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APPLICATION OF THE STATISTICAL MODEL AT THE SIMULATION OF LIQUID FUEL CONBUSTION

The statistical model has been applied to the simulation of the dispersion and combustion of liquid fuel sprays. The distributions of the fuel particles over the space of the burner chamber for three types of fuel: benzene, heptane and tetradecane have been obtained.

The turbulent fluid motion at very high Reynolds numbers is characterized by the irregular and disorder velocity change in time in every point of the stream; the velocity constantly pulses about its average value. The same irregular velocity change occurs from point to point of the stream considered at the specified time moment [1].

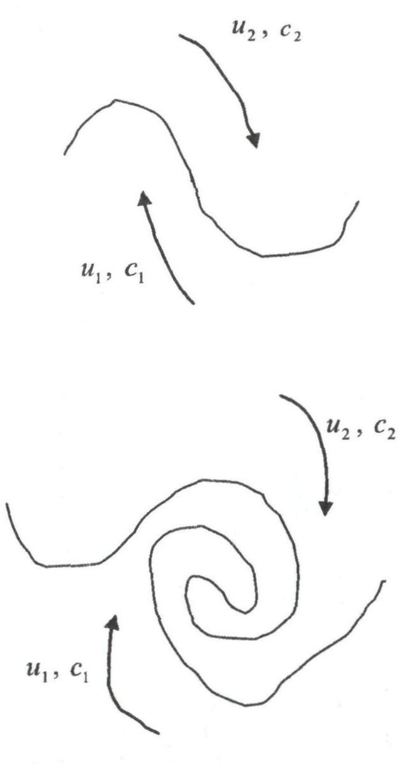


Figure 1. Formation of the turbulence surface

The turbulent flame has two mixing layers with velocitiesU_1 and U_2. Let U_1 carry the concentration C_1 and U_2 - C2 (figure 1). The more difference between the velocities, then the local gradient is greater.

The turbulence intensifies the combustion process and increases the mixture. The evolution of the surface is very complicated; there are pulsations of the velocity and of the temperature in it. To get the average rate of the chemical reactions one should know the statistics, i.e. the fluctuations of the velocity, temperature, concentration and so on. In fact it is necessary to know the probability distribution function – P(C,U,T) which is determined by the following correlation [2-7]:

$$\tilde{\dot{w}}_{ch} = \int P(c,T,u)\dot{w}_{ch}(c,T)dudTdc \ .$$

Here $\tilde{\dot{w}}_{ch}$ is the rate of chamical reaction.

Equation of the particle motion in the gas flow can be written in the following way:

$$\frac{4}{3}\pi r^3 \rho_p \frac{d\vec{u}_p}{dt} = c_D \rho_g \frac{(u_p - u_g)^2}{2}\pi r^2 ,$$

where $c_D = \dfrac{24}{Re}$ is a drag coefficient of particle,

$$Re = \frac{|u_p - u_g| d}{\nu},$$

$$(u_p - u_g)^2 = |u_p - u_g|(\vec{u}_p - \vec{u}_g).$$

The previous equation can be rewritten in the form:

$$\frac{d\vec{u}_p}{dt} = \frac{\vec{u}_p - \vec{u}_g}{\tau_{st}}.$$

One can obtain the expression for τ_{st}.

$$\frac{4}{3}\pi r^3 \rho_p \frac{d\vec{u}_p}{dt} =$$

$$= \frac{24\nu}{|u_p - u_g| 2r}\rho_g \frac{|u_p - u_g|(\vec{u}_p - \vec{u}_g)}{2}\pi r^2 ,$$

$$\frac{2}{3}r^2\rho_p\frac{d\vec{u}_p}{dt}=3\nu\rho_g\left(\vec{u}_p-\vec{u}_g\right),$$

$$\frac{d\vec{u}_p}{dt}=\frac{9\nu\rho_g}{2r^2\rho_p}\left(\vec{u}_p-\vec{u}_g\right),$$

$$\tau_{st}=\frac{2r^2\rho_p}{9\nu\rho_g}.$$

u_g is a instantaneous velocity in the point where the particle is [8].

If the diameter of the particle is greater than the Kolmogorov dissipation scale then the particle do not relax to the laminar flow but to the turbulent one with efficient score of the eddies of the same order as the diameter of the particle. All this affects the dispersion of such particles. It is typical for the diesel engines that the fuel particles are greater then the Kolmogorov scale and that is why the purpose of this work is to take into account this effect.

We suggest changing laminar viscosity in the Stocks model to the effective one:

$$\nu_{tur}\approx d_p\cdot u_{tur},$$

where d_p is the diameter of the particle;

u_{tur} is a turbulence scale determined by viscous dissipation and length scale according to the Kolmogorov theory:

$$u_{tur}\approx\varepsilon^{1/3}d_p^{\;1/3}.$$

Thus a new relaxation time is entered into the mathematical model of dispersion of liquid particles and into the particle motion equation

$$\tau_{St}=\frac{d_p^{2/3}\rho_p}{\varepsilon^{1/3}\rho_g},$$

where instantaneous values of the viscous dissipation ε satisfy the log-normal probability distribution [9]:

$$P(n)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{(n-\langle n\rangle)^2}{2\sigma^2}},$$

where $n=ln\frac{\varepsilon}{\langle\varepsilon\rangle}$,

$$\langle n\rangle=-\frac{\sigma^2}{2},$$

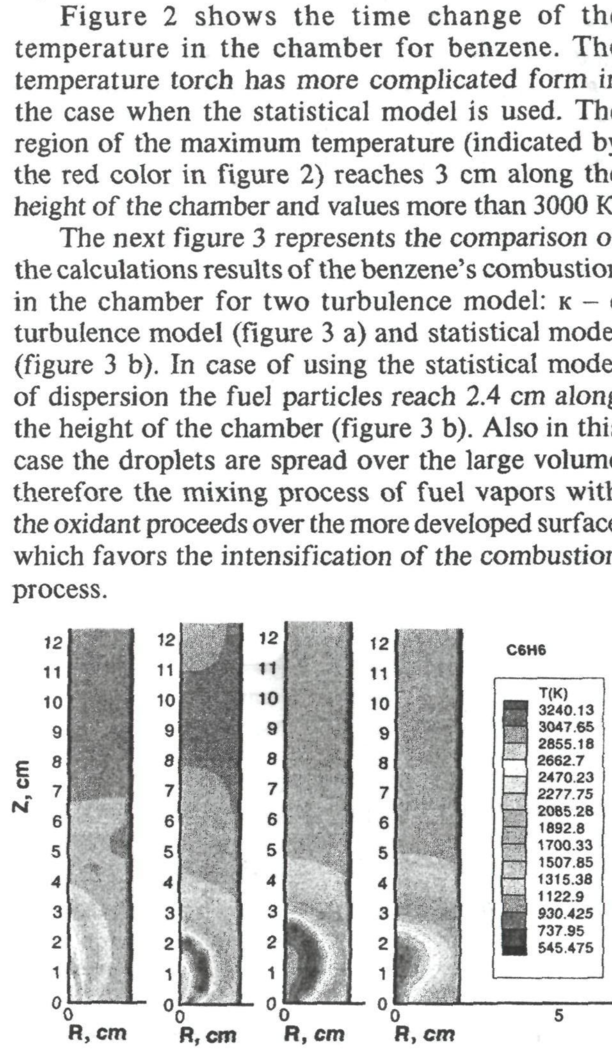
$$\sigma^2=\mu\,ln\frac{L}{\eta}=0{,}4\,ln\frac{L}{\eta},$$

$$\frac{L}{\eta}=Re_L^{3/4}.$$

The results of the numerical experiments of the combustion of three types of the liquid fuel with application of the statistical model are presented in figures 2 – 7.

Figure 2 shows the time change of the temperature in the chamber for benzene. The temperature torch has more complicated form in the case when the statistical model is used. The region of the maximum temperature (indicated by the red color in figure 2) reaches 3 cm along the height of the chamber and values more than 3000 K.

The next figure 3 represents the comparison of the calculations results of the benzene's combustion in the chamber for two turbulence model: κ – e turbulence model (figure 3 a) and statistical model (figure 3 b). In case of using the statistical model of dispersion the fuel particles reach 2.4 cm along the height of the chamber (figure 3 b). Also in this case the droplets are spread over the large volume therefore the mixing process of fuel vapors with the oxidant proceeds over the more developed surface which favors the intensification of the combustion process.



a) b) c) d)

Figure 2. Temperature distribution in the chamber at the benzene combustion at following time moments: a) 0.7 ms, b) 1.6 ms, c) 2 ms, d) 3 ms

Figure 4 represents the distribution of the temperature in the chamber at the heptane combustion at different time moments. The region of high temperatures reaches 3 cm along the height of the chamber at time equal to 2 ms. The hottest value of the temperature is more than 2600 K at this time moment.

It can be seen in the figure 5 that in case of application of the statistical model of dispersion the major part of the droplets is warmed up to 500 K than in the case a). Two sprays are also different by the height: in case b) the droplet reach 1.8 cm in height and 0.5 cm along the radius of the chamber. In the first case the maximum height that the heptane droplets can reach is only 1.1 cm.

Figure 6 represents the temperature values in the chamber at different time moments for the combustion of the tetradecane. At time equal to 2 ms the temperature torch reaches 2 cm and it less than in case of combustion of benzene and heptane.

Analyzing figure 7 one can see that the droplets of tetradecane are spread over the large volume than in case of combustion of heptane and benzene when the statistical model is applied for its simulation.

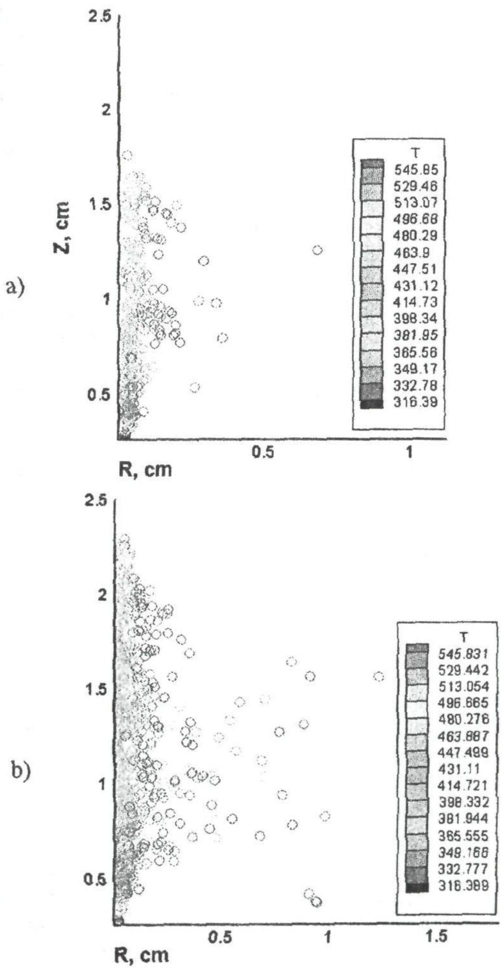
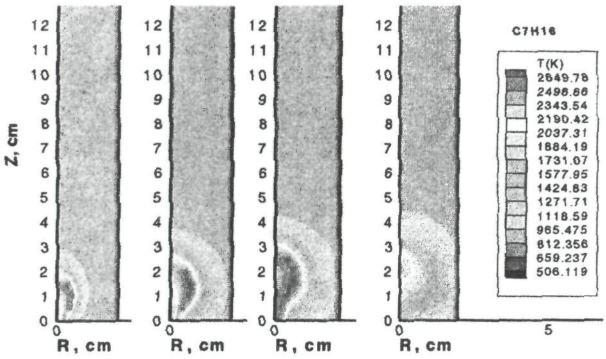


Figure 3 – Benzene droplet distribution in the burner chamber:
a) κ – e turbulence model is used, b) statistical model is applied



a) b) c) d)

Figure 4. Temperature distribution in the chamber at the heptane combustion at following time moments: a) 0.7 ms, b) 1.6 ms, c) 2 ms, d) 3 ms

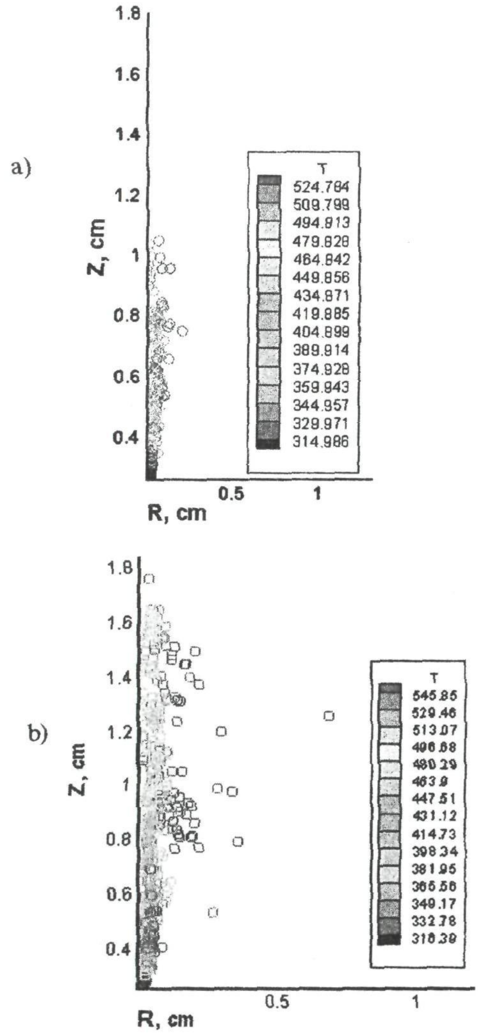
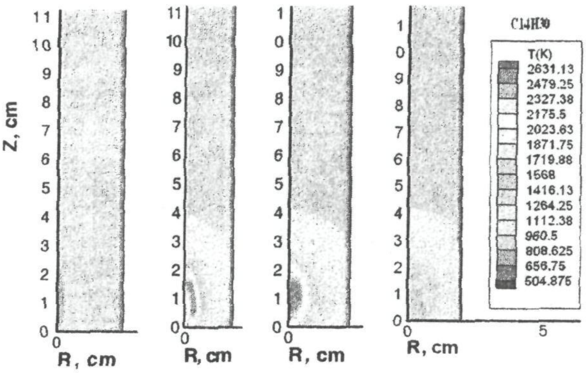


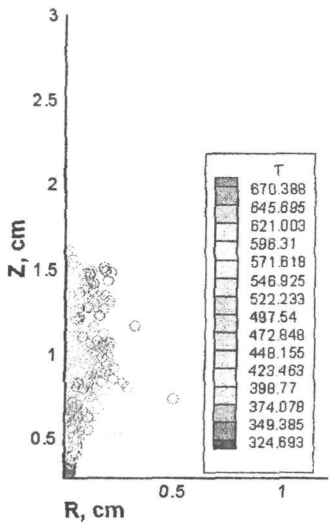
Figure 5 – Heptane droplet distribution in the burner chamber:
a) κ – e turbulence model is used, b) statistical model is applied



a) b) c) d)

Figure 6. Temperature distribution in the chamber at the tetradecane combustion at following time moments: a) 0.7 ms, b) 1.6 ms, c) 2 ms, d) 3 ms

a)



b)

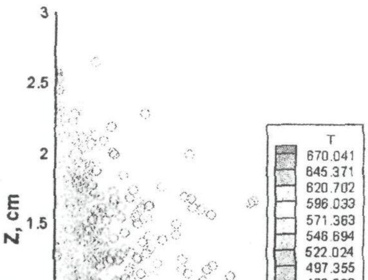


Figure 7. Tetradecane droplet distribution in the burner chamber:
a) к – е turbulence model is used, b) statistical model is applied

In this work the statistical model of turbulence has been used at the simulation of dispersion and combustion of liquid fuel sprays. The distributions of droplets in the space of the chamber for three types of liquid fuel have been obtained.

Taking into account the influence of turbulence on the dispersion of liquid particles in the computations of the liquid fuel combustion it has been found out that the droplets are sprayed over the extended volume and this fact intensifies the combustion process as the mixing of the fuel and oxidant proceeds over the more developed surface.

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Резюме

Сұйық отынның жануының бүркуімен және дисперсияның моделінде турбуленттік модельдің статистикалығы қолданылды. Тетрадекан және гептан, бензин осы отынның үш түрі үшін жану камерасының жазықтығында тамшының таралуы алынды.

Резюме

Была применена статистическая модель турбулентности при моделировании дисперсии и горения впрысков жидких топлив. Получены распределения капель в пространстве камеры сгорания для трех видов топлив: бензина, гептана и тетрадекана.

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