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TECHNICAL REPORT

December 1 1993 through February 28, 1994

Project Title: **CHARACTERIZATION OF COAL PARTICLES
USING RULE BASE ON-LINE IMAGE ANALYSIS**

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ABSTRACT

Different materials in coal reflect light in a different manner and, therefore, can be identified based on their image of light reflectance characteristics (i.e. shade of gray). Furthermore, liberated and nonliberated pyrite particles are surrounded by media of different shades of gray. With these two pieces of information, the degree of pyrite liberation and the degree of purity of coal macerals can be analyzed through a computer program. Ultimately, this image analysis computer program will acquire and analyze different frames of coal image automatically without any intervention of an operator. During the past one year, an in depth database of the light reflectance characteristics of different materials of coal has been established. This process is still being continued to extend the database of coal images. During this quarter, a C-language computer program has been developed. This program reads an image and analyzes it according to the database and decision-making criteria developed in the previous study. Thus far this computer program tends to account more particles than what are presented in an image. This is attributed to the electronic noise produced through the CCD camera. The electronic noises are in the order of 1 or two pixels and can be rectified through an additional decision-making rule. In general, this computer program picked up the particles without any intervention from an operator. In other words, this computer can replace an operator to perform the analysis of ultrafine coal particles.

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EXECUTIVE SUMMARY

In light of the need in coal characterization, especially, pyrite liberation analysis, a rule base on-line image analysis system is proposed. This proposed research represents an extension of a project funded by ICCI.

To obtain the ultraclean fuel, coal must be pulverized into particles of ultrafine sizes. As a result, the characterization of ground coal, in particular, the assessment of pyrite liberation, becomes extremely difficult. The assessment of pyrite liberation is the most important way of determining whether a batch of ground coal obtained through a grinding process is acceptable. At present, the liberation analysis is conducted manually through a microscope with commercial image analysis software. Sometimes, this procedure causes discrepancies from one operator to the other in the interpret of microscopic images. On the other hand, the amount of coal can be inspected in each experiment is limited by the particle sizes of the ultrafine coal and the magnification factor of the microscope. Therefore, a large number of samples must be analyzed in order to assess the degree of pyrite liberation. This makes the present method of liberation analysis of coal a very labor intensive and a very time consuming process. In light of that, an automation procedure based on the principles of image processing is being developed to perform the analysis of pyrite/minerals liberation of coal.

Different materials reflect light in different manners and therefore can be identified based on their image of light reflectance characteristics (i.e. shade of gray). Furthermore, liberated and nonliberated pyrite particles are surrounded by media of different shades of gray. With these two pieces of information, the degree of pyrite liberation can be analyzed through a microcomputer. To make the automated image analysis system possible, an expert knowledge base and a rule base decision mechanism utilizing the light reflectance characteristics of different constituents of coal(pyrites, vitrinite, inertinite, etc.) must be established. This will include the consideration of the effect of the actual operating parameters such as inclined incident of light, uneven focal planes of the sample. It is believed that such an automation process for image analysis of coal particles is very feasible in the laboratory operation involving polished pellet. Recently, the laboratory studies conducted at SIUC have demonstrated that pyrite analysis can be accomplished in a matter of less than one minute rather than a few hours if conducted manually. However, in this evaluation

process, the light reflectance characteristics of pyrite was predetermined manually used as an input into the image analysis program.

It should be pointed out the automation in the recognition of coal particles requires a wide spectrum of optical images of ground coal. Specifically, one should realize that every microscopic image (through an optical microscope) of ground coal exhibits distinct characteristics. This is due to the fact that the distribution of coal particles is different from one frame to another. As a result, the image features such as the average gray level of pyrites, the particles size distribution of each maceral, the material composition etc. are unique for each frame. Under such a circumstance, assessment of pyrite liberation using image analysis with one optical feature (e.g. a fixed value of gray level for pyrite) will be insufficient. Rather, a set of rules simultaneous evaluating the distinct optical and physical characteristics of coal particles (including pyrites) must be established. Recent research results at Southern Illinois University at Carbondale (SIUC) have led to development of several criteria for analyzing images of coal with different characteristics. Undoubtedly, an extensive characterization of coal images is still needed in order to develop a broad expert knowledge base about coal particles.

In addition to the development of a rule base image analysis program, a complete on-line coal characterization system must include the mechanisms for the transport of samples to a stage for measurement. To be more specific, in order to bring the coal sample pellets under an image analysis device (e.g. optical microscope), a conveyor system allowing for an in-plane travel is needed. In addition, a mechanism to bring the specimen into the focal plane of the microscope should be implemented. With today's technology in the digital I/O system, the procedure for motion control of the conveyor and staging system can be interfaced with a computer. As a matter of fact, the development of a computer controlled X-Y table has been completed and tested successfully. The work ahead will be the development and design of an interactive image focus scheme. In other words, the step for bringing an image into focus will be accomplished by the computer instead of by human operator. In this regard, an image analysis technique is necessary for the sensing and adjustment of optical depth of the test sample. Ultimately, it is believed that the procedure for characterization of coal such as pyrite liberation analysis can be fully implemented through a computer from the initial sample preparation to the final image analysis.

The completion of the studies outlined in the previous sections will bring the following advantages:

1. Improves the current coal characterization technology, in particularly, the assessment of pyrite liberation.
2. Greatly reduces the time and effort in performing liberation analysis. The new image analysis procedure developed in this research will provide faster and more accurate pyrite liberation analysis.
3. Provides a realistic assessment of a coal characterization process as a part of the coal cleaning and preparation processes.
4. Offers potentials for the commercialization of research results such as image analysis program for coal particles and design of the on-line system.

Currently, the measurement of the light reflectance characteristics of different materials in coal is still being continued in order to extend the database of coal images. In addition, during this past quarter, the following tasks have been conducted,

- a. A C-language based image analysis computer program has been completely developed. This program contains the database of ultrafine coal particles and the decision-making criteria established in the previous study. This program is designed to analyze the images directly obtained from the CCD camera.
- b. The preliminary evaluation of the decision-making algorithms of the image analysis program versus the results obtained through an human operator has been obtained.
- c. Continue the development of the auto-focus mechanism of the long distance optical microscope stage.

OBJECTIVES

The overall objectives of this project are:

1. To continue the development of a rule base automated image analysis computer program for assessment of pyrite liberation, and
2. To upgrade the image analysis system into an integrated package.

These two phases will be conducted simultaneously. In the laboratory scale, the specimens to be analyzed will be under somewhat ideal conditions. However, the image analysis computer algorithm to be developed in this stage is essentially the foundation for any rule base coal characterization procedure. In addition, the completion of the first goal will represent a drastic improvement of the current technology in the coal characterization such as liberation assessment. For the integrated system, we will attempt to emulate the automated image analysis into a part of the overall coal cleaning process. Under this constraint, a conveyer system as well as an auto-focusing mechanism will be designed and built.

INTRODUCTION AND BACKGROUND

The key emphasis of this research project is to develop an automation process for the determination of pyrite/minerals liberation as well as particle size distribution of ultrafine coal obtained during and/or after coal cleaning. To accomplish this, an image analysis computer program with an expert knowledge base for identifying different constituents (liberated and nonliberated) in coal must be developed. Since different images acquired from a coal sample exhibit different features in particle size distribution and different compositions of material, a rule base decision making algorithm must be established through an extensive laboratory study. In addition to the development of the rule base image analysis program, in this project, we will also attempt to develop and construct a system that will allow an automation in setting up the test specimen under imaging apparatus as well as an automation in bring coal image in focus. It is believed that the results of this research program can greatly reduce the intensive time and effort in the characterization of coal during the liberation and separation processes. Furthermore, the equipment and software design will lead to a new and improved standard in coal characterization.

Needs for the Evaluation of Ultrafine Coal

The coal industries, today, are facing with a very stringent requirement on the emission and/or release of sulfuric compound to the living environment set forth by Environmental Protection Agency (EPA). As a result, the need for producing ultra-clean coal effectively (Yen and Hippo 1990) has greatly increased. It has been reported by McCartney (1969) and Jao (1991) that for the Illinois #6 coal the mean particle size of pyrite is less than 10 micron. Therefore, from the viewpoint of statistics, coal must be ground to ultrafine sizes in order to liberate the microscopically dispersed pyrite particles and to obtain the clean coal that meets the EPA requirements. The development of the procedure for effectively producing ultrafine coal is a difficult task and has been pursued by many researchers. On the other hand, to evaluate the degree of success of each of the newly developed coal pulverization procedures, a method for examining the ultrafine coal is needed. The traditional method (ASTM, 1973) for evaluation of coal fines is a two step approach. First of all, ground coal is subjected to centrifuge in heavy media for the separation of fraction with different specific gravities. Secondly, each fraction of a given specific gravity is then subjected to TGA for element analysis or SEM for the microscopic observation. However, these steps are quite time consuming and labor intensive. For example, the

drying process after the centrifuge usually takes a few hours while the SEM inspection requires a tedious sample preparation. Clearly, the liberation analysis procedures recommended by ASTM is not suitable for the high volume ultrafine coal production which requires a quick analysis of coal particles. In our view, an effective characterization procedure for analyzing pyrite/mineral liberation should require a minimal specimen preparation. The actual measurement of ground coal particles should be conducted by taking the advantage of high speed data processing of computer. This is to ensure that a large number of samples can be accounted for whereby the liberation assessment will be statistically meaningful and will be accomplished in a very short time. Ultimately, a high magnification device (such as optical microscope) is needed to examine the ultrafine coal particles. To develop into an on-line quality assurance mechanism, the sample preparation, sample inspection, and liberation analysis must be integrated into an automated mechanism. It is believed that the recent development of image analysis technique and long distance microscope may make such an integrated system possible.

Optical Microscopic Image Analysis

Image analysis (Dawson 1987, Gonzales et al 1987) is a relatively new technique that is being applied to scientific and engineering research. Basically, image analysis is used to determine the optical characteristics (e.g. intensity of light reflectance) of objects. This is then followed by a logical assessment of the measured data and a comprehensive numerical calculation.

Typically, an optical microscopic image analysis system consists of a microscope, a CCD camera, a monitor, and a personal computer equipped with a data acquisition board (frame grabber). The microscope is to provide a proper image for observation, the video camera along with the data acquisition board are to record the various optical characteristics of different objects, and finally computer software is used to analyze data in order to distinguish different materials, and particle sizes. When an object is presented under a microscope several of its characteristics such as shades of gray, physical dimensions (length, width, area), shape, boundaries, texture are noticeable. Most of these characteristics, in general, are distinct among different objects. In the image analysis, an image is divided by a set of horizontal and vertical grids (or pixels). Within each grid area, optical characteristics are electronically recorded and analyzed through a computer system. Also, using a proper calibration procedure, the actual area represent by a group of grids can be calculated. Such an analysis procedure is referred to as the optical

microscopic image analysis.

Recently, the utilization of optical microscope with the Automated Image Analysis (AIA) has resolved some problems involving the visual interpretation of the objects at microscopic levels. For example, AIA has been applied successfully by Yen et al (1991) to determine the fiber angle orientation and fiber volume ratio of composite materials, and by Huggins et al (1982), Straszheim and Markuszewski (1985 and 1986) to analyze the particle size distribution of ultrafine coal, to identify different minerals and macerals in coal and to assess the pyrite liberation after coal grinding. This is primarily based on the principle that, in general, different materials have different light reflectance. Such characteristics appear as different shades of gray (or colors) under the video camera observation and can be distinguished and analyzed through computer programs.

Current Application of AIA to Liberation Studies

At present, for pyrite liberation analysis (Yen and Hippo 1990, Blankenship 1991, Jao 1991), a pellet is prepared by mounting samples of ground coal in epoxy resin. This pellet is subjected to several steps of polishing. The polished pellet was then brought to an optical microscope for examination and analysis using a commercial image analysis software. This software can only perform a limited number nonsequential routines in image enhancement and image analysis such as picture sharpening, and area counting. In other words, a sequential logical analysis of pyrites with different surroundings (i.e. liberated and nonliberated) is beyond the capacity of this computer program. Therefore, an interaction between operator and the computer program is necessary make a single measurement.

After the image of the desired area of the sample is adjusted for better human interpretation, a threshold gray level value is set for the pyrite particles. The operator records the area of the pyrite particles, their total number on the examined frame and the total area. Then, based on visual inspection, the person has to decide whether or not the pyrite particle is free and label it accordingly. This process is repeated until at least a total of about 200 pyrite particles are analyzed (Florek, 1991). Obviously, this procedure was laborious and time consuming. Even visual inspection is a rather daunting task and the operator is always doubtful as to whether or not the pyrite particle is free. In addition to these problems, due to the extreme brightness of the pyrite particles, the pixels in their neighborhood acquire a glow that makes it all the more difficult to establish the properties of the surroundings. Therefore,

the results varied, depending on the decision made by different operators.

The most challenging task in making image analysis into an automated process is image segmentation, wherein, the classification of image regions into different objects. This is primarily because of the complexity of the image and the contrast variations in the particular video camera setting and in the light source of the object. For this purpose, numerous images of a sample must be analyzed to determine their distribution of shades of gray (i.e. histograms), pixel values along a line, etc. These information are then used to establish an expert knowledge database regarding the relative gray levels of different macerals in coal. This is followed by a decision making through a rule base artificial intelligent (Batchelor 1974, Pavlidis 1977) to detect the liberation of each individual particle.

Development of the Rule Base for Image Analysis of Coal

In analyzing a typical gray level image, one usually determines the pixel distribution of different gray levels (this is referred to as the histogram). During the inspection of ground coal particles, it is possible that the use of histogram may provide the information leading to the pyrite liberation analysis. This is because that different materials in coal appear to have distinct gray levels when a coal image is viewed through the computer monitor. In general, the distinction in gray levels may be interpolated as (a) a gray level with zero pixel in a histogram represents the division between two types of maceral, or (b) the difference in gray level between macerals is greater than that of within the same maceral. In other words, there should be a distinct boundary between pyrites to inertinite and inertinite to vitrinite. Clearly, the images with different composition of particles will result in histograms of distinct characteristics. This suggests that analysis of coal images must be conducted on an individual frame basis.

Theoretically, there should be only four gray levels (or ranges of gray level) with zero pixel in an image. This will naturally divide the ground coal into voids/boundaries (in black), epoxy background, vitrinite, inertinite, and pyrite. However, the data extracted from the histogram of several coal images have shown many gray levels with zero pixel. This will definitely bring confusing in the determination of boundaries between different macerals. On the other hand, since pyrite is the brightest among all the particles in an image, development of a computer algorithm searching for the upper gray scales of zero pixel may be worthy.

To further study the optical characteristics of ground coal, an gray level averaging technique was introduced (Yen and Chu, 1993). In general, in a particle there exists a distribution of (perhaps, continuous) gray levels. One can identify a particle much easier by using its average gray level. In addition, it was found that using the gray level averaging technique particles of the same kind (e.g. vitrinite, inertinite, pyrite) tend to group closer in their gray values. In other words, the relative distance in gray level between vitrinite to inertinite and inertinite to pyrite becomes larger. As a result, the distinction among pyrite, inertinite, and vitrinite using the average gray value approach is possible. More importantly, it was found that, for most of the images studied, the gray level spreads between vitrinite to inertinite (ΔG_1) and inertinite to pyrite (ΔG_2) tend to be the two largest values among the difference in gray level between two particles with adjacent light reflectance. In this regard, the particles that define the two largest differences in gray level are those which define the lowest gray level for pyrites, the highest and the lowest gray levels for inertinite, and the highest gray level for vitrinite. Furthermore, it was found that ΔG_1 usually greater than ΔG_2 .

Several special cases that do not fit the descriptions given in the previous paragraph have also been identified. For example, it is likely to have an image without the presence of pyrites and/or vitrinite. Also, it is possible that the particles involved in obtaining the first two largest gray level difference (i.e. ΔG_1 and ΔG_2) are not the particles define the boundaries between vitrinite to inertinite and inertinite to pyrite. To resolve these cases, it is necessary to investigate the spread in gray level of each individual maceral and mineral, the shape factor and size of each particle, the location where ΔG_1 and ΔG_2 were calculated, etc. Each distinct case of gray level characteristics of an image will then become a case of the overall expert data base for decision making algorithm. Undoubtedly, extensive laboratory characterization of coal samples is necessary to build into a broad data base.

Integrated On-line Image Analysis Stage

It is believed that the automated image analysis system proposed here can be used as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. Based on this concept, there will be

a mechanism to collect coal samples from the cleaning process, a process for sample preparation, a conveyer system to transport coal samples into the inspection station, a mechanism to bring the test sample into the focal plane of the image instrument, and finally the computer program for the characterization of the liberation status. All these subsystems can be integrated into a single interactive feedback and control package illustrated by Figure 4. This integrated system emulates the quality inspection process used in the manufacturing industry. However, the computer programming and data acquisition in this proposed feedback/control system is far more complicated.

Two components of the on-line system have been put together. An X-Y table consists of two stepping motors with platform and a computer interface system have been received. The table has a stepping capability of 0.0025 in. with a resolution of 0.0001 in.. A C-language based computer program was developed to manipulate the motion of the X-Y table. It should be pointed out that this system control program can be integrated as a part of the image analysis program. In the envisioned process, this table will bring coal samples to a position under the viewing path of a long distance video imaging system through the computer algorithm. Next, a z-axis motion has to be introduced to provide an automation mechanism in focusing. This will require an elaborated programming in pattern recognition as well as depth detection through an image correlation.

A long distance imaging system was also integrated during this quarter. This system consists of a long distance microscope (up to 660x), a color CCD video camera, a color frame grabber, and a 486 computer. The light source of the long distance imaging system is provided through a fiber optic ring light attached with the long distance microscope. The minimum working distance of the long distance microscope is 10 mm. It is necessary to calibrate the long distance imaging system so that an optimal working distance for observing coal pellet is obtained.

EXPERIMENTAL PROCEDURES

The overall goals of this project are (1) to continue the development of a rule base automated image analysis system for assessment of pyrite liberation and (2) to upgrade the image analysis system into a bench scale package. These two phases will be conducted simultaneously. In the laboratory scale, the specimens to be analyzed will be under some what ideal conditions. However, the image analysis computer algorithm to be developed in this stage is essentially the foundation for any rule base coal characterization procedure. In addition, the completion of the first goal will represent a drastic improvement of the current technology in the coal characterization such as liberation assessment. In the bench scale, we will attempt to emulate the automated image analysis into a part of the overall coal cleaning process. Under this constraint, a conveyer system as well as an autofocusing mechanism will be designed and built. The specific tasks to be conducted in this proposed study are summarized as follows:

Task 1: Sample preparation

Ultrafine coal (Illinois #6 coal) samples that have different degree of liberation will be used in this study. These samples were prepared through a previous CRSC/DOE project and are available at the Civil Engineering and Mechanics Department, Southern Illinois University. Both pelletized and particulate coal samples are needed. To prepare the pellet sample, ultrafine coal particles will be mixed with epoxy resin and cast into a plastic cylinder. Upon cured, the circular surfaces of the pellet will be subjected to several steps of polishing until they are mirror like. To prepare the nonpelletized sample, ultrafine coal particles will be spread on a thin glass plate. A light brushing will be applied to minimize the overlapping of coal particles. Finally, a second glass plate will be used to clamp the coal particles in place.

Task 2: Determine the Image Characteristics of Pyrite and Coal Macerals

In this task, the expert knowledge base regarding the image characteristics of each coal constituents such as pyrite and vitrinite are to be developed. Normally, the light reflectance of each material in coal will have a band width of shades of gray. However, the gray levels of a material can shift under different light sources. Therefore, it is necessary to determine the gray levels of each material in coal as well as to determine its relative difference in gray levels with other macerals/minerals. Sometimes, in a random sample, the

gray level data may not be sufficient to differentiate one material from the other. In this case, particle characteristics such as shape factor (length to width ratio), particle size, surface texture will then be useful in assisting decision making. Therefore, in this task, we will attempt to measure as many image features as possible for pyrite, minerals, macerals in coal. The image analysis will be primarily conducted using a commercial image analysis software. In the meantime, we will develop an image analysis computer program of the similar capacity.

Task 3: Development of a Rule Base Liberation Criterion

So far, there is no commercial software which can do liberation analysis without the intervention of an operator. In this project, a computer program (to be added on the one being developed under an ICCI grant) will be developed to perform pyrite liberation assessment as well as the analysis of coal particles. It is known that a liberated pyrite particle will be surrounded by the epoxy matrix of the pellet rather than the coal. As a result, base on the analysis of the gray level of the material surrounding to a pyrite particle. The status of liberation may be determined. On the other hand, the liberation status can also be determined based on the difference in gray between a particle and its surrounding. Ultimately, the variation of gray levels of an image containing the liberated and nonliberated particles can be modeled by Fourier series. Based on this mathematical model, the characteristics of the functional changes for liberated particle can be established. In this proposed study, the liberation criteria based on the gray levels of the surrounding to the pyrite particles will be developed into a computer program. Also, the distinct features of different image frame will be documented and will be implemented into the criteria for coal characterization. This program will take an image (in terms of a computer file) and perform the liberation analysis. Interactive computer graphics will be developed and used to show the image with the results of the liberation analysis. The computer program developed in Task 2 will be combined with the computer program developed in this Task to form an integrated interactive image analysis software.

Task 4: Verification Study

It is believed that the image analysis program to be developed here is capable of performing fast and accurate liberation analysis. To verify this, pyrite liberation data and the kinematics of ultrafine coal particles that obtained from the elaborated analysis through human operators will be used to compare with the results obtain

from the image analysis program developed based Tasks 2 and 3. Extensive liberation data as well as particle size distribution of ground coal that established by Yen and Hippo (1990a) will be used as a reference.

Task 5: Design of an On-line System

In our view, the automated image analysis at its ultimate application should be built in as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. Thus far, the plan for this proposed on-line system has been developed (Figure 4). The following steps are to build and to calibrate the conveyer system (X-Y table) and the automation in specimen focusing (Z-axis). For example, a vertical motion mechanism will have to be added to the existing X-Y table. The computer program for the motion control of X-Y table as well as focusing in Z-axis must be developed. In particular, the fine tuning in the focusing step must interact with the attached imaging system equipped with an image correlation program (to be developed). It should be pointed out that the focusing of the test specimen may be substituted by a feedback mechanism between operator and the computer.

RESULTS AND DISCUSSION

Currently, the measurement of the light reflectance characteristics of different materials in coal is still being continued in order to extend the database of coal images. A C-language based image analysis computer program has been completely developed during this quarter. A disk copy of the executable file of this image analysis program with a couple of sample images will be made available upon request. This program contains the database of ultrafine coal particles and the decision-making criteria established in the previous study. This program is designed to analyze the images directly obtained from the CCD camera. The preliminary evaluation of the decision-making algorithms of the image analysis program versus the results obtained through a human operator has also been conducted. The results of this study can be used to modify the decision-making criteria in the image analysis program. To make the automated image analysis system more complete, the development of the auto-focus mechanism of the long distance optical microscope stage is still being continued. A brief discussion of the tasks completed in this quarter is given as follows,

Image Analysis Program

The image analysis computer program is written in C-language with some graphic features. The computer program occupies a memory space of approximately 86,000 bytes (more than a thousand lines in computer command). This program is designed to interact with an operator for the input of images and the visualization of the output features. The output features of this image analysis program are (a) the review of the initial gray level image, (b) the histogram of the image, (c) the image in pseudo colors, (d) the identification of pyrite particles, and (e) a table that summarizes all the particles in the image, (f) option for hard copy of the results summary.

It should be pointed out that this program does not require any operator to do any analysis at all. When the pyrite particles are being reviewed during the option (d) the corresponding particle size and liberation status are reported also. Again, these data are summarized in the option (e). The option (f) gives the overall results of the image analysis computer program. Figures 1 and 2 illustrate the data presentation of the image analysis program. Notice that the analysis results can be stored into a data file.

In general, it is believed that the image analysis computer program contains all the necessary options that we envisioned. The major emphasis in the future is to

compare the data obtained through an operator against the results obtained from the image analysis computer program. It should be emphasized again that this computer program is designed to carry out the image analysis routines automatically once an image file is given. This will allow for a teach-and-learn process leading to the modification of the decision-making criteria of the image analysis computer program. For example, at present, the image analysis program can pick-up small particles at 1 pixel resolution. Knowing the fact that only the pyrite particles can have a particle size as small as one pixel in an image, any particles that have a size of 1 to 2 pixel and a gray level well below that of pyrite must be the noise received by the image equipment (i.e. the CCD camera and the image acquisition board). Naturally, such a consideration can then be used to develop into a new criteria. On the other hand, the image analysis computer program terminates only when all of the pixels have been analyzed. This will require a long time to complete an image analysis. To rectify this, a decision-making rule must be implemented to terminate the analysis routine when the gray level of the background material of the pellet have been reached.

Development of the Auto-focus Mechanism

The development of the auto-focus mechanisms of the automated long distance optical microscope has been conducted during this quarter. The characteristics of the images that depart slightly from the actual focal plane are being studied. Specifically, this will require an understanding of the image blur (distribution of gray level) and edge detection characteristics of a slightly unfocused image. So that a computer program can be developed for the fine adjustment of the focusing stage. The control mechanism of the auto-focusing is the same as the control of the X-Y stage and has been developed in the last year's study. It should be pointed out in order to perform the auto-focusing several successive images must be obtained and analyzed. This will require a huge memory space in computer and will take a long time to complete the task. Therefore, it is recommended that only the central part of an image should be used to conduct the auto-focus. It is estimated that the size of such a reduced image will be approximately 100 x 100 pixels.

COAL IMAGE PARTICLE LIST
filename : e20g5-1.img

<page 1>

PARTICLE	TOTAL_GL	AREA	AVG_GL	AVG_DIF	TYPE	FREE
1	510	2	255.00	0.00	PYRITE	NONFREE
2	760	3	253.33	1.67	PYRITE	NONFREE
3	163168	648	251.80	1.53	PYRITE	NONFREE
4	6798	27	251.78	0.02	PYRITE	NONFREE
5	4505	18	250.28	1.50	PYRITE	NONFREE
6	5755	23	250.22	0.06	PYRITE	NONFREE
7	1496	6	249.33	0.88	PYRITE	NONFREE
8	1689	7	241.29	8.05	PYRITE	NONFREE
9	1590	7	227.14	14.14	INERNITE	
10	219	1	219.00	8.14	VITRINITE	
11	217	1	217.00	2.00	VITRINITE	
12	217	1	217.00	0.00	VITRINITE	
13	648	3	216.00	1.00	VITRINITE	
14	216	1	216.00	0.00	VITRINITE	
15	214	1	214.00	2.00	VITRINITE	

Press <Esc> to Quit or Any Other Keys to Continue

Figure 1 An example of the particle list of the image analysis program.

COAL IMAGE SUMMARY LIST
filename : e20g5-1.img

=====

PYRITE(S) :

Total Number of Pyrite(s) : 8
Pyrite Area : 64
Percentage of Pyrite Area : 0.026%
Percentage of Pyrite Particle(s) : 3.524%
Total Number of Free Pyrite(s) : 0
Total Number of Non_Free Pyrite(s) : 8

INERNITE(S) :

Total Number of Inernite(s) : 1
Inernite Area : 1
Percentage of Inernite Area : 0.000%
Percentage of Inernite Particle(s) : 0.441%

VITRINITE(S) :

Total Number of Particle(s) : 218
Total Area : 244919
Percentage of Vitrinite Area : 99.658%
Percentage of Vitrinite Particle(s) : 96.035%

Press Any Key to Exit

Figure 2 An example of the overall summary of the image analysis program.

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PROJECT MANAGEMENT REPORT

December 1, 1993 through February 28, 1994

**Project Title: Characterization of Coal Particles Using
Rule Base On-Line Image Analysis**

DOE Grant Number: DE-FC22-92PC92521 (Year 2)
ICCI Project Number: 93-1/6.2B-1P
Principal Investigator: S. C. Yen
Department of Civil Engineering
Southern Illinois University
at Carbondale
Other Investigator: P. T. C. Chu
Southern Illinois University
at Carbondale
Project Manager: Ken Ho, Illinois Clean Coal
Institute

COMMENTS

Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials & Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sept. 1, 1993 to Nov. 30, 1993	Projected	11,566	1,463	475	467	3,000	750	1,772	19,493
	Estimated	5,400	0	800	0	0	700	500	7,400
Sept. 1, 1993 to Feb. 28, 1994	Projected	18,132	1,463	950	934	3,000	1,500	2,598	28,577
	Estimated	8,349	0	1,550	400	1,000	1,342	1,152	12,784
Sept. 1, 1993 to May 31, 1994	Projected	24,698	1,463	1,425	1,401	3,000	2,250	3,424	37,661
	Estimated								
Sept. 1, 1993 to Aug. 31, 1994	Projected	53,910	5,939	1,900	2,000	3,000	3,000	6,975	76,724
	Estimated								

*Cumulative by Quarter

COSTS BY QUARTER

Characterization of Coal Particles Using Rule Base On-Line
Image Analysis

O = Projected Expenditures -----

Δ = Estimated Actual Expenditures _____

Total Illinois Clean Coal Institute Award \$76,724

SCHEDULE OF PROJECT MILESTONES

Milestones:

- A. Sample preparation (Task 1).
- B. Determine the image characteristics of pyrite and coal macerals (Task 2).
- C. Development of a rule base liberation criterion (Task 3).
- D. Verification study (Task 4).
- E. Design of an on-line system (Task 5).
- F. Reporting.

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AIM

Association for Information and Image Management

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301-587-8202

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Inches

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