In-line particle measurement in a recovery boiler using high-speed infrared imaging

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Outline

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2. Aim of the Research
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4. Black liquor spray droplets
5. Black liquor guns visualized
Background of Kraft recovery boilers

- Kraft pulping is the most common method of producing pulp.
- Black liquor is a side product of pulping process, and it consists of inorganic and organic materials.
- Black liquor is burned in a recovery boiler.

Photo: A recovery boiler [source: Andritz Group]
Background of Kraft recovery boilers

- A recovery boiler has two main functions:
  1. To recover valuable inorganic cooking chemicals
  2. To utilize combustion energy from organic portion of the black liquor
- In modern pulp mills, the heat and power generation covers more than the internal consumption.
- Globally, black liquor is among the most important fuels in the world.
Recovery boiler lower furnace

[Vakkilainen, 2000]
Aim of the Research

- to detect the shape and angle of a black liquor spray sheet horizontally from the opposite side through an operating boiler furnace,

- to visualize velocities, shapes and sizes of the black liquor spray droplets from close distance and

- to detect black liquor guns and their spray sheets vertically downwards from the above openings

Measurements were done in a functional recovery boiler in a pulp mill.
Shape of black liquor spray sheet

Measurement equipment consisted of

- A high-speed infrared camera operating on the 1.5-5.1 µm atmospheric transmission window

- A suitable optical bandpass filter on 3.5-4.1 µm imaging window

- A gold mirror on a 45 degrees angle for peering inside the boiler furnace and protecting the camera from flying hot particles
Shape of black liquor spray sheet

Camera location: left wall – spray level – middle opening

Captured IR video from the opposite side through an operating boiler furnace, frame rate 870 Hz, integration time 20 µs, pixel resolution 160 x 128:

Average image of the IR video. A black liquor spray is seen on the right opening. The middle opening without a spray nozzle is also seen:
Black liquor spray droplets from close distance

Measurement equipment consisted of:

- The high-speed infrared camera with the bandpass filter
- An endoscope tube, about 1.5 meter long rectangular tube, with protective pressure air flow
- No gold mirrors (endoscope has option to attach small gold mirror at 45 degrees angle for peering up, side or down directions)
Black liquor spray droplets from close distance

Camera location: right wall – spray level - left opening

Captured IR video from black liquor droplets near the endoscope, frame rate 870 Hz, integration time 120 µs, pixel resolution 160 x 128:

An example frame of the IR video, certain droplets were chosen randomly to determine their velocities, shapes and sizes:
Black liquor guns visualized from upper level

Camera location: left wall – upper level - middle opening

Place of the recovery boiler left wall vs. videos

The endoscope now had a small gold mirror at 45 degrees angle, peering at down direction. The shapes of the three black liquor spray guns and fouling around them could be visualized from the IR video.
IR video analysis

- For close distance measurements: velocities, shapes and sizes of the black liquor spray droplets were defined in a more detailed analysis.

- Resulting average velocity of the spray particles was about 9 meters per second.

- For particle size analysis, an image inspection routine including thresholding and particle filters was created. First, two sets of 200 images were selected randomly from different parts of the IR measurement video. Then, 9098 particle sizes were classified according to their sizes - assuming that all particles would be of spherical shape.
Analyzed liquor particle size distribution
Conclusions

- In this study, the particles of black liquor sprays were imaged using a high-speed infrared camera and a suitable optical bandpass filter on mid-infrared spectral range.

- Visibility through hot gas streams was successfully obtained in mid-infrared range and temperatures, sizes, velocities and shapes of the particles could be measured inside the recovery boiler.

- Measurement results were coherent with measurement results of Dr. Kankkunen et.al., which were obtained from the same furnace at the same time.
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