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# Effect of electric fields on the propagation speed of tribrachial flames in coflow jets

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**Abstract**

The effect of electric fields on the propagation speed of tribrachial (or triple) flames has been investigated in a coflow jet by observing the transient flame propagation behavior after ignition. The propagation speed of tribrachial edges when no electric fields were applied showed typical behavior by having an inverse proportionality to the mixture fraction gradient at the flame edge. The behavior of flame propagation with electric fields was investigated by applying high voltage to the central fuel nozzle, thereby having a single-electrode configuration. The enhancement of propagation speed has been observed by varying the applied voltage and frequency for ac electric fields. The propagation speed of tribrachial flames was also investigated by applying positive and negative dc voltages to the nozzle, and similar improvements of the propagation speed were also observed. The propagation speeds of tribrachial flames in both the ac and dc electric fields correlated well with the electric field intensity, defined by the applied electric voltage divided by the distance between the nozzle electrode and the edge of the tribrachial flame.


*Keywords:* Tribachial flame; Propagation speed; Electric fields; Edge flame

## 1. Introduction

Electric fields or plasma-assisted combustion has been an interesting topic since the observation by Brande [1]. The influence of electric fields on premixed and diffusion flames has been investigated extensively [2–4], including burning rate [5–9], flame stabilization [10–12], and emission reduction [13–16]. These behaviors were frequently explained based on either the ionic wind effect caused by the interaction of accelerated ions and neutral particles or the enhancement of chemical reactions by the charged particles accelerated in electric fields, leading to electron-induced or ion-induced reactions.

One of the fundamental observations on the interaction of electric fields and flame is the effect of electric fields on the flame speed of premixed flames. Jaggers and von Engel [5] reported the augmentation of flame speed for hydrocarbon fuels from experiments on propagating premixed flames in a tube applying both dc and ac fields, which were orthogonal to the direction of flame propagation. It has been reasoned that the vibrationally excited states of molecules could increase reaction rates. To the contrary, in stationary flat flame experiments [6], flame speed

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augmentation was found to be minimal. It has been concluded that dc fields that are parallel to the direction of flame propagation had no effect on flame speed. However, Noorani and Holmes [10] observed that even in the case of parallel electric fields, there existed a slight increase in flame speed.

Marcum and Ganguly [9] reported the enhancement of flame speeds in premixed Bunsen flames. They observed wrinkled laminar Bunsen flames and suggested that the flame speed could be enhanced through the flame wrinkling in electric fields caused by the diffusional-thermal instability due to the selective ion movements in the reaction zone under a dc electric potential.

Recently, the characteristics of tribrachial (or triple) flames have been investigated extensively in conjunction with flame propagation behavior in mixing layers and the stabilization mechanism of lifted flames in jets [17–22]. A tribrachial flame, which consists of rich and lean premixed flame wings and a trailing diffusion flame all extended from a single point, can be observed when fuel and oxidizer are stratified [23]. The propagation speed of tribrachial flames has been measured experimentally in free and coflow jets [21–24]. It has been found that the propagation speed is strongly dependent on the mixture fraction gradient. Studies on the effect of electric fields on the propagation speed of tribrachial edges are very limited. Recently, the effect of electric fields on the reattachment of stationary lifted flames in coflow jets has been investigated [25]. It has been observed that the reattachment occurred at a higher jet velocity when an ac voltage was applied to the nozzle. The reason was attributed to the enhancement of the propagation speed of the tribrachial edge by electric fields, based on the observation of transient reattachment processes. Due to the nature of reattachment processes in terms of velocity and flame edge height, the observed range of the experiments was limited. Also, only the effect of ac voltage at 60 Hz was investigated for the propagation speed.

Thus, the purpose of the present study is to elucidate further the effect of electric fields on the propagation speed of tribrachial edges. For this, we have conducted experiments for propagating tribrachial flames after ignition in coflow jets. The electric fields were applied by connecting a high-voltage electrode to the fuel nozzle, and connecting the other electrode to a building ground. This-single electrode configuration has been found effective in extending flame stabilization, including liftoff and reattachment in jet flames [11,25]. The propagation speed of tribrachial flames was investigated by varying the applied voltage and frequency of ac and the applied voltage of dc.

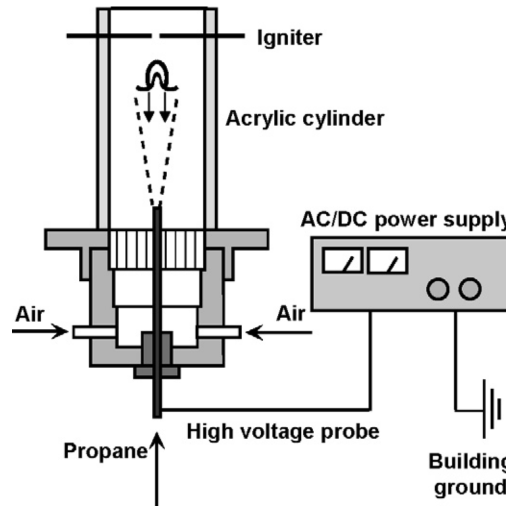


Fig. 1. Schematic of experimental setup.

## 2. Experiment

The apparatus consisted of a coflow burner and flow controllers, a power supply system, and a measurement setup, as schematically shown in Fig. 1. The coflow burner had a central fuel nozzle made of stainless steel with i.d. 0.254 mm and o.d. 1.588 mm. The nozzle length was 10 cm to ensure fully developed parabolic velocity profiles at the nozzle exit, and the nozzle tip was protruded 10 mm above the coflow exit. The coflow air was supplied to a concentric nozzle having i.d. 90 mm through glass beads and honeycomb for flow uniformity. The coflow velocity $V_{CO}$ was fixed at 4.6 cm/s to focus on the propagation speed of tribrachial flames under the influence of electric fields. The effect of coflow velocity on the propagation speed of tribrachial flame has been investigated elsewhere [24]. The whole body of the coflow burner was made of acetal resin for electrical insulation, except the fuel nozzle. To prevent external disturbances, an acrylic cylinder with i.d. 90 mm and length 25 cm was installed at the exit of the coflow air. The fuel was chemically pure propane. The flow rates of the fuel and air were controlled by the mass flow controllers, calibrated with a wet-test gas meter.

Both dc and ac power supplies were used. In the case of ac, the frequency was varied in the range from 60 to 1000 Hz by using a function generator, where the voltage pattern was sinusoidal. The applied voltages were varied up to 6 kV in the RMS value. The voltage and current profiles were monitored by an oscilloscope, a 1000:1 voltage divider (Tektronix, P6015A), and a current probe (Tektronix, TCP312). The high voltage was applied to the central fuel nozzle; thus the nozzle served as an electrode