Experimental Dataset: Experimental investigation of 40 kWth methane-assisted and self-sustained pulverized biomass flames

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Abstract

This data publication contains the quantitative values of the narrow-band imaging and laser Doppler velocimetry measurements published in the paper [1]. Experiments are carried out using a pilot-scale down-fired cylindrical combustion chamber equipped with a swirl burner. Studied operating conditions of the flames of biomass/methane fuel mixtures have an identical thermal output of 40 kW_{th}, with the thermal output share of methane gradually decreasing from 50 vol.% to 0 vol.% while the biomass share (walnut shells) increased from 50 vol.% to 100 vol.% (self-sustained condition). To visualize flame structure and to identify reaction zones, narrow-band imaging is employed. Narrow-band flame imaging is conducted at two different wavelengths (OH* and CH* radical band heads). A detailed flow field characterization of the respective flames is conducted by two-dimensional laser Doppler velocimetry measurements. Radial profiles of axial and tangential velocities have been determined using an optical long-range laser Doppler velocimetry (LDV) system operated in backscatter mode and mounted to a traverse. Solid fuel particles are used as flow tracers. Results and the experimental conditions from the present dataset are in depth described in the journal article "Experimental investigation of 40 kW_{th} methane-assisted and self-sustained pulverized biomass flames" from the present authors [1].

1 Experimental dataset

The present dataset is composed of 2 main *.zip* files based on the two different types of conducted measurements. Each of the *.zip* compressed files, contains the measurement results obtained for all 4 studied flames. Numerical values from experimental measurement results are given in tab separated *.txt* files. The four studied flames employ pulverized fuel, and have constant 40 kW_{th} output with the same stoichometry. Details about the fuel composition are given in table 1 and about operating conditions, in table 2. Flame naming can be summarized as follows:

- W20M20: Flame with a thermal power of 20kW pulverized walnut shell and 20kW methane

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- W30M10: Flame with a thermal power of 30kW pulverized walnut shell and 10kW methane
- W40M00: Flame with a thermal power of 40kW pulverized walnut shell, and initiated with methane flame
- W40M0-NP: Flame with a thermal power of 40kW pulverized walnut shell, and initiated without methane flame

The list of files in the dataset is the following:

1. 'LDV_Profiles_40kW_AIR_CH4_WS.zip', is a compressed file, containing four folders, each corresponding to a studied flame. Each folder contains six *.txt* files corresponding to the velocity profiles obtained at different axial locations in the combustion chamber (more details in section 1.1). The last three characters denote the axial position at which the profile was taken (whereby e.g. 03D corresponds to 0.3 d, 10D to 1.0d etc.). Full listing of the four files are as follows:
   (a) Folder: 'LDV-AIR-40kW-W20M20'
      i. 'AIR_40kW_W20M20_03D.txt'
      ii. 'AIR_40kW_W20M20_05D.txt'
      iii. 'AIR_40kW_W20M20_10D.txt'
      iv. 'AIR_40kW_W20M20_20D.txt'
      v. 'AIR_40kW_W20M20_40D.txt'
      vi. 'AIR_40kW_W20M20_60D.txt'
   (b) Folder: 'LDV-AIR-40kW-W30M10'
      i. 'AIR_40kW_W30M10_03D.txt'
      ii. 'AIR_40kW_W30M10_05D.txt'
      iii. 'AIR_40kW_W30M10_10D.txt'
      iv. 'AIR_40kW_W30M10_20D.txt'
      v. 'AIR_40kW_W30M10_40D.txt'
      vi. 'AIR_40kW_W30M10_60D.txt'
   (c) Folder: 'LDV-AIR-40kW-W40M00'
      i. 'AIR_40kW_W40M00_03D.txt'
      ii. 'AIR_40kW_W40M00_05D.txt'
      iii. 'AIR_40kW_W40M00_10D.txt'
      iv. 'AIR_40kW_W40M00_20D.txt'
      v. 'AIR_40kW_W40M00_40D.txt'
      vi. 'AIR_40kW_W40M00_60D.txt'
   (d) Folder: 'LDV-AIR-40kW-W40M0-NP'
      i. 'AIR_40kW_W40M00_NP_03D.txt'
      ii. 'AIR_40kW_W40M00_NP_05D.txt'
      iii. 'AIR_40kW_W40M00_NP_10D.txt'
      iv. 'AIR_40kW_W40M00_NP_20D.txt'
      v. 'AIR_40kW_W40M00_NP_40D.txt'
      vi. 'AIR_40kW_W40M00_NP_60D.txt'
   (e) 'metadata_LDV.txt', the metadata file, giving the experimental parameters of LDV measurements, such as laser properties, and the size of the measurment volume

2. 'Narrow_band_images_40kW_AIR_CH4_WS.zip', is a compressed file containing four folders, each corresponding to one studied flame. Each folder contains five *.txt* files , two of them are the intensity of narrow-band images obtained using different bandpass filters. The first two characters denote the radical band names (OH* and CH*). Two *.txt* files named as 'y_scale.txt' and 'x_scale.txt' to represent the axis of narrow-band images in unit of (mm). One *.txt* file named as 'metadata' contains the information about the measured flame condition and the settings of the experimental apparatus. Full listing of the four files are as follows:

   (a) Folder: 'Narrow_Band_images_AIR_W20M20'
      i. 'CH_W20M20.txt'
      ii. 'OH_W20M20.txt'
      iii. 'x_scale.txt'
      iv. 'y_scale.txt'
      v. 'Metadata_W20M20.txt'

   (b) Folder: 'Narrow_Band_images_AIR_W30M10'
      i. 'CH_W30M10.txt'
      ii. 'OH_W30M10.txt'
      iii. 'x_scale.txt'
      iv. 'y_scale.txt'
      v. 'Metadata_W30M10.txt'

   (c) Folder: 'Narrow_Band_images_AIR_W40M00'
      i. 'CH_W40M00.txt'
      ii. 'OH_W40M00.txt'
      iii. 'x_scale.txt'
      iv. 'y_scale.txt'
      v. 'Metadata_W40M00.txt'

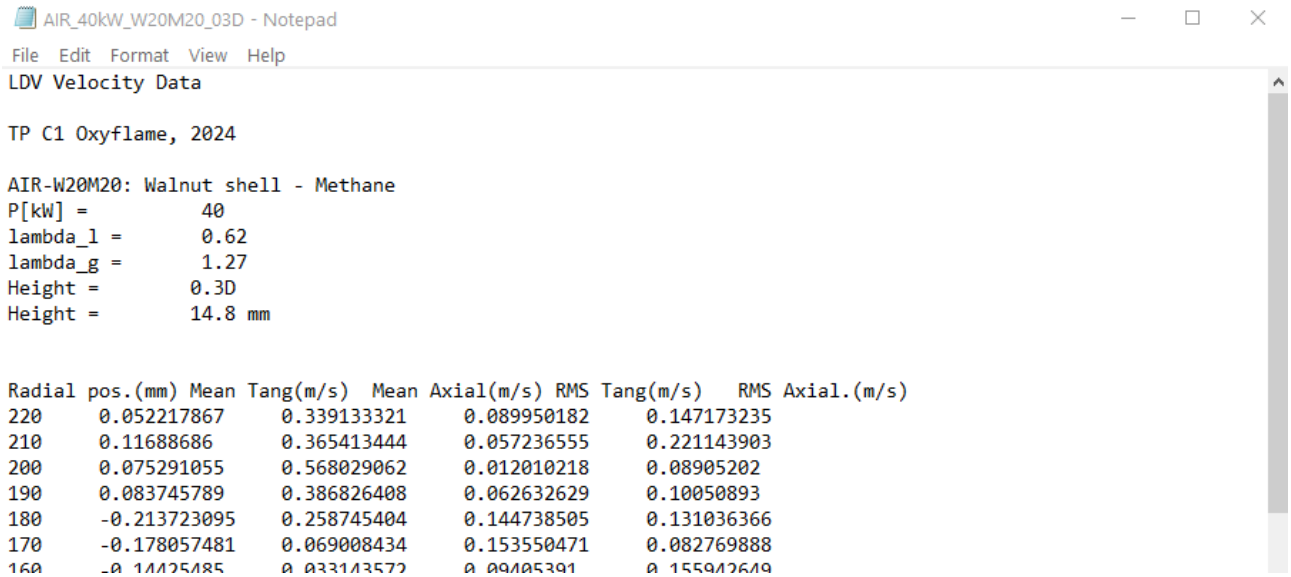
   (d) Folder: 'Narrow_Band_images_AIR_W40M00_NP'
      i. 'CH_W40M00_NP.txt'
      ii. 'OH_W40M00_NP.txt'
      iii. 'x_scale.txt'
      iv. 'y_scale.txt'
      v. 'Metadata_W40M00_NP.txt'

1.1 LDV profile data

The typical structure of the *.txt* files, using as example 'AIR_40kW_W20M20_03D.txt' is shown in figure 1. The first 11 lines contain information about the identifiers of the studied flame (i.e. AIR-W20M20), also about the thermal power P, local λ_l and global λ_g stoichiometric ratios of the flames. Lines 9 and 10 contain information about the relative and absolute distances from the burner where the profile was measured, respectively. Relative distance is shown as a factor of the burner diameter, $D = 49.2\,\text{mm}$. The data is arranged in seven columns (also shown in Line 13 of the LDV text files) as follows:

- Column 1: Radial position R (mm).
- Column 2: Mean tangential velocity component $\overline{U}$ (m/s).

- Column 3: Mean axial velocity component $\overline{V}$ (m/s).
- Column 4: RMS of the tangential velocity component U_{RMS} (m/s).
- Column 5: RMS of the axial velocity component V_{RMS} (m/s).


AIR_40kW_W20M20_03D - Notepad

File Edit Format View Help

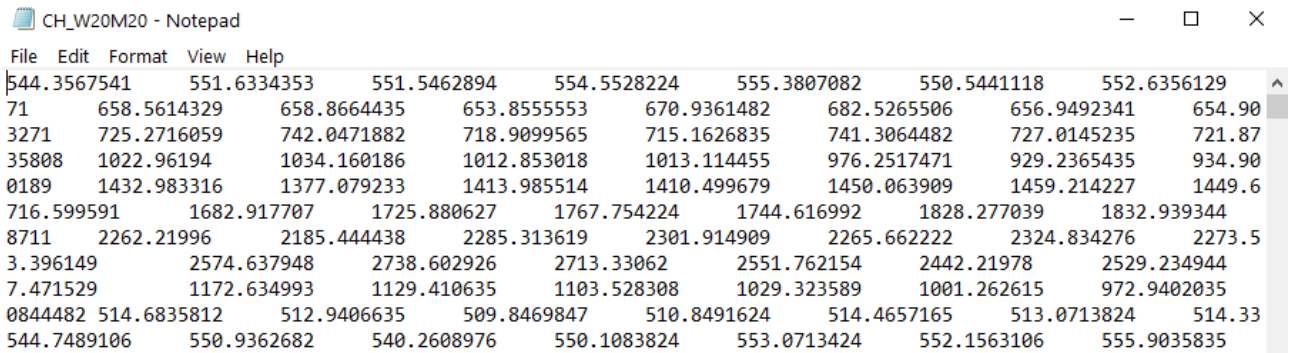
```
LDV Velocity Data

TP C1 Oxyflame, 2024

AIR-W20M20: Walnut shell - Methane
P[kW] =          40
lambda_l =       0.62
lambda_g =       1.27
Height =        0.3D
Height =        14.8 mm


Radial pos.(mm) Mean Tang(m/s)  Mean Axial(m/s) RMS Tang(m/s)   RMS Axial.(m/s)
220     0.052217867     0.339133321     0.089950182     0.147173235
210     0.11688686      0.365413444     0.057236555     0.221143903
200     0.075291055     0.568029062     0.012010218     0.08905202
190     0.083745789     0.386826408     0.062632629     0.10050893
180     -0.213723095    0.258745404     0.144738505     0.131036366
170     -0.178057481    0.069008434     0.153550471     0.082769888
160     -0.14425485     0.033143572     0.09405391      0.155942649
```

Figure 1: Typical *.txt* file containing information about measured velocity profiles, data is arranged in five columns

1.2 Narrow band images

The typical structures of the *.txt* files for intensity i.e. 'CH_W20M20.txt', and positions i.e. 'x_scale.txt' are shown in figure 2. The datasets in 'x_scale.txt' and 'y_scale.txt' are x and y coordinates (in mm) of each pixel intensity given in intensity files. In order to create a narrow-band image, one should plot intensity text files as 2D contour image and use position text files ('x_scale.txt' and 'y_scale.txt') as numerical values on x- and y-axis.

All *.txt* files are set as tab seperated. Metadata of the measeruments i.e. Metadata_W20M20.txt' contains the information about the identifiers of the studied flame (i.e. AIR-W20M20), also about the thermal power P, local λ_{l} and global λ_{g} stoichiometric ratios of the flames. Moreover, the camera settings i.e. 'Pixel size' are listed in metadata files.


CH_W20M20 - Notepad

File Edit Format View Help

```
544.3567541     551.6334353     551.5462894     554.5528224     555.3807082     550.5441118     552.6356129
71      658.5614329     658.8664435     653.8555553     670.9361482     682.5265506     656.9492341     654.90
3271    725.2716059     742.0471882     718.9099565     715.1626835     741.3064482     727.0145235     721.87
35808   1022.96194      1034.160186     1012.853018     1013.114455     976.2517471     929.2365435     934.90
0189    1432.983316     1377.079233     1413.985514     1410.499679     1450.063909     1459.214227     1449.6
716.599591      1682.917707     1725.880627     1767.754224     1744.616992     1828.277039     1832.939344
8711    2262.21996      2185.444438     2285.313619     2301.914909     2265.662222     2324.834276     2273.5
3.396149        2574.637948     2738.602926     2713.33062      2551.762154     2442.21978      2529.234944
7.471529        1172.634993     1129.410635     1103.528308     1029.323589     1001.262615     972.9402035
0844482 514.6835812     512.9406635     509.8469847     510.8491624     514.4657165     513.0713824     514.33
544.7489106     550.9362682     540.2608976     550.1083824     553.0713424     552.1563106     555.9035835
```

Figure 2: Typical *.txt* file containing the intensity or positional information of narrow-band imaging

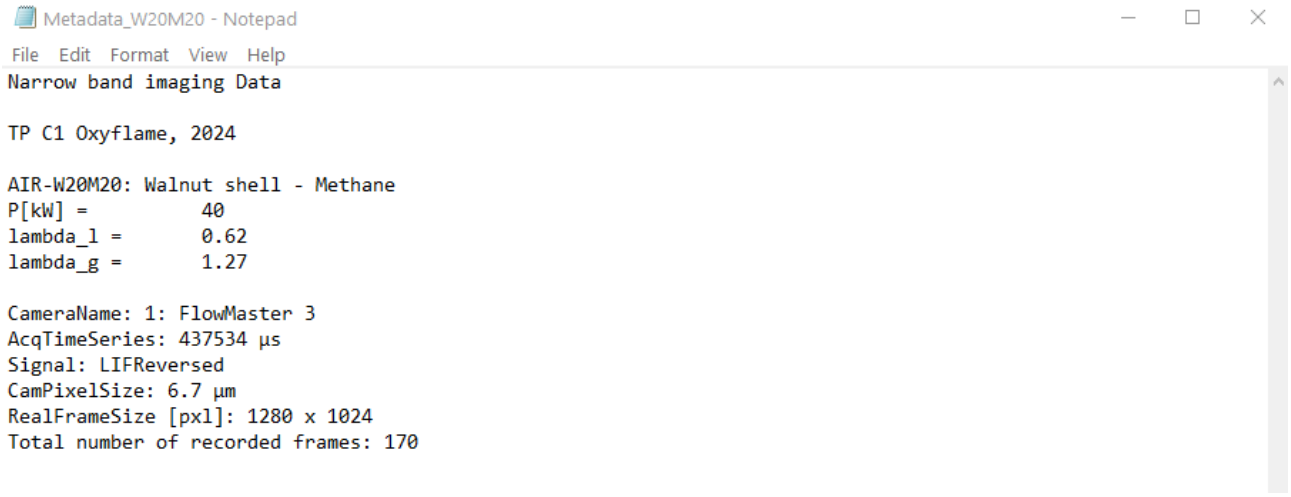


Figure 3: Typical *.txt* file containing the information about the measured flame condition and the settings of the experimental apparatus

2 About the studied flames and experimental setup

Details about the combustion facility and the experimental methods employed can be found in previous published works. A detailed description of the combustion chamber and the main components can be found in [2]. A detailed description of the 40kWth burner is available in [3]. For details on the experimental LDV and narrow-band imaging setups, please refer to [1].

Table 1 shows the ultimate and proximate analysis of walnut shell employed. Table 2 provides details about the investigated operating conditions, including gas mixture compositions, volume flows and gas temperatures at the burner inlets.

Table 1: Chemical composition, and microscopic size analysis of the employed walnut shells.

Component		a.r.[c]	w.f.[d]	d.a.f.[e]
Carbon	[w.-%]	46.11	50.94	51.32
Hydrogen	[w.-%]	5.58	6.16	6.21
Oxygen[a]	[w.-%]	37.95	41.92	–
Nitrogen	[w.-%]	0.10	0.11	0.11
Sulphur	[w.-%]	<0.01	<0.01	<0.01
Water	[w.-%]	9.48	–	–
Ash	[w.-%]	0.66	0.73	–
Volatiles	[%]	72.93	80.57	81.16
HHV[b]	[MJ/kg]	18.445	20.376	20.525
Diameter particle[f]	[µm]	$d_{p,10}$ 101.5	$d_{p,50}$ 140.6	$d_{p,90}$ 178.8

[a] Calculated from difference, [b] HHV: higher heating value
[c] a.r.: as received, [d] w.f.: water free, [e] d.a.f.: dry, ash free [f] volume based

Table 2: Operating conditions

Parameter	Units	W20M20	W30M10	W40M00
Methane volume flow rate[a]	[m^3/h]	2.01	1.005	0.00
Biomass mass flow rate	[kg/h]	3.82	5.72	7.63
Thermal load of biomass/methane	[kW/kW]	20/20	30/10	40/00
Volume flow rate of primary stream[a]	[m^3/h]	12.1	12.1	12.1
O_2 fraction of primary stream	[vol%]	19.5	19.5	19.5
Volume flow rate of secondary stream[a]	[m^3/h]	11.1	11.1	11.1
Volume flow rate of staging stream[a]	[m^3/h]	24.0	24.0	24.0
O_2/N_2 secondary and staging streams	[vol%]	21/79	21/79	21/79
Swirl number secondary stream[b]	[-]	0.958	0.958	0.958
Temperature of secondary / staging stream	[°C/°C]	40 / 900	40 / 900	40 / 900
Local / global stoichiometric ratio[a]	[λ_L/λ_G]	0.623 / 1.270	0.633 / 1.287	0.643 / 1.310

[a] STP = Standard temperature (0 °C) and pressure (1.013 bar); [b] Geometrical swirl number, estimated from burner geometry

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The dataset: `https://doi.org/10.18154/RWTH-2025-04397`

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