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# COMPUTER SIMULATION OF THE FUEL COMPONENT MIXING PROCESS IN THE COMBUSTION CHAMBER OF DETONATION ROCKET ENGINE

*Annatation. The article is devoted to the problems of mixing fuel components in combustion chambers of detonation rocket engines. Computer simulations are used to evaluate this process effectiveness. The scale of turbulence is determined. The diffusion time in the gas mixture compared with the period of the detonation front transition along the annular combustion chamber. The assumption about the impossibility of a qualitatively mixed mixture obtaining in the described schemes of injector heads is confirmed. This explains the low energy performance of existing models of rotary detonating rocket engines.*

*Keywords: detonation rocket engines, diffusion, mixing fuel, injector head.*

**Introduction.** Mixing fuel with an oxidant in rocket and gas turbine engine installations is an important process that affects on the combustion completeness, the combustion structure and the energy characteristics in general.

The combustion reactions is in the combustion chamber of the rocket engine, in which the resultant fuel chemical energy passes into the heat, and then into the kinetic energy of the combustion products [1].

There is much evidence that fuel components must be evaporated before combustion, and thus combustion takes place in the gas phase. However, the components which self-engage in contact with each other, burn in liquid state too. The physical combustion completeness in the combustion chamber is determined by the amount of reacted oxidant and fuel molecules. It depends on the fuel pre-mixing quality in the engine and on the time while the components are contained in the combustion chamber [2].

Mixing of gaseous fuel occurs due to diffusion and stream convection. These processes are the more intense the higher temperatures [3]. Typical is the flow pattern near the nozzle head of the liquid propellant rocket engine, as shown in Fig. 1 [2]:

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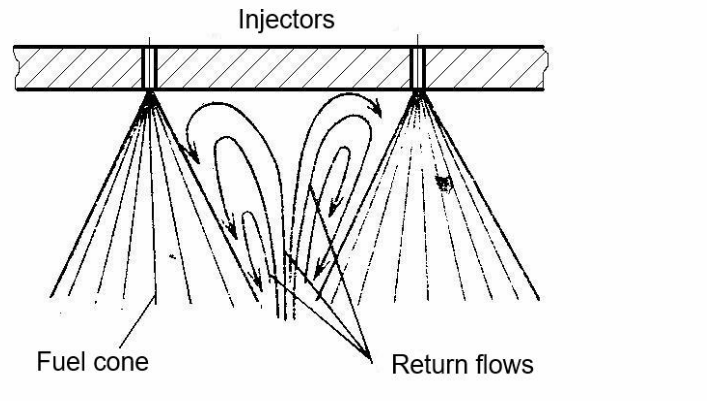

Figure 1 – A flow scheme near the injectors of the liquid fuel rocket engine

In this case there is mixing just in the turbulent streams. Designers faced with the appearance detonation in the combustion chamber just because of the mixture formation improvement, the average size reduction of the component droplets. In some cases there was a detonation that led to accidents. Various constructive solutions have eliminated these problems. In experimental models of detonating engines, the mixing quality is even more important than in liquid fuel rocket engines. Therefore, at first the researchers used gases as fuel components, because they quickly diffused. Gases were chosen with fairly wide limits of concentrations at which detonation took place (for example, oxygen and acetylene, hydrogen and oxygen) [4, 5].

For the realization of detonation combustion in rocket engines, the fuel components as liquid-oxygen and kerosene are more efficient, since there is a great operation experience with them, and they also have a high specific impulse [5]. However, the detonation cell of such components is greater than that of the above mentioned. To design the processes of detonation in conditions closer to those that can occur in the future in rocket engines with the detonation process, it is rational to use pair oxygen - propane.

It should be noted that mixture formation efficiency depends on not only the fuel components, but also from the injector head itself.

**The purpose** of the work is the computer simulation of the flow in the combustion chamber near the injector head of the detonation rocket engine with a continuous detonation wave.

In well-known experiments carried out by American scientists, pressure change graphs were obtained during the model operation of detonation engine with gas fuels in spin detonation wave [6,7].

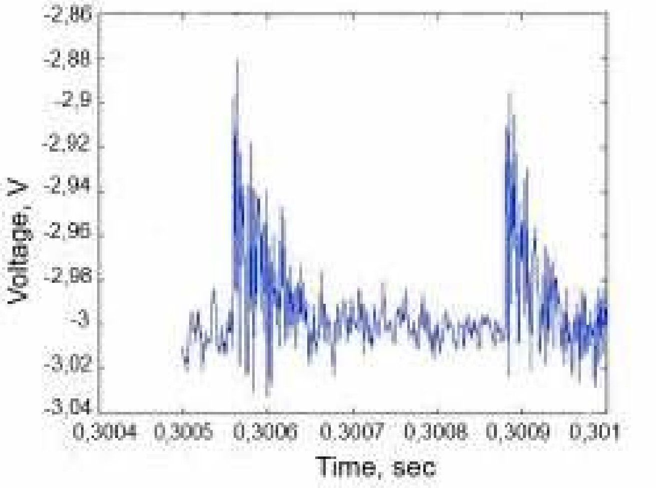

Figure 2 – Pressure deviation

The deviations of the pressure graph (fig. 2) show that the flow structure is uneven. This can be explained by many factors. For example, the head injectors used in this experiment creates a complicated flow for better fuel mixing. However, this fact can also lead to the detonating front interaction with the flow structure of mixed fuel components [8]. The interaction of both the detonation front and the fresh mixture flow from the combustion chamber wall also imposes its influence and manifests itself in uneven pressure. Another factor can be incomplete fuel mixing due to the high frequency of the detonation front. This assumption is also confirmed by the relatively low specific impulse obtained in the experiments.

According to the above factors, it is advisable to evaluate the flow structure and compare the mixing process time with the period of the next detonating front transition.

The geometric model was part of the combustion chamber near the head injector, described in [6, 7]. For experimental studies, its flat model was used - a cutout 1/80 with one jet injector and a part of the slit one [8]. Its scheme is shown in Fig. 3.

In order to find out the mechanism of influence on the mixture quality and, on the energy characteristics of the detonating engine model as a whole, accordingly, experimental flow studies in the flat head injector model were conducted. The blasting was carried out at the stand made at the experimental department of the Institute of Technical Mechanics of the National Academy of Sciences and the State Space Agency of Ukraine [8].

There are 3 chemical process modes with the gas mixtures flow:

- Chemically frozen flow regime;
- Chemically equilibrium flow regime;

- Kinetic flow regime.

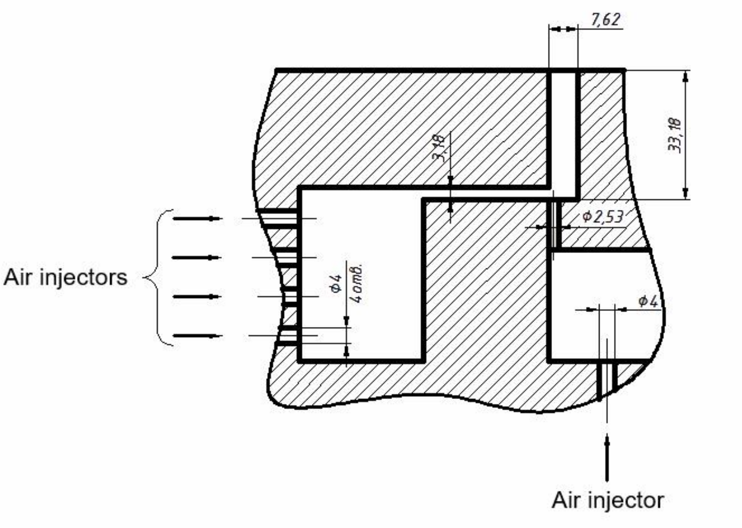

Figure 3 – A flat model scheme of injector device

They follow from the comparison of the time required for the complete chemical reaction and the time of gas-dynamic parameter changing [9]. The regime of chemical reactions in a chamber of a liquid fuel engine can be estimated according to the Dumkeller criteria [4, 9]:

$$Da = \frac{\Delta\tau}{\tau_*} = \frac{m \cdot W_a \cdot L}{\rho \cdot u} \qquad (1)$$

where $\Delta\tau$ – period of detonation front transition;

$\tau_*$ – time of components transformations in the α-chemical reaction;

$W_\alpha$ – the component transformation rate in the α-chemical reaction;

$\rho$ – mixture density;

$u$ – flow velocity;

$L$ – geometric size of the reaction area.

Since a detonating engine is fed not a ready mixture, but pure gases separately, then, in order to determine the regime, it is necessary to match the change rate in the component concentrations at each point of the flow field due to diffusion transfer and chemical reactions. Since at high temperatures the speed of chemical transformations is usually much higher than the diffusion transfer rate, the interaction between the gases will be limited to diffusion. In this case, the reactions are on a narrow front, which looks like a surface. This mode is determined by the Damocler diffusion number [9]:

$$Da_m = \frac{\tau_\partial}{\tau_*} = \frac{m \cdot W_a \cdot S}{\rho \cdot D} \qquad (2)$$

where $m$ – mass of the mixture portion;
$D$ – coefficient of diffusion;
$S$ – surface contact area of fuel components;
$\tau_\partial$ – equalization time of component concentrations.

For gases, the nonstationary diffusion at the boundary of their contact with each other is determined by the Fick`s law [4]:

$$m = D\,\frac{dc}{dx}\cdot S\cdot \tau_\partial \tag{3}$$

The turbulence scale $x$ *is* equal:

$$x = \left(D\,\tau_\partial\right)^{\frac{1}{2}} \tag{4}$$

$D$ – the diffusion coefficient determined experimentally under normal conditions [10]. The value of the turbulence scale, defined by the formula, is the largest allowable, for which fuel components have time to mix before the detonation front arrives. In reality, the diffusion time with the height of the fresh mixture layer $h$ is related to the dependence [4]:

$$h = u\cdot \tau_\partial \tag{5}$$

That is, when the mixing time increases, the detonating layer height also increases. However, when reaching some critical value $h^{*}$, the detonation transfers to the pulsation mode or deflagration combustion.

At gasdinamical experiment, graphs were obtained for the pressure distribution over the flat model volume of the combustion chamber in the injector zone. These values were used for the diffusion coefficient determining.

In a fire tests [6,7], a pair of oxygen / hydrogen was used and for this case the value of the turbulence scale lies in the range $8{,}59\ldots 9{,}34\cdot 10^{-5}$m.

Computer simulation was carried out in the SolidWorks application. Its goal was to determine the turbulence scale and to compare it with the calculated on the experimental data. The simulation result is illustrated in Fig.4.

Fig. 4 shows that the turbulence scale is higher than in calculations with the experimental data. The fuel components do not have time to mix, since the time of mixing is more than 2 times higher the detonation front period. In its turn this leads to a decrease in the specific impulse. In experiments this assumption is confirmed [6,7], but a qualitative estimation of losses on this effect has't yet been carried out.

In order to increase the mixing effectiveness it is advisable to use turbulators, or prechamber [11].

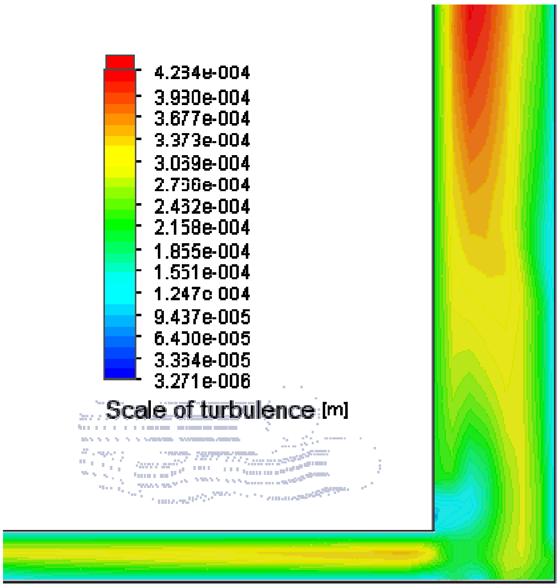

Figure 4 – The turbulence scale

**Conclusion.** The computer flow simulation in a flat combustion chamber model in the head injection zone of a rocket engine with a continuous detonation wave is carried out. The results confirm the assumption that the mixing is not ideal in the existing models of such units. The turbulence scale in the given initial parameters of the experiment conducted by American scientists, was determined. The diffusion gas time in a mixture, which is a limiting factor in this case was compared with the period of the detonation front passing through the annular combustion chamber. The last one is more than 2 times higher, indicating that the injection head is not efficient. Thus, it explains the low specific characteristics of the fire tests conducted by American scientists.

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