Jet type instability of long spark electrical discharge applied for mixing enhancement

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The mixing intensification is of particular importance caused by a limited length of combustion chamber with supersonic flow and due to a controlled mixture required for a stable ignition. The main approach to the mixing intensification is based on increasing the interface between fuel and oxidizer. The submicrosecond spark discharge (E < 2 J/pulse, t <0.1-2μs) is one of candidates to resolve this problem [1].

This work focused on gas-dynamic features, which appeared at the spark discharge interaction with ambient gas, and on its application to mixing intensification in a supersonic airflow. During the research, frames of the early stage of the discharge channel were obtained using high optical magnification. It was observed that at the initial time moment there are small inhomogeneities of boundary along entire length of the discharge channel. The distortion of discharge shape could be based on pinch effect: it was proposed that the origin of these perturbations is of an electromagnetic nature due to interaction of high electric current with the azimuthal magnetic field [2].

The development of jet at the decay of the discharge channel arises due to the departure of shock waves from the boundary of the spark discharge. In the case when discharge channel has bends, divergent and converging shock waves occur. Convergent shock wave results in pressure increase area behind followed by low pressure area that leads to formation of jet structure [3]. Experimental confirmation of this mechanism was performed in this work (Fig.1a). Even small bends lead to significant anisotropy of afterspark channel decay. At the same time is clearly seen that intensification of initial small inhomogeneities takes place up to 100μs because of Rayleigh–Taylor instability and a superposition of this small-scale disturbances and jet flow based on spark channel bends was observed.

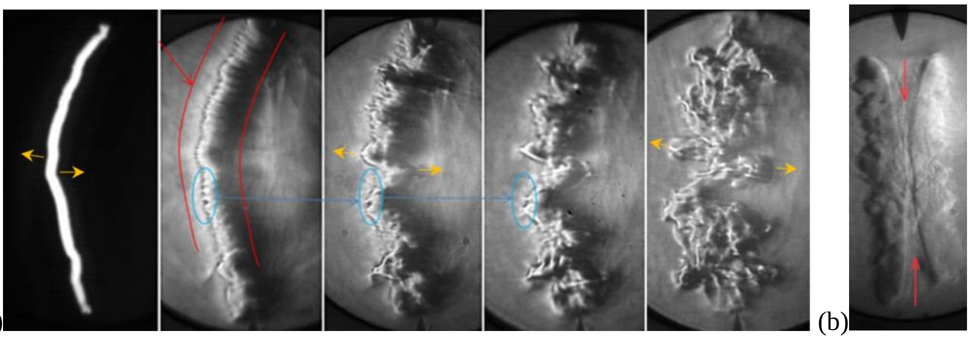
(a)  (b)

Figure 1. (a) Jet instabilities formation by the bends of the discharge (gap 50mm) and superposition of small inhomogeneities with jets (0 μs, 50 μs, 100 μs, 150 μs, 350 μs) (b) Filling the interior with cold gas (240 μs). Arrows indicate the direction motion (gap 35mm).

In the case when discharge channel is closer to straight it is possible to visualize the effect of suction of cold gas from the electrodes area into the center of heat cavity. The basic requirement is that the spark discharge between the electrodes should be short (Fig.1b). The same situation with formation of cold channel on the line between the electrodes was previously obtained for spark discharge (U = 10 kV and peak current up to I = 3 kA) on the surface. During those experiments a strong anisotropy of the jet was revealed. It was observed that the shapes of gas volume affected by discharge is significantly different for presented plans of view for later time moments t >100μs. The perturbed zone appears in a shape of a half of toroid at the enface view and like a jet in a direction normal to surface at the side view. It appears in a form of a half of toroid. It was found that average speed of the jet interface for the first 20 μs is up to 200 m/s depending on energy input [4].

Taking into account all obtained previous experimental and numerical results about spark discharge it was interesting to try spark discharge located near wall and fuel jet (CO_2 in this case) for mixing in supersonic flow. Numerical simulation of gases mixing by electrical discharge in supersonic flow (M=2, Pst=22000 Pa, T_0=170 K) was performed using FlowVision CFD software. The steady-state instantaneous consumption of the fuel injection in the simulation was 0.5 g/s. Influence of plasma filament produced by spark discharge was simulated by various volumetric heat sources with a peak power density of 5.0×10^{14} W/m^3 and a pulse duration of 100 ns. The same approach of taking discharge into account was previously tested for ambient air [3] and supersonic flow [5].

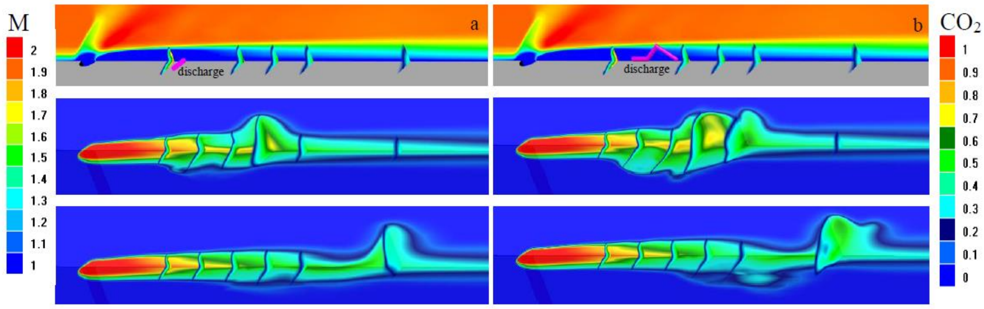


Figure 2. The result of numerical simulation for selected geometries of the discharge:
a – transverse discharge, b - longitudinal curved discharge (50, 130 μs)

As a result of the numerical simulation, it was found that for the same energy input for transverse and longitudinal discharges, the influence on the mixing of the flows is different. Transverse discharge results in more significant perturbations. The large amount of disturbances of the flow in all cases was observed at 30-100 μs. The interface between the fuel and oxidizer was larger in the case of longitudinal curved discharge (Fig. 2). This fact confirms the benefit of using the jet instability for mixing enhancement by electrical discharge.

Acknowledgments

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References

[1] Leonov S. B., Isaenkov Y. I., Firsov A. A., Nothnagel S. L., Gimelshein S. F. and Shneider M. N. - Jet regime of the afterspark channel decay // Phys. Plas., 2010, V.17, I.5, paper 053505, https://doi.org/10.1063/1.3429675

[2] Firsov A.A., Savelkin K.V., Yarantsev D.A., Leonov S.B. - Plasma-enhanced mixing and flameholding in supersonic flow // Philosophical Transactions A, 2015, V. 373, I. 2048, https://doi.org/10.1098/rsta.2014.0337

[3] Shurupov M. A., Leonov S. B., Firsov A. A., Yarantsev D. A., Isaenkov Yu. I. - Gasdynamic instabilities during decay of the submicrosecond spark discharge channel // High Temperature, March 2014, Volume 52, Issue 2, pp 169–178, https://doi.org/10.1134/S0018151X10060179

[4] Firsov A.A., Moralev I.A., Isaenkov Yu.I., Leonov S.B., Soudakov V.G. - Suppression of transonic buffet phenomenon by spark plasma actuator // AIAA SciTech 2018, paper AIAA 2018-2050 https://doi.org/10.2514/6.2018-2050

[5] Falempin F., Firsov A.A., Yarantsev D.A., Goldfeld M.A., Timofeev K., Leonov S.B. - Plasma control of shock wave configuration in off-design mode of M = 2 inlet // Experiments in Fluids, March 2015, 56:54 https://doi.org/10.1007/s00348-015-1928-4