THE EFFECT OF HIGH-FREQUENCY ELECTRIC DISCHARGE ON THE FLAME FRONT SELF-ACCELERATION PROCESSES IN PIPES CLOSED AT ONE END

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***Key words*:** control the turbulent burning velocity, high-frequency electric discharge, deflagration-to-detonation transition

Introduction

The problem of the control of turbulent processes occurring when detonation is triggered is of current interest both in the light of engineering problems and in the light of research in basic problems involving turbulent combustion. As is evident from [1], electric discharges can be used to control the combustion instabilities in model combustion chambers. Specifically, diffuse constant-current semi-self-maintained electric discharges, when applied to the flame zone, will suppress the acoustic instabilities, whereas a constant-voltage discharge will intensify those instabilities. The further development of that technique has demonstrated [2] that electric discharges can be used to control the turbulent burning velocity in pipes closed at one end. This allows electric discharges to be employed to actively control the length of the transition region when detonation is triggered in pipes. The solution of that engineering problem is of vital importance for the creation of pulse-detonation engines. In the case of practical pulse-detonation engines, in which hydrocarbon-air mixtures are used, detonation should be triggered in sufficiently short pipes. The object of the present paper is to investigate the effect of the high-frequency electric discharge whose voltage amplitude is maintained constant (constant-output-voltage-amplitude discharge) on deflagration-to-detonation transition.

Experimental Studies and Discussions

Experiments on controlling predetonation flame propagation were conducted in a circular tube, 1.5-meter long. The tube was closed at one end. An insulated 8-millimeter diameter coaxial electrode was mounted along the tube axis, the tube walls serving as the second electrode. High-frequency power supply for discharge was fabricated on the basis of a 3-megahertz carrier-frequency driving oscillator and a 200-watt amplifier. The amplitude of the high-frequency voltage was maintained constant by the feedback circuit. Experiments were made with propane as a gaseous hydrocarbon fuel.

The experiments have shown that a high-frequency electric discharge with the properties described above increases the turbulent flame propagation velocity by approximately 1.5 times as compared to the case with no discharge.

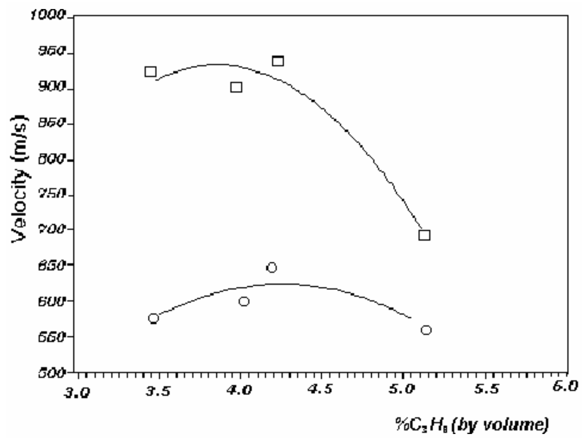

Fig.1. Tube-outlet flame front propagation velocity vs. the propane percentage in the air when a high-frequency electric discharge is applied. . (□- constant-output-voltage-amplitude discharge , ○- no discharge)

Figure 1 shows measured flame propagation velocities at the tube open end vs. the concentration of propane in the fuel-air mixture. It follows from the figure that the high-frequency electric discharge produces a maximum effect on stoichiometric and fuel-lean mixtures.

It is well known that when a high-frequency electric discharge is applied to a stationary flame front at high-frequency field intensities of the order of 400 V/cm and a carrier frequency of 5 MHz the normal burning velocity will increase by the order of 10 to 15 % for stoichiometric mixtures [3]. In the case under investigation the above velocity increase figure is higher, i.e. those results are an indirect evidence that a constant-output-voltage-amplitude electric discharge appears to further turbulize the flame front and, when this occurs, the flame front propagation velocity will increase by approximately 1.5 times. In qualitative terms, the influence of electric discharges on flame front turbulization can be interpreted in the context of the diffusion-thermal combustion wave instability [4]. It is common knowledge that heat conduction will stabilize any instability, whereas diffusion, on the contrary, is a destabilizing influence in the context of the development of spatial flame front disturbances. Assume that the flame front becomes accidentally curved (Figure 6). Then, if the discharge is diffuse and applied to the chemical-reaction zones and the pre-heating zone (the non-equilibrium electron concentration is at its maximum in those zones), additional heat, $\delta Q = (\Delta U)^2/\ \delta R$, will be supplied to the chemical reaction zone in the case of a constant-voltage discharge, where ΔU is the voltage drop in the flame front region, and δR is the resistance of that curved flame front region. For a constant-current electric discharge $\delta Q = I^2 \delta R$, where I is the current flowing through the flame front cross-section. This being so, the higher the amplitude of the flame front curvature, the less heat will supplied to that region when a constant-voltage electric discharge is applied to the flame front, and, on the contrary, the higher the amplitude of the flame front curvature, the more heat will be supplied when a constant-current discharge is triggered. Since concave flame front regions (region A) are in a more favorable position than the convex ones (region B), the constant-current discharge will assist in increasing the normal burning velocity and, hence, in suppressing the

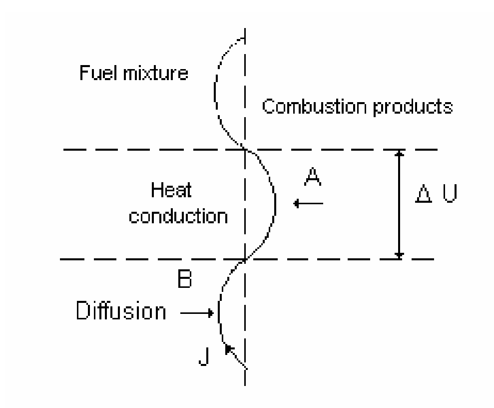

Fig.2. Qualitative representation of the effect of electric discharges on the instability of the flame front to spatial disturbances.

spatial turbulences when the amplitude of those turbulences increases, taking into consideration the stabilizing effect of thermal conduction. Alternatively, a constant-voltage electric discharge will aid in reducing the normal burning velocity and, hence, in intensifying the spatial disturbances.

In the context of an infinitely narrow chemical-reaction zone, it was found as a linear approximation, taking into consideration the effect of electric discharges on the diffusion-thermal instability of the plane combustion wave, that the stability regions of the variance equations obtained for spatial disturbances are substantially modified.

Conclusions

It has been experimentally demonstrated that a high-frequency constant-output-voltage-amplitude electric discharge, when applied to the flame zone in the case of the combustion wave propagating in pipes, will increase the turbulent flame front propagation velocity by approximately 1.5 times.

Electric discharges have been shown, in qualitative terms, to affect flame zone turbulization.

The present authors are planning to conduct further more detailed instrumental and theoretical investigations into the phenomena discussed.

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