The influence of temperature on the spectral emittance of ash deposits taken from a 1.5 MW, pulverized coal test facility

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Introduction

- This work is part of the DOE-sponsored Carbon-Capture Multidisciplinary Simulation Center (CCSMC).
  - Overall CCSMC goal:
    - Create a predictive model of an industrial-scale, high efficiency, advanced ultra-supercritical oxy-coal fired power boiler.
  - One difficulty:
    - Deposits on the interior of the coal boilers significantly affect the heat transfer from the flame to the working fluid.
    - Deposit emittance can vary significantly over the following parameters:
      - Surface temperature
      - Microscopic structure/chemical composition
      - Macroscopic structure/surface morphology
  - Objective of this work:
    - Measure high-temperature emittance data from deposits in a 1.5 MW, pulverized-coal, oxy-combustion furnace (L1500 furnace)

Ash deposits in the L1500 furnace.

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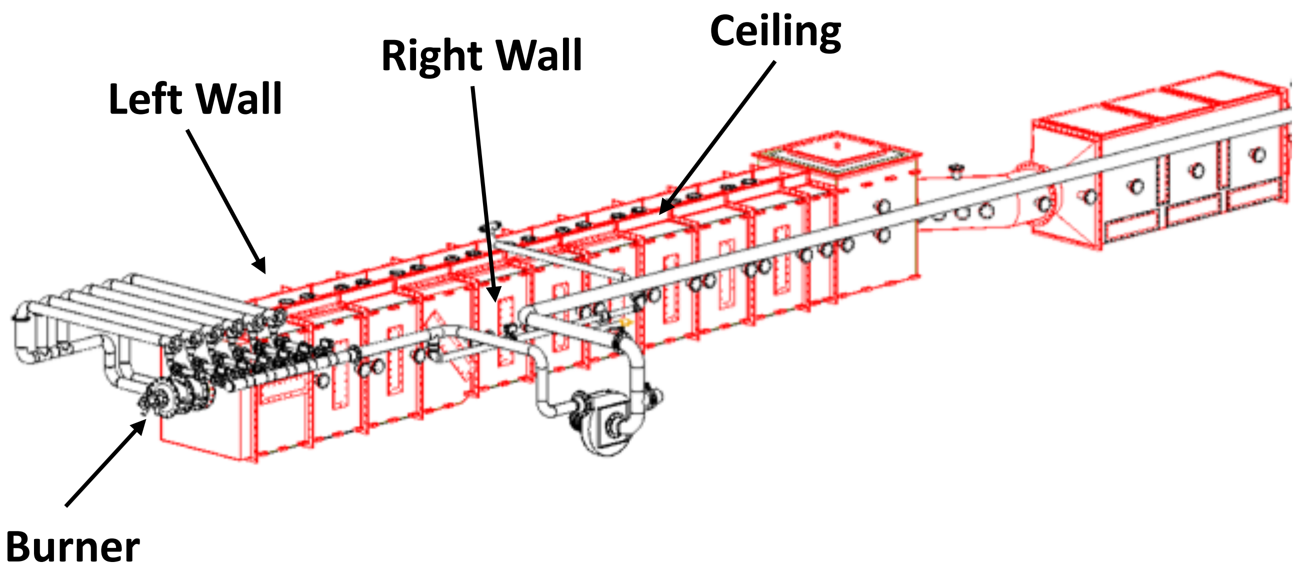
Sample Collection



L1500 furnace (1.1 m x 1.1 m cross section, 13.1 m in length)

- 396 samples were collected from the L1500 interior in a 1 ft x 1 ft grid
  - Surfaces: left wall, ceiling, & right wall

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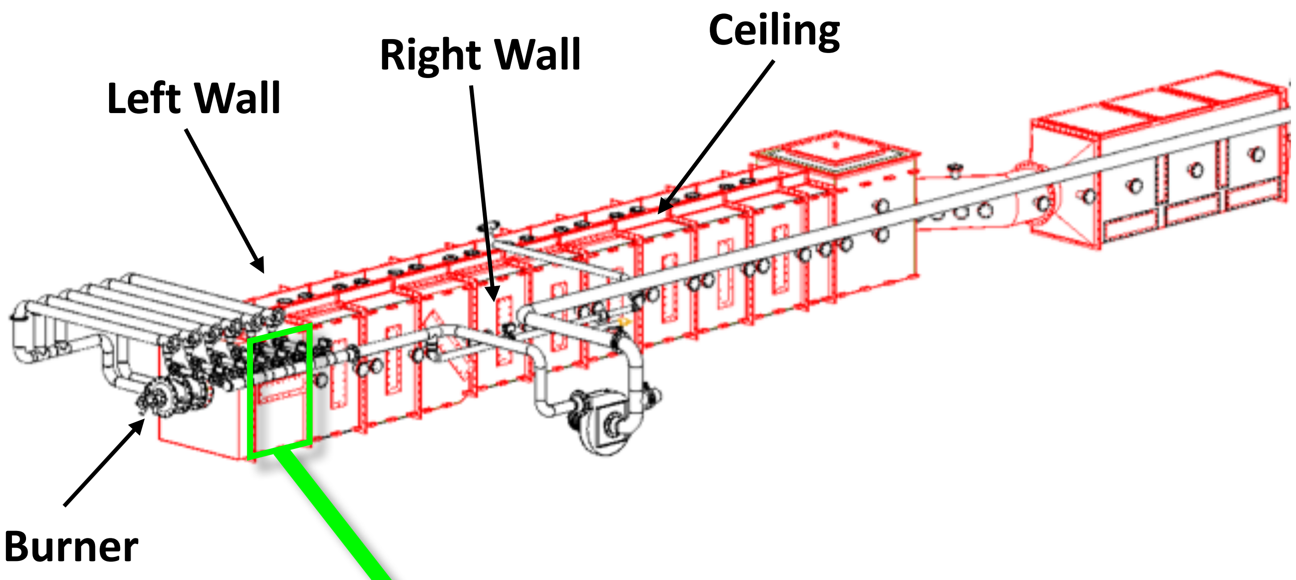
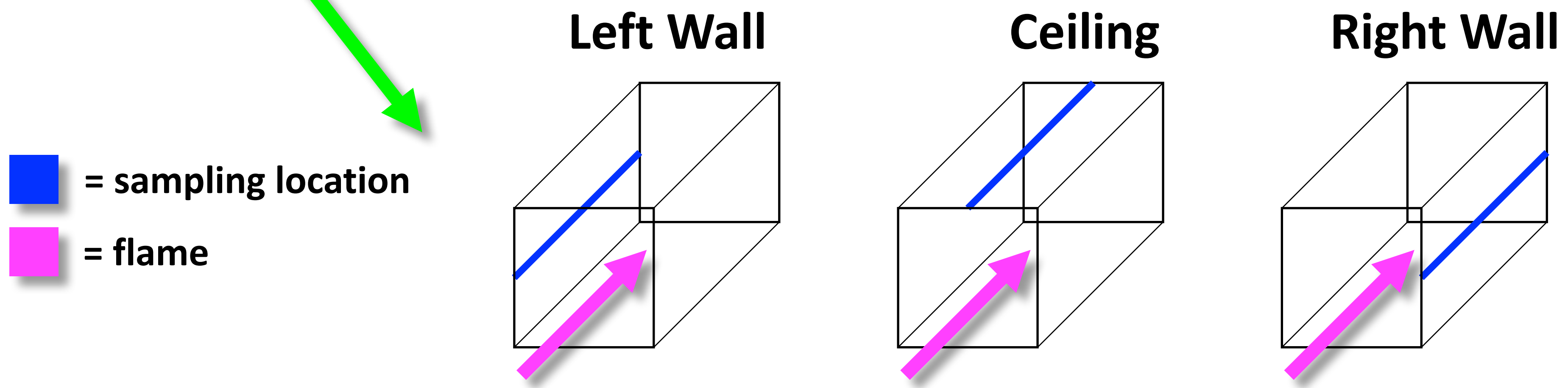
Sample Collection



- 396 samples were collected from the L1500 interior in a 1 ft x 1 ft grid
  - Surfaces: left wall, ceiling, & right wall
- **Five** samples were chosen to be analyzed for emittance at high temperature (up to 1000 °C)
- All five samples were from the first section of the furnace (within 4 ft of the burner)



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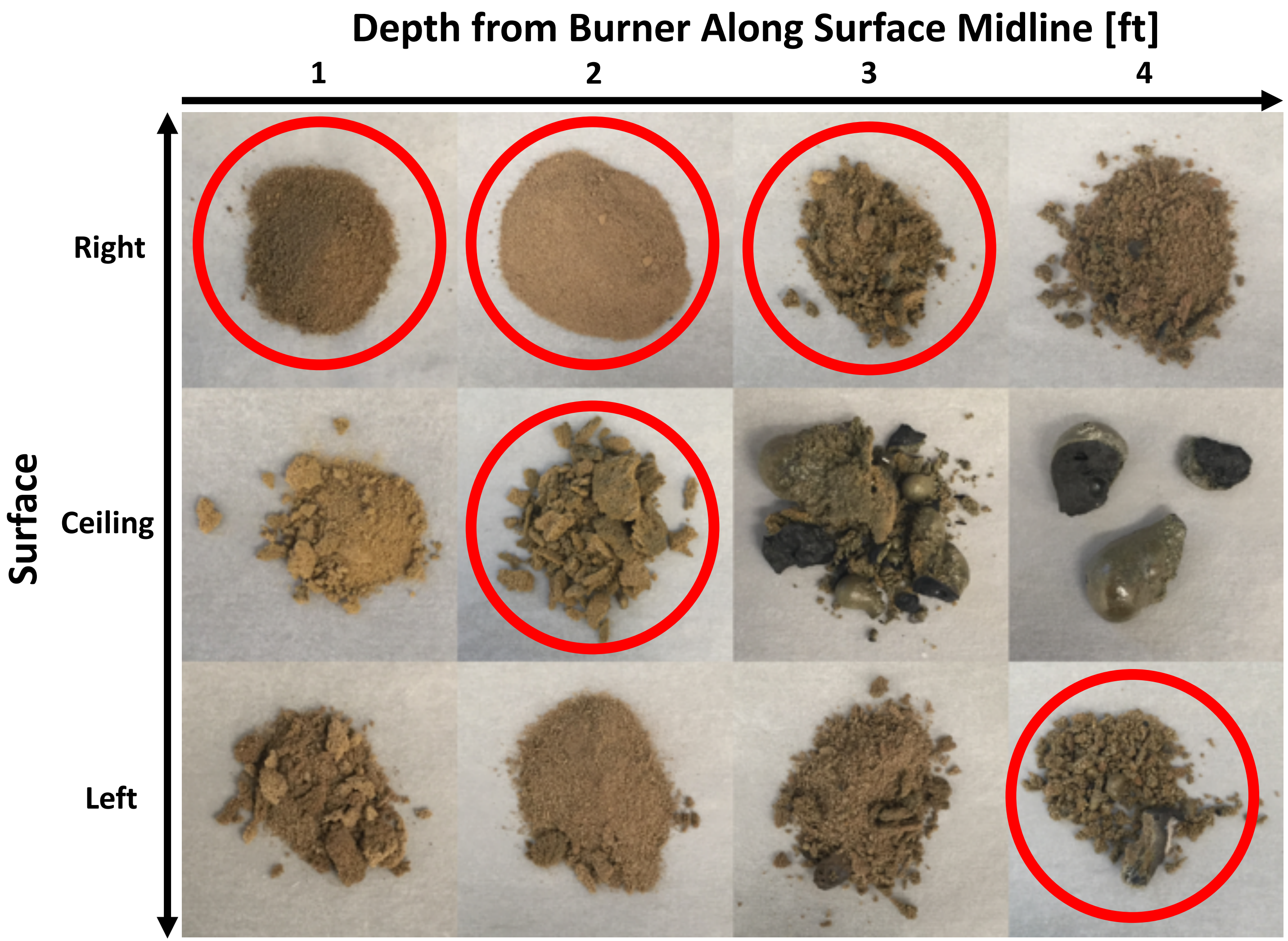
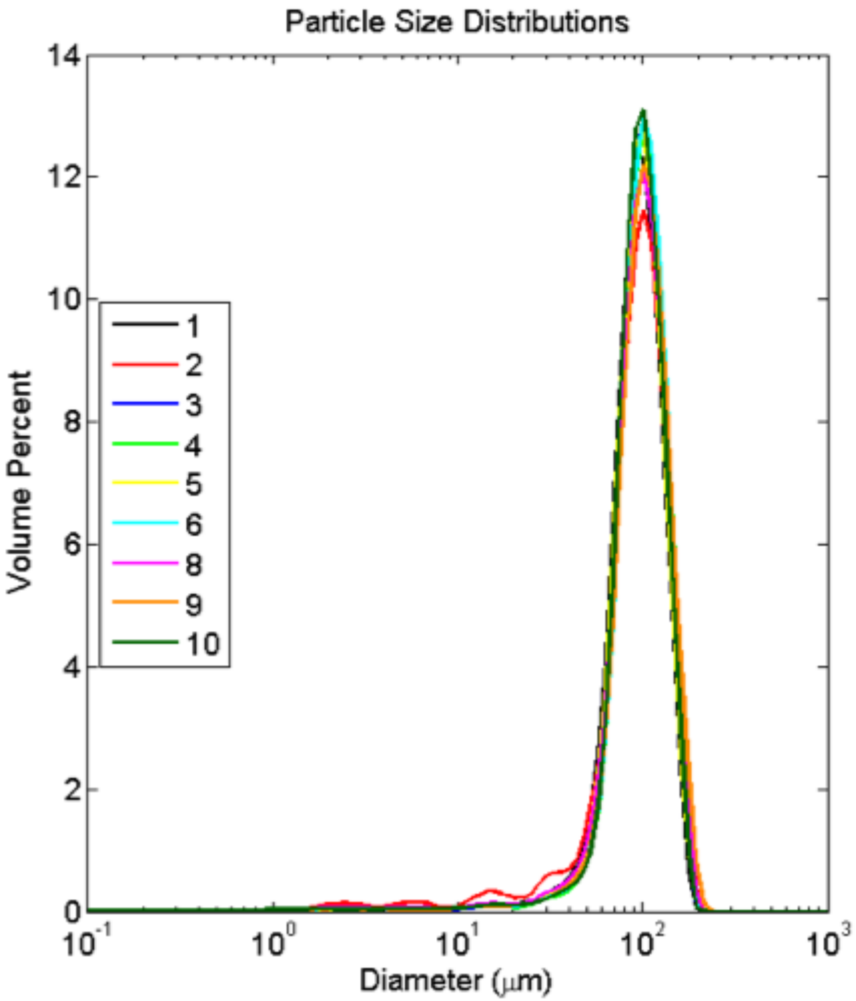
Sample Summary

- 10 measurements were taken
  - Nine measurements were ground and sieved to the same particle size distribution
  - One sample was a solid piece of a slag
  - Five sample locations examined (some of the measurements were to produce replicates)

Name	**Sample #**	**Repetition**	**PSD (µm)**	**Surface**	**Depth (feet)**
1v1	1	1	powder	Right	1
1v2	1	2	powder		
2v1	2	1	powder	Right	2
2v2	2	2	powder		
3v1	3	1	powder	Right	3
6v1	6	1	powder	Ceiling	2
6v2	6	2	powder		
6v3	6	3	powder		
10v1	10	1	powder	Left	4
10sv1	10s	1	solid	Left	4

Sample Preparation

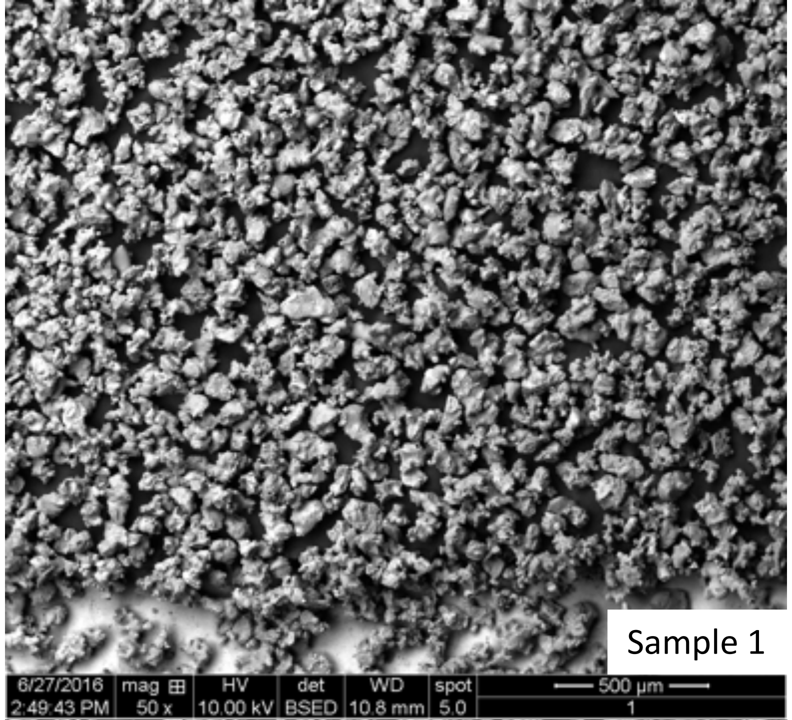


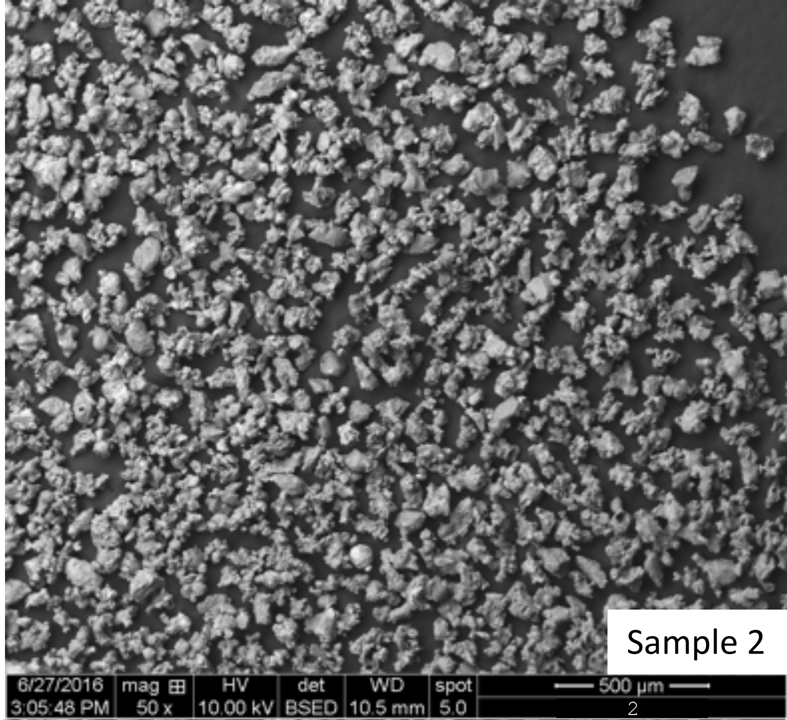


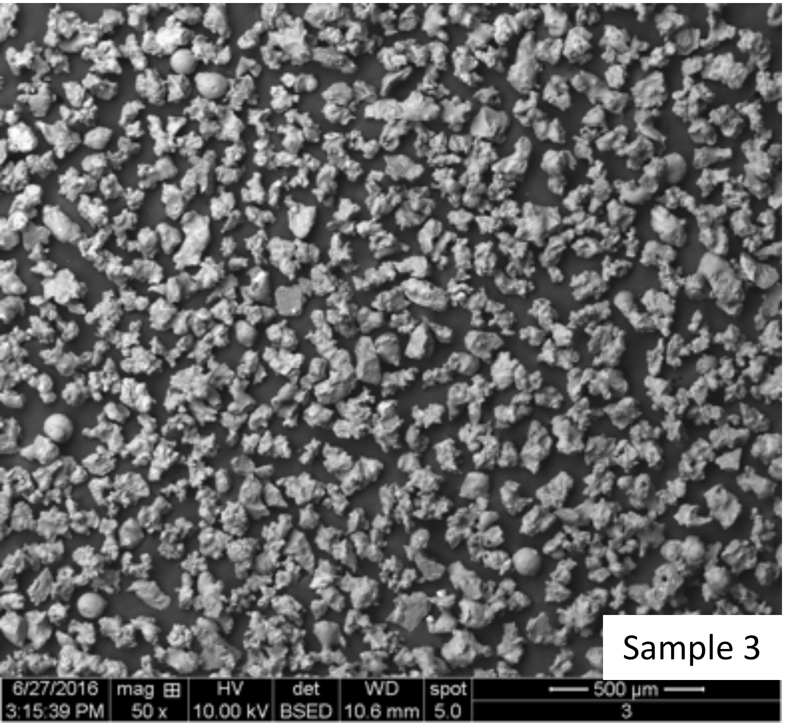
- Samples were ground and sieved so that all would have the same particle size distribution.
  - NOTE: The sample images were taken before grinding and sieving.
- The red circles represent samples measured with high temperature emittance rig.

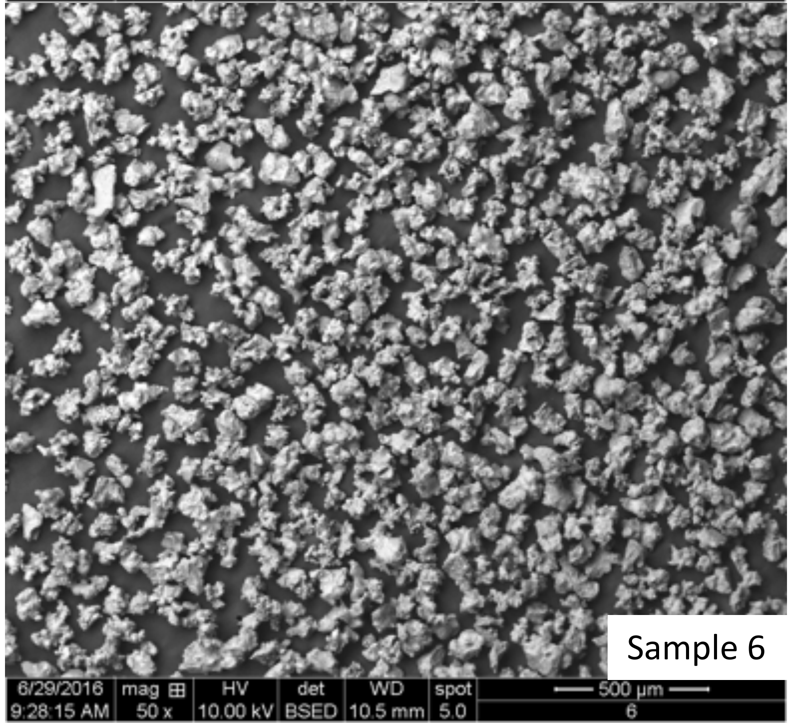
SEM

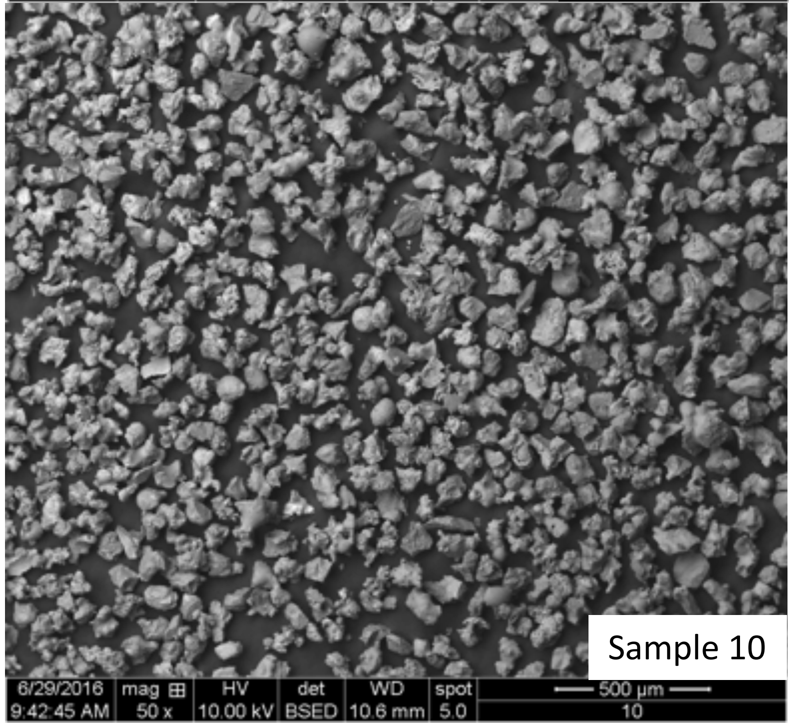
50x magnification

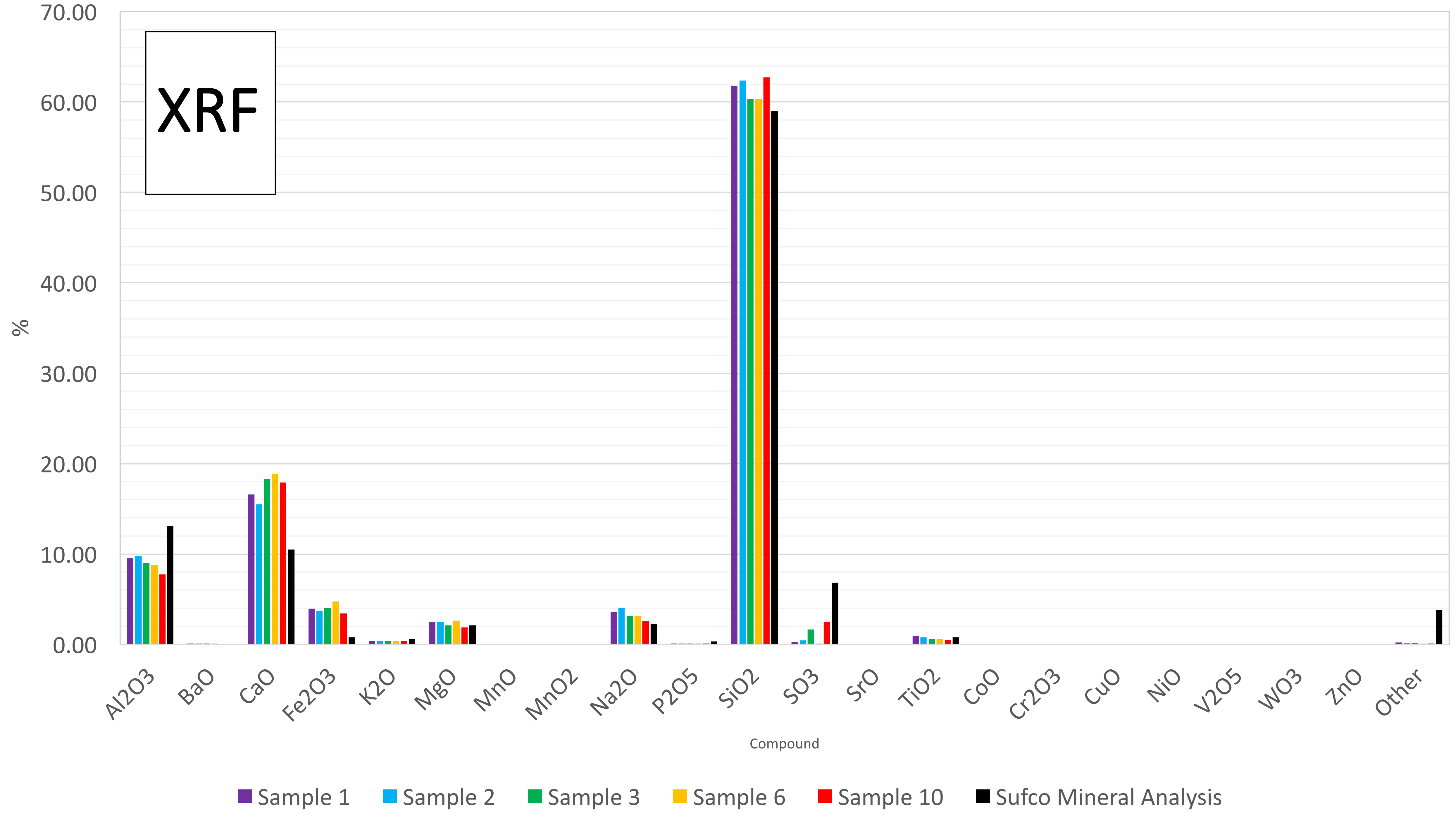








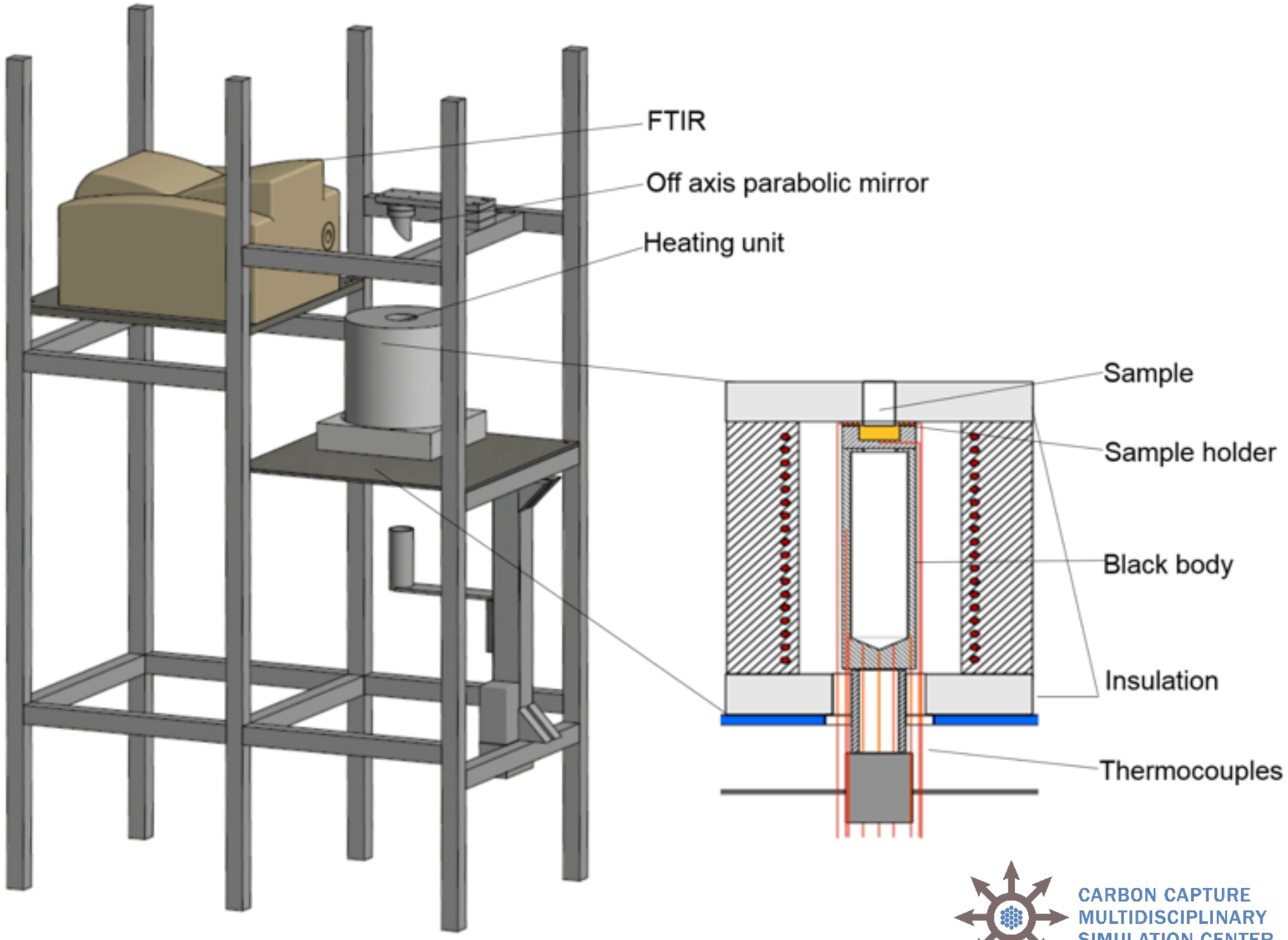




XRF
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
%
Al2O3
BaO
CaO
Fe2O3
K2O
MgO
MnO
MnO2
Na2O
P2O5
SiO2
SO3
SrO
TiO2
CoO
Cr2O3
CuO
NiO
V2O5
WO3
ZnO
Other
Compound
Sample 1
Sample 2
Sample 3
Sample 6
Sample 10
Sufco Mineral Analysis

Experimental Setup

- The radiation test rig located at Ruhr University in Bochum, Germany was used to perform the high temperature emittance measurements (from 500-1000 °C and 0.68-28.5 µm).
- Radiation from the sample inside the rig, $L_S(\lambda, T)$, is directed into and measured with an FTIR.
  - $L_{S,\lambda}(T) \propto E_\lambda(T)$
- Radiation from a blackbody cavity inside the rig , $L_{BB}(\lambda, T)$, is also measured.
  - $L_{b,\lambda}(T) \propto E_{\lambda,b}(T)$
- The ratio of the two FTIR measurements is the spectral emittance.
  - $\varepsilon_\lambda(T) = \frac{E_\lambda(T)}{E_{\lambda,b}(T)} = \frac{L_{S,\lambda}(T)}{L_{b,\lambda}(T)}$
- Emittance vs. emissivity



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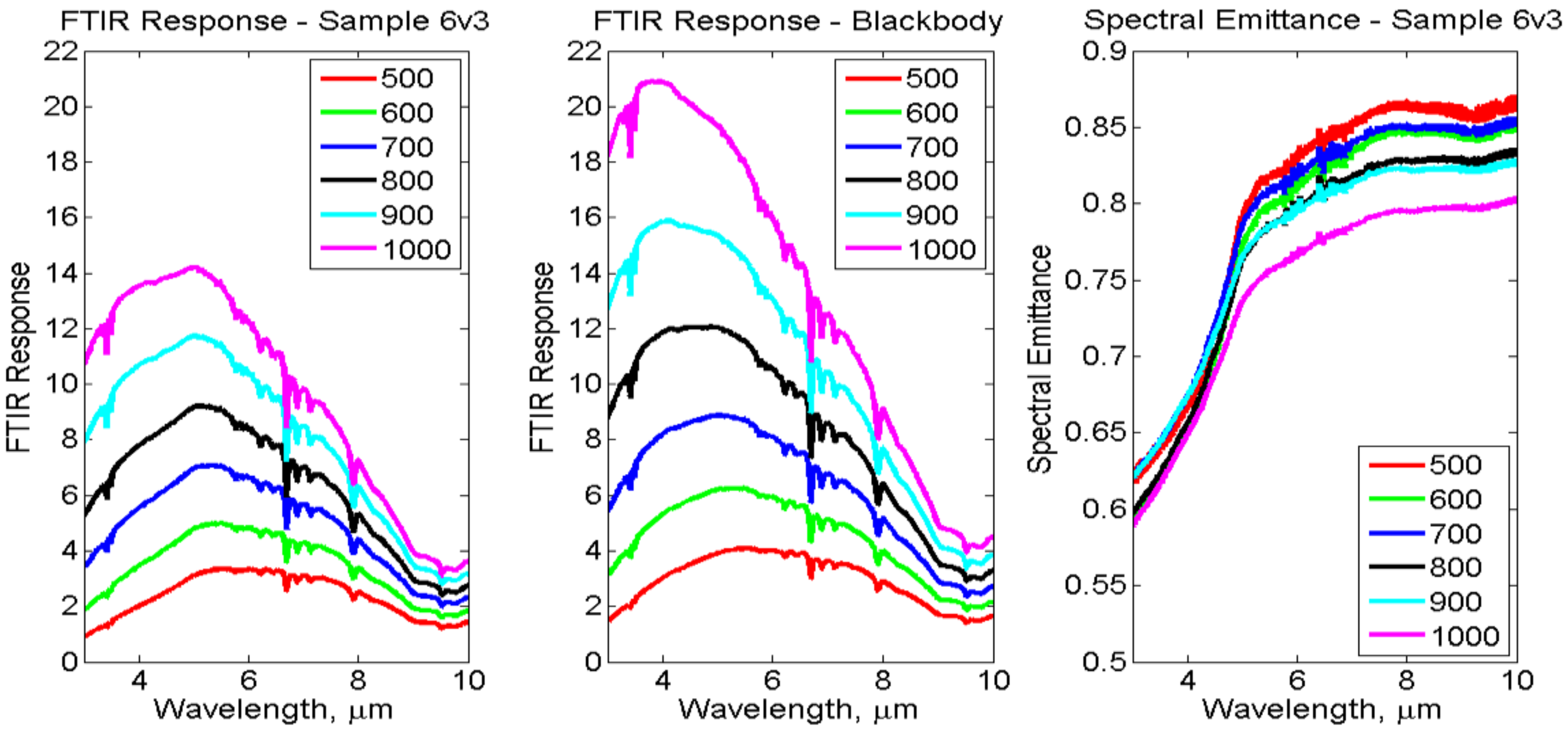
Conversion from FTIR response to spectral emittance



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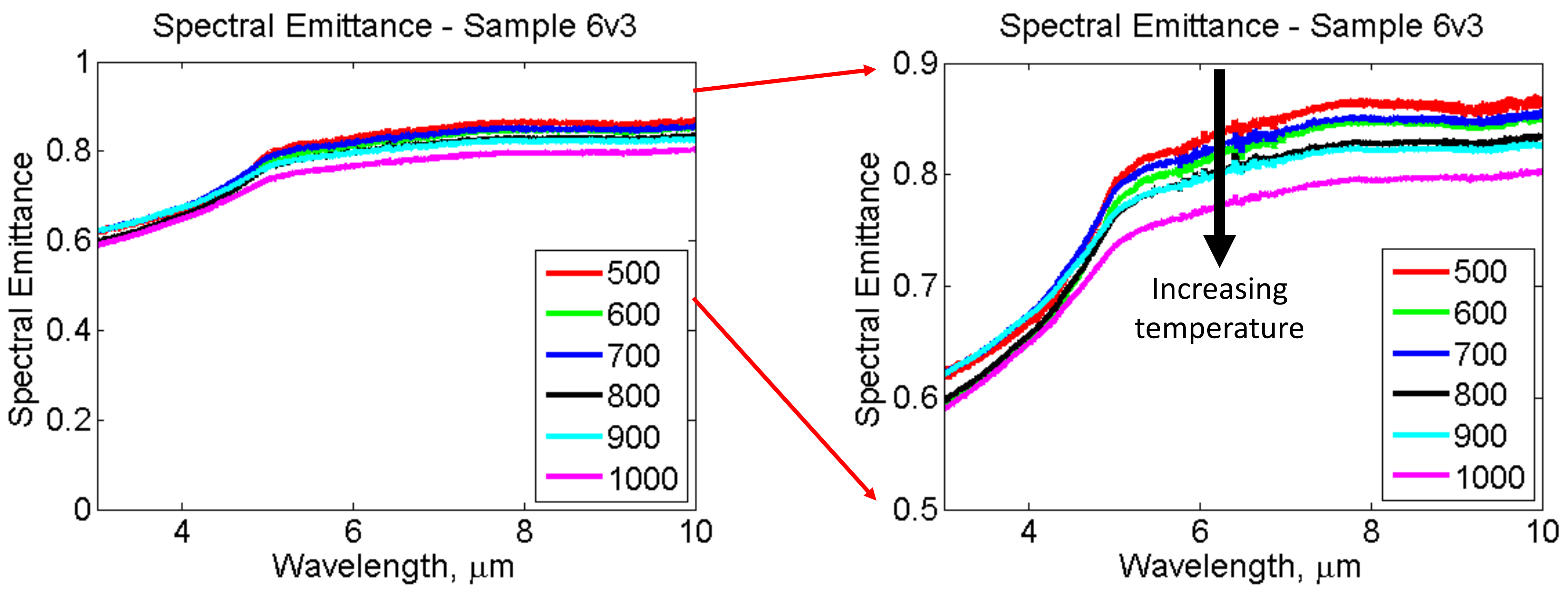
Spectral emittance as function of temperature



- Spectral emittance doesn't change significantly with temperature
- In general, the spectral emittance decreases with increasing temperature

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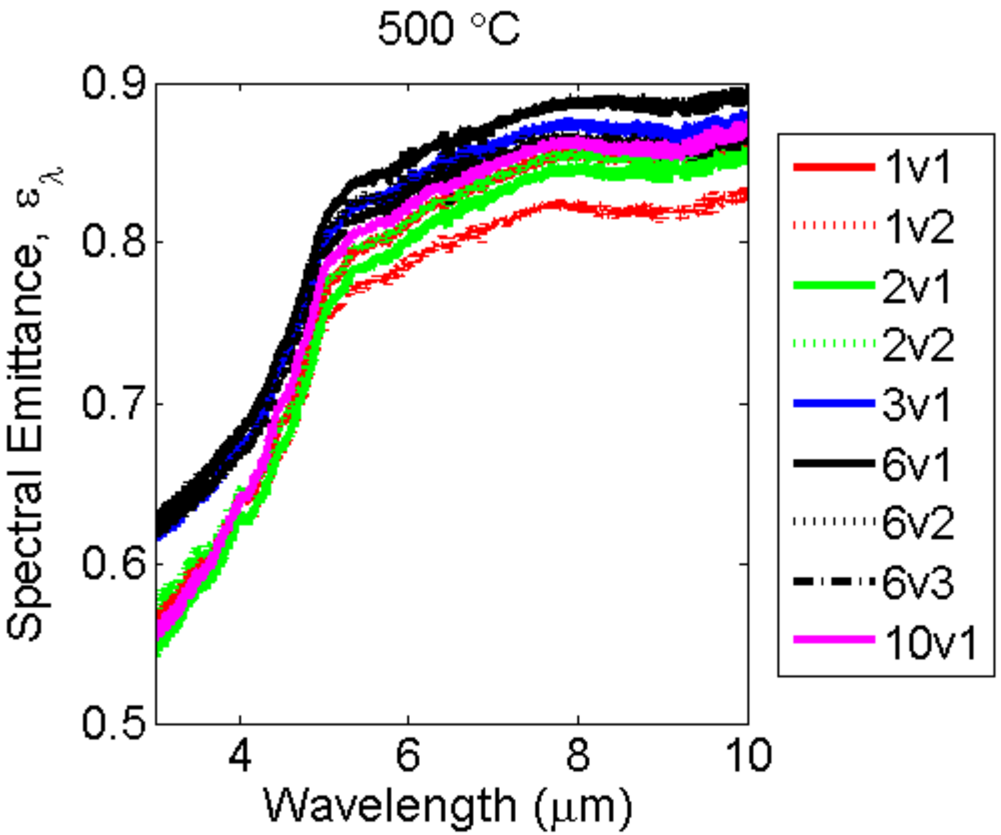
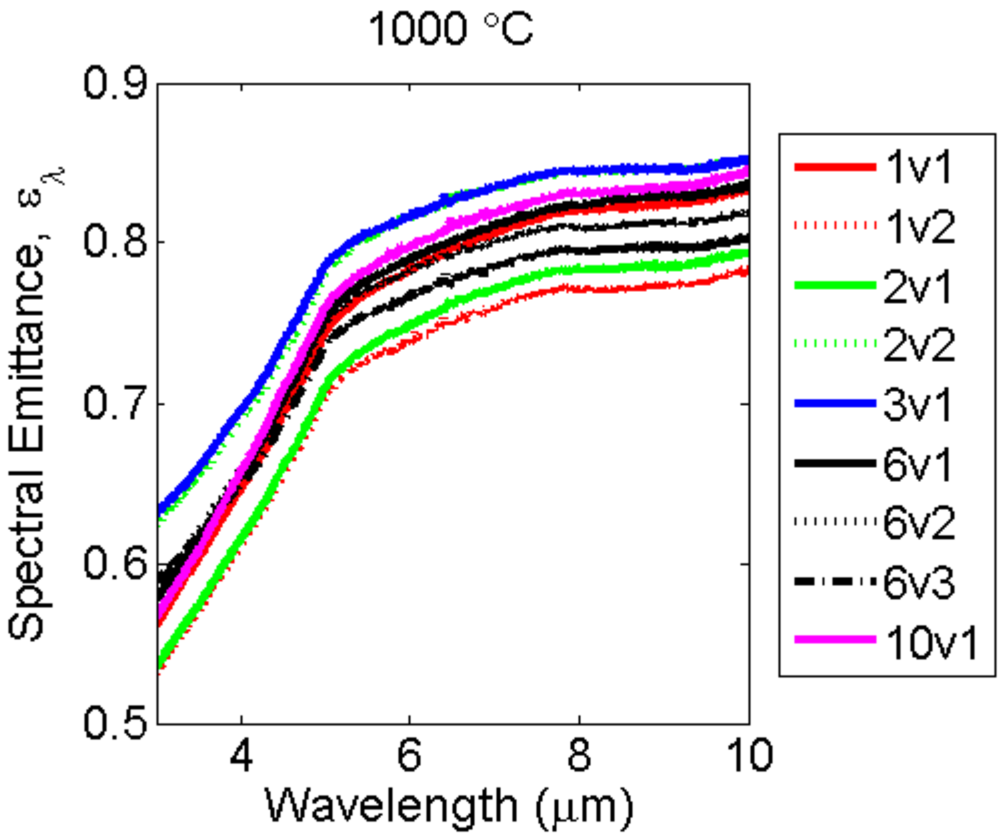
Spectral Emittance for All Powdery Samples





- Spectral emittance for all powdery samples and their replicates
- Spectral emittance at each temperature for all powdery samples is fairly similar
  - Expected given the similarity in the compositions and particle size distributions
- The expected decrease in spectral emittance with increasing temperature is seen

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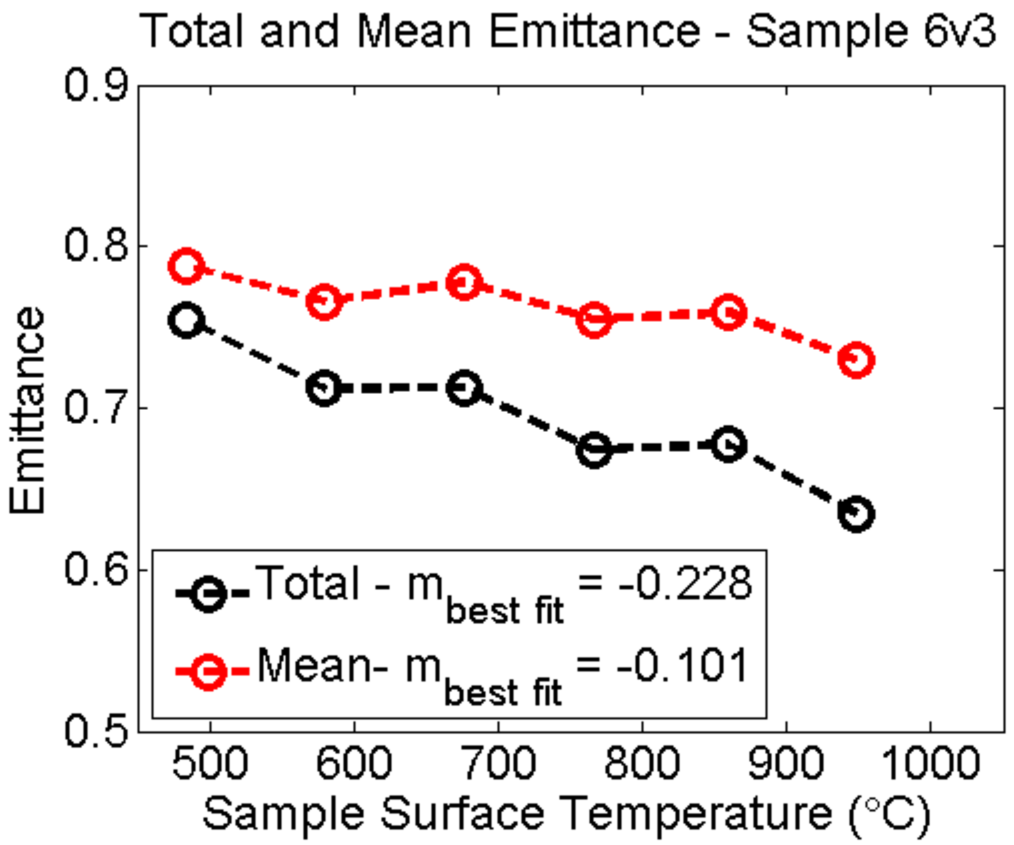
Total emittance as function with temperature

- Total emittance calculation:
  - $\varepsilon_t(T) = \dfrac{\int_0^\infty \varepsilon_\lambda(T) E_{\lambda,b}(T) d\lambda}{\int_0^\infty E_{\lambda,b}(T) d\lambda}$
- Our signal was not strong enough below 3 µm or above 10 µm, so an approximation of the total emittance was calculated:
  - $\varepsilon'_t(T) = \dfrac{\int_{3\,\mu m}^{10\mu m} \varepsilon_\lambda(T) E_{\lambda,b}(T) d\lambda}{\int_{3\mu m}^{10\mu m} E_{\lambda,b}(T) d\lambda}$
- In order to distinguish the contribution to the total emittance from changes in the spectral emittance versus changes in Planck's distribution (whose maximum changes as a function of temperature, a "mean emittance" is also plotted:
  - $\varepsilon'_m(T) = average(\varepsilon_\lambda(T))$
- A downward trend in emittance with temperature is more dramatic for total emittance.
- Thus, take care when making conclusions about spectral emittance from total emittance



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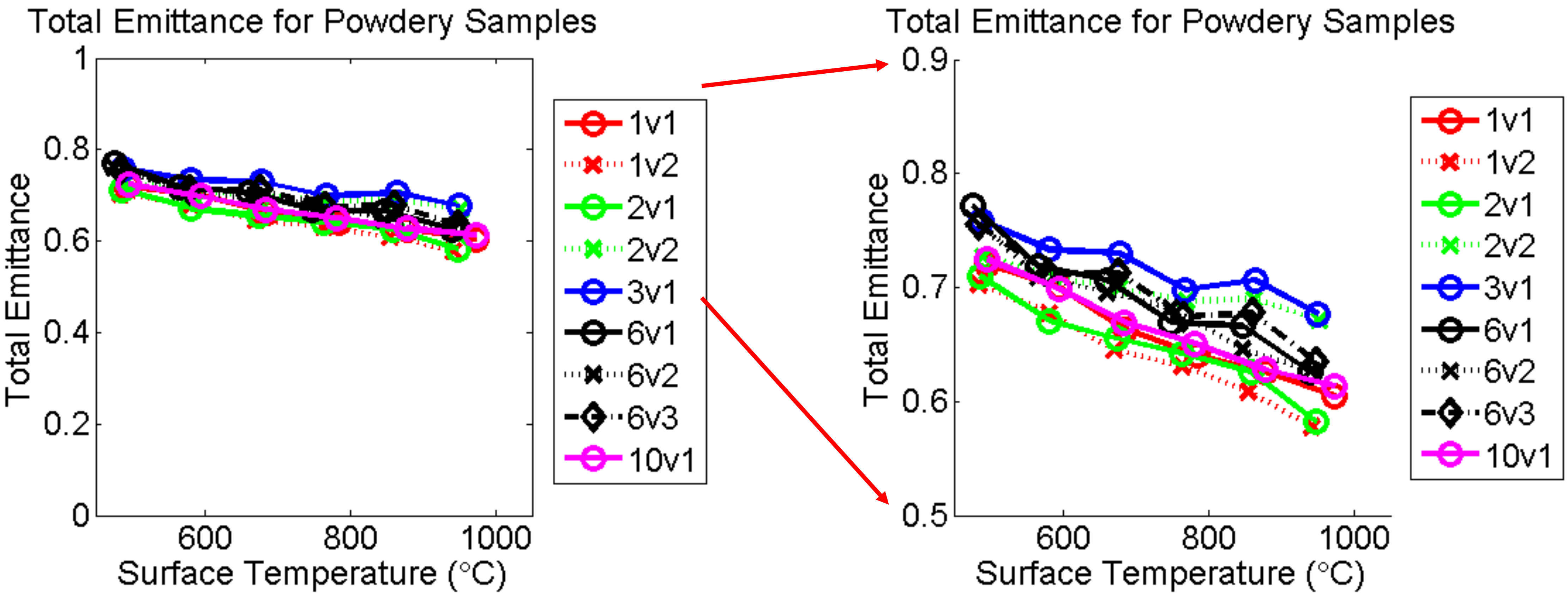
Total Emittance for All Powdery Samples



- Total emittance for all powdery samples is fairly similar
  - Expected given the similarity in the spectral emittances

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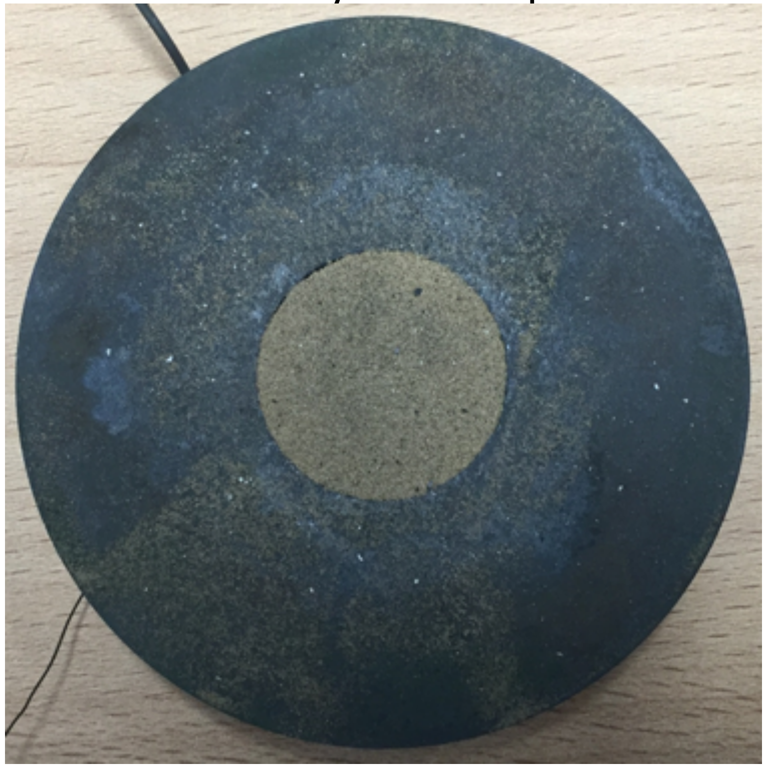
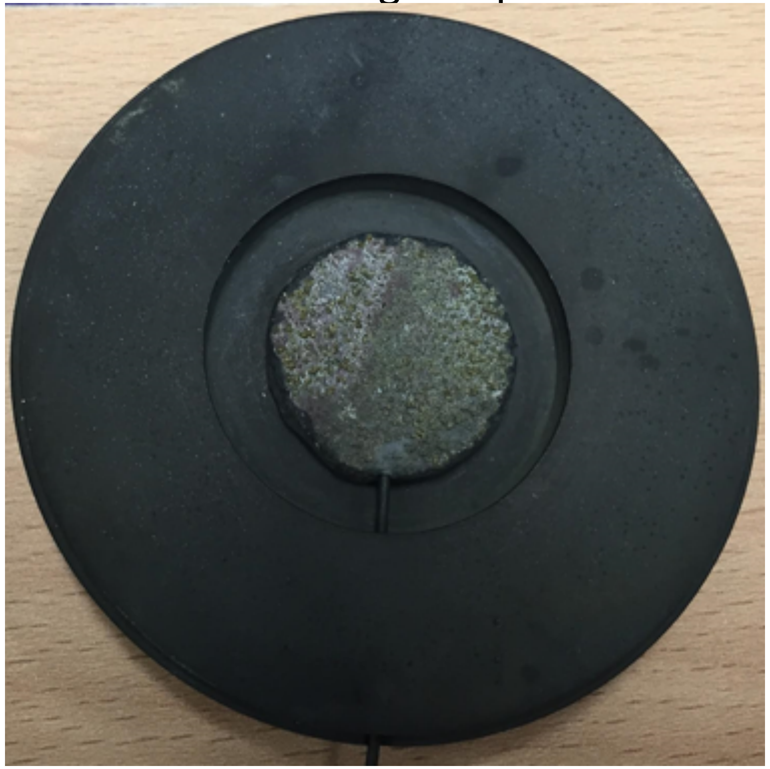
Effect of surface structure: Powder vs. Solid

- Only one sample contained a piece of slag large enough to be machined to fit the sample holder
- Smaller pieces of the slag from the sample were ground and sieved in the same procedure as the other powders
- This measurement isolates the effect of surface structure and temperature since the composition of two samples were identical

Powdery Ash Sample



Solid Slag Sample



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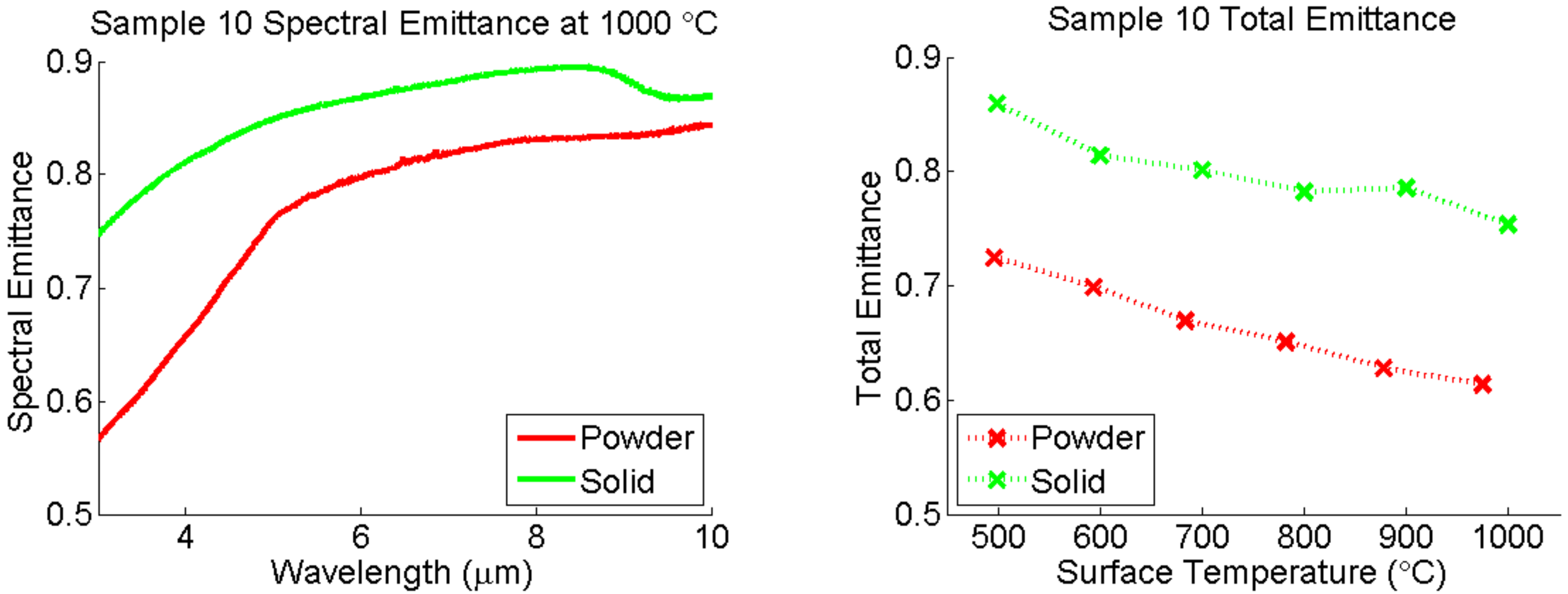
Effect of Surface structure: Powder vs. Solid



- In general, coal slags (solids) have a higher emittance than coal ashes (powders)
- This is seen in both the spectral emittance and the total emittance

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Conclusions

- Despite being from various locations in the furnace, the composition of all samples was very similar
  - Thus, no trend as a function of composition was distinguished
  - The change in emittance between sample location was contained within the changes between sample repetitions
- Spectral emittance did not change drastically (within 8%) in the temperature range examined (500-1000 °C)
- The spectral emittance did generally decrease with increasing temperature (as expected from the literature)
- Total emittance decreased (within 20%) in the temperature range examined (500-1000 °C)
  - The change in spectral emittance with temperature is amplified by weighting with Planck's distribution
- The surface structure (powder vs. solid) of the sample had a very significant effect on emittance
- The solid sample had significantly higher total emittance values (~20%) than the powdered sample

Acknowledgements

We acknowledge the support by the German Science Foundation (DFG) within the Sonderforschungsbereich/Transregio TR 129 “Oxyflame-Development of methods and models to describe solid fuel reactions within an oxyfuel-atmosphere“ for using the radiation test rig.

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Thank you.

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Supplemental Slides

XRD

Diopside present in some samples may have formed in furnace.