Numerical study of heat and mass transfer processes in the internal combustion chamber by method of computer simulation

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Introduction

Mathematical modelling and computational experiment are the main modern tools for the theoretical study of nonlinear processes of heat and mass transfer in moving media, taking into account physical phenomena. Such methods include developing numerical methods and performing numerical calculations. The analysis of the applied model and its adequacy to the real process determine the reliability and efficiency of the methods of mathematical modeling and such simulations largely replace the costly material and labor resources of experimental research [1].

As shown in papers [1-4], simulation can also be useful to study parameters, which provide a cheaper alternative than large-scale studies.

The development of mathematical, physical and chemical models adequate to the real process, methods for solving them and carrying out computational experiments on real thermal power plants, made it possible to create optimized technologically clean processes and systems with the rational use of energy resources.

To describe the processes of heat and mass transfer in high-temperature and chemically reacting flows in the presence of combustion, it is necessary to use a mathematical model, which is a system of non-autonomous three-dimensional nonlinear partial differential equations [2].

At the same time, at present, enough software systems have been developed and used. Such systems are unique and have a few advantages.

Description of the study

For simulation, the greatest problem is the imposition of the computational grid on the computational control volumes as shown in Fig. 1, the real processes of heat and mass transfer are simulated in these control volumes.

The construction and calculation of the fuel combustion model were carried out in the OpenFOAM software package at mesh values of 25x25x80.

The computational experiment consisted in studying the process of fuel combustion in a model cylindrical combustion chamber with a height of 0.15 m and a base radius of 0.02 m and this chamber simulates an internal combustion engine. The initial temperature of oxygen in the chamber is 800K and the initial pressure is 5 MPa. N-tetradecane ($C_{14}H_{30}$) is the fuel under study and its temperature at the time of injection is equal to 320 K and its mass is 6 mg.

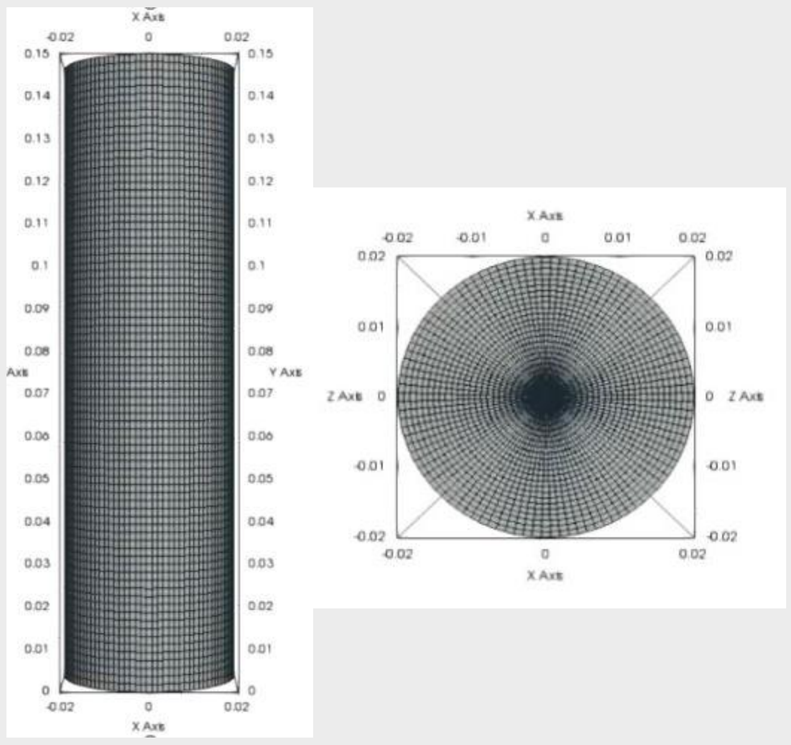

Fig.1. Mesh overlay on the research model using the OpenFOAM program

Results

Fig. 2 shows the distribution of the maximum temperature over the height of the combustion chamber. Ignition occurred at 0.5 ms, and the ignition temperature is 1700 K. Temperature reaches 3000 K in the center of the flame and Tmin = 1450 K along the periphery. The combustion process was completed in 10 milliseconds. The maximum reached temperature was 3100 K at 2 ms.

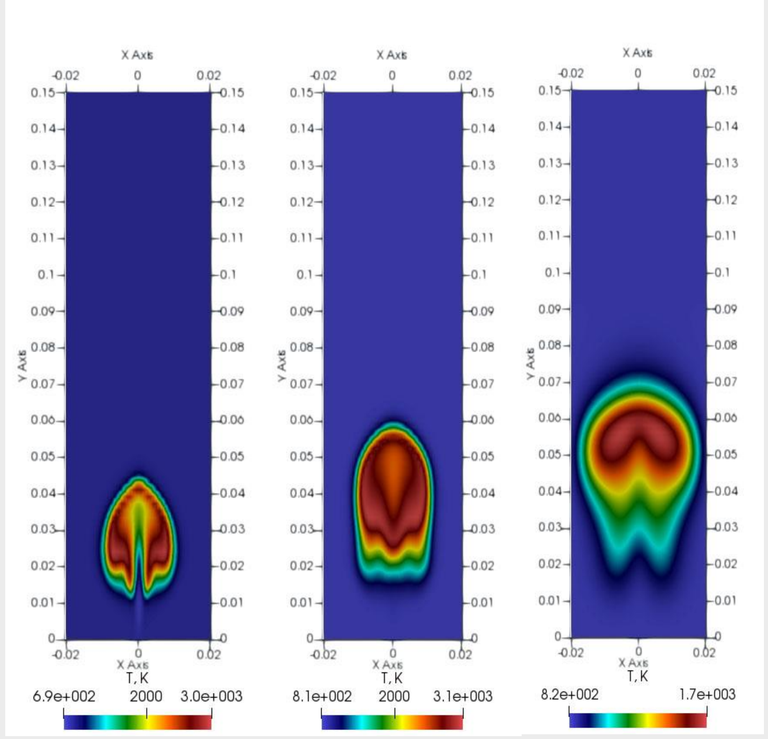

Fig. 2. Temperature distribution at t = 0.55 ms (left); at t = 2 ms (central); at t = 10 ms (right)

The graph of pressure distribution along the chamber height were obtained at the moments of injection (t=0.5 ms), ignition of the fuel (t=2 ms) and after fuel combustion as shown in Fig. 3. The maximum achieved chamber pressure is $5.65 \cdot 10^6$ Pa.

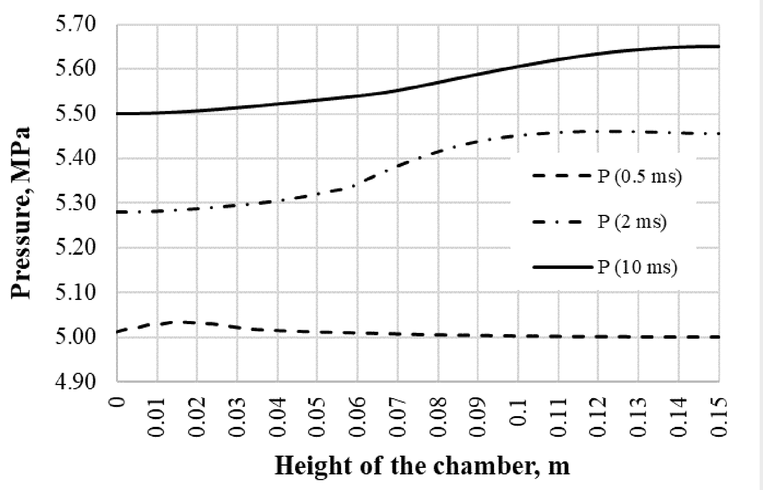

Fig. 3. Pressure, height of the chamber

Fig. 4 shows the graphs of the concentrations of reagents (oxygen and n-tetradecane) and the concentrations of combustion products (carbon dioxide and water vapors) were obtained relatively to the parameters of the chamber at the moments of injection. Thus, at the initial moment of injection t = 0.5 ms, a small value of carbon dioxide is formed, since the evaporation of the fuel is observed here, and chemical transformations are just beginning (Fig.4).

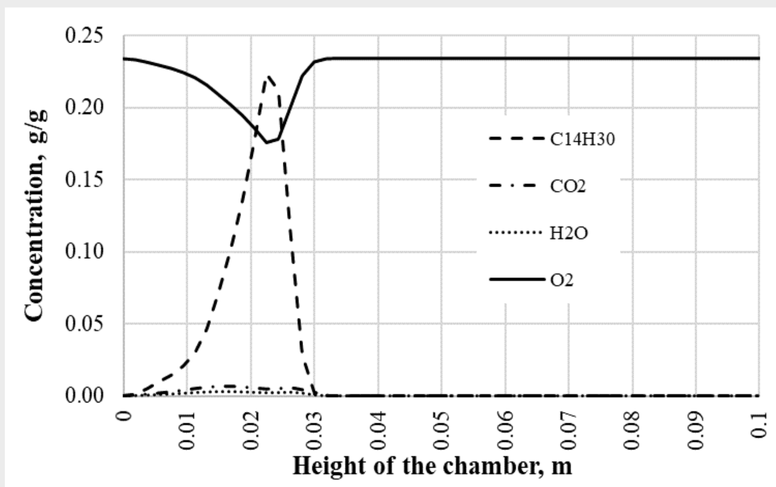

Fig. 4. Concentration, height of the chamber at t= 0.5 ms

Fig. 5 shows the graphs of the concentrations of reagents (oxygen and n-tetradecane) and the concentrations of combustion products (carbon dioxide and water vapors) were obtained relatively to the parameters of the chamber at the moments of combustion of the fuel. Then, due to the chemical reaction of the fuel with the oxidizer (air), the concentration of oxygen and nitrogen sharply decreases. The fuel is oxidized and the formation of carbon dioxide intensifies to 0.19 g / g and water vapor to 0.082 g / g (Fig.5).

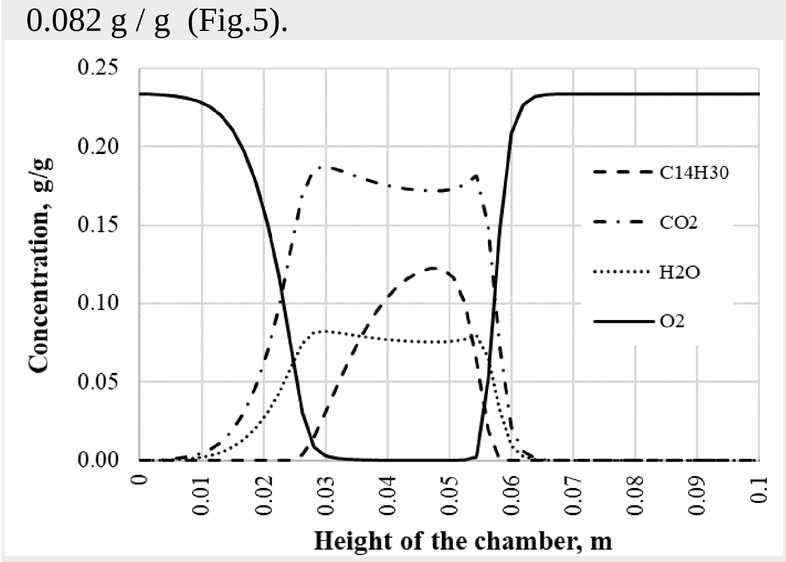

Fig. 5. Concentration, height of the chamber at t= 2 ms

Conclusions

The basic concepts and methods of numerical modelling application in the study of various physical and technical processes are considered in this work.

Based on the results of the work the following conclusions were made:

- The mathematical model built in the OpenFOAM complex is appropriate and describes well the processes of heat and mass transfer. To study the processes of heat and mass transfer in combustion chambers by the method of computer simulation, a grid of 25x25x80 can be used.
- The heat release at the stage of active fuel combustion was 3100 K.
- The maximum achieved chamber pressure is $5.65 \cdot 10^6$Pa.
- The concentration of carbon dioxide did not exceed 0.19 g / g and water 0.082 g / g.
- The study of the process of heat and mass transfer during the combustion of n-tetradecane was carried out using the OpenFOAM software package. The results of this work are consistent with the data obtained by the authors on the numerical study of the tetradecane's combustion processes, performed on the KIVA software package [5].
- In general, the OpenFOAM software package is applicable to the problems of thermophysics for the combustion of liquid fuels.
- The results of the work contribute to the creation of the scientific foundations of intensive technological processes that ensure the integrated use of fuel and its waste, eliminating the harmful effects of production on the biosphere, which suggest a new nature conservation and energy conservation.

References

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