MATEC Web of Conferences **72**, 01001 (2016) DOI: 10.1051/matecconf/20167201001
HMTTSC-2016

TEMPERATURE AND CONCENTRATION TRACES OF SPRAY FLOWS DURING MOTION IN A FLAME

Dmitry V. Antonov[1,*], *Alena* O. Zhdanova[1], and *Mark* D. Kats[1]

[1]National Research Tomsk Polytechnic University, 634050 Tomsk, Russia

Abstract. Heat and mass transfer models are developed on the base of experimental data and using Ansys Fluent software. These models allow prediction of the temperature and concentration traces of droplets. Transfer mechanisms of water droplets from different flames of flammable liquid (ethanol, kerosene и benzine) with temperature gases 450–850 K are analyzed. The paper considers aerosol flows with droplets sizes of 0.04–0.4 mm and concentration of $3.8 \cdot 10^{-5}$ –$10.3 \cdot 10^{-5}$ m^3 of droplets/m^3 of gas. The maximum gas temperature reduction in the trace of a moving liquid is ranged from 850 K to 600 K. The times of keeping the low temperature of the gas-vapor mixture in the droplets trace are from 13 s to 25 s relative to the initial gas temperature.

1 Introduction

At the present time gas-vapor-droplet technologies are used in various industries [1–3], for example, in firefighting, thermal treatment of liquids, ignition of liquid fuels. However, to talk about the broad and active use of high-temperature (over 1000 K) gas-vapor droplet technologies is quite difficult due to a rather limited information base (particularly, the reliable experimental).

Over the last yers researches are conducted [4, 5]. The main objective of various development and research are improving the efficiency of means and methods of atomization in high-temperature heat technology. Unfortunately, the fact is not taken account that the water droplets during motion in high-temperature gases reserve temperature and concentration traces which reduce the temperature in the combustion zone due to the evaporation of water droplets.

The goal of the present work is numerical analyses of heat and mass transfer processes at researches of temperature and concentration traces of spray flows during motion in a typical flame with using Ansys Fluent software.

* Corresponding author: dva14@tpu.ru

2 Physical model of heat transfer

When setting heat and mass transfer problems considered that initial water temperature equals T_{w0}=300 K, initial temperature gases equals T_{g0}=300 K. It was assumed that the thermal characteristics of the materials are not dependent on temperature. Fig. 1 shows the scheme of solution area for spray flow during motion in a flame.

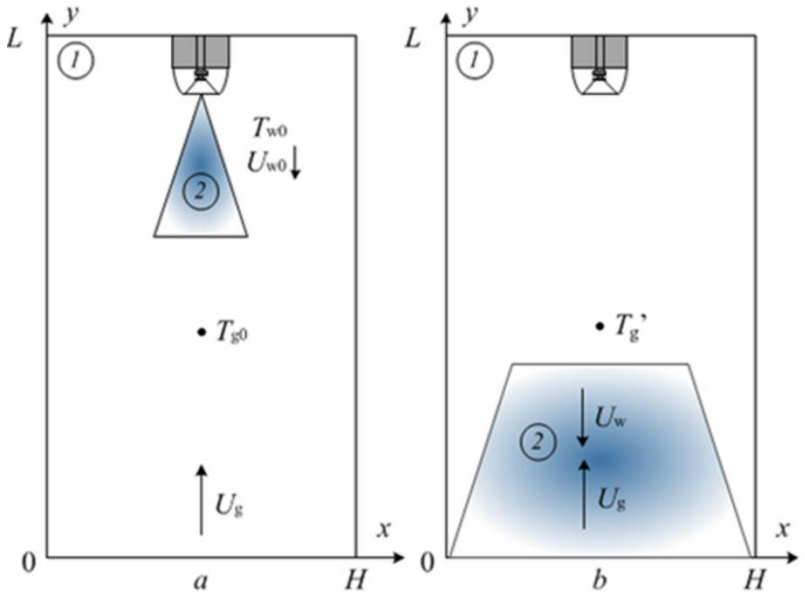

Fig. 1. Scheme of solution area for spray flow during motion in a flame: *1* – high-temperature of the gas-vapor mixture, *2* – spray flows.

3 Mathematical model and decision methods

Initial conditions (t=0): T=T_{g0}, C_w=0, C_g=1, ψ=0, ω=0 at 0<x<H, 0<y<L; T=T_{w0} at 0<r<R_d, 0<φ<2π.
Boundary conditions (t>0):

$$T = T_g, C_w = 0, C_g = 1, \frac{\partial \psi}{\partial y} = U_g \text{ at } y = 0, 0 < x < H; \quad (1)$$

$$T = T_a, \frac{\partial^2 C_w}{\partial y^2} = 0, \frac{\partial^2 C_g}{\partial y^2} = 0, \frac{\partial \psi}{\partial y} = -U_w \text{ at } y = L, 0 < x < H; \quad (2)$$

$$\frac{\partial T}{\partial t} = 0, C_w = 0, C_g = 0, \frac{\partial \psi}{\partial x} = 0 \text{ at } x = 0, 0 < y < L; \quad (3)$$

$$\frac{\partial T}{\partial t} = 0, C_w = 0, C_g = 0, \frac{\partial \psi}{\partial x} = 0 \text{ at } x = H, 0 < y < L. \quad (4)$$

Where t – time, s; T – temperature, K; T_{g0} – initial temperature of gases, K; T_{wo} – initial temperature of water, K; C_w – concentration of water; C_g - concentration of high-temperature gases; $\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$ – rotation vector velocity, s^{-1}; ψ – flow function, m^2/s; x, y – coordinates of the Cartesian coordinate system, m; H, L – dimensions of solution area, m;

r, φ – coordinate of the spherical systems; R_d – radius of droplet, m; T_g – temperature of gases, K; U_g – velocity of high-temperature gases, m/s^2; U_w – velocity of spray flow, m/s^2; T_a – temperature of air, K.

In this formulation of the problem there are adiabatic horizontal and vertical walls with constant temperature $T_g \approx 1170$ K and $T_a \approx 298$ K. Velocity of sray flows and velocity gases equal $U_g = 1.5$ m/s^2 and $U_a = -5$ m/s^2.

Boundary conditions for liquid – gas were set taking into account vaporization:

$$R = R_1,\ 0 < \varphi < 2\pi,\ \lambda_1 \cdot \frac{\partial T_1}{\partial R} = \lambda_2 \cdot \frac{\partial T_2}{\partial R} - W_e \cdot Q_e,\ \rho_2 D_2 \frac{\partial C_w}{\partial r} = W_e, t > 0. \quad (5)$$

Where R_1 – droplet radius at the output of high-temperature gases, m; λ_1 – thermal conductivity of water, W/(m·K); T_1 – water temperature, K; λ_2 – thermal conductivity of water vapor, W/(m·K); T_2 – water vapor temperature, K; W_e – evaporation rate, kg/(m^2·s); Q_e – water vaporization heat, J/kg; ρ – water vapor density, kg/m^3; D_2 – diffusion coefficient, m^2/s.

The simulation used Ansys package. To solve this problem used time steps Δτ = 0.01 s and grid Δx = 0.01 mm.

4 Results and discussion

Fig. 2 shows temperature fields in the channel after injection of aerosol for typical flame (ethanol, kerosene and benzine).

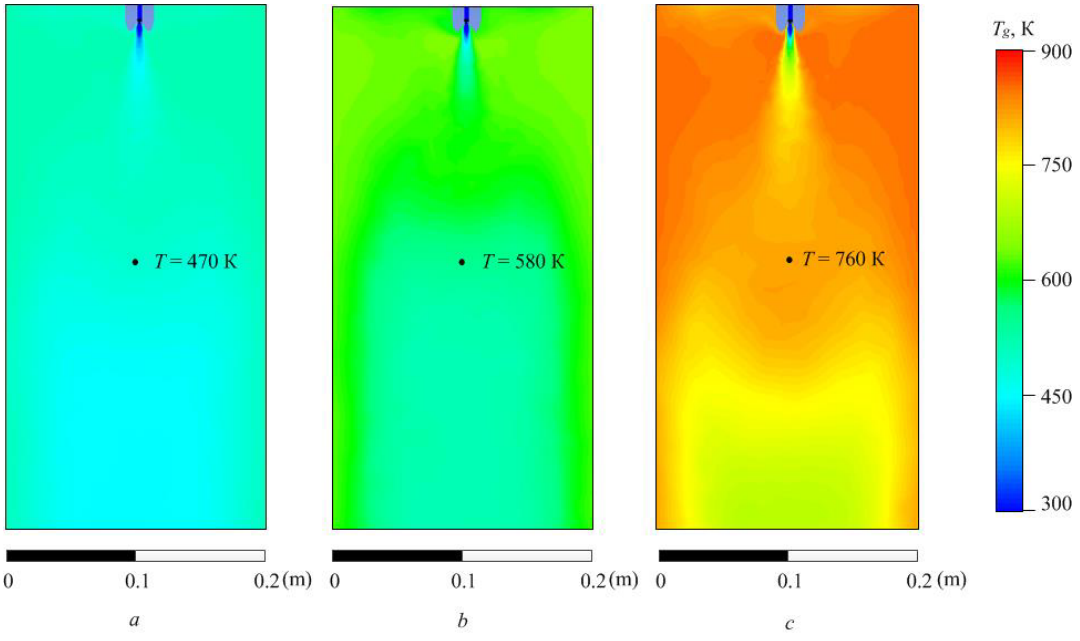

Fig. 2. Temperature fields in the channel after injection of aerosol: *a* – ethanol, *b* – kerosene, *c* – benzene.

Fig. 3 indicates a satisfactory correlation between the maximum temperatures (T_g') in the trace of the aerosol droplets obtained by experiment and when simulating. This allows us to make some conclusions. Firstly, the Ansys Fluent models can be used to predict of temperatures T_g' at different parameters (size, concentration, velocity, initial droplets

temperature) of the aerosol and combustion products (temperature and velocity). Secondly, in the case of the aerosol, water evaporation is a determining mechanism for reducing the temperature in the trace.

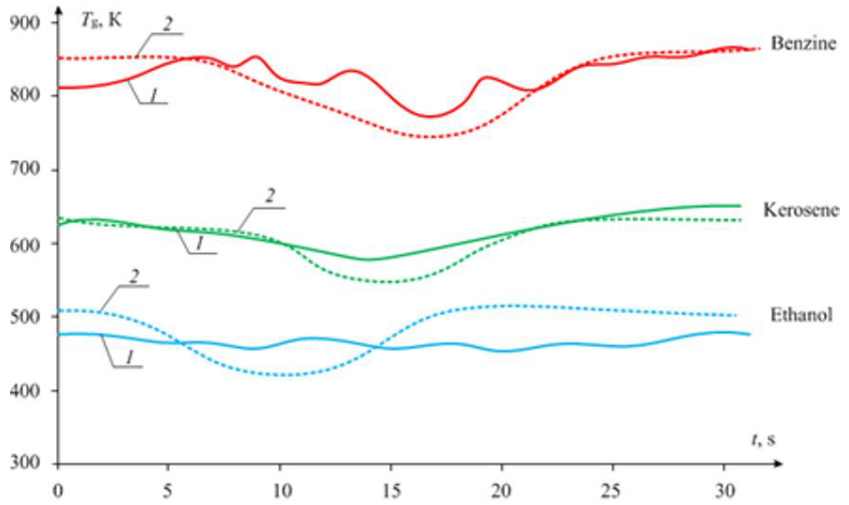

Fig. 3. Maximum temperature in the trace of water droplets: *1* – experimental data, *2* – simulation results.

Fig. 4 shows times of keeping temperature trace depending on droplet size for typical flame: ethanol, kerosene and benzine.

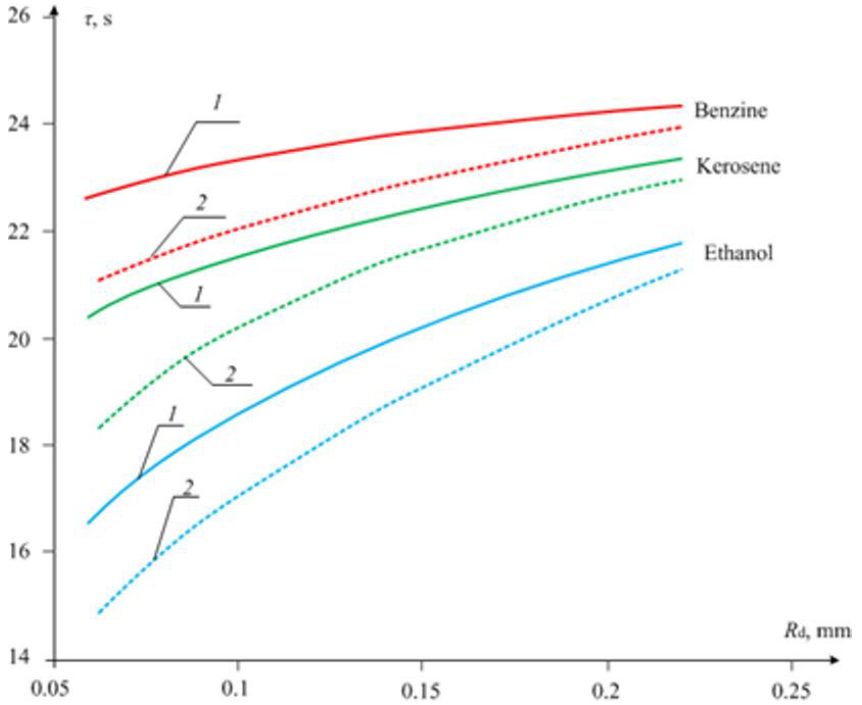

Fig. 4. Times of keeping temperature trace depending on droplet size for typical flame: *1* – experimental data [6], *2* – simulation results.

Dedicated on fig. 4 the experimental and theoretical values of the times of keeping temperature traces illustrate that with increasing deviation of the droplet size is minimized. For small R_d difference between the experimental and theoretical values of τ grows. This can be explained mainly by the fact that the experiments [6] showed rather intense deceleration and turn of small droplets. As consequence, the experimental times τ are longer than those obtained by the mathematical simulation.

5 Conclusion

According to the experimental results, physical and mathematical models of heat and mass transfer have been developed using the Ansys Fluent software. These models can be used in predicting gas temperatures, concentrations of vapor and gases in the trace of aerosol drip flows, as well as times of keeping low temperatures τ. Researches show satisfactory correlation of simulation results and experimental data.

Acknowledgments

The investigations with water aerosol were supported by the Russian Foundation for Basic Research (No. 15-38-20006). The work at the field of modeling of heat and mass transfer processes near boundary "liquid – gas" was supported by the scientific schools grant NSH-7538-2016.8.

References

1. J. E. Splittles, Y. D. Shikhmurzaev, Phys. Fluids **24** (2012)
2. P.A. Strizhak, J. Eng. Phys. Thermophys. **86**, 895 (2013)
3. A. Abbud-Madrid, D. Watson, J.T. McKinnon, Suppression and Detection Research and Applications Conference (2007)
4. Y.V. Lyulin, O.A. Kabov, Appl. Phys. Lett. **39**, 88 (2013)
5. R.V. Maltsev, A.K. Rebrov, J. Appl. Mech. Tech. Phys. **48**, 142 (2007)
6. D.V. Antonov, I.S. Voitkov, P.A. Strizhak, EPJ Web Conf. **110**, Article Number 010001 (2016)