Particle Diagnostics by Laser Levitation

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Objectives:

- Accurately explain mechanism operating in optical trapping of absorbing particles
- Trap much larger particles (1-2 mm) in order to allow model development
- Image trapped particles with CCD cameras
- Observe and model changes in diameter, temperature, mass, and composition of particles as part of combustion characterization
- Characterize drying and devolatilization rates of black liquor droplets under the range of conditions encountered in commercial recovery boilers

Progress to date:

- Preliminary calculations performed to predict maximum particle sizes levitated with a 10-watt laser beam, accounting for both momentum transfer and buoyant forces
- Successful levitation of particles in both horizontal and vertical arrangements
- Program near completion which allows the input of a bitmap image and will then output the temperature for each pixel, thus allowing the prediction of particle temperature profiles
- Began development of free convection velocity profile around suspended particles applying general equations of motion in spherical coordinates

Significant observations:

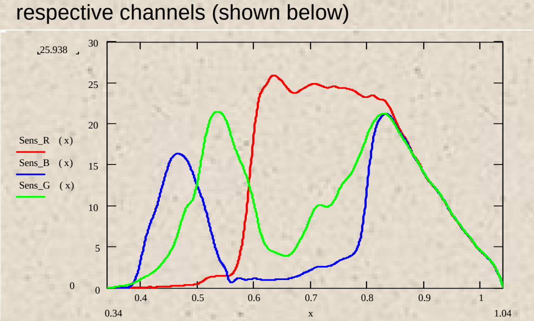
- Particles become trapped near focal point despite beam orientation – even when the beam is directed downward or at an angle
- Performed successful levitation of black liquor, aluminum, and tungsten particles with sizes up to ~40 microns
- Trapping becomes easier when operating at a vacuum of 100-400 torr, however, under extreme vacuum (<50 Torr) particles become more difficult to trap
- Particles are significantly easier to trap with a vertical orientation of the laser beam

Temperature Calculation:

- An algorithm for temperature calculation using a three color CCD camera is applied which generates temperatures for each pixel from intensity data
- Because the reflection of green laser light (532 nm) saturates the optical sensors, the green aspect is filtered using a graphics program
- The equations used to calculate the temperature profiles are shown below:

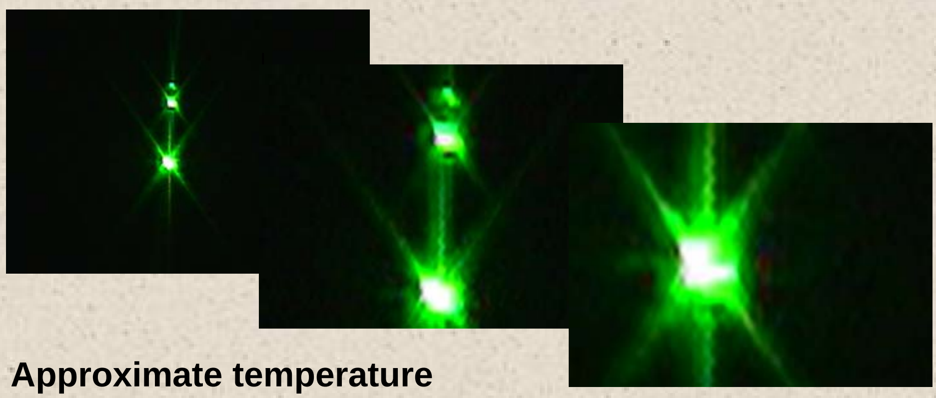
$$\frac{I_B}{I_R}=\frac{\int_{\lambda_1}^{\lambda_2} S_B(\lambda)E(\lambda,T)\,d\lambda}{\int_{\lambda_1}^{\lambda_2} S_R(\lambda)E(\lambda,T)\,d\lambda} \qquad E(\lambda,T)=\varepsilon\frac{c_1\lambda^{-5}}{e^{c_2/\lambda T}-1}$$

- Where I is the intensity value for the respective channel, c_1 and c_2 are constants determined by the camera sensor, and $S(\lambda)$ is the sensitivity curve for the respective channels (shown below)



Particle magnification:

- Below is the progressive magnification of three trapped black liquor particles (the largest of the three is ~40 microns) with a Sony digital camcorder (exact magnification unknown):



Approximate temperature profile:

- Below is an approximate temperature contour of the magnified black liquor particle shown. The constants were estimated and the sensitivity curves were fit to
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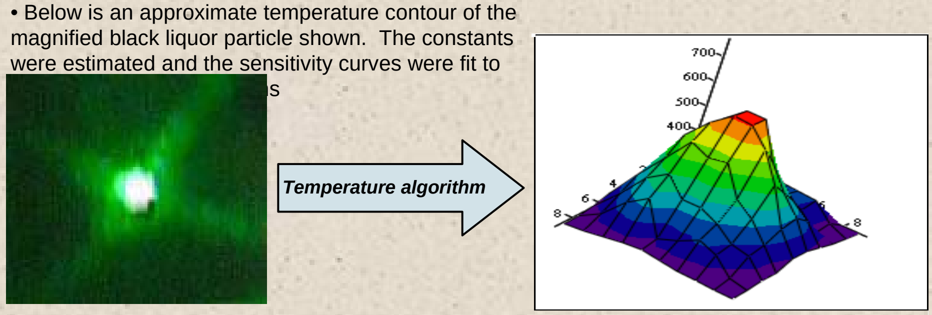

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Major challenges:

- Due to particle size, even minimal air currents affect particle stability and may "blow" them out of the trap
- Difficult to take clear, magnified pictures of trapped particles due to short working distances of camera lenses
- Developing ways to image particles more effectively to qualify particle shapes and orientations while trapped
- Developing temperature calculation algorithm using specific camera sensitivity profiles is made difficult due to limited access to sensitivity curves
- Effectively filter reflected laser light in order to accurately predict temperature profiles without the green aspect skewing results

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