Advances in Automobile Engineering

Extended Abstract

Dielectric barrier discharge actuator for vehicle drag reduction at highway speeds

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Abstract

We propose and demonstrate reduction of aerodynamic drag for a realistic geometry at highway speeds using serpentine dielectric barrier discharge actuators. A comparable linear plasma actuator fails to reduce the drag at these speeds. Experimental data collected for linear and serpentine plasma actuators under quiescent operating conditions show that the serpentine design has profound effect on near wall flow structure and resulting drag. For certain actuator arrangement, the measured drag reduced by over 14% at 26.8 m/s (60 mph) and over 10% at 31.3 m/s (70 mph) opening up realistic possibility of reasonable energy savings for full scale ground vehicles. In addition, the power consumption data and drag reduction effectiveness for different input signals are also presented.

In our previous study, the mitigating effect of dielectric barrier discharge (DBD) on the intensity of end-gas auto-ignition was observed. In this paper, the mechanism of the effect was investigated through chemical analysis and combustion experiments using a rapid compression and expansion machine (RCEM). Comprehensive GC×GC with time of flight mass spectroscopy (GCxGC-TOFMS) was performed, and the generation of alkyl-hydro peroxide (ROOH) was successfully confirmed for the first time, based on accurate mass analysis. To study the mechanism of the mitigation effect, the influence of ozone was assessed using different fuel-air mixtures, such as primary reference fuel (PRF90) and surrogate gasoline (S5R). The addition of ozone showed the same mitigation effect in the case of PRF90, but a lesser effect in the case of S5R. A characteristic blue light was also observed when ozone was mixed in the end gas prior to auto-ignition. Since ozone is known to promote low temperature oxidation (LTO) reactions, the effect of DBD application likely involves the same mechanism. The difference in effect with the different fuels may be explained in terms of an ozonolysis reaction, because S5R contains olefins and PRF90 does not. Since applying DBD to the fuel-air mixture did not show a difference in effect, between S5R and PRF90, the DBD mitigation phenomena is not induced by ozone, but a plausible candidate is the ROOH. To investigate the precursor phenomena to the blue light emission, planer laser induced fluorescence measurement (PLIF) for formaldehyde (HCHO) was employed in the combustion experiment. Without DBD application, the HCHO distribution in the end gas exhibited gradual homogenization before auto-ignition; whereas, with applied DBD, the characteristic blue flame appeared in the inhomogeneous distribution of HCHO in the end-gas region. This result may support the hypothesis that the mitigating effect is caused by the promotion, by DBD-induced ROOH, of inhomogeneous progress in the end-gas chemical reaction. A knock intensity mitigation effect resulting from the application of dielectric barrier discharge (DBD) was experimentally demonstrated.

Dielectric-barrier discharge (DBD) is the electrical discharge between two electrodes separated by an insulating dielectric barrier. Originally called silent (inaudible) discharge and also known as ozone production discharge or partial discharge, it was first reported by Ernst Werner von Siemens in 1857. On right, the schematic diagram shows a typical construction of a DBD wherein one of the two electrodes is covered with a dielectric barrier material. The lines between the dielectric and the electrode are representative of the discharge filaments, which are normally visible to the naked eye. Below this, the photograph shows an atmospheric DBD discharge occurring in between two steel electrode plates, each covered with a dielectric (mica) sheet. The filaments are columns of conducting plasma, and the foot of each filament is representative of the surface accumulated charge. The DBD was utilized to reform fuel–air premixtures. A rapid compression and expansion machine (RCEM) was used for the demonstration experiment. A rectangular combustion channel was installed in the RCEM's cylinder to observe flame propagation and end-gas auto-ignition behavior. The effect of the DBD was investigated by installing a plug-shaped DBD reactor in the combustion chamber. Part of the fuel-air mixture was reformed by the DBD and diffused in the chamber, and the combustion behavior was observed by a color and a monochrome high-speed camera with several different interference filters. In ordinary end-gas auto-ignition, a hot flame rapidly appears throughout the end-gas region, and generates strong pressure oscillation; whereas, in the present study, when the DBD was applied, the magnitude of the pressure oscillation decreased and a blue flame was generated in the end gas before full end-gas auto-ignition. The onset time of the blue flame, and the interval between the onset and the hot flame's appearance, depended on the fuel and initial temperature. The effect was investigated in the case of a primary reference fuel, surrogate gasoline, and n-butane lean mixture; however, though the magnitude of the effect varied, the mitigation effect was demonstrated for every fuel-air mixture. The proposed method is therefore expected to mitigate

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knocking in internal combustion engines and contribute to greater thermal efficiency. A coaxial dielectric barrier discharge plasma-assisted combustion actuator (DBD-PACA) system was set up to study its discharge and optical emission spectrum (OES) characteristics in space in this paper. Results showed that each discharge cycle can be divided into four stages: a, b, c, and d. Discharge-on only occurred in stages b and d. Comparatively, the discharge intensity was larger in stage d due to the memory effect of excited electrons. Moreover, Lissajous figure and current-voltage methods were utilized to calculate the power of the coaxial DBD-PACA, and both methods produced roughly similar results. The power presented an upward trend with increasing input voltage and airflow rate. In addition, numerous second positive system (SPS) excited nitrogen molecules were detected from the OES signals. The intensity of the spectral lines (297.54 nm, 315.76 nm, 336.96 nm, and 357.56 nm) first increased, then maintained, and then increased rapidly with the increased radius; however, the intensity of the spectral lines (380.34 nm, 405.80 nm, and 434.30 nm) basically remained unchanged, then increased, and finally decreased with the increased radius. The vibrational temperature first decreased quickly and then increased and reached the minimum at $r = 18$ mm with the increased radius. The vibrational temperatures at all collection points decreased with the increased input voltage. However, within the range of 0–280 L/min, when r was lower than 15 mm, the vibrational temperatures first increased rapidly and then decreased slowly; when r was greater than 15 mm, the vibrational temperatures first increased and then basically remained stable.