Available online at www.sciencedirect.com
ScienceDirect
Proceedings of the Combustion Institute 35 (2015) 889–895
Proceedings of the Combustion Institute
www.elsevier.com/locate/proci

Modification of sooting tendency by magnetic effects

A. Jocher [a,b], H. Pitsch [b], T. Gomez [a], G. Legros [a,*]

[a] *Sorbonne Universités, UPMC Univ. Paris 06, CNRS, UMR 7190 Institut Jean le Rond d'Alembert, F-75005 Paris, France*
[b] *RWTH Aachen University, Institute for Combustion Technology, Aachen, Germany*

Available online 20 June 2014

Abstract

Experimental investigations assess for the first time the influence of the gradient of the square of the magnetic flux density ($\nabla(\mathbf{B}^2)$) on the soot production in a laminar axisymmetric non-premixed flame. The steady non-smoking ethylene flame is established in a coflowing mixture, composed of oxygen and nitrogen, over a Santoro type burner. This burner is located in an electromagnet. The flame experiences different magnitudes of upward $\nabla(\mathbf{B}^2)$, ranging from 0 to 18.2 T^2/m, as well as different oxygen contents of the coflow, ranging from 21% to 50% in volume. Soot volume fraction is mapped in the flame by Laser Extinction Measurement technique. Increasing the magnitude of the $\nabla(\mathbf{B}^2)$ allows for the modification of soot production in the flame. This modification is enhanced by increasing oxygen content, as oxygen exhibits a relatively high paramagnetic susceptibility. Furthermore, the aforementioned modification is shown to enable the shift among similar soot concentration profiles in the flame, just as the variation of oxygen content can do. Consequently, modification of the inner flame structure by magnetic effects could contribute to the control of oxyfuel combustion.

Keywords: Sooting tendency; Laminar non-premixed flame; Magnetic field

1. Introduction

Major air pollution disasters in industrialised cities, e.g. London smog disaster in 1952, have highlighted the harmful effects of pollutant emissions by combustion devices on human health. Increased risks of cardiac arrest, pulmonary diseases, pregnancy complications and asthma are now associated with the presence of particulate matter, especially fine-particulate soot, in urban air and higher mortality rates [1–3].

Although soot formation and oxidation processes in non-premixed flames have been extensively investigated, they are not fully understood due to the numerous chemical and physical phenomena that drive them. Still, there is now a general understanding that soot production along the combustion process is the result of the following major competing processes: pyrolysis of fuel leading to the formation of soot molecular precursors, nucleation, growth of particle mass via surface reactions and coagulation, and oxidation. Oxidation mainly proceeds through the removal of carbon atoms from soot particles, by reaction with O_2 and OH radicals [4,5]. While O_2 is considered the most important species in the soot oxidation process, the role of OH radicals is more controversial. Conducting numerical simulations,

* Corresponding author. Fax: +33 1 30 85 48 99.
E-mail address: guillaume.legros@upmc.fr (G. Legros).

http://dx.doi.org/10.1016/j.proci.2014.05.139
1540-7489/

Frenklach [4] stated that oxidation by OH radicals is relatively weak, while Kim et al. [5] showed that these radicals are highly soot-oxidising species.

Standard strategies of soot production control involve post-treatment methods, such as filters [6] and/or catalysts [7]. However, using in situ strategies looks like an increasingly promising method. Examples are the design of new fuels [8], addition of exhaust gases to the combustion process [9], or combustion control by electrical fields [10]. Interestingly, none of these strategies utilises magnetic fields.

Yamada et al. [11] observed experimentally and numerically that the O_2 and OH radicals concentration fields are highly sensitive to the gradient of the square of the magnetic flux density ($\nabla(\mathbf{B}^2)$). Among the species contributing to the combustion process, O_2 and OH indeed exhibit relatively high paramagnetic susceptibilities. The magnetic force on the species is directly proportional to the susceptibilities, but indirectly proportional to the temperature. As OH radicals mainly appear in the hot regions of the flame, the magnetic force on OH is negligible small compared to the one acting on O_2 in the coflow. Shinoda et al. [12] studied a premixed methane-air flame and found that the magnetic force acts mainly on O_2, due to its higher mass fraction. The high sensitivity of OH radicals on $\nabla(\mathbf{B}^2)$, shown by Yamada et al. [11], is mainly a result of the modified convection velocity induced by the magnetic force on O_2.

While such a magnetic force can also play a significant role on the stability of non-premixed flames [13,14], its influence on the sooting behaviour of non-premixed flames has never been assessed. Consequently, the present study is a contribution to an original in situ strategy of soot production control by magnetic fields. A steady, laminar, non-premixed ethylene flame is established over the axisymmetric burner, prescribed by Santoro et al. [15]. This configuration is selected due to the available literature about soot production, which delivers both numerical and experimental databases. A non-intrusive optical technique, based on line-of-sight attenuation measurements, provides the maps of soot volume fraction in the flames.

As a result, the modification of the inner flame structure by magnetic effect, is reported in terms of soot volume fraction.

2. Experimental setup

Figure 1 exhibits a schematic of the experimental setup.

2.1. Burner configuration

The non-premixed flames are established over an axisymmetric coflow burner, identical to the one described by Santoro et al. [15]. The burner's axis of symmetry is vertical. This burner was also

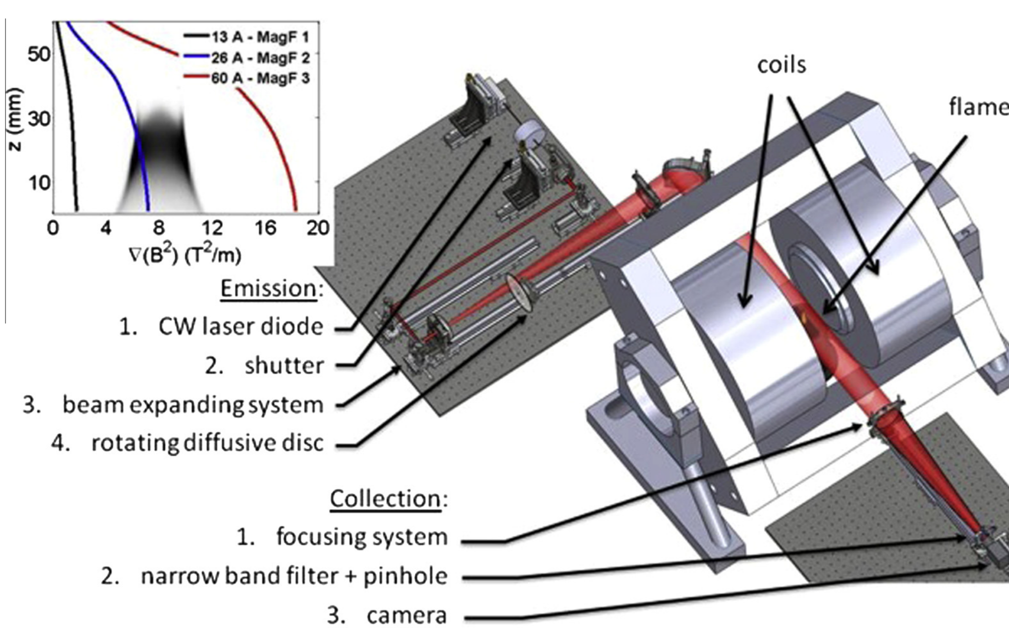

Fig. 1. Schematic view of the experimental setup. This allows soot volume fraction measurements in an axisymmetric ethylene non-premixed flame experiencing different magnitudes of $\nabla(\mathbf{B}^2)$. The insert in the upper left corner exhibits the different profiles of $\nabla(\mathbf{B}^2)$ as a function of HAB. As an illustration, the flame established for $X_{O_2} = 50\%$ and MagF 0 is shown in reversed intensity scale.