Surface Temperature Measurement of Black Liquor Droplet Combustion

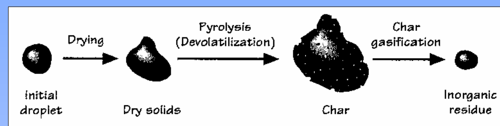
Andrew Mackrory, Elvin Ip, Kenth Svensson, Dale Tree, Larry Baxter

ACERC, Chemical and Mechanical Engineering Departments, Brigham Young University, Provo, Utah

Objective

Simultaneously measure black liquor droplet size and shape (swelling), temperatures (internal and surface), and mass loss during combustion.

Compare these data to predictions from a 1-D transient droplet combustion model.

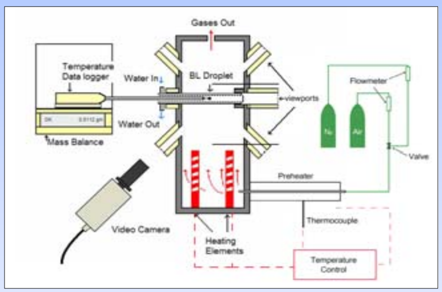


Stages of black liquor droplet combustion.

Background

Droplet entrainment and burning dictate the overall conversion processes in the recovery boiler. There is a need in the literature both for surface temperature measurements and simultaneous measurements of mass, temperature, and size.

Experimental Method



Droplets: 1-5 mm ∅, ~70 % solids content
Furnace gases: Air or Nitrogen
Furnace temperatures: 700 or 800 °C
Camera: UNIQ UC 600 CL RGB CCD camera (30 fps)

A single black liquor droplet is placed on a thermocouple in a furnace. Combustion and data acquisition begin when the water jacket around the thermocouple is retracted.
The thermocouple measures internal temperature, while the camera measures size and surface temperature. Mass loss is recorded with a mass balance.
The three orthogonal viewports allow shape reconstruction using three cameras.

Two-color Pyrometry

Surface temperature is measured using broadband two-color pyrometry. The camera is calibrated spectrally using a monochromator (see plot above), and for sensitivity using a blackbody calibration source.
Calibration images are used to quantify system uncertainty, which is dominated by shot noise.
Custom MATLAB code is used to solve the equations below simultaneously for each pixel in a data image, resulting in a temperature and emissivity* map.

Two-color Equations

P – pixel value from camera
S – pixel sensitivity
E – black body emissive power
ε – emissivity
α – pixel spectral response
λ – wavelength

Subscripts
R – Red
B – Blue
λ – spectral
b – black body

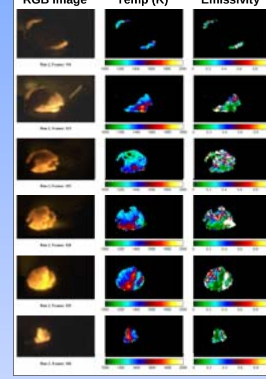
*Gray emissivity is assumed for this application.

Acknowledgements

Funding for this project was provided by the United States Department of Energy and BYU's Mechanical Engineering Department.

Results:

Surface Temperature Measurements*



RGB Image / Temp (K) / Emissivity	Time	Comments
	1.05 s	Drying with ignition at the bottom (Airflow is upwards).
	1.28 s	ISP, devolatilization and char burning.
	1.42 s	Char burning, hole in surface.
	1.52 s	Soot surrounding the particle.
	1.55 s	Char burning dominates.
	2.12 s	Smelt residue at high temperature.

Simultaneous Data

Improvement of Combustion Model using Simultaneous Data

The data was used to improve the 1-D transient combustion model as follows:

1. Devolatilization changed from endothermic to exothermic.

2. Consideration of surface ash to carbon ratio.

Further improvement is likely by including flame heat release and droplet swelling effects in the model.

Conclusions

Simultaneous measurements provide a more complete description of droplet combustion including:

1. Surface temperature data
   (Measurable range: T ≥ 1000 K with -40 ~ +80 K uncertainty)
2. Temperature gradient in droplet ≥ 350 K.

Comparison of data with model predictions (for an oxidizing environment) show the importance of:

1. Enthalpy of devolatilization. (assumed exothermic)
2. Surface ash to carbon ratio during particle burnout.
3. Heat release from the flame.
4. Swelling effects on transport properties.

***Typical Uncertainty of the Camera System**