

**THE PENNSYLVANIA STATE UNIVERSITY**

**Report of Research**

**on**

**PENNSYLVANIA'S COAL RESOURCES**

**Conducted Under the Auspices of the**

**Coal Research Board  
of the  
Commonwealth of Pennsylvania**

**NUMBER IPR-19  
OCTOBER 1, 1966**



**University Park, Pennsylvania**

REPORT OF RESEARCH

conducted by

College of Mineral Industries  
The Pennsylvania State University

on

PENNSYLVANIA'S COAL RESOURCES

under the auspices of the

COAL RESEARCH BOARD

of the

COMMONWEALTH OF PENNSYLVANIA

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Interim Progress Report

Number IPR-19

for the period of

January 1, 1966 through June 30, 1966

Submitted  
via the  
Coal Research Committee  
The Pennsylvania State University

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University Park, Pennsylvania

October 1, 1966

## STATEMENT OF TRANSMITTAL

This Interim Progress Report contains the technical and fiscal reports on Commonwealth Coal Research Board Projects for the six month contract period beginning January 1, 1966. As per established practice, the report consists of two major sections. Section I contains the technical reports, projected plans and information on project personnel. Section II contains the fiscal reports on each project.

During the period, January 1, 1966, through June 30, 1966, fifteen programs of research were active under Coal Research Board Contracts at The Pennsylvania State University. Two Special Research Reports were issued during the period bringing the total to 56. Requests for 353 copies of Special Research Reports were received and fulfilled during the period.

William Spackman, Director  
Office of Coal Research Administration  
Institute for Science and Engineering  
and  
Coal Research Section  
College of Earth and Mineral Sciences

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**SECTION I**

**RESEARCH REPORTS**

## INTERIM RESEARCH REPORT

Contract Number: CR-29

Title of Investigation: The Reduction of Sulfur in Pennsylvania  
Bituminous Coals During Preparation

### SUMMARY OF PROGRESS AND PROJECTED PLANS

#### A. Objectives of Investigation:

The basic goal has been to develop, through a practical study, the efficiency of application and a theoretical understanding of separation mechanisms for the hydrocyclone (i.e. cyclone processing to achieve a gravity separation without the use of a heavy media) in fine coal cleaning to reduce sulfur and ash.

#### B. Present Status of the Investigation:

The investigation has been essentially completed. Financial support from the project funding expired in January 1966. University funding in the interim has permitted completion of the study. The development of the project has been detailed in Interim Research Reports 12 (June, 1963) to 18 (January, 1966). As a result of the studies, Special Report 45, "An Investigation of the Cyclone for Fine Coal Cleaning" was issued in May, 1964. Subsequently, two other Special Reports have been written and will be ready for release shortly:

"A Study of the Collection of Particles by Sizes with a Hydrocyclone" by S.M. Koo and H.L. Lovell as well as "An Investigation of the Cleaning of Bituminous Coal Refuse Fines by an Experimental Hydrocyclone" by Robert A. Falconer and H.L. Lovell.



The final report will be released in the fall under the title "Investigations of the Cyclone Washing of Fine Coal in Water" by Lothar H.E. Weyher and H.L. Lovell. A preliminary paper on the findings was presented at the Annual Meeting of the American Institute of Mining and Metallurgical Engineers in February, 1966 and will be published in the Transactions of that Society in October, 1966. The text of that paper is appended to this report.

C. Recommendations for Further Study:

From the conclusions of the above studies the following suggestions for further study are noted:

1. A controlled and detailed analysis of the influence of the solid-to-pulp ratio in the feed is important for the determination of maximum throughput capacities without impairing the separation.
2. A critical problem appears to be the scaling-up of the cyclone washer. This is suggested as a separate topic for investigation.
3. The influence of the cone angle on the separation has been studied recently by Falconer, which indicated that the obtuse angled cone may not represent an optimum. Further detailed evaluations should be made.
4. The cyclone washer may represent only one step in a washing process for fine coal. It is, therefore, most important to analyze which place each unit of operation must take in the entire process. Such analysis is of economic nature. But it is the research engineer who has to define the operation of successive units in the flow sheet and their mutual interaction. This analysis of the processing system

in its entirety, on the assumption of dynamic interactions of the individual unit operations in a flow sheet is needed in today's processing fields. Modern computational facilities with vast memory capacities can be employed in order to arrive at suitable process models. Such research would not only be a service to the immediate practice but also a benefit to the theoretical discussion.

5. Further research is suggested toward a careful analysis of the flotation of intergrown coal-pyrite particles. Flotation may not yield satisfactory results in the reduction of sulfur in fine coal, although its ability to remove ash is unquestioned. Especially significant would be further investigation of the preparation of the feed pulp for the fine coal flotation circuit.

Prepared by:

H.L. Lovell

PERSONNEL: Harold L. Lovell, Principal Investigator, Associate  
Professor of Mineral Preparation  
Lothar Weyher, Research Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-35

Title of Investigation: The Characteristics and Preparation of Anthracite Breaker Refuse and the Suitability of Derived Products for Industrial Use

### SUMMARY OF PROGRESS AND PROJECTED PLANS

The past period was spent writing reports, while phasing out.

Special Research Report SR-55, Methods Employed for Underground Stowing, was submitted in February. Special Research Report SR-57, The Evaluation of Anthracite Refuse as a Construction Highway Material, will be released during July.

Prepared by:

T.S. Spicer

PERSONNEL: T.S. Spicer, Principal Investigator, Professor of Mineral Preparation Engineering

## INTERIM RESEARCH REPORT

Contract Number: CR-38

Title of Investigation: Investigation of the Technical Aspects of  
Deep Well Disposal of Mine Water

## SUMMARY OF PROGRESS AND PROJECTED PLANS

Objectives: The main objectives of this investigation were:

1. To assist the Bethlehem Mines Corporation in all ways possible in the development, completion, testing and utilization of a well for mine water disposal in the salt sand formation at Marianna, Pa.
2. Perform extensive laboratory tests with formation cores, connate water and acid mine water to determine formation properties, possible chemical reactions and design parameters for the pumping plant.
3. To continue the study of Pennsylvania geologic formations in an attempt to locate suitable subsurface disposal zones in the central Pennsylvania bituminous region and the anthracite area.

Results:

Field work on the well has been temporarily halted since the second hydraulic fracturing treatment and the fourth injection test were performed earlier this year. The decision to suspend operations was made by personnel of Bethlehem Mines Corporation on the basis of two main developments:

1. The conclusion of all parties involved that a pumping pressure of about 1800-2000 psi would be required to inject 150 gallons of acid mine water per minute into the well.
2. Satisfactory completion of the initial phase of a study of acid mine water beneficiation by a more economic process.

The well has been vented with a cap and is presently full of water. If the process referred to above does not prove satisfactory in its later stages, further work probably will be done with the well.

For all practical purposes, the first objective of this investigation has been completed.

The second objective has also been completed to an extent comparable with the development of the well. Porosity and permeability determinations have been made on cores from the well, but the acid water--connate water--formation compatibility tests have not been performed, since urgency was reduced with the cessation of field work.

The staff of this investigation presently is preparing a comprehensive report describing all work performed on the disposal well. This report should be sent to the printer by the end of the summer.

Work on the third objective of this investigation is also being conducted at the present time. Geologic sections of the coal-bearing areas of central Pennsylvania are being constructed from electric and radioactivity well logs. These sections will indicate the formations in this area which might be suitable as disposal zones.

Attempts to find information on the deeper geologic units of the anthracite region have been unsuccessful. Neither the Pennsylvania

Topographic and Geological Survey or the United States Geological Survey has any material on this region.

A separate report will be published on the subsurface geology of central Pennsylvania from the results of this third phase of the investigation.

Prepared by:

R. Stefanko

PERSONNEL: R. Stefanko, Principal Investigator, Professor of  
Mining Engineering  
Karl Vonder Linden, Research Assistant  
James G. Tilton, Consultant

## INTERIM RESEARCH REPORT

Contract Number: CR-39

Title of Investigation: Strip Mining and Land Restoration

## SUMMARY OF PROGRESS AND PROJECTED PLANS

1. Final reports on "Economics of Drilling" and on "Economics of Stripping Shovels" shall be submitted in the Fall of 1966.
2. Small scale blast tests to study casting techniques by explosives continue in Neidigh quarry. Explosive type, borehole layout, loading density, charge size, burden-spacing relations, etc. are tested in order to determine the most effective way for throwing rock into the spoil bank.
3. A short course on Coal Stripping Operations is in preparation to be offered at the end of 1966 or beginning of 1967.

Prepared by:

B.J. Kochanowsky

PERSONNEL: B.J. Kochanowsky, Principal Investigator, Professor of Mining  
L. Perichon, Research Assistant  
B. Trafton, Graduate Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-40

Title of Investigation: Optimization of Mine Production Systems for  
Low Cost Mining

## SUMMARY OF PROGRESS AND PROJECTED PLANS

At the outset of the interim period, field tests for a conventional machine-interference face simulator were conducted at a bituminous coal mine located in Southwestern Pennsylvania. Research conducted here is to be combined with previous studies described in SR-47, SR-49 and SR-56 (written for locomotives) in an attempt to mathematically model an entire coal mining system.

Prepared by:

C.B. Manula

PERSONNEL: C.B. Manula, Principal Investigator, Assistant Professor of Mining Engineering  
Richard L. Sanford, Research Assistant  
Young C. Kim, Graduate Assistant  
Thomas O'Neil, Graduate Assistant



## INTERIM RESEARCH REPORT

Contract Number: CR-43

Title of Investigation: Control of Mine Stream Pollution by Removal of the Impurities from Drainage Streams

## SUMMARY OF PROGRESS AND PROJECTED PLANS

A. Objectives of Investigation:

This study has been concerned with the removal of pollutants from coal mine drainage prior to release of the waters into larger Commonwealth streams by two basic approaches: (1) reaction with finely-divided coal and other low cost solids, (2) naturally-occurring, in situ processes which would be optimized to achieve the greatest desired response.

B. Present Status of the Investigation:

This investigation has been completed as is possible within the available funds. Financial support from the project funding essentially expired January, 1966. It has not been possible to continue further active research; however, report preparation will be completed. The development of the project has been detailed in Interim Research Reports 15 (July, 1964) to 18 (January, 1966). As a result of these studies, Special Report 54, "A Study of the Reactions Between Coal and Coal Mine Drainage", by Robert A. Reese and H.L. Lovell was released in November, 1965. A summary of the results was presented in IPR 18. Three papers have been given at technical meetings as detailed in IPR 18. In review, the concepts developed

under this project, i.e. to react mine drainage waters with coal to achieve an acceptable quality water, has introduced a new, apparently practical and low cost approach to mine water quality control. The results attained during the project established that alkaline minerals associated with as-mined coal reacts with acidic ions, rendering an adequately high pH to precipitate iron compounds, apparently as the hydroxide. The principle has been applied in industry by employing mine drainage as make-up water in a coal preparation plant. Although of limited application, the approach has much to recommend it where it can be feasibly employed. Industrial reports suggest that potential corrosion problems within the preparation plant have not materialized.

It remains the contention of the principal investigator that a further enhanced response can be expected by reaction with the organic coal entities, especially if the coal is subject to some pretreatment; however, much remains to be studied to understand and develop this concept. Limited funding for further studies in this area has been made available from The Pennsylvania State University and the United States Office of Water Resources Research.

An additional special report will be prepared presenting such limited and preliminary data that were acquired concerned with using low cost materials such as fly ash, red dog, etc.

The second phase of this study, which was concerned with naturally-occurring, in situ processes of water management such as mixing of several mine water streams, lagooning, aeration in the course of stream flow by available elevation drop, flow through existing

strata, etc., controlled to enhance iron mineral drop-out and acidity reduction, is much more complex to study. All of the studies initiated were made in the field and were not developed to the point where data could be more rapidly accumulated in the laboratory. A detailed study was initiated in the New Liberty, Pennsylvania area (between Philipsburg and Osceola Mills) as cited in previous interim reports. These data show that significant iron drop-out and acidity reduction does occur and potentially may be enhanced. They further pose a most intriguing question: In the laboratory or treatment plant air oxidation of ferrous iron proceeds very slowly in mine waters which are highly acidic; why then do the same type of waters form heavy deposits of "yellowboy" in stream beds within relatively short distances of emerging from an abandoned mine?

The data developed during the second phase of this project are being studied. The overall results will be presented as a special report which should be ready for release in early 1967. The potential impact of such a development on the beneficiation of polluted waters from abandoned mines suggests a need for immediate and enhanced study. With the current lack of funding, no further study is anticipated in the near future.

Prepared by:

H.L. Lovell

PERSONNEL: Harold L. Lovell, Principal Investigator, Associate  
Professor of Mineral Preparation  
Robert I. Lachman, Research Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-44

Title of Investigation: Study of High Moisture Pulverized Coal  
Flames with Supplementary Study of Time-to-Ignition of Coal  
Dusts and Their Dependence on Moisture Content

## SUMMARY OF PROGRESS AND PROJECTED PLANS

Because of the small balance of remaining funds for this operation, work in the last six months has been restricted to the continued development of the electric furnace investigations. No further work has been possible on the large furnace with the direct water injection although, as reported in the previous summary, the work had reached a demonstration that a flame could be maintained when injecting coal and water in a ratio such that the water was slightly in excess of 50%. This achieved in general terms one principal objective of the program contract: to show that stable flames could be maintained even on quite a small scale using coal-water slurries with the water percentage at 50% or higher.

The reduced level of funds has also prevented the continuous appointment of a graduate or research assistant. The remaining funds have therefore been used (in conjunction with some of the funds from the Special State Appropriation for Research on Anthracite and Bituminous Coal) towards equipment for revision of the electric furnace operation, and measurements have been then carried out by students as and when this was appropriate, at no additional cost to the project.

In addition to the tests using the electric tube furnace, described in the last summary report (January, 1966), further experiments were carried out to develop the temperature-velocity graph in more detail to determine the ignition temperature by extrapolation. Unfortunately, the additional measurements revealed an unacceptable level of scatter in the results whose sources have still not been traced. Temporarily, therefore, this approach using a complete cloud has been suspended, and the equipment has been re-organized to inject single coal particles through a water cooled probe. A supporting reason for adopting this particular alternative approach is the recent development of theory that has tested out satisfactorily on ignition of magnesium, showing that theoretical requirements can be much better approximated by this experimental unit than was hitherto thought to have been the case.

With the modified equipment it has been found possible to inject and observe particles as they float into the furnace, and initial observations in the effect of particle size have been made.

This completes what can be done with the funds available on this contract. The techniques and experience developed, however, are too valuable to be lost, and work on these lines will be continued under whatever support can be found.

Prepared by:

R.H. Essenhigh

PERSONNEL: R.H. Essenhigh, Principal Investigator, Associate Professor  
of Fuel Science  
D. MacLellan, Research Assistant  
L. Meleszewski, Research Aide

## INTERIM RESEARCH REPORT

Contract Number: CR-45

Title of Investigation: Economic Importance of the Coal Industry to  
Pennsylvania

## SUMMARY OF PROGRESS AND PROJECTED PLANS

Field work for this project has been ended. Reports of major significance from a railroad and anthracite producer that had been delaying office work were received during the later part of the period.

There is now no impediment in the way of issuing the report serially as sections are completed. A major gap remains in lack of information from captive coal producers.

Publications and Presentations: It is anticipated that portions of the report after Board approval will appear in the monthly magazine, Pennsylvania Business Survey and a speech is to be prepared for presentation to a professional society during the last half of the year.

Prepared by:

J.J. Schanz, Jr.

PERSONNEL: J.J. Schanz, Jr., Principal Investigator, Professor of Mineral Economics  
George K. Schenck, Instructor of Mineral Economics  
Gary L. Bennethum, Graduate Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-46

Title of Investigation: Investigation of Effective Measures to Combat  
Mine Disasters

## SUMMARY OF PROGRESS AND PROJECTED PLANS

Research Results

Following the underground tests in the Barnes and Tucker No. 20 Mine (reported in the previous progress report), an assessment of the data clearly indicated an abnormal fluctuation in bolt loads as measured by the rings. Initial losses of load due to bleed off were very pronounced and followed those found in laboratory tests. However, a subsequent recovery of load was registered which indicated that the strength of the bolts had been exceeded or that the rings had been loaded beyond their elastic range. Subsequent laboratory tests established the fact that permanent set had occurred in the test rings. Therefore, rings of stainless steel were obtained but laboratory tests showed a tendency to flow even under relatively low loads and thus precluded their use. It is possible that favorable characteristics can be obtained in rings using other alloy steels in the Shelby Tubing forms. This is now being investigated.

Heavier gage, smaller diameter Shelby Tubing sections of mild steel (C-1020) have been obtained and will be tested in a succeeding semiannual period. Due to wartime demands for various steel products, it was not possible to purchase, within economical limits, the new

Shelby Tubing rings in the range of carbon content 1040-1045 which was desired.

#### Projected Plans

Research. Smaller diameter Shelby Tubing rings are to be tested and calibrated in the laboratory. Following this plans have been made to repeat underground tests under conditions similar to the last one. Two other aspects of roof bolting will be investigated. A newly developed shell is to be tested to see if significant improvements can be made in bolt load bleed off. Also, resin grouted bolts are to be tested in underground installations. Laboratory results with resin grouted bolts show that the bleed off is greatly minimized with an embedment of a threaded portion of only four inches.

Short Course. The previous courses on "The Application of Rock Mechanics to Strata Control" attracted full registration and received favorable comments. The next course is scheduled for presentation August 15-19, 1966. This probably will be the last presentation of a full week short course material for a while. In the future one or two day seminars related to specific topics such as roof bolting, subsidence, etc., will be conducted.

Prepared by:

R. Stefanko

PERSONNEL: R. Stefanko, Principal Investigator, Professor of Mining Engineering  
Earl Maize, Assistant Professor of Mining Engineering



## INTERIM RESEARCH REPORT

Contract Number: CR-61

Title of Investigation: A Landscape Architectural Approach to the  
Reclamation, Recreation and Development Potentials of Deep  
Anthracite Strip Pits

## SUMMARY OF PROGRESS AND PROJECTED PLANS

The project is in its final phase of layout and design with a completion date set for August 1.

Recent developments in Hazleton of large tract apartment areas with shopping and recreation facilities has made it necessary to re-evaluate the program of the Harwood-Hazleton Site and its adjacent industrial complex.

Prepared by:

E. Lynn Miller

PERSONNEL: E. Lynn Miller, Principal Investigator, Assistant  
Professor of Landscape Architecture  
Carl W. Wild, Consultant  
Robert Gladstone, Consultant

## INTERIM RESEARCH REPORT

Contract Number: CR-63

Title of Investigation: Evaporate Fog by Increasing the Absorption  
of Solar Energy with a Cloud of Finely-Ground Anthracite Coal

## SUMMARY OF PROGRESS AND PROJECTED PLANS

The research conducted over the past six months has involved three areas of work.

(1) A series of field observations to obtain data on the physical characteristics of fogs. Observations were taken at Philipsburg Airport on the distributions of temperature, wind speed, nuclei concentrations, and drop size. These data have been analyzed and the results are being used in the calculations described in (3).

(2) A series of field trials have been conducted to test the consequences of dispersing powdered anthracite coal into a fog with a dusting aircraft. The observations taken during these trials are being analyzed in order to estimate the potential of evaporating fogs.

(3) Numerical calculations have been conducted on several model fogs (also using data collected in (1) to determine optimum size, concentration, and coverage to give maximum evaporation in typical fogs.

The results of the studies will be presented in the final report.

Prepared by:

C.L. Hosler

**PERSONNEL:** C.L. Hosler, Principal Investigator, Professor of  
Meteorology  
George Imperial, Research Associate  
Larry Davis, Research Assistant  
James Jiusto, Graduate Assistant  
Ronald Ruth, Graduate Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-65

Title of Investigation: Research on Control of Water Quality in  
Coal Preparation Plant Effluent

## SUMMARY OF PROGRESS AND PROJECTED PLANS

A. Objectives of Investigation:

The main objectives of this project are: (1) to conduct a state-wide survey of coal preparation plants to determine types of equipment and operating practices employed in controlling water quality, (2) to develop and present a short course in liquid-solid separation processes which will emphasize the most recent theory and best industrial practices in the unit operations of thickening filtration, clarification, and tailings disposal in coal preparation plants.

B. Present Status of Investigation:Survey Status

An industrial questionnaire has been designed and discussed with industrial personnel for the purpose of obtaining information regarding the present practices in coal preparation plant water quality control, especially effluent clarification. The questionnaire is expected to be circulated during the fall, 1966. It has been designed to make data correlation relatively easy but to maintain company anonymity. Any data relating to a specific plant will be held confidential and only industry-wide trends will be released. Upon completion of the study the conclusions will be made available to the Coal Research Board, probably

in the form of a Special Report.

#### Short Course Status

The course was held June 27 to July 1, 1966 at the University Park campus with 25 engineers in attendance. The group photograph is shown in Figure 1. Wide spread announcements were made through professional and industrial trade journals as well as in local papers. Excellent facilities were made available in the new Conference Center, J.O. Keller Building and the new Earth Science, Deike Building. The enrollees included men from West Virginia, Virginia, Illinois, Alabama, and Delaware in addition to Pennsylvania men from bituminous and anthracite regions.

It appears from personal comments, letters of appreciation (from course enrollees and their supervisors) and course questionnaires that the presentation was helpful and served a significant role. Some typical comments: "Seminars of this type and caliber are a welcome innovation to the coal industry"; "I thought it was very worthwhile"; "I feel it was a week well spent and hope a similar program will continue to be held each year"; "The material that was discussed was of interest and much valuable information was obtained which we can use in our mining and preparation of coal"; "The course was very timely, well handled and thought stimulating".

Numerous indications show the need for a repeat presentation and other short courses, as the following quote: "I would like to suggest that Industrial Wastes and Acid Mine Drainage be considered for a seminar at some future date."



The Short Course on Water Quality Control included the following presentations:

June 27 - Morning Lectures

1. The Need for Water Quality Control in Coal Preparation Plants  
Dr. H.L. Lovell
2. Chemical Aspects of Thickening and Clarification  
Prof. D.C. McLean

June 28 - Morning Lectures

1. Correlation Between Electrokinetics and the Flocculation of Coal with Electrolytes  
Dr. S.C. Sun and Mr. J.A.L. Campbell
2. Correlation Between Coal Sedimentation and Paste Viscosity of Starches and Guar Gums  
Dr. S.C. Sun
3. Theory and Application of Synthetic Flocculants  
Dr. R.B. Booth, Research Manager for Mining Chemicals, and E.W. Gieseke, Regional Metallurgist, American Cyanamid Company, Stamford, Connecticut

June 29 - Morning Lectures

1. Thickener Design and Operation  
Mr. E. Bryant Fitch, Growth Manager and  
Mr. Fred R. Weber, Resident Manager,  
Dorr-Oliver Corporation
2. Clarifier Design and Operation  
Mr. Lawrence A. Dale, Project Engineer, and  
Mr. John Smith, Process Engineer, Eimco Corporation, Palatine, Illinois

Evening

3. Movie and Lecture - Diatomite Precoat Vacuum Filtration  
Mr. G.R. Bell, Research Engineer and  
Dr. J.S. Parkinson, Research Director  
Johns-Manville Corporation, Manville, N.J.

June 30 - Morning Lectures

1. Filtration Plant Design and Operation  
Mr. Lawrence A. Dale, Project Engineer, and  
Mr. John Smith, Process Engineer, Eimco Corporation, Palatine, Illinois

2. Tailings and Settling Pond Design and Operation  
Mr. Edward D. Hummer, Chief Engineer, United States Steel Corporation, Gary, W. Virginia

#### Evening

3. The Philosophy and Role of the Pennsylvania Department of Health in Water Pollution Associated with Coal Mining and Preparation  
Mr. Donald A. Lazarchik, Chief of Industrial Wastes Section, Pennsylvania Department of Health.

#### July 1 - Morning Lectures

1. Water Research at The Pennsylvania State University in Relation to State and Federal Programs  
Dr. Bruce E. Jones, Director, Institute for Land and Water Research - Water Research Center, The Pennsylvania State University
2. Current Practice of Water Control in Coal Preparation Plants in the United States  
Mr. James K. Kindig, and Mr. Robert Falconer, Department of Mineral Preparation, The Pennsylvania State University
3. Current Practice of Water Control in Coal Preparation Plants in Europe  
Dr. David R. Maneval, Director of Research, Pennsylvania Department of Mines and Mineral Industries, Harrisburg, Pennsylvania

#### Afternoon

4. Response of Aquatic Metabolism and Stream Ecology to Pollution  
Dr. Robert Butler, Cooperative Fisheries Institute at The Pennsylvania State University
5. What Are the Major Problems in Water Quality Control in Preparation Plant Operation?
6. What Areas Should Research be Initiated?

#### Afternoon Laboratory Demonstrations

1. Water Quality Measurement and Control
2. Preparation of Flocculant Solutions
3. Determination of Settling Rates
4. Determination of Filtration Rates
5. Flocculant Degradation
6. Thickener Operation
7. Filtration Chemicals
8. Water Clarification



As part of the Short Course, a three volume note series was prepared including: Lecture notes, Laboratory notes, and a collection of Selected References. Considerable interest was developed in these notes and additional copies requested. Accordingly, this entire series of notes will be reorganized and be issued as a Special Report.

It should be noted that excellent co-operation was received from a number of firms including, among others: American Cyanamid, Dorr-Oliver, Eimco, Johns-Manville and United States Steel. The assistance of The Pennsylvania State University Conference Center, especially Mr. David Schuckers, ensured co-ordination in all phases of the program. We were pleased that such an extensive group of outstanding industrial experts could be made available to the enrollees.

Prepared by:

H.L. Lovell

PERSONNEL: H.L. Lovell, Principal Investigator, Associate Professor  
of Mineral Preparation  
D.C. McLean, Principal Investigator, Associate Professor  
of Mineral Preparation

## INTERIM RESEARCH REPORT

Contract Number: CR-66

Title of Investigation: The Effect of Acid Mine Drainage from Strip Mines on the Ground Water Reservoir Under Various Hydrogeologic Environments in the Clearfield Area of Pennsylvania and the Mutation of the Water as It Moves Through the Grough Water Reservoir

## SUMMARY OF PROGRESS AND PROJECTED PLANS

Several of the rock samples obtained from the Clearfield area (established as an area of a marine paleoenvironment for rock comparison and an acid producer) and the Glen Richey area (an area whose rocks were deposited in a continental paleoenvironment and producing little acid) were analyzed for the total sulfur content. In order to obtain a representative segment of the field sample which would be small enough to be placed in a combustion crucible, in preparation for the total sulfur analysis on the Leco instrument, the following procedure was followed:

The field sample was crushed to pass a 4 mm sieve and riffled to a sample size of approximately 350 grams. The 350 gram portion was stored in a glass jar and the bulk of the sample was stored in a cloth field sample bag. The jarred sample, in turn, was ground to pass a 2 mm sieve and riffled into two parts; a 2-4 gram portion and the bulk remainder portion of the sample. The 2-4 gram portion was ground to pass an 88 micron sieve in preparation for a total sulfur analysis. The fineness of the final ground of the 2-4 gram portion was necessary to produce a homogeneous mixture from which to withdraw a 100 mg sample that the Leco will accept and to prevent the particles from exploding due to too large a particle size.

The total sulfur values obtained from the Leco ignition method of analysis varied from 0% to 3.1% and showed an empirical relation between the sulfur content and the color of the sample. It was found that the darker the color of the rock the greater was the sulfur content. The environment conducive to sulfur accumulation, that is a reducing environment, is also conducive to a high organic accumulation and hence the dark color.

Initially a portion of the samples was analyzed according to a sampling pattern which tested the variation between and among samples. It was found that the variation among samples was not significant compared to the variation between samples. It was concluded that the Leco ignition method of sulfur analysis is accurate. However, within a mine the lateral variation of the sulfur content between samples taken along the same coal seam (the Lower Freeport, "D" seam) varied significantly and presents a sampling problem in the field.

Five samples, whose sulfur content varied from 0.3% to 3.1% were selected for acid leaching studies. The bulk samples, which up to this time had been stored in glass jars, were placed in plastic containers arranged to permit humidified air to pass over the sample. The samples were periodically flushed with distilled water and the effluent quantitatively analyzed for the potential free acidity, as defined by Rainwater and Thatcher (Geol. Surv. Water Supply Paper 1454, p. 91).

The potential free acidities of the sample effluents were adjusted to a common base for comparison by weighting the acidity values in compensation for the varying sample sizes and total surface areas. As

expected, the samples with the higher sulfur content produced the most acid. See Figure 1.

However, the high sulfur content samples producing most of the acid in the acid leaching study were collected from the Glen Richey area, which in this investigation has been established as a low acid producer. Obviously a neutralizing agent exists in the area that is effectively offsetting the high acid producing potential of the rocks with the high sulfur content. The neutralizing agent is probably the calcareous material usually occurring in the strata deposited in a continental paleoenvironment. Biesecker and George (Geol. Surv. Cir. 526) in their survey of the stream quality in Appalachia have also suggested a low acid production in areas containing calcareous material.

In this new light, the remainder of the field samples will be analyzed for the calcium carbonate content as well as the total sulfur content and another acid leaching experiment will be performed incorporating a sulfur to calcium carbonate ratio parameter. Hopefully, any particular rock sample can then be evaluated as to its acid producing capacity by analyzing its calcium carbonate and total sulfur content.

Geologic information for both areas was obtained through the courtesy of Dr. Socolow of the Pennsylvania State Geological Survey and has been traced onto a set of base maps. Measured sections of rock outcroppings will soon be obtained. With this information a series of maps will be constructed which will make it possible to accurately determine the geologic environment of any particular water well in the

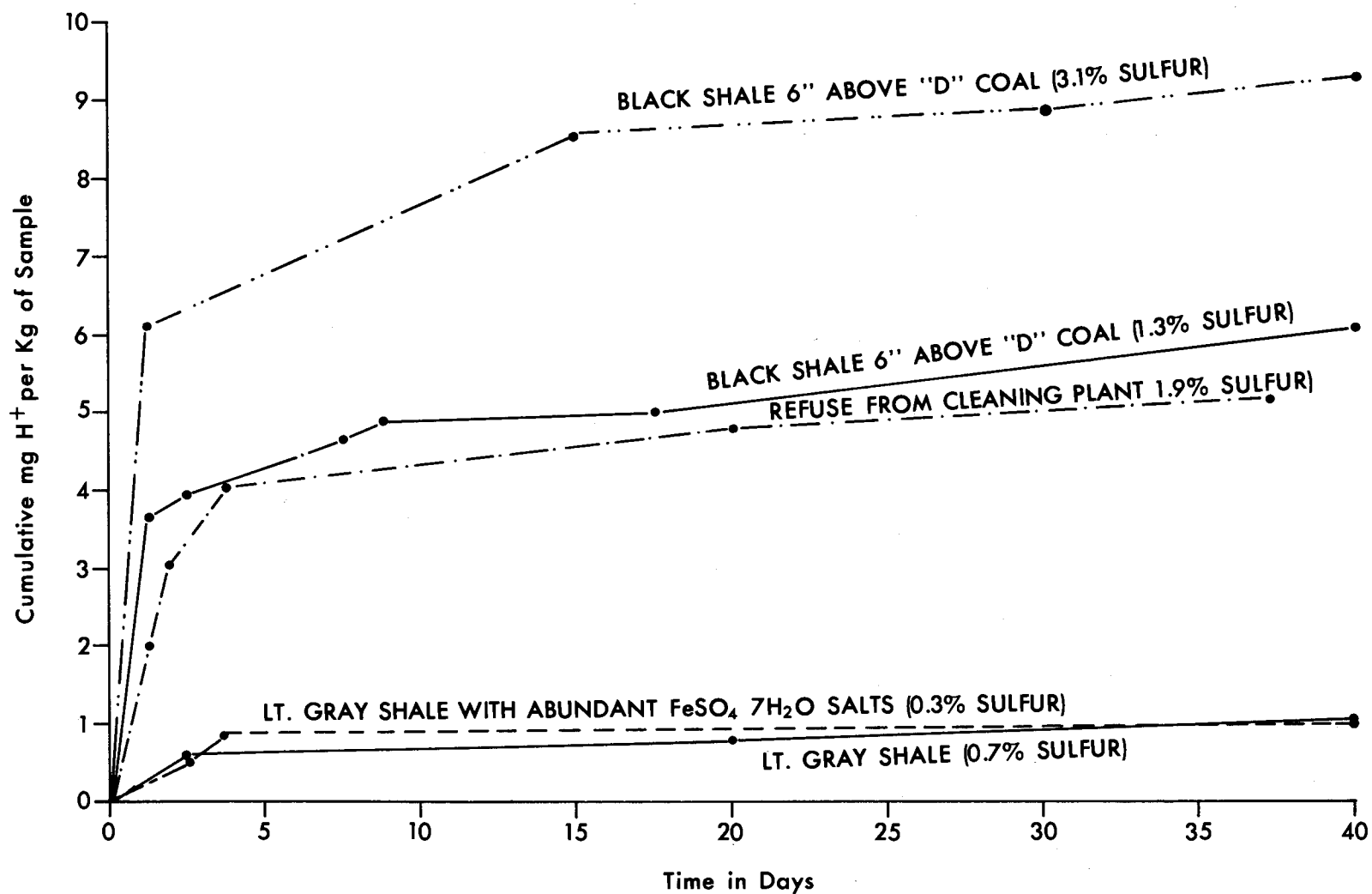


Figure 1 - PLOT OF CUMULATIVE  $H^+$  PER Kg OF SAMPLE VS TIME IN DAYS

areas of study. In this way the chemical quality of the water can be measured and related to the rock through which it passes. Hence it will be possible to trace surface acid water through various courses involving various rock types and noting the interactions.

In this regard, an extensive water survey was made and a water sampling pattern established within the Clearfield area. Twenty-four water samples have been collected from homes having varying well depths and analyzed for calcium, sulfate, pH, acidity, alkalinity, Eh, and specific resistance. pH, Eh and temperature measurements are made in the field during the time of collection. Alkalinity determinations are performed within a six hour period after the time of collection and the remainder of the components are determined within a 24 hour period. This time limit is imposed to eliminate the error due to quality change occurring with aging. All chemical determinations are performed in accordance with methods outlined by Rainwater and Thatcher (op.cit.).

A similar water survey is currently being established in the Glen Richey area to provide a comparison of water quality from areas of a marine and continental paleoenvironment. When the water survey is completed in the Glen Richey area we will be in a position to better determine whether or not additional sampling points, in the form of drill holes, will be required.

Prepared by:

R.R. Parizek

PERSONNEL: R.R. Parizek, Principal Investigator, Associate Professor  
of Geology  
Frank T. Caruccio, Graduate Assistant

## INTERIM RESEARCH REPORT

Contract Number: CR-67

Title of Investigation: Preliminary Investigation of the Design  
Construction, and Operation of a Mine Water Treatment Plant

## SUMMARY OF PROGRESS AND PROJECTED PLANS

The objective of this study has been to assess the feasibility of designing, constructing and operating a large scale mine water treatment plant under University administration. This objective has been attained as the result of visitations, inspections, and discussions held at the following sites:

- a. Department of Mines and Mineral Industries, State College and Harrisburg, Pennsylvania
- b. Consolidation Coal Company, Library, Pennsylvania
- c. Jones and Laughlin Steel Company, California, Pennsylvania
- d. Bethlehem Steel Corporation, Marianna, Pennsylvania
- e. Glen Alden Coal Company, Wilkes-Barre, Pennsylvania
- f. Rosner-Hixson and Company, Chicago, Illinois
- g. National Coal Board of Great Britian, State College, Pennsylvania
- h. Dorr-Oliver Company, Harrisburg, Pennsylvania
- i. Gannett-Fleming, Cordry and Carpenter, Harrisburg, Pennsylvania
- j. New Shawmut Mining Company properties, Hollywood, Pennsylvania
- k. Bethlehem Steel Corporation, Bethlehem, Pennsylvania
- l. Internal discussions at the University



As the result of the aforementioned visitations, inspections and discussions, the following facts became evident:

- a. One authority estimates that of the mine water discharges of the state:
  1. 5-10% may require no treatment;
  2. 5-10% may require a treatment other than alkali neutralization;
  3. 40-60% might be effectively treated with the Rosner-Hixson process;
  4. 20-30% might be effectively treated with the Dorr-Oliver process.
- b. In some instances improvements in mining practices can be used to minimize the magnitude of the individual problems.
- c. Under certain circumstances, mine drainage can be satisfactorily processed by channeling the water through one or more unit operations in a cleaning plant.
- d. In some instances simple plants involving low capital costs and moderate operating costs probably will prove suitable, but in other cases the capital and operating costs will add significantly to the cost of a ton of coal.
- e. Each mine probably represents a more or less unique case and ultimately must be treated as such, in order to operate with maximum efficiency and minimum costs. Because of this, a certain degree of flexibility in the pilot plant is desirable to evaluate the effects of different modes of operation and the use of alternate unit components.
- f. If some of the cost figures on alkali neutralization systems are accurate, other, more sophisticated methods may be competitive and even advantageous from the standpoint of sludge disposal.

The information obtained to date has led to the conclusion that, as suggested by the Coal Research Board, The Pennsylvania State University can usefully serve The Commonwealth and The Commonwealth's coal industry in connection with (1) process evaluation, and (2) the design, construction and twelve month operation of a water treatment plant, built to obtain cost data and other information on the best process system available within the limits of present technology. The information amassed to date indicates that the present "state of the art" appears to be such that it is desirable to construct and operate a full-scale plant (500,000 to 1,000,000 gallons per day capacity) before constructing other large capacity industrial plants. Estimates of the capital costs associated with an experimental, full-scale plant of the aforementioned capacity, range from a low of about \$100,000.00 to over \$1,400,000.00.

Inspection of the prospective site for the proposed plant, including visitation by the University's ground water geologist, has uncovered the detailed information concerning the site that is described below.

1. The main mine entry (Procter No. 2 Mine, New Shawmut Mining Co.) immediately south of houses in Hollywood, Pa.:

- a. showed a discharge of 750,000 - 1,000,000 gallons per day on June 8, 1966.
- b. showed evidence of declining flow, suggesting it might drop below 1,000,000 gallons per day during the summer months.

- c. showed evidence of being 4" - 6" above the stage observed on June 8th within the previous few weeks.
- d. was said, by the occupant of the house immediately overlooking the discharge, to fluctuate in response to seasonal rainfall but never to go dry.
- e. was subject to flash discharge about 3 years ago with a resultant flooding of the immediate area to an appreciable level (at least reaching base of mine house located several feet above present water level) for a period of several days.

2. Domestic water in Hollywood is obtained from a 178 foot well cased to approximately 100 feet. In spite of this, the water was reported to carry an odor and is apparently not particularly high in quality. Water is chlorinated and available in "fair quantities".

3. It is not known whether the Hollywood well penetrates to the underlying Pocono sandstone.

4. Evidence of pollution in streets and gutters of Hollywood suggests a high water table and faulty septic systems.

5. Tyler Run at Route 255 was flowing at about 50 gallons per minute or less on June 8, 1966. The flow diminished to about 35 gallons per minute one-half mile upstream. No appreciable accumulation of iron was noted on the stream bed except near the confluence with the Proctor No. 2 drainage channel.

6. Tyler Run was stated by the local residents to be fed by mine drainage which we did not observe.

7. In Tyler Run flow is likely to be negligible in the dry summer months.

8. The next tributary valley to the east was observed to be fed by two separate discharges each clearly related to a collapsed mine opening. These showed evidence of carrying a high iron content and appreciable acidity. These are related to the same coal seam and the same mine complex as the other discharges in the area.

9. The mine complex was described by men formerly employed in the workings as occupying several square miles with the seam dipping gently to the south.

10. Discharges described in Item 7 did not in aggregate equal the flow out of the main entry on June 8th, but might be used to augment supply with construction of necessary pipelines.

11. Occupant of house near discharges described in Item 7 reported variation in algal growth vs. precipitation if iron, suggesting possible quality variation but he indicated the flow was relatively constant.

12. Rocks in the area are mainly components of a marine sequence of shales, thin bedded sandstones and siltstones.

13. The marine shales, and siltstones do not lend themselves to storing quantities of water and hence are not likely to provide the water necessary to maintain the flow of the smaller streams during dry periods.

14. Two types of sediments characterize the valley floor, point-bar and gravels overlain by flood plain silts, sand and clay beds,

and poorly sorted gravel and clay comprising alluvial fans at the heads of tributaries. Both of these sediment types appear permeable and would not hold water in lagoons without first having been treated by appropriate means. Both would have relatively high bearing capacities capable of supporting lightweight structures. Former channels may be filled with soft clay and organic matter. The presence of these materials could be established by shallow borings in areas where loads are to be concentrated. Three to five feet of sediment overlies these deposits in some areas adjacent to gob piles. These materials are reworked mine tailings deposited during high water. Much of the lowland along but below the level of the railroad tracks appears to be subject to flooding. Lagoons, roads and buildings would have to be protected if they are to be located in this region.

15. The water table in this region (valley bottom) is at land surface or from one to five feet below ground level. Lagoons excavated in the lowland would encounter the water table. Leakage from such lagoons could be minimized by keeping water levels in the lagoons close to that of the water table or by lining their floors and walls.

16. Lagoon leakage would pose more of a problem adjacent to Bennett Branch and on the alluvial fan deposits because the water table is deeper in these areas and the soils are likely to be more permeable.

17. Bennett Branch, because it contains a significant amount of iron and a relatively low pH, will serve as a source of dilution water only to the limits permitted by its own degree of pollution. Flows in Bennett Branch are likely to be highly variable.

18. Based on a limited field examination these does not appear to be suitable clay deposits to line floors and walls of lagoons.

19. Although there are strip mines on the valley walls near Tyler that could be used to store and concentrate the sludge, the availability of the land would have to be assured and the possible consequences examined.

On the basis of the June 8 inspection it is suggested that:

1. The actual mine discharges to be used be identified and these be gauged to determine flow.

2. The minimum acceptable treatment volume for the proposed plant should be clearly defined. (Any single discharge may fall below 1,000,000 gallons per day during a low flow period. The 1,000,000 gallons per day probably can be obtained by pooling discharges from several sites requiring several thousands of feet of pipeline and associated pumps.)

3. If surface water is not suitable for dilution purposes, drilling to 200-400 feet might be necessary to provide water of the required quality. Assuming that such ground water would prove suitable in quality, \$10,000 to \$20,000 could be required in order to make the water available. Were such drilling to be undertaken, its consequence with regard to the local domestic water supply should be examined.

4. In view of the nature of the terrain available for use, the volumes of sludge to be produced should be estimated for this quality and quantity of water and the matter of disposal carefully investigated.

A generalized cross-section of the valley floor at the Hollywood site is presented herewith. This serves to identify the four basic natural components of the valley floor, namely, the alluvial fans, the flood plain deposits, the stream and its tributaries and the point bar gravels.

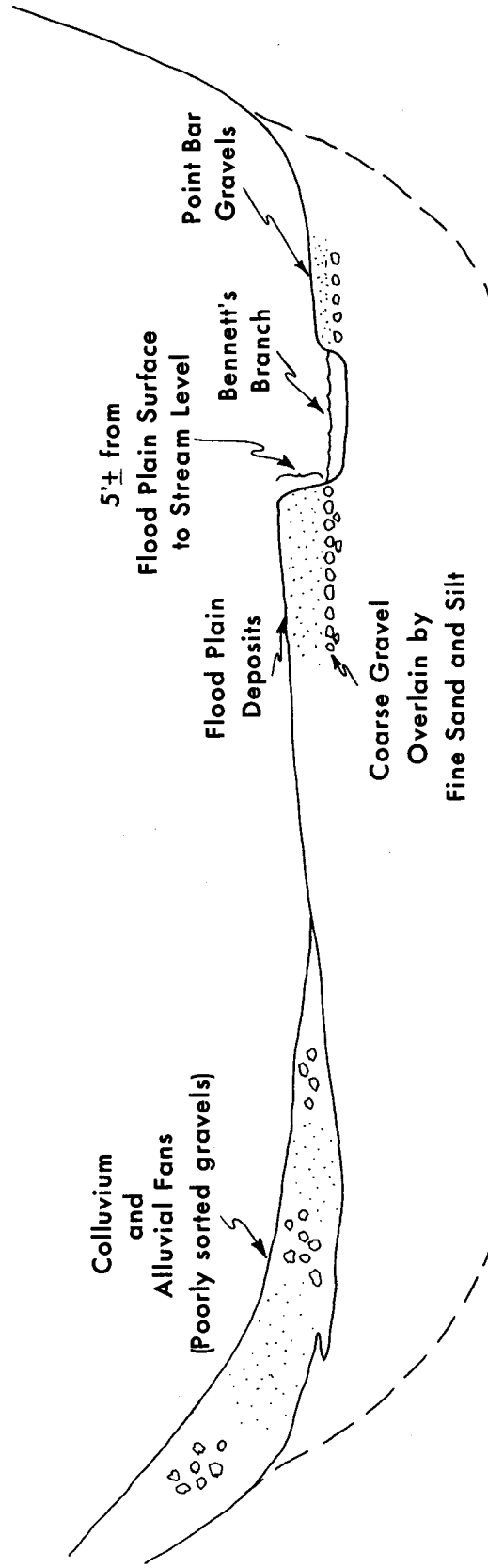
The figure entitled "Characteristics of Natural and Man-Made Surfaces at Treatment Plant Site" identifies the several kinds of surfaces now present in the area as the result of man's occupancy and use of the site. The nature of the materials forming and underlying these surfaces is identified and the characteristics of each kind of site are described. It should be emphasized that Figure 2 is a schematic representation of all surfaces in the general area and therefore is not a section to be encountered at every point along the valley floor.

On the basis of the information described in this report it is concluded that it is feasible for the University to undertake administration of the designing, construction and operation of a 500,000 to 1,000,000 gallon per day, mine water treatment plant. It is further concluded that it is feasible, but may prove somewhat costly, to construct the proposed plant at the afore described site at Hollywood, Pennsylvania.

The preceding paragraph makes evident that the objectives initially described for Coal Research Board Contract CR-67 have been fully attained. Accordingly, it is proposed that the residual funds (identified in the fiscal portion of this Report) remaining in the

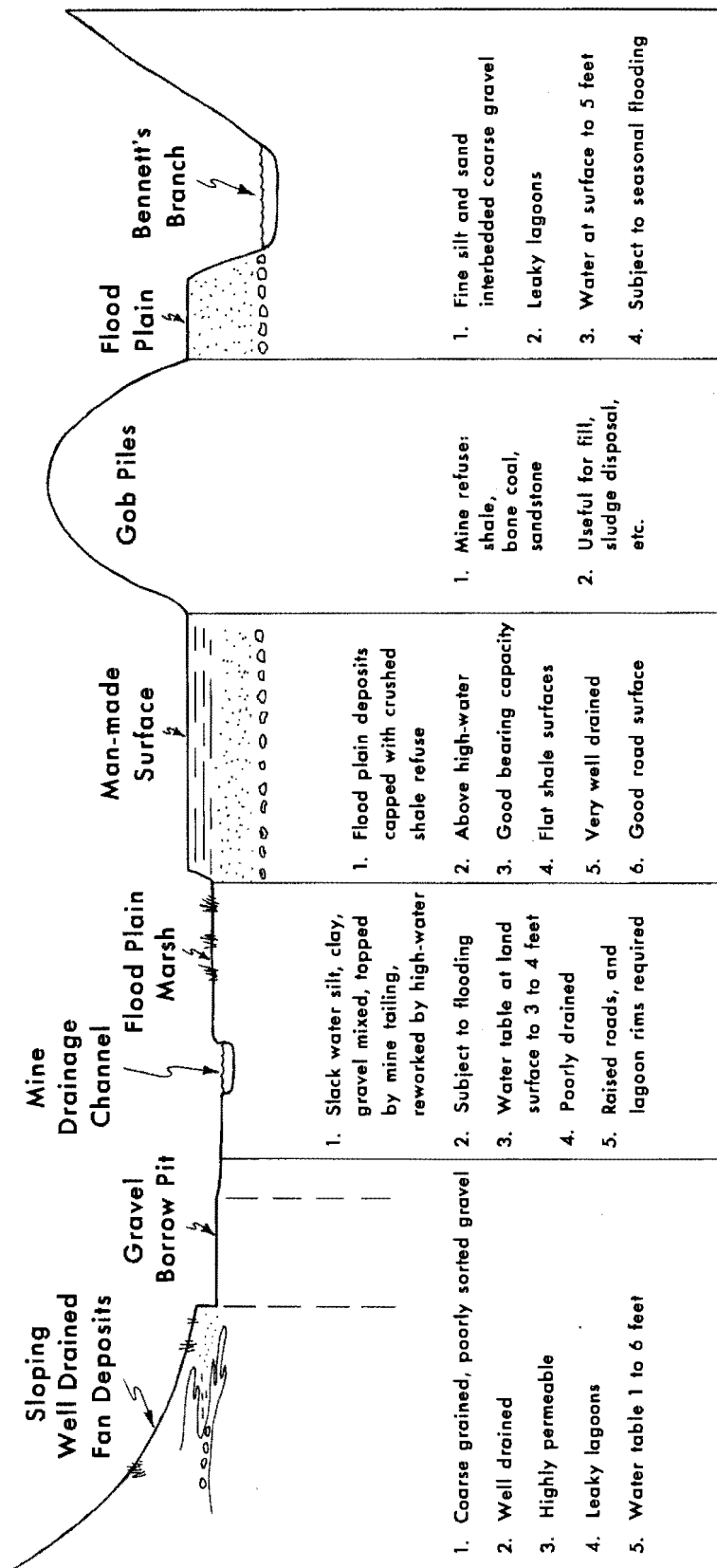
# GENERALIZED SKETCH OF NATURAL FEATURES OF WATER TREATMENT PLANT SITE

## HOLLYWOOD, PENNSYLVANIA





# CHARACTERISTICS OF NATURAL AND MAN-MADE SURFACES AT TREATMENT PLANT SITE



budget associated with this contract be used in large measure for the purpose of reprinting the Special Research Reports for which we have numerous requests and none in stock.

Prepared by:

William Spackman

PERSONNEL: William Spackman, Principal Investigator, Professor of  
Paleobotany

## INTERIM RESEARCH REPORT

Contract Number: CR-70

Title of Investigation: Treatment of Coal Mine Water to Meet Current  
Commonwealth Water Discharge Regulations

## SUMMARY OF PROGRESS AND PROJECTED PLANS

The activities to date can be appropriately grouped into four areas:

1. Pennsylvania Coal Research Board - The Pennsylvania State University contract negotiations and project organization. After much planning and discussion, a proposal was accepted and made effective April 1, 1966 to: (1) design an experimental mine-water treatment demonstration plant suited to neutralization process systems; (2) construction of the treatment plant; and (3) twelve-month operation of the water treatment plant. At The Pennsylvania State University, the project has been established as an interdisciplinary program through the Office of the Vice-President for Research (Dr. E.F. Osborn) in the Institute of Science and Engineering (Dr. Harry Zook), Office of Coal Research Administration (Dr. William Spackman) and the Institute for Research on Land and Water Resources-Water Resources Center (Dr. J.H. Frey and Dr. Bruce E. Jones). The project has been officially registered with the Science Information Exchange at the Smithsonian Institute in Washington, D.C.

2. Project Staff Organization - The project will be under the direction of Dr. H.L. Lovell, Department of Mineral Preparation.

Available to the project director will be an Advisory Committee, chaired by Dr. Harry Zook and including the cited administrative people, project director and such University specialists as may be called in for consultation. Currently, meetings have included: Professor Benjamin Whisler, Department of Civil Engineering; Dr. Robert Stone, Department of Microbiology; Dr. Paul Barton, Department of Chemical Engineering, and Dr. Richard Parizek, Department of Geology and Geophysics. Contract negotiations acquired the services of a Registered Professional Engineer, Mr. Robert Reese, for the project to be effective June 1, 1966. A full time research assistant, Mr. Robert Lachman, a graduate assistant, Mr. Lee Duguay, and an analyst, Miss Elaine Martinec were assigned to the project effective July 1, 1966. Secretarial requirements currently use University personnel; however, project-supported personnel will be made available as needed. Other personnel will be added as can be expeditiously employed.

3. Co-ordination with the Pennsylvania Coal Research Board in Site Selection. A visit to several sites was made on May 5, 1966, and water samples were collected. The analyses of these waters are shown in Table 1. Interest centered at the site located in Hollywood, Pennsylvania where there are four water sources available. The Shawmut Mining Company abandoned deep mine Proctor No. 2 was flowing in early May between 0.5 and 1.0 million gallons per day. This water source is severely polluted as represented by the sample No. 3 in Table 1. The second source, Bennett's Run, is about 1500 feet distant and represents

Table 1

Analyses of Waters from Prospective Plant Sites

<u>Sample No.</u>	<u>Date 1966</u>	<u>Designation</u>	<u>pH</u>	<u>Acidity ppm</u>	<u>Total Iron ppm</u>
1	May 5	Kato	3.1	566	132
2	May 5	Leigh Valley	2.9	917	396
3	May 5	Shawmut Proctor No. 2	2.7	6864	3604
4	May 5	Bennett's Run	3.8	39	88
22	June 6	Tyler Run	3.42	216	120
23	June 6	Proctor No. 2	2.90	8116	4696

a relatively low level of pollution (sample No. 4 in Table 1), flows with a much greater quantity of water. The other sources include: Tyler Run, a stream originating in the mountains immediately north of Hollywood also has relatively minor contamination; and another abandoned mine, Procter No. 1, about 2000 feet east of Procter No. 2. This latter water is high polluted and shows very extensive "Yellowboy" dropout on the stream banks. Although all four of these water sources are spaced for collection at a central treating site, additional expenses would be involved should it be necessary to secure water from more than the Procter No. 2 source. However, it would appear highly desirable to be able to study several water sources and to provide a safeguard should any of the sources reach a greatly reduced flow.

A natural phenomena did occur within the Procter No. 2 mine early in June, which caused a release of huge quantities of water and mine debris from the abandoned mine mouth. Mine caving, following this heavy discharge of water, has reduced this flow substantially. It is

not predictable how this flow will change. Local residents indicate the flow from Procter No. 2 has been reasonably uniform, but that an out-burst of water had also occurred several years ago. University personnel made subsequent visits to the Hollywood site. Analyses of additional samples collected in June are also given in the Table.

4. Preliminary Planning - Numerous conversations have been held regarding the detailed process to be employed and the development of the project. These have included engineering firms, mining firms, equipment manufacturers, chemical companies and research specialists from governmental and academic agencies. The "Yellowboy" trailer of the Pennsylvania Department of Mines and Mineral Industries was moved to the Hollywood site during June. The data from this unit will be helpful in the initial design stages and will be requested for further service on other waters in the area in the future.

Projected Plans - Upon final availability of the site, surveying and soil control evaluations will be made and monitoring of the water quality will be initiated on a regular basis. Preliminary planning for the actual process involves the development of a highly versatile neutralizing facility which will allow modification of reagents and unit operations employed in addition to extensive collection of routine operating data. Included in the flow sheet will be a water-collecting storage lagoon, reactors to treat the water with alkaline reagents and allow air oxidation, as well as solid-fluid separation equipment.

In addition to the basic process, it is planned to include alternative circuits for smaller flows which would be subject to modified processes within the system. In order to acquire maximum data, it is anticipated that the plant will be highly instrumental including automatic controls. This is not only desirable from the standpoint of plant control and data acquisition but is an important operating cost factor which must be evaluated for industrial operation.

A major problem associated with the treatment of such waters will be the handling and disposal of the waste sludge produced by the process. Plans are in progress to evaluate a number of ways of dealing with this most difficult problem. Subject to the complications involving the selection of the site noted above, the activities are progressing in accordance with the proposed timetable.

Prepared by:

H. L. Lovell

PERSONNEL: H.L. Lovell, Principal Investigator, Associate Professor  
of Mineral Preparation  
Robert Reese, Registered Professional Engineer  
Robert Lachman, Research Assistant  
Lee Duguay, Graduate Assistant  
Elaine Martinec, Analyst

## **SECTION II**

### **FISCAL REPORTS**



## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$100,000.00</u>	Contract Number	<u>CR-29</u>
Received to Date	<u>\$100,000.00</u>	Report Number	<u>13</u>
Expended to Date	<u>\$100,000.00</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 00.00</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION The Reduction of Sulfur in Pennsylvania  
Bituminous Coals During Preparation

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$100,000.00

Less Costs Incurred:

## Report Period

Salaries	\$ 726.56
Wages	<u>00.00</u>
Other Expense	<u>5.72</u>
Special Equipment	<u>00.00</u>

Total \$ 732.28

Previous Periods \$99,267.72

\$100,000.00

Cash Balance on Hand

\$ 00.00

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$82,500.00</u>	Contract Number	<u>CR-35</u>
Received to Date	<u>\$82,500.00</u>	Report Number	<u>8</u>
Expended to Date	<u>\$82,500.00</u>	Date	<u>6/15/66</u>
Unexpended	<u>\$ 00.00</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION The Characteristics and Preparation of  
Anthracite Breaker Refuse and the Suitability of Derived  
Products for Industrial Use

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$82,500.00

## Less Costs Incurred:

## Report Period

Salaries	<u>\$ 1,228.65</u>
Wages	<u>00.00</u>
Other Expense	<u>30.80</u>
Special Equipment	<u>00.00</u>

Total \$ 1,259.45

Previous Periods \$81,240.55

\$82,500.00

Cash Balance on Hand

00.00

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$40,000.00</u>	Contract Number	<u>CR-38</u>
Received to Date	<u>\$40,000.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$31,565.52</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 8,434.48</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Investigation of the Technical Aspects  
in the Control and Disposal of Mine Water to Minimize Stream  
Pollution

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$40,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 3,724.00</u>
Wages	<u>125.13</u>
Other Expense	<u>1,671.41</u>
Special Equipment	<u>927.59</u>

Total \$ 6,448.13

Previous Periods \$25,117.39

\$31,565.52

Cash Balance on Hand \$ 8,434.48

Submitted by

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$40,000.00</u>	Contract Number	<u>CR-39</u>
Received to Date	<u>\$40,000.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$31,219.08</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 8,780.92</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Strip Mining and Land Restoration

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$40,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 1,347.00</u>
Wages	<u>422.30</u>
Other Expense	<u>1,223.39</u>
Special Equipment	<u>00.00</u>

Total \$ 2,992.69

Previous Periods \$28,226.39

\$31,219.08

Cash Balance on Hand

\$ 8,780.92

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$30,000.00</u>	Contract Number	<u>CR-40</u>
Received to Date	<u>\$30,000.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$29,542.36</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 457.64</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Optimization of Mine Production

Systems for Low Cost Mining

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$30,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 3,945.00</u>
Wages	<u>122.70</u>
Other Expense	<u>473.94</u>
Special Equipment	<u>00.00</u>

Total \$ 4,541.64

Previous Periods \$25,000.72

\$29,542.36

Cash Balance on Hand \$ 457.64

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$29,500.00</u>	Contract Number	<u>CR-43</u>
Received to Date	<u>\$29,500.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$29,500.00</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 00.00</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Control of Mine Stream Pollution

by Removal of the Impurities from Drainage Streams

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$29,500.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 1,411.50</u>
Wages	<u>00.00</u>
Other Expense	<u>95.77</u>
Special Equipment	<u>00.00</u>

Total \$ 1,507.27

Previous Periods \$27,992.73

\$29,500.00

Cash Balance on Hand

\$ 00.00

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$33,500.00</u>	Contract Number	<u>CR-44</u>
Received to Date	<u>\$33,500.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$33,343.72</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 156.28</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Study of High-Moisture Pulverized Coal  
Flames with Supplementary Study of Time-to-Ignition Temperature  
of Coal Dusts and Their Dependence on Moisture Content

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$33,500.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 00.00</u>
Wages	<u>00.00</u>
Other Expense	<u>220.04</u>
Special Equipment	<u>374.46</u>

Total \$ 594.50

Previous Periods \$32,749.22

\$33,343.72

Cash Balance on Hand

\$ 156.28

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$17,000.00</u>	Contract Number	<u>CR-45</u>
Received to Date	<u>\$17,000.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$15,759.61</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 1,240.39</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION The Economic Importance of the Coal  
Industry to Pennsylvania

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$17,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 540.00</u>
Wages	<u>00.00</u>
Other Expense	<u>157.10</u>
Special Equipment	<u>00.00</u>

Total \$ 697.10

Previous Periods \$15,062.51

\$15,759.61

Cash Balance on Hand

\$ 1,240.39

Submitted by:

William Spackman, Director  
 Coal Research



## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$50,000.00</u>	Contract Number	<u>CR-46</u>
Received to Date	<u>\$50,000.00</u>	Report Number	<u>5</u>
Expended to Date	<u>\$34,759.14</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$15,240.86</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Investigation of Effective Measures to  
Combat Mine Disasters

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$50,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 4,524.00</u>
Wages	<u>00.00</u>
Other Expense	<u>5,365.59</u>
Special Equipment	<u>6.95</u>

Total \$ 9,896.54

Previous Periods \$24,862.60

\$34,759.14

Cash Balance on Hand

\$15,240.86

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$9,500.00</u>	Contract Number	<u>CR-61</u>
Received to Date	<u>\$9,500.00</u>	Report Number	<u>2</u>
Expended to Date	<u>\$5,435.38</u>	Date	<u>6/15/55</u>
Unexpended to Date	<u>\$4,064.62</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE ON INVESTIGATION A Landscape Architectural Approach to  
the Reclamation, Recreation and Development Potentials of Deep  
Anthracite Strip Pits

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$9,500.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 00.00</u>
Wages	<u>00.00</u>
Other Expense	<u>184.55</u>
Special Equipment	<u>00.00</u>

Total \$ 184.55

Previous Periods \$5,250.83

\$5,435.38

Cash Balance on Hand

\$4,064.62

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$14,220.00</u>	Contract Number	<u>CR-63</u>
Received to Date	<u>\$14,220.00</u>	Report Number	<u>2</u>
Expended to Date	<u>\$10,714.83</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$ 3,505.17</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Evaporate Fog by Increasing the  
Absorption of Solar Energy with a Cloud of Finely-Ground  
Anthracite Coal

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$14,220.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 7,464.00</u>
Wages	<u>300.00</u>
Other Expense	<u>3,250.83</u>
Special Equipment	<u>00.00</u>

Total \$11,014.83

Previous Periods \$ 00.00

\$11,014.83

Cash Balance on Hand \$ 3,205.17

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$9,700.00</u>	Contract Number	<u>CR-65</u>
Received to Date	<u>\$9,700.00</u>	Report Number	<u>2</u>
Expended to Date	<u>\$4,596.75</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$5,103.25</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Research on Control of Water Quality  
in Coal Preparation Plant Effluent

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$9,700.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$1,934.88</u>
Wages	<u>73.20</u>
Other Expense	<u>2,424.67</u>
Special Equipment	<u>164.00</u>

Total \$4,596.75

Previous Periods \$ 00.00

\$4,596.75

Cash Balance on Hand \$5,103.25

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$14,400.00</u>	Contract Number	<u>CR-66</u>
Received to Date	<u>\$14,400.00</u>	Report Number	<u>2</u>
Expended to Date	<u>\$ 4,280.58</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$10,119.42</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION The Effect of Acid Mine Drainage from  
Strip Mines on the Ground Water Reservoir Under Various Hydro-  
geologic Environments in the Clearfield Area of Pennsylvania and  
the Mutation of the Water as It Moves Through the Ground Water  
Reservoir

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$14,400.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 330.00</u>
Wages	<u>00.00</u>
Other Expense	<u>3,307.28</u>
Special Equipment	<u>643.30</u>

Total \$4,280.58

Previous Periods \$ 00.00

\$ 4,280.58

Cash Balance on Hand \$10,119.42

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$3,000.00</u>	Contract Number	<u>CR-67</u>
Received to Date	<u>\$3,000.00</u>	Report Number	<u>1</u>
Expended to Date	<u>\$1,055.84</u>	Date	<u>6/15/66</u>
Unexpended to Date	<u>\$1,944.16</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Preliminary Investigation of the  
Design, Construction and Operation of a Mine Water Treatment  
Plant

PERIOD COVERED BY REPORT December 16, 1965 to June 15, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$3,000.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 00.00</u>
Wages	<u>00.00</u>
Other Expense	<u>1,055.84</u>
Special Equipment	<u>00.00</u>

Total \$1,055.84

Previous Periods \$ 00.00

\$1,055.84

Cash Balance on Hand

\$1,944.16

Submitted by:

William Spackman, Director  
 Coal Research

## INTERIM FINANCIAL REPORT

Total Sum Allocated	<u>\$190,000.00</u>	Contract Number	<u>CR-70</u>
Received to Date	<u>\$ 00.00</u>	Report Number	<u>1</u>
Expended to Date	<u>\$ 1,542.99</u>	Date	<u>6/30/66</u>
Unexpended to Date	<u>\$ 00.00</u>		

TO: Hon. H. Beecher Charnbury, Secretary  
 Department of Mines and Mineral Industries  
 Commonwealth of Pennsylvania

TITLE OF INVESTIGATION Treatment of Coal Mine Water to Meet

Current Commonwealth Water Discharge Regulations

PERIOD COVERED BY REPORT April 1, 1966 to June 30, 1966

## FINANCIAL STATEMENT:

Monies Received to Date \$ 00.00

Less Costs Incurred:

## Report Period

Salaries	<u>\$ 00.00</u>
Wages	<u>00.00</u>
Other Expense	<u>1,542.99</u>
Special Equipment	<u>00.00</u>

Total \$1,542.99

Previous Periods \$ 00.00

\$1,542.99

Cash Balance on Hand \$ 00.00

Submitted by:

William Spackman, Director  
 Coal Research

## FINANCIAL SUMMARY

June 30, 1966

<u>Contract Number</u>	<u>Total Sum Received to Date</u>	<u>Expenditures</u>	<u>Balance</u>
CR-29	\$100,000.00	\$100,000.00	\$ 00.00
CR-35	82,500.00	82,500.00	00.00
CR-38	40,000.00	31,565.52	8,434.48
CR-39	40,000.00	31,219.08	8,780.92
CR-40	30,000.00	29,542.36	457.64
CR-43	29,500.00	29,500.00	00.00
CR-44	33,500.00	33,378.72	121.28
CR-45	17,000.00	15,759.61	1,240.39
CR-46	50,000.00	34,759.14	15,240.86
CR-61	9,500.00	5,435.38	4,064.62
CR-63	14,220.00	10,714.83	3,505.17
CR-65	9,700.00	4,596.75	5,103.25
CR-66	14,400.00	4,280.58	10,119.42
CR-67	3,000.00	1,055.84	1,944.16
CR-70	<u>00.00</u>	<u>1,542.99</u>	<u>00.00</u>
Totals	\$473,320.00	\$415,850.80	\$59,012.19



**APPENDIX I**

# The Response of Parameter Variation in the Hydrocyclone Processing of Fine Coal

Lothar Weyher and Harold L. Lovell  
Department of Mineral Preparation  
College of Mineral Industries  
The Pennsylvania State University  
University Park, Pennsylvania

Within the general area of unit operations, a considerable effort has been expended in theoretical and empirical research associated with cyclone operations. The motivation involves the industrial requirement for devices and techniques to manipulate small particles at low operating costs, a situation especially applicable to coal preparation. There are good reasons why the cyclone helps to satisfy this demand, because it combines operational simplicity (no moving parts) with versatility and high throughput capacity per unit area. The cyclone is one of the most widely applied tools in the process technologies. There are areas for potential cyclone application which have been only meagerly explored or not considered at all. This discussion is restricted to a very specific application of the cyclone - its use as a hydrocyclone in the cleaning of fine coal. It represents an initial presentation with a comprehensive report to be subsequently released.

Coal preparation can appropriately claim the hydrocyclone since most of its predominant industrial uses have originated in this area and have spread into other applications, including the broad field of ore dressing, the petroleum industry, chemical processing, nuclear engineering and food technology.

There is one operational principle common in all cyclones: A fluid is tangentially introduced into a cylindrical or conical

container under pressure. A predominantly irrotational flow field<sup>(1)</sup> is established within the cyclone. Figure 1. The uniqueness of this flow is indicated by the variation in tangential velocity across the cyclone radius, which reaches a maximum a short distance from the center and decays toward the cyclone wall. In contrast, the tangential velocity in a centrifuge increases uniformly toward the wall. Usually two products are discharged from the cyclone. They differ in that one discharge consists predominantly of that portion of the feed fluid which moves along the wall axially away from the feed inlet, while the other consists predominantly of fluid spiralling along the central regions of the cyclone, in an axial direction opposite to that of the wall current. Figure 2 indicates these discharge points schematically. The latter product may be termed the vortex-product, since it is discharged with the central vortex-current. In case of conical cyclones, the former product may be referred to as the apex-product. Although the names "over- and underflow" are widely used, many cyclones are operated from extreme angular positions thus the proposed terms are less ~~un~~ambiguous.

The cyclone feed fluid can be laden with solid particles or nonmiscible fluid drops. Such a feed component is discharged from the cyclone, after some residence time, into the one or the other product. Yet, the orifice through which a particle will leave the cyclone is dependent upon a number of factors. These factors, in a statistical sense, determine the path of the particle within the cyclone. Thus, different separation phenomena are possible and different process results attainable by the controllable variation of the particle path. It is then, to attain a fuller understanding of this particle path, to which this study is ultimately directed.

It is anticipated that the detailed study of the data herein reported will allow further elucidation of existing qualitative models. However, the development of a quantitative description of cyclone operation in terms of a mechanism is not currently

feasible. The flow conditions in a cyclone are not fully understood even for a pure fluid, without the added complexity of the inclusion of multiple size-density solid particles. It is hoped that the present data will also assist in an enhanced application of the hydrocyclone and provide a base for further research. Some practical applications drawn from our data will be suggested.

Cyclone operations have been classified according to the main characteristics of the products. Five basic operations may be cited although none is wholly independent of the others.

- 1). Clarification - characterized by a vortex product with a minimum of particles, e.g., dust collecting cyclones.
- 2). Thickening - characterized by a maximum solid/liquid ratio in the apex-product, e.g., preparing the feed slurry for filters.
- 3). Classification - characterized by the separation of particles into size ranges by utilizing the strong influence of the size of a particle on its terminal settling velocity\*, e.g., in closed grinding circuits.
- 4). Gravity separation in a dense liquid or in a dense medium (a suspension of fine dense particles) - characterized by separating the particles according to their specific gravity. This process utilizes the opposed bouyant forces acting on particles of different densities if suspended in a liquid of intermediate density.
- 5). Gravity separation without the use of a dense liquid or a dense media - characterized by force conditions emphasizing particle density.

\*Other factors influencing the terminal settling velocity include the shape of the particle and its density with respect to the density of the surrounding medium, and the effective viscosity of this medium.

### Mechanisms of Gravity Separation in Hydrocyclones

There are three concepts of more or less divergent opinions expressed in the literature. Fontein and Mijksman<sup>(3) (4)</sup> consider that particles in the cyclone are separated predominantly during their residence time in the central region. During this interval, all particles spiralling in the central region toward the vortex finder are accelerated outward. As the influence of particle size on settling velocity is small during the early acceleration period, this period is most responsive to separation according to particle density differences, i.e., the relative rearrangement of settling particles is strongly dependent upon their relative densities.

Tarjan<sup>(5)</sup> assumes a distinct plane for each particle within the cyclone, in which the particle is in equilibrium in response to centrifugal mass and centripetal drag forces. In a given instance characterized by the location of this equilibrium plane in respect to the zero axial velocity plane, higher density particles may develop a dense medium by accumulating along the inner cyclone wall. It is proposed that this wall accumulation, acting like a dense medium, is responsible for the gravity separation in a hydrocyclone. Tarjan includes the influence of the cone angle in his equations defining the location of the two planes. However, considering the particle density distribution of raw coals, this hypothesis could not explain a separation at densities higher than about 1.60. Such separations have been found by several investigators including the present ones.

On the other hand, Visman<sup>(6)</sup> makes an analogy between the hydrocyclone and the rheolauver and related hydraulic devices. His model assumes a particle stratification according to density along the cyclone wall as the most essential factor. - Other concepts of model mechanisms have been outlined by Trawinski<sup>(7)</sup>. Particle velocity retardation relative to the fluid tangential velocity may occur by collision with other particles or from turbulence, thus reducing centrifugal forces on the particles.

The probability for retardation should be greatest for large particles, leading to their probable separation at a somewhat higher density than might be expected without consideration of a collision. The Magnus effect states that particles suspended in a shear flow are effected by a lift force into the direction of positive shear gradient. In cyclones, this force would have an inward direction in all areas outside of the central region of forced rotational velocity profile; thus it would act against the centrifugal forces.

On the basis of the various models cited, certain comparisons of these cyclone functions may be stated:

1. In a classification cyclone, each particle should settle freely and reach its terminal settling velocity prior to being discharged. It is only under these circumstances that particle size effects are maximized.
2. In an ideal heavy medium gravity separation, the density of the pulp in the cyclone is between the density of the apex and vortex products. Here also each particle should move unhindered in a direction determined by the sum of the mass and the drag forces.
3. In a gravity separation in a hydrocyclone, it is probable the particles do not reach their terminal velocity prior to discharge as a vortex product. The influence of particle density on its settling behavior is most pronounced during the acceleration phase. Further, hindered settling conditions seem requisite to establish a pre-stratification of particles by their density along the cyclone wall.

### Test Procedures

The test facilities shown in Figure 3 consisted of a 700 gallon tank with a strong agitator, a four inch volute pump (75-440 gpm at 55-140 ft. head), and an experimental 5.5 inch cyclone with a 120 degree cone angle. This cyclone was designed and constructed for versatility of investigation (Figure 4). All geometrical and pressure variations which have been tested are shown in Table 1. In all tests the cyclone was operated vertically. Entirely free discharge of both the apex and the vortex product eliminated any backpressure.

The majority of the tests were carried out on a feed suspension of the minus 1/4 inch portion of a minus 3/8 inch ROM Pittsburgh seam coal. This coal is regularly cleaned by Deister tables. In our test facility, the coal was recycled. However, on occasion new raw coal was added and slimes removed from the system. Relatively large variations in feed composition did occur. The solid-to-liquid ratio of the feed, as calculated from the products usually varied  $\pm 2$  percent from 14 percent by weight. Of the 170 tests conducted, the products from 152 of them were subject to size analyses by wet screening at 20, 50, 100 and 200 mesh (U. S. Series) with subsequent ash analyses. In addition, all minus 100 mesh samples were subject to sulfur analyses. In the remaining 18 tests, closer sizing was completed with sink-float analyses being carried out on all sizes excepting the plus 6 and minus 400 mesh fractions. This collection of data resulted in several thousands of numbers for evaluation, a task which has been approached by developing digital computer programs. The programs in FORTRAN and DAFT were utilized in an IBM-7074 computer. The computations, as illustrated by the print-out in Figure 5 covered the determination of feed and discharge pulp characteristics, including: capacity, solid-liquid ratio, volume and pulp density. Other aspects included distribution and recoveries of the products as well as the feed sizes, ash and sulfur contents. For those tests which included

sink-float data, washability calculations have been made including partition values for the density recoveries at each size and size recoveries for each density class. The computer has been further utilized to approximate partition values by normal distribution functions which permit integration for the calculation of Tromp-areas.

### Experimental Observations

The washability characteristics of the feed coal are shown in Figure 6 as a Henry-Reinhardt diagram. The run-of-mine coal was fed to the 5.5-inch cyclone in a range between 0.5 and 2.2 ton per hour with an ash content of about 19 percent. The solids in the vortex product ranged from 7 to 18 percent by weight, while the apex product ranged from 35 to 55 percent. When the cyclone parameters resulted in a low recovery of combustible material in the vortex product (about 40 percent), the ash content was 4.0 percent in the plus 200 mesh sizes from a corresponding 12.0 percent feed ash. This represents an 87.0 percent ash rejection. The total size range changed from 18.7 to 19.0 percent ash. These data may overemphasize the significance of the unavoidable high recovery of extreme fines in the vortex product. Sulfur variation gave a rejection of 73.7 and 34.3 percent respectively in the 100 by 200 mesh and minus 200 mesh sizes. The corresponding sulfur assays were from 2.83 and 1.91 to 1.24 and 1.38 percent.

Under contrasting parameters which yielded high combustible recoveries in the vortex product (92.9 percent), the ash content dropped to 7.0 percent from 13.0 for a 53 percent rejection in the plus 200 mesh sizes. The sulfur rejection and assays for the 100 by 200 mesh and minus 200 mesh fractions were respectively: 26.6 percent from 1.63 to 1.26 and 11.4 percent from 1.80 to 1.64.

Partition curves for the sizes from one test are given in



Figure 7. These curves illustrate that the particle size is of reduced influence in this cyclone operation. A comparison of a series of these curves shows that the role of particle size is somewhat more pronounced under those conditions which resulted in low ash values in the vortex product. In contrast, Figure 8 shows the partition curves for the same test, based upon density. Both Figures 7 and 8 demonstrate that the particle size has a relatively small influence on the separation. Thus, in terms of traditional analyses of settling behavior of particles, it would seem that the Newton-Rittinger equation is superior to Stokes' Law in explaining this separation. Yet, both these equations require equilibrium between the mass and the drag forces acting on a particle. The authors suggest that -in a cyclone- such equilibrium can exist only for very fine sizes; additional factors for the equilibrium conditions are the densities of particles and medium, particle shape, effective viscosity of the medium, and also cyclone design. This consideration then leads to the acceptance of the concept of Fontein<sup>(3,4)</sup> which accounts for the pronounced density effect of the particles in this cyclone separation by assuming the particles in a state of acceleration. This, does not, however, imply a judgement on the extent to which Fontien's concept could explain the total mechanism of gravity separation in a hydrocyclone.

The data obtained in this investigation were considered in terms of the influence of the cyclone geometry and feed pressure on the separation. In agreement with previous studies, a change in the diameter of the apex orifice results in the most pronounced effect, as shown in Figure 9. We have considered these effects in terms of a dimensionless ratio rather than the apex-vortex finder diameters individually. The orifice ratio is defined as the diameter dimensions of the vortex finder to the apex. The applicability of this ratio to the test conditions is being considered further. The <sup>inverse</sup> ~~direct~~ relationship of the apex diameter with ash content of the vortex product is noted. The ash

levels in the various sizes is a unique property of the coal. The orifice ratio reduction was maintained constant for the two sets of data presented.

The influence of vortex finder length is expressed in terms of "length of free vortex" - the open distance between the bottom of the vortex finder and the apex orifice. See Figure 10. An increasing vortex finder length may be correlated to a higher separation gravity and is shown by increasing ash values in the vortex product. Simultaneously, the recovery of combustible matter in the vortex product increases. Thus, this parameter becomes critical in establishing the requisite compromise between grade and combustible matter recovery.

The sulfur distribution should also be considered in regard to the grade-combustible recovery compromise. Table 2 shows data indicating that sulfur rejection into the apex product increases rapidly with particle size, as may be expected for the pyritic sulfur. The lower degree of liberation for pyritic sulfur in the larger sizes may invalidate this extrapolation.

As might be expected from theoretical considerations, changes in the vortex finder diameter should effect the separation in a manner proportional to the length of the vortex finder. This trend is shown by the data given in Figure 11. As noted previously, the interrelation between vortex finder diameter and apex orifice must not be ignored.

The influence of feed orifice diameter and feed pressure upon separational characteristics is less pronounced. However, both are important considerations as they control throughput capacity. The data relating the effect of feed orifice diameter and vortex product ash, plotted in Figure 12, seems to go through a maximum. The tendency for the ash content of the vortex product to decrease with increasing pressure, as shown in Figure 13, is noteworthy. The pressure influence was more pronounced for small apex orifices, compared on the basis of a constant

orifice ratio. The feed pressure and other factors affecting throughput capacity, including feed solid/liquid ratios are basic in the evaluation of specific operation costs in terms of cents per ton. In one test, run at 20 percent by weight solid/liquid ratio, a 76 percent recovery of the combustible feed solids was attained as the vortex product. This product analyzed 5 percent ash in the plus 200 mesh sizes which is indicative of a 75 percent feed ash rejection.

### Industrial Applications from These Studies

In terms of sulfur reduction, some comparisons of separation quality between the hydrocyclone and flotation seems pertinent. Table 2 presents data for ash reduction, recovery of combustible matter and sulfur. These data suggest a rather effective sulfur removal for the high organic sulfur Pittsburgh seam coal. Comparable flotation data by Reilly<sup>(8)</sup> are also tabulated. A comparison of the two processes on the basis of partition curves (expressed in terms of probable error or imperfection), would be expected to show the hydrocyclone superior for plus 100 mesh sizes, equivalent in the 100 by 400 mesh range while flotation is superior in the minus 400 mesh fines. By contrast, the shaking table would be expected to result in a somewhat superior sharpness of separation in the coarse sizes as well. However, if the hydrocyclone apex product is reprocessed through a second cyclone linked in series, the combined cyclone product should be equivalent or even superior in quality and recovery values to the table product.

Our data show a negligible rejection of very fine (minus 400 mesh) clay particles at the apex. Thus, to attain a superior product, they must be removed either from the feed or the vortex product. There appears to be advantages in making this separation from the vortex product. It is also observed that substantial amounts of fine pyrites accompanies the vortex product. A

subsequent sizing by the Sieve Bend seems especially appropriate in attaining a maximum quality product.

As regards combustible recovery, our data show values of 65 to 75 percent in the plus 200 mesh sizes when conditions provide a low ash product (5-6 percent). The reject apex product representing 25-30 weight percent feed solids would be expected to respond well to shaking table processing. Such a table could be operated at relatively high capacity since the feed would be deslimed. Table studies by the U. S. Bureau of Mines<sup>(9)</sup> indicate the table to yield relatively sharp separations even for high ash content feeds. An alternative flow (Figure 14) would be to remove the fine pyrite and high ash particles by a Sieve Bend and reprocess the over size through a secondary cyclone at a higher density. The Sieve Bend would be expected to be especially effective in eliminating the fine dense particles due to the achievement of some stratification as the solids cross the Sieve Bend surface and with the development of a slight centrifugal pressure caused by the curvature of the screen. The optimization of these various approaches and the development of the appropriate decision provides an excellent opportunity for the application of Operations Research techniques in the coal processing field.

### Conclusions

1. The hydrocyclone can be operated as a gravity separator in coal preparation using a relatively wide feed size-range and at separation densities in excess of 2.00.
2. The 5.5 inch diameter cyclone satisfactorily accepted throughput capacities of 1.5-2.2 tons per hour.
3. The hydrocyclone may be appropriately combined with other cyclones in a series or with other

unit operations to achieve maximum grade and recovery.

4. The hydrocyclone can be equivalent in separation capabilities to flotation and shaking tables under specific conditions.
5. The hydrocyclone is especially effective in pyrite rejection and generally superior to flotation in all but extremely fine sizes.

#### Acknowledgement

The authors gratefully express appreciation for support of these studies by the Coal Research Board, Department of Mines and Mineral Industries, Commonwealth of Pennsylvania. Such support acknowledges the vital role basic studies can play for the Coal Industry as well as the significant place the Coal Industry shares in industrial progress. The coal used was kindly provided by the Consolidation Coal Company.

## References

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2. Kelsall, D. F., A Study of the Motion of Solid Particles in a Hydraulic Cyclone, Trans. Instn. Chem. Engrs., 30, pp. 87, 1952.
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8. Reilly, J. J., Fourth International Coal Preparation Congress, Harrogate, U. K., paper C6, 1962.
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TABLE 1:  
VARIABLES TESTED IN EXPERIMENTAL CYCLONE

	VARIABLES				
	DIAMETER OF FEED ORIFICE	DIAMETER OF APEX ORIFICE	DIAMETER OF VORTEX FINDER	LENGTH OF FREE VORTEX	FEED PRESSURE
					[psig]
NUMBER OF TEST LEVELS	4	2	4	7	5
LOWEST LEVEL	0.500"	0.500"	0.865"	0.943"	5.000
HIGHEST LEVEL	1.750"	0.750"	2.000"	3.695"	30.000

TABLE 2:

## ASSAY AND RECOVERY DATA

		A S H    I N						R E C O V E R Y    O F		
S I Z E	P A S S E D	A P E X   P R O D U C T		V O R T E X   P R O D.		C A L C.   F E E D		A S H   I N		COMB. MATTER IN
		%	CUM. %	%	CUM. %	%	CUM %	%	A P E X   P R O D.	V O R T E X   P R O D.
	20	34.4	34.4	5.7	5.7	15.5	15.5	75.8	75.8	73.5
	50	25.7	30.8	5.3	5.5	11.5	13.7	68.2	73.0	73.9
	100	21.4	29.5	5.4	5.5	9.8	13.1	60.7	71.6	74.2
	200	25.0	29.3	5.9	5.5	9.0	12.7	45.9	69.9	75.4
	325	32.6	29.4	7.0	5.7	9.8	12.5	36.0	68.0	76.6
	325	43.0	30.0	36.5	13.5	36.8	17.5	6.5	41.4	79.5

		H Y D R O C Y C L O N E				F L O T A T I O N		
S I Z E	P A S S E D	% S U L F U R		% S U L F U R		% R E C O V E R Y	% S U L F U R	% S U L F U R
		I N   A P E X	P R I	I N   V E R T E X	P R I		I N   T R A I L I N G S	I N   F E E D
100	200	4.51		1.26	1.80	41.61		
200	325	10.35		1.54	2.49	44.84		
325		8.39		1.71	2.08	22.34		
50							1.97	1.85

\*(8)



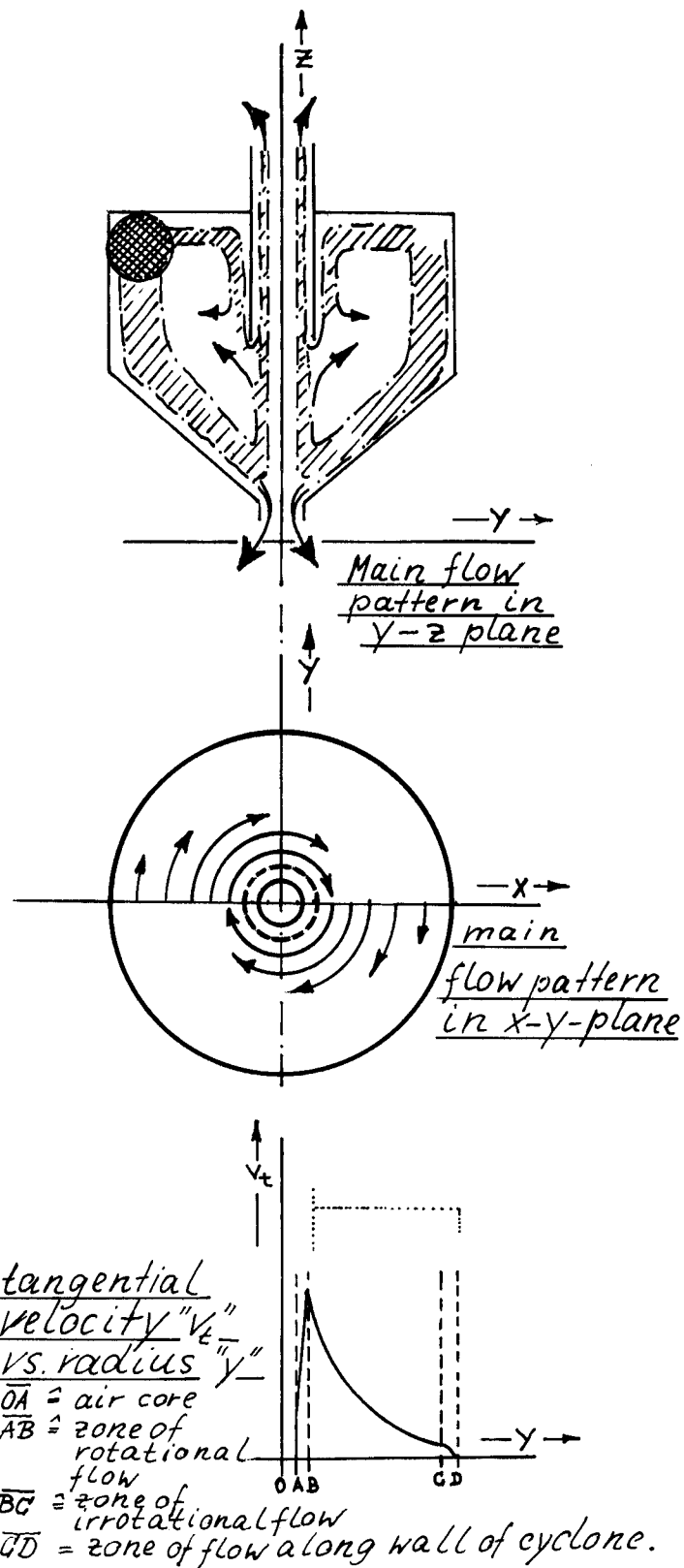
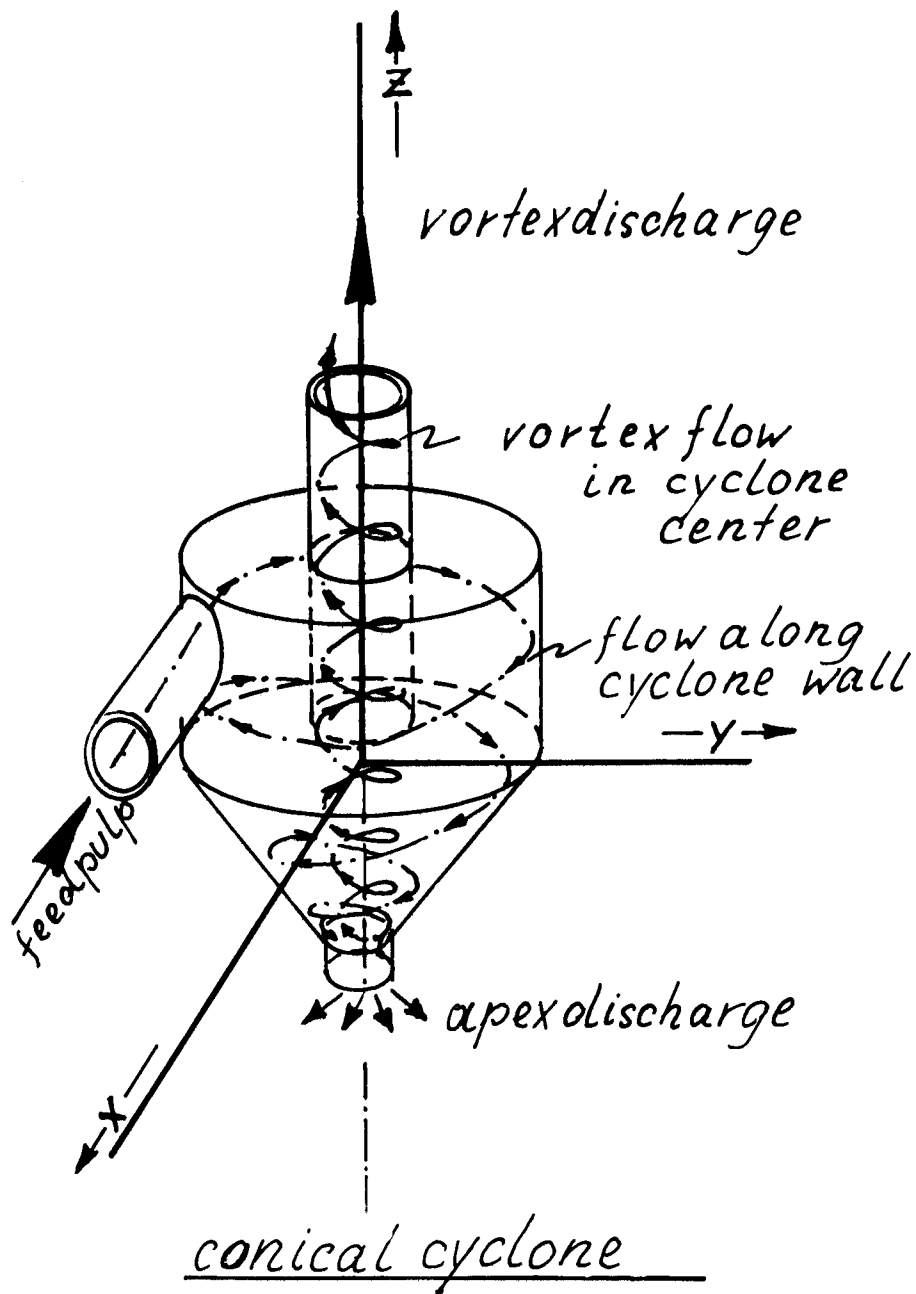


FIG. 1 MAIN FLOW PATTERNS IN HYDROCYCLONES



**FIG. 2**      **ISOMETRIC VIEW OF THE MAIN FLOW IN A HYDROCYCLONE**

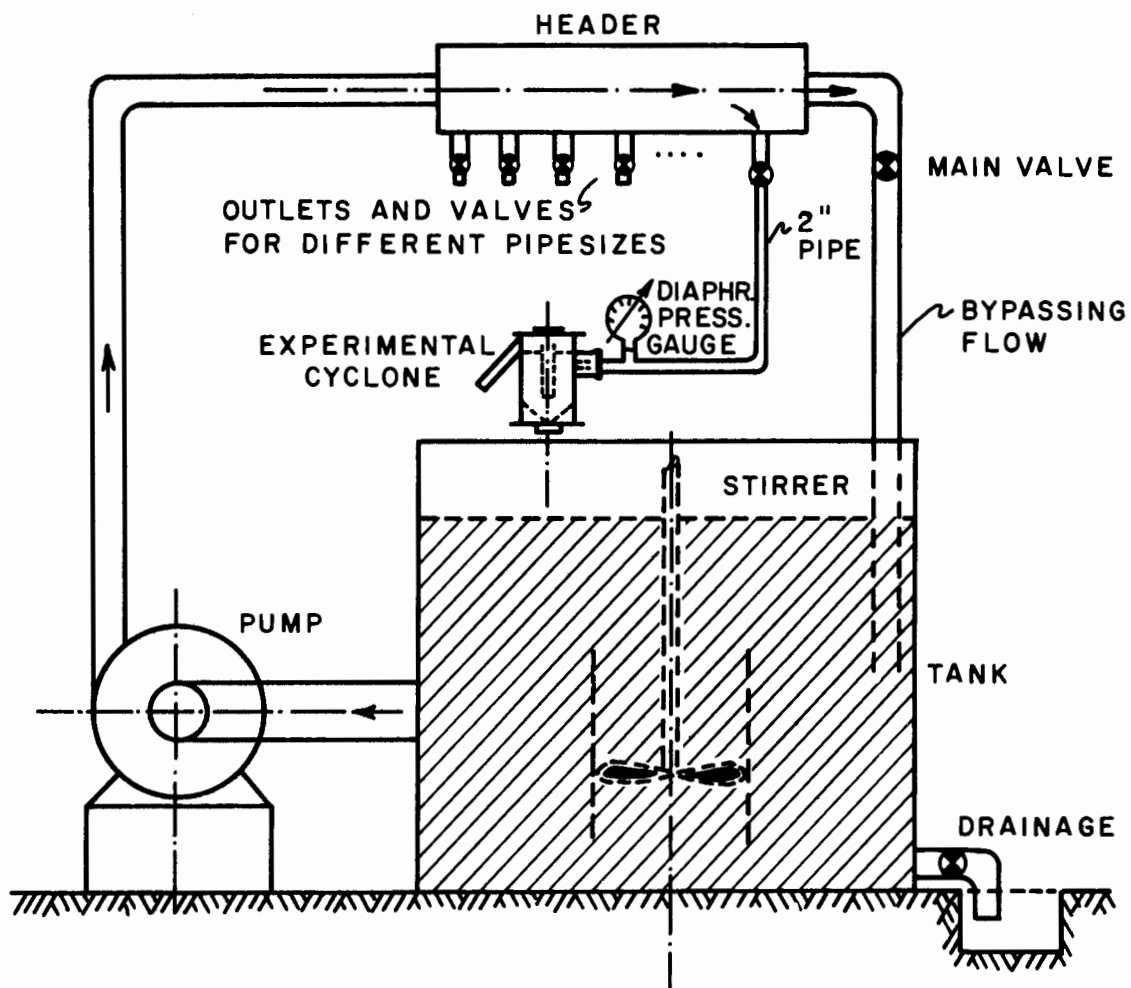


FIG. 3 EXPERIMENTAL CYCLONE INSTALLATION

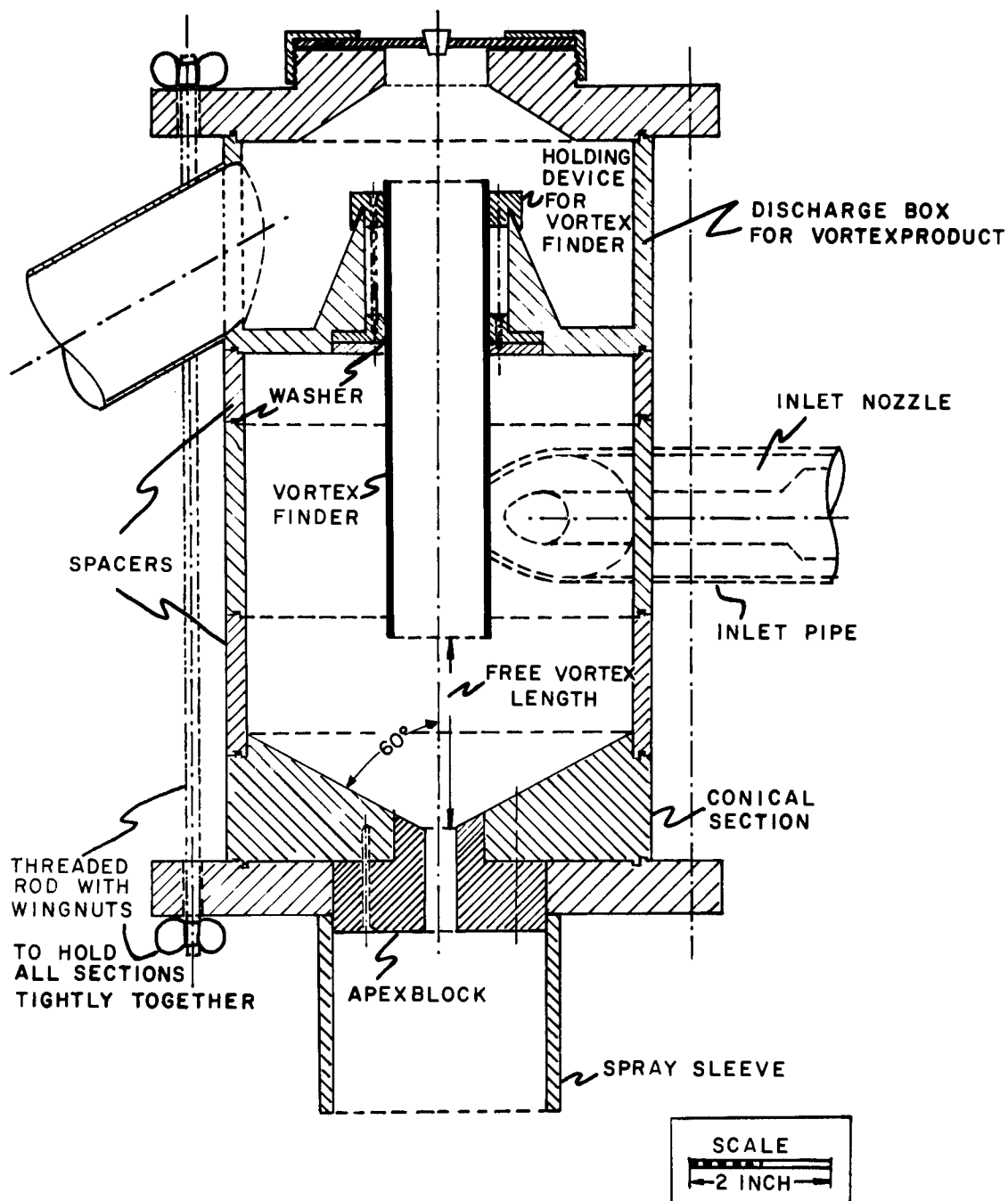


FIG. 4 SCHEMATIC CROSSECTION OF  
 EXPERIMENTAL CYCLONE

SAMPLE - NUMBER = 480200  
\*\*\*\*\*

HOURLY CAPACITIES FOR SLURRY-VOLUME (LIT) AND SLURRY-WEIGHT (KG) AND SLURRY-DENSITIES OF  
APEX-DISCHARGE- 528-120 607-680 1-151  
VORTEXFINDER-DISCHARGE - 8662-200 9283-800 1-072  
FEED (CALCULATED) - 9190-320 9891-480 1-076

SOLIDS-CAPACITIES (KG) /HR-- APEX-DISCHARGE - 283.097 --, VORTEXFINDER-DISCH. - 887.856 --, FEED (CALC.) - 1170.953  
CORRESPONDING SOLID-LIQUID RATIOS - 0.466 0.096 0.118

RECOVERIES OF FEED-SOLIDS IN APEXDISCHARGE, IN VORTEXFINDERDISCH., \* SIZES OF TOTAL FEED (IN PERC. AND CUM. PERC.)  
REPORTING TO APEX- AND VORTEXFINDERDISCHARGE

SIZE	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC
+ 20	34.132	65.868	65.868	10.89	21.01	21.01	10.89	21.01
20X50	30.483	32.552	69.517	18.31	16.93	37.95	7.43	18.31
50X100	27.895	31.809	72.105	68.191	7.70	45.65	2.98	21.29
100X200	16.604	30.412	83.396	69.588	5.65	51.30	1.12	22.42
200X325	10.791	28.994	89.209	71.006	5.12	56.42	0.62	23.04
- 325	5.539	24.177	94.461	75.823	1.14	57.56	1.14	24.18

CALCULATIONS FOR ASH - REFERRED TO AS SOLIDS-COMPONENT AND ABBREVIATED AS -- SOLCOMP --

SOLCOMP (IN PERCENT AND CUM. PERC.) OF THE INDIVIDUAL AND CUMUL. SCREEN-FRACTIONS \*\* FRACT. RECOV. OF \* FRAC. REC. OF ANTI-  
IN THE APEXDISCHARGE THE VORTEXF. DISCH. AND IN THE FEED MAT. \*\* SOLCOMP AT APEX \* SOLCOMP AT VORTF.

SIZE	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC
+ 20	34.37	34.37	5.69	5.69	15.48	15.48	75.79	75.79
20X50	25.65	30.83	5.25	5.49	11.47	13.74	68.18	73.50
50X100	21.37	29.51	5.36	5.47	9.83	13.12	60.67	74.40
100X200	25.00	29.28	5.87	5.52	9.05	12.74	45.89	71.56
200X325	32.64	29.37	7.02	5.65	9.78	12.53	36.00	67.97
- 325	42.97	30.01	36.45	13.53	36.81	17.52	6.47	41.43

CALCULATIONS FOR SULFUR - REFERRED TO AS SOLIDS-COMPONENT AND ABBREVIATED AS -- SOLCOMP --

SOLCOMP (IN PERCENT AND CUM. PERC.) OF THE INDIVIDUAL AND CUMUL. SCREEN-FRACTIONS \*\* FRACT. RECOV. OF \* FRAC. REC. OF ANTI-  
IN THE APEXDISCHARGE THE VORTEXF. DISCH. AND IN THE FEED MAT. \*\* SOLCOMP AT APEX \* SOLCOMP AT VORTF.

SIZE	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC	PERCENT	CUMPERC
100X200	4.51	4.51	1.26	1.26	1.80	1.80	41.61	41.61
200X325	10.35	6.58	1.54	1.39	2.49	2.12	44.84	43.35
- 325	8.39	7.30	1.71	1.60	2.08	2.09	22.34	30.39

FIG. 5 TYPICAL COMPUTER PRINTOUT

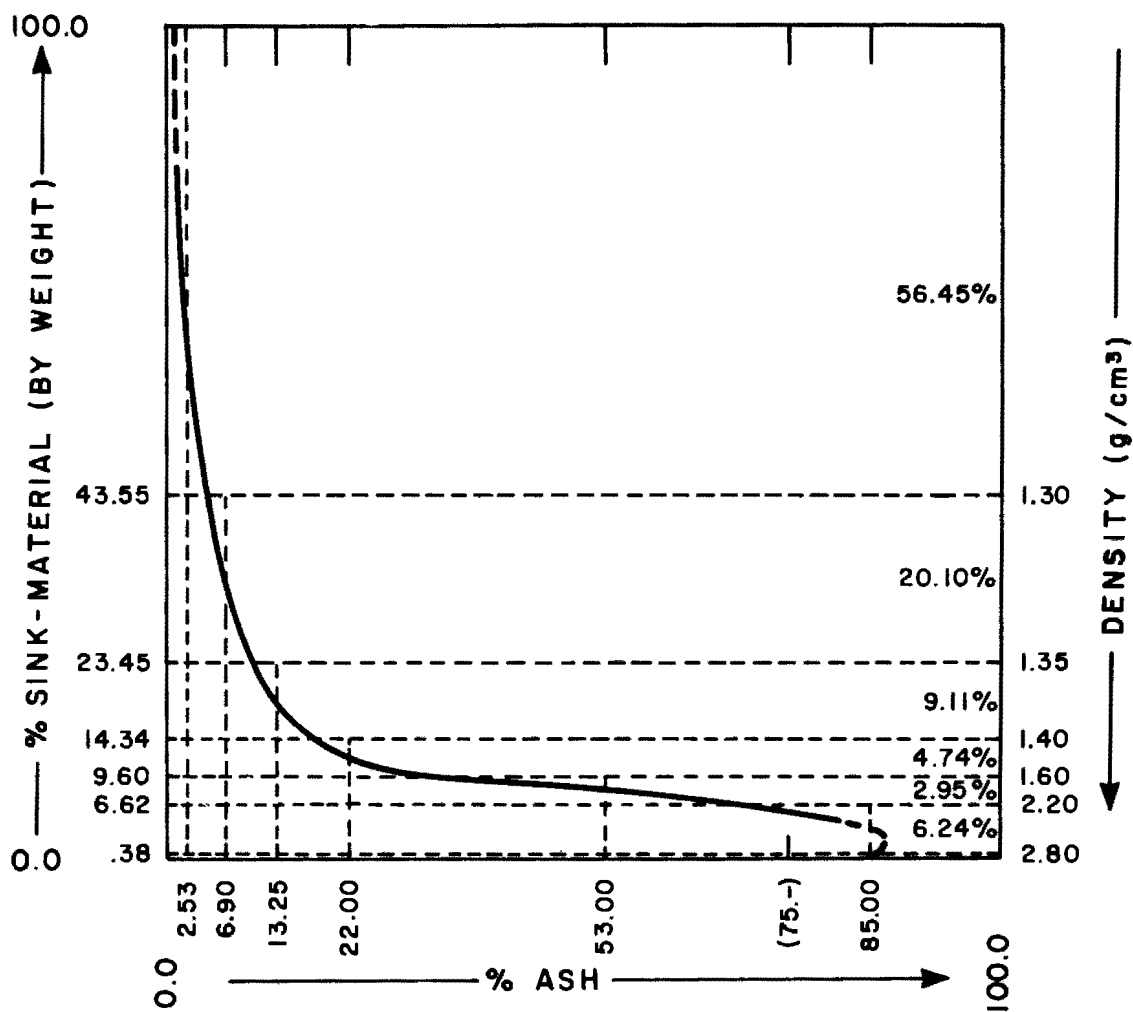


FIG. 6 HENRY-REINHARDT DIAGRAM OF  $\frac{1}{4}$ " x 325 m PITTSBURGH SEAM COAL

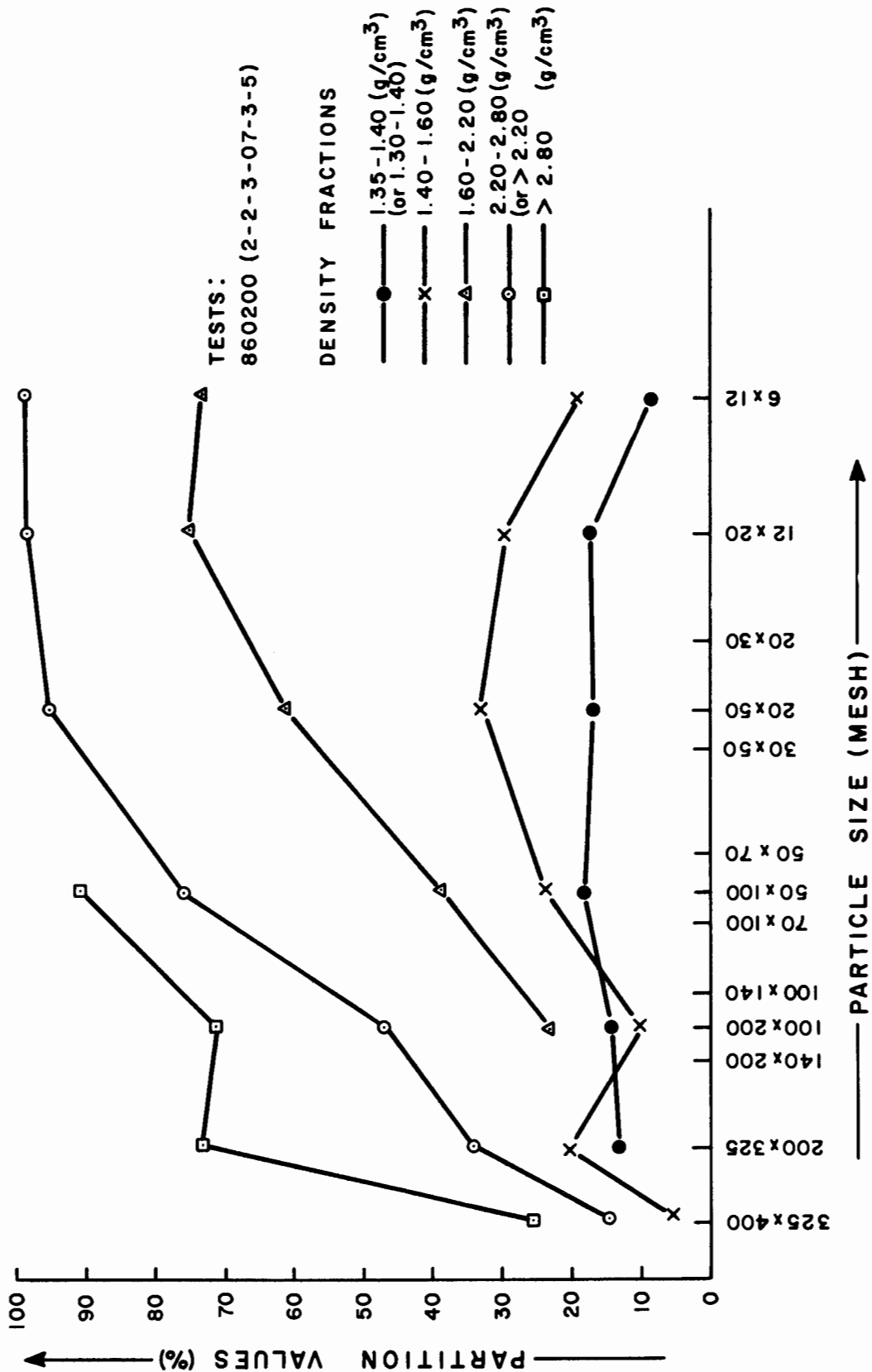


FIG. 7 PARTITION CURVES FOR THE SIZING EFFECT FOR DIFFERENT DENSITY FRACTIONS

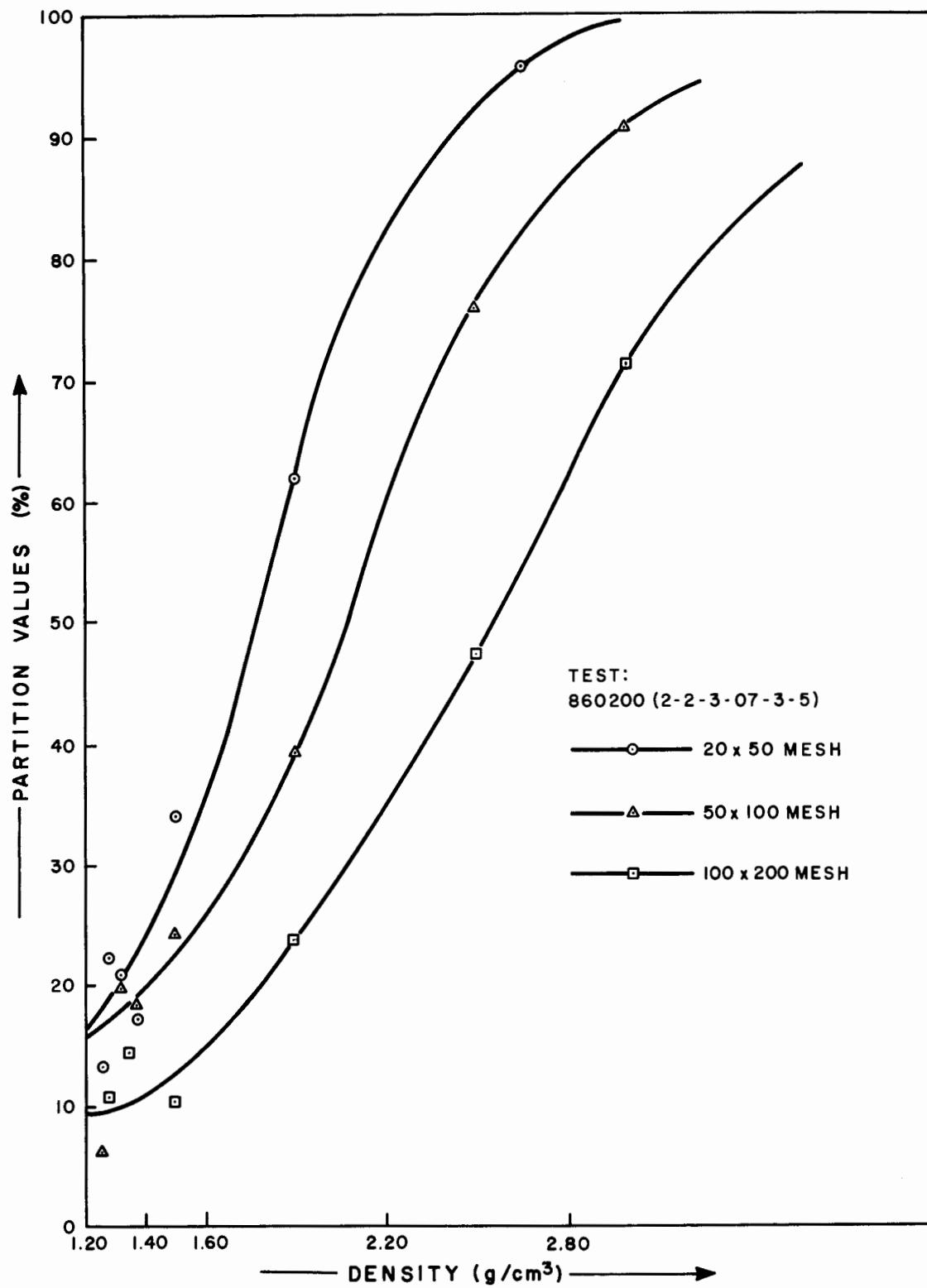


FIG. 8 PARTITION CURVES FOR THE DENSITY SEPARATION



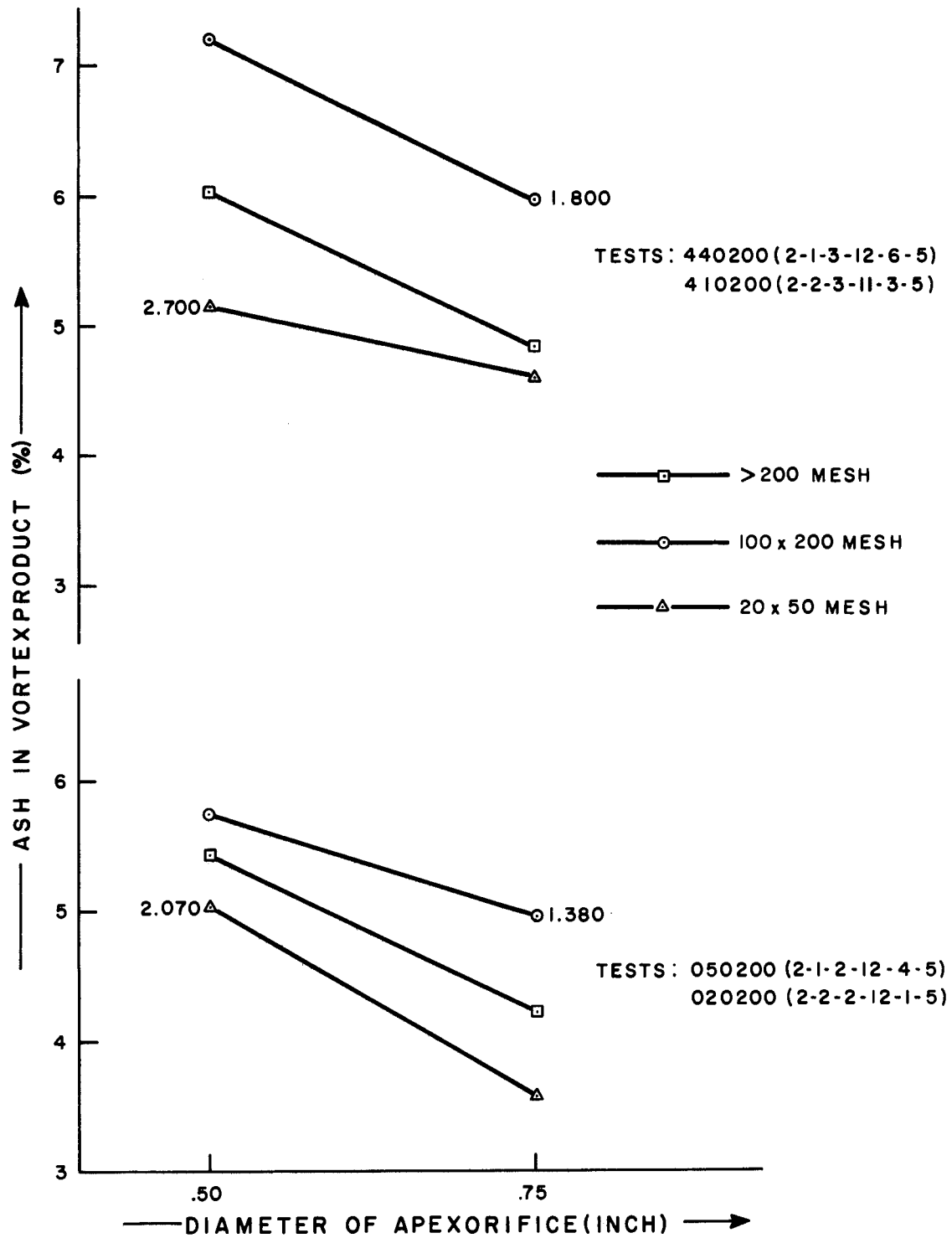


FIG. 9 EFFECT OF APEXORIFICE

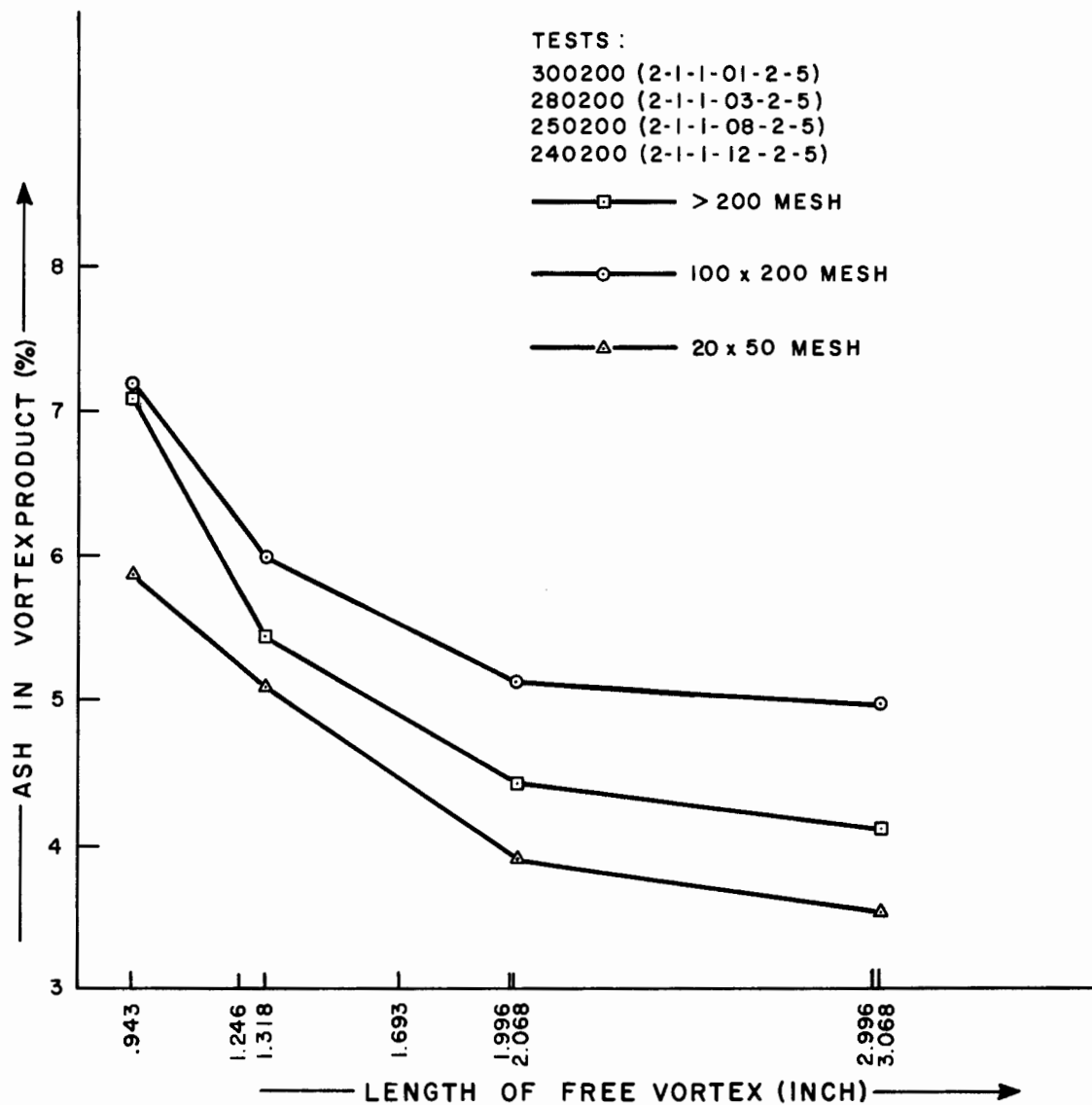


FIG. 10 EFFECT OF FREE VORTEX LENGTH

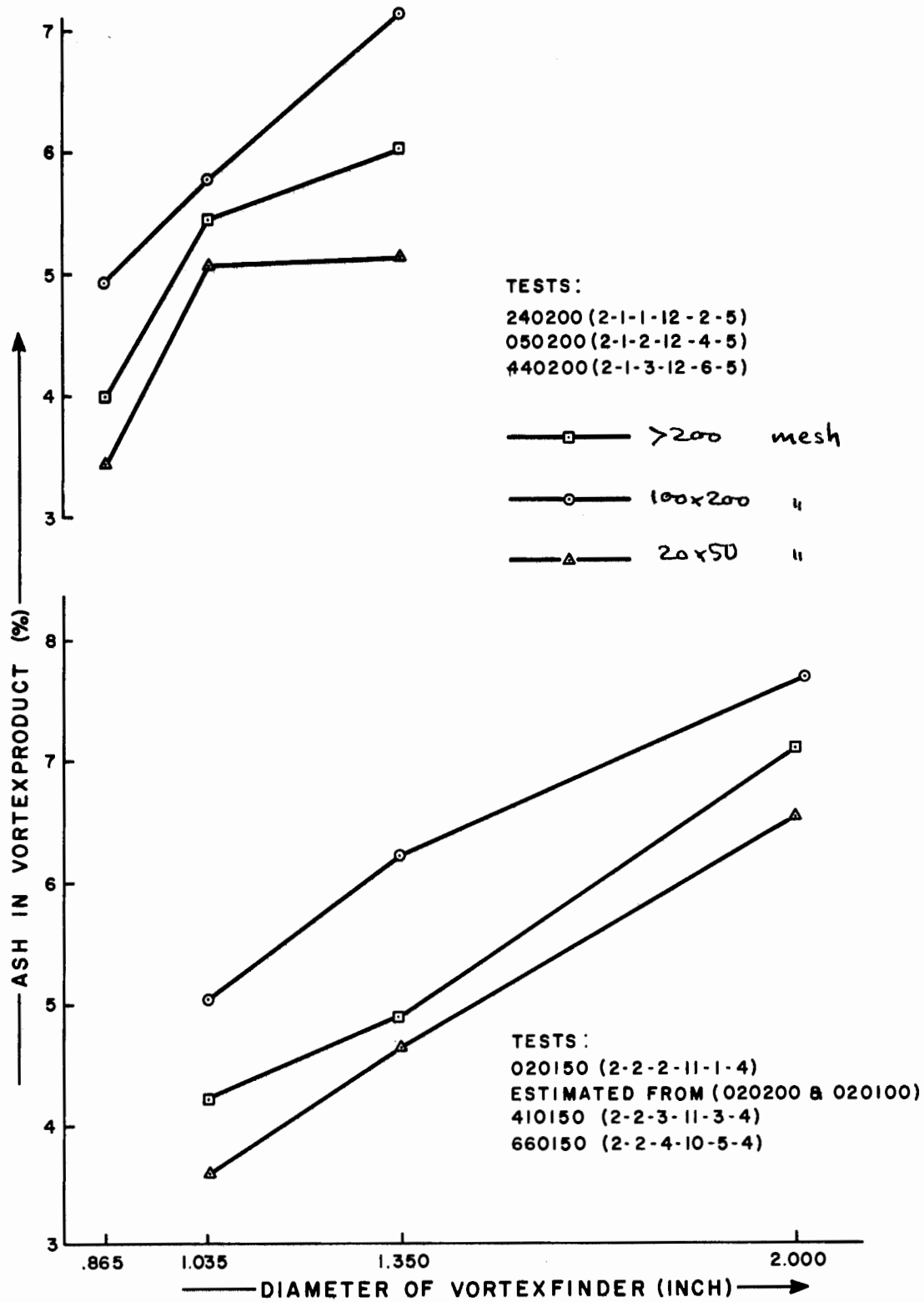


FIG. II EFFECT OF VORTEXFINDER DIAMETER

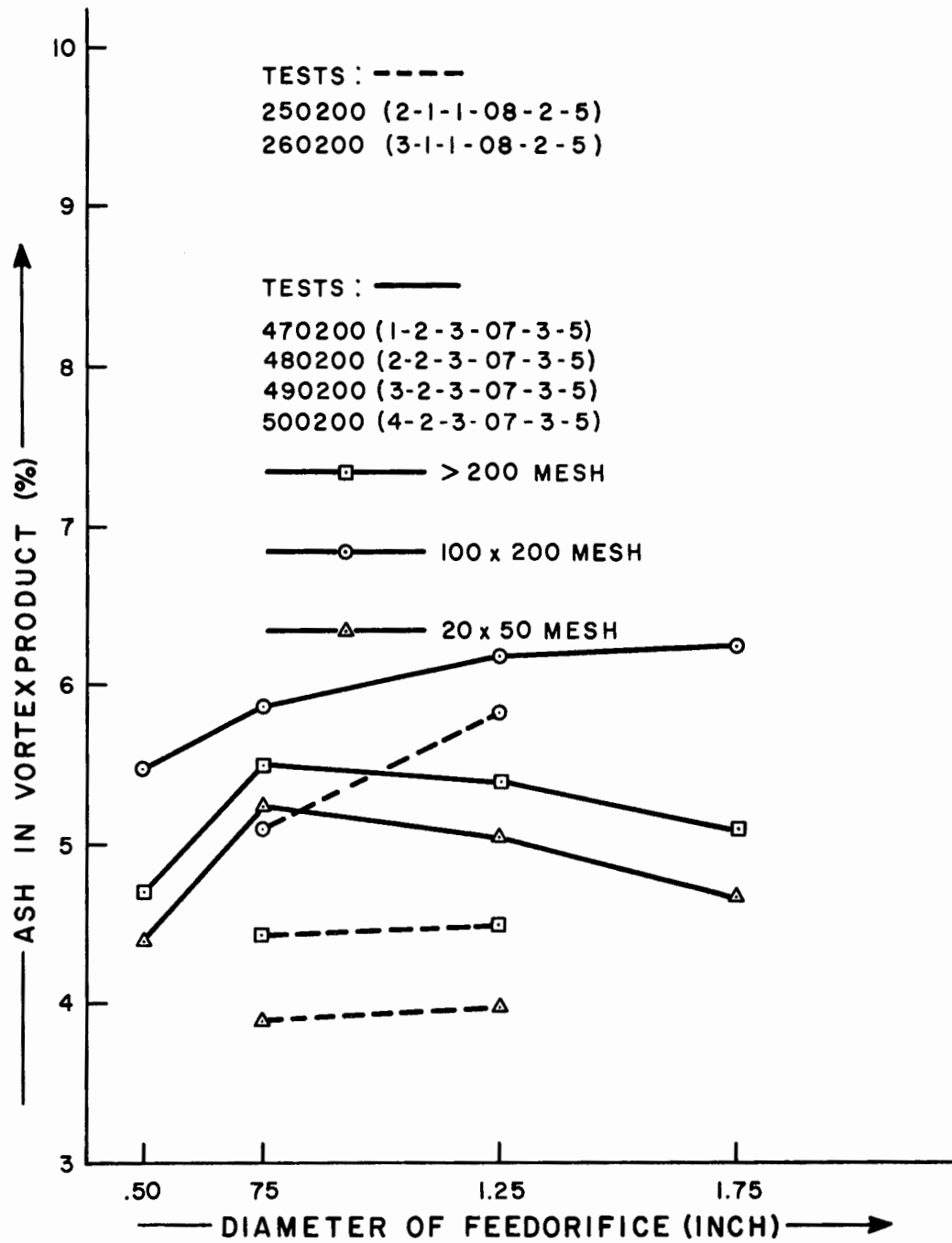


FIG. 12 EFFECT OF FEEDORIFICE

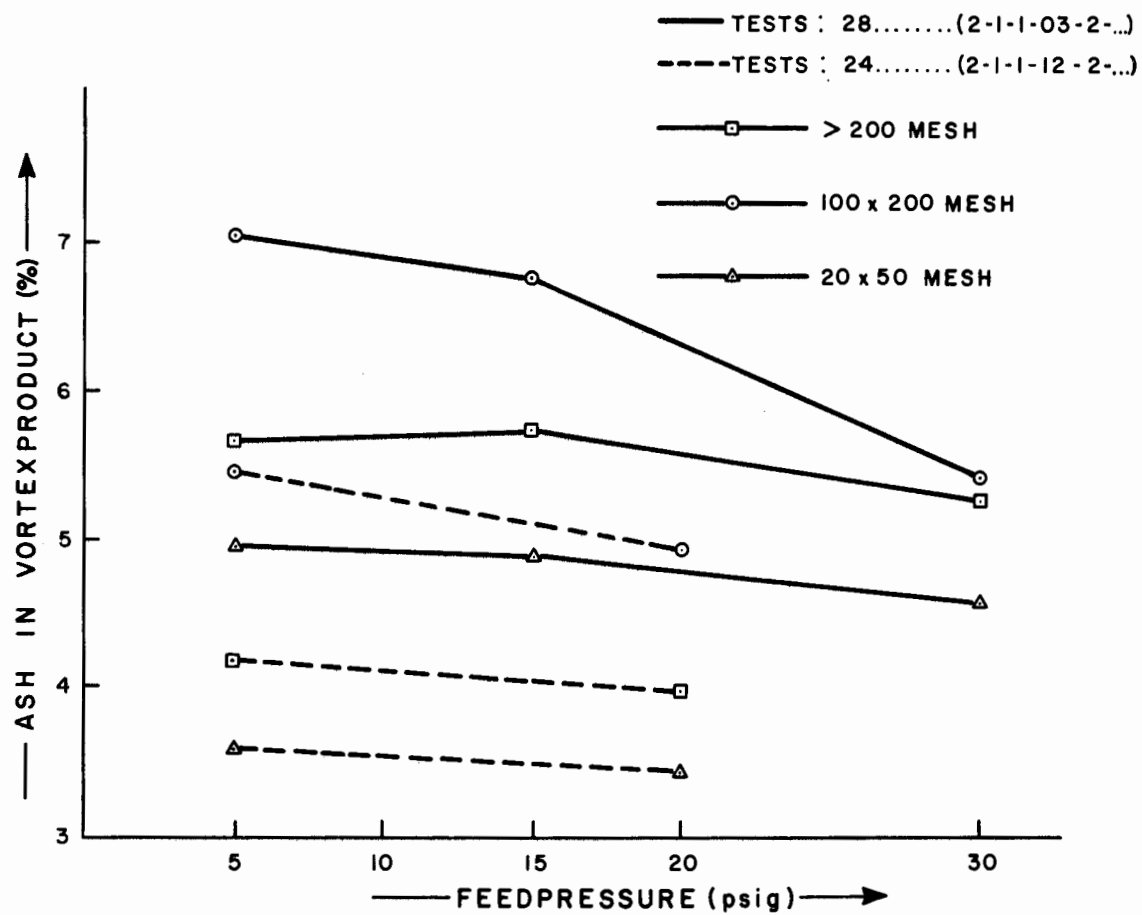


FIG. 13 EFFECT OF FEEDPRESSURE

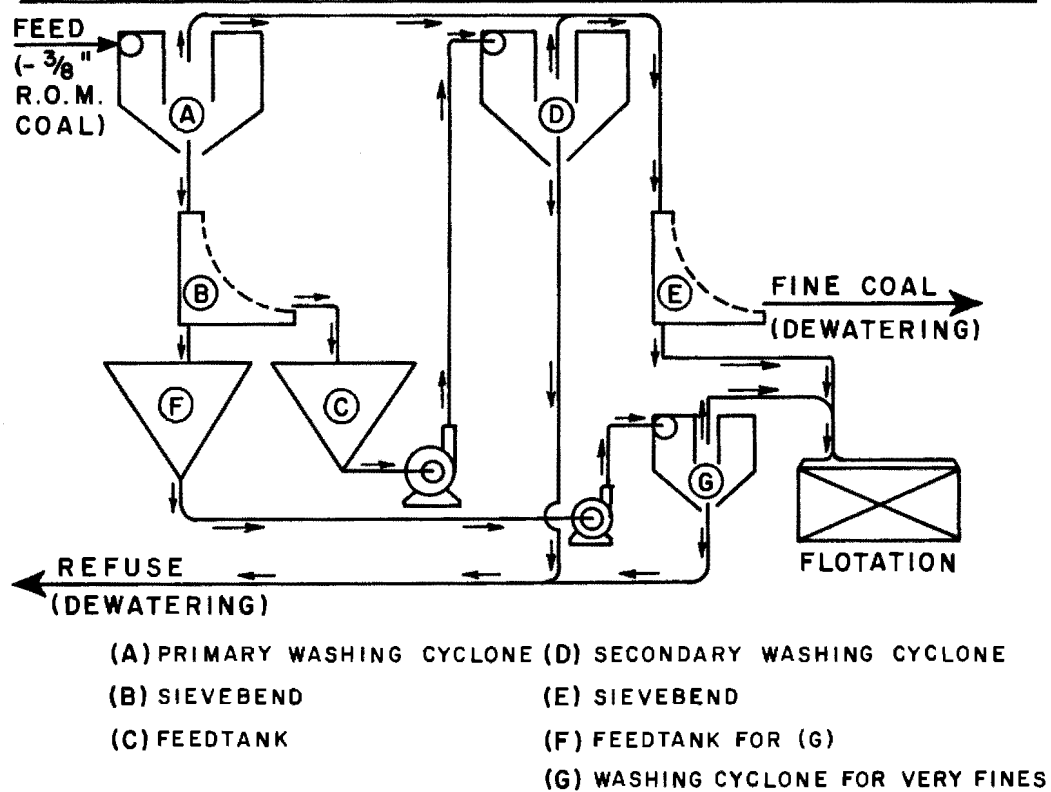
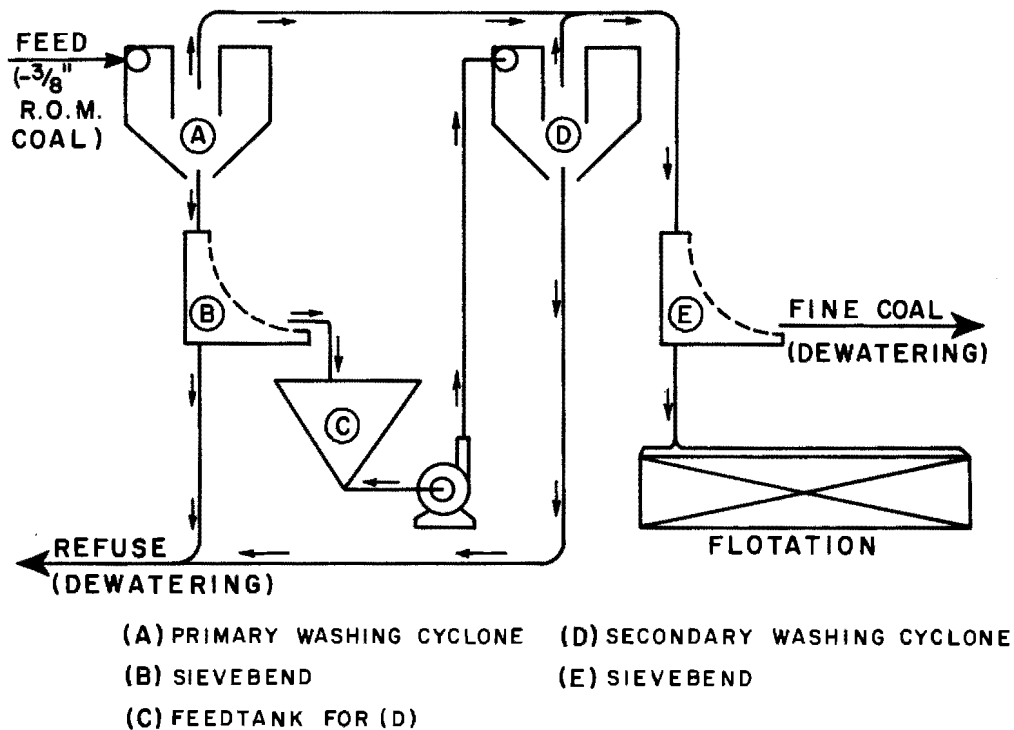


FIG. 14 PROPOSED HYDROCYCLONE FLOW SHEET