Control and Stabilization of Flames with Plasma Assistance

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Résumé

Hydrocarbon-based fuels will represent the main energy source for automotive and aeronautical transportation on a worldwide scale for the foreseeable future. However, increasingly stringent regulations force manufacturers to improve engine technologies to reduce pollutant emissions and greenhouse gases. To achieve these goals, strategies based on the combustion of fuel-lean mixtures or fuel-air mixtures diluted by exhaust gas recirculation [1] have been proposed However, lean or diluted combustion slows the reaction kinetics, leading to irregular ignition, flame instabilities, or incomplete combustion. Thus, a major challenge is to ensure reliable flame ignition and to maintain stable combustion in lean or diluted mixtures. To address these challenges, several innovative plasma technologies have been proposed. Plasma discharges provide an effective way to produce high concentrations of reactive species (radicals, excited species, ions, electrons) to promote combustion kinetics with a small amount of electrical energy [2]. Beneficial effects have been observed in laboratory-scale burners under the action of corona [3,4], microwave [5], gliding arc [6], nanosecond repetitively pulsed [7-9], dielectric barrier [10-11], or volume nanosecond [12-13] discharges.
We report here on nanosecond repetitively pulsed (NRP) discharges which, compared to single pulse nanosecond discharges, present the advantage of producing strong synergistic effects from pulse to pulse, and which can be used in continuous operation. Based on results of fundamental studies, we illustrate the chemical, thermal and hydrodynamic effects of NRP discharges in plasma-assisted combustion. These discharges are shown to produce large amounts of atomic oxygen, with nearly full dissociation of molecular oxygen in the interelectrode gap, as well as some degree of gas heating. The isochoric energy deposition mechanism also induces strong hydrodynamic effects that help redistribute the reactive products over a large volume, effectively enhancing combustion through oxidation reactions and chain propagation reactions. The relative importance of these thermal and chemical effects will be discussed. Then we will present illustrative examples of effective plasma stabilization by NRP discharges in small and medium-scale combustors. These results demonstrate that plasma-assisted combustion is a promising method to improve combustion performance over a wide variety of conditions, but also suggest that additional research is required to translate their utilization in industrial-scale combustors.

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