Adelaide Jet Flame 2
Data File

May 2016

Adelaide Jet Flame 2
C2H4-H2-N2-D58-15K

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1. Citing data and Disclaimer

Any publications making use of these data should reference:

“Mahmoud, S.M., Nathan, G.J., Alwahabi, Z. T., Sun, Z. W., Medwell, P. R. and Dally, B. B. (2016). The Effect of Exit Strain Rate on Soot Volume Fraction in Turbulent Non-Premixed Jet Flames, *Proceedings of the Combustion Institute*, Vol. 36, accepted. (2016).

“Mahmoud, S.M., Nathan, G.J., Alwahabi, Z. T., Sun, Z. W., Medwell, P. R. and Dally, B. B. (2016). The Effect of Exit Reynolds Number on Soot Volume Fraction in Turbulent Non-Premixed Jet Flames, *Combust. And Flame*, submitted. (2016).

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2. Nomenclature

Adelaide Jet Flame 2 is labelled as follows: C2H4-H2-N2-D## - ## K, where:

C2H4-H2-N2 refers to the fuel mixture

D## refers to the diameter of the pipe jet burner (D58 standing for 5.8mm inner diameter)

##K refers to the exit Reynolds’s number of the flame (Re=15,000).

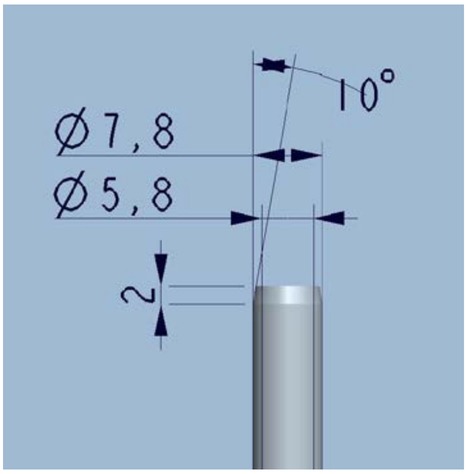

Fig. 1. Front View of the tapered section of the pipe jet burner. All Dimensions are in mm

3. Burner Specifications

Adelaide jet flame 2 was stabilised on a straight pipe jet burner made of Aluminium and mounted in the middle of a contraction delivering co-flowing air at an average speed of 1.1 m/sec. The contraction has a square cross-section, at the exit plane, of dimensions 150mm by 150mm, and the pipe jet burner outlet rises above the contraction edge by a distance of 18mm.

The pipe jet burner has a length of 385mm, including a tapered end at the jet outlet. The pipe inner diameter is 5.8 mm, with a wall thickness of 1mm. A schematic of the jet outlet is shown in Figure 1.

4. Co-Flow Air

Air is supplied through a centrifugal fan at 294K and is delivered as a co-flow to the central jet flow. The co-flow contraction has an almost uniform velocity of 1.1 m/s at 2mm above the jet nozzle level (20mm higher than tunnel exit plane). The turbulence Intensity of the co-flow is 1.5 % on average. Detailed Information is presented in Section 8.

5. Exhaust Hood

An exhaust hood of a conical section is installed to exhaust fume from the flame. The hood consists of a cone of an 800mm diameter at its larger end, and a 250mm diameter exhaust duct connected to the other end, and is always kept at a minimum distance of 300mm from the tip of the flame at all times during the experiments.

6. Fuel Composition

The fuel mixture of the flame consists of Ethylene, Hydrogen, and Nitrogen. All three gases were supplied from gas bottles, 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

The fuel jet mixture by mass for Adelaide Jet flame 2 is 64.5 % C2H4, 4.7 % H2, and 30.8 % N2. And the fuel mixture by volume is 40 % Ethylene, 41 % Hydrogen, and 19 % Nitrogen. The total mixture density at 294K and 101.3 KPa is calculated to be 0.717 Kg/m^3, while the total viscosity (dynamic) is calculated to be 1.210E-05 kg/m.s

The mass and volumetric flow rates for Adelaide Jet Flame 2 are presented in Table 1 below. (SLM = Standard litre per minute at 294K and 1 Bar). The measurement uncertainty is 1.5%, 1.5% and 2% on the flow rates of Ethylene, Hydrogen, and Nitrogen, respectively.

Table 1. Adelaide Jet Flame 2 Composition by Mass and Volume

Adelaide Jet Flame	**Composition**	**C_2H_4**	**H_2**	**N_2**
	% mixture by Mass	**64.5**	**4.7**	**30.8**
	% mixture by Volume	**39.9**	**40.9**	**19.2**
Jet Flame 2 C2H4-H2-N2-D58-15K	Mass Flow Rate *(kg/s)*	5.183E-04	3.786E-05	2.48E-04
	Vol. Flow Rate *(SLM)*	26.8	27.5	12.9

8. Flow Conditions

The flow conditions for Adelaide jet Flame 2 are provided in Table 2 below.

Table 2. Flow conditions of Adelaide Jet Flame 2

	Inner Jet Diameter (D)	Total Flow rate	Mean Exit Velocity	Exit Strain Rate	Exit Re number	Mean Flame Length
			$V=\frac{\underline{flow\ rate}}{(\pi d^2/4)}$	V/D	$Re=\rho VD/\mu$	
Jet Flame 2	*(mm)*	*(l/min)*	*(m/sec)*	*($x10^3\ s^{-1}$)*	(-)	(mm)
	5.8	***67.2***	42.4	7.35	**15,000**	930

9. Mean Exit Velocity and Turbulence Intensity Profiles

The mean velocity and the turbulence intensity profiles of the flow across the nozzle and the co-flow contraction for Adelaide jet flame 2 are presented in Figure 2. The measurements were conducted under non-reacting conditions using hot-wire anemometry. The tabulated data are presented in the data excel file, in a sheet titled: “Velocity Profile”. The mean Velocity and turbulence Intensity at 2 mm above the burner exit were measured to be symmetrical along the burner centreline; therefore, data for only the left “negative” side of the flame is presented.

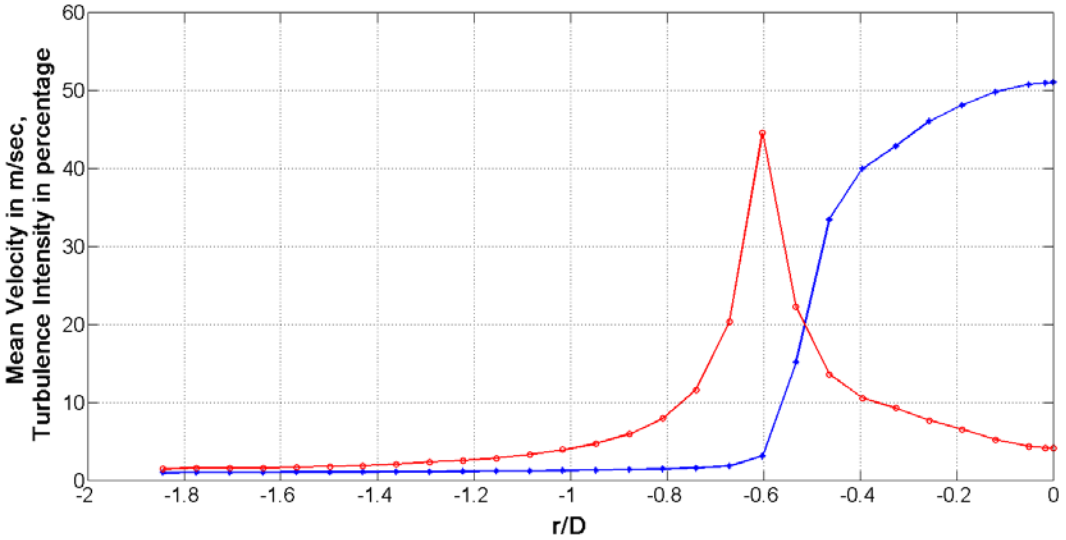

Fig. 2: Velocity Profile (in blue) and turbulence Intensity profile (in red) across the left side of the co-flow tunnel and the jet nozzle (2 mm above burner). Jet diameter D is 5.8 mm. Tabulated Data are presented in Excel file.

10. Centreline Temperature Profile

Centreline temperature measurements for Adelaide Jet flame 2 was measured using an R-type thermocouple of 1mm bead diameter. The readings from the thermocouple were corrected for radiation and convection losses. The temperature profile is shown in Figure 3, while the tabulated data is provided in the data excel file sheet labelled “Centreline Temperature”. The estimated uncertainty is at a maximum of 4% due to uncertainties in exact centreline location (within 2mm) and the measurement fluctuation at this location.

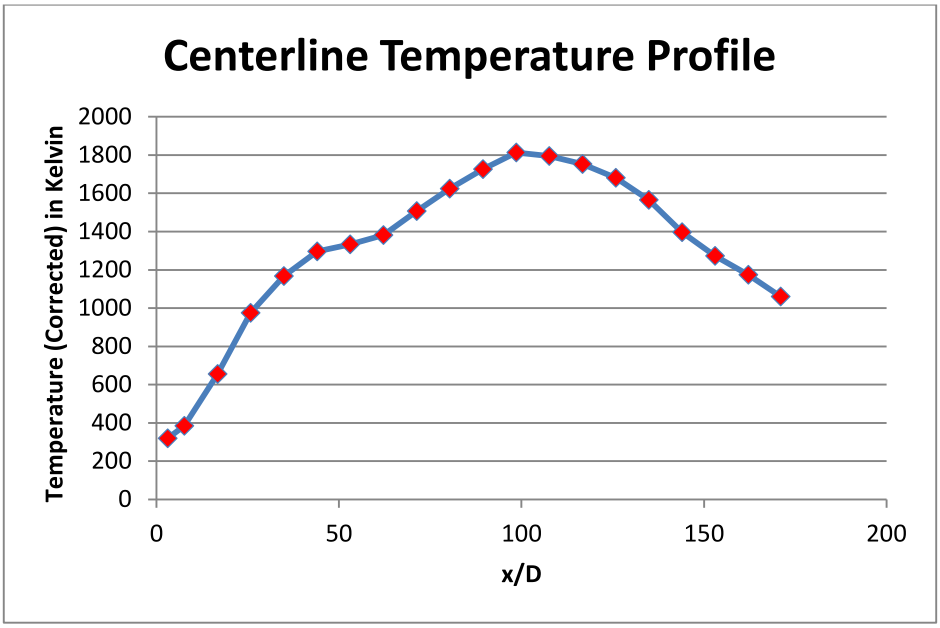

**Fig. 3: Centreline mean temperatures of Adelaide Jet flame 2.
Jet diameter D is 5.8 mm. Tabulated Data are presented in the Excel file.**

11. Soot Volume Fraction Measurements

Soot Volume fraction measurements for Adelaide Jet flame 2 were performed at 12 locations in the flame, spanning all the heights where soot was detected, using Laser Induced Incandescence (LII). The tabulated data for all heights are presented in the data excel file in the sheet labelled “Soot Volume Fraction”. The mean and RMS data provided are calculated over 500 images collected at each location. The high RMS (standard deviation) values at upstream locations is mainly due to the highly sporadic nature of soot at such locations, which drop further downstream though still reading high values due to the intermittent behaviour of soot at all locations. The high RMS values are proven to be independent of the number of images acquired at the heights. (Please refer to Data file *for Adelaide jet Flame 1* for more details). The minimum detection limit is 3ppb (on a shot by shot basis) and the measurement uncertainty on the mean values is approximated at 25%, due to uncertainty in the extinction and calibration constants. The laser sheet thickness in the flame is measured to be 0.75 mm; therefore data is provided at a cubic spatial resolution of 0.76 mm each side length.

12. Global Emissions Measurement

Global emissions of NO_x, CO and CO_2 were measured continuously Adelaide Jet flame 2 using a commercially calibrated Testo 350 flue gas analyzer. A mixture of the combustion products and ambient air was sampled from the flame tip. The CO_2 concentration was measured to calculate the extent of sample dilution with air. The emission rate of CO was expressed as the CO/CO_2 ratio while the emission indices of oxides of nitrogen are presented in g/MJ fuel. The accuracy of NO_x sensor is ±5 ppm (0-99 ppm), and that of CO and CO_2 is ± 5% (under 2,000 ppm) and ± 0.3 Vol. % (under 25% CO_2) respectively. The NO_x emission in the present measurements is up to 30 ppm, and that of CO and CO_2 is up to 250 ppm and 0.07-3.5% respectively. The resolution of NO, NO_x and CO sensors is 1 ppm, and that of CO_2 is 0.01 Vol. %. More details are presented in Table 3.

Table 3: Global emissions of NOx and CO

Flame (ENH2)	**Jet Diameter**	**Mean Jet Exit Velocity**	**Strain Rate**	**Re number**	Fr_e	CO/CO_2	**NOx**
	(mm)	*(m/s)*	$u/d(s^{-1})$	$Re=\rho ud/\nu$	u^2/gd		*(g/MJ fuel)*
C2H4-H2-N2-D58-15K	5.8	42.4	7.35E+03	1.50E+04	3.16E+04	4.39E-03	1.67E+01

13. Radiant Intensity Measurements

A Schmidt-Boelter gauge (manufactured by Medtherm Corporation) was used as the sensor to measure the total radiation from the jet diffusion flame. The heat flux sensor is covered with a sapphire window to transmit 85% nominal radiation over the range of 0.15-5 microns, with a view angle of 150 °. A schematic of the heat flux measurement is shown in Fig.4.

The transducer was positioned at a radial distance of 280 mm from the vertical (*x*) axis of the flame and traversed parallel to it with ±0.5mm precision. Heat flux measurements were taken from the nozzle exit plane (±30mm) to about 1.3 times the flame length. Ten thousand samples were collected at 1000 Hz and averaged to obtain the radiative flux at each of the equi-spaced heights. This was found to be sufficient both for statistical convergence and to ensure that the vast majority of the radiation is captured through this profile. The measurement uncertainty depends on the increment of equal spaced sampling, with a smaller increment leading to a better approximation. However, in our case, the 28 points was deemed to be sufficient because it resolved the profile to within ±2%. On this basis, incorporating the ±3% uncertainty of the heat flux gauge, the overall uncertainty of radiant fraction measurement was ±5%.

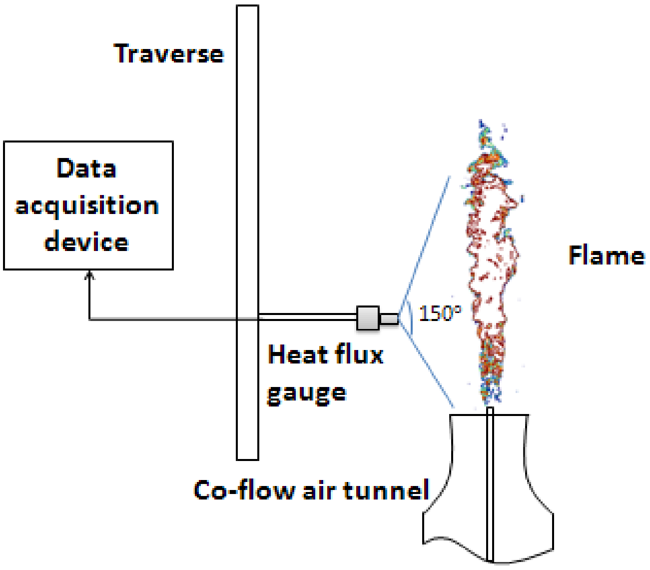

Fig.4. Schematic of heat flux measurement.

Note: this experimental procedure is well established, following Turns and Myhr [1], and many others, with the traverse capturing the energy through the horizontal side of a cylindrical control volume. The length of the vertical traverse is sufficient that the energy irradiated through the top and bottom surfaces of the cylindrical control volume is small. Because radiation is a vector, a wide angle sensor measures all of the flux at that point, while light emitted from any source in the flame in any direction only crosses the control volume in one place. The 150° limitation of the view angle does not limit the measurement accuracy, because the current flame is 666.7 mm long, so that the most extreme angle of emission measured at 1.3 times of flame length is 72°.

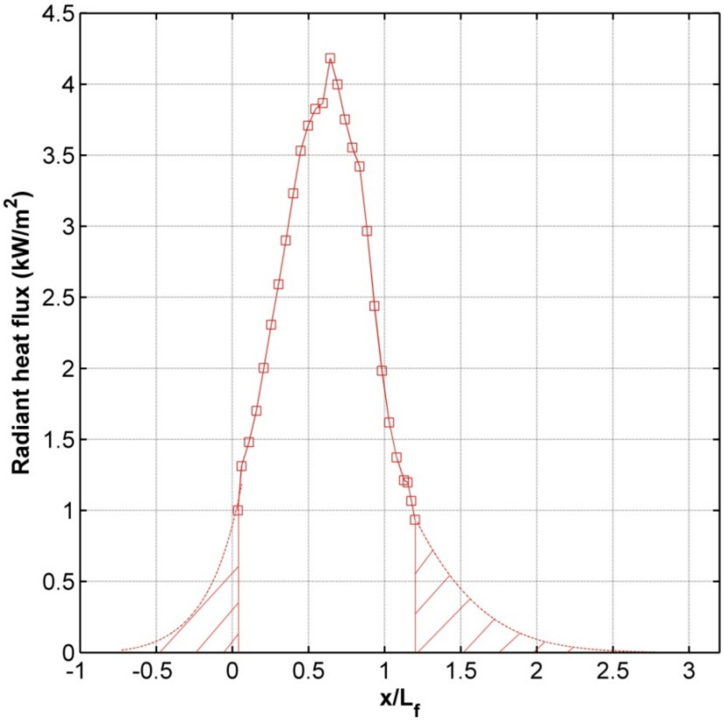

Fig.5. Axial distribution of radiant heat flux of Adelaide Flame ENH2.

The heat lost from this flame via radiation (in kW) is the integral of the axial radiant flux profile from -∞ to + ∞ (kW/m) multiplied by 2 π r (r =0.28m is the distance between the heat flux gauge and the axis of flame). Hence extending of the profile is needed to complete the integral.

Note: The profile in Figure 5 were extended below x/L_f=0 and beyond x/L_f=1.2 to approximate the profile from -∞ to + ∞, shown as the shaded area in Fig.5. The trend of extended profile follows that reported by Gore and Faeth [2], using exponential approximation at both ends of the profile, with heat flux approaching 0 at x/d=365 and -136 respectively (d is the burner diameter) listed the measured heat flux.

The radiant fraction (%) of flame was calculated by dividing radiation from the flame (kW) by total thermal input of flame (kW). The radiant fraction for ENH2 is 0.1600.

[1] S. R. Turns, and F. H. Myhr, “Oxides of nitrogen emissions from turbulent jet flames: Part I—Fuel effects and flame radiation,” *Combustion and Flame,* vol. 87, no. 3, pp. 319-335, 1991.

[2] J. Gore, and G. Faeth, "Structure and spectral radiation properties of turbulent ethylene/air diffusion flames." pp. 1521-1531.