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RADIATIVE PROPERTIES OF ASH AND SLAG

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ABSTRACT

Thermal radiation plays a key role in the operation and efficiency of combustion systems, accounting for over 90% of the heat transfer. The analysis of radiative heat transfer in coal-fired boilers, combustion chambers and other energy systems requires accounting for the effects of inorganic deposits on bounding surfaces and of entrained particulates, such as pulverized coal, char, and fly-ash. These effects can be predicted; however, the accuracy in predicting the radiative properties of entrained pyrolysis (ash) and deposit layers (slag) is limited by inaccurate knowledge of the physical/chemical properties of the materials over a range of material temperatures and radiative wavelengths that is representative of conditions in practical combustion systems. The objective of this project is to make laboratory measurements of the radiative properties of extracted ash and slag deposit samples. During this quarter, measurements were continued for fused, sintered and powdery deposits.

RADIATIVE PROPERTIES OF ASH AND SLAG

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I. INTRODUCTION

Thermal radiation plays a key role in the operation and efficiency of combustion systems, accounting for over 90% of the heat transfer. The radiative heat transfer in coal-fired boilers is dominated by the properties of inorganic deposits and bounding surfaces, and of particulates, which are present in the system. The properties governing the emission, absorption, and attenuation of the radiative energy by deposits and entrained particulates are a key element in accurately predicting the radiative heat transfer. They are also necessary for in-situ determination of current deposit condition (composition, temperature) from optical measurements. The radiative properties of particles are characterized by the extinction efficiency, absorption efficiency (or emissivity) and scattering efficiency. That of deposits by the reflectance, transmittance, and absorptivity. These characteristics depend on the complex refractive index, the particle size or layer thickness and the material's morphology (porosity, inhomogeneities, grain boundaries, etc.).

This project will determine the radiative properties of deposits extracted from combustion devices. Measurements of radiative properties of materials at high temperatures are made by a technique employing a sample heating device that is coupled to a Fourier Transform Infrared (FT-IR) spectrometer to measure emission, hemispherical-directional transmission, and hemispherical-directional reflection of a sample. By this technique, the temperature at the measurement point and the spectral emittance (emissivity) of the surface can both be obtained. The complex index of refraction that is required to calculate emissivities is determined by a transmission spectroscopic technique that employs fine sample particulates suspended in KBr and CsI matrices.

In the previous quarter, technique validation was demonstrated for a wide variety of test materials; and measurements of ash and slag deposits were performed for deposits with surface temperatures ranging from 787 to 1111 K.

In this quarter, emphasis was placed on achieving higher deposit temperatures for measurement of radiative properties, and to begin comparing measured properties with predictions.

II. PROGRESS SUMMARY

II.1. Task 1 - Project Implementation Plan

Completed in the third quarter and approved in the fourth quarter.

II.2. Task 2 - Measurement Technique Validation

This task was completed in the seventh quarter and discussed in detail in the seventh quarterly report. High lights of this task include:

- Success in heating samples to moderately high temperatures, up to 1475 K and measuring reflection (specular and diffuse), transmission, and radiance from a surface.
- Identification using the reflectance and transmittance of a spectral region for many materials where they exhibit essentially no reflectivity or transmittivity, thereby defining the emissivity to be 1.0 at this spectral region. **This phenomenon has been identified as the Christiansen dip.** The surface temperature can be determined directly from the radiance measurement at this region, which then allows for the calculation of the entire spectral emittance.
- Determination of the spectral emittance as calculated from the measured directional reflectance and transmittance (**closure**) and use of this emittance to determine the sample temperature from the radiance measurement.
- With both the Christiansen dip and closure methods there is good agreement between the emissivities and temperatures determined by the two methods.
- Excellent agreement for many of the test samples between our determined spectral emittance and results from other investigators reported in the literature.

In an effort to elevate deposit samples to higher temperatures, improvements in the flame geometry of our oxygen/acetylene torch heating system were investigated on a 0.188" thick slab of sintered Al_2O_3 ceramic, which was shown to exhibit a Christiansen Dip at 995 cm^{-1} .

Figure 2.1 demonstrates the high surface temperature achieved when the Al_2O_3 slab is directly heated with the flame on the surface being measured. Overlaid on the Al_2O_3 radiance spectrum is the theoretical black-body radiance spectrum that matches the Al_2O_3 radiance at the Christiansen Dip region (emissivity = 1.0), thus determining the surface temperature to be 2210 K. Also overlaid is the radiance of the isolated combustion products of the flame (CO_2 and H_2O). The amplitude of the gas species that cross the optical path are much less than that of the sample, and contribute only in well defined spectral regions. The small CO_2 contribution in the Al_2O_3 spectrum could be subtracted out. Thus, with the proper positioning of the front flame with respect to the measuring point, high temperatures can be achieved with a minimum of interference from the combustion products. Samples can of course, be only back-heated, which results in no radiance contribution from hot CO_2 , but the maximum measured surface temperature obtainable will be more dependent on the thickness of the sample.

Figure 2.1. Comparison of Radiance of Al_2O_3 at 2210 K when Heated from the Front with an $\text{O}_2/\text{C}_2\text{H}_2$ Torch with Radiance of Combustion Products from Torch when Sample is Removed.

By employing two O_2/C_2H_2 torches to back-heat the Al_2O_3 sample, a maximum surface temperature near 2000 K was obtained. To study the uniformity of heating with the torches, the temperature across a surface of Al_2O_3 was monitored by incrementally translating the sample and the two O_2/C_2H_2 torches that were back heating the sample across the FT-IR collection optics. The temperature was determined from the radiance amplitude at the Christiansen dip. Figure 2.2 plots the measured surface temperature with respect to position on the surface, which was 17 mm across. The focal spot size measurement area was ~ 3 mm in diameter. The measurements taken at positions -8 mm and +8 mm were considered to be partially off the sample surface, since high levels of hot CO_2 were observed in the spectrum. No hot CO_2 was observed when the focal spot was completely on the surface (-7 mm to +7 mm). The plot indicates that except for near the edges, the surface is uniform to ± 25 K when near 2000 K. The difference on each side of the center point is attributed to slightly different flame conditions of the two torches. On each side of the center point, however, are 3 mm to 4 mm diameter regions that exhibit temperature uniformity to ± 5 K. To have established this degree of temperature uniformity over an area larger than the spectroscopic focal area is extremely good considering: 1) the non-optimized heating geometry used, and 2) that sintered Al_2O_3 is a worst-case sample due to its porosity and low thermal conductivity.

Maximum measurement speed is demonstrated in Figure 2.3. The figure presents single scan radiance measurements from an Al_2O_3 surface with the FT-IR spectrometer set to measure at a rate of 0.11 sec/scan. The Christiansen dip technique was employed to determine the surface temperature of the sample as it rapidly cooled from a stable high temperature condition (time = 0, temperature = 2210 K) after the torch was removed from the sample. The surface temperature was measured to decrease 88 K in the first 0.11 sec of cooling. These spectra demonstrate that the FT-IR spectrometer can be used to measure extremely rapid changes in temperature and emissivity, which may be useful for possible in-situ applications in the future.

Figure 2.4 shows the spectral emittance calculated from the rapid radiance measurements and the surface temperature ($\epsilon_\nu = R_\nu / BB(T)_\nu$), and indicates that in the high absorbance region of the Al_2O_3 (the Christiansen dip region) the emittance is constant with temperature, but changes in emittance are observed with temperature in other spectral regions. This is in agreement with Fig. 2.5, which shows an array of data for Al_2O_3 , compiled in Ref. 1. There are differences between results obtained by different research workers, but when only one level of purity, and one temperature are compared, much of the scatter goes away (1). Our example shows how rapidly emittance data can be obtained as a function of temperature.

II.3.a. Task 3.a - Deposit Sample Acquisition

Table 3.1 list the deposit samples acquired for this program. Sample origin and physical descriptions are also indicated.

II.3.b. Task 3.b - Deposit Sample Characterization

Absorbance spectra of the ground samples suspended in KBr and CsI media were presented in the previous quarterly report. From such spectra, work was initiated on the measurement of the optical constants, n_ν and k_ν , by the method described in the Project Implementation Plan for this program. Figure 3.1. shows the optical constants determined for the sintered slag deposit (sample #1). These will be used in Task 4 as input for models to predict the spectral emittance for slag deposits.

Figure 2.2. Measurement of Surface Temperature for Al_2O_3 as the Surface is Incrementally Translated across the FT-IR Collection Optics.

Figure 2.3. Radiance Spectra from Al_2O_3 (McDaniel Refractory Co.) with Theoretical Black-body Curves Corresponding to the Surface Temperature. Each Spectrum is a Single Scan with the FT-IR Spectrometer set to Collect Data at a Rate of 0.11 sec/scan. a) Time = 0 has the Surface being Heated with a $\text{O}_2/\text{C}_2\text{H}_2$ Flame; b-i) Flame Removed from Sample to Measure Radiance as the Sample Rapidly Cools.

Figure 2.4. Spectral Emittance Calculated from Radiance Measurements and Determined Surface Temperature from Figure 2.3. (ϵ = Radiance/ $BB_{\text{surface temperature}}$).

Figure 2.5. Normal Spectral Emittance of Aluminum Oxide (from Ref. 1).

TABLE 3.1
SLAG AND ASH SAMPLES

SAMPLE NO.	SLAG OR ASH DESCRIPTOR	ACQUIRED FROM	COAL	FIRE AT	PHYSICAL DESCRIPTION
1	Slag from refractory back wall of BCTU*	B & W	Illinois No. 6 (bituminous)	B & W	Sintered Deposit
2	Slag from top of slagging panel in BCTU	B & W	Illinois No. 6 (Bituminous)	B & W	Fused Deposit
3	Slag from Tube No. 2 of slagging panel in BCTU	B & W	Illinois No. 6 (Bituminous)	B & W	Dusty Deposits
4	Slag from Tube No. 4 of slagging panel in BCTU	B & W	Illinois No. 6 (Bituminous)	B & W	Dusty Deposits
5	One-time molten pool of slag from inside BCTU	B & W	Illinois No. 6 (Bituminous)	B & W	Fused Deposit
6	Eagle Butte Ash	Stanford University	Eagle Butte (Subbituminous)	Paynee Station Brush, Colorado	Powdery Ash
7	San Miguel Ash	Stanford University	San Miguel (Texas Lignite)	San Miguel Station San Miguel, TX	Powdery Ash
8	Illinois No. 6 Ash	Stanford University	Illinois No. 6 (Bituminous)	Labadie Station	Powdery Ash
9	BYU Furnace Wall Refractory	BYU	-----	BYU	Hard Alumina & Chromium Based Material
10	BYU Slag	BYU	Illinois No. 6 (Bituminous)	BYU	Fused Deposit

* BCTU: Basic Combustion Test Unit at B & W

Figure 3.1. Measured Real and Imaginary Parts of the Index of Refraction, $N_v = n_v + ik_v$, for Sintered Sample #1.

Elemental x-ray analysis of the deposits resulted in only qualitative analysis at this time, due to the lack of instrument calibration for high levels of such components. Qualitative analysis does show the main constituents to be silica, calcia, and iron oxides, as expected. The normalized concentrations for the elements determined by our analyzer, presented in their oxide form, are shown in Table 3.2. Slight variations are observed between the slag samples removed from the Basic Combustion Test Unit at B&W, which originated from the same coal. Large variations are observed in the powdery ash received from Stanford University, which originate from lignite, bituminous, and subbituminous coals.

Plans and Objectives for Next Quarter

Continue the measurement of the optical constants, n_p and k_p , for the deposit samples.

II.4. Task 4 - Measurement of Radiative Properties of Ash Deposit Samples

In this quarter, emphasis was placed in three areas: 1) elevating the samples to higher temperatures than in the previous quarter to monitor possible changes in the radiative properties as a function of temperature, 2) effects of "particulate" size differences encountered in sintered deposits, and 3) to begin comparing measured spectral emittance with predictions from the measured optical constants in Task 3.b.

Figure 4.1.a shows the spectral emittance determined by reflectance closure ($\epsilon = 1 - \text{reflectance}$) for an opaque slab (transmittance = 0) of fused slag (sample #5, top surface) while being back heated with a O_2/C_2H_2 torch. Figure 4.1.b shows the radiance measurement; and Fig. 4.1.c and 4.1.d indicate the determined surface temperature from these measurements (surface temperature = Radiance/ ϵ) to be $1630 \text{ K} \pm 10 \text{ K}$. Figure 4.2.a compares the closure emittance to the emittance calculated from the radiance measurement and the determined surface temperature ($\epsilon = 1 - \text{reflectance}$ vs. $\epsilon = \text{Radiance}/BB_{1630 \text{ K}}$), and good agreement is demonstrated. In the previous quarter, this same analysis was presented for the surface at 945 K (Seventh Quarterly Report, pp. 66-67) with a similar results (Fig. 4.2.b). There is apparently negligible changes in the spectral emittance for this sample over this temperature range. Slight variations observed below 1500 cm^{-1} , which is the characteristic region of infrared band absorption for mineral species found in ash and slag, could be due to either chemical changes upon heating to the higher temperature or variations in composition at different measurement spots. These possibilities can be proved or disproved with position controlled and cyclic temperature controlled experiments.

Figure 4.3 compares the determined spectral emittance for all of the fused slags acquired ranging in temperature from 767 K to 1630 K . All exhibit a high spectral emittance (≥ 0.9). The variations observed below 1500 cm^{-1} again indicates the sensitivity of the technique to discrete changes in mineral species for the samples. Shaded in the figure are the interference regions of the combustion products (CO_2 and H_2O) of the flames used to heat the samples. In sample #2, at 787 K , the region of the spectrum becomes noisy above 5000 cm^{-1} because of the lack of available energy radiated by the sample in this region at this low temperature.

A drop in spectral emittance was observed for the sintered deposit (sample #1). This sample was very brittle and irregular shaped on the surface. Precise alignment for specular reflection was impossible for this surface due to the low detectable reflection signal. As Fig. 4.4a shows, less than 0.10% energy was collected at the presumed specular position. However, constant

TABLE 3.2

COMPOSITIONAL X-RAY ANALYSIS FOR ASH AND SLAG DEPOSIT SAMPLES

Inorganic Component	Sample #1 Sintered Deposit (Ill No. 6, Bit. Coal)	Sample #2 Fused Deposit (Ill No. 6, Bit. Coal)	Sample #5 Fused Deposit (Ill No. 6, Bit. Coal)	Sample #6 Powdery Ash (Eagle Butte, Subbit. Coal)	Sample #7 Powdery Ash (Texas Lignite)	Sample #8 Powdery Ash (Ill No. 6, Bit. Coal)
Na ₂ O	0	0.05	2.76	0.07	2.11	0.33
MgO	0	0	1.47	3.28	0	0
Al ₂ O ₃	10.96	11.12	18.16	12.80	17.11	11.37
SiO ₂	52.17	59.28	56.21	23.61	70.63	47.35
K ₂ O	2.23	2.04	1.47	0.59	1.55	2.02
CaO	7.22	4.96	4.13	37.77	4.32	4.58
TiO ₂	1.08	1.04	1.01	1.65	1.05	1.04
SO ₃	2.56	0.09	0.12	7.08	0.94	9.20
Fe ₂ O ₃	23.71	20.97	14.68	13.00	2.53	23.91

Figure 4.1. Spectral Emittance and Surface Temperature from Total Reflection and Radiance Measurements for Slag from Babcock & Wilcox's Basic Combustion Test Unit, Sample #5, Top Surface. a) Emittance = 1-Reflection, b) Radiance Measurement, c) Calculated Temperature Spectrum (temperature = radiance/emittance) Overlaid with Best Fit Theoretical Black-body Temperature Curve, and d) Extent of Deviation ± 20 K from Best Fit Curve.

Figure 4.2. Comparison of Spectral Emittance Calculated from $\epsilon = 1\text{-Reflectance}$ vs. $\epsilon = \text{Radiance/BB}$ for Fused Slag (Sample #5, Top Surface) at: a) 1630 K and b) 945 K.

Figure 4.3. Comparison of Measured Spectral Emittance for Several Fused Slag Samples over a Wide Temperature Range.

Figure 4.4. Spectral Emittance and Surface Temperature Determination for Babcock & Wilcox Sintered Slag, Sample #1. a) Reflection at the 15° and 45° Angle, b) Radiance Measurement, c) Spectral Emittance Calculated at Three Temperatures (773 K, 793 K, and 813 K), and d) Spectral Emittance at 793 K. A Surface Bonded Thermocouple Indicated a Temperature of 793 K.

gray-body emittance is indicated above 4000 cm^{-1} by the flatness of the reflectance in both the 15° and 45°C measurements.

The radiance measurement of Fig. 4.4b was ratioed by theoretical black-body temperature curves until a constant gray-body feature was demonstrated above 4000 cm^{-1} . Figure 4.4c shows three emittance calculations at 20 K intervals. The spectra are "noisy" at high wavenumbers due to the lack of high energy radiation emitted by an 800 K surface. Clearly, a temperature of 793 K produces a constant (flat) emittance above 4000 cm^{-1} .

A surface bonded thermocouple indicated a temperature that gradually increased from 785 K to 801 K during the radiance measurement. The average thermocouple temperature of 793 K is the same as that which produces the constant gray-body feature above 4000 cm^{-1} . Figure 4.4d isolates the emittance determined at this temperature. Also worth noting is that all of the spectral features in the reflectance measurements are present in the emittance spectrum, even though they were produced from completely separate measurements.

The emittance of the sintered deposit deviates from the fused deposit samples. A possible explanation for this drop in emittance is that the sintered deposit consists of small individual mineral particles that are weakly held together, whereas the fused deposits are a solid mass. The "particulate" characteristics of the sintered deposit increase the scattering efficiency of the material, which will cause a wavelength dependent drop in emittance. Figure 4.5 compares the measured spectral emittance of the sintered deposit to the same material after grinding the material to smaller particles and pressing into a wafer, and to the same material in the molten and solidified fused states. The molten and solidified fused states compare to previous fused samples. The ground and pressed wafer, however, exhibits a lower spectral emittance than the original sintered deposit because of an increase in the scattering efficiency of the material. This indicates that the spectral emittance of sintered deposits will be influenced by deposition parameters that effect the size of their particle-like nature.

The same trend in spectral emittance was observed for the San Miguel ash (sample # 7) that originated from a Texas lignite. Figure 4.6a shows the spectral emittance of a pressed wafer of the powdery ash calculated from reflectance closure ($\epsilon = 1 - \text{reflectance}$). Reflected IR radiation was detected from the 15° specular angle out to 75° . The 2 mm wafer was opaque to the incident IR radiation ($\tau_v = 0$).

The emittance spectrum indicates that both the reflectance closure analysis and the Christiansen dip analysis can be applied to determine the surface temperature. Figure 4.6b is the radiance measurement of the surface overlayed with a theoretical black-body spectrum which matches the ash wafer radiance measurement at the Christiansen dip region. A temperature of 1242 K was used to calculate the black-body radiance. In Fig. 4.6c, the surface temperature is independently determined from the radiance measurement and the spectral emittance calculated from $1 - \text{reflectance}$. The best fit black-body radiance corresponds to 1242 K , the same as the Christiansen dip technique. Figure 4.6d compares the closure emittance to the emittance calculated from the radiance measurement and the determined surface temperature ($\epsilon = 1 - \text{reflectance}$ vs $\epsilon = \text{Radiance}/\text{BB}_{1242\text{ K}}$), and good agreement is demonstrated.

After fusing the ash with a high temperature flame, the emittance of the material corresponds with the other fused samples. Figure 4.7a shows the spectral emittance calculated from

Figure 4.5. Measured Spectral Emittance for Sintered Slag Deposit (Sample #1) Compared to the Material after Grinding and Pressing into a Wafer; and after Thermally Fusing the Material.

Figure 4.6. Spectral Emittance and Surface Temperature from Total Reflectance and Radiance Measurement for a Pressed Wafer of San Miguel Powdery Ash (Sample #7). A Christiansen Dip is also Observed. a) Emittance = 1-Reflectance, b) Radiance Measurement Overlayed with 1242 K Theoretical Black-body Curve, c) Surface Temperature = Radiance/ ϵ_1 -reflectance Overlayed with BB = 1242 K, and d) ϵ_1 -reflectance Compared to $\epsilon = \text{Radiance}/\text{BB}_{1242\text{K}}$.

Figure 4.7. Spectral Emittance and Surface Temperature from Total Reflectance and Radiance Measurement for a Fused Slab of San Miguel Powdery Ash (Sample #7). A Christiansen Dip is also Observed. a) Emittance = $1 - \text{Reflectance}$, b) Radiance Measurement Overlayed with 1093 K Theoretical Black-body Curve, c) Surface Temperature = $\text{Radiance} / \epsilon_1 - \text{reflectance}$ Overlayed with BB = 1093 K, and d) $\epsilon_1 - \text{reflectance}$ Compared to $\epsilon = \text{Radiance} / \text{BB}_{1093\text{K}}$.

reflectance closure; again a Christiansen dip region is observed where $\epsilon = 1.0$. Figure 4.7b is of the radiance measurement, and matching at the Christiansen dip region is a black-body corresponding to 1093 K. The surface temperature from Radiance/ $\epsilon_{1-\text{reflectance}}$ is in Fig. 4.7c, and again a black-body temperature of 1093 K is indicated. Figure 4.7d demonstrates the good agreement in the spectral emittance determined from the two methods.

As demonstrated for the sintered sample, the spectral emittance of the pressed wafer of powdery ash deviates substantially from the spectral emittance of the fused material. Both are shown in Fig. 4.8.

All of the fused surfaces measured demonstrated a high (≥ 0.9) and relatively constant (flat) spectral emittance in regions not associated with absorption bands for component mineral species. This observation was used to monitor the rapid decrease in temperature of a bead of molten slag as it cooled and solidified. With the FT-IR spectrometer set to measure at a rate of 0.11 sec/scan, single scan radiance measurements were initiated while the O_2/C_2H_2 flame maintained a bead of slag in the molten state. The flame was removed while single scan measurements continued. Spectral emittance at several time intervals are presented in Fig. 4.9. These were calculated from the radiance measurements and a temperature that would produce a constant emittance, as previously demonstrated for fused slags. The apparent Christiansen dip region where $\epsilon = 1.0$ for the hottest cases also confirms the temperature. As the surface cools, the spectral emittance does not undergo substantial changes. This was expected based on the fused slags presented previously. The melting point of the slag was determined by thermocouple measurements to be ~ 1400 K.

To predict the spectral emittance from n_ν and k_ν (see Task 3.b for determination of optical constants), the surface condition of the sample must be considered to choose an applicable model. For opaque slabs, which can be used to describe the fused deposits, the emittance can be calculated from Bohren and Huffman (2).

$$\epsilon_\nu = 1 - \frac{(n_\nu - 1)^2 + k_\nu^2}{(n_\nu + 1)^2 + k_\nu^2} \quad (1)$$

Figure 4.10a compares the predicted and measured spectral emittance for the fused surface of the sintered deposit. The prediction is in reasonable agreement with the measured emittance for this and the other fused surfaces. Discrepancies may be attributed to the model assuming a smooth homogeneous surface, which seems to be a good approximation, but not necessarily absolute for the fused surfaces.

For a pressed wafer of ground material, the surface and sub-surface is comprised of tightly packed particles. This suggests that an inhomogeneous model should be used that recognizes both the discreteness of each scattering particle and multiple scattering effects. We report here the results of calculations based on a two component model derived by Bohren (3). In this model,

$$\epsilon_\nu = 1 - \frac{(\sqrt{1-\overline{w}_o g} - \sqrt{1-\overline{w}_o})}{(\sqrt{1-\overline{w}_o g} + \sqrt{1-\overline{w}_o})} \quad (2)$$

Figure 4.8. Measured Spectral Emittance for Powdery Ash (Sample #7) Compared to the Emittance after Thermally Fusing the Material.

Figure 4.9. Rapid Emittance and Temperature Measurements of Fused Surface of Originally Sintered Sample #1. Each Measurement is from a Single Scan taken at a Rate of 0.11 sec/scan. Time = 0 has the surface being directly Heated with an $\text{O}_2/\text{C}_2\text{H}_2$ Flame. The Flame is not Present in Subsequent Measurements as the Sample Cools from a Molten to Solid State.

Figure 4.10. Measured Emittance Compared to Prediction for a) Fused Sintered and b) Ground Sintered Samples.

where the single scattering albedo $\bar{W}_0$ is defined by the efficiency ratio $Q_{\text{scattering}} / (Q_{\text{scattering}} + Q_{\text{absorbance}})$, and g is the asymmetry parameter which lies between 1 (strict forward scattering) and -1 (strict backward scattering).

Figure 4.10b compares the measured spectral emittance for a pressed wafer of ground sintered deposit with that calculated from Eq. 5. For the ground material, a particle size distribution centered around $1.0 \mu\text{m}$ was used with n_p and k_p to determine $\bar{W}_0$, and $g = 0.6$ for this case. The agreement is reasonably good. Better agreement should be achieved when the actual particle size distribution is better defined and when g is input as a function of wavelength.

Plans and Objectives for Next Quarter

Work will continue on spectral emittance measurements of ash and slag by the techniques described. The physical characteristics of the material are attributed to causing the largest changes in spectral emittance, and work will concentrate on identifying the parameters necessary as input for model predictions. Changes in emittance as a function of chemical composition will also be investigated.

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