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# Disperse admixtures in flame plasma influence on the heterogeneous combustion rate in the electrostatic field

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**Abstract.** The paper presents experimental study results of the disperse admixtures in a flame plasma influence on the polymethylmethacrylate combustion rate change under the action of an electric field in a model hybrid rocket engine. It is shown that increase of disperse admixtures concentration in flame leads to the influence of the field on combustion intensification. An explanation of the results obtained on the basis of the ion-wind mechanism is proposed.

## 1. Introduction

Hydrocarbon fuels combustion is the most common method of energy obtaining in thermal devices. Investigation of the electric field action on heterogeneous combustion mechanism makes it possible to develop power plants parameters control methods. Studies conducted on model systems, as well as on a test hybrid rocket engine, show the possibility of the combustion rate controlling by imposing an electric field [1-3].

The dispersed combustion products (soot) presence in the flame allows to consider flame as a dust plasma. The dusty plasma with external fields interactions differ from the classical approaches describing combustion processes. The disperse admixtures introduction into the combustion zone makes it possible to control the dust plasma electrical properties in the flame [4], which affects the resulting combustion rate change under the influence of an electric field.

The aim of this work is the hybrid rocket engine combustion rate change in the presence of disperse admixtures in the gas phase and under the action of an electrostatic field study.

## 2. Experiment Procedure

Investigation of the disperse additives influence on the net field effect during combustion was performed on an engine with a coaxial arrangement of fuel blocks [5]. The combustion chamber of the engine is formed by two coaxially located fuel blocks: the outer block is a thick-walled pipe with an internal diameter of 32 mm and a wall thickness of 5 mm, inner block - cylinder with a diameter of 12 mm. The length of the blocks is 50 mm. The central block was made by extrusion or carved on the machine. In the gap between the blocks an oxidizer - gaseous oxygen is blown. Electrodes for creating an electric field are located: the first - outside the outer fuel block, the second - a metal rod, placed along the axis of the inner block. With this configuration, the inner fuel block acts as an insulator for the electrode. The outer fuel block combustion rate was studied, the combustion rate determination method is described in [1].

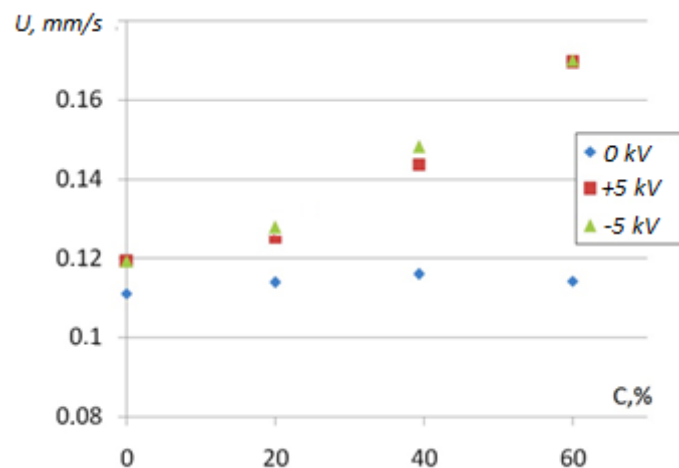


Disperse admixtures adding into the combustion zone was accomplished by filling the inner fuel block. To create blocks with a given mass concentration of admixtures, a mixture of polyethylene and admixtures was prepared. The mixture was then extruded into the primary preform. The primary preform was extruded three times to ensure uniform mixing of the components, after which the final block was formed. Thus, good mixing was achieved, as evidenced by the lack of own conductivity of the block. In experiments the following fuel block compositions was used: the outer fuel block is made of polymethylmethacrylate (PMMA); inner block - polyethylene (PE) with a disperse admixture (iron oxide). The compositions of the inner blocks are: PE, PE + 20% of the disperse admixture, PE + 40% of the disperse admixture, PE + 60% disperse admixture.

### 3. Experimental Results

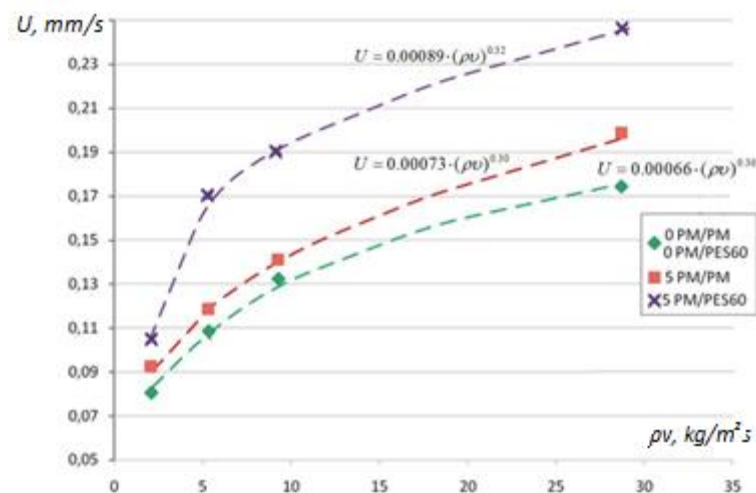
Preliminary experiments conducted with inner blocks of different compositions showed that outer block combustion rate is determined only by the oxidant flow and external electric field intensity. The potential difference between the electrodes in experiments with the field was 5 kV.

The influence of the disperse admixtures concentration in the inner block on the outer block combustion rate change is shown in Fig. 1. The oxidizer flow rate is 5 kg/m<sup>2</sup>s. The legend shows the central electrode polarity. The disperse admixtures concentration in the inner fuel block is plotted along the horizontal axis.



**Figure 1.** The outer block combustion vs various disperse admixtures concentrations.

As can be seen from the presented results, with an increase in the disperse admixtures concentrations the field effect increases. The direction of the field is not important.



**Figure 2.** The outer fuel block linear combustion rate vs oxidant flow rate.

Investigation of the combustion law, i.e. the outer fuel block linear combustion rate dependence on the oxidant flow rate, was made with a central fuel block of polyethylene + 60% of the disperse admixture and with a central block of PMMA. The results are shown in Fig. 2. In the legend, the compositions of the blocks are designated: outer and inner blocks of PMMA - PM/PM; outer of PMMA, inner of polyethylene with admixtures - PM/PES60.

The combustion laws obtained from the experimental results:

$$U = 0.00066 \cdot (\rho v)^{0.30} \quad U = 0.00089 \cdot (\rho v)^{0.32} \quad (\text{without field})$$

$$U = 0.00073 \cdot (\rho v)^{0.30} \quad (\text{in the field without admixtures})$$

$$U = 0.00089 \cdot (\rho v)^{0.32} \quad (\text{in the field with admixtures})$$

On average, the combustion rate in a field without admixtures increases by 10%, and with admixtures by 30%.

#### 4. Discussion of results

The experimental results show that the disperse admixtures introduction into the gas phase of the combustion zone substantially increases the effect of the field influence on the condensed component combustion rate. To explain the combustion rate change in the field, the "ion wind" mechanism is most often used [6]. Under the "ion wind" we mean the charged particles of a flame motion under the action of an electric field. As shown in [7], disperse particles in a flame accumulate an essential electric charge and, therefore, begin to interact with an electric field. The particles, being in the flame, acquire a high temperature, and shifting under the influence of the field, cause the heat flux to the condensed phase change. This leads to a change in the gassing rate. Consequently, the admixtures concentration increase will lead to field effect intensification (Fig. 1) and the pre-exponential factor in the combustion law increase (Fig. 2). In the electric field, with the introduction of dispersed impurities, an insignificant change in the combustion regime is observed: the degree in the combustion law varies by 7%, which also confirms the proposed explanation. The absence of field direction influence on the resulting combustion rate change is due to the fact that the dispersed particle charge depends on the time of its staying in the combustion zone [7,8]. Consequently, an additional heat flux can be created both negatively and positively charged particles of the disperse phase.

#### 5. Conclusion

The paper presents study results of the disperse admixtures influence on the combustion rate change under the action of an electric field in a hybrid rocket engine. It is shown that the polymethylmethacrylate mass combustion rate increases regardless of the electric field direction. The field effect on combustion increases with the disperse admixtures introduction. The combustion laws of the investigated substance are obtained. An explanation for the observed effect is proposed on the ion-wind mechanism basis.

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