Local Chemiluminescence Measurements of OH*, CH* and C2* at Turbulent Premixed Flame-Fronts

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Summary. Local chemiluminescence measurements of OH*, CH* and C2* were carried out at the flame-front of a premixed turbulent methane flame to understand the details of the reaction zone and flame-front structures. Cassegrain optics were used to detect these chemiluminescences simultaneously. The developed system allows us to measure each chemiluminescence at high temporal resolution of 4 \( \mu \text{s} \) and high spatial resolution of 0.1 mm in diameter and 0.8 mm long. The relationship between the turbulent scale and the flame-front thickness was investigated by simultaneous measurements of these three chemiluminescences as well as those derived from LDV. It was found that the time series chemiluminescences could describe the flame-front duration and inter-arrival time, and that the variations in OH*, CH* and C2* chemiluminescences occurred simultaneously, which indicates the strong relationship between OH* to CH* and OH* to C2* reactions at the flame-front. Furthermore, the flame-front structure could be characterised by the time scales of chemiluminescence intensities, which was found to correspond to the flame-front thickness and the local Damköhler number. A new measurement technique to measure the local flame-front structure by means of local chemiluminescence measurements was proposed and its performance was proven.

Key words. Turbulent Premixed Flames, Local Flame-Front Structure, Chemiluminescence, Cassegrain Optics, Local Damköhler Number

Introduction

Numerous studies have been made regarding the effects of turbulent flow and its properties on flame-front structure and chemical reactions (Damköhler et al. 1940, Summerfield et al. 1955, Karlovitz et al. 1951, Ballal 1979). Turbulent premixed flames may be defined by their characteristic local flame-front structure and the combustion reaction rate at this flame-front (also referred to as the "reaction..."
The flame-front travels from burned to unburned gas with a shape and size that is primarily dictated by turbulence, but it is also affected by characteristics of the chemical reaction such as the heat release rate, temperature gradient, reaction rate, preferential diffusion, radiation, and so on. Relationships to turbulent scales such as the Kolomogorov scale and reaction zone thickness (Furukawa et al. 1990, Bedat et al. 1995) have been widely used to classify the features of turbulent flame structures. There are several theories regarding these flames. The first is that the flame-front structure is similar to that of a wrinkled laminar flame when the turbulent intensity is weak and its scale is smaller than the flame-front thickness (Buschman et al. 1996). Another theory is that the turbulent flame consists of the distributed reaction zone when the turbulent intensity is extremely high (Summerfield et al. 1955, Yoshida et al. 1992).

The flame-front thickness has been reported by several researchers as less than 1 mm (Furukawa et al. 1990, Buschmann et al. 1996). The flame-front may be defined by the several physical or chemical quantities present in this area.

Many researchers have emphasized the importance of precise and detailed experimental data for the flame-front structure and have tried to obtain this data, but it has not been measured directly. If possible, this data would determine the flame structure in space and its evolution in time.

The flame-front is not fixed in space, but rather travels through the turbulent flow field of unburned fuel. The turbulent scale is related to the flame-front movement, but not directly. The movement and shape of the flame-front do not coincide with the turbulent eddies. They are instead determined by reaction speed, turbulent flow characteristics, thermo-chemical properties, and heat balance.

Local flame-front structures have been investigated to determine the effects of turbulence-chemistry interaction (Kuznetsov et al. 1990), vortex interaction with the surface (Tabaczynski et al. 1978), stretch rate (Kuo 1986), and so on. Analysis of this data has almost always been performed using time-averaged statistics.

Laser techniques have greatly enhanced researchers' ability to measure the flame-front structure and its features. Laser-induced fluorescence (LIF) (Hanson et al. 1988, Deschamps et al. 1996) has been a very powerful tool to visualize the front of OH or CH concentration and its evolution over time (Nguyen et al. 1996, Renfro et al. 2000). Laser Doppler Velocimeter (LDV) measurements have been used to identify the turbulent scale and its intensity. This is made possible by the instrument's fine spatial resolution of 50 μm. Thermocouple or electrostatic probe have been used to characterize the effect of turbulence on the flame configuration or burning velocity (Yoshida et al. 1982, Furukawa 1998). Unfortunately, intrusive probes may disturb the flow field. In addition, it is impossible to measure the same point in space with the LDV, thermocouple, and electrostatic probe at the same time.

Current measurement techniques can provide either detailed information on the instantaneous spatial structure of the flame with high temporal resolution (LIF, Schlieren, etc.), or temporal behavior with fine spatial resolution for a single point.