Temperature measurement in the PMMA k-phase during combustion in a high enthalpy flow under the electrostatic field influence

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Abstract. The purpose of present work is to clarify the mechanisms of the electrostatic field influence on the polymers (PMMA) combustion in high enthalpy flows. For this, the PMMA temperature profiles during combustion in a hybrid rocket engine studies were carried out. Based on the results obtained the assumption about the intensification of the substance entrainment from the polymer surface combusting in a high-enthalpy flow under the electrostatic field influence is confirmed.

1. Introduction
The mechanism investigation of the electrostatic field influence on the polymers combustion in a high enthalpy flow is important because the lack of knowledge in this area reduces the practical application of electric fields as a tool for power plants controlling possibilities.

The background of these possibilities is shown in the articles [1-2], where the polymer (PMMA) combustion process in the model hybrid rocket engine intensification with an electrostatic field was demonstrated. The combustion rate was increased by 30% and the thrust increased by 15%. It’s known [3] possible processes explaining PMMA combustion intensification. The most interesting process among them is number of nucleation (gasification) centers change during volumetric pyrolysis [2]. As experimental data show, the number of gasification centers increases by an average by 30% under the electrostatic field influence with a 5 kV potential difference. This leads to the substance dispersion from the surface intensification, which manifests itself in the combustion rate increasing. This work task is to clarify the field effect mechanism on combustion processes in the high enthalpy flow, therefore, temperature measurements and the temperature gradients in the polymer changes estimation were carried out.

2. Experiment Procedure
For experiments, a bench with a model hybrid rocket engine is used [1]. Temperature measurements are made by chromel-alumel thermocouples with a junction diameter of 60 μm. The PMMA fuel block is cut across, thermocouples are installed at the cut point at specified distances from the combustion surface, then the halves of the block are glued together with dichloroethane. Thermo-EMF is recorded by an analog millivoltmeter in order to minimize the electrostatic field effect on the thermocouple readings. The error of temperature measurement does not exceed 10 °C.
3. Experimental Results

The Fig. 1 contains temperature over time graphs with an oxidizer consumption of 30.6 kg/m², a block length of 200 mm, combustion channel initial diameter of 20 mm and a voltage between electrodes of 0 and 5 kV are presented.

The shape of the curve at \( U = 0 \) kV is in qualitative agreement with the data of [4]. According to [5], the PMMA thermal decomposition start temperature is in the range [150-200] °C. The Fig. 1 contains inhomogeneities are observed in this temperature range, which arise due to thermocouple junction contact with the gas bubbles in the subsurface of the polymer. It was not possible to determine the exact value of the temperature at which the thermocouple exits to the surface, however, in the literature [4-5], the possible value lies in the range [380-450] °C.

![Figure 1. Temperature vs. time.](image)

In order to determine the electrostatic field influence features on the temperature distribution in the PMMA k-phase, the temperature gradient was calculated for various oxidizing agent flow rate values in the presence of field and without it. Fig. 2 shows graphs of the calculated gradients depending on the temperature value; the legend shows the oxidizer consumption in kg/(m²s). The letter \( U \) at the flow rate indicates the presence of an external field in the combustion zone.
4. Discussion of results

It can be seen that with gas flow rate increasing the temperature gradient also increases. At the same time, the electric field application decreases the gradient. Given the fact that the heat transfer by heat conductivity between the flame and the polymer surface is 90% of the total heat flux [5], the reduction of the temperature gradient in the fuel shows the decrease of the heat flux following deep into the polymer under the electrostatic field. This could be due to the surface processes of gas formation and dispersion intensification by an electrostatic field [6]. As a result much more heat is carried away from the fuel surface in the field presence.

During combustion, part of the heat is transferred by radiation. According to [5], the heat flux radiant component goes to the PMMA decomposition with the bubbles formation in the entire heated layer volume. The electric field effect leads to the fuel decomposition constants change [7–8]. It increases the number of bubbles in the surface layer. Hence this increases the thermal radiation absorption on the surface, reducing the temperature gradient as well.

5. Conclusion

Thus, the paper presents the temperature measuring in the polymer during combustion in a high enthalpy stream results. It is shown that under the electrostatic field influence, the temperature gradient in polymer decreases. An explanation of the detected effects is proposed.

References

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