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

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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 Texasgulf for off-line analysis of dry flotation concentrates. 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, a new prototype sample presentation system for the optical analyzer has been developed. This new approach appears to solve the problems encountered with previous prototypes. A qualitative comparison of the images obtained with the new system and those obtained with the previous prototypes indicates that the new system provides much smoother, clearer images. The new sample presentation system is currently being integrated with the image analysis computer and a patent disclosure has been filed with the university.
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 Texasgulf 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 third quarter of this project.
PROJECT TASKS

Task 1 - Project Planning

All project planning activities under Task 1 are now completed. Periodic meetings with personnel at Pittston Coal Company are being held to keep them apprised of progress on the development of the optical ash analyzer.

Task 2 - Laboratory Testing

The purpose of this task is to establish the appropriate software configuration and mathematical correlations necessary to determine ash content from image analysis of a coal slurry. Included in this effort is the study of the gray-level spectra obtained from images of coal slurries containing various ash and solids contents. In addition, a variety of methods for illuminating the slurry are being investigated.

During the first two quarters of this project, all equipment and commercial software for the PC-based image processing system were purchased, and work was initiated on the development of specific software programs for on-line coal analysis and neural network pattern recognition. Software development work has continued during the third quarter; although the bulk of this work is on hold pending the development of the sample presentation system (Task 3).

Test work has also been initiated on the use of monochromatic light as a means of enhancing the images obtained with the optical analyzer. This work is being conducted by Mr. Jerry Lilly as part of his UCR Summer Internship at Virginia Tech. Initially, a monochromator providing a range of output light from near-infrared to near-ultraviolet was employed in this study; however, the intensity of the monochromatic light generated
was insufficient to provide an adequate image. As an alternative, several glass filters were purchased which cover the wavelength range within the visible spectrum from 400 - 700 nm. Although the filters do not provide a continuous variation in wavelength as does the monochromator, they have the advantage that they can be used with the existing sample illumination and presentation system (see Task 3). Since the current illumination system utilizes a more powerful light source than the monochromator, and since the filters have much larger bandpasses, ample light is able to pass through the filters and reflect off the slurry resulting in much better images. The present illuminator has been modified to allow positioning of the filters firmly inside the illuminator housing. This approach ensures constant monochromatic lighting conditions and provides an easy mechanism for changing the filters. Three filters, generating orange, red and green light, were initially tested, and all were found to provide sufficient illumination to obtain adequate detail in the resultant image. Test work is continuing to quantify the affect of monochromatic illumination.

**Task 3 - Bench-Scale Testing**

The purpose of this task is to develop a sample presentation system and to test the system in conjunction with the image analyzer and software developed under Task 2. A major part of this effort is involved with finding a means of presenting a flowing coal slurry in a smooth and consistent manner so that the camera can obtain a clear image for analysis. During the first two quarters of this project, two sample presentation systems were evaluated; however, neither was capable of providing an adequate image for analysis. A third system has since been developed and tested. The following is a description of this latest prototype.
The third prototype sample presentation system is shown in Figure 1. It consists of a PVC tube approximately 65 cm in length by 9 cm in diameter. The upper portion (2) of the tube is used to house the camera (11), cooling fan (15) and reflected light illumination system (5), while the lower portion (7) houses the transmitted light illumination system (6) and the slurry level control system (12,13). The upper portion of the tube (2) is bolted to the lower portion (7) with a Plexiglas disk, and rubber gasket material (14) is placed between the two sections to ensure that an air tight seal is achieved. The camera (11) is held rigidly in place by a threaded cap (16), with the lens placed directly on the Plexiglas disk (14). A cooling fan (15) is mounted on the side of the camera housing to prevent overheating of the camera (11). Reflected light illumination is provided by a fiber optic ring light (5) mounted around the lens of the camera (11). Transmitted light illumination is provided by an additional fiber optic ring light (6) mounted at the bottom of the lower tube (7). Constant illumination is maintained by reading the resistance output from a photocell (11) and making adjustments to the illumination controller as necessary. The tube is designed to be inserted into a sump or tank, and the level of the slurry in the tube is controlled by two electronic air valves (12), a solenoid-type air input valve and a proportionally controlled solenoid-type pressure relief valve. Conductivity sensors (13) mounted on the side of the tube indicate the level of the slurry within the tube. The air inside the tube is either released to adjust the slurry level to the proper focal plane of the camera, or is rapidly added to flush slurry from the tube and acquire a fresh sample.
The overall video analysis system is shown in Figure 2. The system consists of a computer(1) equipped with a frame grabber board, a black and white television camera, a video monitor (3) and a fiber optic illuminator (4) with reflected (5) and transmitted (6) light illumination systems. The camera (housed in the top portion of the sample presentation tube) is connected to the computer/frame grabber input (1), and the video monitor (3) is connected to the frame grabber output port. The sample presentation tube is mounted in a sump or tank (8) in which the slurry is mixed by some means such as a motor-controlled impeller (9,10).

The operation of the system is as follows. Initially, the sample presentation tube (7) is flushed with air. The electronic relief valve (12) then releases air to the atmosphere, allowing the slurry to enter the sample chamber. The conductivity sensors (13) indicate the slurry level in the chamber, and when a predetermined level is achieved, the relief valve is closed, holding the slurry level constant. The predetermined level is that which places the slurry in the optimal focal plane of the camera (11). The slurry sample, illuminated by either reflected (5) or transmitted (6) light, is then imaged and digitized into gray level information by the frame grabber (1). This information is processed by the computer to determine ash content, percent solids, etc. Finally, the sample chamber is flushed with air in order to acquire a new slurry sample and the analysis procedure is repeated.

Preliminary tests with the new sample presentation tube, indicate that this approach provides excellent image quality as shown in Figure 3. The swirls of dark coal along with light ash and clay minerals are clearly visible in the image. This is in contrast to Figure 4 from the second prototype sample presentation system in which the ripples
present in the flowing slurry create streaks and reflections which obscure the true gray level information contained in the image.

Thus, it appears that the new sample presentation system solves the problems associated with the previous prototypes. It provides a very clear image of a moving coal slurry, it is constructed as an insertion tube so that it can be easily inserted into an existing tank or sump (i.e., no sophisticated sampling system is required), and multiple images can be easily included as part of a single analysis simply by pulsing the air in the sample tube and bringing in a fresh sample. Some concern has been expressed by Pittston representatives that frother present in the flotation reject stream might cause froth to form in the sample presentation tube; however, preliminary tests in which frother was added to the sump did not show this to be a problem.

At the present time, the new sample presentation system is being integrated with the image analysis system so that the entire sensor can be tested during the coming quarter. In addition, a patent disclosure on the sample presentation system has been submitted to the university.

Task 6 - Sample Analysis and Characterization

The samples being used to test the sample presentation system have been acquired from Pittston’s Middlefork preparation plant. The feed to this plant is dredged from an existing tailings impoundment and treated by a combination of spiral concentrators and column flotation. To date, two five-gallon samples of column feed and tailings have been collected on two different occasions. The product streams have not be sampled as they are considered too “dark” to be analyzed using the optical technique. Once the samples
were acquired, splits were taken to determine percent solids and ash content. Column feed samples were found to vary from 38 to 46% ash with percent solids values ranging from 6.3 to 11.2%, while column tailings samples varied from 69 to 76% ash with percent solids values ranging from 4.5 to 3.4%. The variation in solids and ash percentage is most likely due to the randomness of the feed material entering the plant, and is the primary reason that Pittston is interested in the development of the optical sensor for use in an on-line column control system. In fact, the variation in feed and tailings ash content is known to be much greater than what is shown here from these two samples.
SUMMARY STATUS AND FUTURE WORK

Major accomplishments during the past quarter are listed as follows:

1. A method for illuminating coal slurry with monochromatic light has been devised and tests are underway to quantify the effect of this light source on the resulting image.

2. A new prototype sample presentation system has been developed which appears to solve problems encountered with previous prototypes. The new system is an insertion tube which can be placed directly into a sump. The resulting image obtained with this device is extremely clear despite mixing and turbulence within the sump. The sample presentation system is currently being integrated with an image analysis computer, and a patent disclosure has been filed with appropriate officials at Virginia Tech.

As shown in Table 1, the project appears to be on schedule at this point. During the coming quarter, it is expected that the integration of the image analysis computer and sample presentation system will be completed in preparation for initial in-plant data collection which is expected to begin in October. It is also expected that monochromatic light studies will be completed, and any positive findings generated from this work will be incorporated into the sensor.
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Figure 1a.

Figure 1b.

Figure 1. Plan view (a) and plan view cross-section (b) of the prototype three sample presentation system.
Figure 2. Schematic diagram of video-based slurry analyzer with prototype three sample presentation system.
Figure 3. Digitized image from prototype three sample presentation system using reflected light.
Figure 4. Digitized image from prototype two sample presentation system using reflected light.