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COMPUTER SIMULATION OF LIQUID FUEL SPRAY AND COMBUSTION AT DIFFERENT INJECTION VELOCITIES

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Keywords: liquid fuel, heptane, combustion, numerical modeling.

Abstract. The problems of combustion are widely studied now by the scientists of the world. Increasing level of ecological pollution of the environment, reserve depletion of hydrocarbon fuel and economic growth of many countries causing increase of demand for energy - all these factors gave rise to the problem of finding of more economic and ecological way of fuel combustion [1].

In order to solve this problem it is necessary to study thoroughly the combustion process itself and that is why the methods of numerical simulation are getting wide spread in the science. The turbulence plays great role in many devices using combustion process and its study is maybe one of the most complicated sections of hydrodynamics. It is also necessary to take into account additional factors such as various chemical reactions and radiation [2].

Thus, computer simulation becomes more and more important element of study of combustion process and of designing different installations burning liquid fuel. It can be forecasted that the role of the numerical experiment will increase in future. The purpose of this work is to study the influence of liquid fuel spray velocity on the fuel combustion by means of numerical simulation on the basis of the solution of differential equations of turbulent reacting flow.

One of the priority tendencies of the scientific and technological development of Kazakhstan is the research on simulation of formation of polluting clouds and their dispersion in the atmosphere. This problem has a great value because of the increasing concern for the ecological situation in Kazakhstan as the atmospheric air in the cities of Kazakhstan is daily polluted by different hazardous substances (NO_2, CO, CO_2, soot and so on). For the recent years the dispersion of the liquid sprays in the neutral atmospheric flows has been well studied by means of numerical, laboratory and natural researches. In these researches the main attention has been given to the dispersion of chemically reactive scalar admixture in the free convective flows.

The investigation of the formation of polluting clouds will allow to create the methods for the decrease of contain of hazardous substances in the atmosphere and for the prevention of formation of such clouds which contain hot liquid particles and these particles are the reasons of the formation of such polluting clouds. That kind of problems is one of the significant and insufficiently explored tasks for the present days. In this region of research the numerical experiments on the combustion of liquid fuel sprays in the burner chamber have been carried out. In this work it has been researched the dependence of maximal temperature of combustion of the liquid fuel from the velocity of the spray by means of the numerical modeling on the basis of the solution of differential two-dimensional equations of the turbulent reactive flows.

Main equations of mathematical model of dispersion and combustion of spray of liquid fuel are presented below [1-3]. Continuity equation for component m:

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

Momentum equation:

$$\frac{\partial(\rho\vec{u})}{\partial t}+\vec{\nabla}(\rho\vec{u}\vec{u})=-\frac{1}{a^{2}}\vec{\nabla}p-A_{0}\vec{\nabla}\left(\frac{2}{3}\rho k\right)+\vec{\nabla}\vec{\sigma}+\vec{F}^{s}+\rho\vec{g}. \tag{2}$$

Energy equation:

$$\frac{\partial(\rho I)}{\partial t}+\vec{\nabla}(\rho\vec{u}I)=-p\vec{\nabla}\vec{u}+(1-A_{0})\vec{\sigma}\vec{\nabla}\vec{u}-\vec{\nabla}\vec{J}+A_{0}\rho\varepsilon+\dot{Q}^{c}+\dot{Q}^{s}, \tag{3}$$

where

$$\vec{J}=-K\nabla T-\rho D\sum_{m}h_{m}\nabla\left(\frac{\rho_{m}}{\rho}\right).$$

Equations of k-e turbulence model:

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

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

We have studied heptane combustion depending on the spray velocity. Heptane is the main component of diesel fuel. It's used in passenger, freight and private vehicles. Liquid fuel is injected into the combustion chamber through a circular nozzle, located in the center of the bottom of the chamber. The overview of the combustion chamber is presented in fig.1.

The chamber is a cylinder with height equal to 15 cm and diameter is 4 cm. After the injection there is a rapid evaporation of fuel and the combustion is processing in the gas phase. The burning time of fuel is 4 ms. Time of injection of fuel droplets is 1.4 ms. The temperatures of the walls of the combustion chamber is 353 K. The initial temperature of gas in the chamber is 900 K. The temperature of the injected fuel is 300 K. The initial mean radius of injecting drops is 3 micrometers. The pressure in the combustion chamber is $4\bullet10^{6}$ Pa.

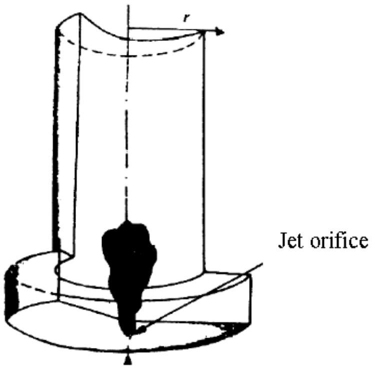


Figure 1 – Overview of the combustion chamber

In the work the dependence of maximum temperature of fuel combustion from spray velocity has been obtained. Liquid fuel spray velocity was ranging from 150 to 350 m/s. It has been found out that at low velocities of liquid fuel spray the process of combustion does not occur.

Heptaneh as been an object of research and its chemical formula has the following form as C_7H_{16}. For this type of fuel the global chemical reaction of combustion leading to the formation of carbon dioxide and water is written in the following way:

$$C_7H_{16}+11O_2\rightarrow 7CO_2+8H_2O.$$

This reaction is exothermal, i.e. it proceeds with huge calorification.As the result of the conducted numerical experiments it has been determined that minimal velocity of liquid heptane's spray is equal to 200 m/s. This velocity is enough for the combustion to take place in the burner chamber. The most effective combustion proceeds at the velocity of the injected fuel varying from 260 to 320 m/s, under these conditions temperature reaches values from 2023 K to 2048 K (fig.2).

However figure 3 shows the dependence of the distribution of CO_2 concentration on the rate of injection of heptane where the highest concentration of CO_2 is equal from 0.115 to 0.117 g/m^3 accounts for the velocity of the injected fuel varying from 270 to 320 m/s.

But the rate of injection heptane equal 260 m/s CO_2 concentration reaches the minimum value from the land 0,114 g/m^3.

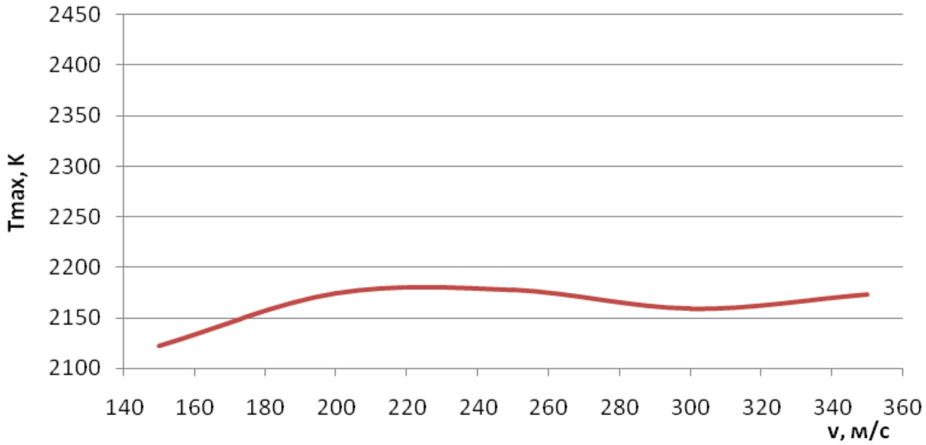


Figure 2 – Change of maximum temperature in the burner chamber depending on the velocity of the injected liquid fuel

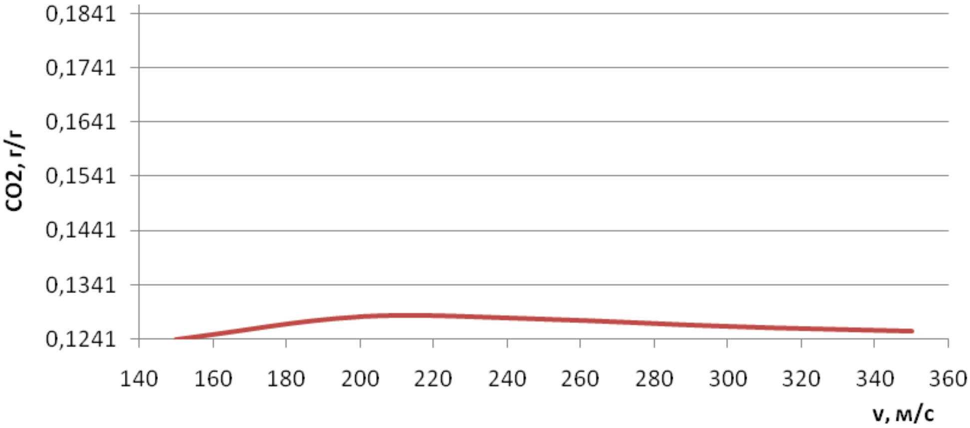
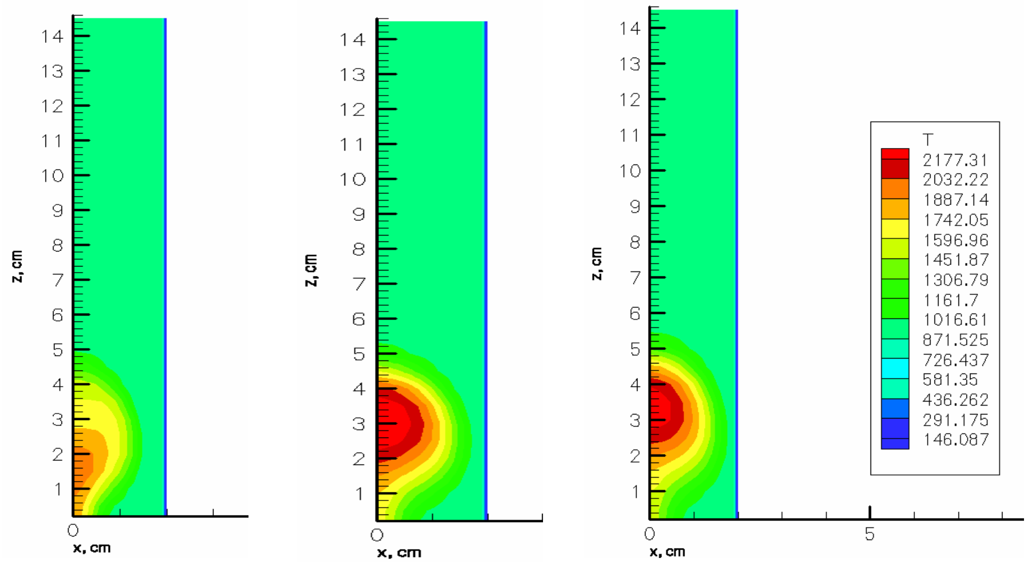


Figure 3 – The dependence of the distribution of CO_2 concentration on the rate of heptane injection

For the optimum velocity equal to 260 m/s, the plots of the temperature change in time and of the fuel concentration in the burner chamber have been obtained.

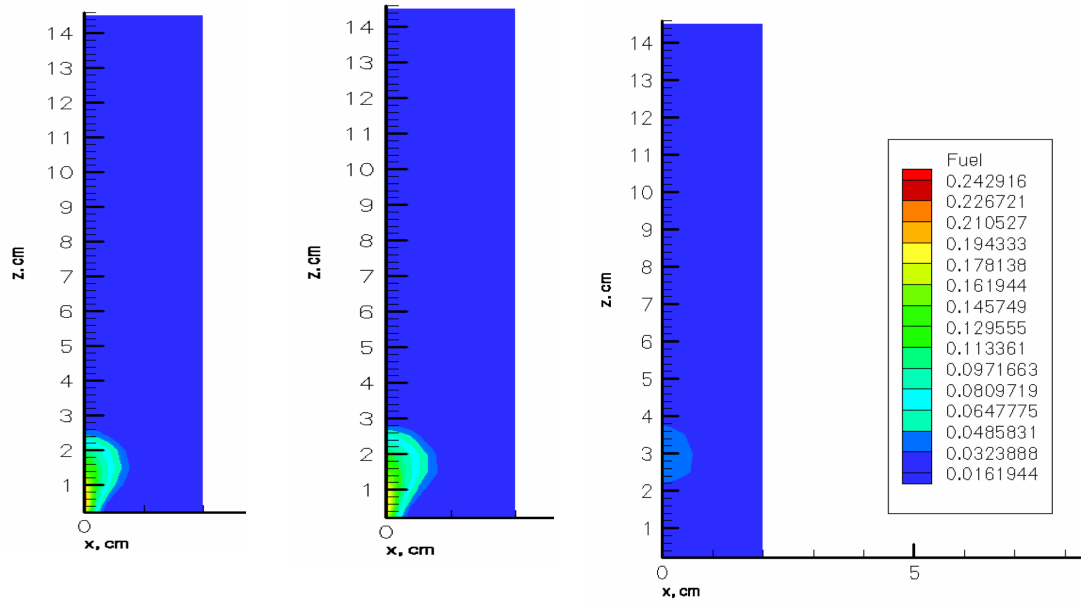
Figure 4 shows the distribution of the temperature in the space of the burner chamber for the velocity of spray equal to 260 m/s at different times: 1.1 ms, 1.8 ms, 3 ms, 4 ms correspondingly. At the final time moment the temperature reaches 2023 K and it can be seen that the temperature torch fills up almost all of the space of the chamber.

The distribution of the fuel concentration is presented in fig. 5 for the same time moments as for the temperature and for the spray velocity 260 m/s. At the initial moment the concentration of fuel has minimal value and then increases because of the fuel injection in the chamber. The fuel quickly vaporizes, the vapors are mixed with the oxidant and the mixture ignites and burns down for 4 ms. At the final moment the fuel concentration equals zero.



a) b) c)

Figure 4 – The temperature distribution in the combustion chamber during combustion of heptane at various time moments: a) 1.1 ms, b) 1.8 ms; c) 3 ms for the velocity of the spray 260 m/s

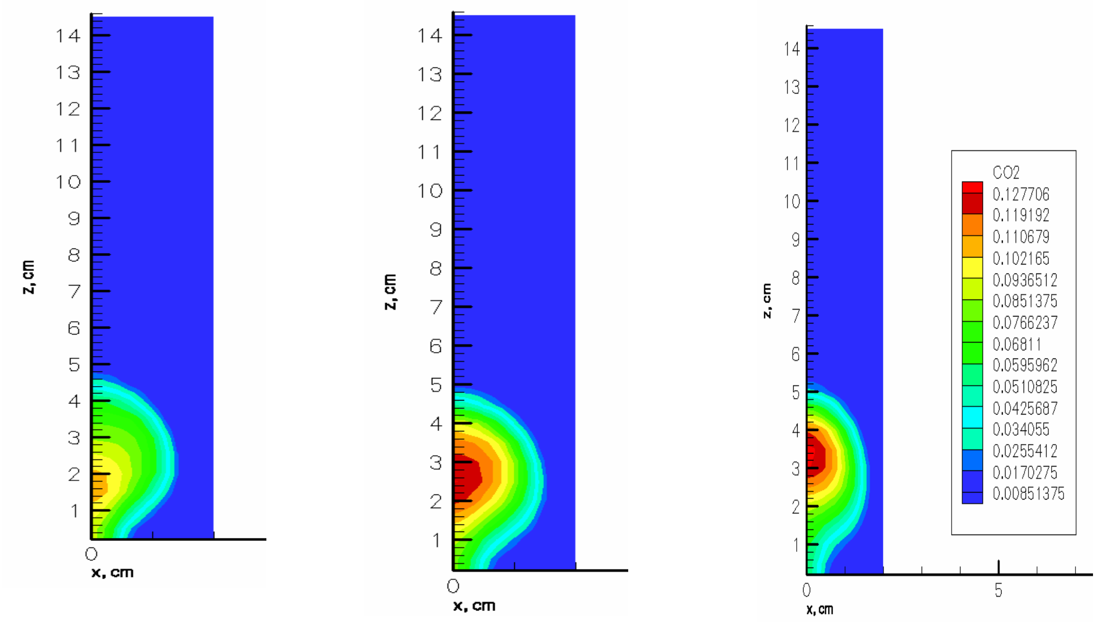


a) b) c)

Figure 5 – The distribution of fuel vapor concentration in the burner chamber at different time moments: a) 1.1 ms, b) 1.8 ms; c) 3 ms for the velocity of the spray 260 m/s

Figures 6 show the dynamics of the distribution of reaction products concentration on time for the spray velocity 260 m/s.

In this work the influence of the spray velocity of liquid heptane on its combustion has been studied. The distributions of maximum temperature and of CO_2 concentration depending on the spray velocity, time distributions of the fuel, CO_2, H_2O concentrations and temperature of the gas in the burner chamber for the effective velocity have been obtained. Also the change of maximum temperature in the burner chamber depending on the velocity of the injected liquid fuel has been obtained.



a) b) c)

Figure 6 – The distribution of CO_2 in the combustion chamber during combustion of heptane at various time moments:
a) 1.8 ms, b) 3 ms, c) 4 ms for the velocity of the spray 260 m/s

The further study of the combustion of liquid sprays will let not only to develop methods for the decrease the contain of harmful substances in the atmosphere and prevention of formation of polluting clouds, but also to improve the work of the engines of the internal combustion, of rockets, aviation engines and to make them more efficient and ecologically safer.

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ӘРТҮРЛІ БҮРКУ ЖЫЛДАМДЫҚТАРЫНДАҒЫ СҰЙЫҚ ОТЫННЫҢ БҮРКУ ЖӘНЕ ЖАНУЫН КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

А. С. Асқарова, С. А. Бөлегенова, И. Э. Березовская, Ж. К. Шортанбаева,
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Тірек сөздер: сұйық отын, гептан, жану, сандық модельдеу.

Аннотация. Қоршаған ортаның экологиялық ластануы, көмірсутекті отын қорының азаюы және көптеген елдердің экономикалық өрлеуі энергия тұтынымына деген сұранысты арттыра түсті. Осы факторлардың барлығы отынды неғұрлым тиімді және экологиялық зиянсыз жағу тәсілдерін іздеуге түрткі

болды. Осы мәселені шешу үшін жану процесін мұқият зерттеу керек және осыған байланысты сандық модельдеу әдістері кеңінен қолданылып келеді. Осы жұмыстың мақсаты – сұйық отынды бүрку жылдамдығының гептанның жану процесіне әсерін турбуленттік екіфазалы ағынның дифференциалдық теңдеулерін шешу негізінде сандық модельдеуден тұрады.

КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ РАСПЫЛА И ГОРЕНИЯ ЖИДКОГО ТОПЛИВА ПРИ РАЗЛИЧНЫХ СКОРОСТЯХ ВПРЫСКА

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Ключевые слова: жидкое топливо, гептан, горение, численное моделирование.

Аннотация. Повышение уровня экологического загрязнения окружающей среды, истощение запасов углеводородного топлива и экономический рост многих стран, вызывающих увеличение спроса на энергию - все эти факторы привели к проблеме нахождения более экономического и экологического способов сжигания топлива. Для того чтобы решить эту проблему, необходимо тщательно изучить процесс горения и именно поэтому методы численного моделирования широко распространены в науке. Целью данной работы является изучение влияния скорости впрыска жидкого топлива на горение гептана с помощью численного моделирования на основе решения дифференциальных уравнений турбулентного реагирующего потока.

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