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Technical Progress Report

Fifth Quarter

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

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DISCLAIMER

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, the current prototype of the on-line optical ash analyzer was subjected to extensive testing at the Middlefork coal preparation plant. Initial work focused on obtaining correlations between ash content and mean gray level, while developmental work on the more comprehensive neural network calibration approach continued.

Test work to date shows a promising trend in the correlation between ash content and mean gray level. Unfortunately, data scatter remains significant. Recent tests seem to eliminate variations in percent solids, particle size distribution, measurement angle and light setting as causes for the data scatter; however, equipment warm-up time and number of images taken per measurement appear to have a significant impact on the gray-level values obtained.

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 fifth 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 four 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. In addition, a detailed study on the use of monochromatic illumination was completed from which it was concluded that standard white light produced a more favorable resolution of ash content than did any of the monochromatic sources tested.

Work during the past quarter has primarily focused on the development of neural network software for pattern recognition, and the identification of various statistical parameters of the gray-level distribution that can be used by the neural network software as "learning" parameters.

The identification of statistical parameters can be summarized as follows. A rectangular area of the image is characterized by the distribution of the tones of the pixels that form the image. Each of these tones is represented by a value between 0 and 255, which correspond to a gray value between black (i = 0) and white (i = 255). A frequency distribution of the gray values is calculated and represented as a 255-element vector whose elements are the number of pixels in the image corresponding to each gray value. From this distribution, several statistical parameters are calculated, which are descriptive of the mean tone and texture of the image.

The distribution variables currently being investigated include:

1. mean - the average gray value of the image.

$$\sum_{i=0}^{255}(No.\,pixels_i \bullet i) \Big/ \sum_{i=0}^{255} No.\,pixels_i$$

2. mode - the gray value which occurs most frequently in the image.
3. median - the gray value at which the cumulative frequency distribution first equals or exceeds 0.5.
4. skewness - a statistical measure of the symmetry of the distribution around the mean.

$$\left(\sum_{i=0}^{255}\left[No.\,pixels_i \bullet (i - mean)^3\right] \Big/ \sum_{i=0}^{255} No.\,pixels_i - 1 \right) \Big/ (\text{standard deviation})^3$$

5. kurtosis - computed like the skewness, but the fourth power is used instead of the cube. It is considered to be a measure of the heaviness of the tails in a symmetric manner.
6. range - the difference between the maximum and minimum gray values in the image.

7. interquartile range - an indicator of the spread of the gray values. It is defined as the range of the middle 50 percent of the pixels, that is, the range calculated after the brightest 25 percent and the darkest 25 percent of the pixels are discarded.

For each sample, 20 images are acquired, the histograms (or frequency distributions) of the images are determined and averaged, and the variables listed above are then calculated from the mean distribution.

In the next stage, these statistical parameters and the corresponding ash values will be scaled prior to being used to train a neural network. The neural network will then "learn" a relationship between distribution parameters and ash values so that when the sensor is later presented with new samples that were not part of the training data, it can provide a sufficiently accurate ash percentage. Three types of neural networks are being considered. These include (i) a linear network, in case the relationship can be approximated by a linear function, (ii) a backpropagation network, and (iii) a radial basis network. The latter two networks are commonly employed for nonlinear functions. During the next quarter it is expected that the software necessary to implement each of these neural network methodologies will be completed.

Task 3 - Bench-Scale Testing

All work associated with the design and development of a slurry sample presentation system is now complete. Refinements to this system will continue to be made as new information is collected during testing and calibration of the optical ash analyzer.

Task 4 - Pilot-Scale Testing

The purpose of this task is to provide a range of ash values and test conditions that can be used to calibrate the optical ash analyzer. Originally, it was proposed that this work would be conducted using a pilot-scale flotation bank under carefully controlled conditions; however, the convenience of the plant site and the ability to save images on a video cassette recorder made it much easier and more practical to conduct this task on site. Furthermore, the normal variations in the feed material to the Middlefork preparation plant, made it possible to collect a large data base over a wide range of conditions in a relatively short period of time.

During the past quarter, three trips were made to the Middlefork preparation plant for extended testing of the optical ash analyzer. The following is a summary of the results obtained from those trips and some of the operational difficulties encountered.

Middlefork Plant Visit #1

In the early part of October 1995, the sample presentation system for the optical ash analyzer, along with a Super-VHS video cassette recorder to save images collected by the system, were taken on-site to the Middlefork preparation plant. The sample presentation tube was installed in a small sump which was periodically filled with column flotation tailings. Samples were also collected at the same time to be analyzed later for percent solids and ash content. Twelve samples were placed in the sump with four images of each sample recorded on video-cassette for later analysis. The samples were acquired from three of the five operating columns in time intervals of approximately twenty minutes. During this trip the preparation plant experienced a lengthy power outage and the collection of images and samples was hampered. Also, the video equipment was adversely affected by the loss of power and some image information was corrupted. Thus, in the following analysis, it should be noted that samples 1-7 were collected prior to the power failure and samples 8-12 were collected after the power failure.

The samples taken for determination of ash content and percent solids were brought back to the lab and analyzed. Table 1 shows the percent solids and ash content along with corresponding mean gray levels and standard deviations (based on four images per sample) for the samples collected. Percent solids values ranged from 1.7 to 4.3 and percent ash varied from 65.1 to 80.8. These variations are normal for this preparation plant due to the nature of the feed material (i.e., dredged from a tailings impoundment).

Sample Number	Column Number	Percent Solids	Percent Ash	Mean Gray Level	Standard Deviation
1	1	2.2	80.1	101.5	---
2	2	2.7	77.3	90.8	3.7
3	3	2.9	75.9	91.8	4.6
4	1	2.7	77.1	81.8	2.2
5	2	2.8	77.7	84.0	3.8
6	3	2.9	76.8	85.6	2.3
7	1	4.2	71.0	74.7	3.3
8	2	4.3	65.1	61.3	1.9
9	3	2.7	74.2	67.7	2.7
10	1	1.7	80.4	80.4	3.0
11	2	1.1	80.8	83.3	1.7
12	3	1.7	74.0	70.4	1.7

Table 1. Ash content, percent solids, mean gray levels, and mean-gray-level standard deviations for twelve samples from Middlefork preparation plant visit # 1.

Figure 1 shows the mean gray levels plotted versus ash content for each of the 12 samples. As shown, there is a definite trend indicating an increase in mean gray level with increasing ash content; however there appears to be appreciable scatter in the data. Upon closer examination, it appears that samples 1-7 fall along one line, while samples 8-12 fall along a second line which lies below the first line. It has since been learned that the camera requires a warm-up period of approximately 1.5-2 hours, during which time the gray levels recorded by the sensor slowly increase. Thus, it appears that the lower gray levels recorded for the latter five samples may be a result of the power failure and subsequent camera warm-up time. This warm-up phenomenon will be discussed in greater detail later in this report. Subsequent testing has also shown that four images per sample are not sufficient to eliminate statistical "noise" from the measurement. This topic will also be discussed in more detail later in this report.

In light of the possible causes of data scatter, the data obtained from the first extended test of the optical ash analyzer were very encouraging. Pittston personnel indicated that a resolution for the optical analyzer of five percentage points (e.g., the difference between 70 and 75% ash) would be a best-case scenario as far as they were concerned. Even with the appreciable scatter, the data shown in Figure 1 indicate that this resolution is an attainable goal.

Middlefork Plant Visit #2

During the latter part of October, a second extended test of the optical ash analyzer was conducted at the Middlefork preparation plant. The setup described earlier for the previous plant visit was used once again. In order to reduce the standard deviation from the mean gray levels for each sample, the number of images recorded per sample was increased from four to ten. Once again, three of the five operating columns were sampled in time intervals of approximately twenty minutes, with a total of 21 samples collected for analysis. At the request of Pittston personnel, feed and product samples were also collected at the same time as tailings sample no. 20 for evaluation of flotation column performance. Finally, the samples were brought to the lab and analyzed for ash content and percent solids, and the videotaped images were analyzed to obtain mean gray level values for each sample.

Table 2 shows the ash content, percent solids, mean gray levels, and standard deviations obtained for all samples. The percent solids values ranged from 0.36 to 5.04 and the percent ash varied from 65.3 to 85.2. Several samples had extremely low percent solids and high ash values due to movement of the dredge that provides feed to the plant. The feed and product ash content and percent solids values for sample no. 20 are also included at the bottom of this table.

Sample Number	Column Number	Percent Solids	Percent Ash	Mean Gray Level	Standard Deviation
1	1	2.0	73.4	102.3	2.5
2	2	2.8	70.8	96.1	2.4
3	3	4.7	68.7	101.5	11.5
4	1	2.8	74.7	108.6	3.1
5	2	5.0	65.3	97.8	2.7
6	3	5.0	68.1	98.9	4.5
7	1	3.6	71.3	106.7	3.7
8	2	2.6	73.5	107.8	2.8
9	3	3.3	72.5	106.4	2.1
10	1	0.5	85.2	160.8	4.2
11	2	1.7	69.5	115.9	2.2
12	3	3.0	71.6	128.6	3.6
13	1	1.6	75.9	125.3	2.1
14	2	3.1	70.1	124.3	3.2
15	3	2.2	79.1	146.7	1.9
16	1	0.6	84.3	171.3	2.9
17	2	0.4	82.6	194.0	3.4
18	3	0.9	70.7	173.0	1.9
19	1	3.4	66.6	189.6	4.7
20	2	3.0	72.9	152.2	6.1
21	3	2.6	75.9	132.3	10.5
20	feed (2)	4.2	49.0		
20	prod. (2)	12.3	7.9		

Table 2. Ash content, percent solids, mean gray levels, and mean-gray-level standard deviations for 21 samples from Middlefork preparation plant visit # 2.

Figure 2 shows the mean gray levels for all 21 samples plotted as a function of slurry ash content. Once again, as in the first plant visit, there is a definite correlation between ash content and mean gray level; although there also appears to be appreciable scatter in the data. It is interesting to note that most of the scatter seems to be associated with those points collected near the end of the sampling campaign (i.e., samples 17-20). Furthermore, a glance at the data in Table 2 does not seem to indicate any relationship between percent solids and the data scatter, nor do points 17-20 seem to exhibit any excessive standard deviation. If points 17-20 are eliminated, the remaining data seem to fit a reasonable relationship with a percent ash resolution within the desired limit specified by the Pittston Coal Company.

Based on the results obtained from the first two extended sampling campaigns, it was felt that a systematic study was in order to identify those parameters that might be responsible for the data scatter. The experience gained with the optical analyzer from the first two field tests indicated that the parameters most likely to contribute to data scatter were percent solids, particle size distribution, incident light intensity, sample presentation tube tilt angle, number of images collected per sample and system warm-up time. The latter parameter was suggested by the fact that there seemed to be a consistent increase in gray level as a function of time. Slurry samples brought back from plant visit no. 2 were used in this systematic study. The following is a summary of the findings from this work.

Effect of Percent Solids:

Five slurry samples, each containing 76% ash and varying from 1-5% solids in one percent increments, were prepared from a sample brought back from plant visit no. 2. Six images were collected per sample and averaged to produce the results shown in Table 3.

Percent Solids	Mean Gray Level	Standard Deviation
1	76.9	1.2
2	76.6	1.3
3	78.9	2.2
4	78.9	1.9
5	79.6	2.5

Table 3. Mean gray levels for percent solids varying from 1-5% for a 76% ash sample.

As shown, the overall mean gray level changes by less than three gray level increments over the range from 1-5% solids. When these data are plotted on the same scale as the previous sensor calibration curves (Figure 3), it is clear that the effect of percent solids is within the statistical "noise" of the optical measurement.

Effect of Size Distribution:

With percent solids essentially eliminated as a cause of data scatter, it was decided to pick two samples of approximately the same ash content, but with widely varying mean gray levels, and to compare the size distributions obtained from each of these samples. The two samples selected for this investigation were samples 5 and 19 in Table 2. As shown, samples 5 and 19 are nearly identical in terms of ash content (65.3 and 66.6, respectively); however, their mean gray levels differ by over 90 gray level increments. The size distributions obtained from these two samples are shown in Table 4. As shown, the size distributions are remarkably similar. Considering that this material is being reclaimed from a tailings impoundment and that the two samples were collected over four hours apart, the similarity of the size distributions is extraordinary. Thus, it does not appear that variations in particle size distribution are the cause of data scatter in this particular case.

Size (mesh)	Sample 5 Weight %	Sample 19 Weight %
+100	0.4	0.6
100 x 200	3.2	3.1
200 x 400	7.0	6.6
-400	89.4	89.7
Total	*100.0*	*100.0*

Table 4. Size distributions for samples 5 and 19 from plant visit # 2.

It should be noted that this simple comparison is not a rigorous study of size distribution effects. It is expected that a tailings sample containing a significant quantity of +28 mesh (-0.6 mm) coal would be difficult to analyze using the current methodology, as the coarse coal would tend to settle in the sump and, thus, would not be seen by the analyzer. Therefore, a more systematic study of particle size effects should still be performed as part of this investigation.

Effect of Incident Light Intensity:

The effect of incident light intensity was investigated in order to define a relationship between the measured light intensity inside the sample presentation tube and the mean gray values measured for a given sample. The normal set-point for light intensity was 1.60 kΩ as measured by the photocell mounted inside the sample presentation tube. The light setting was varied from 1.58-1.62 kΩ, and the same slurry sample as that used to study the effect of percent solids was used in this investigation. The results of this study are shown in Table 5 and Figure 4. As shown, the relationship between the incident light setting and the mean gray level is nearly linear with a slope of approximately 2.5 gray level increments per 0.01 kΩ of light intensity. Since the built-in light controller normally controls the light setting to within 0.01 kΩ as measured by the photocell, any variations in light intensity are once again within the statistical "noise" of the gray level variation.

Light Intensity (kΩ)	Mean Gray Level	Standard Deviation
1.58	78.3	3.1
1.59	75.6	0.5
1.60	72.7	1.4
1.61	70.0	1.5
1.62	68.5	0.5

Table 5. Mean gray levels for light settings varying from 1.58-1.62 kΩ for a 76% ash sample.

Effect of Sample Presentation Tube Tilt Angle:

The sample presentation tube is rigidly mounted to the small sump in which the flotation column tailings are placed for analysis. The tube angle can be varied from 48° to 53° in the sump and is normally placed at an approximate angle of 50° from the horizontal. The tube undergoes some shock when samples are placed in and removed from the sump, as well as when the high pressure air is pulsed through the sample tube permitting acquisition of fresh samples. It was theorized that movement of the tube during in-plant testing of the sensor may have contributed the data scatter. Therefore, the effect of two extreme sample tube angles was investigated to determine the effect of tube angle on the mean gray levels obtained for a given sample. Once again, the slurry used for studying percent solids and incident light intensity was used in this investigation.

Tube Angle	Mean Gray Level	Standard Deviation
48°	77.8	2.3
53°	78.1	2.4

Table 6. Mean gray levels for two extreme tube angle settings for a 76% ash sample.

Table 6 shows the mean gray levels obtained when the tube was placed at 48° and 53°. The minimal difference of 0.3 in mean gray level for the two extreme tube angle conditions shows that sample tube angle has an insignificant effect on the gray levels obtained.

Effect of Number of Images Collected Per Sample:

A systematic study was conducted to determine the appropriate number of images to collect for each sample in order to minimize the standard deviation from the mean gray level. In this investigation, 40 images were collected from the same 76% ash slurry that had been used in the previous test work. Based on these images, the individual mean gray level for each image was determined, and the cumulative mean gray level for all images was calculated. These results are shown in Figure 5 in which the deviation from the overall mean gray level after 40 images is plotted on a scatter diagram. As shown, the cumulative mean gray level does not truly represent the ultimate mean gray level of the sample until at least 15 images are included in the average. In fact, the deviation from the true mean gray level can be significant for less than 5 images. Thus, it appears that this factor may have played some role in the data scatter exhibited by the earlier sensor tests. In order to ensure that future mean gray levels are truly representative of the slurry being analyzed, it was decided to use a conservative number of 20 images in future analyses. Image capture and analysis are quite rapid, and this should pose no serious time constraint for the on-line application of this analyzer.

Effect of Warm-Up Time:

As mentioned previously, the data collected from both field tests seemed to show a pattern of increasing gray level as a function of time for slurries with similar ash contents. This pattern can be clearly seen in Figure 6 which shows four samples (samples 2, 7, 12 and 14) from field test no. 2 plotted as a function of analysis time. These four samples were chosen because they have nearly identical ash (70.1-71.6% ash) and solids (2.8-3.6%) contents. As shown, there appears to be a clear upward drift in mean gray level as a function of time.

It was theorized that the phenomenon observed in Figure 6 might be due to the "warming-up" of some electrical component in the system. In order to verify this theory, a controlled laboratory test was conducted with the optical analyzer. A 76% ash slurry sample was placed in the sump, and, starting with a cold system, multiple images were collected at ten-minute intervals over a period of several hours.

Since there was some concern that the appearance of the slurry might actually change while it is allowed to mix in a sump over several hours, a supporting test was also performed. The system was shut down and allowed to cool overnight. The following day the same process was repeated over several hours with a piece of paper placed inside the sample presentation tube. This was done to ensure that the camera was imaging the exact same object each time.

Figure 7 shows the mean gray levels obtained over time for both the slurry and the paper. In order to provide an easier basis for comparison of the two sets of data, the mean gray levels for the paper have also been scaled to match those obtained for the slurry. It is clear that the overall gray level values increase in nearly the exact same fashion for the slurry and the paper. The optical analyzer appears to reach equilibrium after about 120 minutes, after which, the resulting gray level is essentially constant with time.

Thus, there is clearly a "warm-up" period which must be considered before data collection can begin. This factor, along with the need to include a sufficient number of images in the analysis, appear to be the most likely parameters contributing to the data scatter observed in the first two field tests.

Middlefork Plant Visit #3

Around the end of November, a third sampling visit was made to the Middlefork preparation plant. On this trip, however, it was decided that the entire image analysis system, including the PC with frame grabber board and monitor, would be taken to the plant site. This was done to eliminate the possibility of any information loss due to intermediate storage on video cassette. Based on the findings from the systematic study described previously, the system was allowed to "warm-up" for two hours before any images were collected. Also, it was decided to collect 20 images per sample.

After the initial setup and warm-up of the sensor, it was found that the Plexiglas disk, which fits against the camera lens and is used to create an air-tight seal for pressurizing the sampling tube, was fogging due to the extremely cold weather at the plant site. It appeared that the disk, when presented with the much warmer slurry from the plant, would fog making it impossible to collect a clear image. After repeated attempts to clean the disk and warm the entire system, the in-plant testing effort was abandoned for this trip, and 7 two-gallon samples of slurry where collected over the course of the day. These samples were then brought back to Virginia Tech for testing in the laboratory.

The results of the laboratory testing are shown in Table 7 and Figure 8. As shown, on this particular day, the material feeding the plant was much more consistent in terms of ash content. Thus, the samples were not particularly good for determining a calibration trend. However, it is interesting to note that for the five values whose ash contents are near 73%, the mean gray levels are very consistent. Thus, it does appear that the use of an increased number of images collected per sample and the allowance for instrument warm-up time, have substantially helped to reduce the data scatter.

Sample Number	Column Number	Percent Solids	Percent Ash	Mean Gray Level	Standard Deviation
1	3	3.5	77.6	73.6	2.1
2	2	1.7	72.6	74.7	1.1
3	3	5.7	80.6	88.7	2.3
4	2	0.9	73.3	83.2	1.1
5	3	3.4	72.5	81.3	1.4
6	2	2.8	72.7	81.7	1.1
7	3	1.4	73.2	84.7	1.3

Table 7. Ash content, percent solids, mean gray levels, and standard deviations for seven samples from Middlefork preparation plant visit # 3.

Based on the findings from all three sampling visits during this past quarter and from the results obtained from the systematic laboratory study, it was decided that the only way to truly test and calibrate the sensor is to acquire a substantial data base. Thus, plans for the upcoming quarter call for several multi-day, on-site sampling campaigns, which will make it possible to acquire the kind of data base needed to statistically verify the accuracy and resolution of the optical ash analyzer.

Task 5 - In-Plant Testing

Task 5.1 - Procurement and Fabrication: Much of the software and hardware needed for this task have already been purchased in order to carry out the developmental work. The primary purchases remaining largely involve fiber optics cables and communications equipment for transmitting images from the sensor to the control room where the computer will eventually be installed. It is anticipated that the final items required for the sensor interface will be purchased after the sensor has been calibrated and is ready to be installed for long-term testing over the final six months of this project.

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. Flotation tailings samples have generally been found to vary from 65 - 85% ash while feed samples range from 38 - 50% ash. As testing of the sample presentation system and calibration of the image analysis system proceed, numerous samples will continue to be collected as needed.

SUMMARY STATUS AND FUTURE WORK

Major accomplishments during the past quarter are listed as follows:

1. The optical ash analyzer has been tested on-site in three separated plant visits. The initial tests showed considerable scatter in the mean gray-level data obtained for a given ash content.
2. A systematic laboratory study was carried out to identify the parameters responsible for the data scatter. Laboratory tests indicated that the analyzer was relatively insensitive to percent solids, particle size distribution, sample presentation tube angle, and incident light intensity over the range of values normally encountered by each of these parameters.
3. The number of images collected per sample appeared to be a major contributor to data scatter. Laboratory testing indicated that 20 images should be collected per sample to ensure accurate gray-level readings.
4. The camera was found to exhibit a warm-up period during which the resulting mean gray level of a given image gradually increased. As a result, a two-hour warm-up period is now allowed before collecting any data.
5. Preliminary indications from the last on-site visit seem to show that modifications to the operating procedures based on conclusions 3 and 4 above produce much more consistent results and substantially reduce data scatter. This finding must still be verified with a larger data set.

As shown in Table 8, the project appears to be on schedule at this point. Tasks 1 and 3 are complete and Task 4 is at its midpoint. During the coming quarter, it is expected that a substantial data base will be collected with which to complete the testing and calibration of the optical ash analyzer. It is also expected that much of the neural network learning software will be in place by the end of the next quarter.

Table 8. Project Schedule

Task	Month 2 4 6 8 10 12 14 16 18 20 22 24
Task 1 - Project Planning	
Task 2 - Laboratory Testing	
Task 3 - Bench-Scale Testing	
Task 4 - Pilot-Scale Testing	
Task 5 - In-Plant Testing	
Task 5.1 - Procurement and Fabrication	
Task 5.2 - Installation and Calibration	
Task 5.3 - Operation/Testing/Refinement	
Task 6 - Sample Analysis & Characterization	

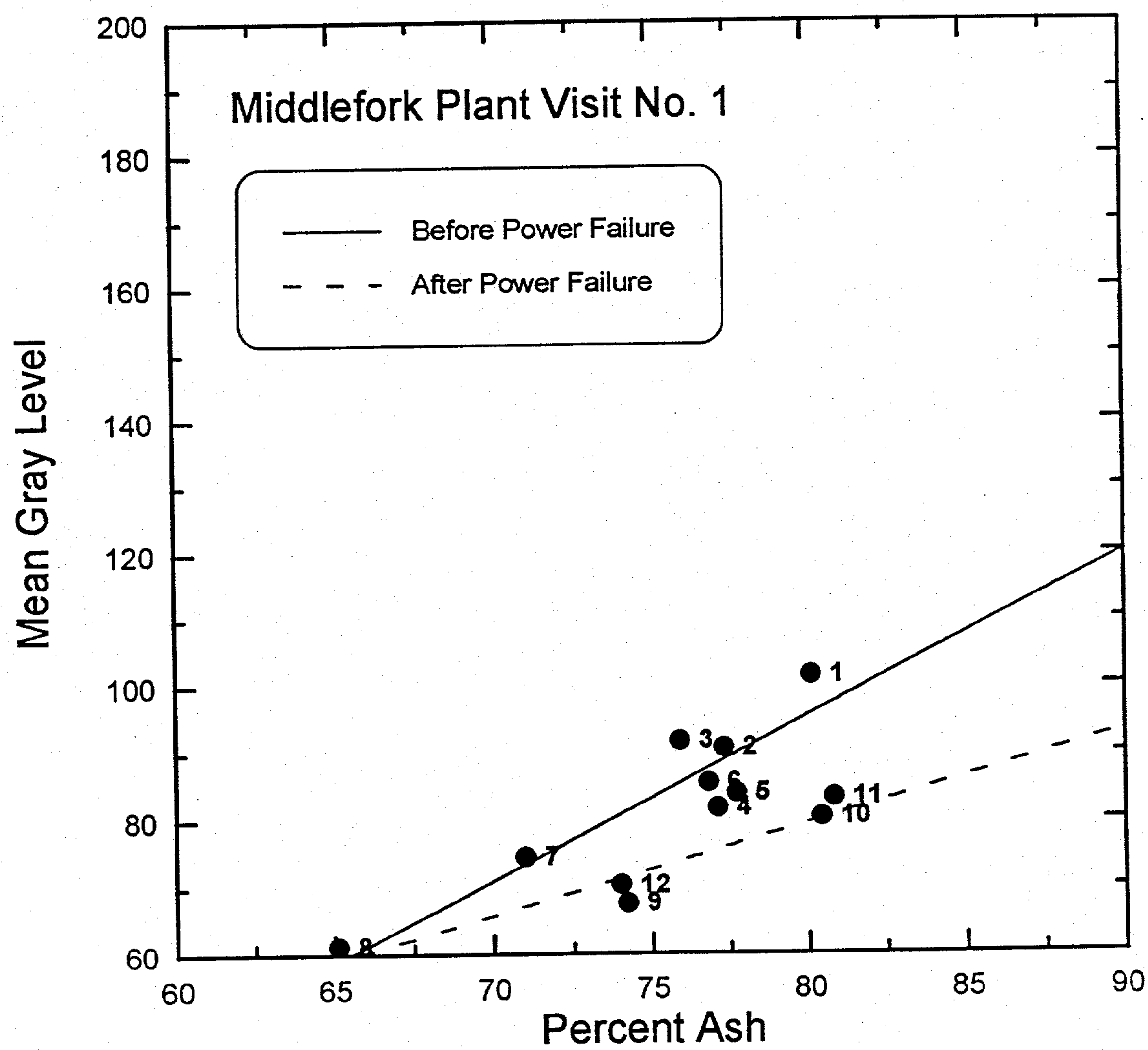

Figure 1. Mean gray level versus ash content for 12 samples collected during Middlefork preparation plant visit #1.

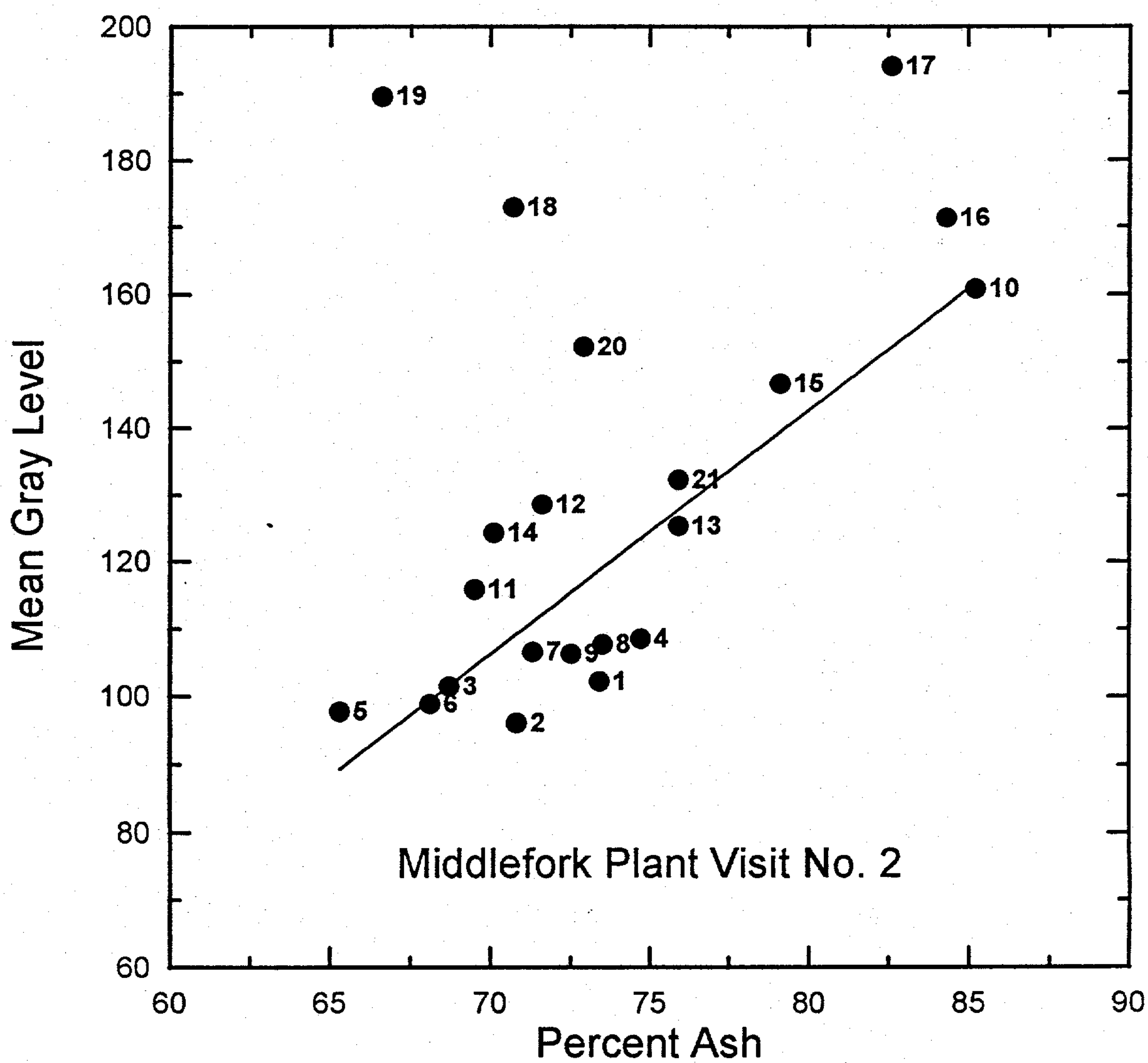

Figure 2. Mean gray level versus ash content for 21 samples collected during Middlefork preparation plant visit #2.

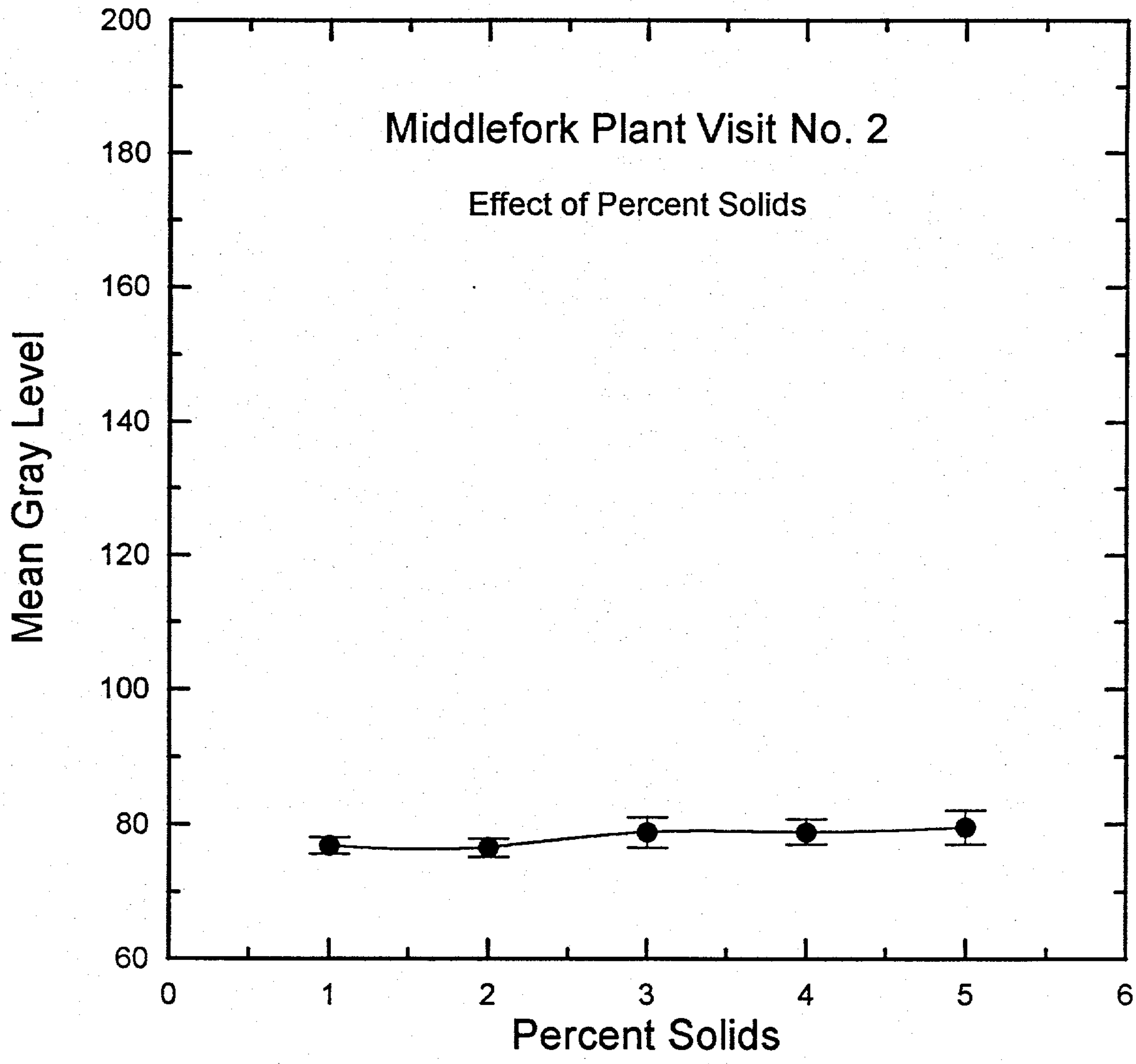

Figure 3. Effect of percent solids on mean gray level for a 76% ash slurry sample.

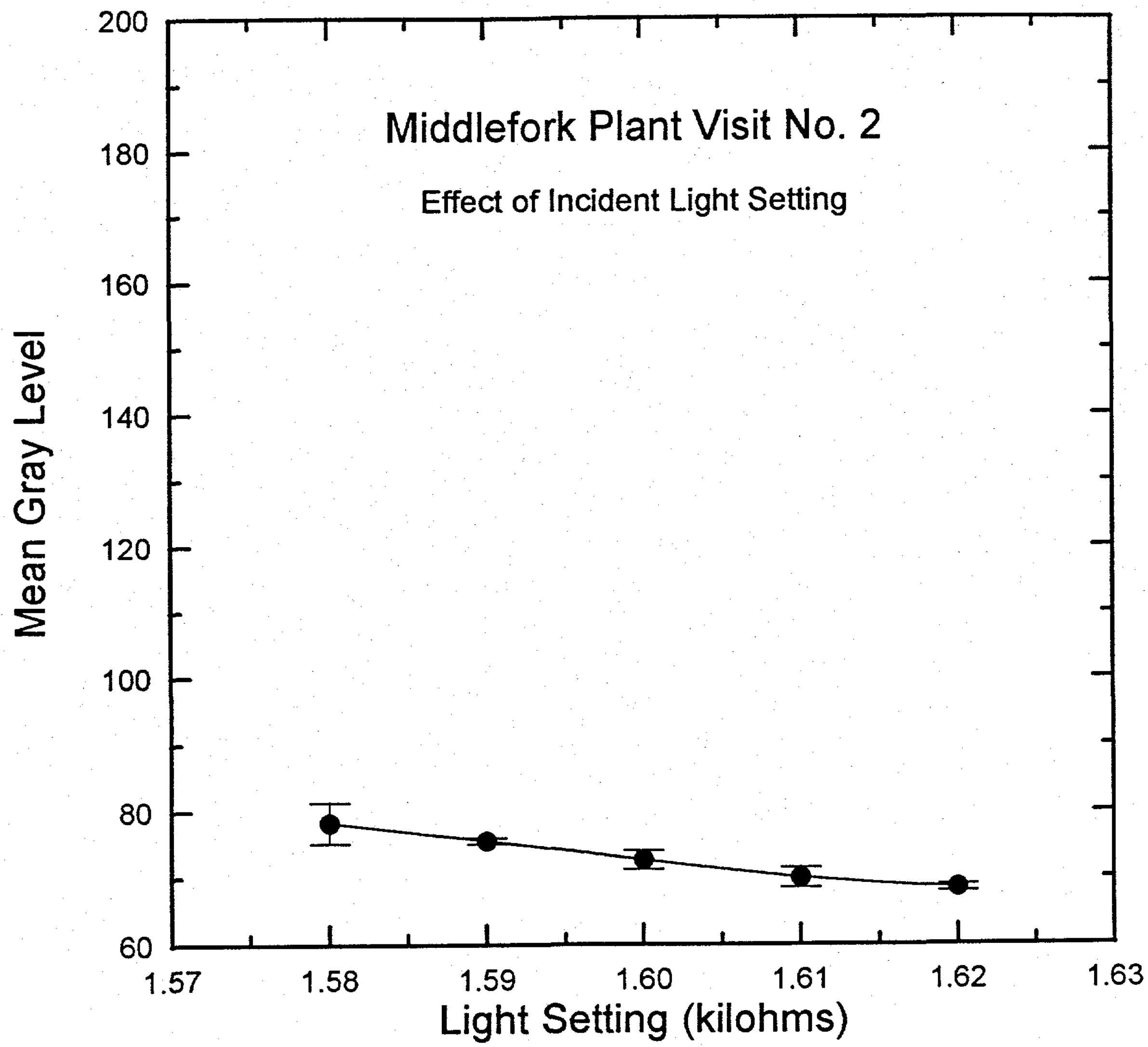

Figure 4. Effect of incident light intensity on mean gray level for a 76% ash slurry sample.

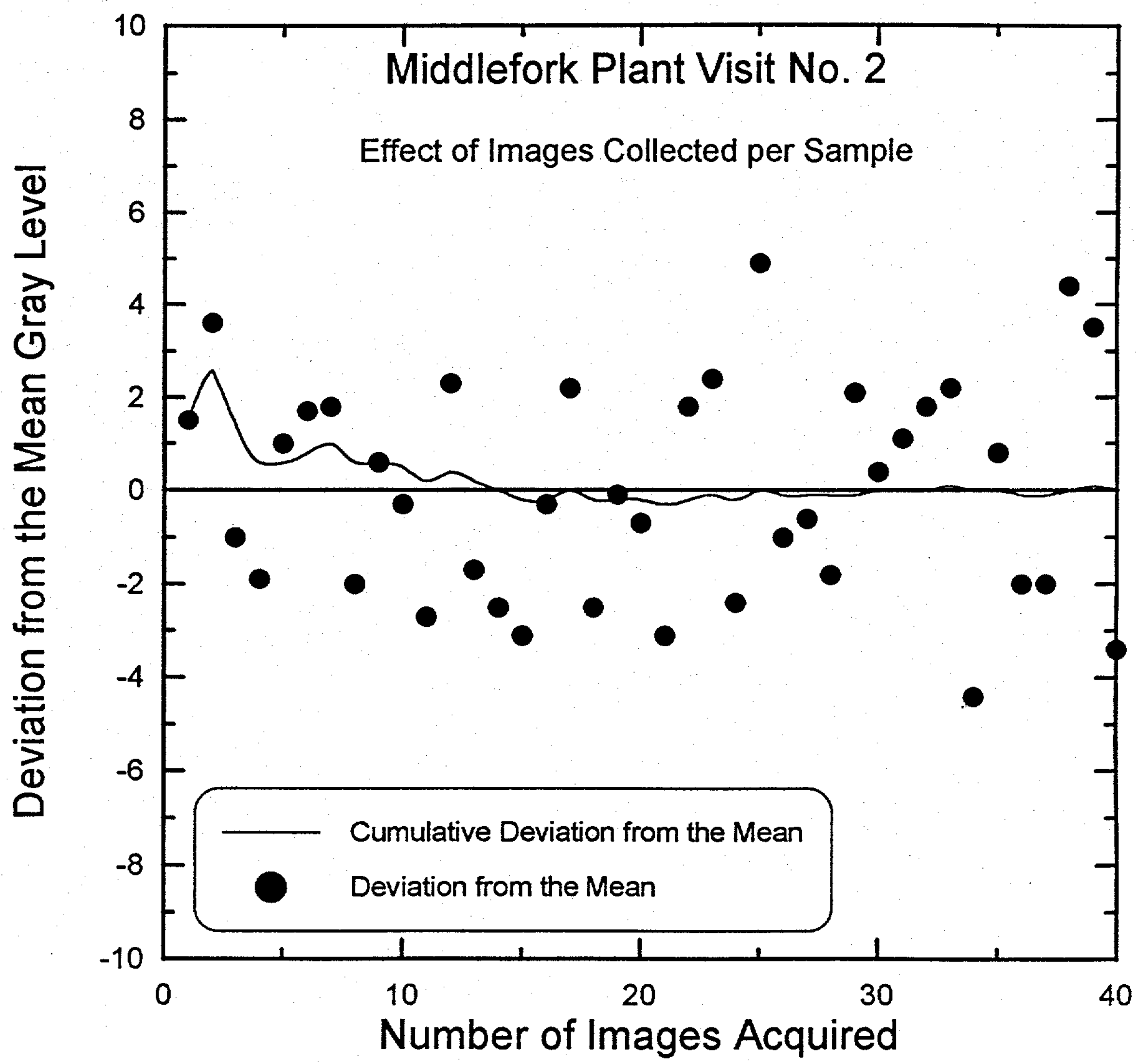

Figure 5. Effect of number of images collected per sample on the overall average mean gray level measured for a 76% ash slurry sample.

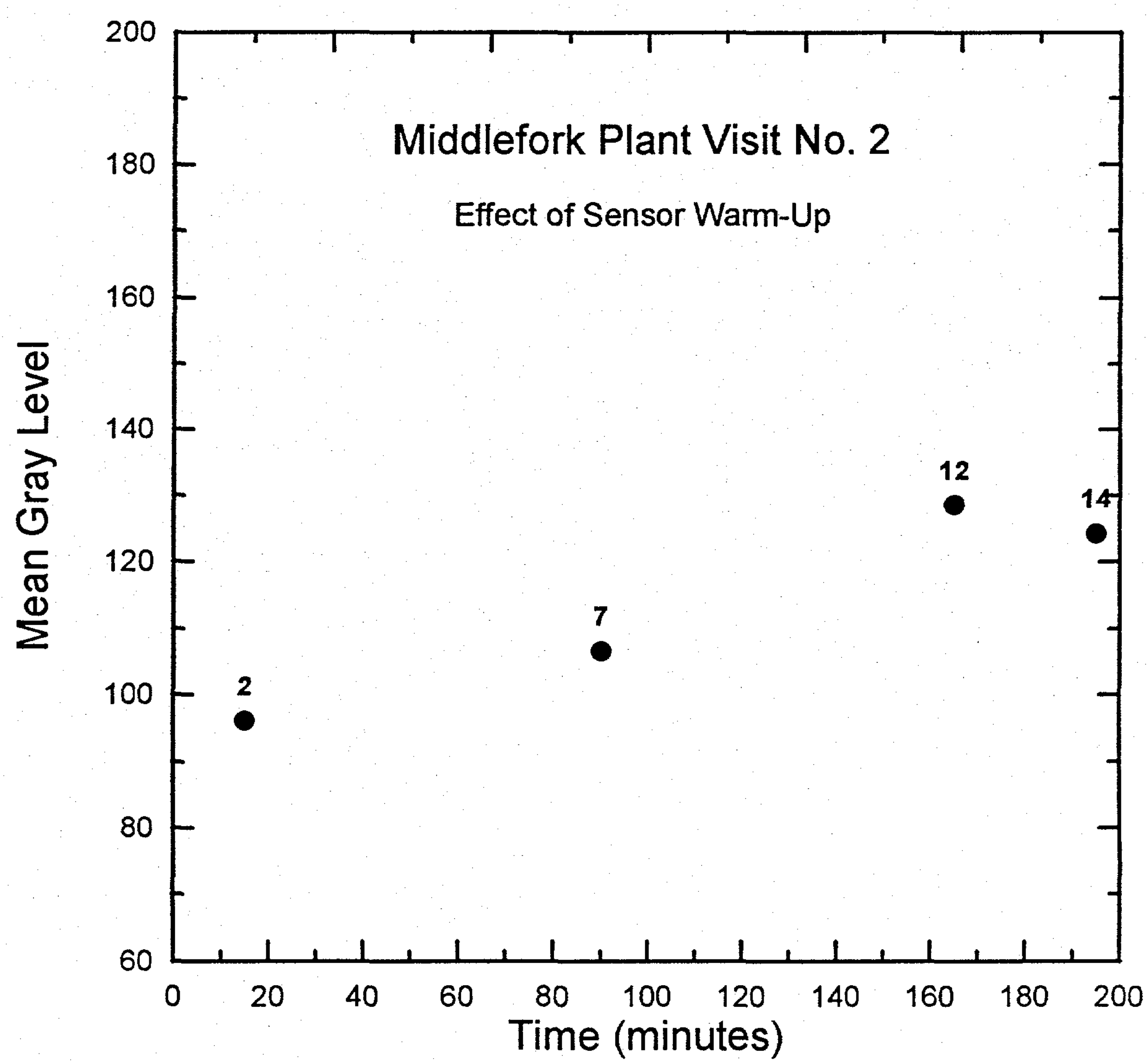

Figure 6. Mean gray level as a function of sample collection time for slurry samples with similar ash content and similar percent solids.

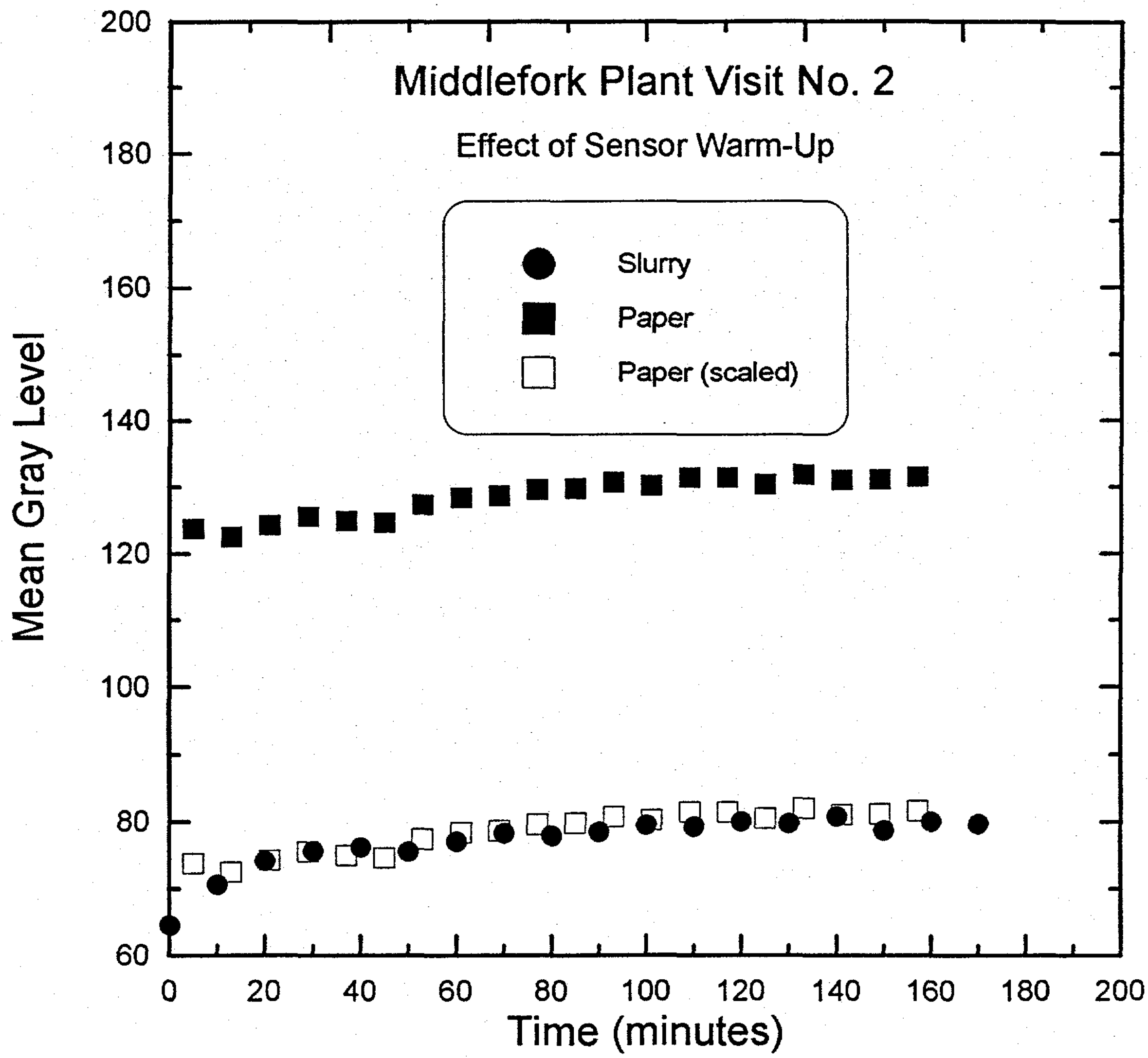

Figure 7. Effect of warm-up time on mean gray level values obtained using coal slurry and paper.

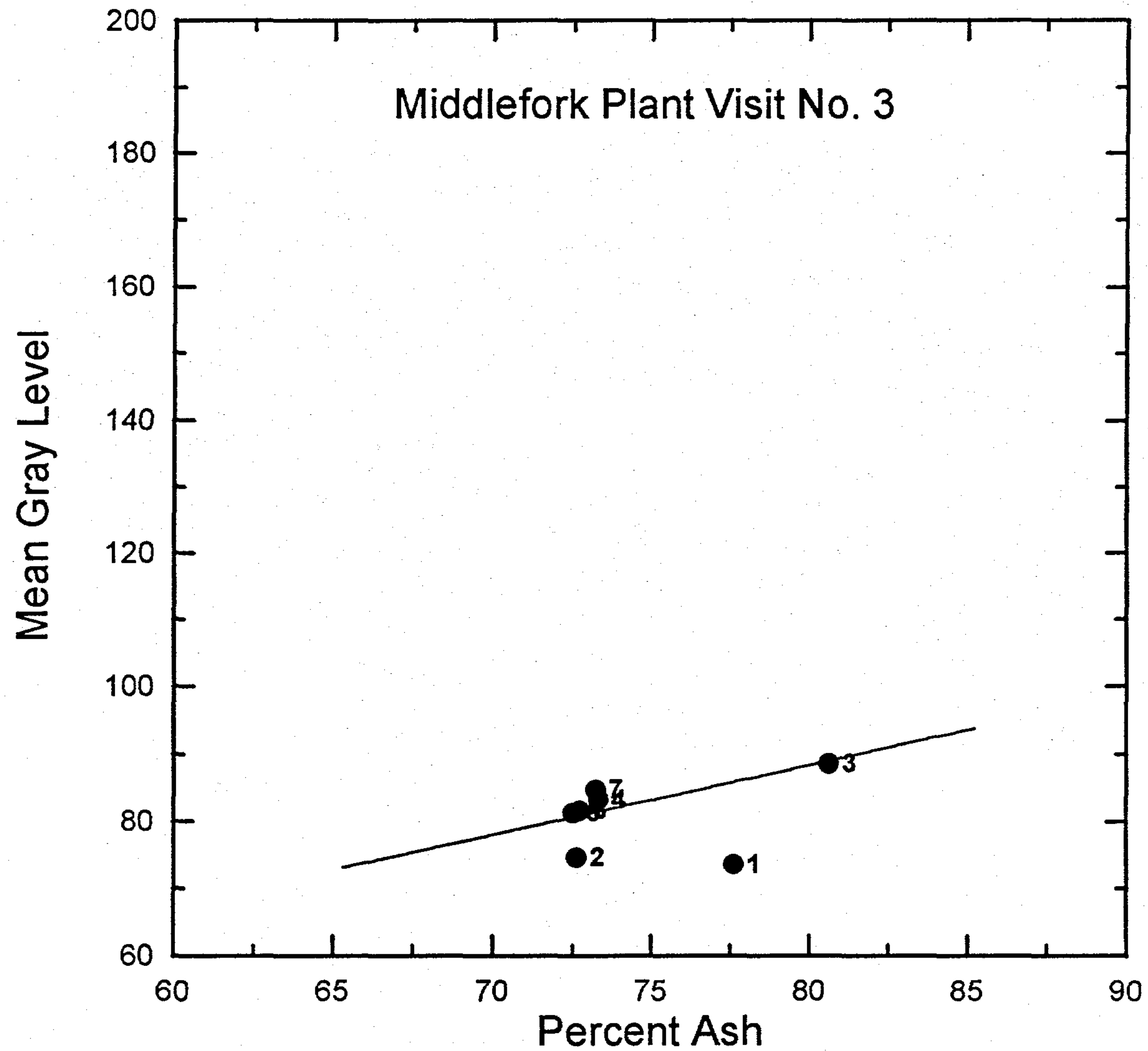

Figure 8. Mean gray level versus ash content for 7 samples collected during Middlefork preparation plant visit #3.