DEVELOPMENT OF A VIDEO-BASED SLURRY SENSOR
FOR ON-LINE ASH ANALYSIS

Principal Investigators
G.T. Adel and G. H. Luttrell
Department of Mining and Minerals Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

Contract Number
DE-FG22-94PC94226

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DOE Project Officer
Richard B. Read
United States Department of Energy
Pittsburgh Energy Technology Center
P. O. Box 10940
Pittsburgh, Pennsylvania 15236-0940

October 22, 1996

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ABSTRACT

Automatic control of fine coal cleaning circuits has traditionally been limited by the lack of sensors for on-line ash analysis. Although several nuclear-based analyzers are available, none have seen widespread acceptance. This is largely due to the fact that nuclear sensors are expensive and tend to be influenced by changes in seam type and pyrite content. Recently, researchers at VPI&SU have developed an optical sensor for phosphate analysis. The sensor uses image processing technology to analyze video images of phosphate ore. It is currently being used by PCS Phosphate for off-line analysis of dry flotation concentrate. The primary advantages of optical sensors over nuclear sensors are that they are significantly cheaper, are not subject to measurement variations due to changes in high atomic number minerals, are inherently safer and require no special radiation permitting. The purpose of this work is to apply the knowledge gained in the development of an optical phosphate analyzer to the development of an on-line ash analyzer for fine coal slurries.

During the past quarter, installation of the video-based ash analyzer at the Middle Fork plant site was completed. A method of measuring and automatically adjusting for small variations in the sensor illumination scheme was developed and implemented. Initial on-line testing of the ash analyzer has yielded adequate calibration information, and the sensor is currently operating on-line. The on-line performance of the sensor is under review and the information from this review will be included in the final report.
INTRODUCTION

Automatic control of fine coal cleaning circuits has traditionally been limited by the lack of sensors available for on-line ash analysis. Although a number of nuclear-based slurry analyzers have been tested, none have received widespread acceptance. This is largely due to the fact that nuclear sensors are very expensive for the limited accuracy available. They also tend to be influenced by changes in seam type and pyrite content.

Over the past three years, the principle investigators of this work have developed and installed two optical phosphate analyzers at the PCS Phosphate operation near Aurora, North Carolina. These devices use image processing technology to analyze video images of phosphate flotation concentrates and determine the $P_2O_5$ content and $CaO/P_2O_5$ ratio. They are currently being used in an off-line configuration on dry samples.

The primary advantages of optical sensors over nuclear sensors are that they are significantly cheaper (i.e., approximately 10% of the cost), are not subject to measurement variations due to changes in high atomic number minerals, are inherently safer and require no special radiation permitting. Previous experience has also shown that they are more easily understood and accepted by plant operators.

The purpose of this project is to apply the knowledge gained in the development of the optical phosphate analyzer to the development of an on-line sensor for measuring ash content in fine coal slurries. Included in this effort is fundamental research to determine the appropriate light source, image processing algorithms and sample presentation scheme necessary for coal slurry analysis. The following is a summary of work completed during the eighth quarter of this project.
PROJECT TASKS

Task 1 - Project Planning

All project planning activities under Task 1 are now complete.

Task 2 - Laboratory Testing

All work associated with the development of software and mathematical correlations for video-based ash analysis is now complete.

Task 3 - Bench-Scale Testing

All work associated with the design and development of a slurry sample presentation system is now complete.

Task 4 - Pilot-Scale Testing

All work associated with the calibration and testing of the video-based ash analyzer has now been completed. The outcome of this task was the development of an analyzer which has a resolution of 0.46% ash per gray level increment and an accuracy of ±2% ash, absolute (2.5 - 3.0% ash, relative) when tested under controlled conditions.

Task 5 - In-Plant Testing

Task 5.1 - Procurement and Fabrication: The hardware and software needed for this task were already purchased in order to carry out the developmental work. The primary additional purchases made included fittings and other material used to equip the sample presentation system to accept the plant tailings sample. All components of the industrially-hardened system are now in place and on-site at the Middle Fork preparation plant.
Task 5.2 - Installation and Calibration: Installation of the industrially-hardened video ash analyzer is now complete. A schematic of the installed sensor system is shown in Figure 1. The basic modifications that were made at the plant site are described as follows.

The five operating flotation columns at the Middle Fork preparation plant already have a sampling system which allows samples to be taken from each individual column or any combination of columns for each of the three process streams (feed, tailings and clean coal). The existing tailings sample lines were modified to provide a continuous flow of tailings slurry from all five columns to the sample presentation system. Initially the tailings sample presented to the ash analyzer has been a combination of the tailings from all of the columns. This configuration may be changed at a later date to allow for tailings ash analysis of any particular column. The slurry is gravity-fed from the sample line to the sample presentation system sump eliminating the need for any intermediate pumping system.

In addition to the sample line, the Middle Fork plant has installed a dedicated 120-volt electrical line to power the sample presentation system. An air line was also installed to provide a means of pulsing the slurry in the sample presentation tube.

The PC image analysis system was placed on the top floor of the plant in the operator control room. The sample presentation system is located on the bottom floor of the plant near the existing sampling ports. These two components of the video-based ash analysis system are linked by a video cable and a low voltage signal line. The video cable transmits the live image from the camera to the PC for image analysis and subsequent ash
determination. The low voltage signal line provides signals from the PC to the solenoid valve in the sample presentation tube to allow a fresh sample to be acquired from the sump. Currently these lines are temporarily installed. Permanent conduit will be added once a workable configuration is established.

A heavy duty industrial cabinet is used to house the sample presentation system. It serves to eliminate any problems which may occur due to the harsh environment in which the sensor is operating. The electrical and air lines have been permanently placed on the cabinet wall to provide power and air for the system. The sample sump is bottom-fed through the cabinet wall, and a launder is used to collect the overflowing slurry. Finally, the overflowing slurry exits through the cabinet wall and is discharged into a nearby floor sump.

In order to calibrate the video ash analyzer, slurry samples were collected from the overflow launder. These samples were then analyzed and the results compared to those obtained by the video analyzer. Figure 2 shows the current linear calibration being used by the sensor based completely on in-plant data.

**Task 5.3 - Operation/Testing/Refinement:** Throughout the development of the video ash analyzer, it was noticed that small fluctuations in sample illumination often caused added noise in the data. Although these fluctuations were kept to a minimum, it was felt that an in-situ light standard might provide a means of further minimizing or eliminating these fluctuations. Thus, a method for identifying and automatically correcting for small variations in the sample system illumination was developed and incorporated into the operation of the ash analyzer. The sample presentation tube was modified to include a
one-inch diameter sealed PVC tube attached to the inner wall of the sample tube. One end of the one-inch tube was sealed against the Plexiglas disk that separates the camera lens from the sample presentation tube. The other end of the one-inch tube was sealed with a gray disk at the focal length of the camera. This gray disk serves as an illumination standard. It is positioned in such a way that a portion of the disk is always visible in the field of view of the video camera. Figure 3 shows a cross-section view of the sample presentation tube, showing the placement of the illumination standard within the effective image area.

Once the illumination standard had been successfully installed in the sample presentation tube, testing was carried out to quantify the relationship between gray level changes of the illumination standard and the slurry samples. A series of samples were analyzed at two lighting conditions each. First, the samples were analyzed at a predetermined optimal illumination condition, and then the same samples were reanalyzed at a slightly different lighting condition. These results are shown in Table 1.

**Table 1.** Comparison of slurry and illumination standard gray levels under varying lighting conditions.

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The varying lighting conditions for each sample caused differing gray level measurements for the illumination standard and the slurry. The percentage change in the gray levels for both the illumination standard and the slurry were then calculated for each sample. Figure 4 shows the percentage change in the slurry sample gray level plotted versus the percentage change in the illumination standard gray level. As shown, there appears to be a fairly good linear relationship between the gray level change in the standard and in the slurry sample with a slope of approximately 2.3. Thus for every one percent gray level change in the illumination standard, the gray level measurement of the slurry should be adjusted by 2.3% in order to maintain a consistent calibration and a consistent ash measurement regardless of light fluctuations. It is important to note that the scatter in the data appears to increase as the percentage change in the gray level (i.e., the severity of the light fluctuation) increases. However, the data clearly indicated that this type of correction is suitable for the small fluctuations in light intensity normally encountered due to variations in line voltage.

The video-based ash analyzer is currently operating on-line at the Middlefork plant site. Several visits have been made to the plant site, and an initial calibration of the sensor is complete. The sensor appears to be giving similar results to those obtained previously in the development phase (i.e., an accuracy of approximately +2% ash). Visits to the plant are continuing to permit software improvements, operator training, and continual improvement of the sensor calibration. However, from the standpoint of the original objectives of this UCR grant, this project has now been successfully completed with the installation of an on-line video-based ash analyzer in an operating coal preparation plant.
**Task 6 - Sample Analysis and Characterization**

All necessary samples have now been acquired from Pittston’s Middlefork preparation plant, analyzed for ash content and percent solids, and used in testing and calibrating the video-based ash analyzer. Thus, this task is now complete.

**SUMMARY STATUS AND FUTURE WORK**

Major accomplishments during the past quarter are listed as follows:

1. The video-based ash analyzer has been completely installed and is operating on-line at the Middle Fork preparation plant.

2. The sensor has been monitored on-line, allowing for improvement and refinement of the sensor gray level versus ash content calibration.

3. A method of identifying and automatically correcting for variations in the sensor illumination scheme has been developed and incorporated into the sensor operation.

4. Plant operators have learned the operating principles of the ash analyzer and how to use the analyzer interface software.

As shown in Table 2, this project has now been successfully completed. A video-based ash analyzer has been developed and installed in an operating coal preparation plant. The sensor is providing a resolution of 0.46% ash per gray level increment and an accuracy of ±2% ash, absolute (2.5 - 3.0% ash, relative) over the range of 65 - 85% ash. It is expected that refinements in the sensor and improvements in the software will continue to be made in conjunction with additional funding provided by Pittston Coal Company. However, from the point-of-view of this UCR grant and the original work plan, this project has been a rousing success, with all expectations met or exceeded.
Table 2. Project Schedule

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<td>Task 3 - Bench-Scale Testing</td>
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<td>Task 4 - Pilot-Scale Testing</td>
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<td>Task 5 - In-Plant Testing</td>
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<td>Task 5.1 - Procurement and Fabrication</td>
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<tr>
<td>Task 5.2 - Installation and Calibration</td>
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<tr>
<td>Task 5.3 - Operation/Testing/Refinement</td>
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<tr>
<td>Task 6 - Sample Analysis &amp; Characterization</td>
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</tbody>
</table>

Figure 1. Schematic of the industrially-hardened video-based ash analyzer.
Video-Based Ash Analyzer Calibration - 10/17/96

Figure 2. Current (10/22/96) gray level versus ash content on-line calibration for the video-based ash analyzer (with illumination correction).
Figure 3. Cross-sectional schematic of the sample presentation system showing the illumination standard.

Figure 4. Slurry gray level percent change versus illumination standard gray level percent change for varying lighting conditions.