A Method of Measuring the Emittance of Ash Deposits in a Coal Fired Reactor

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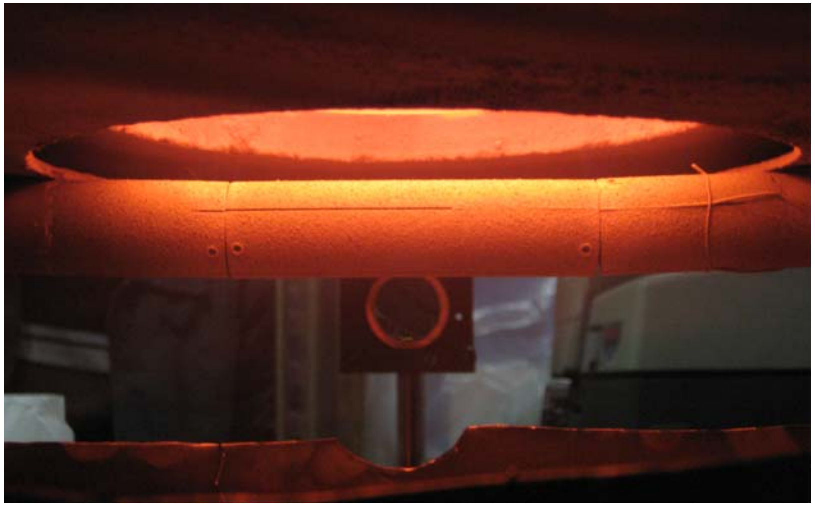

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Grand Challenges for Engineering in the 21st Century:

- Make solar energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse-engineer the brain
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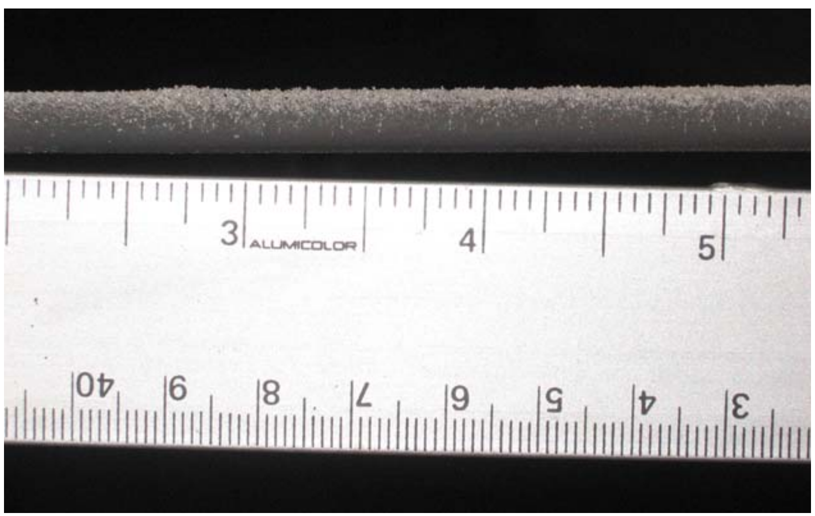
Coal as an Energy Source

- The United States has more high quality coal than any country in the world (reserves to last 250 years)
- Presently, coal is used to power 57% of U.S. electrical generation
- By 2030, coal will account for 48% of the world's electrical power

Background

In a coal fired reactor, ash is formed and accumulates on the walls of the combustion chamber. This deposited ash can significantly affect the thermal transport in the boiler.



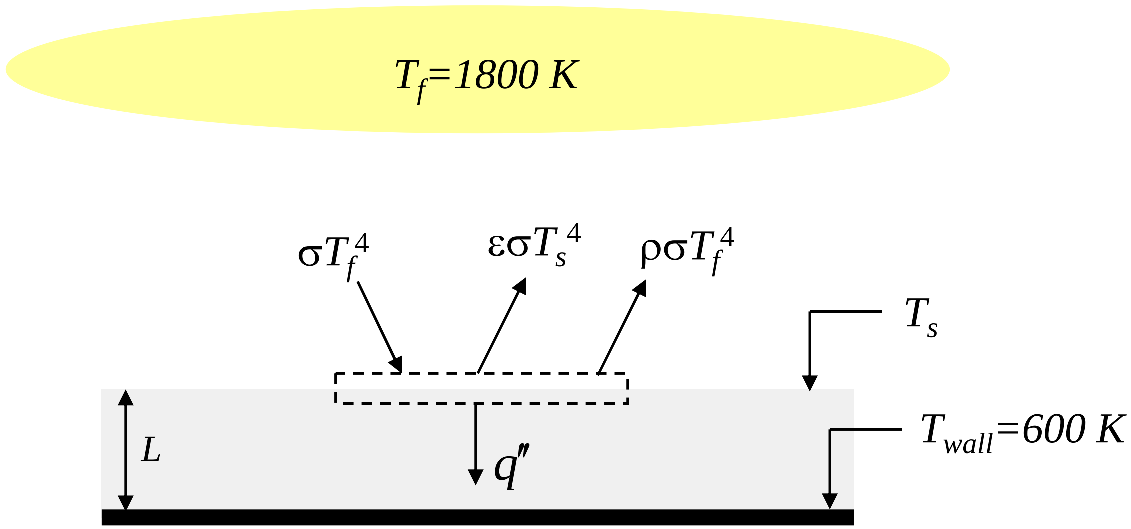
(Zbogar et al)

Objectives

1. Develop a method to simulate the deposition of ash on reactor walls.

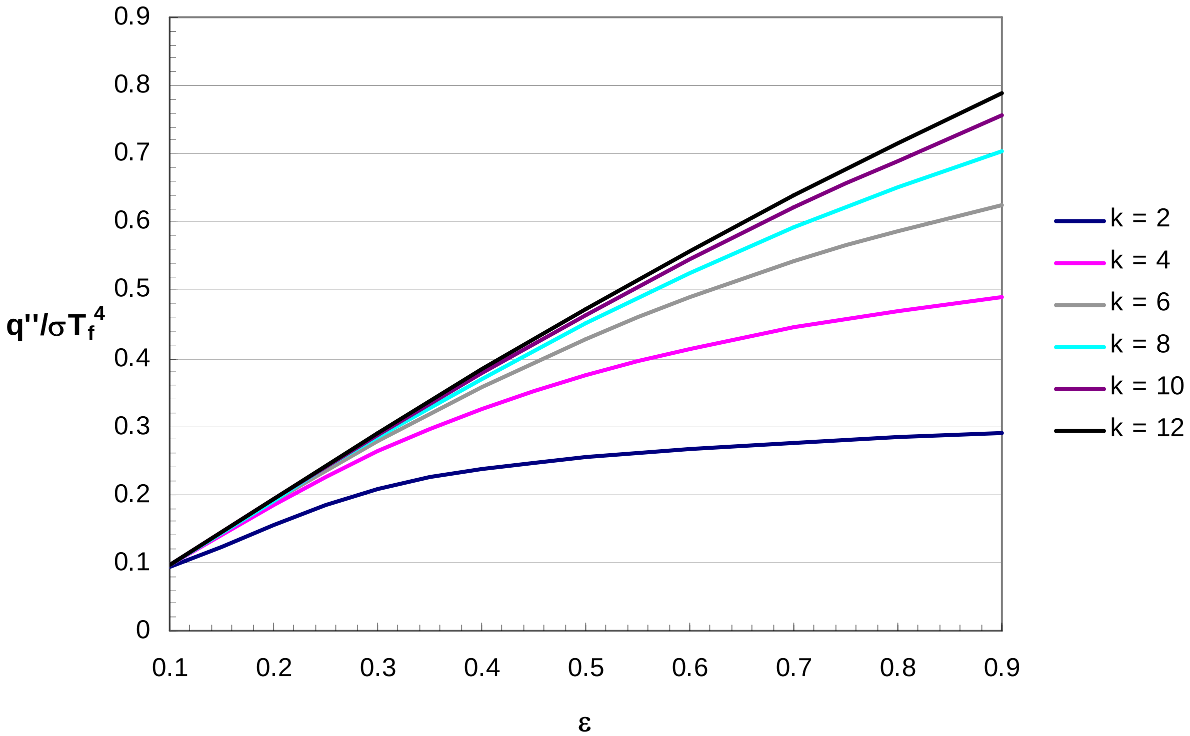
2. Develop a procedure to make accurate, *in situ* measurements of the emittance of the deposited ash.

Importance



$$\frac{q''}{\sigma T_f^4} = \varepsilon\left[1-\left(\frac{T_{wall}}{T_f}+\frac{L\sigma T_f^3}{k}\frac{q''}{\sigma T_f^4}\right)^4\right]$$

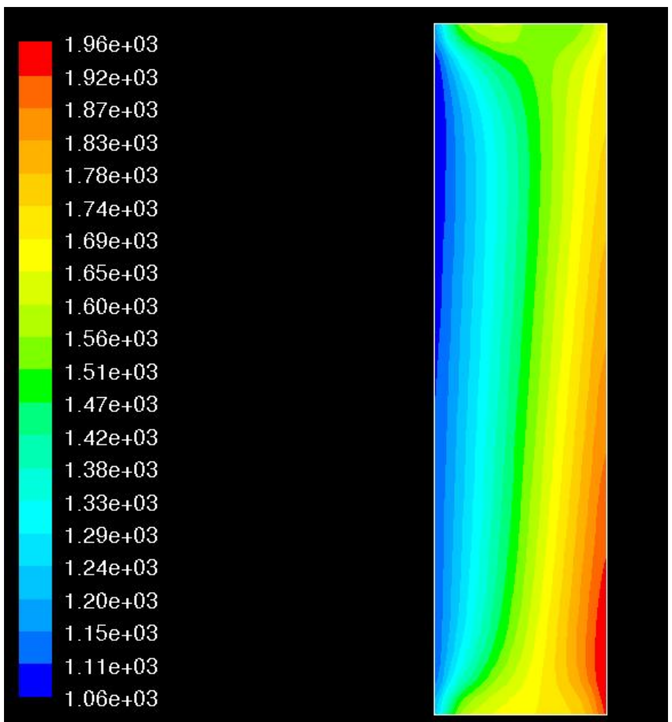
Importance

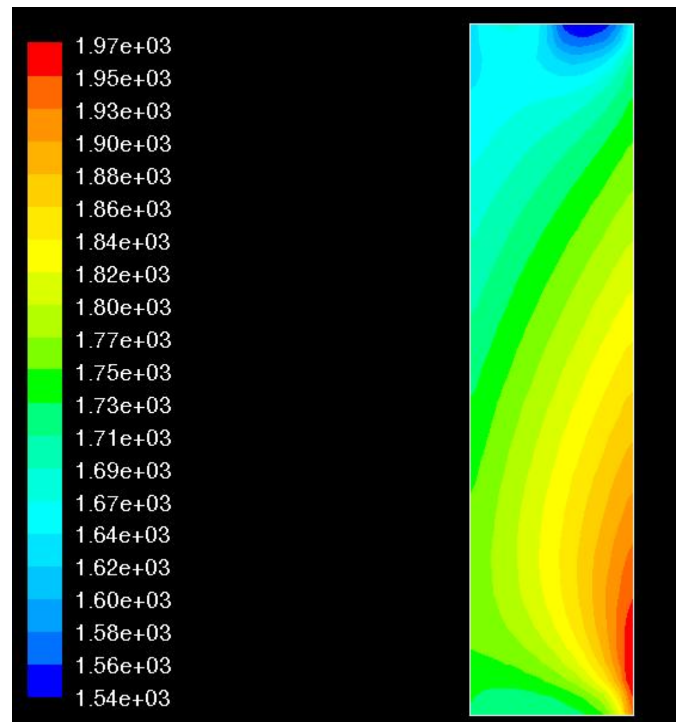


Effect of emittance and thermal conductivity of ash layer on heat flux.

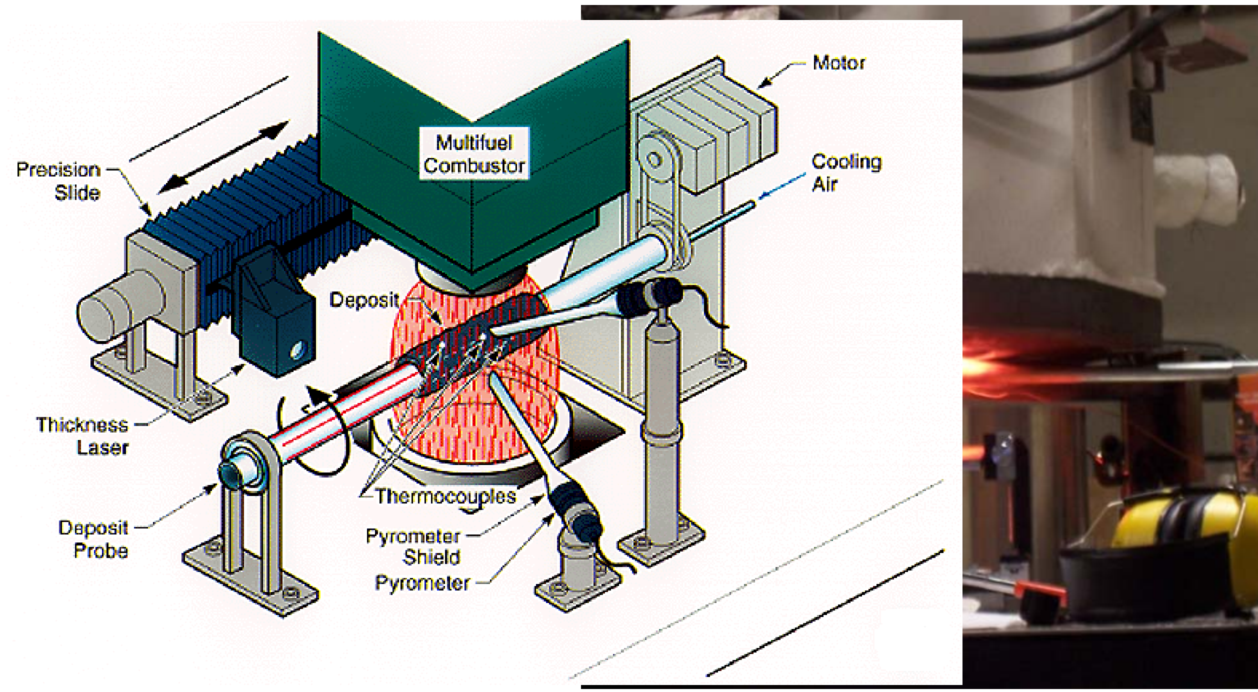
Importance

Knowledge of the properties of the ash deposits will result in better modeling capabilities and improved optimization of the design of coal fired reactors.





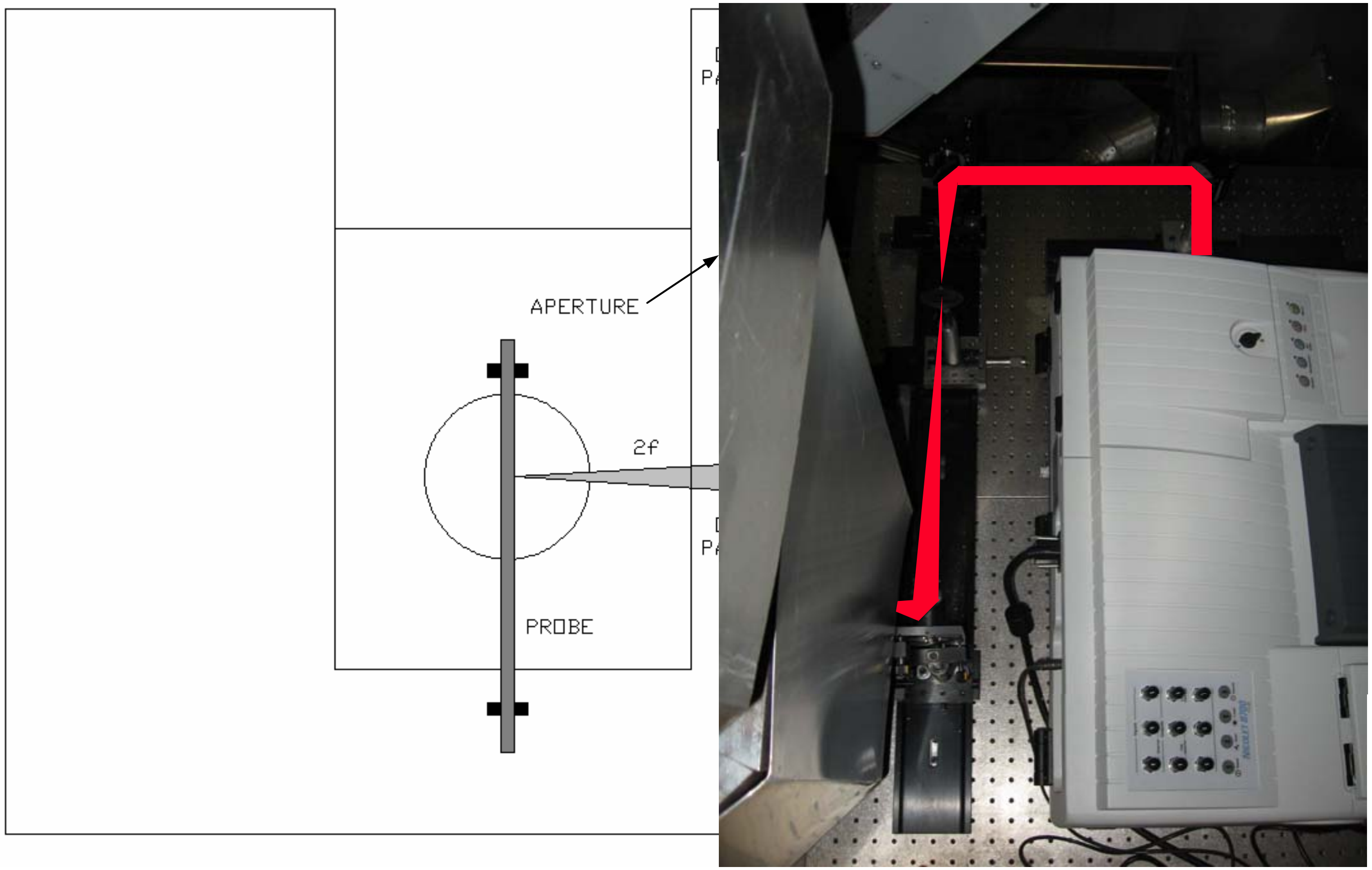
Simulating Ash Deposition



Method

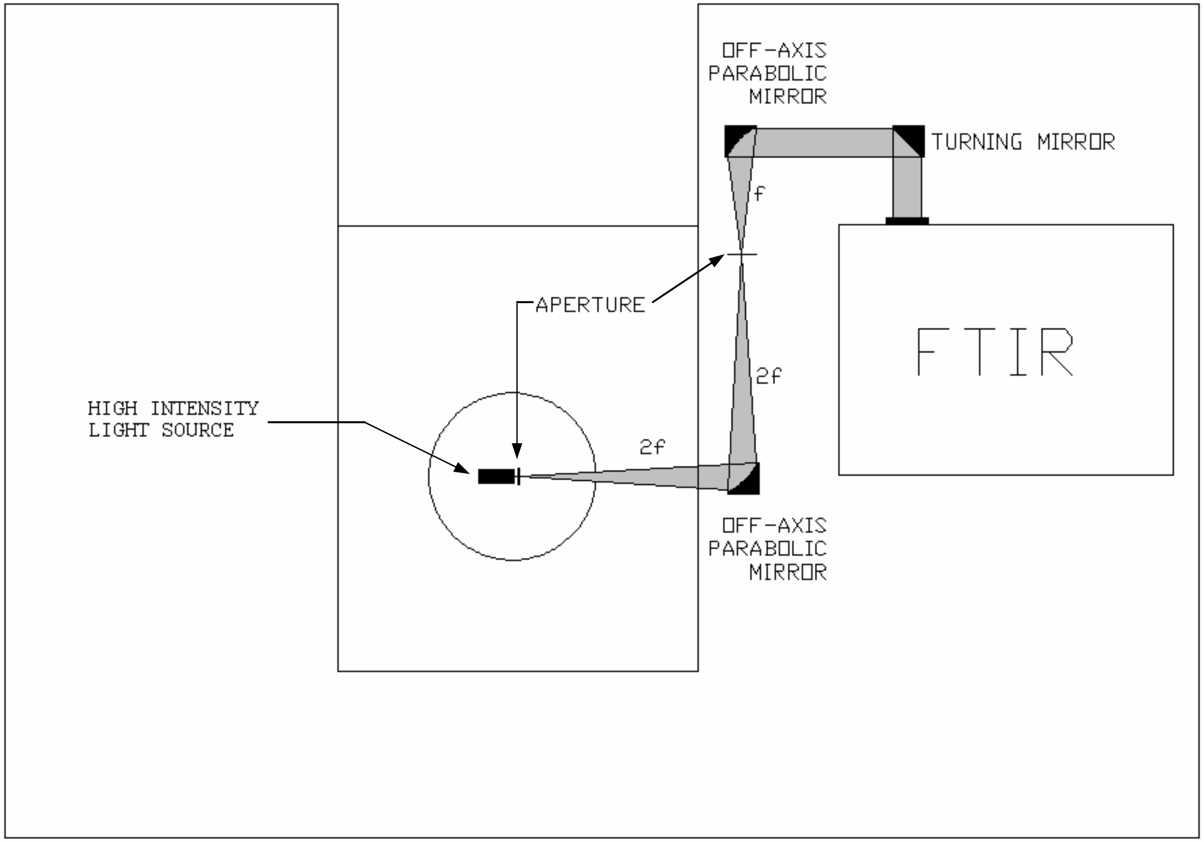
An air-cooled, circular steel probe is placed at the outlet of a multi-fuel combustor. Coal is injected into the top of the furnace and the noncombustible ash constituents accumulate on the probe. Various *in situ* measurements may be made on the deposited ash layer.

Optical Path



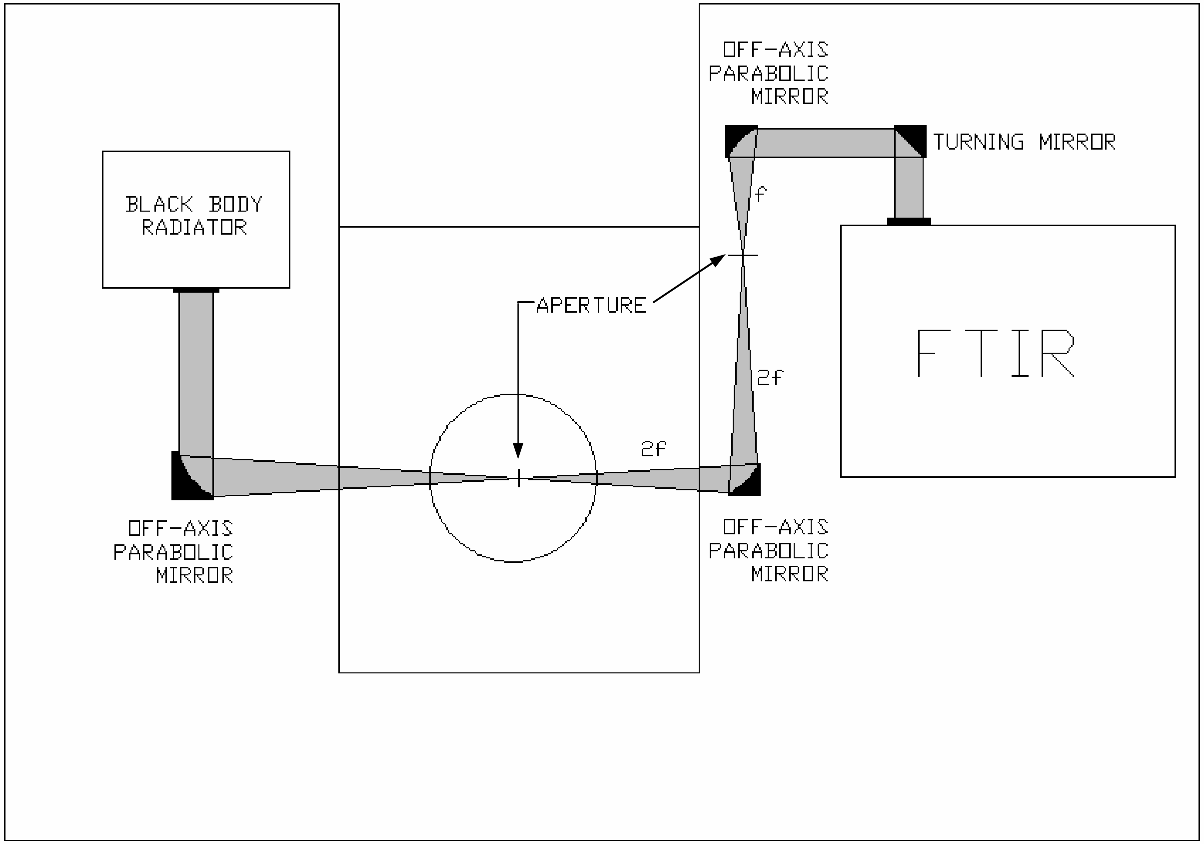
Optical path used to collimate the radiative energy from the deposited ash on the probe and direct it into the Fourier Transform Infrared Spectrometer (FTIR Spectrometer).

Alignment Procedure



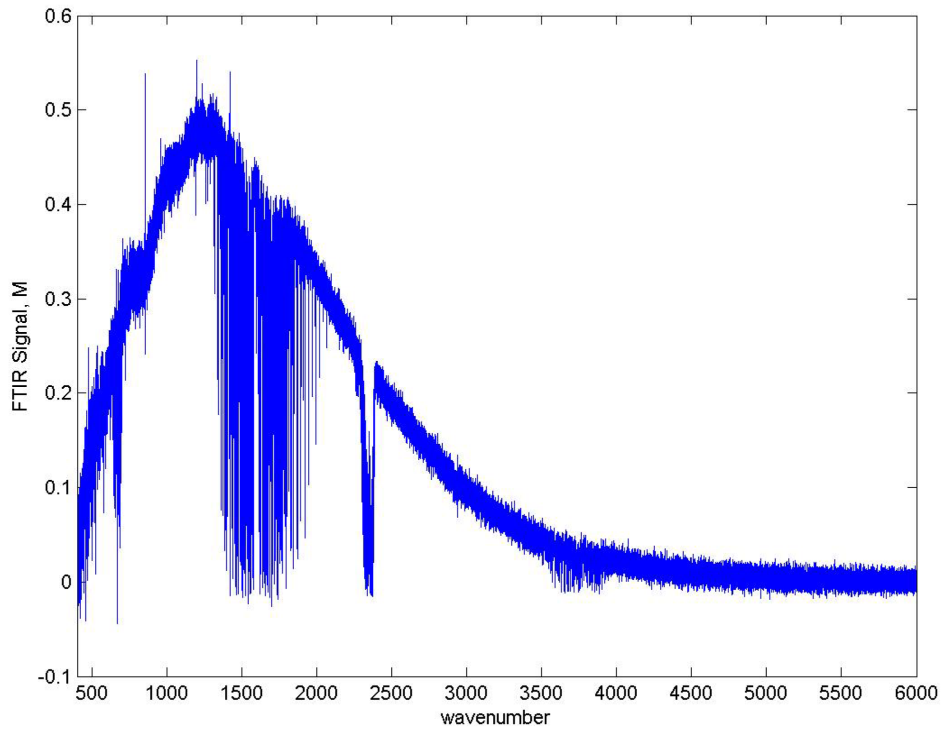
A high intensity fiber optics light is directed through an aperture positioned in the location of the probe. The result is a point source of visible light that follows optical path.

Instrument Calibration



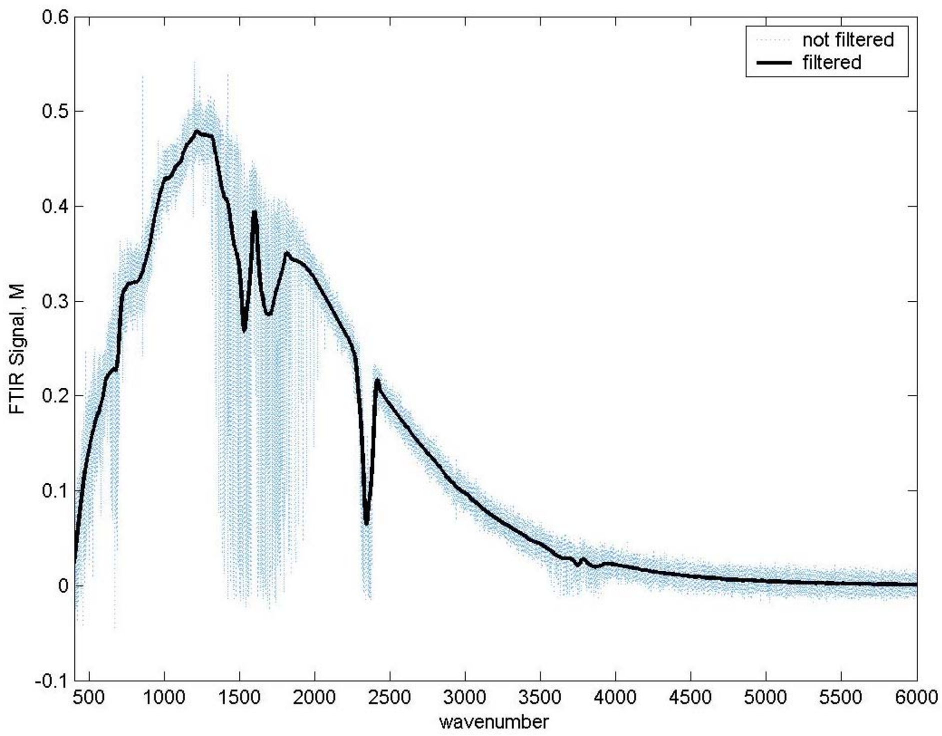
The radiative energy of a black body radiator is focused to the probe location, resulting in a point source of black body radiation that follows the optical path.

Instrument Calibration



Emission signal collected from a black body radiator at 465º C.

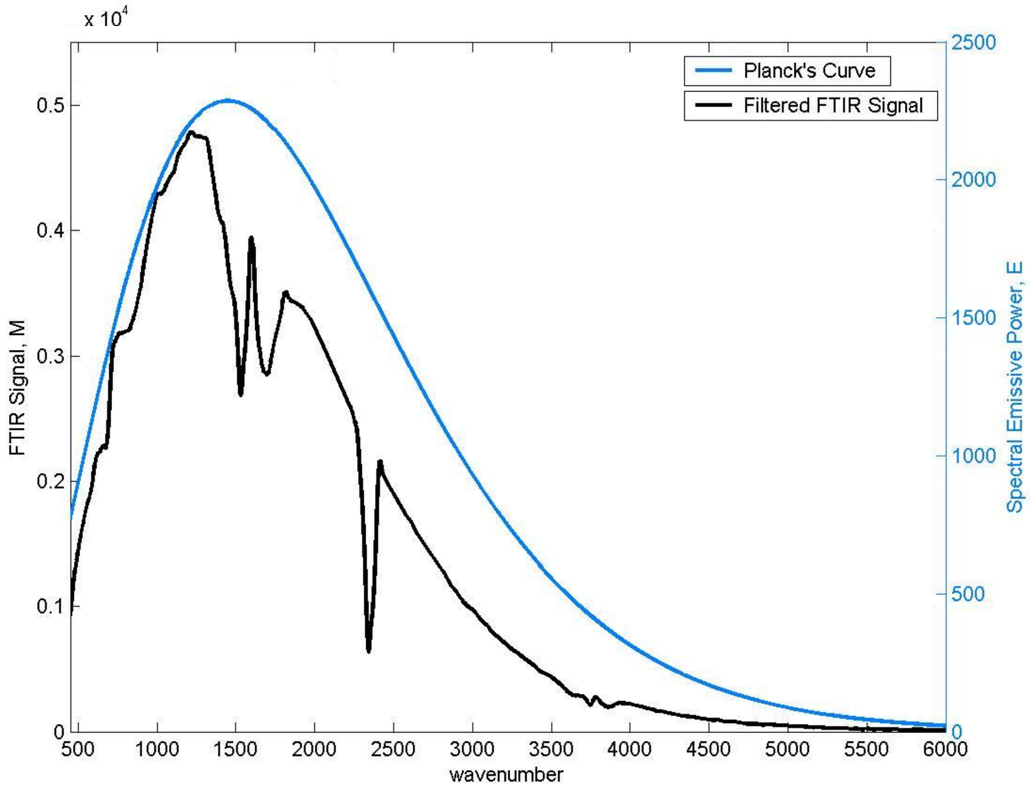
Instrument Calibration



Filtered emission signal from black body radiator at 465º C. The filtering scheme fits quadratic curves over a large number of small intervals.

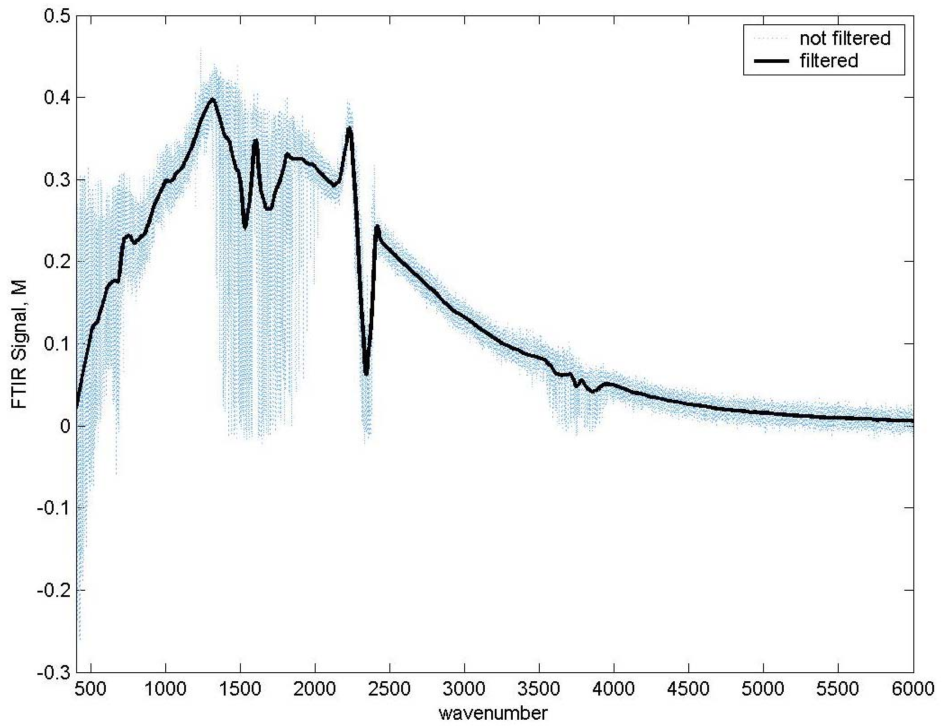
Instrument Calibration

$$IRF(\nu, T_b) = \frac{E_\nu(\nu, T_b)}{M_\nu}$$



The instrument response function (IRF) provides a relationship between the signal measured by the FTIR and the emissive power of the source.

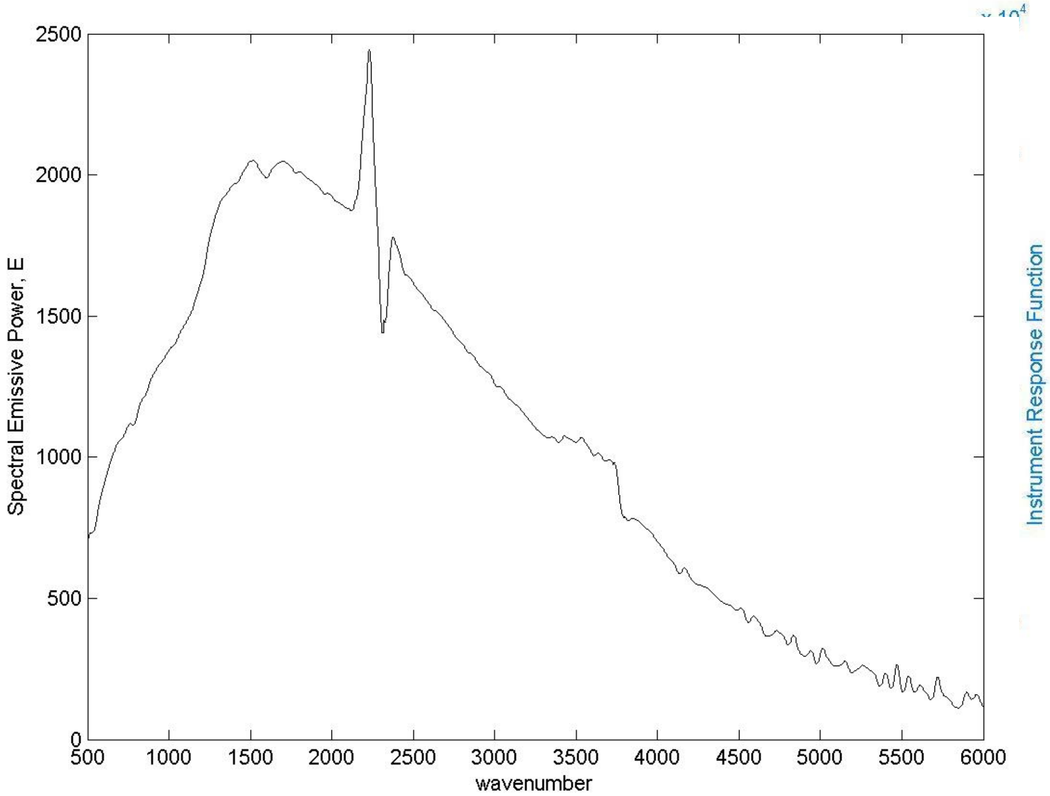
Data Reduction



The emission signal measured by the FTIR from a layer of deposited ash on the probe.

Data Reduction

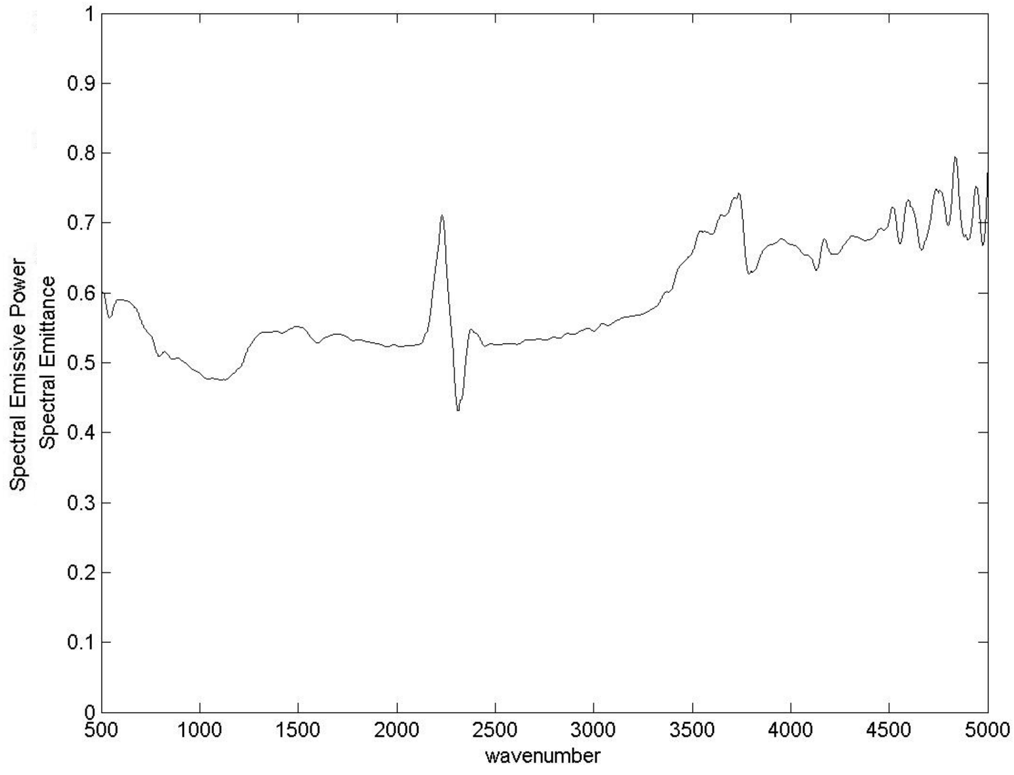
$$E_\nu(\nu, T_s) = IRF(\nu) \cdot M_{\nu,f}$$



The spectral emissive power of the ash deposit can be found by multiplying the FTIR signal by the IRF found during the calibration process.

Data Reduction

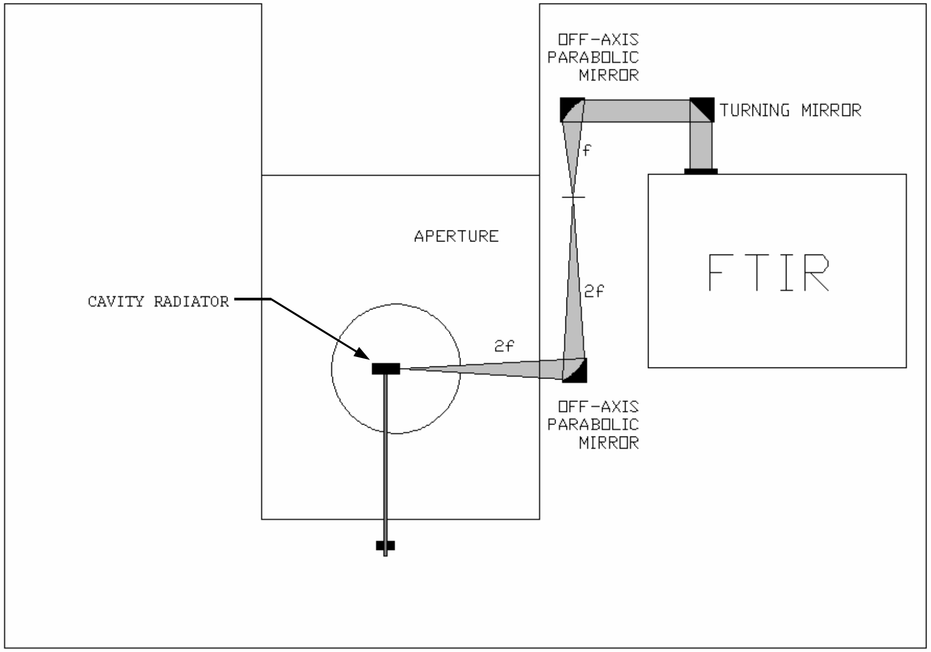
$$\varepsilon_\nu(\nu, T_s) = \frac{E_\nu(\nu, T_s)}{E_{b,\nu}(\nu, T_s)}$$



The spectral emittance of the ash deposit is the ratio of the spectral emissive power of the ash deposit to the black body emissive power at the same temperature.

Future Work

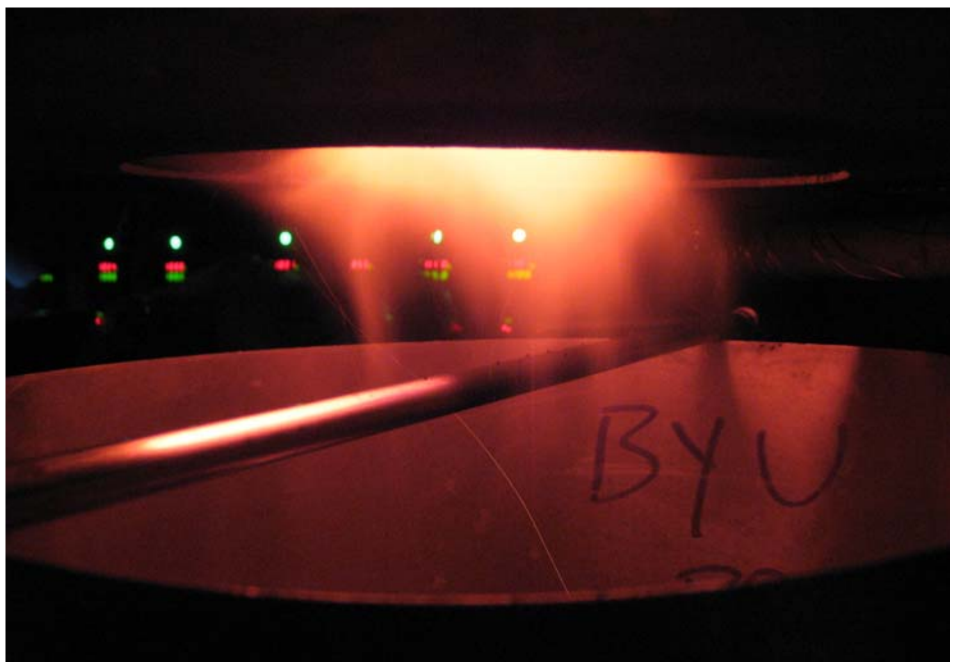
Validation of Method

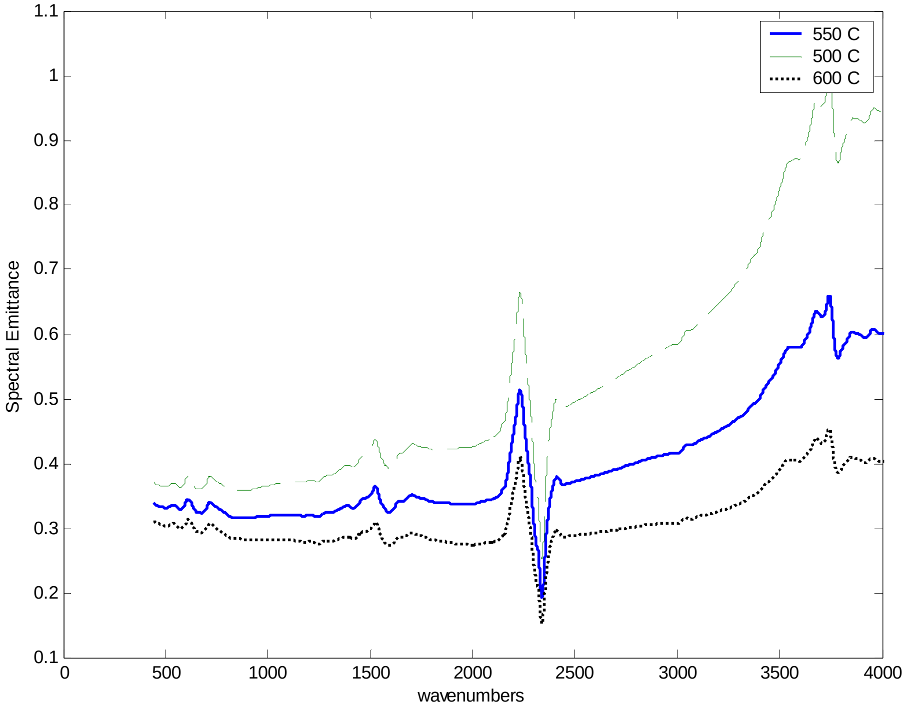


The effective emittance of a cavity radiator will be calculated and compared to the measured emittance.

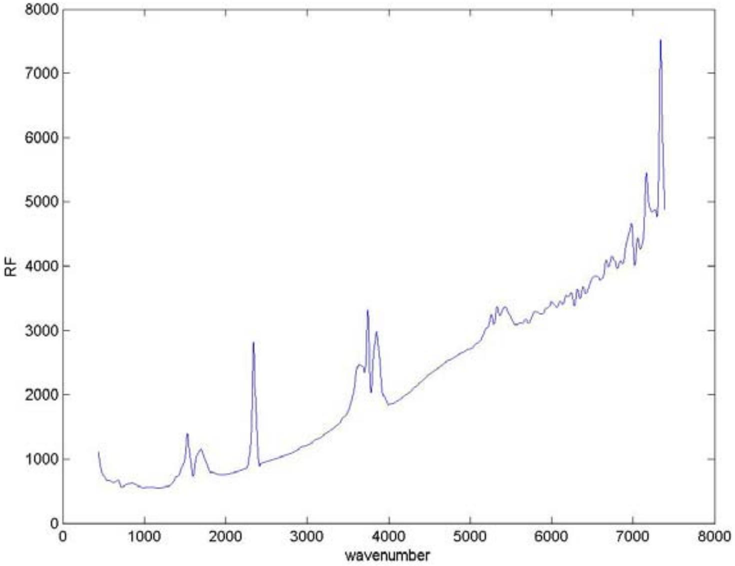
Future Work

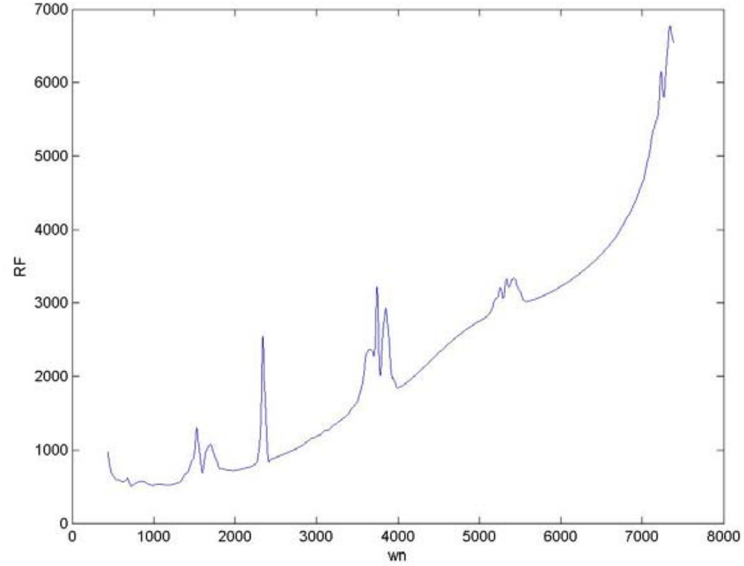
Planned future work includes measuring the emittance of the ash deposits formed by six different coals under both oxidizing and reducing conditions.





Spectral Emittance
wavenumbers
550 C
500 C
600 C
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
500
1000
1500
2000
2500
3000
3500
4000


8000
7000
6000
5000
4000
3000
2000
1000
0
RF
0
1000
2000
3000
4000
5000
6000
7000
8000
wavenumber

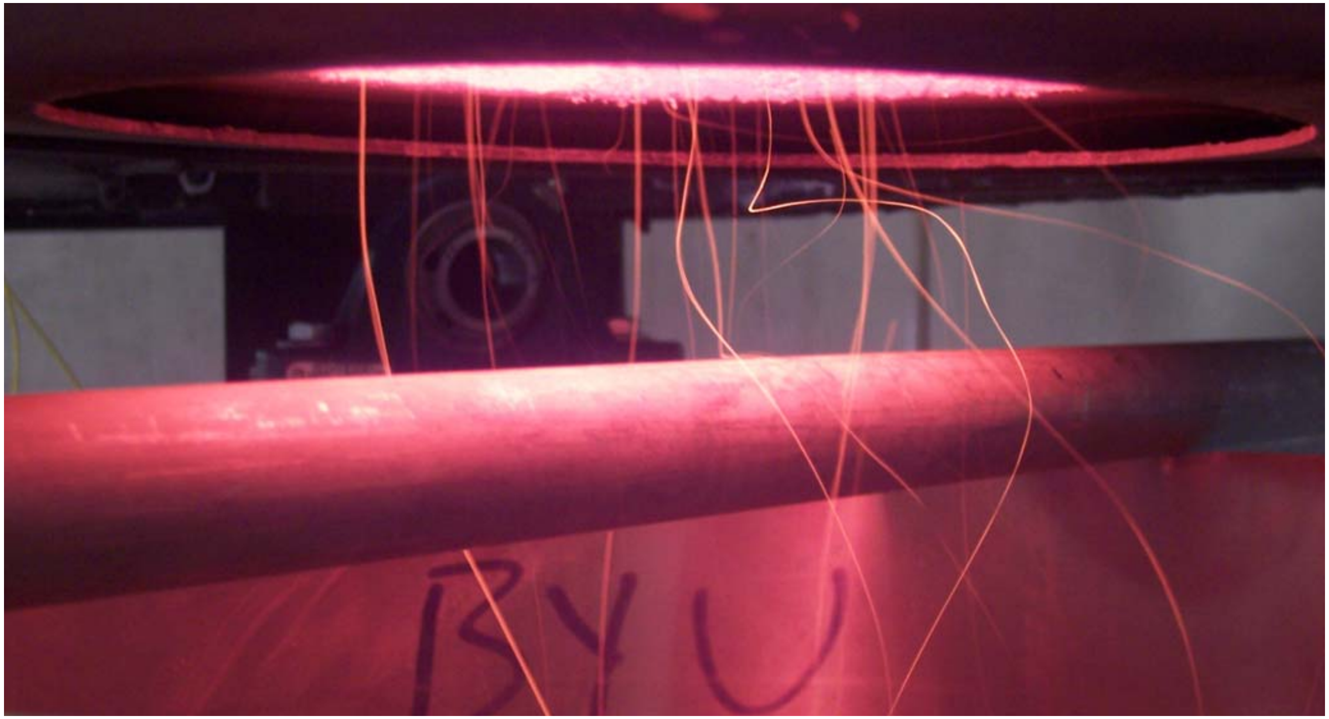

7000
6000
5000
4000
3000
2000
1000
0
RF
0
1000
2000
3000
4000
5000
6000
7000
8000
wn

b = spectral radiance

$$b_1 = \frac{c_1 \varepsilon_1}{\lambda_1^5} \exp(-c_2 / \lambda_1 T) \qquad b_2 = \frac{c_1 \varepsilon_2}{\lambda_2^5} \exp(-c_2 / \lambda_2 T)$$

$$\frac{b_2}{b_1} = \frac{\varepsilon_2 \lambda_2^{-5} \exp(-c_2 / \lambda_2 T)}{\varepsilon_1 \lambda_1^{-5} \exp(-c_2 / \lambda_1 T)}$$

$$\frac{1}{T} = \frac{\lambda_1 \lambda_2}{c_2(\lambda_2 - \lambda_1)} \left[\ln(b_2 / b_1) + 5 \ln(\lambda_2 / \lambda_1) + \ln(\varepsilon_1 / \varepsilon_2) \right]$$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