Data files for Adelaide C2H4-H2-N2 laminar diffusion sooting flames

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Contents

1. Citing data and Disclaimer

Any publications making use of these data should reference:

Zhiwei Sun, Bassam Dally, Graham Nathan and Zeyad Alwahabi, '*Effects of hydrogen and nitrogen on soot volume fraction, primary particle diameter and temperature in laminar ethylene/air diffusion flames',* (2016) Combustion and Flame, Submitted

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2. Nomenclature

T	flame temperature
f_v	soot volume fraction
d_p	primary soot particle diameter
LII	laser-induced incandescence
Tire-LII	time-resolved laser-induced incandescence
TLAF	two-line atomic laser induced fluorescence (indium)
SLM	litres per minute

3. Burner specification

All flames were stabilized on a Santoro-type burner. The burner consists of two concentric brass tubes of 1 mm thickness. Fuel was injected through the central tube with an inner diameter (ID) of 10.5 mm while co-flow air was fed through the outer tube (ID = 97.7 mm). The central fuel tube extends 4 mm above the lip of the air co-flow tube. Stainless steel honeycomb (with cells with ID = 1 mm and 10 mm in height) was encased at the exit of the air co-flow tube to straighten the flow. The fuels were burned at atmospheric pressure. The burner was mounted on a traverse and moved vertically so measurements can be performed at different heights above the fuel tube (HAB). See the top view of the central part of the burner surface shown in **Figure 1**.

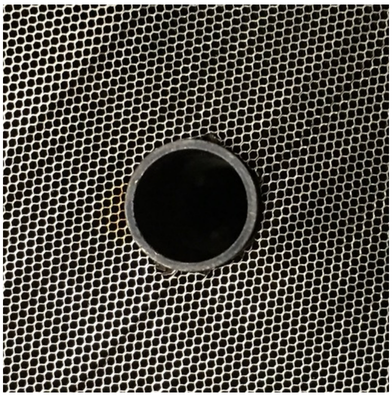

Figure 1. Top view of the burner surface.

4. Co-Flow Air

The air co-flow supply was kept at 284 Litres per minute (SLM) at 20 ^{o}C for all the flames, corresponding to a velocity of 0.642 m/s. The air co-flow rate has a typical uncertainty of 3%.

5. Exhaust Hood

An exhaust hood of 100 cm in square was used, however, it was always kept more than 1 meter above the small flames. Therefore, it is reasonable to assume it as a no chimney-condition.

6. Fuel Composition

The fuel mixture of the flame consists of Ethylene, Hydrogen, and Nitrogen. All three gases were supplied from gas bottles (BOC), where the fuel composition of each bottle is as follows:

Ethylene 99.00 % C_2H_4, 50 ppm moisture
Hydrogen 99.50 % H_2, 4000 ppm O_2, 1000 ppm N_2, 100 ppm moisture
Nitrogen 99.99 % N_2, 10 ppm O_2, 10 ppm moisture

7. Fuel Jet Composition

Two series of laminar C2H4/H2/N2 diffusion flames were investigated in this study. The various combinations of flow rates of fuel and diluents, with their associated volumetric fractions, are summarized in Table 1.

In the first set of flames (set I), the flow rate of C2H4 was held constant as 0.207 SLM, while H2 or N2 was added to the fuel (I-0) at a volumetric fraction of 20% or 40%. Flame I-5 has a mixture of C2H4/H2/N2 by 40%/40%/20%, which is identical to that of a turbulent non-premixed sooting flame, “Adelaide simple jet flame”, that has been adopted as a ‘target’ for the International Sooting Flames Workshop. For the other set (set II), the total flow rate of the mixture was held constant at 0.259 SLM, corresponding to a bulk exit velocity of 0.050 m/s, while the volumetric fractions of C2H4, H2 and N2 were varied. Flame II-7 also has the same composition as the turbulent flame, but the flow rate is only half of that of flame I-5. Flames I-5 and II-7 can also be used to assess the effect of strain rate on soot formation in laminar 2-D flames.

For C2H4, the uncertainty of flow rate is (0.003 SLM + 0.3% of reading), while that for N2 is 0.005 SLM. The estimated uncertainty of the H2 flow rate is 0.006 SLM

All flames were laminar and non-smoking, although some slight unsteadiness was found in the downstream region of the flames (typically for HAB > 40 mm), corresponding to a movement of ± 0.2 mm in the flame envelope, which was revealed when processing the laser-based imaging results.

Table 1. Initial flow conditions for the flames reported in this study.

Set I: The flow rate of ethylene is kept as constant, while H_2 and/or N_2 was added.													
Flame	Ethylene (SLM)	% (vol.)	Hydrogen (SLM)	% (vol.)	Nitrogen (SLM)	% (vol.)	Total flow rate, *Q* (SLM)	Exit flow velocity, *u* (*m/s*)	Reynolds number, *Re*	*Global strain rate (s^{-1})	Stoichiometric molar ratio, *S* (air/fuel)	Froude number, *Fr*	Note
I-0	0.207	100%	0	0%	0	0%	0.207	0.040	47.7	0.55	14.3	0.124	
I-1	0.207	80%	0.052	20%	0	0%	0.259	0.050	49.0	0.67	11.9	0.155	also as II-1
I-2	0.207	60%	0.138	40%	0	0%	0.345	0.066	51.1	0.87	9.5	0.207	
I-3	0.207	80%	0	0%	0.052	20%	0.259	0.050	52.2	0.72	11.4	0.155	also as II-4
I-4	0.207	60%	0	0%	0.138	40%	0.345	0.066	61.7	0.99	8.6	0.207	
I-5	0.207	40%	0.207	40%	0.104	20%	0.518	0.100	63.5	1.33	6.7	0.311	
Set II: The total flow rate is constant as 0.259 SLM.													
Flame	Ethylene (SLM)	% (vol.)	Hydrogen (SLM)	% (vol.)	Nitrogen (SLM)	% (vol.)	Total flow rate, *Q* (SLM)	Exit flow velocity, *u* (*m/s*)	Reynolds number, *Re*	Global strain rate (s^{-1})	Stoichiometric molar ratio, *S* (air/fuel)	Froude number, *Fr*	Note
II-0	0.259	100%	0	0%	0	0%	0.259	0.050	59.7	0.51	14.3	0.155	
II-1	0.207	80%	0.052	20%	0	0%	0.259	0.050	49.0	0.67	11.9	0.155	also as I-1
II-2	0.181	70%	0.078	30%	0	0%	0.259	0.050	43.7	0.79	10.7	0.155	
II-3	0.155	60%	0.104	40%	0	0%	0.259	0.050	38.3	0.94	9.5	0.155	
II-4	0.207	80%	0	0%	0.052	20%	0.259	0.050	52.2	0.72	11.4	0.155	also as I-3
II-5	0.181	70%	0	0%	0.078	30%	0.259	0.050	49.1	0.86	10.0	0.155	
II-6	0.155	60%	0.000	0%	0.104	40%	0.259	0.050	46.3	1.05	8.6	0.155	
II-7	0.104	40%	0.104	40%	0.052	20%	0.259	0.050	31.7	1.53	6.7	0.155	

**The Global strain rates are calculated using the averaged exit flow velocity divided by the flame length.*

Figure 2 presents photographs of all the flames.

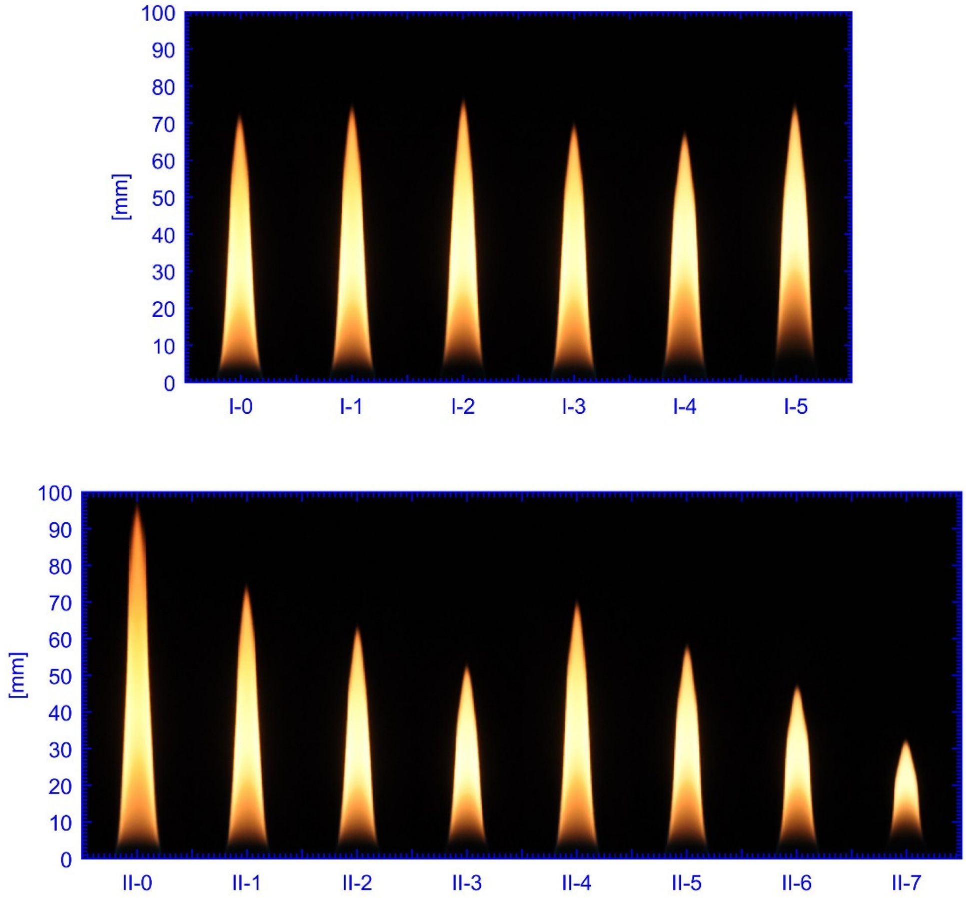

Figure2. Flame photograph recorded with the same settings (exposure time and ISO) for the digital camera

8. Soot volume fraction

Planar laser-induced incandescence (LII) was applied to provide two-dimensional results of f_v. LII measurements were calibrated against ling-of-extinction measurements in the studied flame. The measurements uncertainty is ± 10%.

9. Flame temperature

Planar two-line atomic fluorescence (TLAF) of indium was applied to provide the results of flame (gaseous) temperature. The precision is estimate to be ±100 K.

A 75 µm R-type thermocouple (Pt–Pt/13% Rh) was also used to measure the temperature along the flame centreline and that in the radial direction at 3 mm above the burner surface. No radiation correction was performed.

10. Primary soot particle diameter

Planar time-resolved laser-induced incandescence (TiRe-LII) was applied to provide two-dimensional results of d_p. In the methodology, it is assumed that soot particles are non-aggregated and dp has a mono-disperse distribution, i.e. $\sigma(d_p) = 0$.

11. Data files

All the data are presented as '*.xlsx' files, which are easily accessed. Details of the folders are:

1) 'Soot_volume_fraction.xlsx': Soot volume fraction; Unit: [**ppm**]
   The physical dimension of the images is 100 mm (height) × 20 mm (width), i.e. Height = [***0, 100 mm***] and Radial = [***- 10 mm, 10 mm***]. The spatial resolution of the current measurement is ~ 300 micrometres, estimated with the thickness of the laser sheets.

2) 'Primary_soot_diameter.xlsx': primary particle diameter; Unit [***nm***]
   The dimension of the images is 100 mm (height) × 10 mm (width), i.e. Height = [***0, 100 mm***] and Radial = [***- 10 mm, 0 mm***], corresponding to the laser beam incident side.

3) 'Gas_temperature.xlsx': flame temperatures measured by TLAF; Unit [**Kelvin**]
   The dimension of the images is 100 mm (height) × 10 mm (width), i.e. Height = [***0, 100 mm***] and Radial = [***- 10 mm, 0 mm***], corresponding to the laser beam incident side.

4) 'Gas_temperature_Centerline_thermocouple.xlsx': flame temperature (in [K]) along the centreline measured using a 75 µm thermocouple, without thermal radiation correction.

5) 'Gas_temperature_height_3mm_thermocouple.xlsx': flame temperature (in [K]) measured in the radial directions (in [mm]) at 3 mm above the burner, using a 75 µm thermocouple without thermal radiation correction.