**MONITORING POWER PLANT EFFICIENCY USING THE MICROWAVE-EXCITED
PHOTOACOUSTIC EFFECT TO MEASURE UNBURNED CARBON**

Quarterly Technical Progress Report

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ABSTRACT

Three test instruments are being evaluated to determine the feasibility of using photo-acoustic technology for measuring unburned carbon in fly ash. The first test instrument is a single microwave frequency system previously constructed to measure photo-acoustic signals in an off-line configuration. This system was assembled and used to test parameters thought important to photo-acoustic signal output. A standard modulation frequency was chosen based upon signal to noise data gained from experimentation. Testing in the sixth quarter focused on initial testing for a magnetic photo-acoustic effect, loss tests and photo-acoustic tests on coal samples, and extending the testing range for the photo-acoustic effect over the octave of 900 MHz to 1800 MHz. Previous testing on this project was done at 1 GHz. In parallel with the photo-acoustic testing, some preliminary design considerations were investigated for the on-line monitor to be fabricated and testing in phase three of this project.

Keywords: fly ash, carbon monitor, unburned carbon, boiler instrumentation, coal

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INTRODUCTION

The objective of this project is to explore the use of the microwave-excited photoacoustic (MEPA) effect for quantitative analysis of granular and powdered materials. The focal point of the research centers on the measurement of unburned carbon in fly ash, an important parameter in the electric utility industry used to determine plant efficiencies. The culmination of this project will be an on-line carbon-in-ash monitor for coal-fired power plants. However, evaluations will be made on other powdered solids, particularly coal.

The approach to this project includes work with three MEPA instruments. The first instrument is a single microwave frequency, off-line instrument built at Iowa State University as part of proof-of-concept evaluations. It is being used to evaluate precision and accuracy of the MEPA technique. The second instrument is being constructed as a microwave spectrometer based on MEPA. It will be used to evaluate a variety of industrial important powders, including fly ash and pulverized coal. The final instrument will be built based on the results of work with the previous two instruments and will be used as an on-line monitor of unburned carbon in fly ash.

EXPERIMENTAL

The MEPA Spectrometer, Off-Line Instrument

Testing continued on variables that affect the photo-acoustic effect. These effects are being incorporated in the design for the on-line monitor to be fabricated in the third phase of this effort. The air volume above the sample appears to be one of the largest variables in the photo-acoustic effect. The efforts to test an accelerometer technique to measure the photo-acoustic effect rather than using a microphone have continued this period. An accelerometer technique

will allow the sample to be in intimate contact with the sensor. A microphone needs to be protected from the analyte volume to prevent the analyte from contacting the sensitive diaphragm of the microphone. The air volume between the analyte and the microphone appears now to be one of the largest variables in sensor response.

As indicated in the fourth quarterly report, the microwave spectrometer sources for 0.5 to 4 GHz and 4 GHz to 10 GHz were completed that quarter. This quarter the microwave work continued on using the sources to make measurements using the power control loop to keep power levels constant over a long period of testing. Figure 1 shows this control loop. The figure is replicated from previous reports.

Figure 1: Leveled Amplifier System

Measurements during the sixth quarter included further testing on fly ash and on magnetic materials to further determine the utility of the MEPA spectrometer for discriminating between magnetic losses and dielectric losses in the samples.

The On-line Monitor

The third phase of this work is to design an on-line carbon monitor based on the microwave-excited photoacoustic effect. The original concept is illustrated in Figure 2 (repeated from the previous report). In this arrangement, fly ash flows between the stripline and one of the duct walls. Acoustical access through this wall would allow a microphone to detect the photoacoustic signal.

Figure 2. Concept for on-line carbon in ash monitor

Testing in phase I revealed a difficulty with this original design: the photoacoustic signal is strongly dependent on the volume of gas between the granular sample and the microphone face. Since this volume would be difficult to control in the presence of flowing particles, precision of the photoacoustic signal would suffer.

We investigated changes in signal detection that would avoid this difficulty. We determined that instead of detecting the thermal acoustic wave generated in the gas volume (the present method), it would be better to detect the thermal elastic wave that is generated in the presence of microwave excitation. The thermal elastic wave arises from a periodic volume

expansion of the bulk sample that results from periodic heating as opposed to the production of an acoustic wave that reaches the surface of the sample from only a thin surface layer. A

conceptual view of this

structure is shown in Figure

2. There appears to be only a

small difference between

Figure 2 and Figure 3 but

this difference is very

significant. Last period's

report presented the

theoretical basis of this

difference.

Figure 3. Concept for using an accelerometer sensor

RESULTS AND DISCUSSION

The MEPA Spectrometer, Off-Line Instrument

As reported last period, the linearity of the signals reported from fly ash did not provide a linear response signal versus percent carbon as expected. These data were repeated this period also. The results are shown in Figure 4. Based on the results from these tests, it has been determined that the carbon content of the samples needs to be independently measured to verify the accuracy of the test specimens. This analysis is to be done in the next period and the photo-acoustic responses will be checked again.

Figure 4: Photo-acoustic response versus total organic carbon (parameter - frequency-GHz)

Figure 4 also shows the response from 1 GHz to 1.6 GHz and demonstrate the measurements over nearly an octave in L-band (1-2GHz). Measurements made this period were in the range of 900 MHz to 1.8 GHz. The test cell will be modified the next period to allow measurements up to approaching 4 GHz. The VSWR of the cell with test specimen will be measured also to determine whether higher frequencies present any high VSWR responses.

Loss Measurements of Coal Samples

During this period, several coal samples were measured for loss characteristics. This was preliminary to determining the expected photo-acoustical response of the samples. The coal samples from the Penn State Coal Sample and Database. It is interesting to plot the carbon content versus moisture content of the samples. This was done to determine whether there is any

correlation between the content variables. Figure 5 shows a graph of the carbon content of these coal samples versus moisture content. There is a definite correlation between moisture content and carbon content. This correlation must be considered in any analysis of data measured on the samples.

Figure 5: Carbon content versus moisture content for coal samples.

Figures 6A-6I show the loss of various coal samples measured from very low frequencies through 30 GHz. The rapid changes in loss in the 25 to 30 GHz range are a result of moding in the connectors used and are therefore artifacts of measurement.

Figure 6A
Coal - 2 % moisture (sample decs23)

Figure 6B
Coal - 2.06 % moisture (sample decs30)

Figure 6C

Coal - 2.79 % moisture (sample decs20)

Figure 6D

Coal - 6.81 % moisture (sample decs18)

Figure 6E

Coal - 10.43 % moisture (sample decs2)

Figure 6F

Coal - 17.34 % moisture (sample decs7)

Figure 6G

Coal - 17.67 % moisture (sample decs27)

Figure 6H

Coal - 26.3 % moisture (sample decs26)

Figure 6I

Coal - 33.38 % moisture (sample decs11)

Figure 7 gives the loss of the coal samples at 10 GHz versus moisture percentage. That curve shows that there is another element contributing to the loss of the coal samples. That element is likely to be carbon. Further analysis needs to be done to extract the loss of the water and then quantify the remaining loss and attempt to correlate it to carbon. There are a couple of anomalies in the curve in Figure 7 that suggest that another element might also be involved. One of the anomalies is at about 17 percent moisture. The other is when there is a very low percentage carbon. Especially at low moisture content, other elements likely will play a larger ratio in the total loss.

Figure 7: Loss at 10GHz versus moisture percentage

The lower loss specimen has a higher ash content but a lower carbon content and sulfur content. Additional analyses would be necessary to quantify these various element percentages to microwave response.

The loss of water has been studied in the literature (1). Those studies indicate that the dielectric constant of water is given by:

$$\epsilon_w = \epsilon_{w\infty} + \frac{\epsilon_{w0} - \epsilon_{w\infty}}{1 + j2\pi f\tau_w}$$

This equation indicates that the loss due to water versus frequency should have a change in slope in the 5 to 10 GHz region. That is the region of frequencies given by the relaxation frequency of the dielectric constant. Our curves do show a change in slope. Further analyses could be done to determine how that slope change correlates to the change in dielectric constant of water.

The On-line Monitor

Several iterations of design drawings were considered. The anticipated change to the use of accelerometer measurements and considerations of the ash flow path required several iterations. That process is underway and will be an area of concentration for the next period in anticipation of completing that in the third portion of this project.

CONCLUSION

Significant progress has been made in using the MEPA spectrometer. Measurements will continue on tests to determine the magnetic response of samples. Some significant microwave loss measurements were made on coal samples and indicate that loss measurements might be useful in determining the dielectric properties of coal. Some attempt will be made in the next period to correlate the dielectric loss measurements to the photo-acoustic properties of the coal samples in the microwave frequency range.

In addition, during the next quarter further design considerations will be made for the on-line monitor.

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