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In-Situ Soot visualization using Low power 405nm laser shadowgraphy for premixed and non-premixed flames

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Abstract

An ultra-simple method for investigate soot formation during gas and combustion by visualization of premixed and non-premixed flames shadowgrams. A low power 405nm laser diode is used to backlight the investigated flame to generate a large flow field shadowgraph on a distant florescent screen. The method exclude expensive optical components such as high power lasers, low loss lenses, filters, image intensifiers and high speed ICCD cameras. The imaging system is compact, low cost and reliable, suiting different type and size of burners. Discrete images or video can be captured using any type of digital cameras.

Keyword: Simple shadowgraphy, Soot visualization, Premixed and non-premixed flames, Low power 405nm laser diode.

Introduction

One of the major problems in the field of combustion is the soot formation detection and prevention. As a result of the incomplete reaction, soot is emitted into the space air during the burning of fossil fuels, biofuel, and biomass. Soot contains amorphous carbonaceous particles with minor amounts of sulfur, metallic ashes and some other chemicals [1]. The presence of soot may cause harmful or useful effects; as an example, the presence of soot in Furnace Flames promotes radiation and raises the heat transfer by radiation resulting in improving the efficiency [2]. However in such cases, soot is to be generated in a way that satisfies particles oxidation before exiting to the stack. Another example is the Production of carbon black in which a maximum yield of soot from the flame pyrolysis of hydrocarbon feedstock is required. [3], [4], and [5]. As for the environmental and adverse health impacts, the presence of soot reflects poor combustion conditions, loss of efficiency and may result in reduced atmospheric visibility, increased particle fallout, carcinogenic polycyclic aromatic hydrocarbons, deposition on the surfaces of internal combustion engines (particularly diesel

engines) and gas turbine combustors; resulting in deteriorating maintenance and efficiency, so there are many good reasons to avoid soot formation altogether. Finally, the presence of soot in fires in one hand increases radiation heat transfer that result in serious spread of fire, while on the other it may be a source of light as in a candle flame [3].
The emission of soot is a phenomenon that occurs in flames of all types of hydrocarbon fuels including: (a) laminar and turbulent flames, (b) premixed, partially premixed and diffusion flames, (c) flames of different hydrocarbon fuels.[8]
Soot detection and visualization may be accomplished by laser induced florescence or high speed uv laser shadowgraph or optical extinction photometry. [9] Hence, all of the mentioned techniques require special laboratory instrumentation and operation condition that may not be easy to practice during field testing of industrial burners. [10] Therefore we designed an easy-to-install flame imaging system that is capable of visualizing soot particles formation for most common combustion applications. This system is simple and requires only few numbers of components. It has proven very efficient in visualizing soot growth through flame envelops.

Experimental setup

As shown in Figure 1, a low power 20 mW Compact CW laser diode is used to generate in-situ shadowgrams for different flames issued from premixed or non-premixed burners for soot visualization. The shadowgraph is formed on a mobile florescent screen under throw by 405nm laser that have a relatively good propagation characteristics through atmosphere compared to shorter wavelength of high power lasers used before in other studies. [9,10]

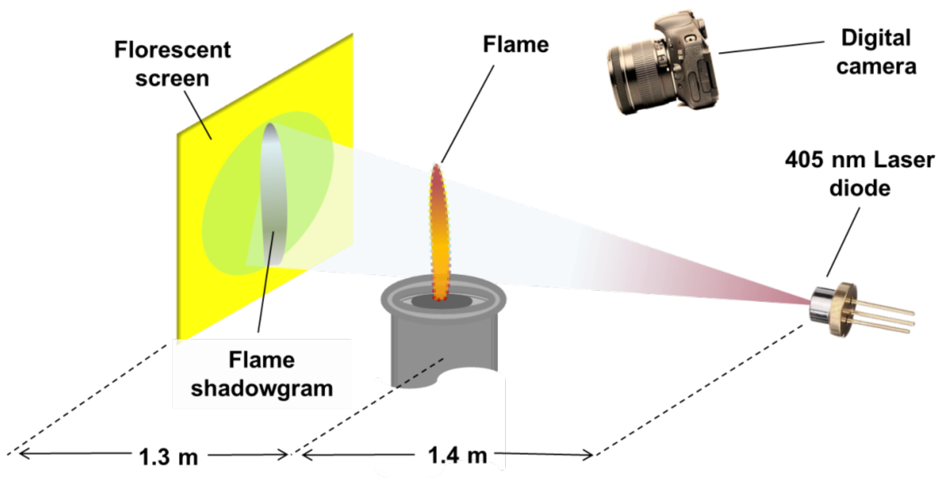

Figure 1. Experimental setup illustration

The florescent screen is made of standard fluorescent sticker paper (Figure 2a) that appears pale under the illumination of burners flames (Figure 2b) but glows under ultraviolet and blue laser radiation (300-420 nm), with green bright light due to the presence of fluorescein dye ($C_{20}H_{12}O_5$). [9,10]

(a) (b)

Figure 2. Florescent screen components and mounting (a) A2 Standard florescent sticker paper (b) Florescent paper placed behind the flame

The setup was realized and tested on several burners, placed 1.3 meter away from the imaging screen and backlighted by the 405nm laser diode. The resulting shadowgrams shows the flames flow field and the details of sooty zones that appear of dark contrast on the glowing screen due to the presence of carbon particles. Also the layers of different refraction coefficients and temperatures are easily visualized as seen in Figure 3.

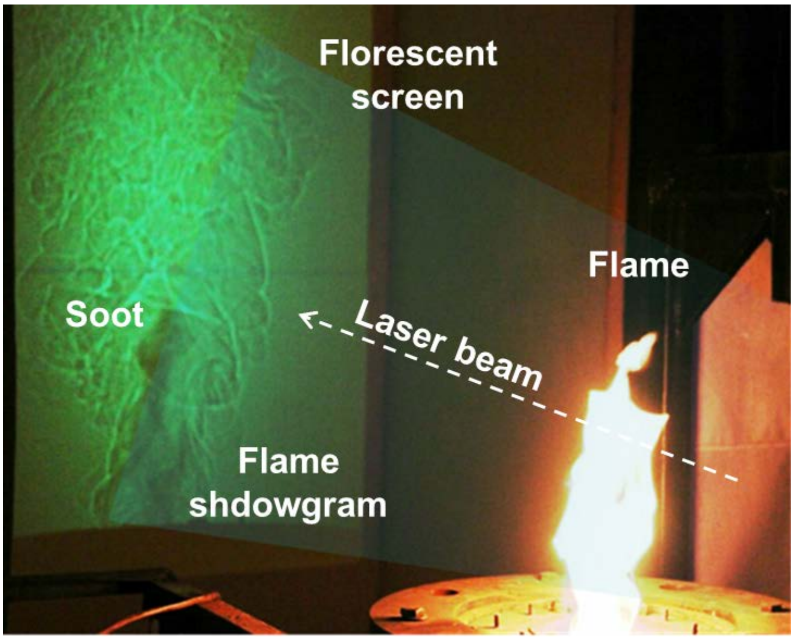

Figure 3. Premixed EV burner flame shadowgraphy

Results and discussion

After experimenting different flame types, we were able to distinguish between combustion zones of both premixed and non-premixed flames, and video recording the combustion behavior of such burners at different operation conditions.
Figure 4a shows a non-premixed flame issued from elliptic burner with blue color indicating good mixing and low soot particle formation. The shadowgram image gives a uniform distribution of flow field and no dark zones which identify the flame characteristics.
Figure 4 b the flame has a yellowish color indicating a soot luminous particulates formed due-to soot oxidation. The shadowgram shows clearly the soot constellation as dark zones through the flame envelope.
At Figure 4 C and Figure 4 D, the shadowgram images shows very accurate response to the flame propagation changes which indicates the high precision images formed using this technique

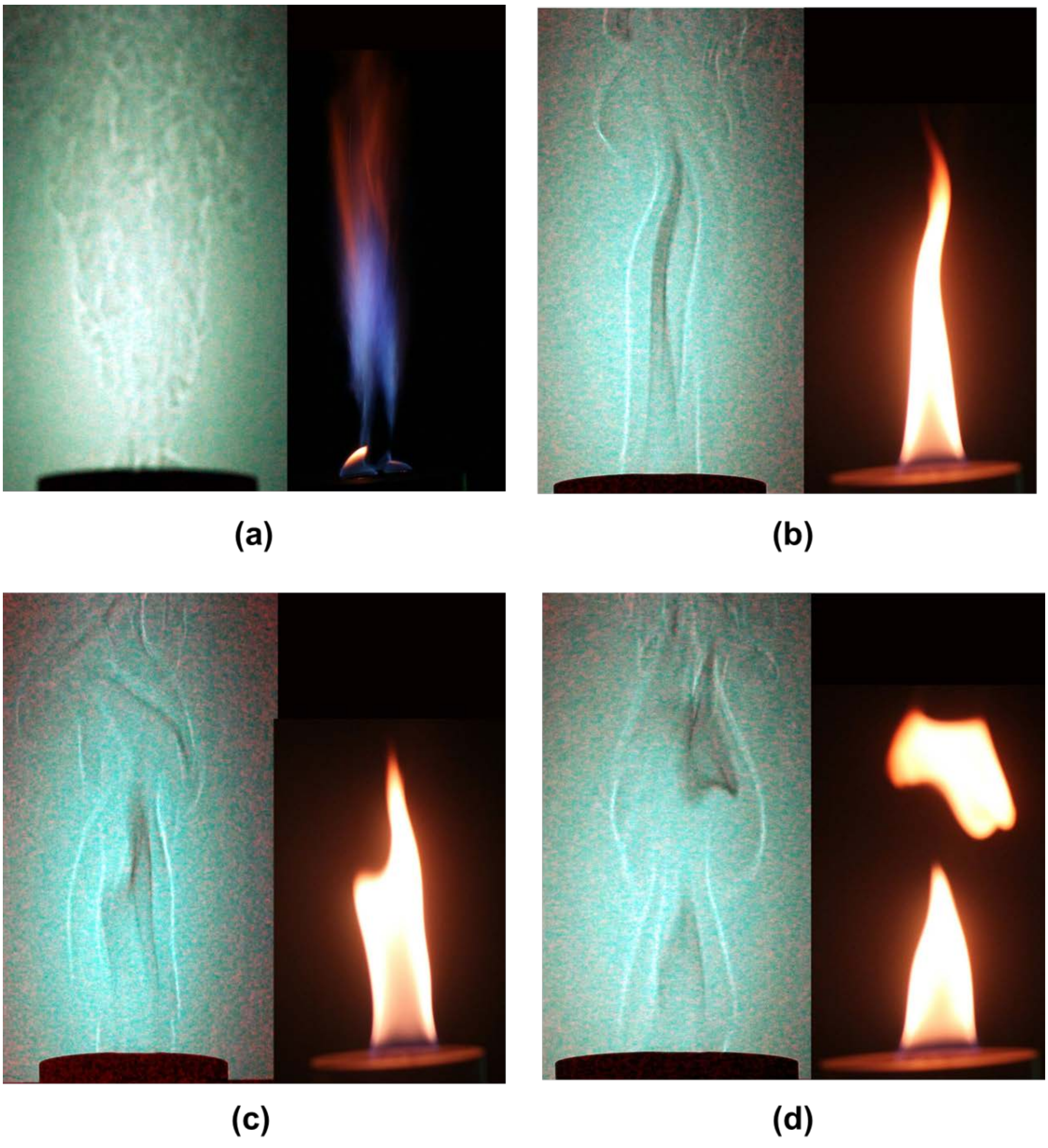

Figure 4. Non-premixed elliptic burner flame shadowgraphy

Conclusion

Only one low power laser diode can be used to generate in-situ shadowgrams for different flames issued from premixed or non-premixed burners for soot visualization. The method is simple and requires only few numbers of components. It has proven very efficient in visualizing soot growth through flame envelops. The shadowgraph is formed on a mobile florescent screen under throw by 405nm laser that have a relatively good propagation characteristics through atmosphere compared to shorter wavelength of high power lasers used before in other studies

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