Oxy-combustion Characteristics of Biomass Pellets in a Drop Tube Furnace

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Outline

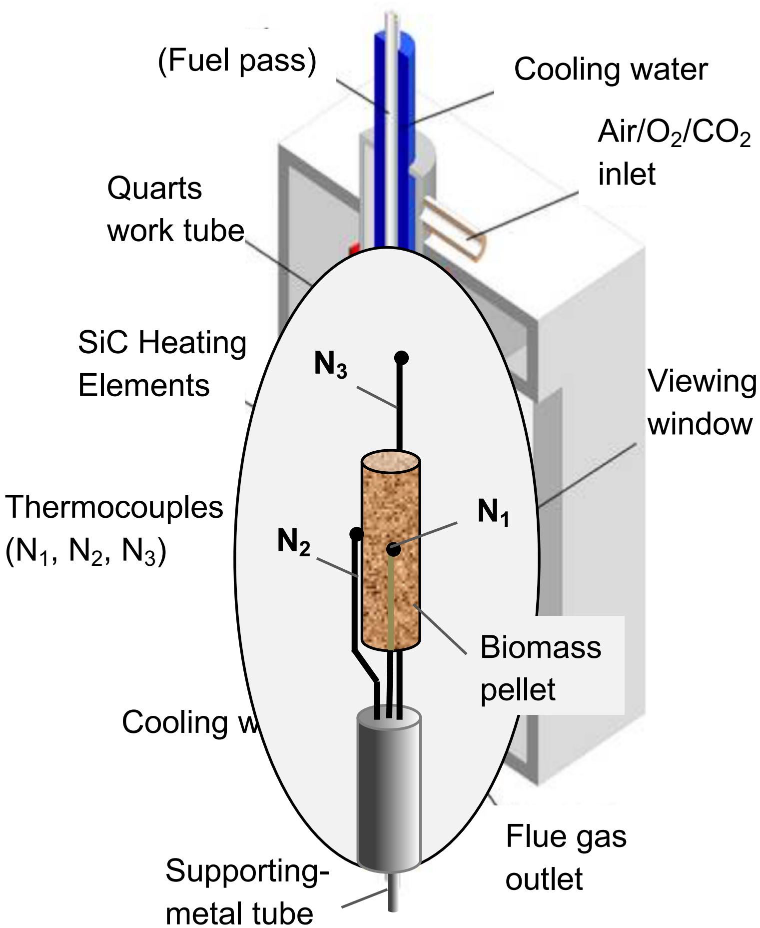
- Background
- Experimental set-up
- Test conditions
- Measurement
- Results and discussion
- Concluding remarks

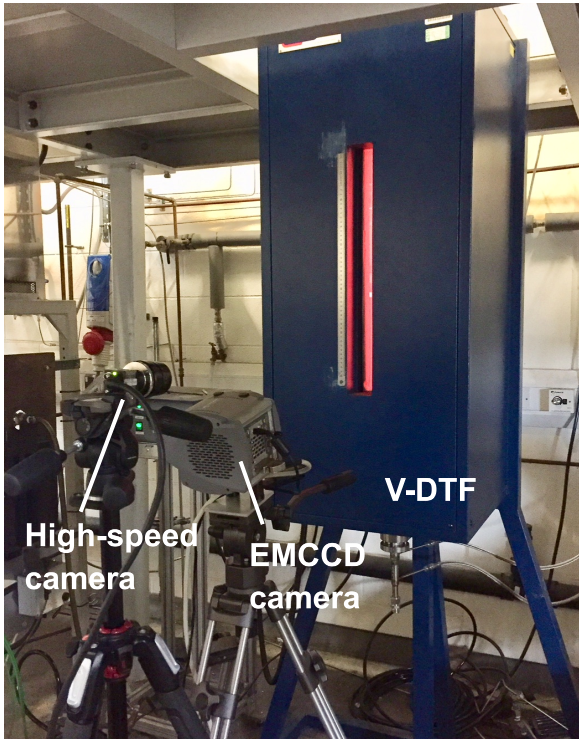
Background

- Biomass fuels have widely been accepted as renewable energy in new and retrofitted power/thermal plants (pulverised, fluidised bed, or grate chain boilers).
- Biomass fuels, however, can vary widely in properties, composition and structure, leading to drastically different 'fuel performance', particularly under oxy-combustion conditions.
- Limited work has been undertaken for the fundamental understanding of the combustion behaviours of biomass fuel under oxy-conditions.
- A combination of high-speed imaging and image processing techniques is employed to investigate the combustion behaviours of single biomass pellets in a V-DTF (Visual Drop Tube Furnace) under both air and oxy conditions.

Experimental set-up

- **V-DTF**- an electrically heated drop tube furnace equipped with a quartz tube@50 mm inner diameter and 1400mm long, capable of maintaining gas temperature up to 1050 °C.



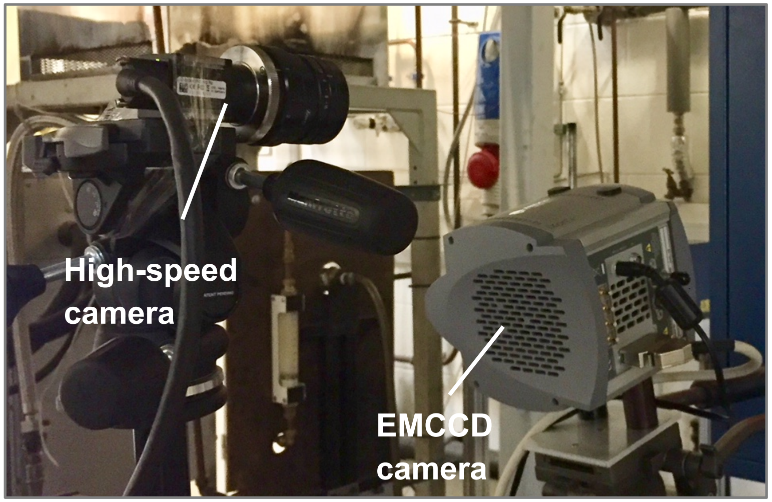


Experimental set-up

- **Key features of imaging systems**
  - A high-speed camera (IDS UI-3130CP Rev. 2)- acquiring videos of burning biomass pellets.
  - An EMCCD camera (Andor iXonEM+ 897)- acquiring videos of spectral intensities of alkali metals (Na and K) during the biomass pellets combustion.

<u>High-speed camera</u>
Sensor type: CMOS, RGB
Frame rate: 575 fps@800(H)x600(V),
up to 900fps with a reduced image resolution
Resolution: 0.48 MPix
Interface: USB 3

<u>EMCCD camera</u>
Spectral range: UV to near IR
Multiplication factor: 1000
Cooling temp: −85˚C
Dark current: <0.001 e−/pix/s
Image resolution: 512 × 512 pixels



Fuel properties and test conditions

- **Five typical biomass pellets**


Miscanthus


Peanut


Straw


Torrefied wood


Wood

Proximate analysis (wt%, as received)

Biomass	Moisture	Ash	Volatile matter	Fixed carbon
Miscanthus	4.42	3.67	75.91	16.00
Peanut	7.73	2.78	68.50	20.99
Straw	4.00	7.57	73.96	14.47
T wood	6.40	1.97	72.90	18.73
Wood	7.32	0.35	76.96	15.37

Ultimate analysis (averaged by wt%)

Biomass	C	H	N
Miscanthus	45.55	6.13	0.66
Peanut	46.69	6.42	1.38
Straw	44.03	5.93	0.67
T wood	49.32	6.04	0.51
Wood	46.68	6.44	0.24

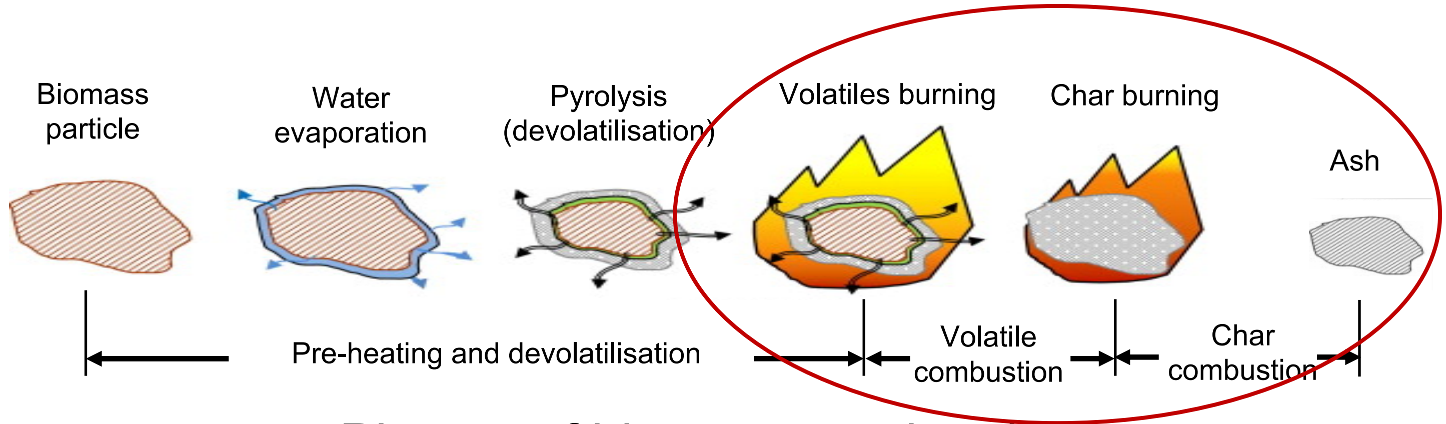
Fuel properties and test conditions

- The pellets of tested biomass burnt under the following conditions for the pre-set temperatures of 800˚C and 900˚C which replicate the working temperatures of a typical biomass-fired fluidised bed boiler (fixed bed).

Condition	O_2 (l/min)	CO_2 (l/m)
Air (l/min)	10	
O_2@21%	2.1	7.9
O_2@25%	2.5	7.5
O_2@30%	3.0	7.0

- The size and mass of all the pellets were measured before the tests. Their volume and density were then computed and used to normalise the results for fair comparisons.

Measurement



Phases of biomass combustion

- **Volatile combustion**
  - Size and shape of flame
  - Ignition time
  - Burning velocity/rate
  - Temperature and its distribution
  - Spectral intensity of radicals (Alkali metals such as Na and K)
- **Char combustion**
  - Burning velocity/rate
  - Temperature and its distribution

Measurement

- For each test condition,
  - three samples of each biomass fuel were burnt.
  - videos of the complete combustion process of each sample were recorded.
  - temperatures (flame, surface and inner) of the burning pellet were measured concurrently using the thermocouples.
  - videos of alkali metals (Na and K) emissions were also recorded using the EMCCD camera.

- Videos were processed and the characteristic parameters of the burning pellets were computed for different combustion phases.
- The combustion behaviours of burning pellets in relation to the test conditions were then quantified.

Results and discussion

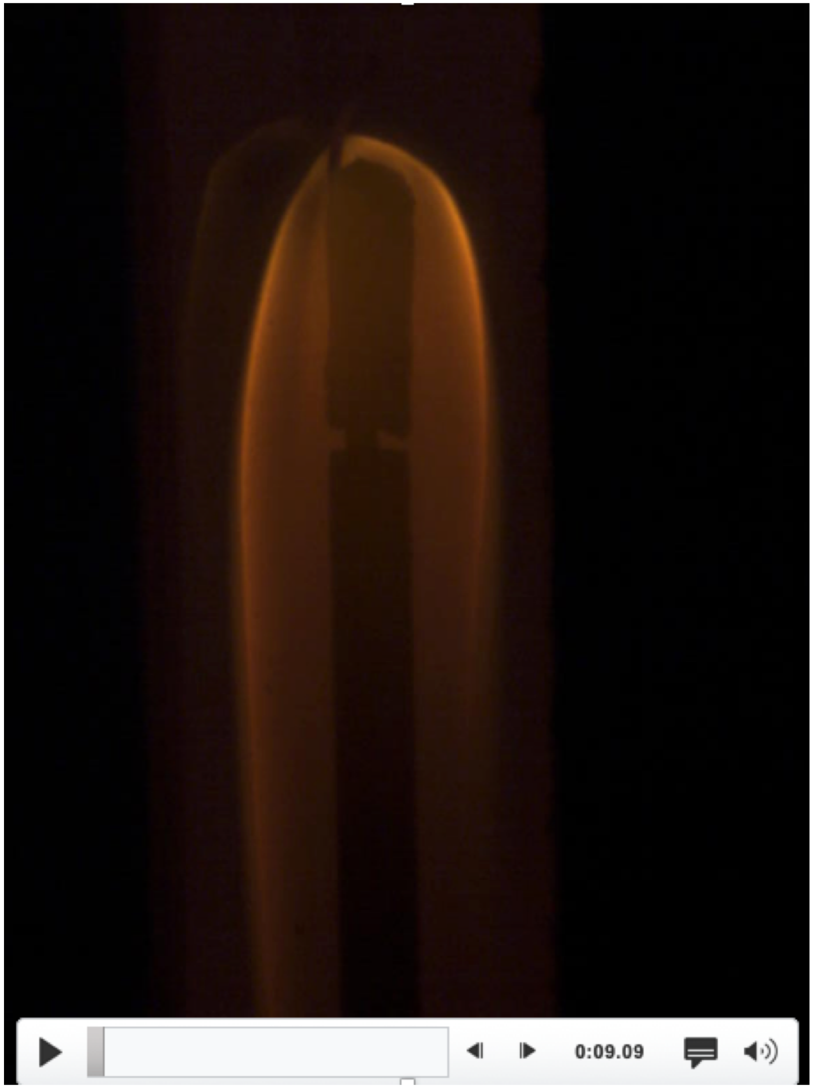
Flame video

(Miscanthus,

O_2@21%,

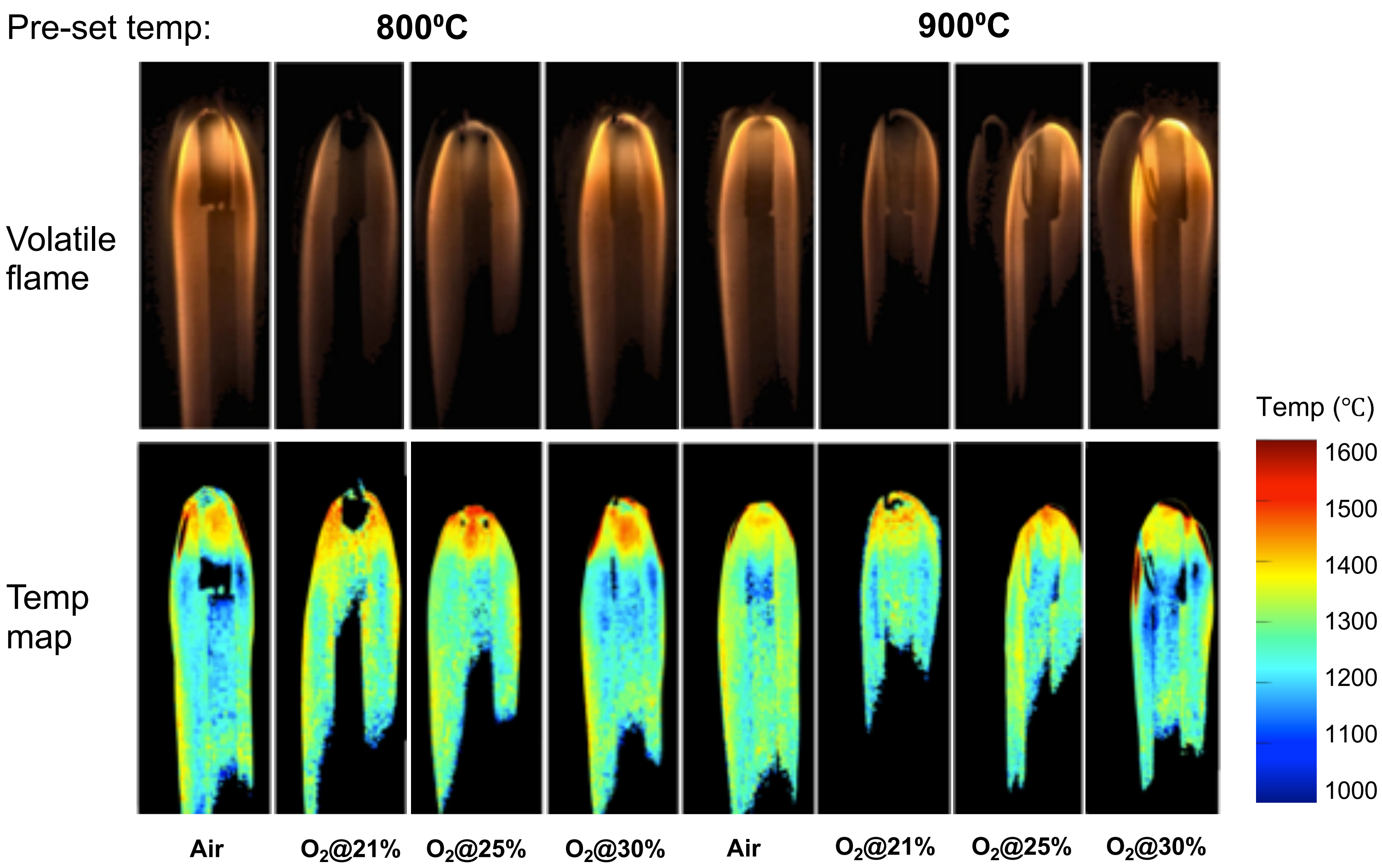
CO_2@79%

800°C)



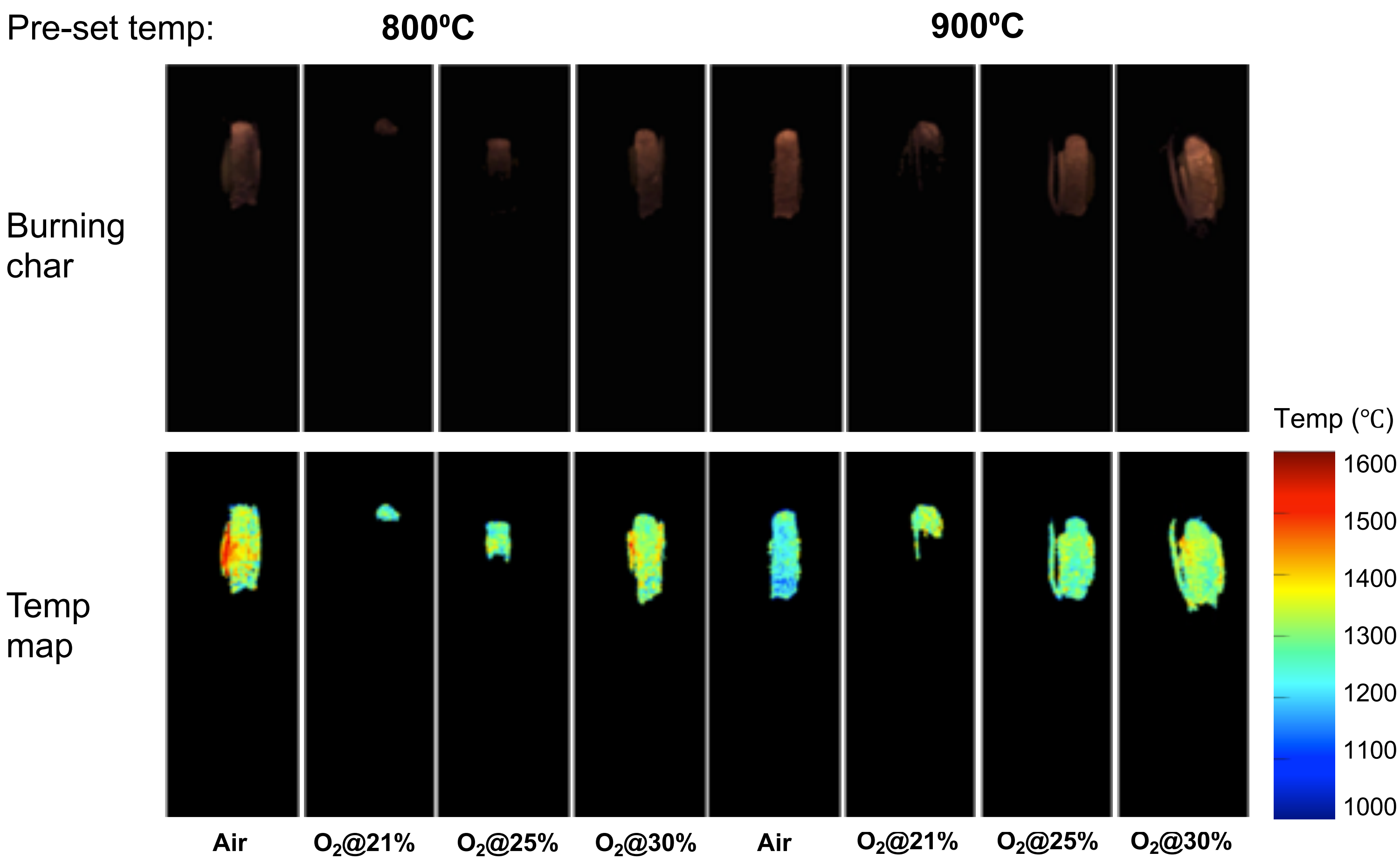
Results and discussion

- **Volatile flame images & temp maps of Miscanthus pellets**



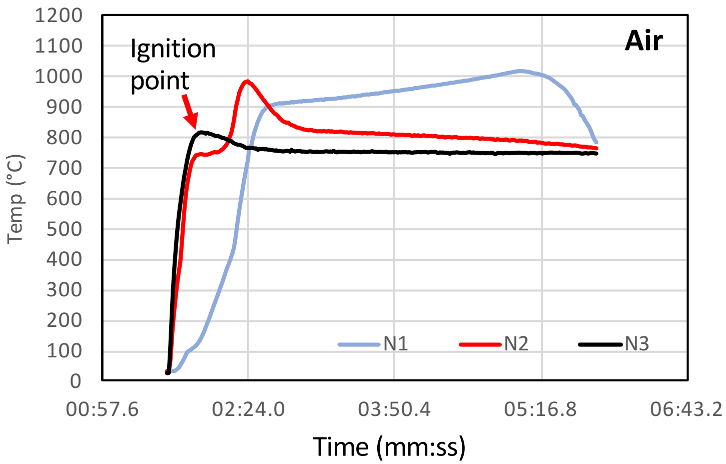
Results and discussion

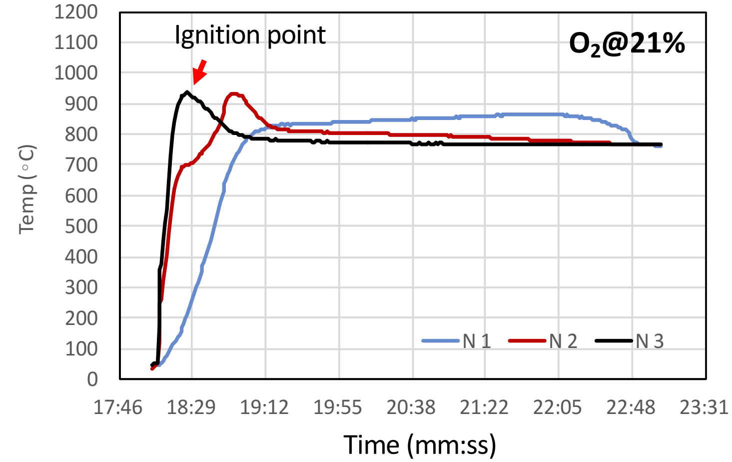
- **Burning char images & temp maps of Miscanthus pellets**

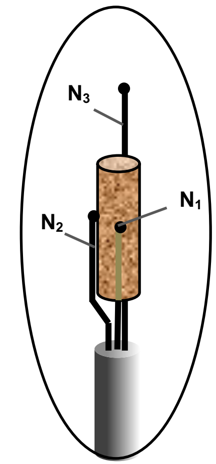


Results and discussion

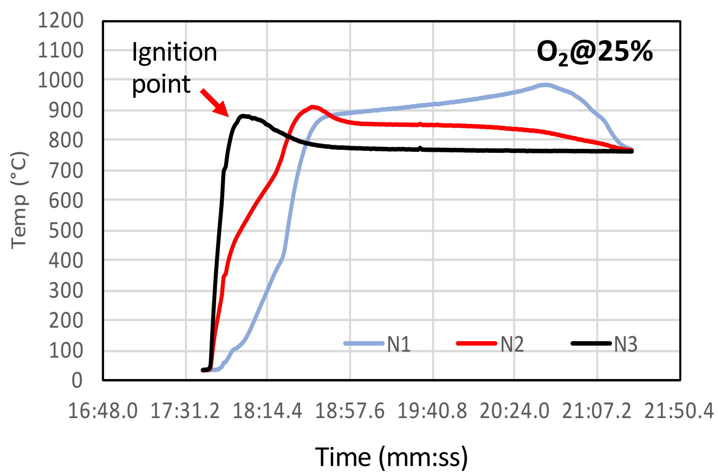
- Temperature of a burning Miscanthus pellet under air and oxy combustion for the pre-set temperature of 800 °C

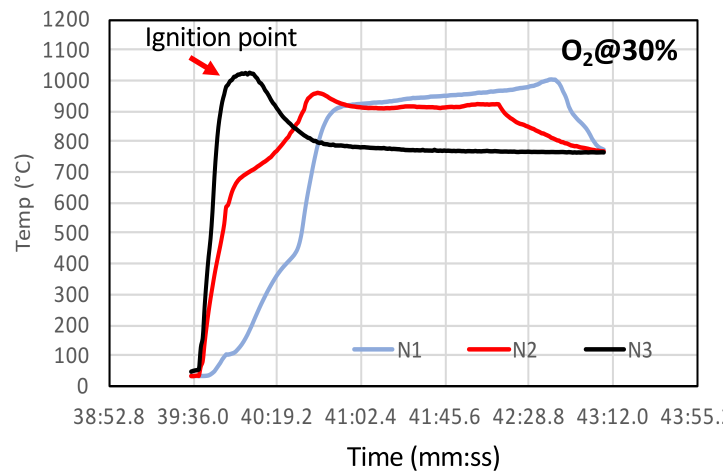






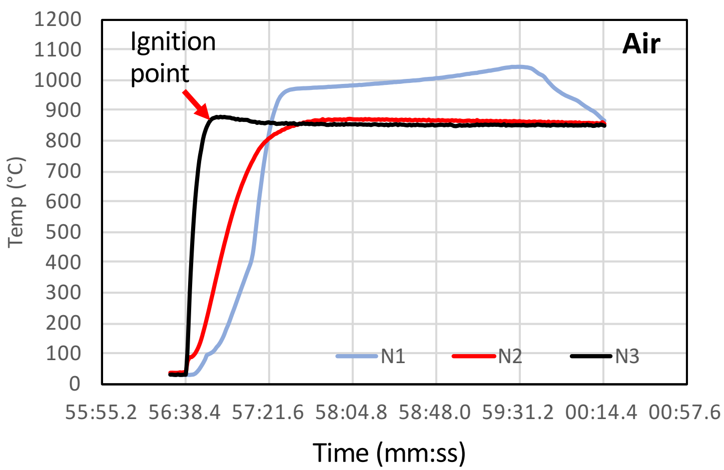
Thermocouples (N_1, N_2, N_3)

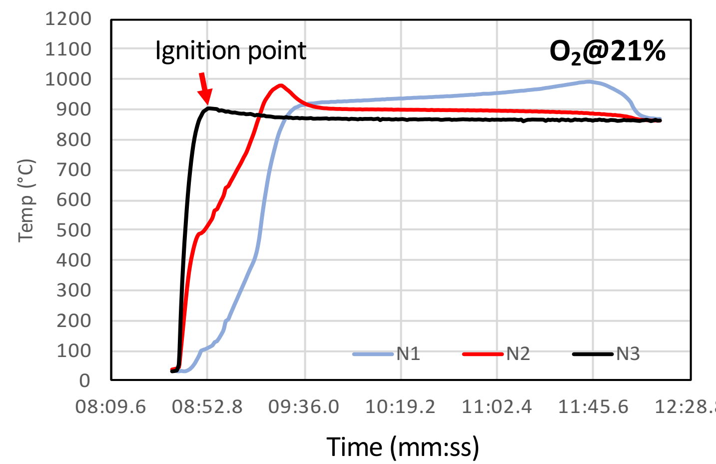


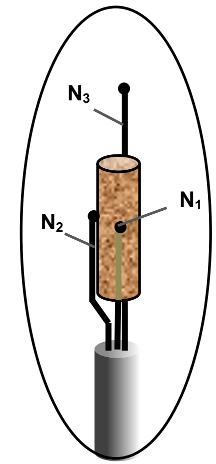


Results and discussion

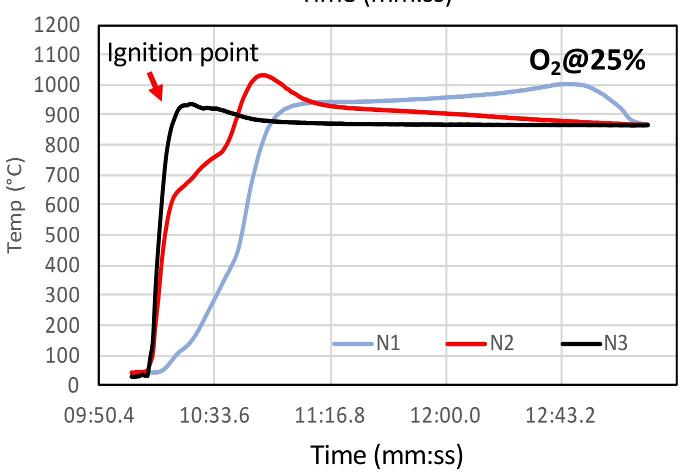
- Temperature of a burning Miscanthus pellet under air and oxy combustion for the pre-set temperature of 900 °C

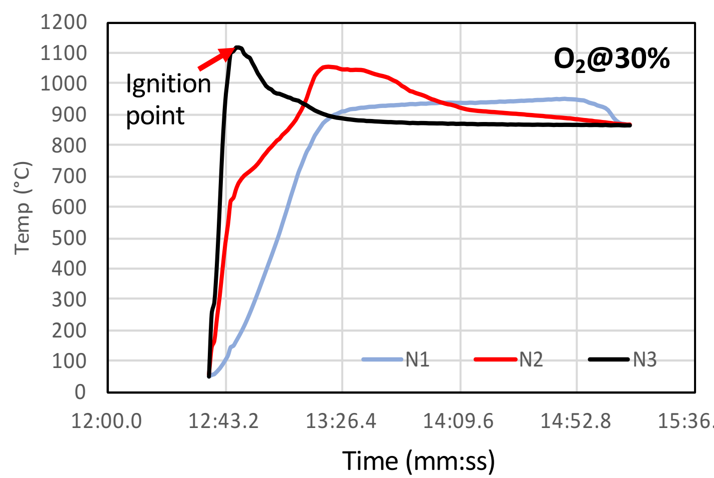






Thermocouples
(N_1, N_2, N_3)





Results and discussion

- **Samples and burning times**

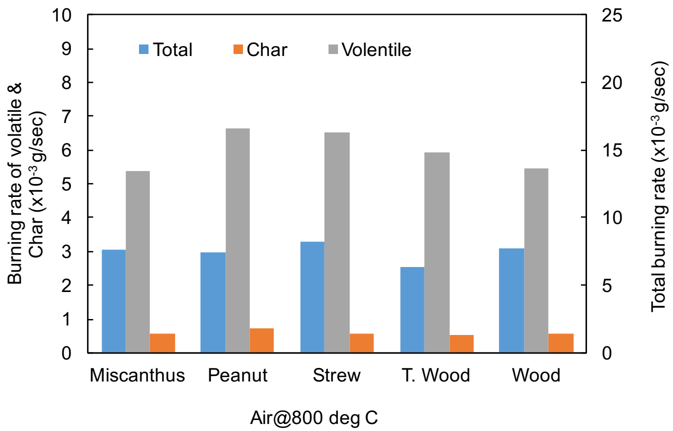
  (Note: only Miscanthus is included as example)

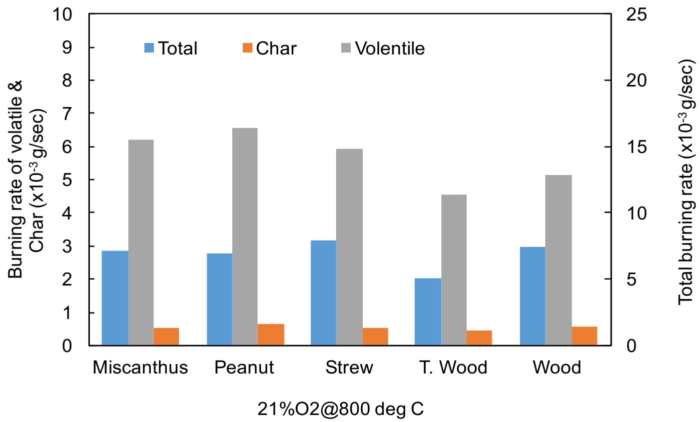
800 deg C								900 deg C						
					Time (sec)							Time (sec)		
Condition	Sample	Volumn (cm3)	Density (g/cm3)	Total burning time taken in test (sec)	Total Combusiton	Volentile Combustion	Char Combustion	Sample	Volumn (cm3)	Density (g/cm3)	Total burning time taken in test (sec)	Total Combusiton	Volentile Combustion	Char Combustion
Air	M1	1.27	0.52	242.0	240.0	38.0	202.0	M4	1.37	0.50	207.0	210.0	39.0	171.0
	M2	1.37	0.48	226.0	224.0	41.0	183.0	M5	1.45	0.55	222.0	218.0	41.0	177.0
	M3	1.45	0.52	219.0	220.0	38.0	182.0	M6	1.62	0.43	205.0	207.0	40.0	167.0
	ave	1.36	0.51	229.0	228.0	39.0	189.0	ave	1.48	0.49	211.3	211.7	40.0	171.7
O2@21%	M20	1.61	0.52	289.0	265.0	38.0	227.0	M7	1.43	0.49	204.0	199.0	42.0	157.0
	M21	1.55	0.48	338.0	275.0	37.0	238.0	M8	1.50	0.52	215.0	214.0	42.0	172.0
	M22	1.46	0.53	308.0	285.0	40.0	245.0	M9	1.48	0.57	228.0	225.0	42.0	183.0
	ave	1.54	0.51	311.7	275.0	38.3	236.7	ave	1.47	0.53	215.7	212.7	42.0	170.7
O2@25%	M23	1.25	0.52	199.0	200.0	38.0	162.0	M10	1.21	0.56	177.0	173.0	38.0	135.0
	M24	1.35	0.54	214.0	209.0	37.0	172.0	M11	1.47	0.51	177.0	173.0	37.0	136.0
	M25	1.28	0.52	211.0	199.0	36.0	163.0	M13	1.54	0.53	189.0	184.0	41.0	143.0
	ave	1.29	0.53	208.0	202.7	37.0	165.7	ave	1.41	0.53	181.0	176.7	38.7	138.0
O2@30%	M26	1.44	0.49	173.0	173.0	37.0	136.0	M14	1.46	0.50	147.0	145.0	36.0	109.0
	M27	1.18	0.51	168.0	160.0	37.0	123.0	M17	1.27	0.45	124.0	127.0	35.0	92.0
	M28	1.15	0.53	168.0	161.0	36.0	125.0	M19	1.26	0.52	150.0	149.0	39.0	110.0
	ave	1.26	0.51	169.7	164.7	36.7	128.0	ave	1.33	0.49	140.3	140.3	36.7	103.7

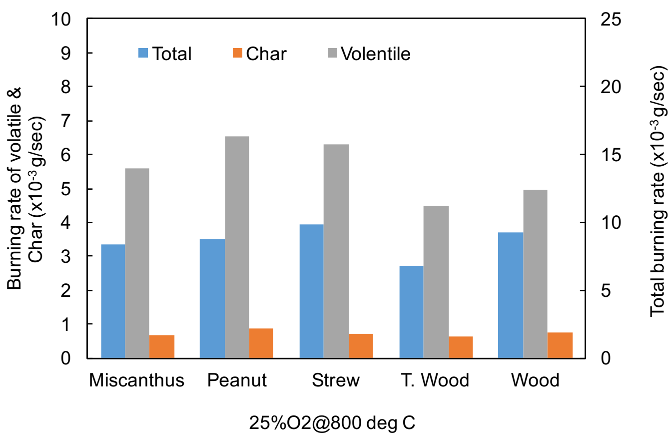
Results and discussion

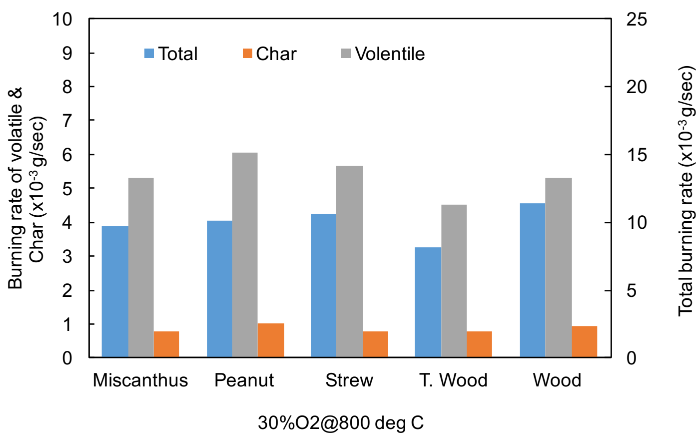
- **Burning rate of different biomass pellets @ 800 °C**

  - computed using the masses (weight) of total (i.e., pellet), volatile matter and fix carbon (according to the proximate analysis) divided by the corresponding total, volatile, and char burning times, respectively.





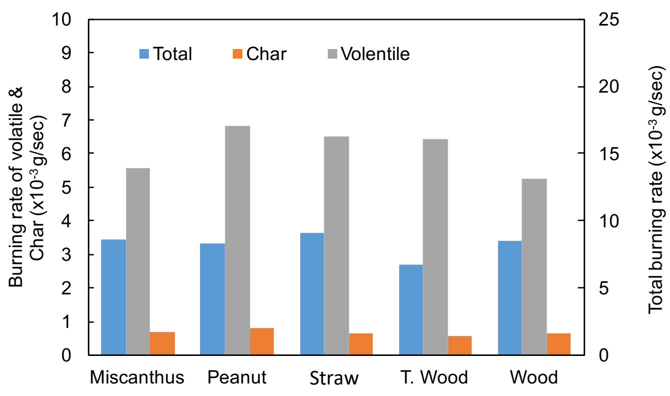




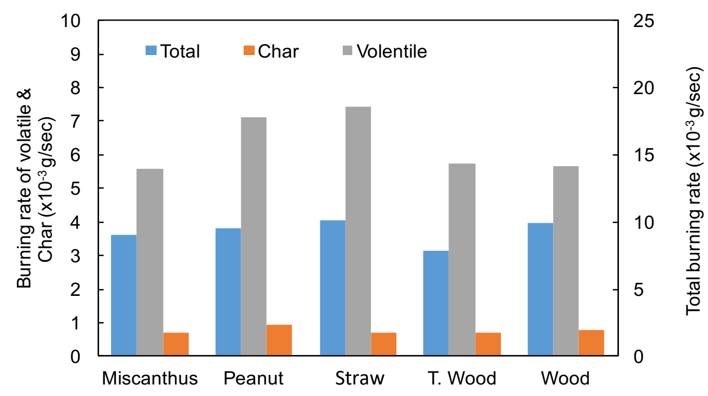
Results and discussion

- **Burning rate of different biomass pellets @ 900 °C**

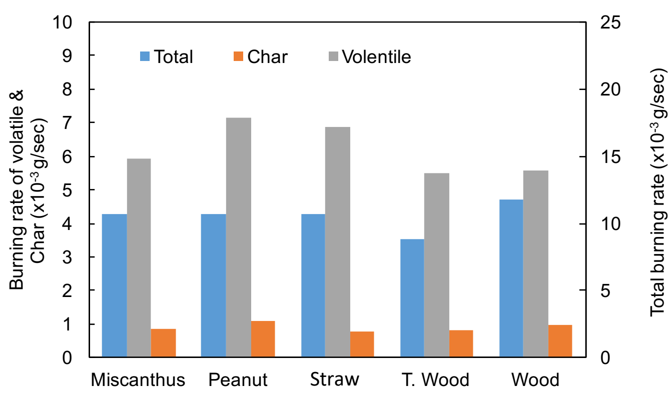
  - computed using the masses (weight) of total (i.e., pellet), volatile matter and fix carbon (according to the proximate analysis) divided by the corresponding total, volatile, and char burning times, respectively.



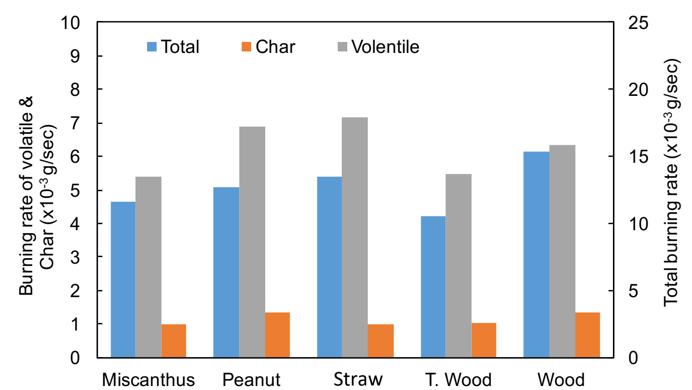
Air@900 deg C



21%O2@900 deg C



25%O2@900 deg C

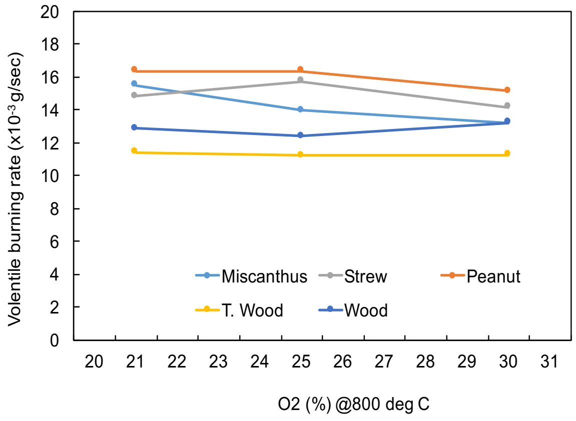


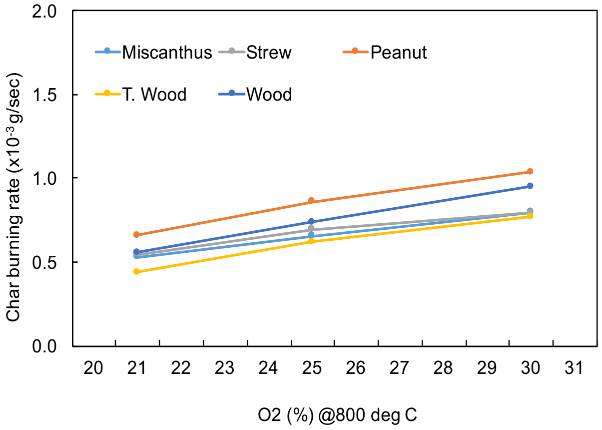
30%O2@900 deg C

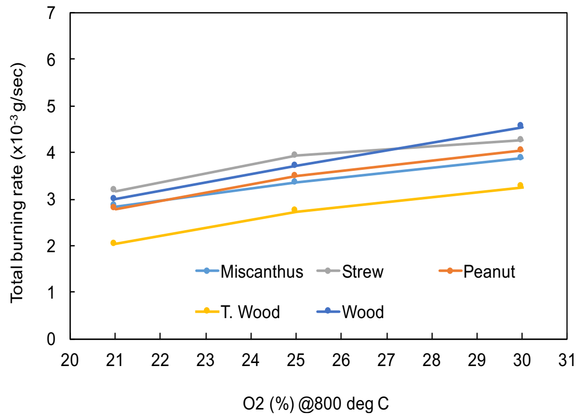
Results and discussion

- **Burning rate of biomass pellets for different O_2 supplies @ 800 °C**

  - computed using the masses (weight) of total (i.e., pellet), volatile matter and fix carbon (according to the proximate analysis) divided by the corresponding total, volatile, and char burning times, respectively.



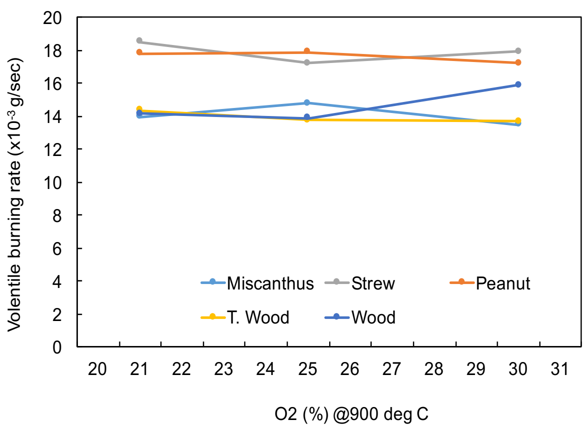


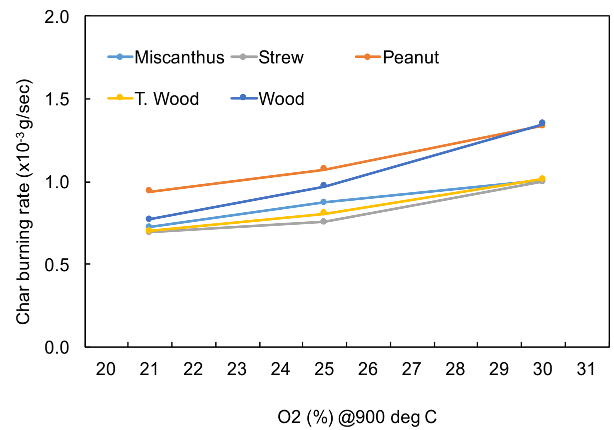


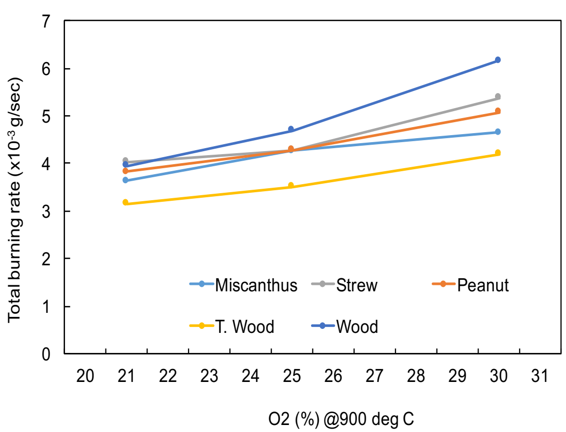
Results and discussion

- **Burning rate of biomass pellets for different O_2 supplies @ 900 °C**

  - computed using the masses (weight) of total (i.e., pellet), volatile matter and fix carbon (according to the proximate analysis) divided by the corresponding total, volatile, and char burning times, respectively.







Remarks:

- An increased O_2 flow increased the burning rate of char and thus the total combustion rate of the biomass pellets.
- The pre-set furnace temperature has a little impact on the burning rate of volatile matters.
- Combustion behaviours of the biomass pellet under the O_2@25% oxy-condition show to be similar to that under the air combustion.

Concluding remarks

- Experiments were carried out on a V-DTF to study the combustion behaviours of individual biomass pellets through digital imaging and image processing techniques.
- The combustion processes of five different biomass pellets were recorded for both air and oxy conditions under the pre-set furnace temperatures of 800 °C and 900 °C.
- The different combustion phases of (total, volatile and char) of each biomass pellet were separated and the associated periods of time are determined.
- The temperatures of the burning pellets (e.g., ignition and surface) were measured and their relationship with the combustion phases were quantified.
- Results have shown a strong correlation between the burning rate of the biomass pellets and O_2 flows. In particular, the burning rate of char and thus the total combustion rate increases with the O_2 flow.
- The data processing is continuing to quantify and compare the combustion behaviours of different biomass materials (e.g., colour, and spectral intensities of free radicals) for both air and oxy conditions.

Acknowledgement

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