed system of equations was solved numerically using an iterative procedure according to the temperatures of the gas and droplet surfaces.

The dependence of the state change of the condensed medium on the ratio of gas and liquid flow rates g_0, the dispersion of the liquid spraying and the way of droplet heating was investigated numerically in two – phase “gas–droplets” dispersed system under different conditions of heat and mass transfer. When a single droplet is evaporating in a gas flow then it is assumed that $g_0=0$.

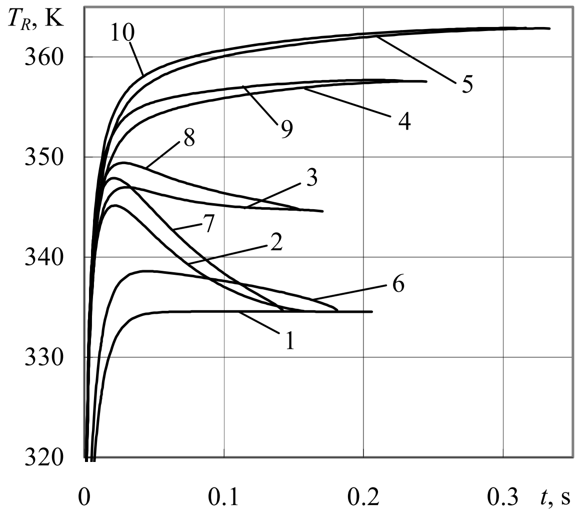

Figure 1. The dependence of evaporating droplet surface temperature on the droplet heating way: *1* – conductive; *2-5* – convective; *6* – radiant-conductive; *7*-10 – radiant-convective. Initial dimensionless flow rate $g_0 = G_{l,0} / G_{g,0}$: *1,2,6,7* – 0; *3,8* – 0.1; *4,9* – 0.5; *5,10* – 1. Slip velocity of droplet in gas $\Delta w_0 = w_{g,0} - w_{l,0}$, m/s: *1* – 0; *2-10* – 10.

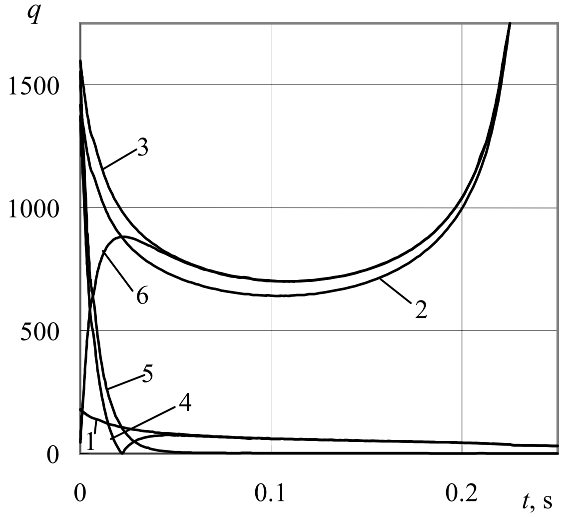

Figure 2. Variation of heat fluxes on the surface of evaporating droplet in the case of radiant–conductive heating q, kW/m^2: *1* – $q \equiv q_r^+$; *2* – $q \equiv q_c^+$; *3* – $q \equiv q_\Sigma^+$; *4* – $q \equiv q_c^-$; *5* – $q \equiv q_\Sigma^-$; *6* – $q \equiv q_f$. $T_{g,0}$=1500K. R_0=0.0001 m.

The temperature mode of the evaporating droplets significantly depends on the initial state of the “gas–droplets” system and the way of droplet heating (Fig. 1). During droplet evaporation the heat fluxes on the droplet surface continuously change (Fig. 2).

CONCLUSION

The change of state of two-phase “droplet-gas” flow can be classified according to the peculiarities of the interaction of combined transfer processes, presenting the initial, transient and final periods. The conduction component in the total heat on the droplet surface flux plays a very important role in the interaction of the transfer processes. During the initial period this component corresponds to the part of the external convective heat flux that heats the droplet. During the transient and final periods the conduction component indicates the part of radiant energy flux absorbed in the droplet and it is used for droplet evaporation. The main factors influencing the regularities of the transfer process interaction are the ratio of the initial gas flow by sprayed liquid flow, the dispersity of sprayed liquid and the way of droplet heating.

REFERENCES

1. Miliauskas, G., Regularities of Unsteady Radiative-Conductive Heat Transfer in Evaporating Semitransparent Liquid Droplets, *Int. J. of Heat and Mass Trans.*, Vol. 44, pp 785-798, 2001.
2. Gylys, J., *Hydrodynamics, Heat and Mass Transfer Under the Cellular Foam Systems*, Technologija, Kaunas, 1998.
3. Abramzon, B., Sirignano, W.A., Droplet vaporization model for spray combustion calculations, *Int. J. of Heat Mass Trans.*, Vol. 32, pp 1605-1618, 1989.