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# Experimental Study of Complex Combustion Processes in Higher Education

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**Keywords:** Combustion, Concentration, Educational research, Injection, Liquid fuel, Numerical modeling, Soot.

**Abstract.** Institution of higher education - is an educational institution, where in addition to training highly qualified personnel in the field, carried out research in various fields of science and technology. The deterioration of the environment, particularly atmospheric pollution of cities by industrial and transport vehicles, aims to detailed study of combustion processes in the industrial sectors. Within the walls of the university, during the educational process and as final papers, students conduct research on the burning processes of various fuels. The obtained results allow determining the optimal parameters of combustion, to offer technological and constructive solutions, which in turn can solve partially or completely the problem of minimizing harmful emissions and efficient combustion of hydrocarbon fuel.

## Introduction

In order to prepare qualified engineers in the field of thermal physics students learn the course of a numerical method of thermal physics, which is widely covered by the combustion process. Numerical modeling of the combustion of different fuels is a complex task [1-4], as it requires large amounts of complex accounting related processes and phenomena: chemical multistage chain reaction transfer of momentum, heat and mass by convection, molecular transport, emission, turbulence, evaporation of liquid droplets, etc. [5]. Therefore, computer modeling is becoming an increasingly important element in the study of combustion processes and the design of various devices that use the combustion process [6-9]. You can expect that his role will increase in the future. At the same time talk about the complete replacement of experimental research by numerical calculations would be wrong—it is about design approaches, which should complement each other [10-12].

## The State of the Art

Combustion is a self-sustaining and self-propagating physic-chemical process of converting fuel and oxidant molecules into reaction product molecules. Depending on the state in which the fuel and oxidant are in the aggregate state, two types of combustion are divided: homogeneous combustion - combustion of gases; heterogeneous - combustion of liquid and solid fuels. In homogeneous combustion, the chemical reaction proceeds in a volume where there is fuel and an oxidizer, with such combustion, a physical or chemical process can play a big role. In heterogeneous combustion chemical reaction occurs at the interface, a major role is played by physical processes: diffusion and convection. In this paper, the process of homogeneous combustion of a sputtered fuel is investigated.

## Experimental Description of Task

As the experimental course of discipline is difficult to put in the walls of the university, it was developed the virtual laboratory complex by using a computational method [13-19]. This allows fully describe the combustion process, given the concentration fields, temperature, volatile components, as the concentration of harmful emissions. The mathematical model of the problem of the combustion of fuel injection includes the equation of continuity for the component m (1), the momentum equation (2), the energy equation (3), the equations of the k-ε turbulence model (4-5):

$$\frac{\partial \rho_m}{\partial t} + \vec{\nabla}(\rho_m \vec{u}) = \vec{\nabla}\left[\rho D \vec{\nabla}\left(\frac{\rho_m}{\rho}\right)\right] + \dot{\rho}_m^c + \dot{\rho}^s \delta_{m1}, \tag{1}$$

$$\frac{\partial (\rho \vec{u})}{\partial t} + \vec{\nabla}(\rho \vec{u}\vec{u}) = -\frac{1}{a^2}\vec{\nabla}\text{p-A}_0\vec{\nabla}\left(\tfrac{2}{3}\rho k\right) + \vec{\nabla}\vec{\sigma} + \vec{F}^s + \rho\vec{g}. \tag{2}$$

$$\frac{\partial (\rho \vec{I})}{\partial t} + \vec{\nabla}(\rho \vec{u}\vec{I}) = -\rho\vec{\nabla}\vec{u} + (1 - A_0)\vec{\sigma}\vec{\nabla}\vec{u} - \vec{\nabla}\vec{J} + A_0\rho\varepsilon + \dot{Q}^c + \dot{Q}^s. \tag{3}$$

$$\frac{\partial \rho k}{\partial t} + \vec{\nabla}\cdot(\rho\vec{u}k) = -\frac{2}{3}\rho k\vec{\nabla}\cdot\vec{u} + \sigma\cdot\nabla\vec{u} + \vec{\nabla}\cdot\left[\left(\left(\frac{\mu}{\mathrm{Pr}_k}\right)\vec{\nabla}k\right)\right] - \rho\varepsilon + \dot{W}^s. \tag{4}$$

$$\frac{\partial \rho\varepsilon}{\partial t} + \vec{\nabla}\cdot(\rho\vec{u}\varepsilon) = -\left(\frac{2}{3}c_{\varepsilon 1} - c_{\varepsilon 2}\right)\rho\varepsilon\vec{\nabla}\cdot\vec{u} + \vec{\nabla}\cdot\left[\left(\left(\frac{\mu}{\mathrm{Pr}_\varepsilon}\right)\vec{\nabla}\varepsilon\right)\right] + \frac{\varepsilon}{k}\left[c_{\varepsilon 1}\vec{\sigma}\vec{\nabla}\vec{u} - c_{\varepsilon 2}\rho\varepsilon + c_s\dot{W}^s\right]. \tag{5}$$

In the chosen work, it was necessary to carry out a computational experiment on burning different hydrocarbon liquid fuel. The combustion chamber has the form of a cylinder (Fig. 1) with a radius 2 cm and a height 15 cm. Chamber filled with air at a temperature of 900 K and at a pressure of 32 bar. Liquid fuel is injected into the combustion chamber through a circular nozzle located in the center of the lower part of the chamber. After the injection, the fuel rapidly evaporates, the fuel vapor is mixed with the oxidant, and combustion is carried out in the gas phase.

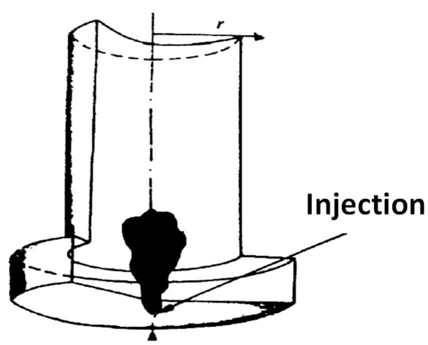


Figure 1. Geometry of combustion chamber.

## Results of Numerical Modeling

All data after the calculation can be presented in a graphical form, also in the form of an animation. All calculations are carried out by each student individually, minimizing such facts as the use of other people's data, also teaches students to independent solution of the task.

The distribution of the average temperature in the combustion chamber with the combustion of three types of fuel (gasoline, heptane and tetradecane) shows that the maximum temperature value is the process of burning gasoline: the chamber warms up to 2600 K (Fig. 2 a); For heptane (Fig. 2 b) and tetradecane (Fig. 2 c), the average temperatures in the chamber reach respectively 1700 and 1500 K. The rest of the combustion chamber is heated to 1000 K in the case of burning gasoline and up to 1200 K when burning heptane and tetradecane.

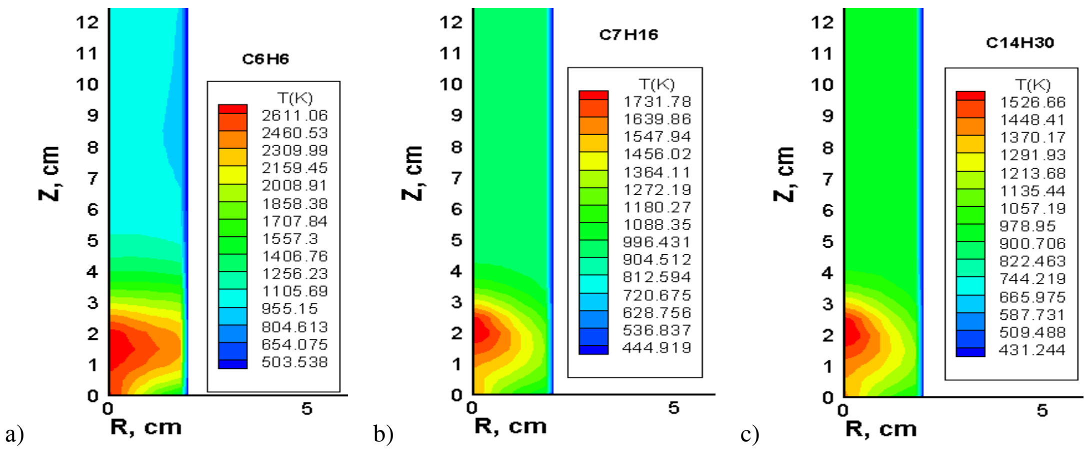


Figure 2. The average temperature in the combustion chamber when burning: a) gasoline, b) heptane, c) tetradecane.

The following figures 3-5 shows the results of a numerical experiment on the combustion of three fuels, taking into account the formation and oxidation of soot in the developed turbulence. The graphs represent the average fields of the concentration of the reaction components.

Figure 3 represents the average concentration of carbon dioxide in the combustion chamber for three types of liquid fuel (gasoline, heptane, tetradecane). For the three types of fuel tested, intensive formation of carbon dioxide takes place on the axis of the combustion chamber in the region up to 2 cm along the height of the chamber. The highest value of the resulting gasoline is 0.1410 g/g (Fig. 3 a). When the heptane burns, the concentration of carbon dioxide takes a maximum value of 0.0733 g/g (Fig. 3 b). Accordingly, for tetradecane, the concentration of carbon dioxide in the combustion chamber reaches a maximum value of 0.0592 g/g (Fig. 3 c).

Figure 4 shows the average concentration of carbon monoxide for gasoline, heptane, tetradecane, respectively. The concentration of the produced carbon monoxide is of little importance because the mass of liquid fuel injected into the combustion chamber is very small (18,8 and 6 mg). The average concentration of carbon monoxide produced by burning three types of liquid fuel does not exceed 1.8•10-5 g/g. Most of the carbon monoxide then burns to carbon dioxide CO2.

The formation of soot upon burning of the three types of liquid fuels studied is shown in figure 5. Analysis of figure 5 shows that the highest concentration of carbon black is produced by burning heptane and equal to 0.3335 g/m3. When burning tetradecane, the value of the concentration of soot formed is the smallest (Fig. 5 c).

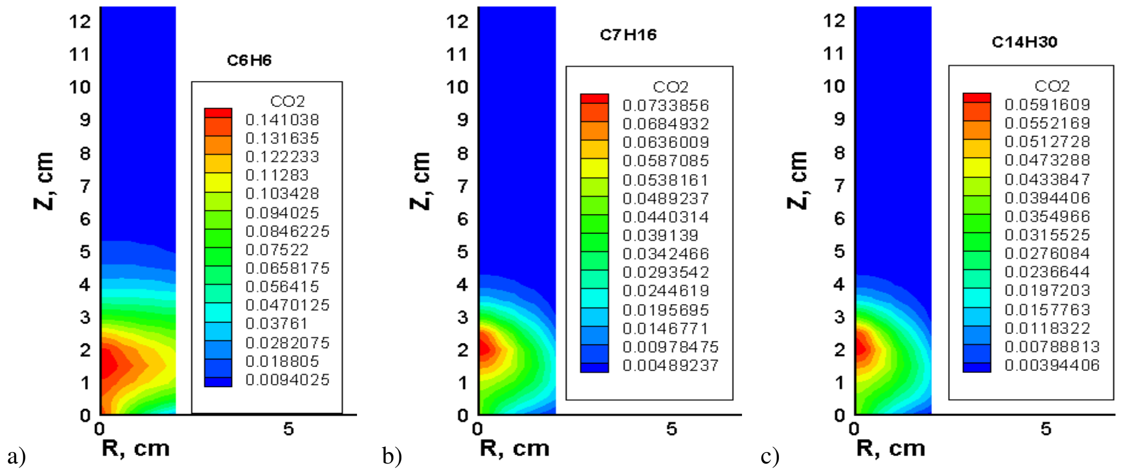


Figure 3. The average concentration of carbon dioxide $CO_2$ in the combustion chamber in the combustion chamber: a) gasoline, b) heptane, c) tetradecane.

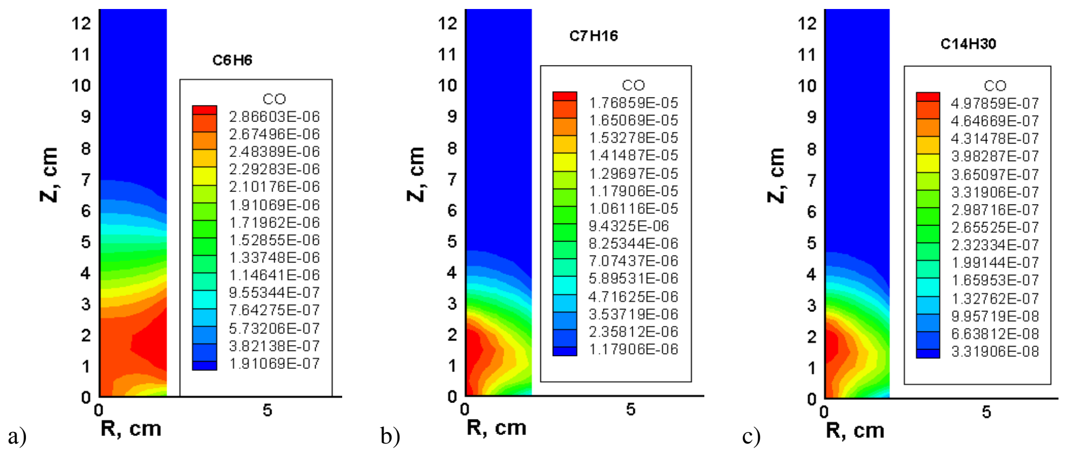


Figure 4. The average concentration of carbon monoxide CO in the combustion chamber during combustion: a) gasoline, b) heptane, c) tetradecan.

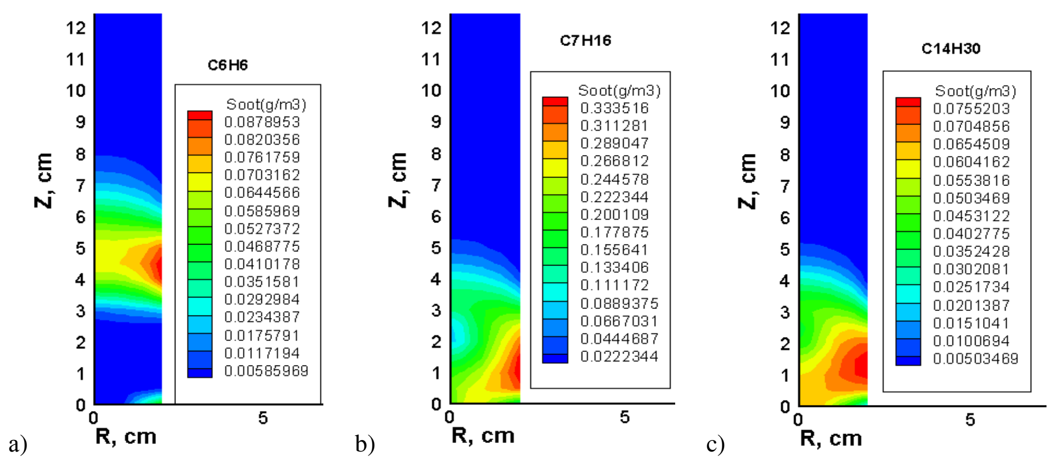


Figure 5. The average concentration of soot in the combustion chamber during combustion: a) gasoline, b) heptane, c) tetradecane.

According to the analysis of the work done on the whole, it is possible to draw a conclusion about the ongoing processes in combustion chambers using liquid fuel about the parameters of substances during combustion, which would be difficult to learn by an experimental method. Thus, the computational experiment is the most effective and low-cost in the study of combustion processes.

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