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An experimental study on oscillating behaviour of the radiation spectrum of self-sustained biomass flames at different thermal loads

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Summary

- The goals of the present study are:
  - To build and test beam extinction method to measure mass flow rate of solid fuel particles
  - To examine the spatio-temporal fluctuations in temperature of the self-sustained pulverized biomass swirl flames
  - To investigate the relation between oscillating behaviours of the flame and the solid fuel feeding
- Main conclusion: The fluctuation in solid fuel feeding has no direct effect on the transient behaviour of the studied self-sustained walnut shell flames.

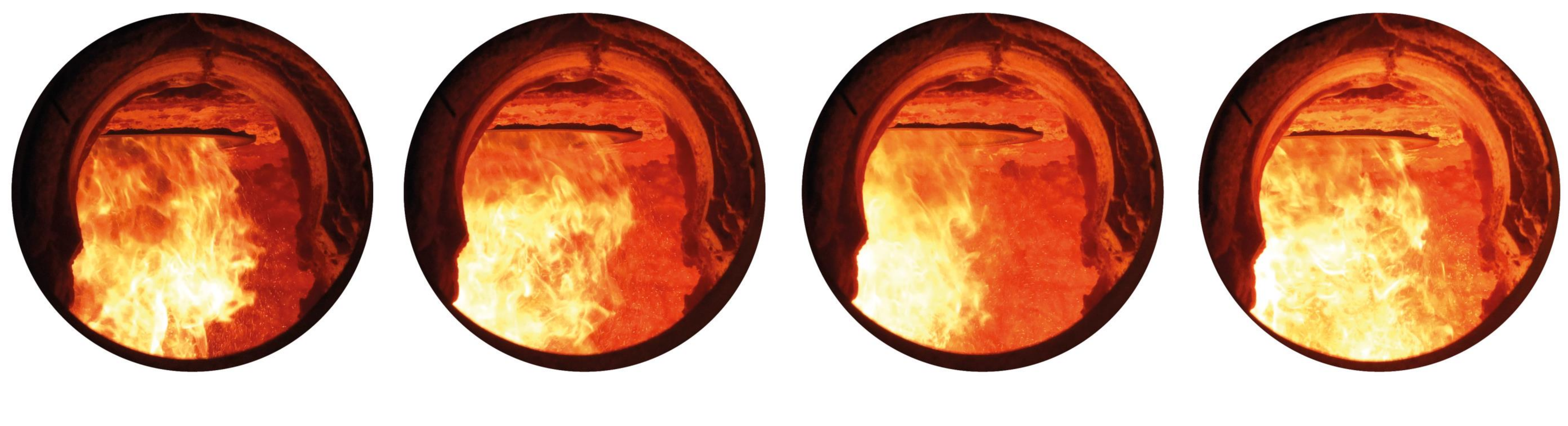

Figure 1: Images of studied self-sustained walnut shell flames with four different thermal loads

Experimental Configuration

Combustion chamber

- Pilot scale, down- fired, cylindrical
- Traversable burner port
- A swirl-type burner with a diffuser
- Optical access via observation port

Operating conditions

- Four different thermal power:
  - 60, 80, 100, 120 kW
- Oxidizer atmosphere: Air
- Two oxygen-fuel ratios:
  - Local (λ_{I+II} = 0.8), Overall ($\lambda_{I+II+III}$ = 1.3)
- Wall temperature: 1000-1100 °C
- Fuel: Pulverized walnut shell (100-250 μm)

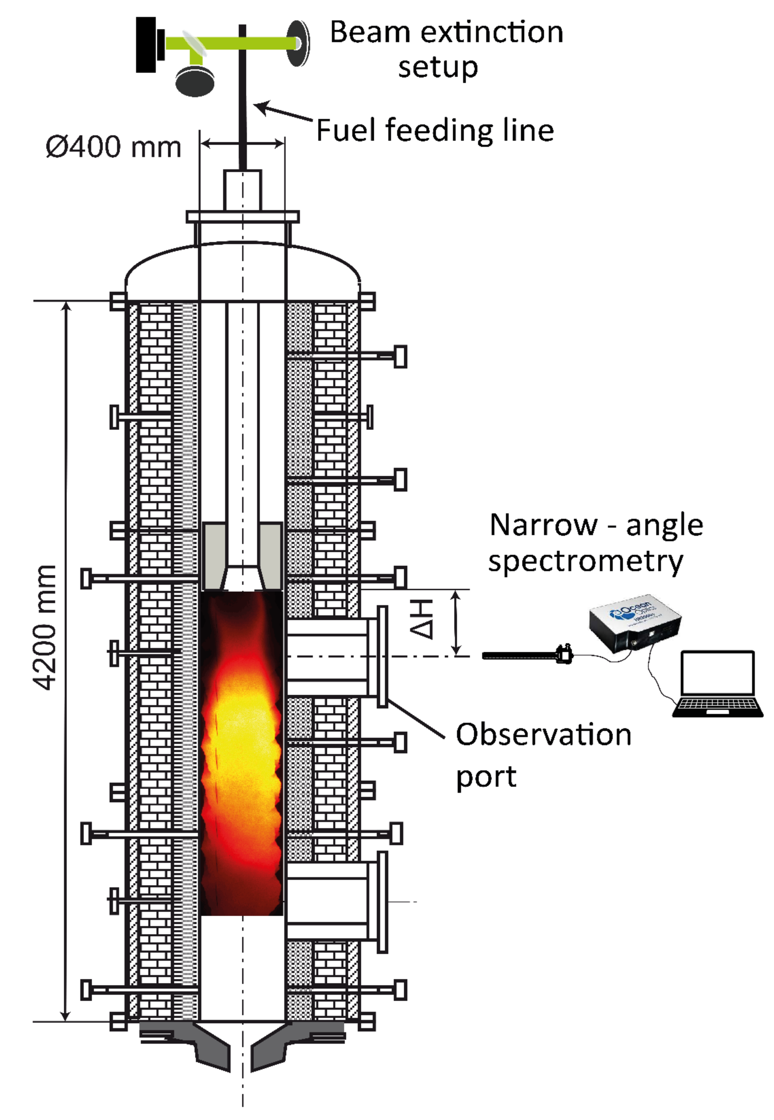

Figure 2: Vertical cross section of the combustion chamber

Measurement Methods

Narrow angle spectrometer

- Spectrometer model: OceanOptics HR2000+
- Integration time: 4 ms
- Number of scans to average: 10
- Experimental time: 10 s
- Planck's law is fitted on radiation spectrum to obtain mean flame temperature.
- Flicker frequency:

$$Flicker = \frac{\sum_{k=0}^{N-1} |X(f_k)| f_k}{\sum_{k=0}^{N-1} |X(f_k)|}$$

N : Number of frequency component
f_k : k^{th} frequency
$X(f_k)$: Power density of the k^{th} frequency component

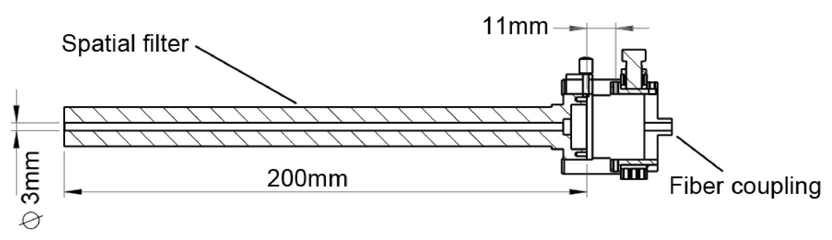

Figure 3: Sketch of narrow angle probe

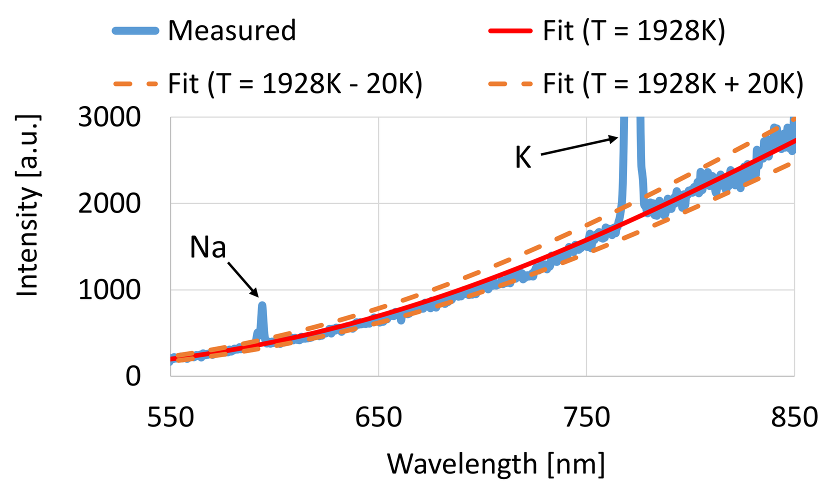

Figure 4: Planck's law fitting

Beam extinction method (BEM)

- Small portion of the feeding line is changed to transparent glass tube.
- Light source: 532 nm point laser module
- Lambert-Beer's law:

$$\dot{m}_p = -\frac{\dot{Q}_{flow}\, \rho_p\, D_p}{3\, D_t}\left(\ln\left(\frac{I_2}{I_1}\right) - \ln\left(\frac{I_{2,ref}}{I_{1,ref}}\right)\right)$$

$\dot{m}_p$: Mass flow rate of the particles [kg/s]
$\dot{Q}_{flow}$: Volumetric flow rate of medium in the tube [m³/s]
ρ_p : Density of the particle [kg/m³]
D_p : Particle diameter [m]
D_t : Tube diameter [m]
I_1 : Intensity of light before glass tube [mW]
I_2 : Intensity of light after glass tube [mW]

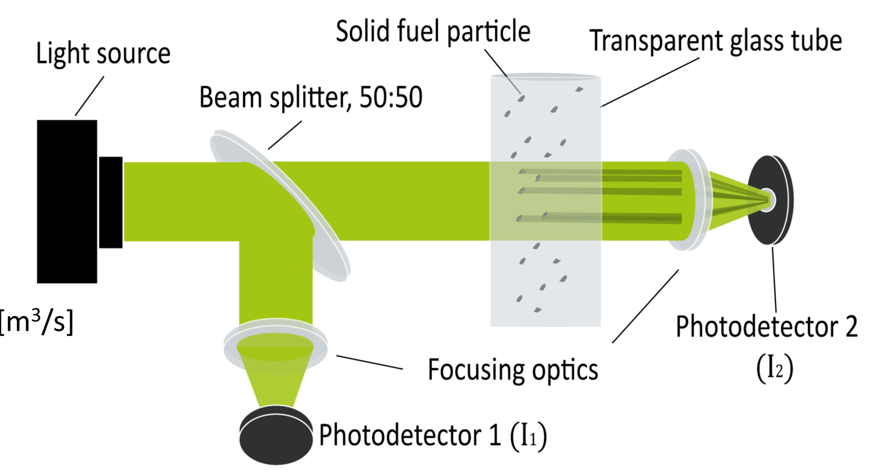

Figure 5: Beam extinction method setup

Results & Discussion

Laboratory experiments with dynamic weighing scale

- Reliability of BEM is put under test.
- BEM gives matching results with weighing scale for three different mass flow rates.

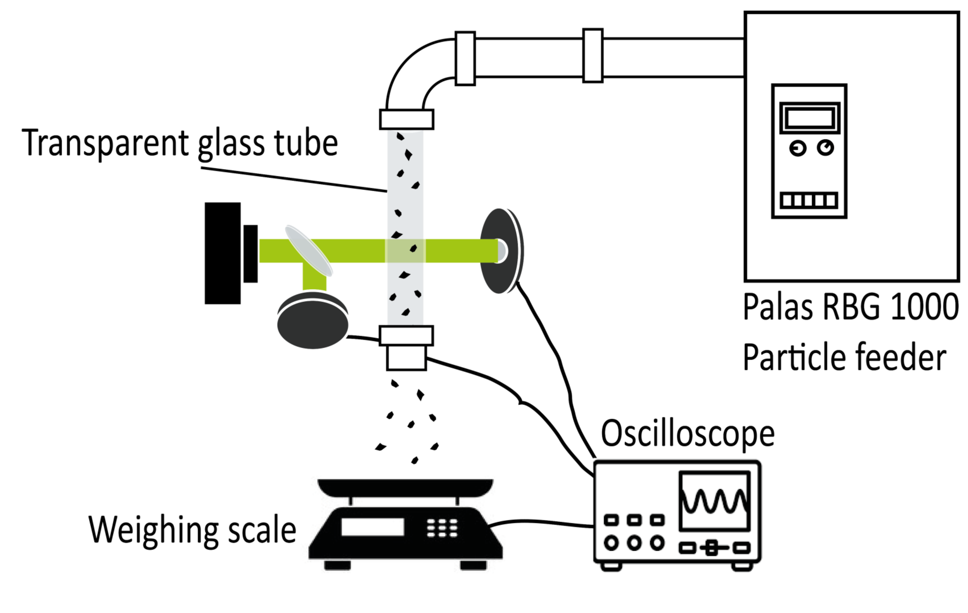

Figure 6: Sketch of laboratory experimental setup

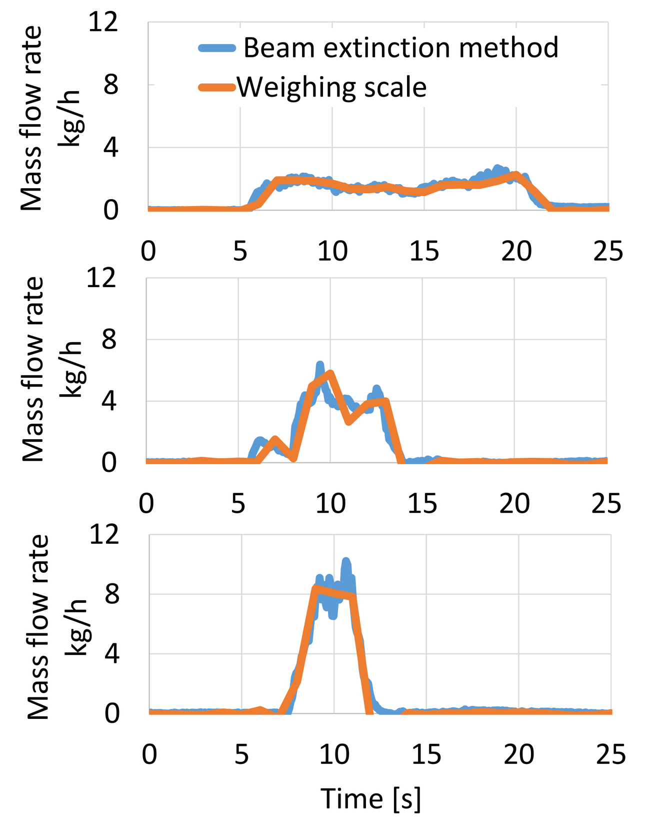

Figure 7: Mass flow rates measured by BEM and the weighing scale

Results & Discussion

Combustion chamber experiments

Characteristics of the solid fuel feeder (Twin screw feeder)

- Standard deviation (std) and flicker frequency of the mass feeding rate ($\dot{m}$) increases with the mean mfr.

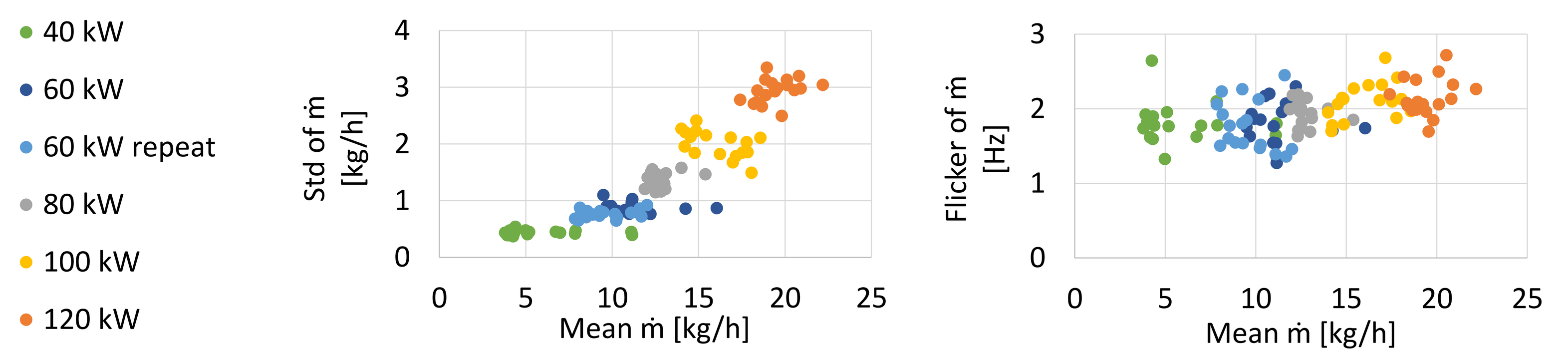

Figure 8: Statistical analysis on biomass feeding into the combustion chamber: Mean, standard deviation and flicker frequency

Fluctuations in flame temperature

- Both, standard deviation and flicker frequency, first decrease and then increase as getting away from the dump plane.

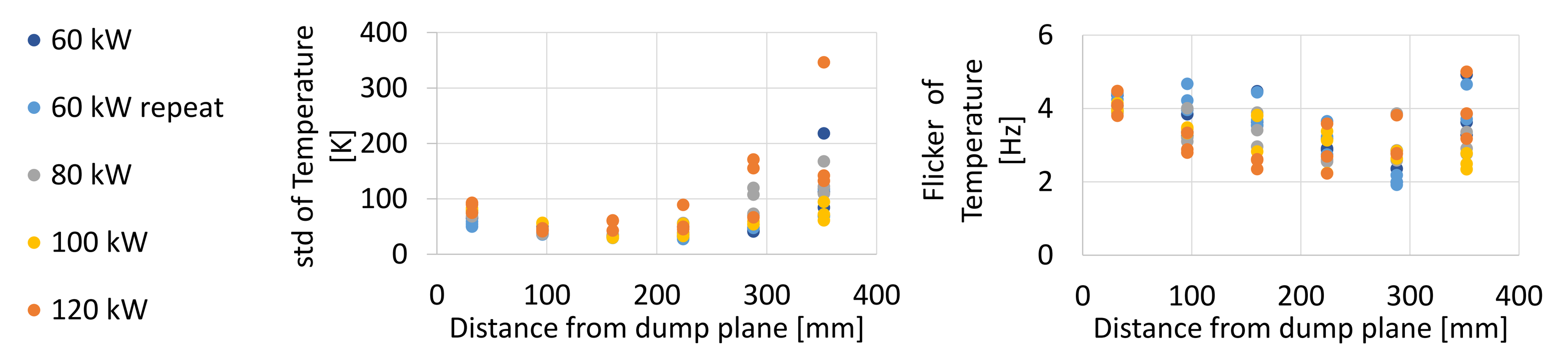

Figure 9: Oscillatory behaviour in flame temperature (T) at different sections of the flame

Effect of fluctuations in solid fuel feeding on the flame temperature

- The fluctuations in the particle feeding line has no significant effect on the transient flame behavior.
- This is attributed to the fact that the oscillatory behavior of the particle mass flow rate is not strong enough to cause distinguishable change in the flame.

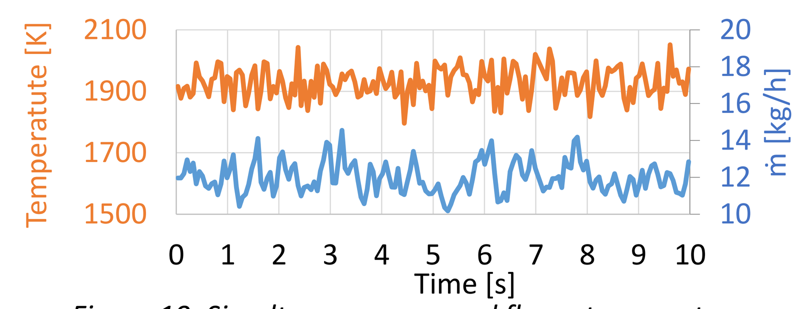

Figure 10: Simultanous measured flame temperature (orange) and biomass mass feeding rate (blue)

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