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UV-LASER SHADOWGRAPHY OF TWO SLOT AND FOUR SLOT EV BURNER FLAME FLOW FİELD

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INTRODUCTION

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 including [1, 2, and 3].

The presence of soot may cause harmful or useful effects; as may be explained by the following examples:

(i) Furnace Flames: In which the presence of soot promotes radiation and raise the heat transfer by radiation resulting in improving the efficiency. However in such cases, soot is to be generated in a way that satisfies particles oxidation before exiting to the stack. [4, 5, and 6].

(ii) Production of Carbon Black: In which a maximum yield of soot from the flame pyrolysis of hydrocarbon feedstock is required. [7]

(iii) Environmental and Adverse Health Impacts: The presence of soot reflects poor combustion conditions and 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.

(iv) Fires: Where the presence of soot 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.

Soot can be characterized by the total amount of the condense phase (Aerosol) and is expressed by: [8, 9, 10, and 11].

1- The soot volume fraction, (ϕ), [cm3 soot/cm3)
2- The number of soot particles, N, [particles/cm3]
3- The size of the particle, d, [mm]

It is worth mentioning that the size distribution of soot particles is relatively narrow and hence the average size would be sufficient. The above three quantities (ϕ, N and d) are very much related to the different stages of the soot formation process; the soot particle formation stage (the source of N) and soot surface growth stage (the source of ϕ). Therefore it is most convenient to consider N and ϕ as the independent variables in the process. Finally, the third one is the soot oxidation stage. A brief explanation to these three stages is exhibited in what follows **(Fig1)**:

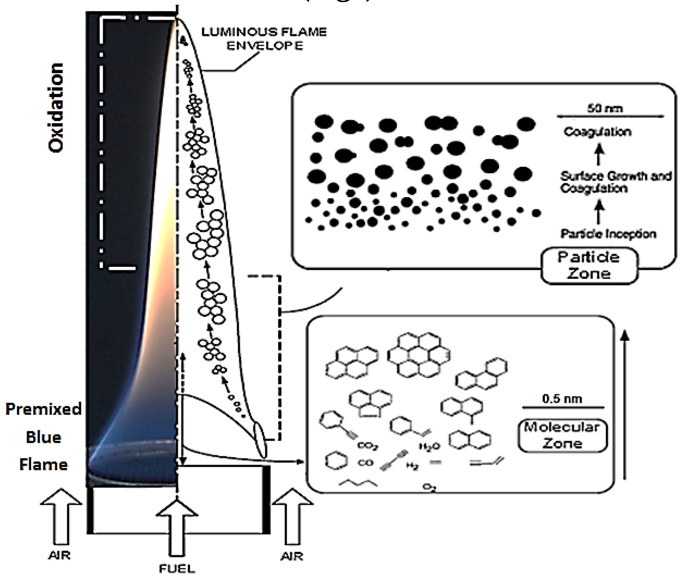

Figure 1: The stages of soot formation

Swirl-stabilized EV-burner The EV-burner (EV-environmental) consists of displaced half cones with two slots between them for the 2-slot EV burner and four quarter with four slots between them for the 4-slot EV burner, such that air is forced to enter into the cone circumferentially [42]. In Fig. 3.1 is shown an EV-10 burner with an outlet outer diameter of nearly 100 mm that was used in this study. At each of burner slots, main fuel can be injected through 62 boreholes, 0.7 mm diameter, that are distributed equidistantly between the apex and the burner exit. [12, 13, and 14]

Laser- fluorescence (LF) is a laser-based method for combustion analysis. The experiment described below is aimed at introducing the basic techniques and instrumentation used in LF measurements.

The direct subject of the measurement is the ultraviolet (UV) fluorescence of the polyaromatic hydrocarbons (PAHs) that can be excited in a wide UV region. The excitation wavelength was 405 nm, and the fluorescence shadowgraph was studied.

In this experiment a comparison between the swirl flames established from 2-slot and 4-slot EV burner was performed. The fuel was LPG. The strongest PAH fluorescence signal can be obtained using the LF technique the light source used for the excitation was a 405 nm frequency diode laser. Fluorescence is a phenomenon that occurs when a substance absorbs radiation of a certain wavelength, or group of wavelengths, and re-emits photons of different wavelength. When certain compounds absorb light, an electron is excited to a higher vibrational energy state. The molecule then loses its excess of vibrational energy by collisions and falls to the lowest vibrational level of the energy state. Black lights (UV source) to demonstrate this phenomenon.

EXPERIMENTAL SET UP, FACILITIES AND EXPERIMENT PERFORMANCE

The present work aims to visualize the soot emission from gaseous swirl stabilized premixed flames issuing from a 2 slot and 4 slot EV burners associated with the variations of the gas constituents and flow conditions, experimentally. Using shadowgraph technique for that purpose, Lpg gaseous fuel is used with different equivalency ratio (ϕ).

To ensure accurate settings of the experiments together with reliable data collection, the following considerations are taken:

1- Vertical arrangement of the burner is chosen to eliminate buoyancy effects on the developed turbulent flames.

2- The following steps are followed to eliminate the effects of natural draft on the developed flames:

(a) A co-flowing air stream at high axial velocity 28 m/s is admitted through the annular passage of the coaxial burner configuration.

(b) The burner arrangement is contained within a room with side glass walls that prevent the influence of natural draft. The size of this room ensures the proper conditions for free developed jet flames; i.e. no boundary effects on flame characteristics.

3- Ensure accurate and controllable flow rates of the various gas streams at such high flow rate values (ranging from 0- 41 Lit /min).

The schematic of the experimental set-up is illustrated in **(Fig2).**This set-up essentially consists of:

1- The EV burners and combustor.
2- UV laser (405 nm).
3- Florescence screen.
4- High speed digital camera

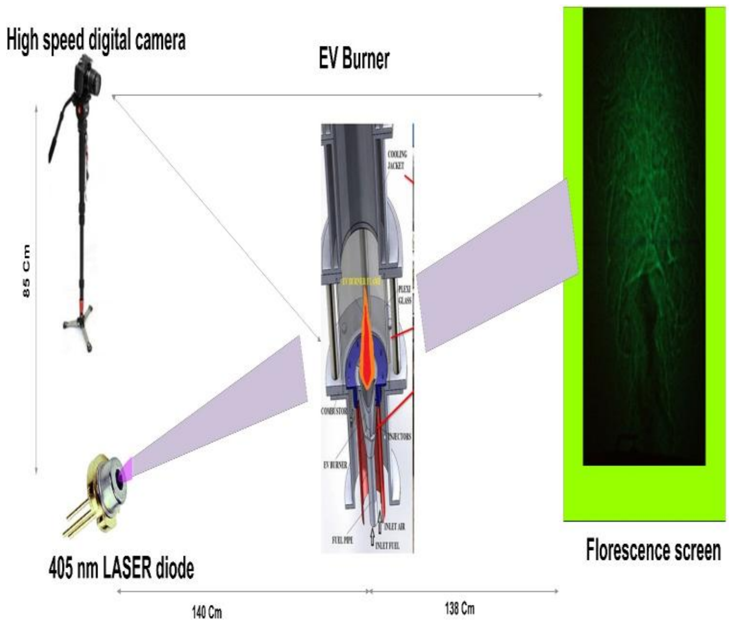

Figure2: Schematic diagram of system set-up

TWO SLOT BURNER:

To perform the objectives of this study, the design of the test rig should facilitate the following:

- Co-axial jets burner.
- Double concentric tubes (centric and outer), two fluid supplies to the passages of the air jets to enable separately easy control of the air mass flow rate.
- Separated fuel supply to the first annular line to facilitate easy control of the fuel mass flow rate.
- Precise control of the fuel mass flow.
- Accurate vertically support of burners to avoid changes in jets direction.

The tested burner as shown in **(Fig3)**consists of an air jet surrounded by a fuel jet which is also surrounded by an outer air jet. The burner is made of two cast iron pipes as detailed on the figure.

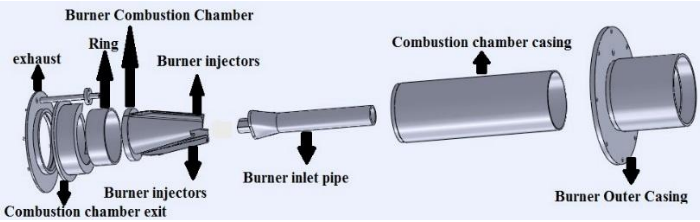

Figure3: Assembly of EV burner components

The EV-10 shown in **(Fig4)** consists of two shifted half cones with two slots between them, such that air is forced to enter into the cone circumferentially. The resulting swirling airflow generates a recirculation zone along the centerline at the EV-10 outlet.
The main fuel is injected through 62 boreholes, 0.7 mm diameter each, that are distributed equidistantly along the two air slots.
The main fuel is mixed with the swirling air resulting in a nearly premixed combustion

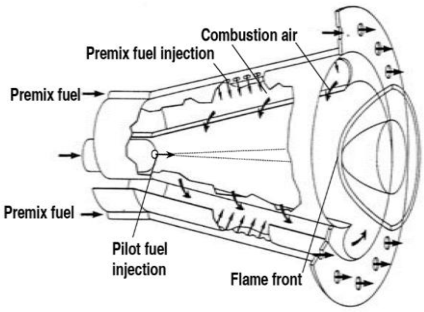

Figure 4: Two slot EV burner.

<u>Four Slot burner:</u> (Fig5)

- <u>EV Burner:</u>
  (a) <u>Conical Passage with 4-Slots</u>

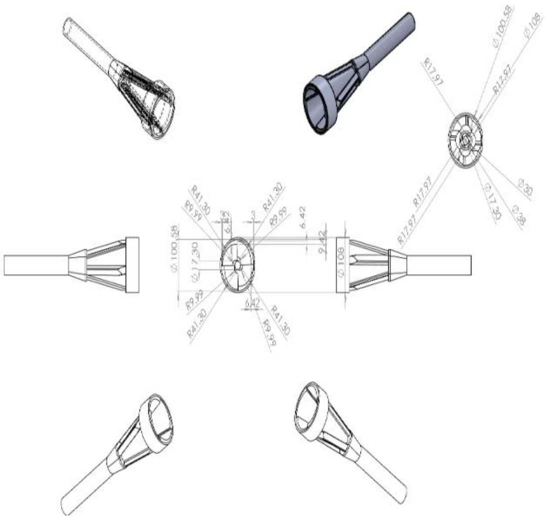

Figure 5: four slot EV burner.

(b) <u>Air Passages</u>

Four circumferential air slots displaced (formed by quarter cones with four slots between them).Air is forced to enter into the cone circumferentially.

(c) <u>Fuel Admission:</u>

At each of burner slots, main fuel is injected through equidistantly holes located along the entry of each air passage between the apex and the burner exit.

<u>Combustor</u> (Fig6)

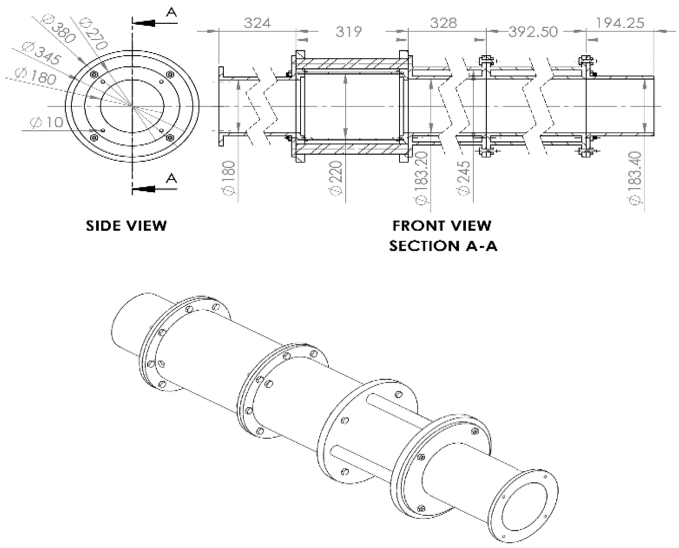

Figure 6: Combustor

<u>2- UV laser (405 nm):</u> (Fig7)

Diode laser, 405nm, 20mW Compact CW diode laser with TEC temperature control Emission wavelength: 375nm Optical output power: 20mW Beam diameter: 1.1mm (1/e²) +/- 0.2mm M²: <1.15, (1,05 typical) CW in ACC and APC mode Analogue modulation: >1.5MHz Electronic Shutter: >150kHz

Figure 7: 405 nm UV laser diode

3- Florescence screen

The florescence screen is wooden box covered with florescence material. Fluorescence is a phenomenon that occurs when a substance absorbs radiation of a certain wavelength, or group of wavelengths, and re-emits photons of different wavelength. The resulting spectrum is a combination of a number of factors: (a) the reflectance of the non-fluorescing materials; (b) the absorbance of the fluorescent material due to the excitation of electrons to a higher energy state; (c) the emission spectrum of the fluorescing material. Inorganic fluorescent materials are perhaps the least utilized for industrial applications and named fluorescen. Most all of the compounds are also only activated by UV to very Near-VIS radiation (300-420 nm)

4- High speed digital camera

Flame images were taken using Canon EOS camera with CMOS sensor, records brilliant color images or crisp monochrome images at full 1.3 Mega Pixel resolution at more than 2,900 fps, 1 Mega Pixel resolution at more than 3,590 fps and 720p HD resolution at more than 3,900 fps. The camera supports wide screen viewing of critical high-speed imaging events, keeping the subject in frame longer.

Experimental Program

The interpretation of the experimental data integrates between the results being obtained at two stages to form a full picture of the variations in the shadowgraph of the flames issuing from a 2 slot and 4 slot Ev burners associated with the changes of the fuel equivalency ratio and flow conditions. Particular emphasis is given to the variations in the soot different conditions.

Stage (1): Visual analyses of the flame structure; whereby digital images of the different flame are taken for; different fuel constituents for flames issuing from 2 slot Ev burner. For all cases, the variations in visual flame as well as the variations the shadowgraph images are compared and analyzed.

Stage (2): comparing the previous results with the digital images for the flames and its shadowgraph that established from the 4 slot Ev burner.

Table (1) Experimental Program

cases			1	2	3
Stage 1 2 slot EV burner	V_{air} = 873 l/min	Φ	1	0.87	0.75
		V_F (l/min)	32	28	24
Stage 2 4 slot EV burner		Φ	1	0.87	0.75
		V_F (l/min)	32	28	24

Before conducting any experiment, the following steps are followed:

1- The experimental setup is checked for leaks to ensure not only a safe working environment but also to satisfy accurate measurements of the flow rates through the different gas supply passages.

2- The burner is aligned in the vertical position.

3- The flow rate of the co-flowing air is adjusted to the set value (3 l/min); a value which is maintained throughout the whole experiments.

4- The flow rate of NG is adjusted at the required values and the flame is initiated.

5- The flow rates of the diluent (Argon) and/or acetylene are admitted and their flow rates are set at the prescribed values.

RESULTS AND DISCUSSION

[Fig 8 and Fig 9] Show the visual digital images of the flame shapes and shadowgraph of the LPG issued from a 2-slot burner and 4-slot burner with the decrease of the equivalency ratio; Careful examinations of the flame images (boundaries, colors and contours) indicate:

(a) The flames are attached to the burner outer rim with a progressive increase in its cross sectional area along the flame length where the flame cone is located at the center line. This is coupled with a linear decrease of the flame length with the progressive decrease of the fuel flow rate.

(b) At certain point, as the fuel is premixed and diluted by the air, the stoichiometric interface begins to move back into the fuel region, eventually reaching the axis at the flame height. Now the streamlines pass through increasingly linear regions as the height above the burner increases, finally approaching and passing through the flame zone where particle oxidation becomes very rapid.

(c) The flame envelop is a thin layer separating the oxidant side from the fuel side. The existence of the counter flowing air eliminates irregularities in the flame boundaries and makes it a well-defined envelops.

(d) At low flow rates (run 3), the images show short blue flames. With incremental increases of the fuel flow rate, this color changes with the progressive increase of the fuel flow rate to dark and orange zones, (run 1). These colors signify the stages of soot formation and oxidation along the flames. The soot formation zone is divided into two successive zones; namely the soot inception zone, (dark zone) and the soot growth zone, (orange zone). These are followed by the soot oxidation zone, (yellowish and white luminous).

(e) The shadowgraph images shows the following (i) as the fuel constituent increase as in case 1 the soot particles amount and size increase. (ii) Decreasing the equivalency ratio the amount and size of soot particles decreases

(f) Increasing the swirling leads to better mixing decreasing the soot formed through the established flames this is clearly appeared in comparing the shadowgraph of the flames issued from the 4-slot burner with better mixing with the flames delivered from the 2-slot burner

Case 3
2-slot

Case 2
2-slot

Case 1
2-slot

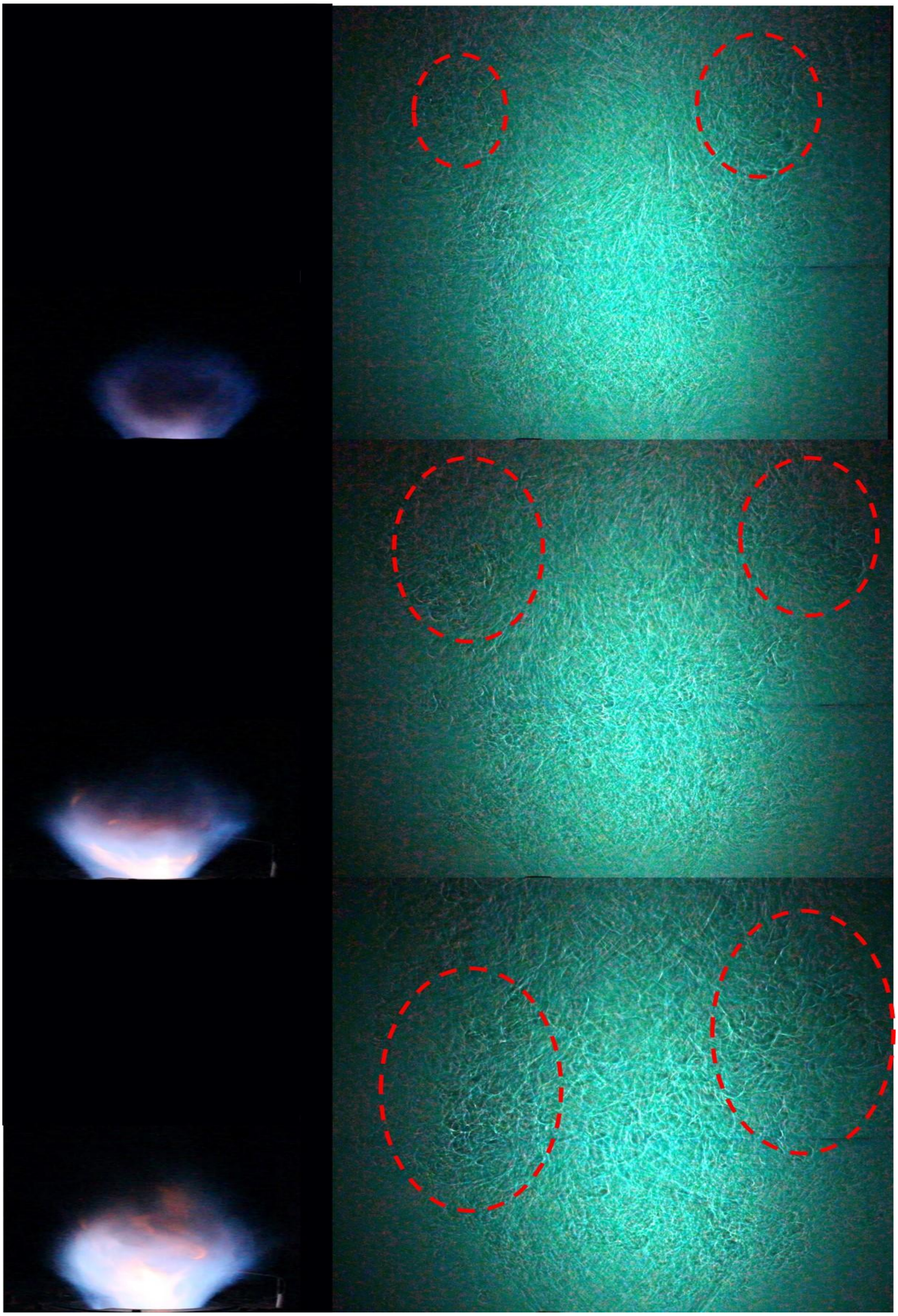

Figure 8: Visual and shadowgraph images for 2-slot burner

Case 3
4-slot

Case 2
4-slot

Case 1
4-slot

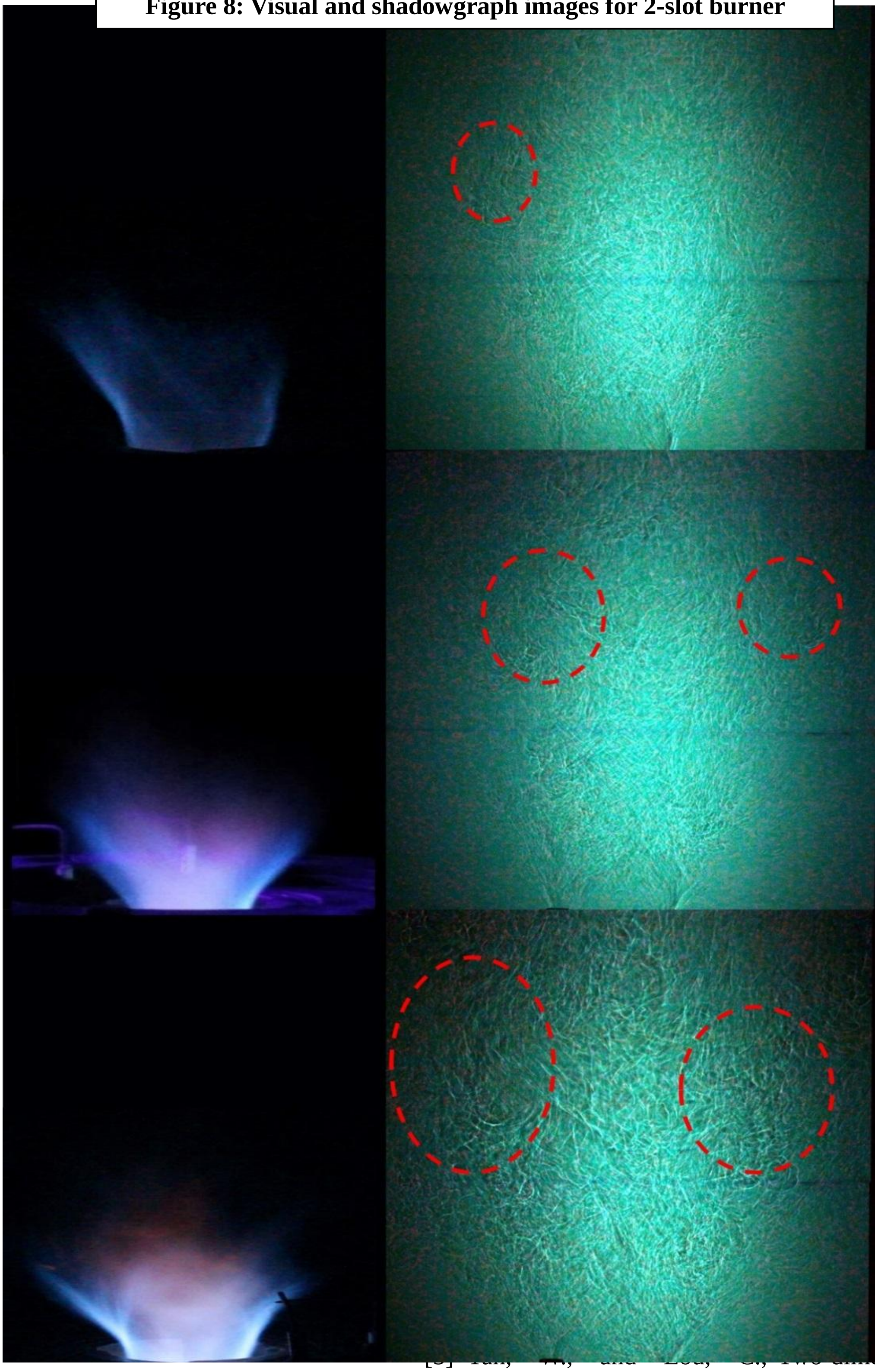

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Figure 9: Visual and shadowgraph images for 4-slot burner

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