FEASIBILITY STUDIES FOR COLLIERIES

PAKISTAN MINERAL DEVELOPMENT CORPORATION

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT

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FOR

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FOREWORD

The coal mineral deposits of Pakistan have been exploited for many years to some degree. During the p st two or more decades the Government of Pakistan has recognized the desirability of exploiting their known and potential coal deposits in the most economically efficient manner.

As a result, a number of excellent technical coal studies have been completed by qualified, expert personnel and laboratories in Pakistan, England, Germany, France, Japan, the United States, and other countries.

These studies have considered the geology, mineralogy, mining, composition and classification, benefication, markets and uses, as well as the program of development of the industry. Continuous investigation on the subject will not exhaust the fruitful possibilities of this industry. Sufficient reliable data and information has been accumulated in each of the technical areas to provide the greatest opportunity for meaningful contributions, under this contract study, by providing specific technology to initiate a program of filling areas to extend previous studies. The aim of the investigative work is to assist attaining solutions to permit early widespread commercialization of new deposits and to extend the economic mobility of existing deposits.

The coals of Pakistan which have been discovered to date are bituminous or subbituminous in nature. They are high in both pyritic and organic sulfur in comparison to the coals being presently utilized for metallurgical purposes. The complexity of these impurities is further increased by their fine subdivision and distribution. The ash content of these coals is considered high and also well dispersed throughout the coal seam. The high volatile matter/content associated with finely dispersed pyrites of microscopic particle size makes many of these coals subject to spontaneous combustion in storage under conditions where the heat of autooxidation cannot be removed.

These properties are the principal quality deterrents to the widespread use of these coals for the production of metallurgical coke and its related by-products required to fulfill the requirements of the developing economy of Pakistan.

Except for coke, the other products from coal are competitive generally with petroleum, natural gas and wood as well as agriwastes on the farms. At present Pakistan is unable to produce sufficient petroleum for its requirements; its wood resources and gas are limited. Therefore a strong economic incentive exists to save foreign exchange through the increased usage of solid fossil fuels for heat, power generation, coke production, etc.

Before this can be accomplished economically efficient methods are required to lower ash and sulfur content of these coals and to provide, in some instances, a smokeless fuel based on Sharigh and Lakhra coals.

A ready market exists for coals with improved qualities since presently Pakistan import substantial quantities of coal and coke from the world market.[1] Reported requirements for coal are approximately 1.4 million metric tons per annum and are estimated to go to 2 million tons by 1985. A more recent survey, made in considerable detail,[2] projects consumption between 2.3 and 1.9 million metric tons by 1985 plus an additional 1 million tons at Lakhra for power generation and about $\frac{1}{4}$ million tons for metallurgical purposes. This provides estimates of between 3.5 and 3.1 million tons per year by 1985.

Domestic production for 1973-74 is reported[3] as 1.039 million metric tons which constitutes a decline of about 250,000 tons from the prior year. Further declines can be expected if technical improvements in property management, mining, product quality, transport and distribution are not made.

In order to fulfill the economic requirements of Pakistan, to conserve its resources, and to provide fuel for its development by the 1980 decade, an accelerated implementation of the programs for property management, exploration, mine development, beneficiation and product improvement, transportation and distribution, marketing and price structuring are necessary.

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(1) Energy Resources Survey, Acres International, Toronto, Canada.

(2) ESSESJAY CONSULT LTD., "Marketing Study of Coal," p. 105 et seq.

(3) PAKISTAN YEAR BOOK, E. W. Pub. Co. of Lahore (1975) p. 419.

The work reported herein has been primarily directed to the improvement of product quality by beneficiation for ash and sulfur removal, smokeless fuel production, and the upgrading of coals from Sharigh and Lakhra for the potential production of liquid products.

Other aspects of related topics: coking properties, blending with other coals, uses in iron ore reduction, and the overview of economic considerations are included in order to provide as wide a scope to this study as experience will permit.

The initial point of departure in this program was to review reports of previous investigations and other reports in order to avoid duplication of effort. During the course of this visit to Pakistan samples of the candidate coals and seams were obtained and shipped to the U.S.

On receipt of these samples, they were analyzed for uniformity of composition and between seams of each coal after which chemical and petrographic analyses were made. A description of this work follows in some detail.

ACKNOWLEDGMENTS

Our sincerest thanks in appreciation are due to Mr. F. K. Khilji, Chairman of Pakistan Mineral Development Corporation, for his planning, guidance, and understanding in giving us this opportunity to conduct studies on the Sharigh and Lakhra coals of Pakistan.

Dr. A. A. Malik, Technical Director, has our gratitude and appreciation for his hospitality and technical guidance in acquainting us with the objectives of PMDC.

Without the guidance and understanding of Dr. A. H. Kazmi, Chief Geologist, this work would not be possible.

We are also grateful to Mr. Khurshid Ali Siddiqui, Senior Mining Geologist, for his hospitality, technical assistance, and for his diligent effort to provide us with reports and documents relative to this project.

Mr. Khalid Aziz, of the Baluchistan District, has earned our gratitude for data and discussions relative to his district, and for the understanding provided in the laboratories during the course of the investigation.

Appreciation is also extended to Mr. M. A. Bari , Director, PASMIC and his staff and Dr. A. H. Chotani of PCSIR and his staff.

We are also grateful to Mr. Mushtaq Ahmad of Federal Chemical and Ceramics Corp., Ltd. for data relative to Calcium Carbide and data related to chemicals, solvents, etc. in Pakistan.

And last, but not least, to all those personnel too numerous to specifically enumerate, who have made our work in Pakistan possible and productive, we wish to say thank you.

PROJECT OBJECTIVES

The principal objectives of the experimental work reported herein were as follows:

(1) Beneficiation - Economically viable methods for reduction of ash and sulfur in Sharigh and Lakhra coals.

Any proposed benefication process considered must accommodate the characteristics of the ash and sulfur components, the particle size and dispersion of these impurities. The size reduction necessary to "unlock" the impurities from the coal is an important economic criterion with coals of the type occurring in Pakistan.

Where extremely fine grinding becomes necessary to about 0.5 microns to unlock the impurities, the energy and cost of size reduction present serious economic barriers.

Previous beneficiation studies have been reported, generally on coarse coal sizes. In order to complete the subject, separation studies herein will concentrate on fine size coals within permissible economic ranges of size reduction.

(2) Coking Studies - Coking studies were made on the Sharigh coals after benefication with the objective of arriving at possible means for improvement in coke properties in the Beehive or Slot oven.

Blending studies of various coals with Sharigh coal could not be completed due to (a) small samples available (b) blending candidate coals have not been selected (3) it is more economical to perform slot oven tests (500 lbs. charge minimum) in an experimental oven in Pakistan. The slot oven tests were considered to be outside of the scope of the program stated in the contract between PMDC and S & P.

(3) Smokeless Form Coal - A method of converting Lakhra and Sharigh coals to a smokeless, odorless fuel at economically permissible costs would increase the market acceptance of these coals for industrial heating and domestic consumption. A type or form of coke or coal was considered more desirable than the present sized product.

(4) Economic Upgrading - The use of Lakhra coal for thermal power generation constitutes an economically viable product.[1] However, the devolatilization of these coals may provide economically more desirable liquid and tar fractions without affecting the basic economics of the thermal plant in which a mixture of coal and char could be consumed.

Carbonization studies were undertaken to uncover any possible problems which might evolve considering the plan of PASMIC to market the coke oven tar products from the steel mill coke plant.

(5) Solution Processes for Purification - Many bituminous coals have been found to be highly soluble (above 85%) in coal tar fractions. These solutions in many cases, either with or without "cutter" solvent to reduce viscosity, may be filtered to remove ash and pyritic sulfur. The filtered solution is then coked to a volatile content of 14-16 percent and then mixed with a coal charge for coking. Where this has been permissible, the coke quality is greatly improved.

However, these solution processes are applicable only on special coal types.

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(1) Lakhra Power Project - WADDA.

(6) New Proprietary Processes - Many new proprietary processes have been reported in conjunction with the U.S. Energy Research and Development Administration (ERDA) by organizations attempting to achieve financial support from this agency for further development and possible commercialization. For the sake of completeness, many of these processes are discussed in conjunction with Sharigh and Lakhra coals.

(7) Coal Hydrogenation - The subject has been studied in conjunction with Sharigh and Lakhra coals in terms of the "State of the Art" developments with the objective of isolating meaningful economically feasible experiments to increase liquids from these coals.

(8) Economic Analysis - Where possible, preliminary range figures are reported for production of smokeless form coal and methods of beneficiation where applicable.

SUMMARY AND CONCLUSIONS

The following conclusions result from the work reported herein:

Sharigh Coal

(1) The Sharigh coal can be used for the production of metallurgical coke by blending the washed fractions with other mid-volatile, low-sulfur and low-ash coals.

Strength of Sharigh-derived cokes can be improved by the use of small amount of devolatilized coal aggregates or coke "breeze" as "blocking agents."

(2) An improvement in ash and pyritic sulfur content can be made in both top and middle seams by coarse crushing the run of mine and screening off the fines (which are high in ash and pyrite content). Fine crushing and washing the resultant fractions of coarse primary material can produce sulfur contents as low as 3.5 percent and ash as low as 8 percent at substantial sacrifice in recovery. Washing curves are presented which correlate the yields of washed coal against the sulfur and ash content as well as the reliability or ease of separation at each specific gravity.

(3) Petrographic analysis shows this coal to be metamorphised with micron and submicron particles of pyrites and ash minerals. These particulates are economically impossible to separate by physical means.

(4) The use of heavy media separation is not encouraging for the above reasons. From an economic standpoint, water washing in cyclones or equivalent equipment appears to be the preferred method.

(5) The separation of sulfur is difficult from these coals since about half of the sulfur occurs as organic sulfur and half as pyrites. The organic sulfur can be partially removed by steam treating during coking; the major portion of the pyrites by washing. Steam treatment during coking can affect the strength and porosity of the coke, therefore must be carried out with some caution.

(6) The Sharigh coal can be mixed with lime or limestone and a small amount of water (mesh sizes of 200 mesh are employed) to form a hard shippable briquette. The quantity of additive is based on the molar quantity of sulfur present in the coal and the quantity of sulfur to be tied up in the ash. A molar ratio of 200 percent of lime to sulfur appears to cause essentially all the sulfur to report to the ash.

The process appears to be economically feasible at this preliminary stage and should be explored further. to produce industrial and domestic fules for market tests.

(7) Carburization of the Sharigh coal is not recommended for reasons of logistics, market demands, etc.

The hydrogenation and hydroliquefaction of this coal is not recommended due to the difficulty of dissolution and colloidizing to permit filtration of the ash and unreacted coal fractions. The vitrines are mixed with a large portion of insoluble and nondispersible semivitrines, making this coal a poor raw material for liquefaction processes.

(8) The Sharigh coal is subject to spontaneous combustion to some degree, however not as readily as Lakhra coal.

Mining plans and handling of this coal should consider this problem of primary importance.

Lakhra Coals

(1) The Lakhra coals can serve as fuel to a thermal power generating plant. They may be burned with the addition of limestone to neutralize the sulfur content of the fuel. The slag may be a candidate material for feed to a cement kiln by adjusting the $Fe_2O_3/CaO + MgO$ ratio.

Cyclone burners have been employed in burning this type of coal, hence they should be tested for this purpose. Experience by S & P has been developed in direct burning of low sulfur lignitic coal in North Dakota, U.S.A. in two thermal generating units of 234 MW and 438 MW respectively.

(2) The economic parameters appear to justify further investigation of the feasibility of carburizing Lakhra coal to remove fixed gases and tar liquids. The char can be fired directly from the carburizer in cyclone burners or in a fluid bed furnace. The production of tar chemicals by PASMIC in the steel mill coke plant should be considered in arriving at decisions regarding carbonization.

(3) Lakhra coal can be formed into briquettes with limestone or lime to produce a hard briquette which on combustion will report the sulfur to the ash in accordance with the molal sulfur to lime ratios employed.

A briquette with clean-burning properties can be made from washed Lakhra coal with a 20 percent ash content. Costs appear to be in a range to permit market development for industrial and domestic fuels. Briquettes can be stored under controlled conditions without spontaneous combustion.

(4) Lakhra coal can be washed to reduce pyritic sulfur and ash. Washing curves are given relating recovery of washed product to sulfur and ash content at each specific gravity. The difficulty of separation is also known.

(5) Hydroliquefaction and hydrogenation processes as well as solvent refining processes do not appear to be economically sound with the Lakhra coals.

(6) Lakhra coal is pyrophoric and subject to spontaneous combustion, hence the power station should be adjacent to the mine. Furthermore, the main entries and mine development should be arranged with suitable fire doors to isolate any section of the mine as necessary. Remote reading temperature instruments should be installed at strategic locations to monitor conditions and temperatures in the event of a fire.

Mining plans should consider the spontaneous combustion problem of primary significance in the establishment of methods, machinery, etc.

RECOMMENDATIONS - The recommendations resulting from this study follow:

(1) Studies be continued at PCSIR or in PMDC laboratories on the briquetting of Lakhra coal with limestone additives in accordance with the findings herein and that market studies be made through the introduction of this product in the industrial and domestic market.

Similar studies should be made with the washed Sharigh coal.

(2) The Lakhra coal be subjected to carbonization, as reported herein, to produce fuel char and fixed gases for the thermal station and tar liquids for the chemical industry. Further work on recoveries and economic parameters is warranted.

The location of the power generating station might present favorable economic factors adjacent to the mine and permit great flexibility in development.

(3) Further exploratory drilling is recommended for the Lakhra deposits with close spacing (max. 1/2 mile centers) with cores taken to crystalline rock basement.

(4) The addition of limestone to the Lakhra coal is suggested to report the sulfur to the ash and avoid corrosion. The addition can be made to provide a $Fe_2O_3/CaO + MgO$ ratio to permit the use of cyclone burners during combustion.

The slagged ash should be investigated as feed to a cement plant.

The Sharigh coals may be washed in hydroclones to produce a suitable blending stock for slot oven coke production comprising up to 10-12 or more percent of the charge, depending on washing and composition of the other coals.

In general, we recommend the conservation of the Sharigh seam coals for use in coking. The binding properties of the high vitrine content of these coals makes them suitable for the agglomerization of iron ores for pellet making and for direct reduction where sulfur content is considered to present lesser problems than in metallurgical cokes.

Regulations for safety, property management, leaseholdings, labor relations, shipping and marketing of coal in Pakistan need improvment and further implementation. However, these valuable minerals will not be conserved for the benefit of future generations without strict enforcement of existing as well as new regulations.

It is strongly recommended that PMDC expand their technical activities in coal processing and preparation either by establishment of their own laboratories or in those of PCSIR. A briquetting press, petrographic laboratory and a 500-pound charge, moving wall, test slot coke oven are necessities along with all the standard laboratory analytical supplies.

The work at PCSIR in progress with fixed bed coking of Sharigh coal and studies of low-temperature tars be encouraged and accelerated.

Further exploratory drilling be carried on in the Sharigh coalfields. Portable drilling rigs will be most economical and mobile.

RAW MATERIAL RESOURCE ANALYSIS

SHARIGH AND LAKHRA COAL DEPOSITS

The carbon content of the earth's crust structure down to a depth of 5000 meters amounts to about 0.1 percent. Of this quantity only about one part in 5000 occurs in such form as to be capable of reacting with oxygen. Only this "available" carbon is considered to be useful from a thermodynamic standpoint. Hence the amount of useful "available" carbon in our globe amounts to about one part in twelve million.

Carbon is among the most important elements and is indispensable i the existence of life; a main source of energy; the basis of foodstuffs, fibers, fuels; reductant for iron, aluminum, copper, etc.; fertilizers; drugs; dyes; etc.

Nature has fortunately provided carbon to us in concentrated forms as fossil fuels. These fossil fuels were produced as accumulations of solar energy over the course of millions of years. These fossil fuels occur in either liquid, gaseous or solid states. The former two we classify as petroleum products, the latter as coal, lignite, peat, etc. The petroleum fuels are considered to be largely of marine origin while coals arise from plant materials. Gas may be formed by chemical conversion of both plant and animal fossil materials.

In ancient times, the use of coal was for a long time restricted because of the evil-smelling sulfurous fumes emitted during its combustion; however in a period of 20 generations the coal industry has developed to a world consumption of approximately 3000 million tons per year or more.

Lignite consumption exceeds 1000 million tons per year in addition.

The total earth's coal and lignite reserves are virtually impossible to estimate. Of all the fossil fuels, estimates of reserves amount to over 10×10^{12} tons; however, coal and lignite account for about $\pm$ 92 percent of the total tonnage. The important factor is the reatio of coal to petroleum reserves, despite the inherent inaccuracy in the estimates.

Through the past century the ratio of consumption of coal to petroleum has changed. The convenience of handling, burning and transport of liquid products coupled with the relative moderate cost for exploration and production has favored increased consumption of petroleum until the present.

The increased difficulty and cost of finding new petroleum deposits, particularly offshore, has once again changed the economic balance in favor of solid fuels. Coal reserves can be found at a lower cost than petroleum and its reserves can be more accurately estimated than gas or oil.

The cost of development of self-sufficiency of Pakistan in oil and gas could easily exceed exploration costs of 3.5 to 4 billion U.S. dollars or more, depending on elapsed time and the inflationary framework of costs. The development and exploration of coal in Pakistan probably would amount to less than 25 percent of this figure. Relative costs of development of gas and oil production should be balanced against the cost of development and total exploration of coal deposits. Coal costs can be estimated more accurately than petroleum.

The purpose of this comparison is not intended to influence programs for exploration of oil, gas and coal, but rather to point out the value of the coal resources of Pakistan and the necessity to practice diligent conservation in the mining recovery, use at maximum economic levels, and general importance of solid fossil fuels to the well-being of Pakistan's future economic health.

Classification of Pakistan Coals - The coals of Pakistan are chemically immature and can be classified as subbituminous (Sharigh) and lignite (Lakhra). Both coals are high in mineral matter (ash) and pyritic and organic sulfur.

The Sharigh coals demonstrate some coking properties, and were sulfur and ash reduced to acceptable values, these coals could become candidate charge stocks in major proportions for production of metallurgical coke.

The Lakhra coal borders on lignite. Many pitch and wax inclusions may be identified in the seam samples. This coal displays no coking qualities. Generally, the Lakhra coal-producing areas are located in semiarid zones, hence the as-mined moisture content will be found to be lower than the normal lignites of the Western Hemisphere or Europe.

The elemental analysis of the Lakhra coal approximates (Dry basis - ash free):

Carbon	70.23
Hydrogen	5.60
Sulfur	6.50
Nitrogen	1.5
Oxygen	17.11

The coal is pyrophoric when stored in piles of more than one meter in height for three weeks.

GEOLOGY AND TECTONICS - Sharigh - The principal subbituminous coal deposits of the southeastern foothills of the central mountain ranges are concurrent with Eocene-Palaeocene sedimentary rocks.

These coal deposits appear to be a result of early marine-associated moraines which have been subjected to considerable fresh water leaching. The marine evaporites presently can be found in the Salt range. This leaching, while serving to transplant evaporites, also resulted in the deposition of carbonates, iron, hydrogen sulfide, etc. in the uplifted coal seams.

Tectonic action followed by surface erosion has further tilted the coal beds and exposed outcrops at various points in the Khost - Sharigh - Harnai coalfields. Beds are steeply dipping and are suspected to contain numerous faults and folds presently only partially mapped.

Much geological investigative work has been done in the Khost - Sharigh - Harnai coal belt; however, much remains to be done. Additional detailed stratigraphy and tectonics showing major faults, folds, and movement are necessary to fully exploit these deposits through efficient mine and production planning.

The geological areas are considered to be beyond the scope of this study, and while much data (not inspected by the consultant) may be available, nevertheless it appears that additional exploration and core drilling is highly desirable. Attention should be directed to the deeper elevations to crystalline rock basements. Only after such drilling can reserves be determined accurately and an economical program developed.

The fields of Quetta and Kalat cover an area of between 80 to 120 square miles. The range of these figures indicates the reliability which can be placed on the coal reserves of the area.

The outcrop of the tilted and surface eroded bed is about 35 miles in length along the strike from Harnai to Chaffar Rift. Seams range from inches to 5 feet or more in thickness. The top seams from $1\frac{1}{2}$ to 2 feet thick, and the middle seams are being mined on a commercial scale. The bottom seam has from time to time been mined to shallow depths. However, little is known of the beds at greater depths we believe due to water and other roof and floor problems. Little data is reported on roof and floor conditions which can be anticipated during mining of these deposits. Reports are that the roof and floor consist of friable shales of greater stability than those of the Sor Range.

Lakhra - This field covers an area of about 80 square miles (see Figure 1). The deposits are of the Renikat formation of the Palaeocene Era.

In general, the seam structures are flat to slightly dipping and appear to be relatively undistrubed tectonically. At a depth of about 68 to 364 feet the principal seam varies in thickness from 2.5 to over 10 feet.

Since drilling and exploration have been carried out in the area, sufficient information is available to justify going ahead with preliminary mining plans.

Geological exploration to date identifies some of the faults, synclines, and anticlines in the proposed mining area. PMDC has by November 17, 1975 drilled 35 exploratory drill holes with an additional 55 proposed and

an added 24 holes to be drilled. The locations to be selected after logging the prior scheduled grid drillings. This will provide a drill hole for every 1.3 square miles. The adequacy of drill holes will depend upon the consistency of the data, stratigraphy and other results of the coal analysis developed; however, it appears that the spacings should be at no more than $\frac{1}{2}$ mile apart with depths to crystalline rocks before final commitments are made.

RESERVES AND GEOGRAPHY - Sharigh - The coal reserves at Sharigh are reported to be 7 million tons. The production of this coal is shown in Table 1 which indicates that the sales of the coal reached a peak in 1969-70. The declining sales of Sharigh coal are an impetus to PMDC to seek new markets for this coal and to solve problems in transport, marketing and distribution. Also in Table 1 are the price levels for this coal, which indicate that the price has increased, reflecting the general world price increase for energy.

The quality of this raw coal makes it unsuitable for metallurgical coal unless new techniques are designed to reduce the sulfur content and increase the coke strength. The present market for this coal is steam, cement and brick manufacturing. In marketing this coal, some difficulty could be experienced by the limited rail capacity within the country. It may require purchase of cars if a significant increase in production of this coal is realized.

TABLE 1

P.M.D.C. STATEMENT SHOWING PRODUCTION AND SALES OF SHARIGH COLLIERIES FROM 1960-61 TO 1974-75

Year	Production (Tons)	Sales (Tons)
1960-61	28,607	22,122
1961-62	20,841	24,061
1962-63	20,326	22,189
1963-64	25,417	25,648
1964-65	27,180	28,195
1965-66	38,053	24,648
1966-67	31,788	33,004
1967-68	58,003	45,498
1968-69	58,953	55,788
1969-70	58,935	58,598
1970-71	68,981	43,468
1971-72	31,153	45,398
1972-73	27,458	29,282
1973-74	28,508	23,151
1974-75	38,242	33,658

AVERAGE SELLING PRICE OF SHARIGH COAL

1971-72 . . . . . Rs. 83.09 Per Ton

1972-73 . . . . . Rs. 82.72 Per Ton

1973-74 . . . . . Rs. 109.00 Per Ton

1974-75 . . . . . Rs. 248.00 Per Ton

The PMDC cost of mining of Sharigh coal is reported in Table 2:

TABLE 2

Cost of Mining Sharigh Coal in
Rupees/Metric Ton, Run of Mine

Item	Cost
Foreign Supplies	2.50
Mining Timbers	36.25
Fuel	10.00
Coal Cutting	38.00
Fringe Benefits	6.74
Repairs	5.25
Packing	1.50
Production Salaries and Wages	17.31
Depreciation	26.20
Amortization/Dev. Cost	1.75
Maintenance	4.30
Selling & Distribution	12.01
Administration Cost:	
Staff	10.35
Salaries & Wages	10.63
Overhead	14.60
Financial Expense:	
Head Office	4.40
Interest on Local Loan	17.58
Interest on Foreign Loan	31.48
Interest on Working Capital	1.74
Total Cost R$	253.14

Current maximum sales price is fixed for PMDC at R$ 300/ton.

CHARACTERISTICS OF THE DEPOSITS

PMDC properties cover 7 miles of outcrop out of a total of 35, hence the major portion of the properties are under the control of the private sector, consisting of owners of either limited financial resources or those not willing to make large investment on their mining properties.

These operators tend to "high grade" their properties, taking the most easily mined coal and leaving the remainder. This practice makes for low recovery of the ore and makes it virtually impossible to conduct secondary mining under economically viable conditions.

The product cost of these "high graded" products is reported to be as follows:

Cost of Contract Mining Sharigh Coal ex Mine in Rupees per Metric Ton, Run of Mine

Item		Cost
Contract Mining Labor	R$	50
Timbers		35
Fuel		12
Indirect Cost		30
Transport to Tipple		15
Total R$		142

In order to conserve this valuable ore resource, a study is recommended to establish methods of mining and regulations for safety to make these resources available to future generations and to improve the working conditions in the industry.

The land and water availability at the site are more than adequate for a preparation plant and coke-making facility at Sharigh. Three cubic feet per second of water are available at Sharigh.

Prior Studies - Sharigh Coal *

A resumé of data from the excellent prior studies of the Sharigh coals is included here to permit a comparative analysis with the washing of fine size fractions made in this study.

The prior work is based on primary crushing the run of mine to top size of 25.4 mm followed by screening and size reduction.

Reference:

* Washability and Coking Characteristics of Sharigh Top Seam and Middle Seam Coals by H. J. Heinrich and R. H. Malik, Coke Research Section, Australian Iron and Steel Pty. Ltd., Port Kembla, N. W. W. Australia, November 1973.

TABLE 3 - SIZE ANALYSIS OF ROM (AS RECEIVED) SHARIGH COALS

Size	Top Seam		Middle Seam	
	Wt. %	Cum.% Ret.	Wt. %	Cum. % Ret.
76.2mm	1.6	1.6	0.9	0.9
50.8mm	20.2	21.8	11.4	12.3
25.4mm	31.8	53.6	38.8	51.1
12.7mm	18.9	72.5	22.3	73.4
6.35mm	12.5	85.0	12.6	86.0
3.02mm	5.8	90.8	5.7	91.7
1.68mm	3.1	93.9	2.7	94.4
0.85mm	2.1	96.0	1.8	96.2
0.50mm	1.0	97.0	0.9	97.1
-0.50mm	3.0		2.9	

TABLE 4 - FLOAT/SINK ANALYSIS OF +0.50mm ROM SHARIGH COALS

Relative Density	Top Seam		Middle Seam	
	Yield %	Cum. Yield %	Yield %	Cum. Yield %
F 1.30	51.5	51.5	5.0	5.0
1.35	10.8	62.3	28.0	33.0
1.40	5.9	68.2	18.2	51.2
1.45	4.7	72.9	10.1	61.3
1.50	3.8	76.7	6.7	68.0
1.55	2.6	79.3	4.3	72.3
1.60	3.1	82.4	3.7	76.0
1.65	1.6	84.0	3.7	79.7
1.70	1.2	85.2	2.0	81.7
S 1.70	14.8		18.3	

TABLE 5 - SIZE ANALYSIS OF 10.50mm ROM SHARIGH COALS CRUSHED TO TOP SIZE OF 25.4mm

	Top Seam		Middle Seam	
Size	Wt.%	Cum.% Ret.	Wt.%	Cum.% Ret.
19.1mm	18.5	18.5	16.1	16.1
12.7mm	23.3	41.8	19.6	35.7
6.35mm	26.8	68.6	28.8	64.5
3.02mm	12.7	81.3	15.2	79.7
1.68mm	7.8	89.1	8.6	88.3
0.85	4.9	94.0	5.3	93.6
0.50mm	2.2	96.2	2.4	96.0
-0.50mm	3.8		4.0	

TABLE 6 - FLOAT/SINK ANALYSIS OF +0.50mm ROM SHARIGH COALS CRUSHED TO TOP SIZE OF 25.4 mm WITH RESULTANT -0.50mm MATERIAL REMOVED

	Top Seam		Middle Seam	
Relative Density	Yield %	Cum. Yield %	Yield %	Cum. Yield %
F 1.30	52.5	52.5	13.1	13.1
1.35	13.7	66.2	27.8	40.9
1.40	4.3	70.5	15.8	56.7
1.45	4.0	74.5	9.1	65.8
1.50	3.1	77.6	5.2	71.0
1.55	2.6	80.2	3.9	74.9
1.60	2.2	82.4	2.5	77.4
1.65	2.2	84.6	2.3	79.7
1.70	0.8	85.4	1.5	81.2
S 1.70	14.6		18.8	

TABLE 7 - EXPECTED SIZE ANALYSIS OF ROM SHARIGH COALS CRUSHED TO TOP SIZE OF 25.4mm (MINIMUM FINES PROCESS)

	Top Seam		Middle Seam	
Size	Wt.%	Cum.% Ret.	Wt.%	Cum.% Ret.
19.1mm	18	18	16	16
12.7mm	22	40	19	35
6.35mm	26	66	28	63
3.02mm	13	79	14	77
1.68mm	7	86	9	86
0.85mm	5	91	5	91
0.50mm	2	93	2	93
-0.50mm	7		7	7

TABLE 8 - WASHABILITY DATA OF ROM TOP SEAM CRUSHED TO TOP SIZE OF 25.4mm (-0.50mm NOT WASHED)

Relative Density	Yield %	Ash %	Cum. Floats Yield %	Cum. Floats Ash %	Cum. Sinks Yield %	Cum. Sinks Ash %
F 1.30	49.0	3.0	49.0	3.0	44.3	30.4
1.35	12.8	5.8	61.8	3.6	31.5	40.4
1.40	4.0	11.2	65.8	4.0	27.5	44.6
1.45	3.7	14.1	69.5	4.6	23.8	49.4
1.50	2.9	18.4	72.4	5.1	20.9	53.6
1.55	2.4	22.0	74.8	5.7	18.5	57.8
1.60	2.1	25.0	76.9	6.2	16.4	62.0
1.65	2.1	28.9	79.0	6.8	14.3	66.8
1.70	0.7	34.0	79.7	7.0	13.6	68.5
S 1.70	13.6	68.5	93.3	16.0		
-0.50mm	6.7	40.8				
Total			100.0	17.7		

TABLE 9 - WASHABILITY DATA OF ROM MIDDLE SEAM CRUSHED TO TOP SIZE OF 25.4mm (-0.50 mm NOT WASHED)

Relative Density	Yield %	Ash %	Cum. Floats Yield %	Cum. Floats Ash %	Cum. Sinks Yield %	Cum. Sinks Ash %
F 1.30	12.2	3.8	12.2	3.8	81.0	24.7
1.35	25.9	6.1	38.1	5.4	55.1	33.4
1.40	14.7	12.1	52.8	7.2	40.4	41.2
1.45	8.5	16.8	61.3	8.6	31.9	47.6
1.50	4.9	20.6	66.2	9.4	27.0	52.6
1.55	3.6	24.0	69.8	10.2	23.4	57.0
1.60	2.3	28.8	72.1	10.8	21.1	60.0
1.65	2.1	33.6	74.2	11.4	19.0	63.0
1.70	1.5	36.7	75.7	11.9	17.5	65.2
S 1.70	17.5	65.2	93.2	21.9		
-0.50mm	6.8	37.2				
Total			100.0	23.0		

TABLE 10 - ANALYTICAL DATA OF -0.50mm FRACTIONS FROM SHARIGH COALS

(a) ROM -0.50mm

	Top Seam	Middle Seam
Moisture % (adb)	3.1	2.7
Ash % (db)	26.3	28.0
VM % (db)	39.3	42.6
B.S. Sw. No.	2½	2½
Specific Gravity	1.56	1.59
Sulphur % (db)	4.62	7.47

(b) -0.50mm produced by subsequent crushing of +0.50mm ROM fraction to top size of 25.4mm

	Top Seam	Middle Seam
Moisture % (adb)	3.8	2.9
Ash % (db)	52.5	44.1
VM % (db)	26.6	32.7
B.S. Sw. No.	1	1
Specific Gravity	1.92	1.81
Sulphur % (db)	4.43	5.74

TABLE 11 - ANALYTICAL DATA OF FLOAT/SINK FRACTIONS FROM +0.50mm ROM SHARIGH COALS CRUSHED TO TOP SIZE OF 25.4mm PRIOR TO WASHING

(a) Top Seam

	Float/Sink Fraction									
	F 1.30	S 1.30 F 1.35	S 1.35 F 1.40	S 1.40 F 1.45	S 1.45 F 1.50	S 1.50 F 1.55	S 1.55 F 1.60	S 1.60 F 1.65	S 1.65 F 1.70	S 1.70
Moisture % (adb)	3.4	3.4	3.4	3.4	3.4	3.2	3.2	3.1	3.1	2.2
Ash % (db)	3.0	5.8	11.2	14.1	18.4	22.0	25.0	28.9	34.0	68.5
VM % (db)	48.0	47.9	45.6	44.1	41.6	40.0	38.6	36.7	35.5	27.8
B.S. SW. No	4½	4	3½	3½	2½	1½	1½	1	1	< 1
Specific Gravity	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	2.48

(b) Middle Seam

Moisture % (adb)	3.5	3.4	3.4	3.4	3.4	3.1	2.0	2.0	1.9	1.5
Ash % (db)	3.8	6.1	12.1	16.3	20.6	24.0	28.8	33.6	36.7	65.2
VM % (db)	50.5	50.1	47.8	45.3	42.6	40.8	39.8	38.9	38.2	24.6
B.S. Sw. No.	4½	3½	3½	3	2½	2	2	1½	1	< 1
Specific Gravity	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	2.3[illegible]

TABLE 12 - ANALYTICAL DATA OF -25.4+0.50mm $^{\leq}$F 1.70 (= Clean Coal)

SHANGHI COALS

	Top Seam	Middle Seam
(a) Proximate		
Moisture % (adb)	3.3	3.0
Ash % (db)	7.0	11.9
Min. Matter % (db)	9.2	14.4
Wh (db, % MM)	5.2	4.6
Vol. Matter + % (db)	45.8	46.4
Fixed Carbon % (db)	46.6	40.7
Carbon Dioxide % (db)	0.58	0.98
Total Sulphur % (db)	4.49	7.82
Pyritic Sulphur % (db)	1.31	1.31
Phosphorus % (db)	0.004	0.012
Gross Cal. Value (MJ/kg, db)	30.81	28.52
Specific Gravity	1.34	1.40
(b) Ultimate		
Vol. Matter % (dmmf)	49.9	53.4
Vol. Matter ++ % (calc.)	46.0	43.0
Carbon % (dmmf)	81.5	82.5
Hydrogen % (dmmf)	5.93	5.77
Nitrogen % (dmmf)	1.75	1.81
Sulphur % (dmmf)	3.34	7.14
Oxygen * % (by diff.)	7.5	2.8
Gross Cal. Value (MJ/kg, dmmf)	33.93	33.32
Gross Cal. Value ++ (MJ/kg, calc.)	34.02	34.31
(c) Laboratory Carbonisation		
B.S. Swelling Number	4½	4
Gray-King Coke Type	F	F-G

TABLE 12 - Continued

	Top Seam	Middle Seam
(c) Laboratory Carbonisation		
Audibert-Arnu Dilatometer		
Temp. Initial Movement °C	360	355
Contraction %	33	36
Temp. Max. Contraction °C	405	395
Dilatation %	-17	+37
Temp. Max. Dilatation °C	435	445
(d) Analysis of Ash (% of Ash)		
SiO_2	28.4	34.9
Al_2O_3	12.3	14.1
TiO_2	0.85	0.75
Fe_2O_3	39.4	29.9
CaO	10.7	10.0
MgO	1.29	1.52
Na_2O	0.69	0.79
K_2O	0.70	1.50
Mn_3O_4	0.14	0.17
P_2O_5	0.13	0.25
S	2.93	3.38
Ignition Loss	2.1	2.4
(e) Petrographic Analysis (vol %)		
Vitrinite	87	87
Inertinite	3	1
Exinite	4	1
Minerals	6	11
Mean Max. Vitrinite Reflectance	0.53	0.48

NOTES:

(i) adb = air-dried basis
db = dry basis
dmmf = dry mineral matter free basis

(ii) Vol. Matter+ % (db) is corrected for carbon dioxide

(iii) Vol. Matter++ % (calc.) and Gross Cal. Value ++ (MJ/kg, calc.) are calculated according to Seyler's equations from Carbon (dmmf) and Hydrogen (dmmf) values.

(iv) Oxygen* % (by diff.) = 100-C-H-N-S all (dmmf) values.

TABLE 13 - ANALYSIS OF ASH (% OF ASH) OF -0.50mm AND SINKS 1.70 FRACTIONS FROM SHARIGH COALS

	Top Seam			Middle Seam		
	(1)	(2)	(3)	(1)	(2)	(3)
SiO_2	37.7	34.3	32.0	25.6	22.6	20.2
Al_2O_3	13.0	11.2	10.0	9.5	8.5	8.0
TiO_2	0.75	0.59	0.48	0.42	0.30	0.25
Fe_2O_3	19.8	20.9	22.0	16.9	19.8	21.0
CaO	15.6	19.6	22.5	26.4	28.7	30.4
MgO	1.33	1.32	1.32	1.77	1.90	1.94
Na_2O	0.41	0.30	0.23	0.36	0.28	0.22
K_2O	1.38	1.20	1.15	1.02	0.73	0.60
Mn_3O_4	0.11	0.10	0.10	0.24	0.27	0.28
P_2O_5	0.29	0.35	0.35	1.11	0.95	0.88
S	3.08	3.27	3.38	3.86	4.65	4.90
Ignition Loss	6.3	6.3	6.2	12.6	11.8	11.2

NOTES:

(1) = -0.50mm fraction from ROM sample.

(2) = -0.50mm fraction produced by crushing +0.50mm ROM to top size of 25.4mm.

(3) = Sinks 1.70 fraction from washing -25.4 +0.50mm coal.

TABLE 14 - RESULTS OF COKING SHARIGH CLEAN COALS IN THE 25 kg x 150mm TEST OVEN (95% -3.0mm GRIND, 790 kg/m^3 DRY BULK DENSITY)

Coal	100% Top Seam Clean Coal	100% Middle Seam Clean Coal	50% Top Seam 50% Middle Seam
Ash % (db)	7.0	11.9	9.4
VM % (db)	46.4	47.4	46.9
S % (db)	4.49	7.82	6.16
P % (db)	0.004	0.012	0.008
B.S. Sw. No.	4½	4	4
G. K. C. T.	F	F-G	F
A-A Dilatometer	-17d.	+37d.	+8d.
Vitrinite % (vol)	87	87	87
Coke Details			
Yield % (db)	61.5	60.8	61.1
Mean Size (mm)	35.1	49.8	43.5
Breeze (% -25.4mm)	32.7	15.3	16.7
Coke Ash % (db)	11.4	19.6	15.4
Coke Sulphur % (db)	3.85	6.37	5.03
A.S.T.M. Stability	8	16	12
A.S.T.M. Hardness	60	65	62

TABLE 15 - RESULTS OF COKING SHARIGH/METROPOLITAN CLEAN COAL BLENDS IN THE 25 kg x 150mm TEST OVEN. (95% -3.0mm GRIND, 790 kg/m^3 DRY BULK DENSITY)

Sharigh* %	0	85	80	75	Special Blend**
Metropolitan %	100	15	20	25	
Charge Details					
Ash % (db)	13.1	9.9	10.1	10.3	11.7
VM % (db)	18.1	42.6	41.1	39.7	28.5
S % (db)	0.35	5.29	5.00	4.71	2.54
P % (db)	0.060	0.016	0.018	0.021	0.042
B.S. Sw. No.	1	4	4	4	2½
G. K. C. T.	C	F	F	F	D
A-A Dilatometer	10c.o	-17d.	-22d.	-29d.	24c.o.
Vitrinite % (vol)	28	78	75	72	51
Coke Details					
Yield % (db)	82.5	64.4	65.5	66.5	74.9
Mean Size (mm)	57.3	45.7	47.9	52.8	54.8
Breeze (% -25.4mm)	15.7	13.4	12.7	7.4	8.8
Coke Ash % (db)	15.9	15.4	15.4	15.5	15.6
Coke Sulphur % (db)	0.40	4.44	4.05	3.86	2.01
A.S.T.M. Stability	25	17	19	26	37
A.S.T.M. Hardness	35	57	57	56	45

NOTES:

(1)* Sharigh coal consisted of 50% Top Seam/50% Middle Seam Clean Coals.

(2)** Special Blend actually consisted of:
18.0% Top Seam
21.0% Middle Seam
58.5% Metropolitan
2.5% -0.21mm Breeze
but, for purposes of comparison, may be considered equivalent to
39% of 50% Top Seam/50% Middle Seam
61% of Metropolitan

TABLE 16 - RESULTS OF COKING SHARIGH COAL/-0.21mm COKE BREEZE BLENDS IN THE 25 kg x 150mm TEST OVEN. (95% -3.0mm GRIND, 790 kg/m^3 DRY BULK DENSITY)

Sharigh* %	95	90	87
-0.21mm Breeze %**	5	10	15
Charge Details			
Ash % (db)	9.8	10.1	10.4
VM % (db)	45.0	42.0	39.1
S % (db)	5.82	5.79	5.75
P % (db)	0.009	0.011	0.013
B.S. Sw. No.	4	4	4
G. K. C. T.	F	F	D-F
A-A Dilatometer	-28d.	27 c.o.	24 c.o.
Vitrinite % (vol)	83	78	74
Coke Details			
Yield % (db)	62.6	64.8	67.0
Mean Size (mm)	48.9	48.4	48.2
Breeze (%-25.4mm)	15.4	15.8	17.1
Coke Ash % (db)	15.6	15.6	15.5
Coke Sulphur % (db)	4.79	4.53	4.20
A.S.T.M. Stability	11	10	12
A.S.T.M. Hardness	63	52	39

NOTES:

(1)* Sharigh coal consisted of 50% Top Seam/50% Middle Seam Clean Coals.

(2)** Properties of Breeze

Ash % (db)	16.0
VM % (db)	0.3

Sizing	Cum. % Retained
0.21mm	1
0.15mm	21
0.075mm	62
(-0.075mm)	(38)

Lakhra Coal - The coal reserves at Lakhra are reported to number 20,662,762 tons. The high sulfur, moderately high ash lignite has been committed to a thermal power plant to be located near Hyderabad. This plant is projected to use one million tons of Lakhra coal per year. The quality of the coal is that of a typical high-sulfur, moderately high-ash lignite. Details are shown in Tables 17 and 18.

The mine should be located in a relatively flat area with ample availability for the plant site adjacent to the mine. Water could be brought in by pipeline from the Indus River.

The geology and tectonics studies of the Lakhra coal basin have been planned and in fact partly executed. It is recommended that the proposed drilling explorative program be enlarged, particularly in the lower horizons. A possibility exists that new coal structures may be uncovered, and that these lower zones may possess more desirable metallurgical properties than the upper zone occurrences.

A detailed study of the geology and tectonics of the coal deposits in Pakistan is outside the scope of this project.

Literature Review of the Lakhra Coal - There has been a very limited amount of chemical investigation and few preparation studies done on the Lakhra coal. With the exception of some geological work and mining proposals, the only available detailed information is shown in the analyses on the following pages.

The Lakhra deposit is a lignite-type coal with a relatively low BTU, high-moisture content, and a high percentage of sulfur. The coal has a high volatile content.

Analyses indicate the devolatilization and desulfurization of the coal should yield high quantities of fixed gas, liquids, char and sulfur. If there were a market for the sulfur and volatile products, the char could be sold to the proposed power plant. The power plant is to require 3,000 tons per day of Lakhra coal.

TABLE 17
ANALYSIS OF LAKHRA COAL

PROXIMATE ANALYSIS		As Received/ Moist Sample	Air Dried	Moisture Free	Moisture and Ash Free
Moisture	%	28.19	10.40	--	--
Ash	%	14.19	17.70	19.76	--
Volatile matter	%	28.72	35.83	40.00	49.88
Gross calorific value	BTU/lb	7351	9184	10,250	12,770
Fuel heating value	BTU/lb	6707	8661	9,822	12,240
Fixed Carbon	%	28.90	36.07	40.24	50.12
ULTIMATE ANALYSIS					
Carbon	%	40.47	50.49	56.35	70.23
Hydrogen	%	3.26	4.07	4.54	5.60
Sulphur	%	3.75	4.68	5.22	6.50
Nitrogen + Oxygen	%	10.14	12.66	14.13	18.61

Bulk density of coal 56.56 lbs per cu. ft.
Specific gravity of coal 0.0556 lbs per cubic inch

ASH ANALYSIS

SiO_2 %	Al_2O_3 %	Fe_2O_3 %	M_gO %	CaO %	SO_3 %	Therest %
31.20	25.48	24.91	7.0	1.0	8.96	1.45

Specific gravity of ash ---- 0.1149 lb per square inch

FUSIBILITY OF ASH

According to B.S. No. 1016

	Conditions Reducing	Conditions Oxidizing
Initial deformation	1490	1580
Softening spherical	1922	2102
Softening hemi-spherical	2264	2480
Fluid	2318	2534

SULPHUR

Air Dried					Moisture and Ash Free			
Total Sulphur %	Sulphate %	Pyritic Sulphur %	Ash Sulphur %	Combustible Sulphur %	Organic Sulphur %	Total Sulphur %	Pyritic Sulphur %	Organic Sulphur %
3.75	0.40	2.04	0.25	3.50	1.31	6.50	3.53	2.28

TABLE 18
LAKHRA COAL

U.S. Bureau of Mines

Ref: Report of Nusrat Siddique

Location	Basis	PROXIMATE ANALYSIS Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	ULTIMATE ANALYSIS Hydrogen %	Carbon %	Nitrogen %	Oxygen %	Sulphur %	Calorific Value BTU/lb	
Lailian Colliery Seam	AR	31.8	30.0	29.2	9.0	6.8	42.1	0.8	38.0	3.3	7530	Non-coking.
	MF		43.9	42.9	13.2	4.8	61.7	1.1	14.3	4.9	11050	Ash fuses at 2520-2640° F
	MAF		50.6	49.4	--	5.5	72.1	1.3	16.4	5.7	12730	
Lailian Colliery Seam	AR	31.8	30.8	30.0	7.4	6.8	43.0	0.8	38.4	3.6	7660	Non-coking.
	MF		45.1	44.1	10.8	4.9	63.1	1.2	14.7	5.3	11230	Ash fuses at 2620-2730° F
	MAF		50.6	49.4	--	5.4	70.7	1.3	16.6	6.0	12590	
Boring L-16 Lailian Seam	AD	35.7	23.0	25.8	10.5	7.0	38.7	0.7	39.3	3.8	7010	
	MF		43.5	40.1	16.4	4.7	60.3	1.1	11.5	6.0	10910	Ash fuses at 2000-2390° F
	MAF		52.0	48.0	--	5.7	72.1	1.3	13.8	7.1	13040	
Boring L-25 Lailian Seam	AD	9.3	40.9	34.7	15.1	5.1	53.1	1.0	18.2	7.5	9640	Sp. Gravity 1.[illegible]
	MF		45.1	38.3	16.6	4.5	58.5	1.1	11.0	8.3	10630	Ash fuses at 2280-2390° F
	MAF		54.0	46.0	--	5.3	70.2	1.3	13.3	9.9	12740	

V Sampling Program - Sharigh Coal

On December 19, 1975 Mr. Khurshid Siddiqui, Senior Geologist of the Pakistan Mineral Development Corporation (PMDC), and Dr. William E. Foreman representing Sanderson & Porter, Inc. went to Sharigh to take samples of the coal. See Photo 1. The Sharigh deposit is located approximately forty miles in a straight line due east of Quetta. Quetta is located in Baluchistan approximately 980 miles due north of Karachi.

The sampling program was discussed with Mr. Khurshid Siddiqui, Mr. Mohammed Mobeen, Assistant Mine Engineer, and Mr. Sohail Hasmat Mir, Assistant Geologist. It was decided to sample one day's production from the mine.

The mine is presently producing 100 tons of coal per day. The following shows the production and number of mine cars, or tubs, from each lease and seam along with the amount of sample taken from each location and seam.

Lease	Production Ton/Day	Tubs Top	Tubs Middle	Amount of ROM Sample Pounds Top	Amount of ROM Sample Pounds Middle
151	40	5	None	75	None*
160	30	20	10	475	500
94	30	15	15	475	500
TOTAL	100	40	25	1025	1000

*Middle seam was not being mined.

Photo 1. Photograph showing (left to right) Mr. Mir, The Mine Foreman, Mr. Siddiqui, and Mr. Mobeen of the PMDC at Sharigh.

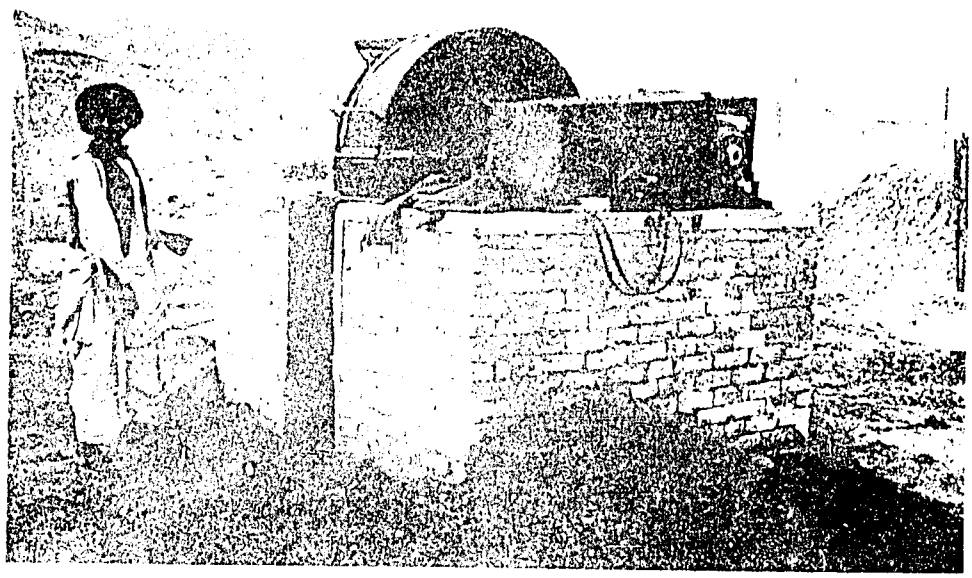


Photo 2. Photograph showing ring crusher at Sharigh used to crush coal samples.

Photo 3. Photograph of alternate shovel method used for sampling coal at Sharigh.

Photo 4. Photograph showing fabrication of drums for use in sampling program of Sharigh and Lakhra coals.

The amount of the sample was weighted on the production per day. Each tub was sampled by shovel as it was brought out of the mine to give approximately the proper weight of sample. The top size of the coal was approximately six inches. Each seam of coal was bagged separately.

The coal was transported to the mine shop area where it was reduced to 3/4" x 0 in size by a ring crusher. See Photo 2. Each sample of top and middle seam coal was kept separate and reduced by the alternate shovel method to approximately 120 pounds. See Photo 3.

The sample was then put into two welded-seam drums of 1.2 cubic feet capacity and the lid bolted down with gasket cement and a rubber gasket seal and labeled. The welded steel drums had been constructed in Karachi to our design specifications. See Photo 4. The purpose of the welded and sealed drums was to keep the coal from oxidizing. In addition, painting of the drums was recommended to reduce the risk of air leakage.

The top seam coal was put into two drums and the middle seam coal was put into another two separate drums. One drum of coal from each seam was readied for shipment to the United States for laboratory analysis. The purpose of keeping the two seams separate was to give flexibility to the blending of these two seam coals for the testing program.

On December 21 Mr. Siddiqui and Dr. Foreman returned to Quetta. There they met with the Chief Mining Engineer, Mr. Khalid Aziz, of the PMDC Baluchistan District who provided the following data on coal consumption.

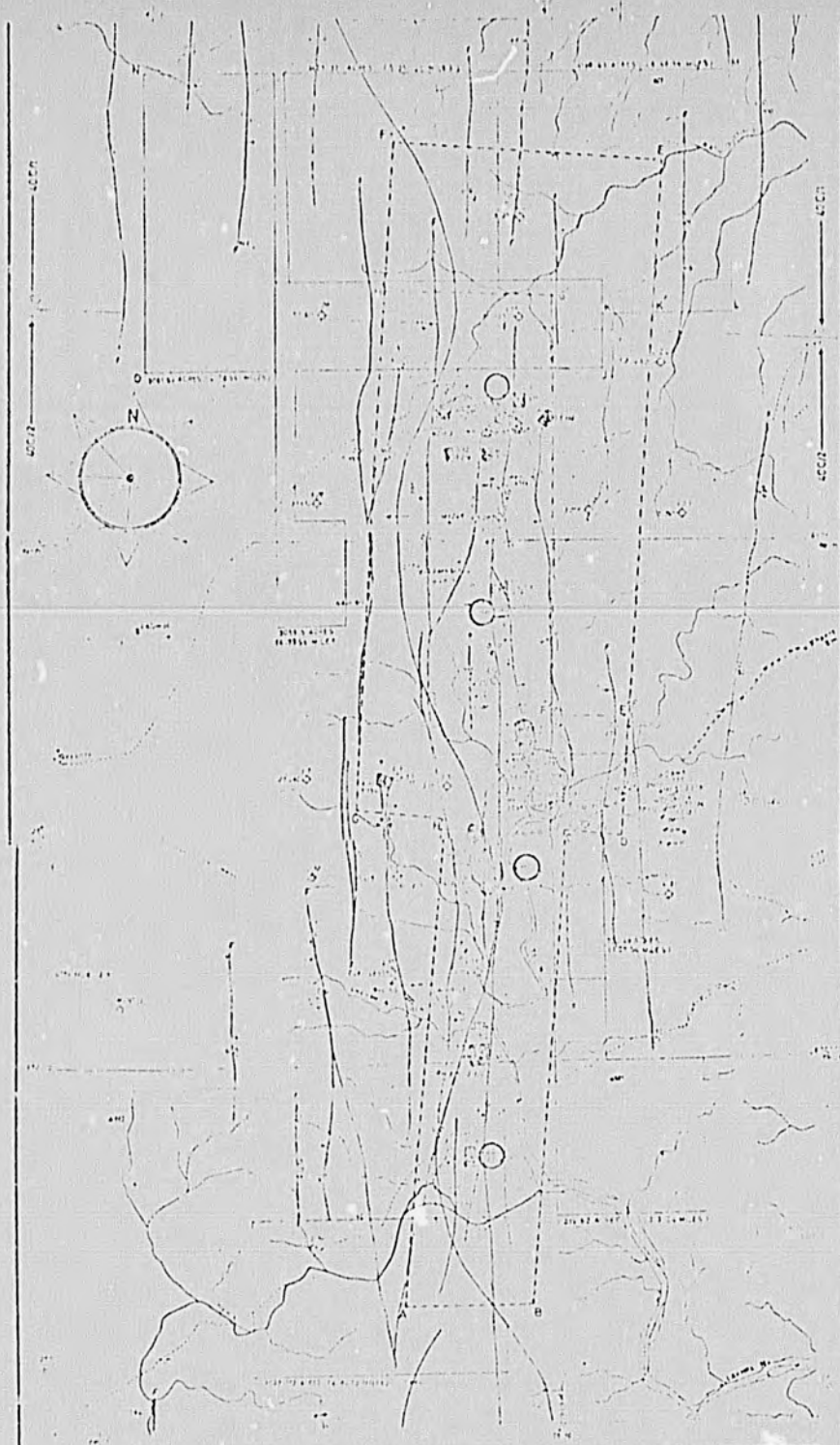
Source	Tons of Coal Per Year
Briquetting Plant	15,000
Quetta Power Station	50,000
Brick Kilns in Punjab	62,000
Defense	30,000
Home Heating	3,000

Sampling Program - Lakhra

Mr. Siddiqui and Dr. Foreman returned to Karachi on December 22 and then left for Hyderabad on December 26 carrying four empty drums for sampling purposes. At the Lakhra mine with Mr. Abdus Sattor Meman, Project Manager, they reviewed the sampling program for the following day. It was decided to sample freshly mined coal as it was being brought out of the pit. There were no facilities to crush the coal, so the material was sampled as mined. Top size was approximately six inches. See Photo 5.

The locations of the samples taken are shown in the map on the following page. These locations were active mines and are noted on the map as WM 1, HM 12, IM 2 and HIM 3.

Photo 5. Photograph showing sealing of sampled coal at Lakhra.



EXPLANATION

AREA FOR DETAILED SURVEY & EXPLORATION TO PROVE COAL RESERVES FOR THE PROPOSED 240 MW POWER PLANT BASED ON LAKHRA COAL

P.M.D.C. LEASE

AREA GEOLOGICALLY MAPPED ON 1:12,000

WORKED OUT/DESTROYED AREA OF COAL STREAM

FOOD UNMETALLED

FOOT PATH

FAULT EXPOSED

FAULT INFERRED

ANTICLINE AXIS

SYNCLINE AXIS

EXECUTED BORE HOLE WITH THICKNESS AND DEPTH OF LAKHRA COAL SEAM

EXISTING/ABANDONED MINE WITH THICKNESS AND DEPTH OF LAKHRA COAL SEAM

TAMPER LOCATION

PAKISTAN MINERAL DEVELOPMENT CORPORATION,
REGIONAL OFFICE, HYDERABAD

LAKHRA COAL PROJECT | FIG: 1

PLAN OF THE AREA FOR DETAILED EXPLORATION, LAKHRA COAL FIELD, DISTT. DADU, SIND

TOPO-SHEET NO. 40 C/1 & 2 | SCALE: 1:50,000

COLLECTED BY: [illegible] | SHAH ALAM | TRACED BY: [illegible]

PETROGRAPHY AND PHYSICAL TESTING

PETROGRAPHY OF SHARIGH & LAKHRA COALS

I Petrographic Analysis of Coals

A detailed petrographic analysis of a coal is of invaluable assistance in determining:

- variability of the bed
- indications of geology and conditions of formation
- composition and constitution of the coal elements and their origin
- composition and occurrence of the ash impurities as well as the pyritic sulfur and indications of potential benefication methods
- indication of the coking properties and coke characteristics which may be expected
- indications of improvements in coke properties through blending with coals of variant properties
- possibilities for solvolysis and purification

II Nomenclature and Definitions

The nomenclature employed herein differentiates between rock types and the more or less homogeneous constituents which are termed macerals.

Macerals can be classified into the following types as employed herein. The following are derived from woody or cortical tissues:

(1) Vitrinite (Anthraxylan) - The principal coal maceral and primary constitutent of bright coal. A polished section presents a more or less clear picture of the structure of the woody tissue. When structure is apparent the term "telenite" further identifies this form of vitrine. If the vitrine is structureless, it is termed "collinite," which is the colloidal medium which permeates all bright coals.

Vitrinite can be identified in transmitted light from its light to dark orange-colored translucence; under reflected light it is dark to light gray in appearance.

(2) Fusinite - This maceral is formed in fossil charcoal. It always shows a cellular structure of carbonified cell walls and hollow lumens. Cell walls sometimes are crushed. Thin sections are completely opaque; polished faces show a strong reflectivity. Physically, fusinite appears dull black, friable and is very hard.

(3) Semifusinite - This is a transition stage between vitrinite and fusinite. Its cellular structure is not easily identified; however, its reflective power is intermediate between that of fusine and vitrine.

The following macerals originate from plant material other than woody tissues. This group constitutes:

(4) Exinite - The fossil remains of spores and cuticles. The appearance of these remains can usually be easily identified. Thin

sections show a yellow translucence, while polished faces show a low reflectivity. It generally occurs as a major constituent in "dull" coals.

(5) Resinite - The fossil remains of plant waxes and resins, generally shaped round or oval, and occur as inclusions in vitrinite of bright coals. Transmitted light reveals resinite a strong light yellow to orange color; under reflected light resinite is dark.

(6) Sclerotinite - These are the fossil remains of fungal sclerotia. The morphological appearance of this material is also easy to recognize. It is opaque and very reflective.

(7) Alginite - The remains of algal bodies. This maceral has a characteristic shape. Under transmitted light, alginite is light yellow in color and black by incident light. Bog coal contains much alginite.

A maceral whose origins cannot be traced to any specific vegetable matter is:

(8) Micrinite - This maceral lacks structure and appears to be derived from humic muds arising from strongly decayed vegetable matter. It is opaque in transmitted light with a high reflectivity more nearly like fusinite. Occurs as inclusions in "dull" or "bright" coals as "granular" micrinite or as massive micrinite as the principal component in durain (dull coal).

Micron - In the identification and measurement of petrographic sections the term one micron indicates a distance of 10^{-3} (.001) millimeters or 10^{-6} meters.

Genesis of Macerals - The genesis of the individual macerals will be considered in order that the petrographic examination which follows will reveal as much information as possible

The woody tissue of coal-forming materials can result in at least three or more macerals, viz. vitrinite, fusinite, semifusinite, and possibly micrinite. The difference in end products which result from the coalification of similar parent substances must arise from differences in the conditions under which formation of coals occurred.

Generally the formation of fusinite is associated with coalification under dry, or arid, conditions. The similarity between fusain and charcoal lend credence to the belief that its formation was due to forest fires, or production by an exothermic microbiological process similarly leading to spontaneous combustion.

There is no question that fusinite was coalified or carburized rapidly under dry conditions.

Vitrinite and its occurrence with fusinite leads us to believe that it also was formed under dry conditions such as a swamp with ground water only slightly below the surface. It can be concluded that the dead plant material sank rapidly into the weak humus soil and became bedded in a stagnant water medium. The amount of dissolved oxygen present in this medium is too low to support anaerobic bacteria; therefore, in this toxic (to bacteria) media the material is protected from micro-

organisms and becomes mummified to coal.

Under wet conditions of a swamp the coalification process proceeds under sufficiently high ground water cover so that the oxygen supply is replenished by the drift which recurs. Under these conditions plant debris is decomposed to a higher degree, leaving only the more resistant fragments. Under these conditions durain is formed with little vitrinite. The durain will contain exinite, high spore content from Articulatae, a flora or very swampy soils.

The difference between macerals in coal are due to variations in the water content of the swampy soils.

The petrographic analysis permits the construction of a seam profile which is characteristic of the progenesis of the seam.

Petrographical Composition and the Properties of Coals

The importance of petrographic analysis of a coal seam is that it permits an understanding of the technological properties which may be anticipated from the coal.

Macerals such as fusinite, semifusinite and micrinite show the behavior of inert substances on heating, hence they are sometimes grouped as "inertite" or "carbinite" since they have a higher fixed carbon content than vitrinite.

Exinite decomposes in heating to a very plastic melt which distills over as tar, hence exinite may also be considered as noncoking for this reason.

Alginite and Resinite have similar properties. Both possess high hydrogen contents and can be grouped as "hydrinite" for this reason.

Vitrinite is the most likely coke-forming maceral if its content of volatile matter lies between 19 and 33 percent.

Coking coals can be classified by the contents of vitrinite, carbinite, and hydrinite, and the plasticity during coking may be anticipated. Furthermore, coals may be blended to provide a mixture of these constituents to provide orthoflow characteristics in the slot or beehive coke oven.

III Petrographic Analytical Methods

All petrographic analysis was done by reflected light utilizing polished microblocks of particulate coal. Microblocks were cast in 1 1/4 inch diameter molds by mixing 5 grams of riffled -20 mesh coal with 6 grams of epoxy and cured at room temperature and pressure. Five microblocks were constructed from each sample. Grinding and polishing of the microblocks was achieved by following ASTM procedure D2797-69T section 7, using 120, 240, 400, and 600 grit silicon carbide papers for grinding; and 5 micron and 0.05 micron polishing compounds for rough and final polishing respectively.

Petrographic analysis consisted of a point count approximation of maceral composition, and a point count approximation of pyrite content and type.

The maceral content was determined using a 1 X 1 mm. grid spacing, resulting in approximately 200 counts per microblock, or 1000 counts per sample. The average maceral composition of the sample was determined by averaging the maceral counts of all five microblocks.

Three maceral suites were recognized in the coals: Vitrinite, Exinite, and Inertinite. The vitrinite suite contains only the maceral vitrinite. Vitrinite composes the majority of all coals, and formed from the woody material of the peat forming plants. Upon coking the vitrinite behaves in two ways. Part of the vitrinite reacts as volatile matter, and escapes as a gas. Some of the vitrinite becomes plastic and flows during part of the coking cycle. The ratio of these two vitrinite types depends mainly on the rank of the coal. Exinite is composed of the macerals sporinite, cutinite, alginite, and resinite. These macerals are composed of the tough exines of plants or waxes or oils produced by plants. The coking behavior of these macerals is very similar. They volatilize at relatively low temperatures, and escape as gas. The inertinite suite consists of fusinite, semifusinite, micrinite, and sclerotinite. These macerals are all very high in fixed carbon, and are inert during coking. These macerals, in the coke, act as aggregate, and the plastic vitrinite forms the binding cement between the aggregate grains.

The packing theory between aggregate and cementitious materials developed by the "concrete industry" is found to be applicable to coking processes, viz., "the strongest structures result from a gradation of aggregate to provide a size distribution in the aggregate to progressively fill the voids between the aggregate particles." The fines provide the minimum thickness to the continuous cementitious carbon from the vitrinite.

This forms the theoretical basis for the use of "coke breeze" in the coal charge to produce a stronger and "blockier" coke. If too much inert is employed, the aggregate is not cemented by the vitrinite and the coke strength is diminished.

The quantity of telenite fractine in vitrinite will sometimes indicate the adaptability of the coal to be solubilized in tar fractions, i.e. for hydroliquefaction. High telenite contents will prevent colloid formation of the coal in the solvent with resultant high viscosities and poor filtration characteristics.

Mineral Analysis - Pyrite and Ash

A single microblock was randomly selected from each sample for pyrite analysis. The pyrite analysis consisted of first determining the percentage of coal exposed on the polished face of the microblock. To achieve this, 1000 points (0.5 X 1mm grid) were counted as either coal or epoxy. The percent coal exposed was calculated from this. The same microblock was then counted for pyrite types using a .2 X .2 mm. grid spacing until 100 pyrite grains were encountered.

Pyrite was classified by type, size, maceral association, origin, and proximity to the edge of the crushed coal particle. Four pyrite types were recognized:

(1) Massive

(2) Patches

(3) Framboids

(4) Isolated euhedral crystals.

Massive pyrite types are typically singular irregular grains. Size ranges from less than five microns to the 800 micron limit to which the coal was crushed (20 mesh). Masses are generally irregular in shape, or cast into coal cavities or fractures.

Patches of discrete euhedral and subhedral pyrite crystals are common. Crystals within the patches average 0.5 microns in size. Patches are usually lenticular, but irregular shapes are common. Maximum patch dimensions range from 2 microns to greater than 500 microns, but average between 10 and 50 microns.

Framboidal pyrite is a spherical aggregate of euhedral to anhedral crystals. The term framboid is derived from the "raspberry-like" form of the aggregate (Vallentyne, 1963). Crystals making up

the framboids are generally 0.5 to 2 microns in size. Framboids range in diameter from 4 to greater than 100 microns, but most are 10 to 50 microns in diameter.

Isolated euhedral crystals are dispersed throughout the coals. Sizes range from less than 0.1 micron to a 10 micron arbitrary upper limit which separates them from the massive grains. The average crystal size is 0.5 micron.

Pyrite content, on a volume basis, was calculated from the percent of the polished face which was coal, and the number of counts required to achieve 100 pyrite counts. With 100 pyrite grains counted, then, the percent of any pyrite type is equal to the number of times the type was encountered.

IV Sample Selection

The Sharigh coals have previously been shown to have coking properties. Therefore petrographic examination was concentrated on these coals, rather than on the Lakhra samples.

From each canister containing the Sharigh top and middle seams, four random samples were removed. These are later refered to as STS-1 through STS-4, and SMS-1 through SMS-4, and represent the Sharigh top and middle seams respectively. These samples were used for variability studies. These eight samples were stage ground to -20 mesh for petrographic analysis. Each canister was then riffled to obtain another split representative of the entire sample. These splits were riffled to obtain approximately four pounds of each sample to be stage ground

V Petrographic Analysis - Results

A description of the macerals and minerals (by volume) follows for the Sharigh top and middle seam coals, including a discussion of the variability of these constituents within each seam.

Sharigh Top Seam - Petrographic analysis of the Sharigh top seam - Vitrinite suite: Vitrinite content ranged from 53.4% to 77.5% in the random, uncleaned samples. The vitrinite content averaged 66.3% (Table 2, page 5-35). Vitrinite content increased to 89.3% in the coal cleaned at 1.60 specific gravity. The majority of the vitrinite was interspersed with other macerals and minerals. Little of the vitrinite occured as "pure" bands within the coal, and very few bands thicker than 100 microns (.1 mm) were noted (Figure 1). The most intimately mixed maceral within the vitrinite is cutinite (Figure 2) which commonly occurred as cell walls within the vitrinite bands (Figures 3, 4 and 5).

The vitrinite has a low reflectance, approximately 1.1%, placing this coal in the high volatile bituminous range. According to this reflectance measurement, approximately 30% of the vitrinite reacts as volatile matter.

Exinite suite: Exinite content varied from 1.6% to 3.2% in the random samples, but averaged 2.3% (Table 2, page 5-35). Sporinite accounts for half of the exinite, and cutinite the other half. Spores are generally rare, and scattered throughout the coal (Figures 6, 7, 8 and 9). Cuticles are found within vitrinite as previously stated, and as thicker individual cuticles (Figure 10). Alginite and resinite were not noted in the samples.

Inertinite suite: Inertinite is very rare in these samples, ranging from 0.4% to 0.7%, and averaging 0.6% (Table 2). Semifusinite is the most common of the inertinite macerals, but this is only present in amounts up to 0.5% (Figure 11). Fusinite (Figure 11) is rare (0.2%), and micrinite and sclerotinite (Figure 12) were noted only very rarely.

Washing Sharigh top seam at 1.60 specific gravity can increase the vitrinite content to 89.3 ± 10% in the overflow.

The coking properties of this coal are based on a plastic-forming vitrinite content of 62.5 ± 10%.

Exinite suite amounts to 2.3% which will distill as tars during coking.

Inertinite averaging 0.6% is low in this coal.

It appears that the coke properties of this coal could be improved by the blending of a fine particle size inertinite (i.e. coke breeze) to bring the latter suite to 8 - 10%.

Mineral matter: Clays are the most common minerals present in these samples of the Sharigh top seam. They varied from 15.4% to 30.7%, but averaged 23.5% (Table 2). The majority of the clay occurs as large, nearly pure, grains in the minus 20 mesh fraction. These

probably represent fragments of much larger partings in the coal, and their easy removal from the coal by cleaning indicates that this is the case (Figures 13 and 14).

Thin bands of nearly pure clay are common (Figure 15), but clays are also intimately mixed with the vitrinite in thin, 1 to 20 micron (.001 to .020 mm) thick, bands (Figure 16). These layers and lenses constitute the major portion of clays remaining in the cleaned coal.

Pyrite is the second most common mineral in the Sharigh top seam (STS). Pyrite ranges from 2.6% to 9.9% in the random samples, averaging 5.5% (Table 2, page 5-35). Pyrite is reduced in the cleaned coal to 1.9%. Pyrite types vary considerably within the random samples (See pages 5-22 through 5-32 for detailed analysis). Massive pyrite types ranged from 78 to 18% of the pyrite. Large (larger than 500 microns (.5mm)) grains were very prominant in STS-2 (Figure 17). Massive fracture filling pyrite (Figure 18) was less than 2% of the pyrite, but massive dendritic pyrite ranged from 25% of the pyrite in sample STS-1, to 0% of the pyrite in STS-2 (Figures 19 and 20). Patches of discrete crystals made up 61% of the pyrite in STS-3, but only 15% of STS-2. The most common patches were small lenses of less than 30 microns (.03 mm) in lateral extent (Figure 21). Some patches were mixed with framboids (Figure [illegible] and some were

clearly primary in origin, and replaced, or filled cell walls (Figure 23). Framboids were nearly constant in occurrence in the four random samples, varying from 19% to 7% of the pyrite. Framboids were scattered throughout the coals, either individually (Figure 24) or in clusters (Figure 25). Isolated euhedral pyrite crystals were very rare and scattered throughout the coals. They varied from 0% to 6% of the pyrite in the samples (Figure 24).

Total pyrite was reduced to 1.9% in the cleaned STS coal, but the relative amounts of the various pyrite types remained the same. This seems to support the interpretation that all of the pyrite types are intimately mixed with the coal, and are only removed when they become concentrated enough in the coal to cause a significant increase in the specific gravity of the grain.

Calcite is another common mineral in the random samples. Calcite ranged from 0.4% to 1.3% in the random samples, and averaged 0.7%. The calcite content is generally the same in all four samples. This mineral occurred as fracture fillings within the coal (Figures 26 and 27). The fractures vary from less than 5 microns (.005 mm) thick to much greater than 800 microns (.8 mm).

Gypsum is another common fracture filling mineral in these coals. Fracture filling occurrences of gypsum are

very similar to those of calcite (Figures 28 and 29).

Gypsum also occurs as a primary mineral, forming as the coal formed, and intimately mixed with it. This type of gypsum occurs as pods 10 to 100 microns (.01 to .1 mm) in length within vitrinite (Figures 30 and 31).

Hematite was noted very rarely in these coals, and probably results from the oxidation of pyrite.

VARIABILITIES WITHIN THE SHARIGH TOP SEAM - Variability within the Sharigh top seam is indicated by petrographic analysis. Variations in the composition, and maceral content, of the random samples indicates a degree of variability perpendicular to bedding through the seam. Some macerals and minerals are better indicators of the variability than others. The major component, vitrinite, varies considerably, indicating that some portions of the seam may be cleaner and better for coking (because of their higher vitrinite content) than other portions. Variations in mineral matter content also indicate this. Pyrite amounts and types vary considerably among the four random samples, strongly indicating that portions of the Sharigh top seam are considerably freer from pyrite than other portions. Figures 32, 33 and 34, on pages 5-37, 38 and 39, illustrate the variabilities discussed. More exploratory work is needed to determine where variability occurs to see if raw and/or clean coal quality can be improved by the implementation of mining methods to control quality. The thickness of the

Sharigh top seam and the method of mining appear to make this possibility only of theoretical interest.

The possibility strongly exists that substantial beneficiation through lowered ash and some pyrite content can be effected by screening the run of mine coal at -20 to -40 mesh. The coarse should contain lower ash and pyrites contents. A crushing and screening section can be devised to sequentially crush and screen to discard the -20 mesh fines.

Sharigh - Middle Seam

Vitrinite suite: Vitrinite content ranges from 49.4% to 68.5% in the random uncleaned samples, but averaged 59.5% (Table 3, page 5-36). Cleaning this coal at 1.60 specific gravity increased the vitrinite content to 84.7%. As in the Sharigh top seam, very little of the vitrinite occurs as "pure" bands, and most is intimately interspersed with other macerals and minerals (Figures 35 through 38), especially cutinite. Vitrinite in this seam has the same reflectance, 1.1%, as the Sharigh top seam. This should indicate a similar behavior upon coking.

Exinite suite: Exinite content varied from 0.5% to 4.3%, and averaged 2.6% (Table 3). Cutinite accounts for about 2/3 of the exinite in this seam, in contrast to 1/2 of the exinite in the Sharigh top seam. The increase in cutinite in this seam is represented by more cuticles intermixed with the vitrinite (Figures 37, 38 and 39) and the presence of more very large cuticles such as in Figure 40). Spores (Figure 41) are very rare in this coal.

Inertinite suite: Inertinite is extremely rare in this coal. Only very rare occurrences were noted in the random samples, but 0.3% was noted in the cleaned coal (Table 3).

The addition of coke breeze is also indicated here as in the Sharigh top seam.

Mineral matter: Clays are again the predominant minerals in this coal, as in the Sharigh top seam. Clay content varies from 20.1% to 30.5%, and averages 27.6%. As in the top seam the majority of the clays are in large grains (Figure 42) which probably represent large clay partings in the coal. This coal can be cleaned down to 5.9% clay in a 1.60 specific gravity solution, which also indicates that much of the clay is present in the seam as large partings. More clay appears to be intimately mixed with this coal than the top seam, however, resulting in a higher clay content in the cleaned coal.

Pyrite is also the second most common mineral in this coal. Variability of pyrite content is small in this seam, from 3.0% to 7.1%. A large portion of this pyrite remains in the cleaned coal, 4.5%. The variation in pyrite types in this coal is low. Massive pyrite types account for less than 33% of the pyrite, and account for only 1% of the pyrite in sample SMS-3. Massive dendritic pyrite was half of the massive pyrite types in all random samples (Figure 43). -Large massive grains, Figure 44, and fracture filling pyrite (Figure 45) were rare, but accounted for most of the remaining massive pyrite. Most of the pyrite in all of the random samples was patches of discrete crystals. These patches were lenticular (Figure 46) or obvious replacements of

cell walls (Figures 46, 47 and 48). Isolated euhedral crystals represent 0% to 11% of the pyrite (Figure 49). Framboids are the second most common pyrite types in this coal (Figure 50). Lesser amounts of massive pyrite types (which are more easily cleaned from the coal) and increased amounts of patches and framboids (which are intimately mixed with the coal and more difficult to remove) result in the Sharigh middle seam being more difficult to clean of pyritic sulfur even though the absolute amounts are smaller.

Calcite is present in the Sharigh middle seam coal just as it is in the Sharigh top seam coal, in both mode of occurrence and quantity.

Gypsum is very common in the Sharigh middle seam. It occurs as fracture filling material, and also as primary pods within vitrinite. The primary type is more common, and more abundant in this coal than in the top seam. It also occurs in large pods or lenses in the middle seam (Figure 51).

Hematite was also rarely noted in this seam.

VARIABILITY WITHIN THE SHARIGH MIDDLE SEAM - Variability within the Sharigh middle seam is indicated by petrographic analysis. Variability in maceral composition between the four random samples indicates the same degree of variability in this seam, as in the top seam. Vitrinite and mineral matter content are the main indicators. Pyrite types and amounts are less variable in this seam than in the top seam.

CONDITIONS OF COAL FORMATION - SHARIGH

Conditions were dry with groundwater below the surface.

Waters contained $Ca(HCO_3)_2$ which reacted with sulfates and CO_2 to produce metamorphosis gypsum with calcite in the vitrain lattice.

Periodically strong wind-borne clays and sands inundated the area followed by cycles of growth. This explains the clay bandings.

Tectonic activity provided sulfurous fumeroles permitting waters containing H_2S to inundate the coal beds. Reactions occurred between soluble ferrous salts to provide finely dispersed pyrites as well as organic sulfur in the ring bridges in polyaromatic compounds.

Individual Sample Petrographic Analysis

of

Samples

STS-1

STS-2

STS-3

STS-4

STS-1.60 Float

SMS-1

SMS-2

SMS-3

SMS-4

SMS-1.60 Float

SAMPLE STS-1

MACERAL ANALYSIS

Vitrinite	69.9%	Vitrinite suite	69.9%
Sporinite	0.8%		
Cutinite	0.8%	Exinite suite	1.6%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.2%		
Semifusinite	0.5%	Inertinite suite	0.7%
Micrinite	0.0%		
Pyrite	4.6%		
Clay	22.2%		
Quartz	0.0%	Mineral Matter	27.8%
Calcite	0.5%		
Gypsum	0.5%		

Vitrinite in this sample is of relatively low reflectance(compared to a high volatile coal such as the Pittsburgh in Brooke county). The vitrinite is also impure, and contains many mineral and maceral inclusions on a scale of less than .1 micron to 10 microns.

Fusinite content is much lower than the typical coal (1 to 5%)

Mineral matter is mainly clay which occurs both as thick(>200 microns) bands and very thin bands in the vitrinite.

Calcite and Gypsum occur as fracture and cleat fillings. Size of these fillings is from several microns to several hundred microns (up to the 840 micron size to which the coal was crushed).

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 3.69%

Pyrite easily separated from the coal.

Massive fracture filling and primary pyrite = 11%

Size consist of this pyrite is 10 - >200 microns.

Pyrite not easily separated from the coal.

Massive dendritic, patches, framboids and isolated crystals intimately associated with the coal = 89%

Ground to -20 mesh only 45% of the pyrite grains are broken free of the coal or exposed at the edge of the grains.

This coal is very high in pyrite. Almost all of this pyrite is intimately mixed with the coal or clay. Clay bands contain 21% of the pyrite. Cleaning this coal to remove large percentages of the pyrite would be very difficult, and this will be further inhibited by the "dirty" nature of the vitrinite.

SAMPLE STS-2

MACERAL ANALYSIS

Vitrinite	53.4%	Vitrinite suite	53.4%
Sporinite	0.9%		
Cutinite	0.8%	Exinite suite	1.7%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.1%		
Semifusinite	0.3%	Inertinite suite	0.4%
Micrinite	0.0%		
Pyrite	9.9%		
Clay	30.7%		
Quartz	0.0%	Mineral Matter	44.5%
Calcite	1.3%		
Gypsum	2.4%		
Hematite	0.2%		

Vitrinite in this sample is of reflatively low reflectance. The vitrinite is also impure, and contains many mineral and maceral inclusions on the scale of less than 0.1 micron to 10 microns.

Fusinite content is much lower than the typical coal (1-5%).

Mineral matter is mainly clay which occurs as thick (>200 microns bands, and as very thin bands in vitrinite.

Calcite and gypsum occur as fracture and cleat fillings. Size of these fillings is from several microns to several hunderd microns (up to the 840 micron size to which the coal was crushed).

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 10.73%

Pyrite easily separated from the coal.

Massive fracture filling and primary pyrite = 78%

Size consist of this pyrite is 20 to greater than 200 microns.

Pyrite not easily separated from the coal.

Patches, framboids, and isolated crystals intimately mixed with the coal = 22%

Ground to -20 mesh, only 22% of the pyrite grains are broken free of the coal or exposed at the edge of the grains.

This coal is extremely high in pyrite. Much of the pyrite is as massive grains, but these too are intimately mixed with the coal. Cleaning this coal to remove large percentages of the pyrite would be very difficult, and this will be further inhibited by the "dirty" nature of the vitrinite.

SAMPLE STS-3

MACERAL ANALYSIS

Vitrinite	64.3%	Vitrinite suite	64.3%
Sporinite	1.6%		
Cutinite	1.6%	Exinite suite	3.2%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.1%		
Semifusinite	0.2%	Inertinite suite	0.4%
Micrinite	0.1%		
Pyrite	5.0%		
Clay	25.7%		
Quartz	0.0%	Mineral Matter	32.2%
Calcite	0.4%		
Gypsum	1.1%		

Vitrinite in this sample is of relatively low reflectance (compared to a high volatile coal such as the Pittsburgh in Brooke county). The vitrinite is also impure, and contains many mineral and maceral inclusions on a scale of less than 0.1 micron to 10 microns.

Fusinite content is much lower than the typical coal (1 to 5%)

Mineral matter is mainly clay which occurs both as thick (>200 micron) bands and very thin bands in the vitrinite.

Calcite and Gypsum occur as fracture and cleat fillings. Size of these fillings is from several microns to several hundred microns (up to the 840 micron size to which the coal was crushed).

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 6.31%

Pyrite easily separated from the coal.

Massive fracture filling pyrite and patches = 16%

Size consist of this pyrite is 20 to > 200 microns.

Pyrite not easily separated from the coal.

Massive dendritic, patches, framboids and isolated crystals intimately associated with the coal = 84%

Ground to -20 mesh only 32% of the pyrite grains are broken free of the coal or exposed at the edge of the grains.

This coal is extremely high in pyrite. Almost all of this pyrite is intimately mixed with the coal or clay. Clay bands contain 21% of the pyrite. Cleaning this coal to remove large percentages of the pyrite would be very difficult, and this will be further inhibited by the "dirty" nature of the vitrinite.

SAMPLE STS-4

MACERAL ANALYSIS

Vitrinite	77.5%	Vitrinite suite	77.5%
Sporinite	2.0%		
Cutinite	0.9%	Exinite suite	2.9%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.3%		
Semifusinite	0.1%	Inertinite suite	0.7%
Micrinite	0.3%		
Pyrite	2.6%		
Clay	15.4%		
Quartz	0.0%	Mineral Matter	19.0%
Calcite	0.5%		
Gypsum	0.5%		

Vitrinite in this sample is of relatively low reflectance (compared to a high volatile coal such as the Pittsburgh in Brooke county). The vitrinite is also impure, and contains many mineral and maceral inclusions on a scale of less than .1 micron to 10 microns.

Fusinite content is much lower than that of the typical coal (1 to 5%).

Mineral matter is mainly clay which occurs both as thick (>200 microns) bands and very thin bands in the vitrinite.

Calcite and Gypsum occur as fracture and cleat fillings. Size of these fillings is from several microns to several hunderd microns (up to the 840 micron size to which the coal was crushed).

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 4.51%

Pyrite easily separated from the coal.
Massive primary and fracture filling pyrite = 17%
Size consist of this pyrite is 20 to >200 microns.

Pyrite not easily separated from the coal.
Massive dendritic, patches, framboids and isolated crystals intimately associated with the coal = 83%

Ground to -20 mesh only 35% of the pyrite grains are broken free of the coal or exposed at the edge of the grains.

This coal is high in pyrite. Almost all of the pyrite is intimately mixed with the coal or clay. Clay bands contain 27% of the pyrite. Cleaning this coal to remove large percentages of the pyrite would be very difficult, and this will be further inhibited by the "dirty" nature of the vitrinite.

SAMPLE STS-1.60 Float

MACERAL ANALYSIS

Vitrinite	89.3%	Vitrinite suite	89.3%
Sporinite	2.0%		
Cutinite	3.6%	Exinite suite	5.6%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.2%	Inertinite suite	0.3%
Micrinite	0.0%		
Sclerotinite	0.1%		
Pyrite	1.9%		
Clay	3.2%		
Quartz	0.0%	Mineral Matter	5.3%
Calcite	0.1%		
Gypsum	0.1%		
Hematite	0.0%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, and contains many mineral and maceral inclusions.

Inertinite content is extremely low.

Mineral matter is predominantly clay which is intimately mixed with the vitrinite.

Calcite and gypsum occur as minute fracture fillings in vitrinite.

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 1.52%

Pyrite easily separated from the coal.

Massive fracture filling pyrite = 0%

Pyrite not easily separated from the coal.

Patches, framboids, and isolated crystals, plus massive dendritic pyrite intimately mixed with the coal = 100%

Ground to -20 mesh, only 17% of the pyrite grains were broken free of the coal, or exposed at the edge of the grains.

This coal is still high in pyrite, and the pyrite remaining is all very intimately mixed with the coal. Massive dendritic pyrite accounts for 33% of the pyrite, and this type of pyrite is usually very intermixed with the cleaner portions of the vitrinite. Three percent of the pyrite is in the remaining clay.

SAMPLE SMS-1

MACERAL ANALYSIS

Vitrinite	68.5%	Vitrinite suite	68.5%
Sporinite	1.2%		
Cutinite	3.1%	Exinite suite	4.3%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.0%	Inertinite suite	0.0%
Micrinite	0.0%		
Pyrite	3.0%		
Clay	20.1%		
Quartz	0.0%	Mineral Matter	27.3%
Calcite	0.3%		
Gypsum	3.8%		
Hematite	0.1%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, and contains many mineral and maceral inclusions.

No inertinite is in this sample.

Mineral matter is mainly clay which occurs as thick (>200 microns) bands, and very thin bands within the vitrinite.

Calcite and gypsum occur as fracture and cleat fillings of less than 0.1 micron thickness to greater than 200 microns. Gypsum also frequently occurs as pods of primary gypsum which formed along with the coal, as such is intimately mixed with the coal.

PRYITE FORMS ANALYSIS

Total percent pyrite (% volume) = 3.22%

Pyrite easily separated from the coal.

Massive grains of pyrite = 4%

Pyrite not easily separated from the coal.

Massive dendritic, patches, framboids, and isolated crystals intimately mixed with the coal = 96%

Ground to -20 mesh, only 10% of the pyrite grains are broken free of the coal, or exposed at the edge of the grains.

This coal is high in pyrite, but very nearly all of this pyrite is very intimately mixed with the coal. Only 11% of the pyrite is in clay bands, and may be removed with them upon cleaning. The rest of the pyrite would be very very difficult to clean from the coal.

SAMPLE SMS-2

MACERAL ANALYSIS

Vitrinite	56.6%	Vitrinite suite	56.6%
Sporinite	0.9%		
Cutinite	2.4%	Exinite suite	3.3%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.0%	Inertinite suite	0.0%
Micrinite	0.0%		
Pyrite	5.4%		
Clay	30.5%		
Quartz	0.0%	Mineral Matter	40.1%
Calcite	0.3%		
Gypsum	3.9%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, and contains many mineral and maceral inclusions.

No inertinite is present in this sample.

Mineral matter is mainly clay, which occurs as thick (>200 micron) bands, and as very thin bands within the vitrinite.

Calcite and gypsum occur as fracture and cleat fillings, but most of the gypsum is present in the form of primary lenses deposited with the coal, and as a result are intimately mixed with the coal. These lenses vary from 10 to greater then 500 microns in length.

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 4.14%

Pyrite easily separated from the coal.
Massive grains = 2%

Pyrite not easily separated from the coal.
Massive dendritic, patches, framboids, and isolated crystals intimately mixed with the coal = 98%

Ground to -20 mesh, only 29% of the pyrite grains are broken free of the coal, or exposed at the edge of the grains.

This coal is high in pyrite, but very nearly all of this pyrite is very intimately mixed with the coal. Clay bands and gypsum pods contain 35% of the pyrite, and this pyrite may be removed by cleaning.

SAMPLE SMS-3

MACERAL ANALYSIS

Vitrinite	63.5%	Vitrinite suite	63.5%
Sporinite	0.2%		
Cutinite	2.4%	Exinite suite	2.6%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.0%	Inertinite suite	0.0%
Micrinite	0.0%		
Pyrite	6.2%		
Clay	24.1%		
Quartz	0.0%	Mineral Matter	33.8%
Calcite	1.3%		
Gypsum	2.2%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, and contains many mineral and maceral inclusions.

No inertinite is present in this sample.

Mineral matter is mainly clay, which occurs as thick (>200 micron) bands, and as very thin bands within the vitrinite.

Calcite and gypsum occur as fracture and cleat fillings, but most of the gypsum occurs as primary lenses within the coal 10 to greater than 500 microns in size. This gypsum is intimately mixed with the coal.

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 6.50%

Pyrite easily separated from the coal.
Massive grains = 0%

Pyrite not easily separated from the coal.
Patches and framboids = 100%

Ground to -20 mesh, only 16% of the pyrite grains are broken free of the coal, or exposed at the edge of the grains.

This coal is very high in pyrite, and this pyrite is all intimately mixed with the coal, and will be very very difficult to remove. Clay bands contain 22% of the pyrite, and this may be removed by cleaning processes.

SAMPLE SMS-4

MACERAL ANALYSIS

Vitrinite	49.4%	Vitrinite suite	49.4%
Sporinite	0.2%		
Cutinite	0.3%	Exinite suite	0.5%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.0%	Inertinite suite	0.0%
Micrinite	0.0%		
Pyrite	7.1%		
Clay	35.6%		
Quartz	0.0%	Mineral Matter	49.9%
Calcite	0.6%		
Gypsum	6.6%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, containing many mineral and maceral inclusions.

No inertinite is in this sample.

Mineral matter is mainly clay, which occurs as thick (>200 micron) bands, and as very thin bands in vitrinite.

Gypsum and calcite occur as fracture and cleat fillings, but most of the gypsum occurs as primary lenses within the coal.

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 5.33%

Pyrite easily separated from the coal.

Massive grains = 2%

Pyrite not easily separated from the coal.

Patches, framboids, isolated crystals, and massive dendritic pyrite intimately mixed with the coal = 98%

Ground to -20 mesh, only 22% of the pyrite grains are broken free of the coal, or exposed at the edge of the grain.

This coal is very high in pyrite, and almost all of the pyrite is intimately mixed with the coal, and will be very difficult to remove. Clay abd gypsum contain 23% of the pyrite, and this pyrite possibly could be removed by cleaning processes.

SAMPLE SMS-1.60 Float

MACERAL ANALYSIS

Vitrinite	84.7%	Vitrinite suite	84.7%
Sporinite	1.6%		
Cutinite	2.5%	Exinite suite	4.1%
Alginite	0.0%		
Resinite	0.0%		
Fusinite	0.0%		
Semifusinite	0.3%	Inertinite suite	0.3%
Micrinite	0.0%		
Pyrite	4.5%		
Clay	5.9%		
Quartz	0.0%	Mineral Matter	10.8%
Calcite	0.1%		
Gypsum	0.3%		

Vitrinite in this sample is of relatively low reflectance. The vitrinite is also impure, containing many mineral and maceral inclusions.

Inertinite is very low in this sample.

Mineral matter occurs mainly as clay in very thin bands in the vitrinite.

Gypsum and calcite are present as fracture and cleat fillings. Gypsum also occurs as pods of primary mineral in vitrinite.

PYRITE FORMS ANALYSIS

Total percent pyrite (% volume) = 2.00%

Pyrite easily separated from the coal.

None.

Pyrite not easily separated from the coal.

Massive dendritic, patches, framboids, and isolated crystals intimately mixed with the coal = 100%

Ground to -20 mesh, only 8% of the pyrite grains are broken free of the coal, or exposed at the edge of the grains.

This coal is still high in pyrite, and the pyrite remaining is very very intimately mixed with the coal. Only 3% of the pyrite is in clay or gypsum. The pyrite remaining in this coal represents the large portion that cannot be easily removed from this coal by standard cleaning processes.

Point Count

Point count maceral approximation, as explained by Chayes, 1949, consists of examining the entire microblock with a specific grid spacing (1 X 1mm. in this report). The cross hairs of the microscope are the intersections of the grid, and the microscope stage is advanced by steps to produce the grid. The maceral or mineral falling under the crosshairs at each step is identified and counted. The entire microblock is traversed in this manner, and the points tabulated. If, for example, 1000 points were examined, and 743 fell on vitrinite, the approximation of the vitrinite content of the microblock would be 74.3%. The accuracy of the approximation can be increased by counting more points.

Table 1. PHI (ϕ), millimeter, and mesh size equivalents. Used to convert from sieve size to ϕ units for plotting sieve fractions on probability paper.

ϕ	Diameter, mm	Equivalent U.S. Standard Mesh	Equivalent Tyler Mesh
-3.00	8.000	5/16 in.	2 1/2
-2.75	6.727	0.265 in.	3
-2.50	5.657	3 1/2	3 1/2
-2.25	4.757	4	4
-2.00	4.000	5	5
-1.75	3.364	6	6
-1.50	2.828	7	7
-1.25	2.378	8	8
-1.00	2.000	10	9
-0.75	1.682	12	10
-0.50	1.414	14	12
-0.25	1.189	16	14
0	1.000	18	16
0.25	0.841	20	20
0.50	0.707	25	24
0.75	0.595	30	28
1.00	0.500	35	32
1.25	0.420	40	35
1.50	0.354	45	42
1.75	0.297	50	48
2.00	0.250	60	60
2.25	0.210	70	65
2.50	0.177	80	80
2.75	0.149	100	100
3.00	0.125	120	115
3.25	0.105	140	150
3.50	0.088	170	170
3.75	0.074	200	200
4.00	0.062	230	250
4.25	0.053	270	270
4.50	0.044	325	325
4.75	0.037	400	400

Table 2. Petrographic analysis of Sharigatop seam random and cleaned samples.

	MACERAL/ MINERAL	STS-1	STS-2	STS-3	STS-4	AVERAGE	1.60 FLOAT
	Vitrinite	69.9%	53.4%	64.3%	77.5%	66.3%	89.3%
Car	Sporinite	0.8	0.9	1.6	2.0	1.3	2.0
	Cutinite	0.8	0.8	1.6	0.9	1.0	3.6
	Alginite	0.0	0.0	0.0	0.0	0.0	0.0
	Resinite	0.0	0.0	0.0	0.0	0.0	0.0
Inertinite	Fusinite	0.2	0.1	0.1	0.3	0.2	0.0
	Semifusinite	0.5	0.3	0.2	0.1	0.3	0.2
	Micrinite	0.0	0.0	0.1	0.3	0.1	0.0
	Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.1
Mineral	Pyrite	4.6	9.9	5.0	2.6	5.5	1.9
	Clay	22.2	30.7	25.7	15.4	23.5	3.2
	Calcite	0.5	1.3	0.4	0.5	0.7	0.1
	Gypsum	0.5	2.4	1.1	0.5	1.1	0.1
	Hematite	0.0	0.2	0.0	0.0	0.0	0.0

Table 3. Petrographic analysis of the Sharighmiddle seam random and cleaned samples.

MACERAL/ MINERAL	SMS-1	SMS-2	SMS-3	SMS-4	AVERAGE	1.60 FLOAT
Vitrinite	68.5%	56.6%	63.5%	49.4%	59.5%	84.7%
Sporinite	1.2	0.9	0.2	0.2	0.6	1.6
Cutinite	3.1	2.4	2.4	0.3	2.0	2.5
Alginite	0.0	0.0	0.0	0.0	0.0	0.0
Resinite	0.0	0.0	0.0	0.0	0.0	0.0
Fusinite	0.0	0.0	0.0	0.0	0.0	0.0
Semifusinite	0.0	0.0	0.0	0.0	0.0	0.3
Micrinite	0.0	0.0	0.0	0.0	0.0	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0
Pyrite	3.0	5.4	6.2	7.1	5.4	4.5
Clay	20.1	30.5	24.1	35.6	27.6	5.9
Calcite	0.3	0.3	1.3	0.6	0.6	0.1
Gypsum	3.8	3.8	2.2	6.6	4.1	0.3
Hematite	0.1	0.0	0.0	0.0	0.0	0.0

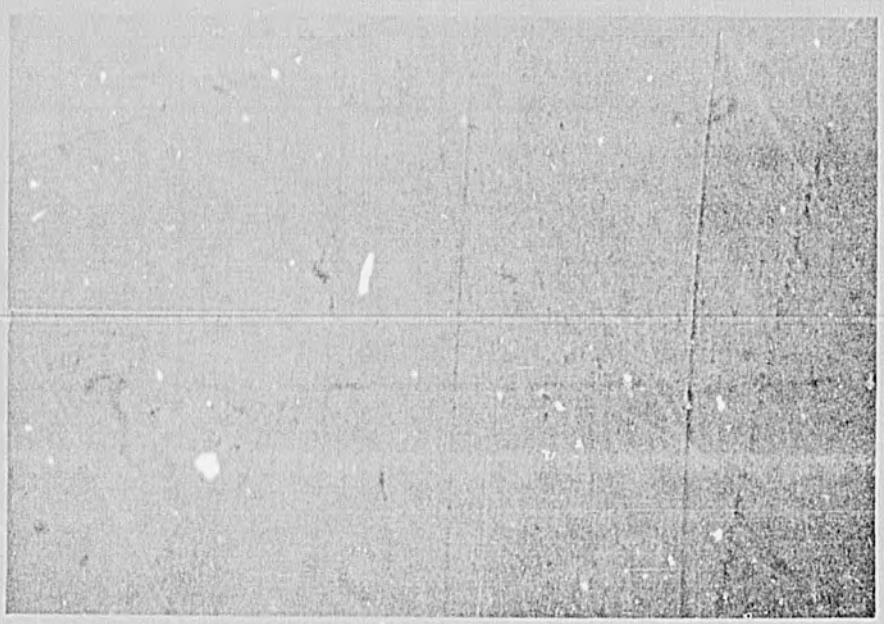


Figure 1. Nearly pure vitrinite in the Sharigh top seam. This type of occurrence was very rare.

Figure 2. Vitrinite in the Sharigh top seam. The vitrinite (V) is commonly interspersed with cutinite (C) and pyrite (P). This type occurrence of vitrinite is common in the Sharigh top seam.

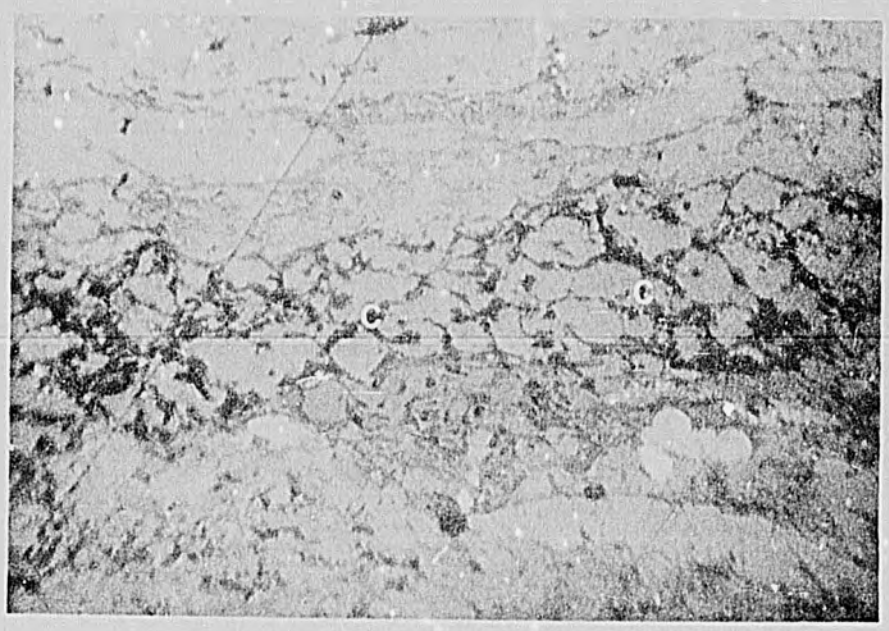


Figure 3. Vitrinite in the Sharigh top seam containing intimately mixed cutinite(C) in the form of very thin cell walls.

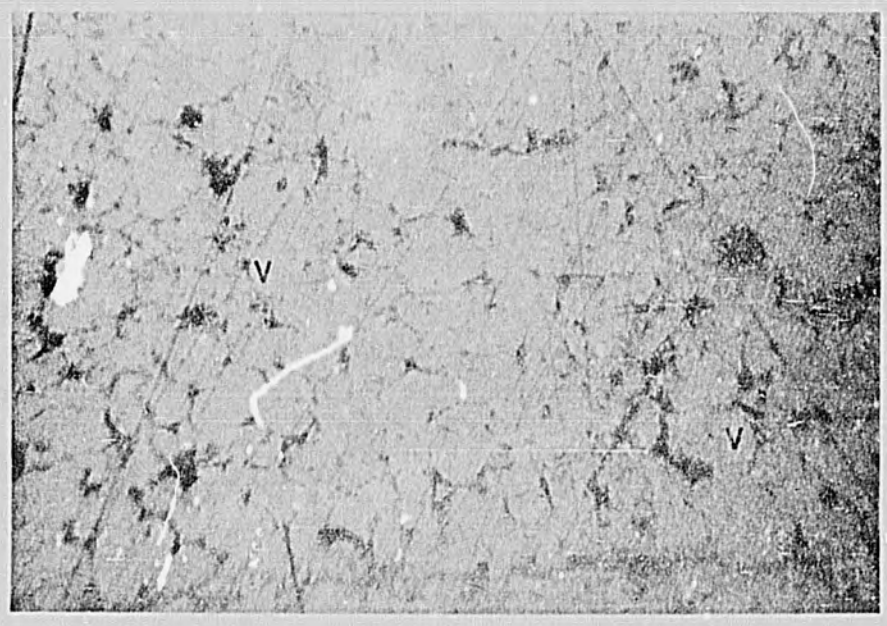


Figure 4. Vitrinite (V) containing cell walls composed of cutinite. Sharigh top seam.

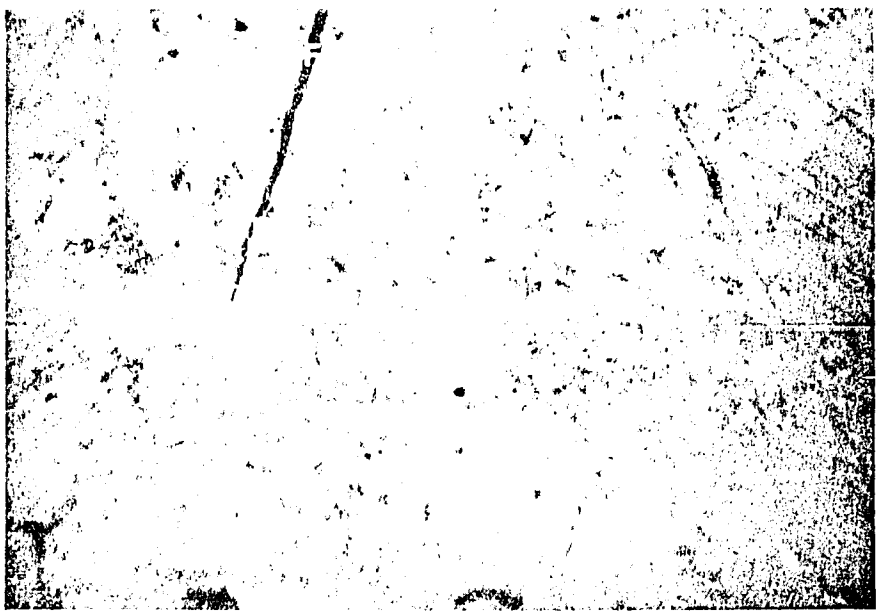


Figure 5. Vitrinite (V) in the Sharightop seam interspersed with extremely thin cutinite (C). The fracture (F) is fillied with calcite.

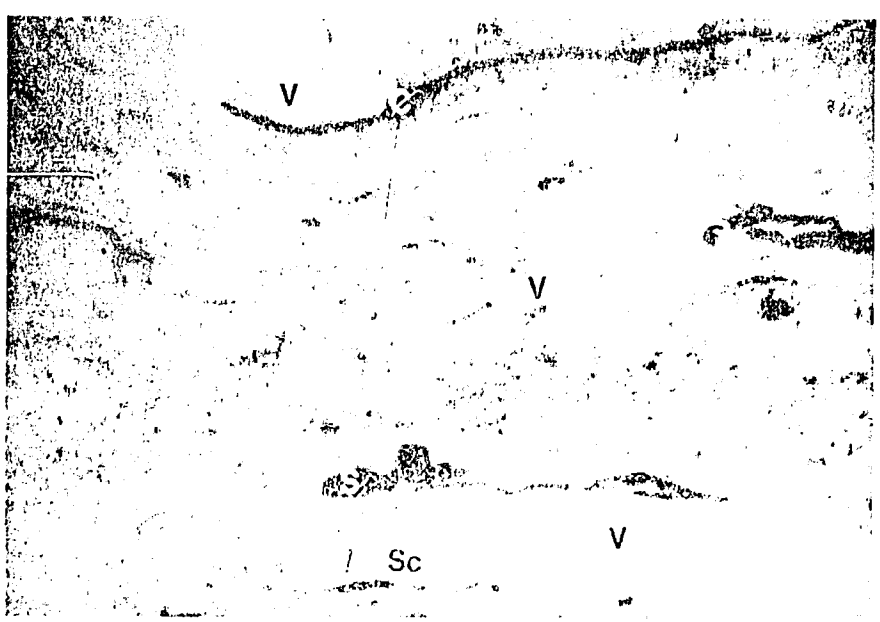


Figure 6. Sporinite in the Sharightop seam. Spor. S), cuticles (C), and sclerotia (Sc) are dispersed in vitrinite (V).

Figure 7. Sporinite (S) in granular vitrinite.

Figure 8. Cluster of spores (Sporinite, S) in vitrinite in the Sharigktop seam.

Figure 9. Sporangia (reproductive body containing many spores) (S) in the Sharightop seam.

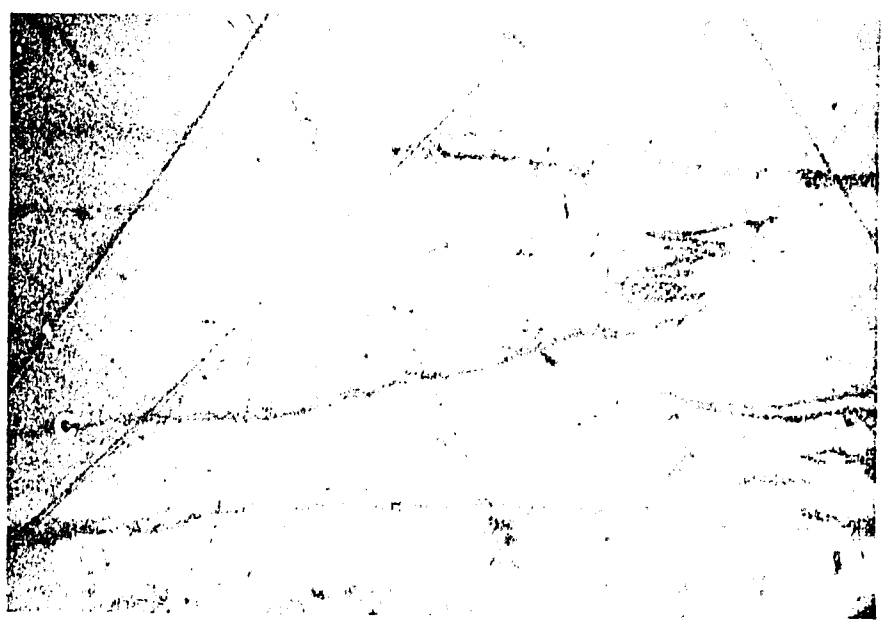


Figure 10. Long cuticles (C), cutinite, in nearly pure vitrinite in the Sharightop seam.

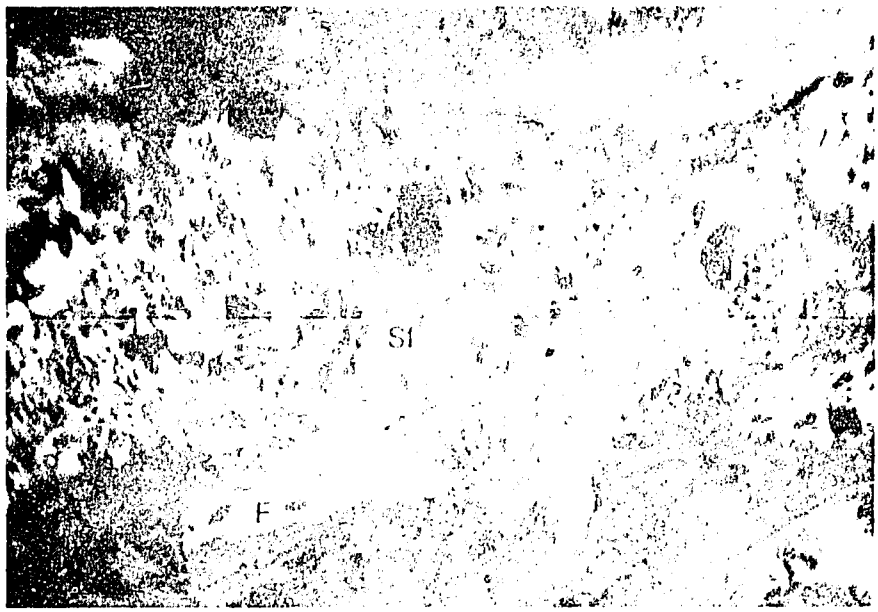


Figure 11. Semifusinite (Sf) and fusinite (F) in the Sharightop seam. These macerals are very rare in this seam.

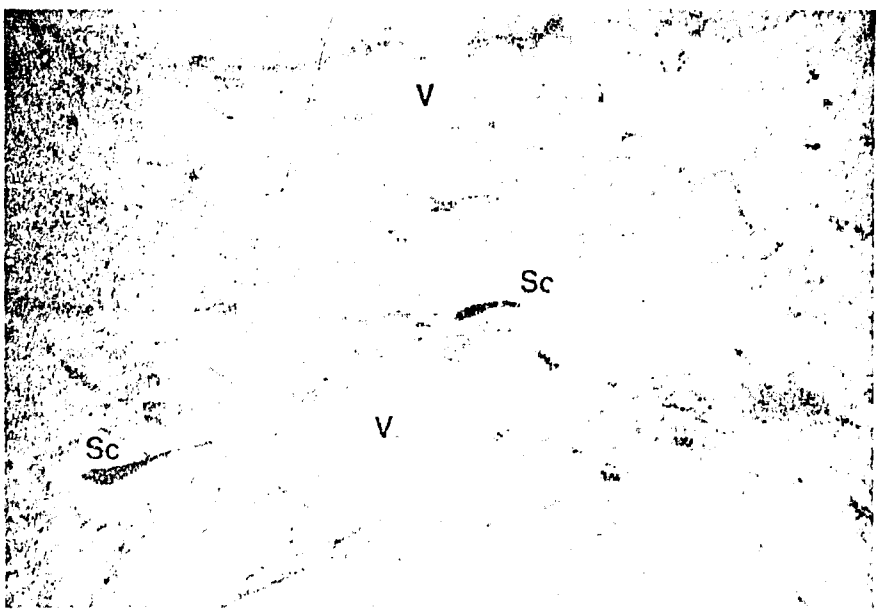


Figure 12. Two sclerotia (sclerotinite, Sc) in vitrinite (V) in the Sharightop seam. These macerals are also very rare in this coal, and represent the resting stages of fungi in the peat.

Figure 13. Clay in the Sharightop seam. This large fragment of clay, containing thin lenses of coaly material (V) and pyrite (P), probably is from a larger parting in the coal. This type of clay is easily removed by cleaning in a gravity medium.

Figure 14. Another large fragment of clay in the Sharightop seam containing both golden (g) and brown (b) clay.

Figure 15. A 30 micron thick band of nearly pure clay in vitrinite (V).

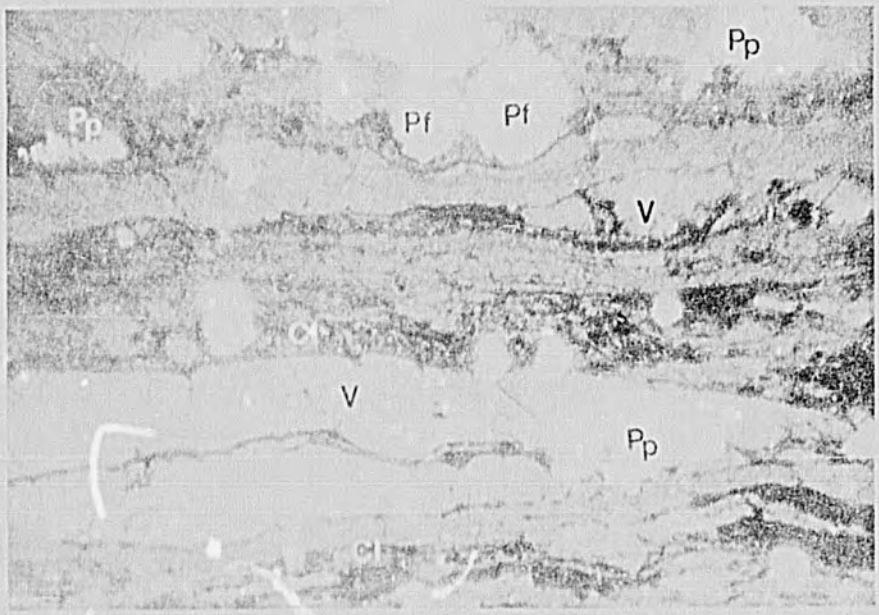


Figure 16. Very thin bands of clay (Cl) in vitrinite. Also in the vitrinite (V) is framboidal pyrite (Pf) and pyrite patches (Pp). Sharightop seam.

Figure 17. A large, greater than 500 micron, grain of pyrite (P) in Sharightop seam random sample STS-2.

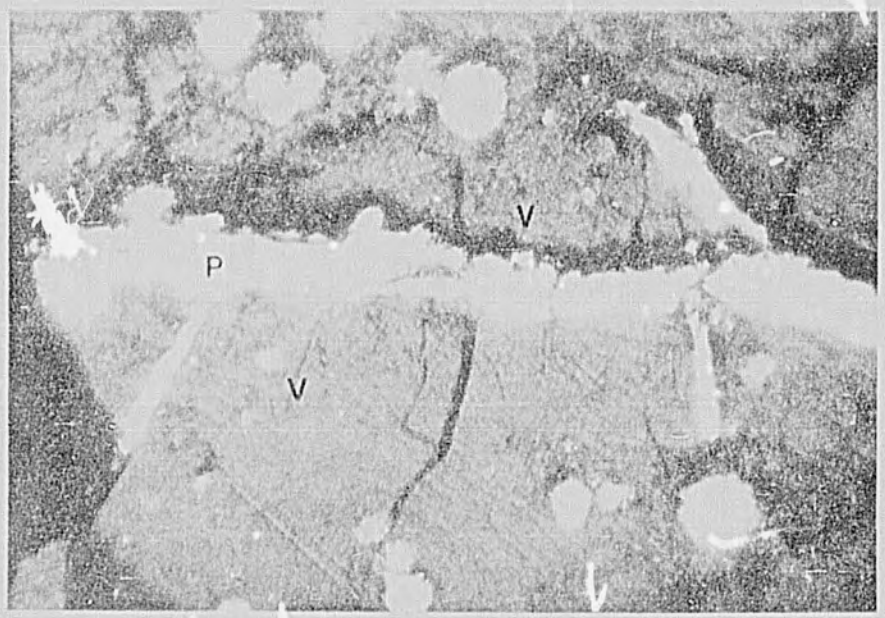


Figure 18. Massive fracture filling pyrite (P) in vitrinite in the Sharightop seam. Framboidal pyrite is also dispersed through the vitrinite (V).

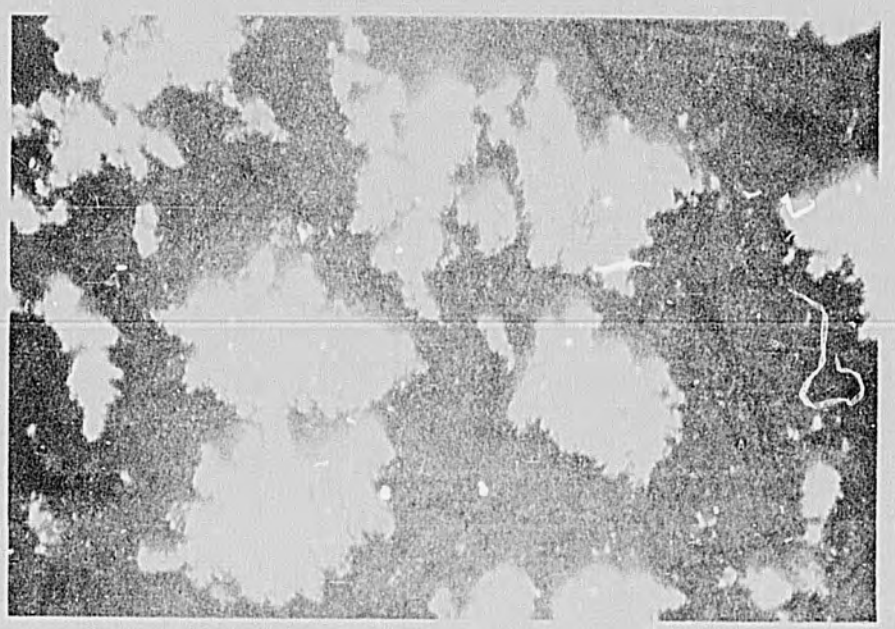


Figure 19. Massive dendritic pyrite in vitrinite in STS-1. This type of pyrite formed 25% of the pyrite in this random sample.

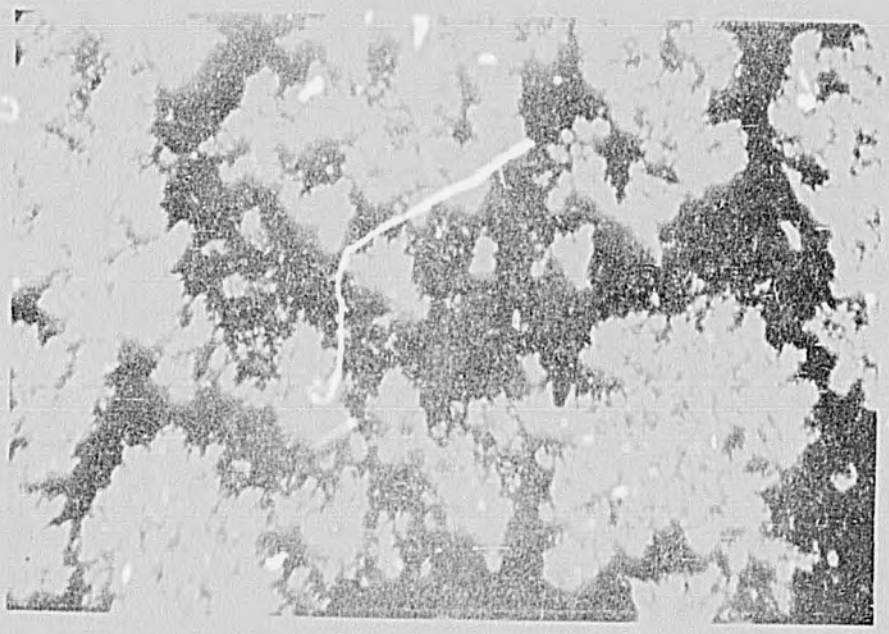


Figure 20. Aggregates of dendritic pyrite in the Shartghtop seam. These aggregates are in vitrinite.

Figure 21. Patches of discrete 0.5 micron crystals in vitrinite in the Sharightop seam. The patches are lenticular with maximum dimensions of 2 to 10 microns parallel to bedding.

Figure 22. A large, 40 micron, patch containing framboids (f). The patch is parallel to bedding in vitrinite. Sharightop seam.

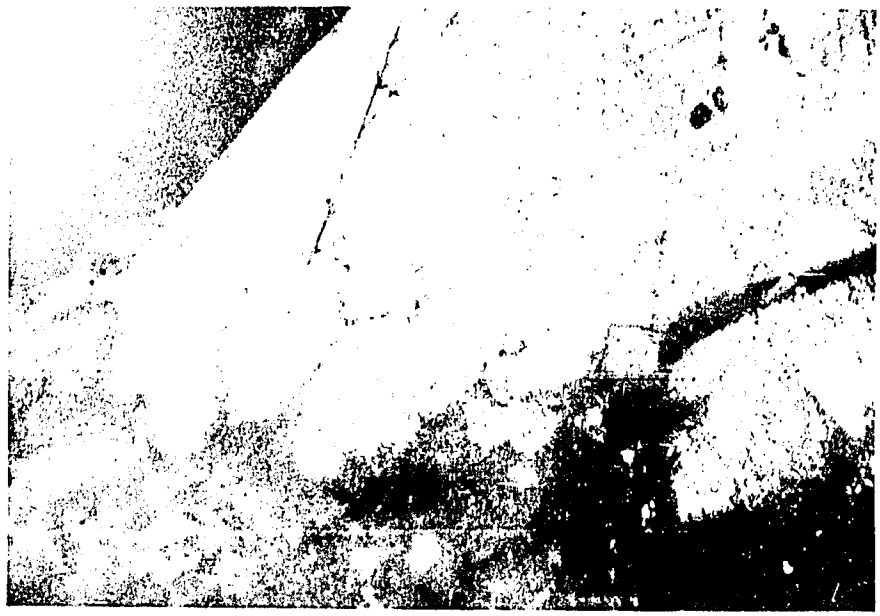


Figure 23. Patches of primary pyrite which selectively formed in vitrinite within cells, and did not form in the cell walls. Sharightop seam.

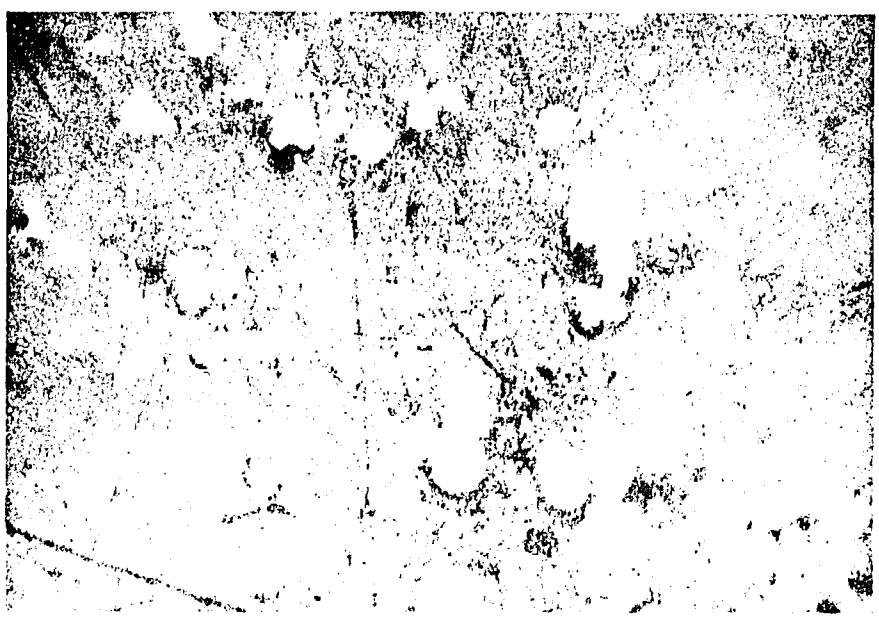


Figure 24. Individual framboids scattered in vitrinite in the Sharightop seam.

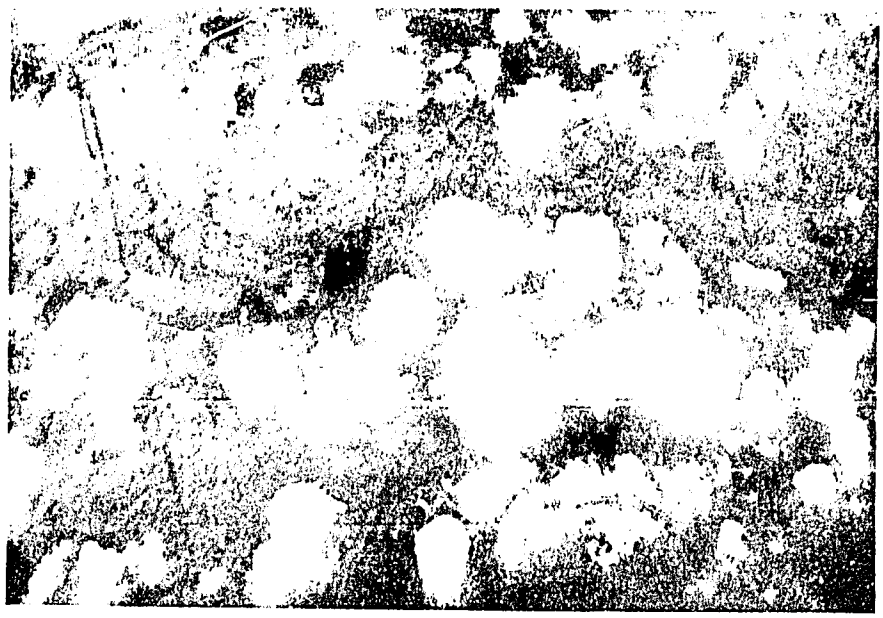


Figure 25. A large, 60 micron, cluster of framboids in vitrinite in the Sharightop seam.

Figure 26. Calcite (C) fracture fillings in vitrinite in the Sharightop seam. The fractures filled by calcite are typically thin, less than 10 microns.

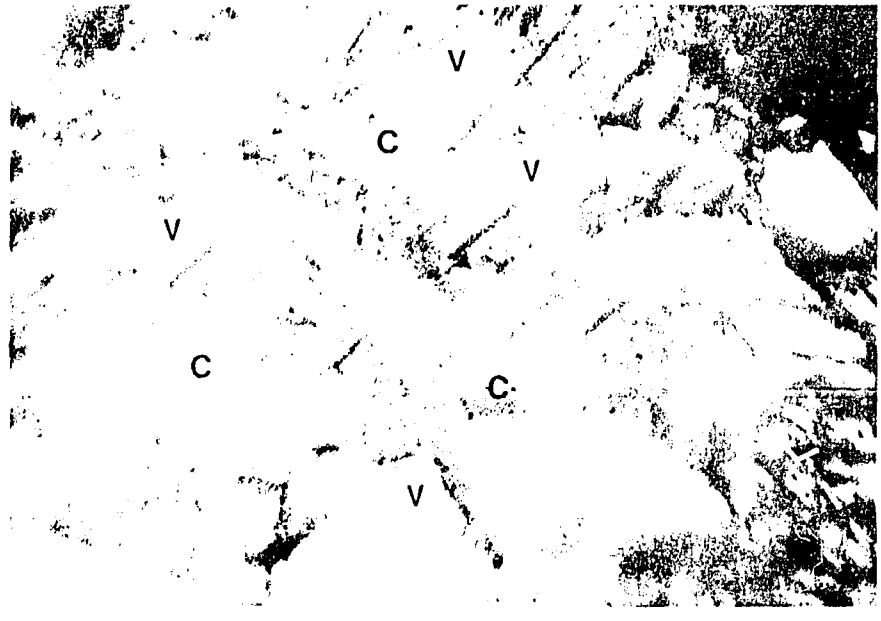


Figure 27. Calcite containing fragmented vitrinite (V). In the Sharig top seam. Calcite (C).

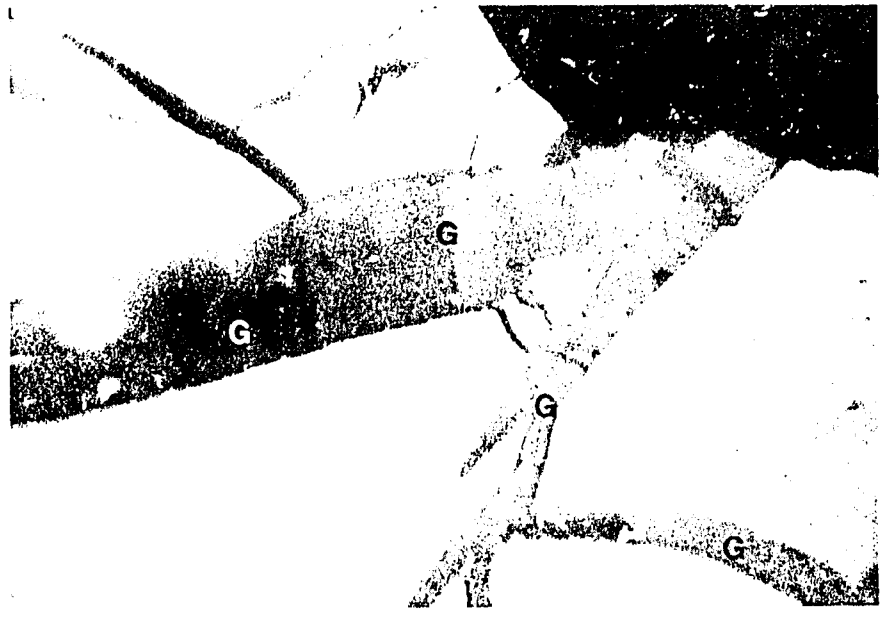


Figure 28. Fracture filling gypsum (G) in vitrinite in Sharigh top seam.

Figure 29. Fracture filling gypsum (G), in vitrinite in the Sharigh top seam. Zonations indicate the gypsum grew from the edges of the fracture toward the interior.

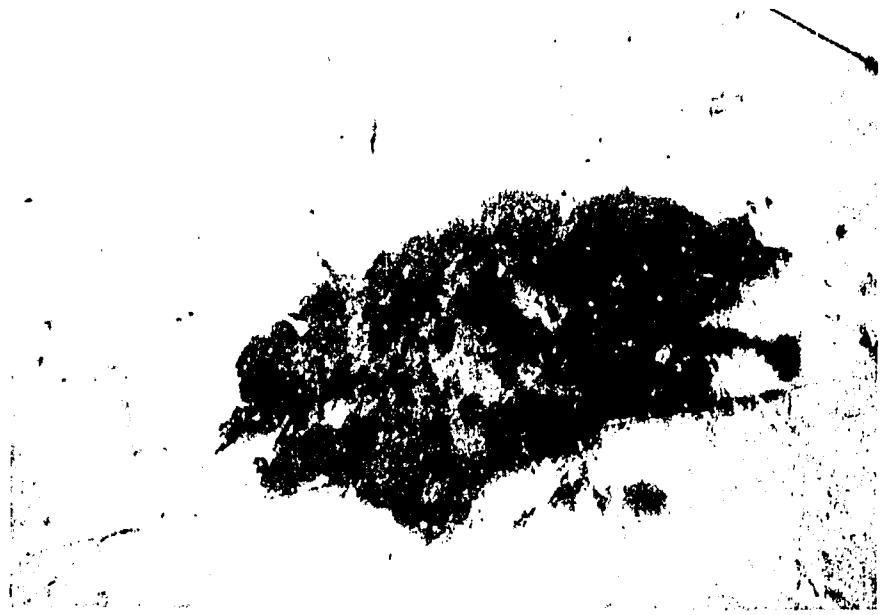


Figure 30. A 50 micron pod of primary gypsum in vitrinite in the Sharigh top seam. This type of gypsum formed as the coal was deposited, and is intimately mixed within the coal.

Figure 31. Pods of primary gypsum in vitrinite in the Sharigh top seam. Gypsum (G) of this type is very difficult to remove by gravity separation.

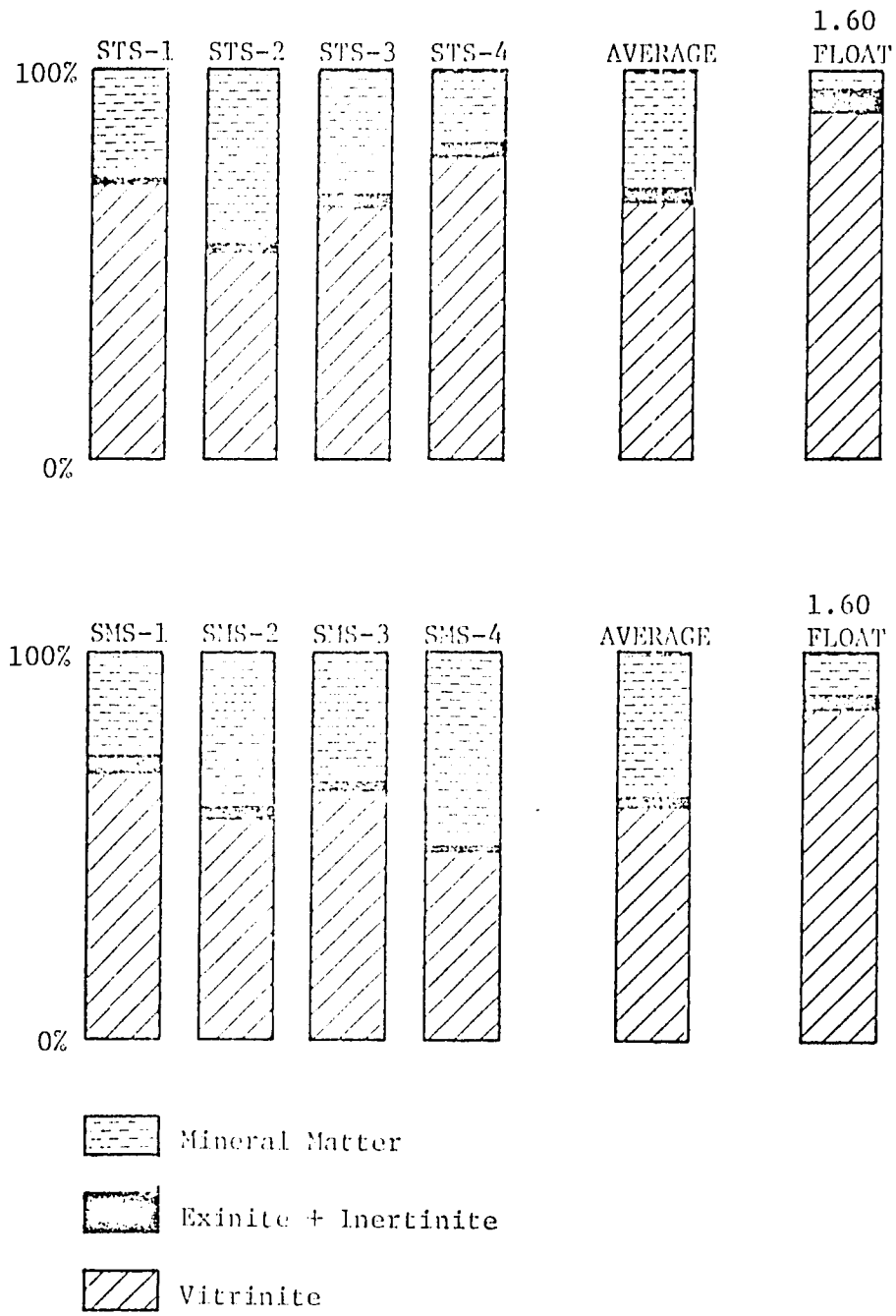


Figure 32. Variations in petrographic composition of the Sharigh coals. Samples STS-1 thru STS-4, and SMS-1 thru SMS-4 were random samples. The average composition is the average of the four random samples, and the 1.60 float sample was cleaned in 1.60 specific gravity solution prior to examination.

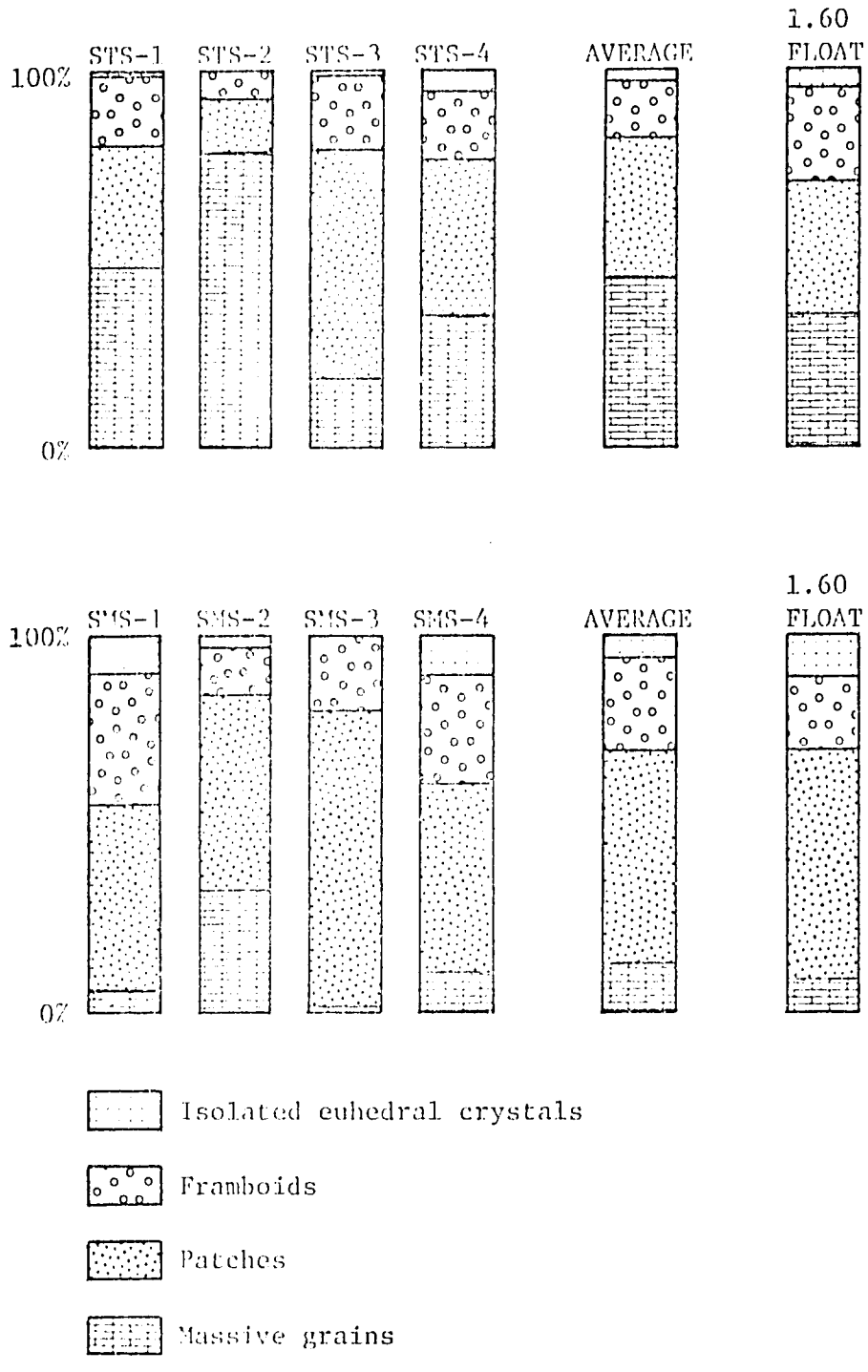
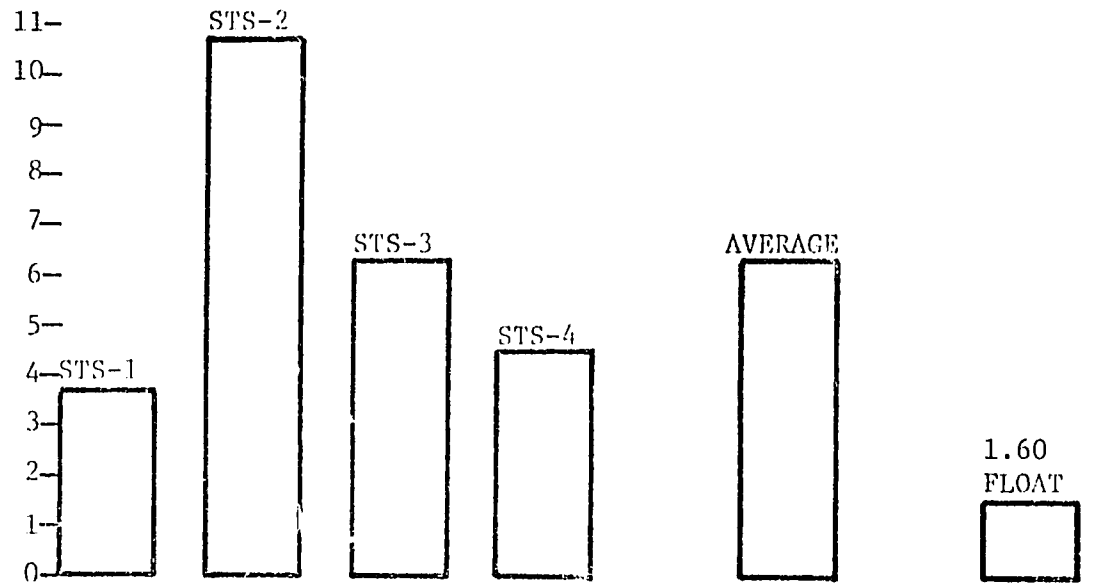


Figure 33. Variations in pyrite types in the Sharigh coals. Samples STS-1 thru STS-4 and SMS-1 thru SMS-4 were random samples. Variation in the Sharigh top seam is greater than the variation in the middle seam.



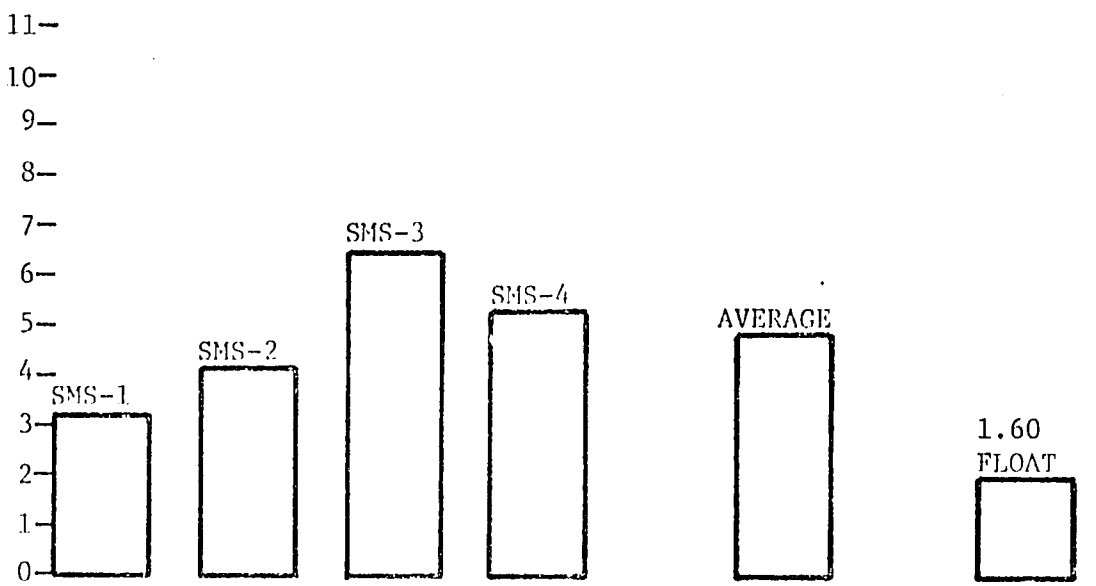


Figure 34. Variations in pyrite content of the Sharigh coals. Samples STS-1 thru STS-4, and SMS-1 thru SMS-4 were random samples. The pyrite content was determined by point count method. The largest variations are exhibited by the Sharightop seam.

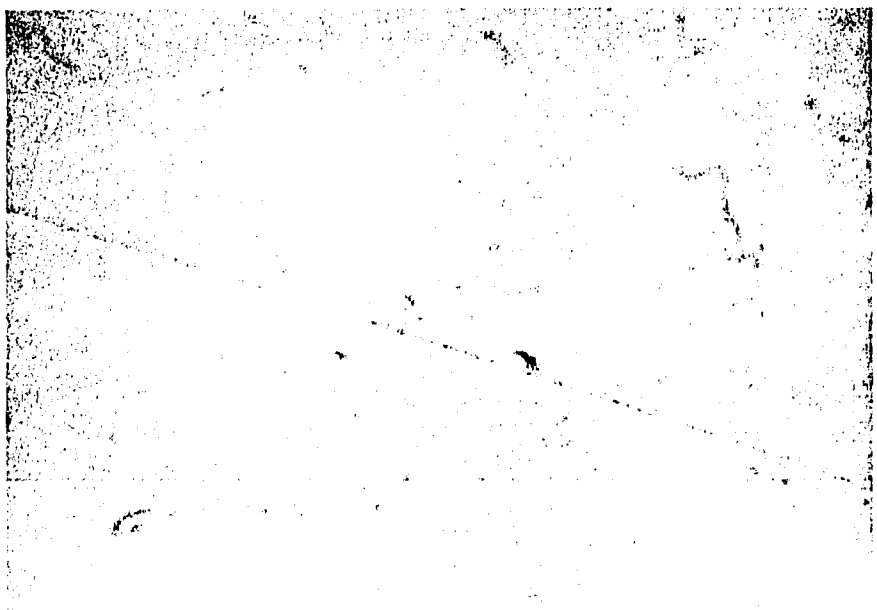


Figure 35. Very pure vitrinite, containing very small clay grains in the Sharigh middle seam. This type of vitrinite is rare in this seam.

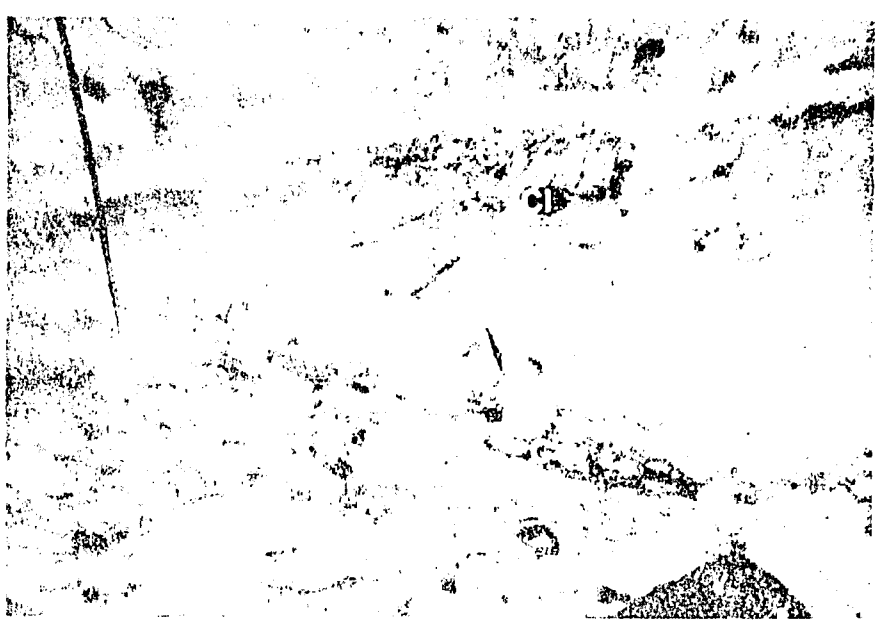


Figure 36. A more common vitrinite type for the Sharigh middle seam. This vitrinite (V) contains many thin cuticles (C) and layers of clay (Cl).

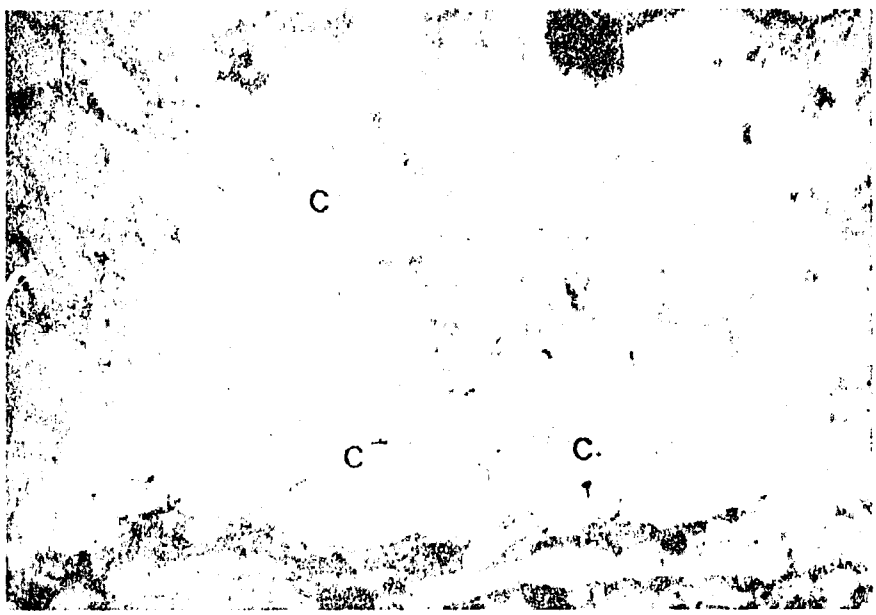


Figure 37. Vitrinite in the Sharigh middle seam containing very thin and discontinuous cutinite cell walls (C).

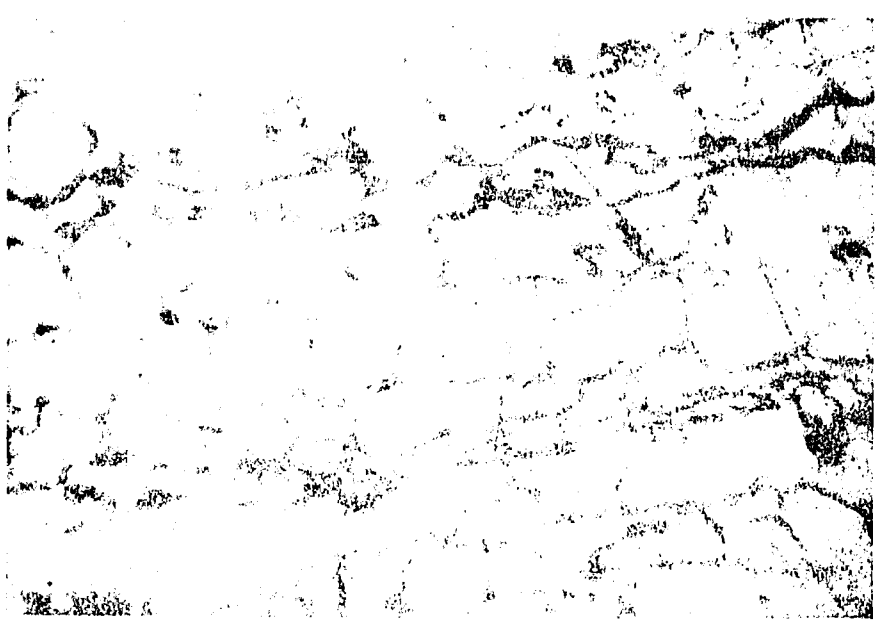


Figure 38. Vitrinite containing thicker cutinite cell walls and layers of scattered 0.5 micron pyrite crystals.

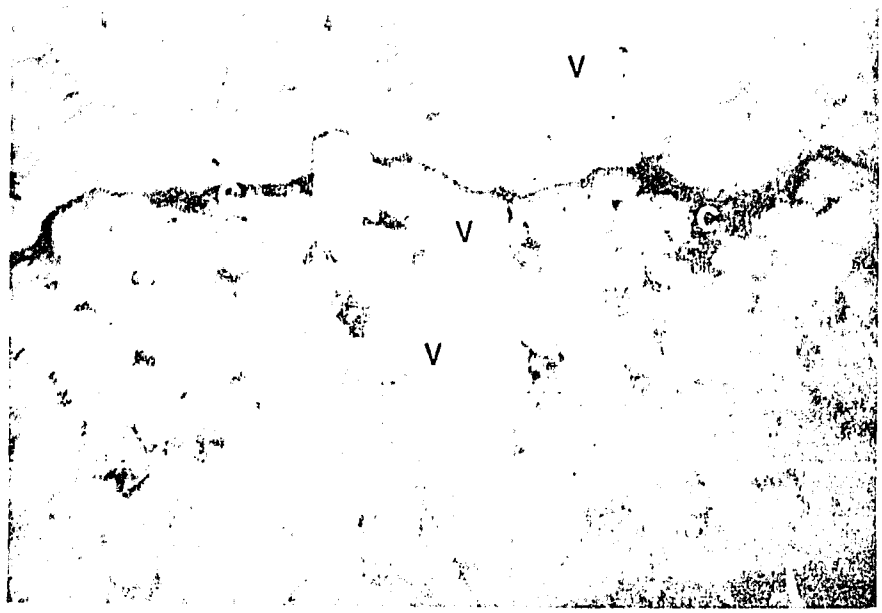


Figure 39. Cutinite (C) in vitrinite (V) in the Sharyh middle seam.

Figure 40. A very large cuticle (C) in the Sharyh middle seam. This type of cutinite is very rare in the Sharyh top seam, but slightly more common in the Sharyh middle seam. Large masses of exinite, such as this, could be the reason the SMS coke has larger and more fragile pores.

Figure 41. Spores, such as this one (S), are very rare in the Sharighmiddle seam. Here the spore is isolated in vitrinite, as is the pyrite framboid (P).

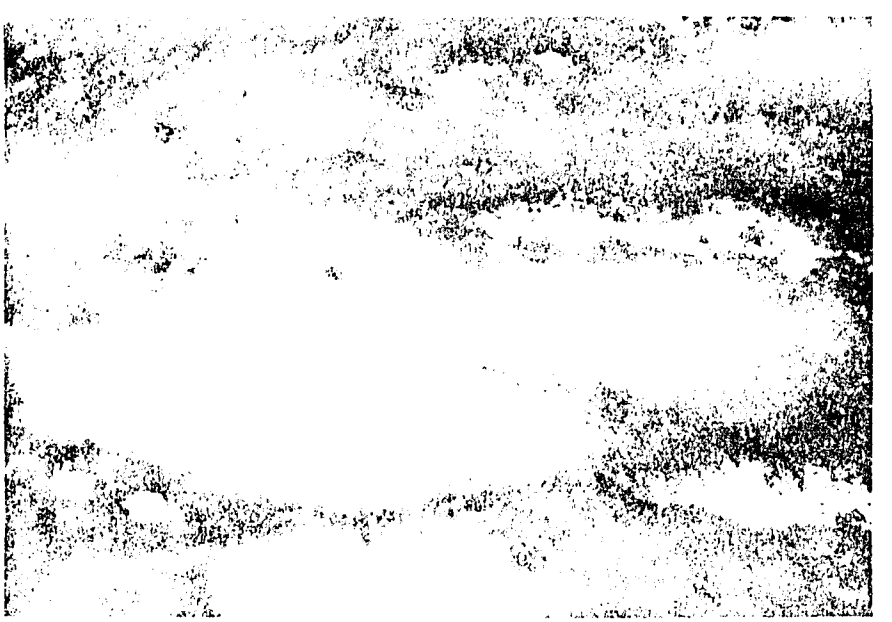


Figure 42. A large clay grain in the Sharighmiddle seam. The clay in this seam, like that of the top seam, is predominantly in partings which can be separated from the coal by cleaning.

Figure 43. Massive dendritic pyrite in vitrinite. This type of pyrite was half of the massive pyrite in all random samples of the SMS coal. This pyrite type is intimately mixed with the coal, and is difficult to remove.

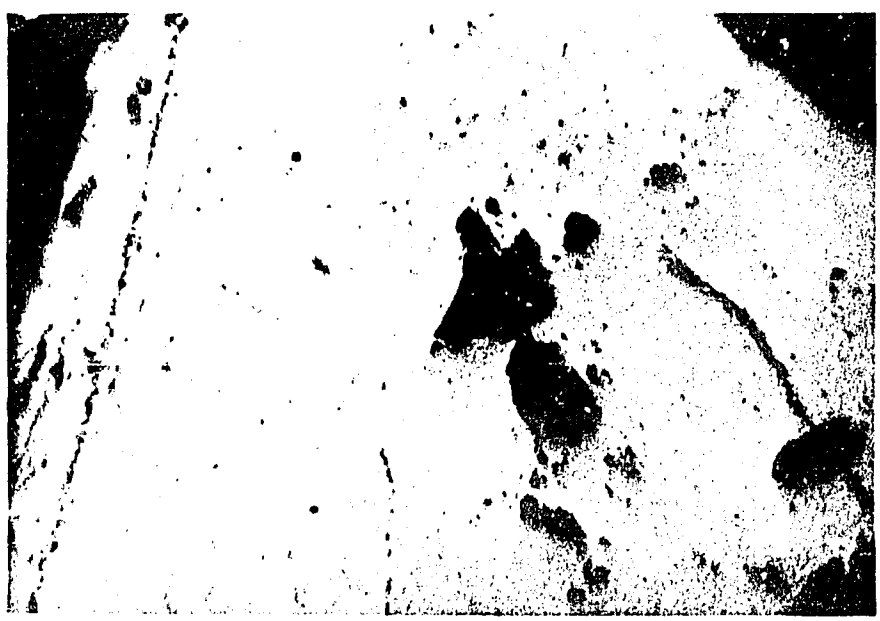


Figure 44. A large massive grain of pyrite in the Sharighmiddle seam.

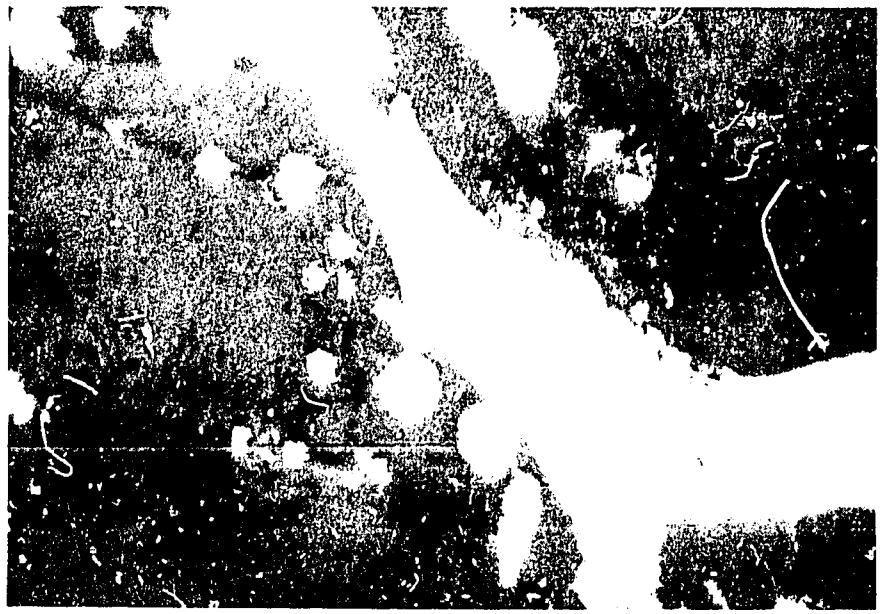


Figure 45. Massive fracture filling pyrite in the Sharigh middle seam.

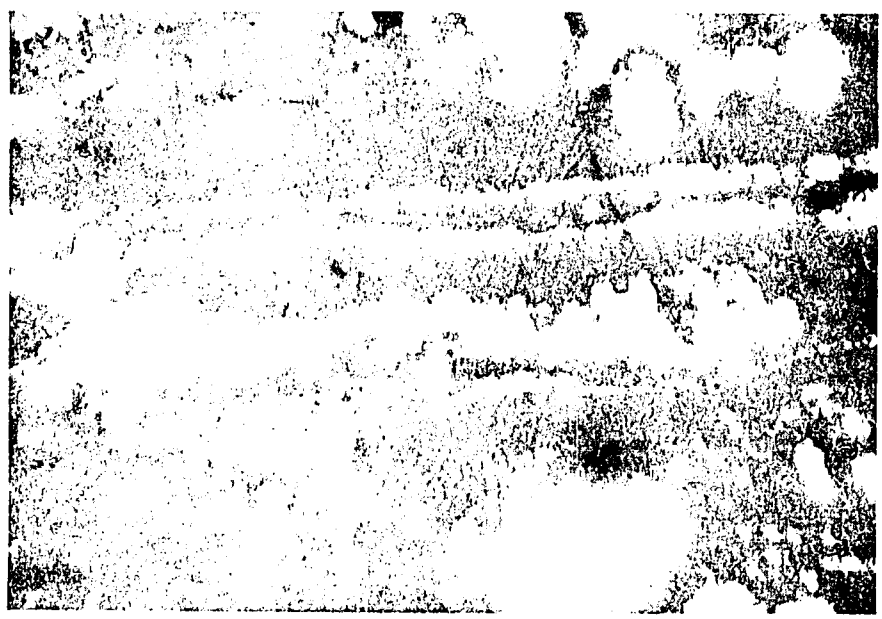


Figure 46. Various forms of patches of discrete crystals in the Sharigh middle seam. This type of pyrite is extremely difficult to remove by conventional coal cleaning processes.

Figure 47. Small crystals of pyrite which replaced cell walls in vitrinite in the Sharigh middle seam.

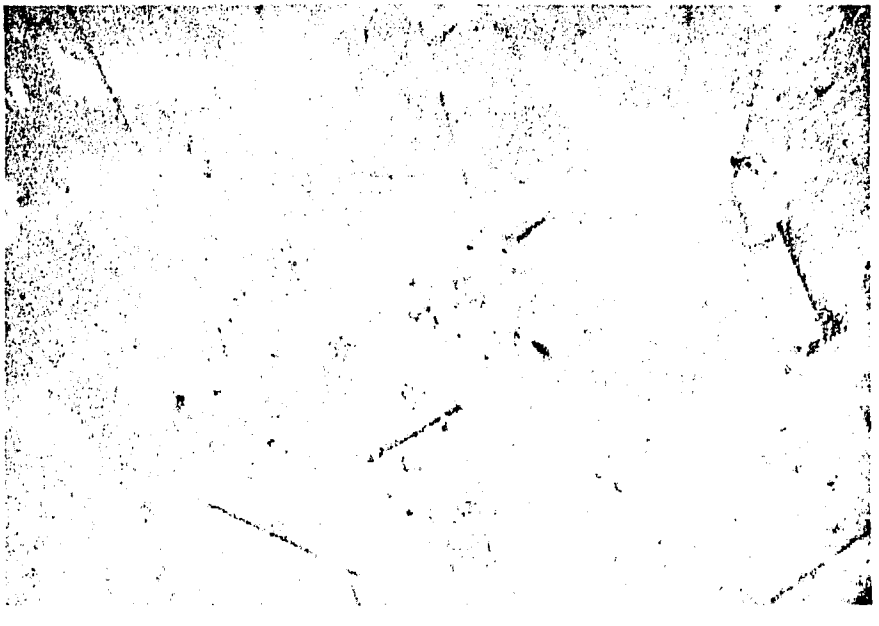


Figure 48. Patches of discrete crystals that replaced cell walls in the Sharigh middle seam. This type of pyrite is also very difficult to remove from the coal.

Figure 49. Isolated euhedral crystals scattered in vitrinite in the Sharighmiddle seam. This pyrite type represents 0% to 11% of the pyrite in the random samples, this pyrite is the most difficult to remove.

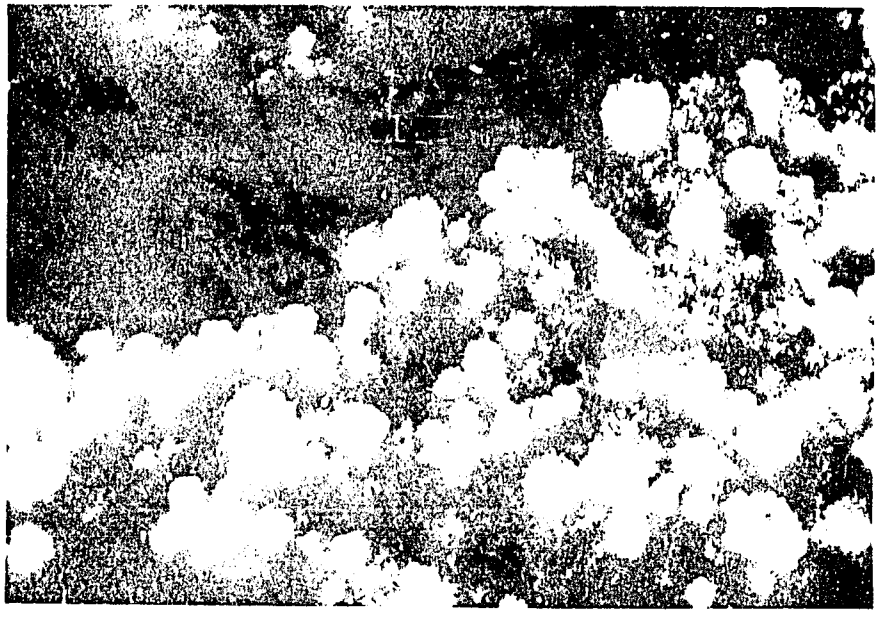


Figure 50. Framboids in the Sharighmiddle seam. This pyrite type is the second most common in this seam.

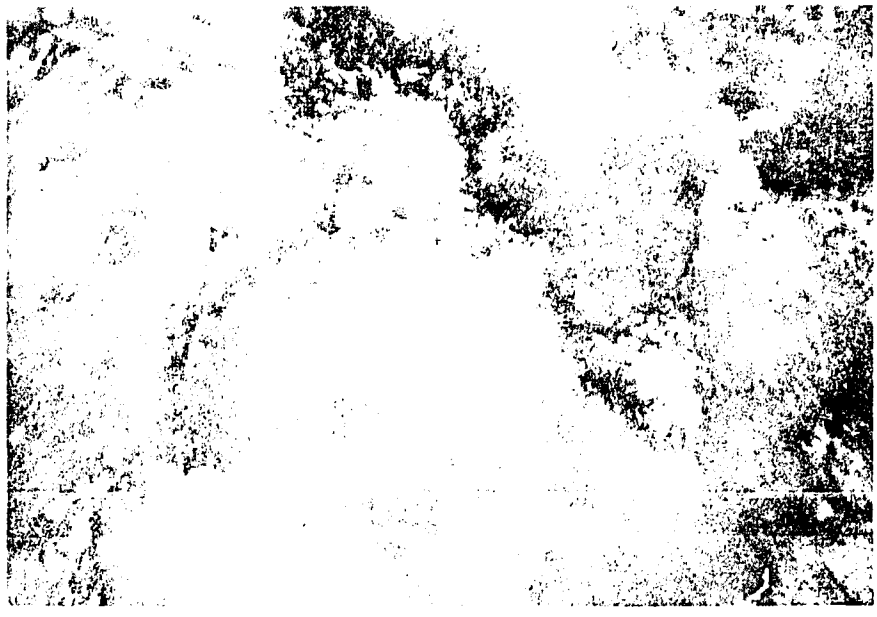


Figure 51. A portion of a very large pod of primary gypsum in the Sharighmiddle seam. This type of gypsum is generally difficult to remove, however, if pods are large enough they may break free of the coal and be cleaned from the coal.

PHYSICAL TESTING

A testing program was implemented to determine the physical properties of the Sharigh and Lakhra coals. The areas of testing involved random sampling, crushing, screening, and magnetic separation.

Random sampling - In the evaluation of any coal reserve, a knowledge of the variability of each seam within that reserve is very important. For example, if a seam has a high variability, one section of a mine may produce a coal significantly different in coking properties from another section. In this case the coal from the section with the better coking properties could be kept apart from the rest of the mine's production and either sold separately or used in blending with that portion of the mine's production used in coking. Also, a knowledge of the variability of a seam will allow the anticipation of changes in the average characteristics of the coal produced as mining progresses.

The ideal procedure for determining variaiblity is to sample the entire property by core drilling along a grid pattern, spaced closely enough to allow a complete statistical analysis. Steeply dipping seams, of course, pose special drilling problems. However, any samples collected by drilling are helpful or, if a drilling program is not practical, samples collected from each working section of the mine. In cases in which none of the above pro-

cedures can be applied (i.e., only a single, composite sample of the seam is available), the technique of random sampling has application.

Random sampling is used here in an attempt to determine the geologic coal preparation potential of the Sharigh coals. Four samples were taken from the STS and DMS containers in such a manner as to infer the variability of each seam. For a detailed discussion of the sampling technique, see the section titled "Methods, Procedures and Equipment". Briefly, one grab sample was taken from each of four sites in the container, without mixing the coal either before or during sampling. Each sample was tested for giesler plasticity (Table 10, page 5-52).

Some variation in coking properties was found for both coals, especially the STS sample. This indicates that a possibility for exploiting the geological features of these seams in mining and preparation may exist. However, a complete delineation of these coal reserves, by the type of drilling program mentioned earlier, would be required before a complete evaluation could be made.

Screening - A screen analysis was made of the samples as shipped (Tables 7, 8 and 10, pages 49, 50, 52) in order to determine if a useful separation could be made on the basis of size alone. All samples were wet screened to eliminate the problem of sticking or clumping.

These tests indicate that there is little opportunity for cleaning these coals by size alone. The most important parameters of ash and sulfur content, and coking properties are not sufficiently altered by simple screening. The finer sizes of the SMS coal did have somewhat better coking properties, but this was offset by the accompanying increase in sulfur.

A second test was devised in order to determine if grinding the coal before screening could effect a useful separation. The results of this test are summarized in Table 9, page 5-51. Three tests were performed on both HLM3 and STS 1.60 float samples. A portion of the sample was first analyzed (indicated as the plus mesh size in Table 9) and then ground by stages until approximately 80% passed either a 100, 200 or 325 mesh screen. Each test produces two samples, the plus mesh size or head sample and the minus mesh size.

The results of this test were very unusual in comparison to United States coals in that in every case the finer size fractions were higher in both ash and sulfur. It appears that both the ash and sulfur content of these coals are easily reduced in size (or liberated) by grinding and therefore both tend to report to the finer size fraction. Because size separations depend on a difference in friability to effect a separation, this type of process appears to have little application to these coals.

Friability properties are exploited for separation by systems in which some form of size reduction is applied to the coal, followed by a size separation. The effectiveness of size reduction equipment on coal components varies widely between minerals such as pyrite and coal macerals such as fusain. This method of separation is very cost-efficient in some instances and therefore this separation process was evaluated for possible application to Pakistan coals. Tests were performed by crushing and separating coal into a number of size fractions by screening. Each size fraction was analyzed to determine if a useful separation had been made.

Petrography can also provide information on mineral forms and occurrences which are important factors in coal separation. In this study particular attention was paid to pyrite forms analysis because pyrite removal appeared to offer the most likely means of sulfur reduction in the Sharigh coals.

The effectiveness and efficiency of any coal separation process will depend on the size of the dispersed ash or pyrites and the particle size of the ground coal. The ideal case arises when the coal particle is smaller than the dispersed impurity phase.

The pyrites and much of the ash is finely dispersed (about 0.5 micron). The power required to grind the mine run to this size is uneconomical. It is therefore anticipated that grinding to nominal sizes will only admit partial removal of ash and pyrites regardless of the process selected.

PHYSICAL TESTING AND PROCEDURES

A testing program was implemented to determine the physical properties of the Sharigand Lakra coals. The areas of testing included random sampling, crushing, screening, washability studies, magnetic separation, and pulverizing to fine sizes and blending after washability determinations.

Four random samples were taken from each of the four samples (Sharig Top Seam, Sharig Middle Seam, Lakra - Sample HHM3, Lakra - Sample WMI) to approximate random sampling throughout the coal seam. The samples were taken in the following manner: Two samples were removed from the round, steel container (approximately 12 inches diameter by 30 inches high) by a metal scoop, approximately four inches below the level of the coal (as it was shipped) and two inches from the perimeter and the remaining two samples were taken from the bottom in relatively the same area as the top two samples. The container was tilted to a 45° angle to facilitate the removal of the two bottom samples. The analyses of the sixteen samples can be found in the table titled Random Samples.

A portion of each of the four coal samples was removed by riffling to perform a screen test. These portions were crushes in a jaw crusher so that 100% would pass through a 3/8" screen, and screened through a Ty-lab Testor screening device so as to retain portions on the following screens: 3 Mesh, 14 Mesh, 28 Mesh, 48 Mesh, 100 Mesh, and a bottom pan to retain the -100 Mesh coa Each fraction was weighed, reduced by riffling and pulverized to -60 Mesh for analyical analysis. The conclusions of this testing program may be found in the tables under Screen Analyses.

The procedure for screen analysis was repeated to obtain samples for a washability program. Each of the four samples were subjected to 1.25, 1.30, 1.40, 1.50 and 1.60 specific gravity separations using perchlorethylene (1.60 specific gravity) and naptha (1.00 specific gravity) to obtain the

required gravities. Each fraction was then weighed, crushed and pulverized to analyical size and subjected to chemical analysis. The results of this program may be found under the corresponding coal, under the general heading of Washability Study.

Only the Sharigh Top Seam and Sharigh Middle Seam were subjected to a magnetic beneficiation procedure. This test was performed using the Frantz Isodynamic Magnetic Separator - illustrated in the accompanying schematic drawing. By virtue of past experience the forward inclination was set at 5 degrees below the horizontal and the lateral inclination at 10 degrees with the vertical plane. The attached vibrator was kept at a constant setting of 7 on a scale of 10. By periodically adjusting the current to 3.5 amps D.C. a magnetic force field of 10,700 gauss was maintained throughout the tests. Analyses of these tests can be found in the table entitled Magnetically Treated Samples.

A program of fine pulverization of Sharigh Top Seam and Lakha Coal - Sample HIM3 was initiated to determine if any beneficiation could be obtained. Three tests were made on each coal by pulverizing the samples to 80 percent passing a 100 mesh screen, 80 percent passing a 200 mesh screen and 80 percent passing a 325 mesh screen. The results of this program are included in the table designated Finely Ground Samples.

The table "Washability Blends" includes analyses of analytically ground samples from the washability study blended together by weight so as to create a coal washed at the indicated gravity.

TABLE 4

PERCENT SULFUR RETENTION, ASH AND CRUSH STRENGTH ON FIRED PELLETS OF LAHIRA AND SHARIGH COALS

Coal	% Stoichiometric Addition		% Sulfur Retention		% Ash		Crush Strength psi	
	Lime,	Limestone	Lime,	Limestone	Lime,	Limestone	Lime,	Limesto
WMI	100	100	48.06	53.27	23.20	23.03	1740	1090
	150	150	71.40	77.41	28.26	28.21	600	960
	200	200	101.5	85.26	33.66	30.65	1130	630
HIM-3	100	100	36.96	41.10	29.11	28.94	1400	1350
	150	150	69.28	68.18	34.98	33.69	1210	1210
	200	200	98.78	84.36	39.72	36.55	1300	1210
STS	100	100	51.59	33.15	19.54	19.85	1040	720
	150	150	71.63	46.56	24.93	21.10	1060	920
	200	200	80.00	53.71	28.48	23.52	1300	870
SMS	100	100	51.69	43.28	30.31	27.31	1620	1740
	150	150	70.37	46.15	36.36	30.56	1570	1210
	200	200	69.08	46.06	38.93	32.61	1690	1880

TABLE 5

RANDOM SAMPLES

Sharigh Coal - Top Seam

		1	2	3	4
Moisture	=	3.9	3.9	4.0	3.9
Ash	=	23.9	25.2	24.0	24.8
VM	=	39.6	38.9	39.7	39.0
FC	=	36.5	35.9	36.3	36.2
FSI	=	3	3	2½	2½
BTU	=	10,818	10,525	10,728	10,626
Total S	=	6.84	6.82	7.00	6.91
Sulfate S	=	0.09	0.07	0.07	0.07
Pyrite S	=	3.11	2.82	3.16	3.14
Total Inorganic S	=	3.21	2.89	3.23	3.22
Organic S	=	3.63	3.92	3.77	3.69

Sharigh Coal - Middle Seam

		1	2	3	4
Moisture	=	3.2	3.1	3.2	3.3
Ash	=	35.2	36.5	35.5	35.0
VM	=	39.4	39.2	39.3	38.8
FC	=	25.4	24.3	25.2	26.2
FSI	=	3	2½	3	3½
BTU	=	9,161	8,980	8,976	8,955
Total S	=	8.35	8.12	8.52	8.51
Sulfate S	=	0.25	0.19	0.25	0.25
Pyrite S	=	3.38	3.11	3.36	3.20
Total Inorganic S	=	3.63	3.29	3.61	3.44
Organic S	=	4.72	4.83	4.92	5.08

Note: Analyses determined on moisture-free basis

TABLE 6

RANDOM SAMPLES

Lakra Coal - Sample HIM3

	1	2	3	4
Moisture	29.1	23.2	28.1	29.6
Ash	11.6	30.2	14.2	17.8
VM	42.2	34.1	42.7	42.8
FC	46.2	35.7	43.1	39.4
FSI	0	0	0	0
BTU	11,950	7,572	11,044	10,609
Total S	5.50	17.96	6.70	4.68
Sulfate S	0.16	0.47	0.21	0.14
Pyrite S	3.03	12.15	3.76	1.49
Total Inorganic S	3.19	12.62	3.96	1.63
Organic S	2.31	5.34	2.74	3.22

Lakra Coal - Sample WMI

	1	2	3	4
Moisture	24.4	26.0	27.2	26.7
Ash	26.1	22.8	19.9	15.6
VM	39.2	38.8	40.2	42.4
FC	34.7	38.4	39.9	42.0
FSI	0	0	0	0
BTU	9,116	9,665	9,875	10,800
Total S	12.15	9.53	6.77	5.51
Sulfate S	1.20	0.45	0.67	0.48
Pyrite S	6.41	4.64	2.87	2.11
Total Inorganic S	7.61	5.08	3.54	2.59
Organic S	4.54	4.45	3.23	2.92

Note: Analyses determined on moisture-free basis

TABLE 7

SCREEN ANALYSIS

Sharigh Coal - Top Seam

	+3M	3M x 14M	14M x 28M	28M x 48M	48M x 100M	-100M
Wt. gms.	438	3,270	2,098	1,291	1,194	751
% Wt.	4.84	36.16	23.20	14.28	13.21	8.31
Moisture	2.9	3.4	3.4	3.4	3.2	3.5
Ash	26.0	30.1	22.5	20.8	2.17	28.8
VM	42.6	37.4	40.4	40.3	40.2	37.6
FC	31.4	32.5	37.1	38.9	38.1	33.6
FSI	2½	2½	2½	3½	3½	3
BTU	10,676	9,909	11,020	11,257	10,917	9,844
Totals	8.64	7.40	7.22	6.89	6.63	7.21
Sulfate S	0.14	0.09	0.07	0.07	0.09	0.20
Pyrite S	5.00	4.02	3.46	3.15	2.90	3.28
Total Inorganic S	5.15	4.11	3.53	3.22	3.00	3.48
Organic S	3.49	3.18	3.69	3.67	3.64	3.73

Sharigh Coal - Middle Seam

	+3M	3M x 14M	14M x 28M	28M x 48M	48M x 100M	-100M
Wt. gms.	525	3,911	1,917	1,135	1,038	857
% Wt.	5.60	41.68	20.43	12.10	11.07	9.13
Moisture	2.6	2.5	2.5	2.4	2.3	2.6
Ash	35.4	39.4	27.8	30.4	31.3	36.6
VM	39.2	37.7	42.4	41.1	40.8	38.4
FC	25.4	22.9	29.8	28.5	27.9	25.0
FSI	2	2	3½	4	3½	3½
BTU	9,004	8,495	10,251	9,761	9,700	8,596
Total S	8.99	8.75	8.53	8.39	8.21	8.11
Sulfate S	0.18	0.14	0.17	0.24	0.27	0.49
Pyrite S	4.27	4.25	3.18	3.16	2.95	3.04
Total Inorganic S	4.46	4.39	3.35	3.39	3.21	3.53
Organic S	4.54	4.36	5.18	5.00	4.99	4.58

Note: Analyses determined on moisture-free basis

TABLE 8

SCREEN ANALYSIS

Lakra Coal - Sample HIM3

	+3M	3M x 14M	14M x 28M	28M x 48M	48M x 100	-100M
Wt. gms.	128	2,774	272	47	194	124
% Wt.	3.02	78.38	7.69	1.32	5.48	3.51
Moisture	22.2	25.7	21.8	19.4	20.2	15.4
Ash	25.7	25.8	26.9	29.4	30.5	33.2
VM	40.1	39.6	38.5	36.6	36.5	35.0
FC	34.2	34.6	34.6	34.0	33.0	31.8
FSI	0	0	0	0	0	0
BTU	9,673	9,383	9,174	8,720	8,577	8,142
Total S	6.13	6.58	6.68	6.61	6.78	9.12
Sulfate S	0.19	0.23	0.23	0.26	0.30	0.55
Pyritic S	2.67	3.53	3.30	3.36	3.58	5.33
Total Inorganic S	2.87	3.76	3.53	3.62	3.88	5.87
Organic S	3.26	2.83	3.15	2.79	2.89	3.25

Lakra Coal - Sample WMI

	+3M	3M x 14M	14M x 28M	28M x 48M	48M x 100M	-100M
Wt. gms.	137	3,702	403	167	189	204
% Wt.	2.85	77.09	8.39	3.48	3.94	4.25
Moisture	24.2	24.4	21.5	17.8	13.3	11.1
Ash	23.6	23.5	26.5	30.5	46.9	48.4
VM	38.1	38.4	38.2	36.1	27.1	26.7
FC	38.3	38.1	35.3	33.4	26.0	24.9
FSI	0	0	0	0	0	0
BTU	9,408	9,466	8,899	8,412	6,204	5,987
Total S	8.72	8.41	8.87	9.28	8.49	13.83
Sulfate S	0.30	0.62	1.04	1.03	0.74	0.62
Pyritic S	4.38	4.51	4.28	4.95	5.16	9.87
Total Inorganic S	4.68	5.13	5.32	5.99	5.89	10.48
Organic S	4.04	3.28	3.54	3.30	2.60	3.34

Note: Analyses determined on moisture-free basis

TABLE 9

FINELY GROUND SAMPLES

Sheridan Coal - Top Seam

1.60 Float

					III	
	+100 Mesh	-100 Mesh	+200 Mesh	-200 Mesh	+325 Mesh	-325 Mesh
Ash	7.9	9.7	7.7	10.0	8.1	11.4
Total S	4.79	5.56	4.72	5.95	5.37	6.17
Sulfate S	0.04	0.09	0.04	0.10	0.07	0.13
Pyrite S	1.31	1.83	1.19	1.95	1.56	1.99
Total Inorganic S	1.35	1.92	1.23	2.05	1.63	2.12
Organic S	3.44	3.74	3.49	3.90	3.74	4.05

Lakota Coal - Sample HIM3

1.60 Float

	I		II		III	
	+100 Mesh	-100 Mesh	+200 Mesh	-200 Mesh	+325 Mesh	-325 Mesh
Ash "	20.8	23.6	19.4	24.5	20.1	25.0
Total S "	5.42	6.32	5.27	6.45	5.43	6.50
Sulfate S "	0.23	0.13	0.26	0.27	0.27	0.28
Pyrite S "	2.51	3.21	2.29	3.56	2.51	3.50
Total Inorganic S "	2.74	3.52	2.55	3.83	2.78	3.78
Organic S "	2.68	2.80	2.72	2.62	2.65	2.72

Note: Samples, I, II, III were gound so that 80% passed the 100, 200, and 325 mesh screens respectively.

TABLE 10

GIESLER PLASTICITY

Random Samples

Coal	Sample	Maximum Fluidity (D.D.P.M.)	°C @ Max. Fluidity	°C Start (1 D.D.P.M.)	°C Final (1 D.D.P.M.)	°C Ran
Sharigh Middle Seam	1	123	393	357	420	63
Sharigh Middle Seam	2	100	393	354	414	60
Sharigh Middle Seam	3	87	396	360	414	54
Sharigh Middle Seam	4	123	390	354	414	60
Sharigh Top Seam	1	3	396	369	405	36
Sharigh Top Seam	2	2.5	396	369	411	42
Sharigh Top Seam	3	2.5	399	378	414	36
Sharigh Top Seam	4	2.5	399	378	411	33

Screen Samples

Coal	Size Fraction	Maximum Fluidity (D.D.P.M.)	°C @ Max. Fluidity	°C Start (1 D.D.P.M.)	°C Final (1 D.D.P.M.)	°C Ran
Sharigh Middle Seam	+3M	5	384	363	399	36
Sharigh Middle Seam	3Mx14M	14	396	360	411	51
Sharigh Middle Seam	14Mx28M	700	387	333	399	66
Sharigh Middle Seam	28Mx48M	260	393	357	420	63
Sharigh Middle Seam	48Mx100M	235	396	357	426	69
Sharigh Middle Seam	-100M	82	393	354	417	63
Sharigh Top Seam	+3M	2	405	369	414	45
Sharigh Top Seam	3Mx14M	2	402	378	411	33
Sharigh Top Seam	14Mx28M	3	405	369	414	45
Sharigh Top Seam	28Mx48M	3.5	399	372	411	39
Sharigh Top Seam	48Mx100M	4	399	381	411	30
Sharigh Top Seam	-100M	3	399	366	408	42

Physical Testing

This portion of the research included several phases: a brief study of the possibility of using geologic factors in the mining and preparation of these coals, and an evaluation of the possibilities of cleaning these coals by screening and by magnetic separation. Based on this work, the following conclusions were reached.

(1) The possibility of using geologic factors to improve the value of these coals is indicated. However, much further research and exploratory drilling are required to fully evaluate the potential of this process.

(2) Screening does not have a good potential as a separation mechanism for these coals.

(3) Magnetic separation does not appear to be useful in reducing the sulfur content of these coals, but can reduce the ash content.

Magnetic Separation

Magnetic separation relies on the difference in magnetic susceptibility of pyrite and coal for a separation of the two materials. Some form of pre-treatment may be used to increase the magnetic properties of the pyrite such as thermal steam-air treatment. However, some studies have indicated that pre-treatment is unnecessary. The response of coals to magnetic beneficiation is variable, but in many cases the sulfur reduction obtainable is substantial. Although this process is not developed, it is reasonably well established from bench scale tests and was therefore tested for application to the Sharigh coals. Nevertheless, the effectiveness of the process is limited to the near removal of pyritic sulfur, which can be more readily achieved using commercial, conventional processes that are based on gravity separations. If this process becomes commercial, it will more than likely find application at the power plant rather than at the mine, since finely pulverized coals are a requirement.

Magnetic separation - The results of the magnetic separation tests are shown in Table 11, page 5-55. Neither of the test coals (SMS and STS) exhibit a significant sulfur reduction after treatment, although in some cases fairly large ash reductions were achieved. However, the use of magnetic separation for ash reduction would probably not be cost-efficient.

TABLE 11

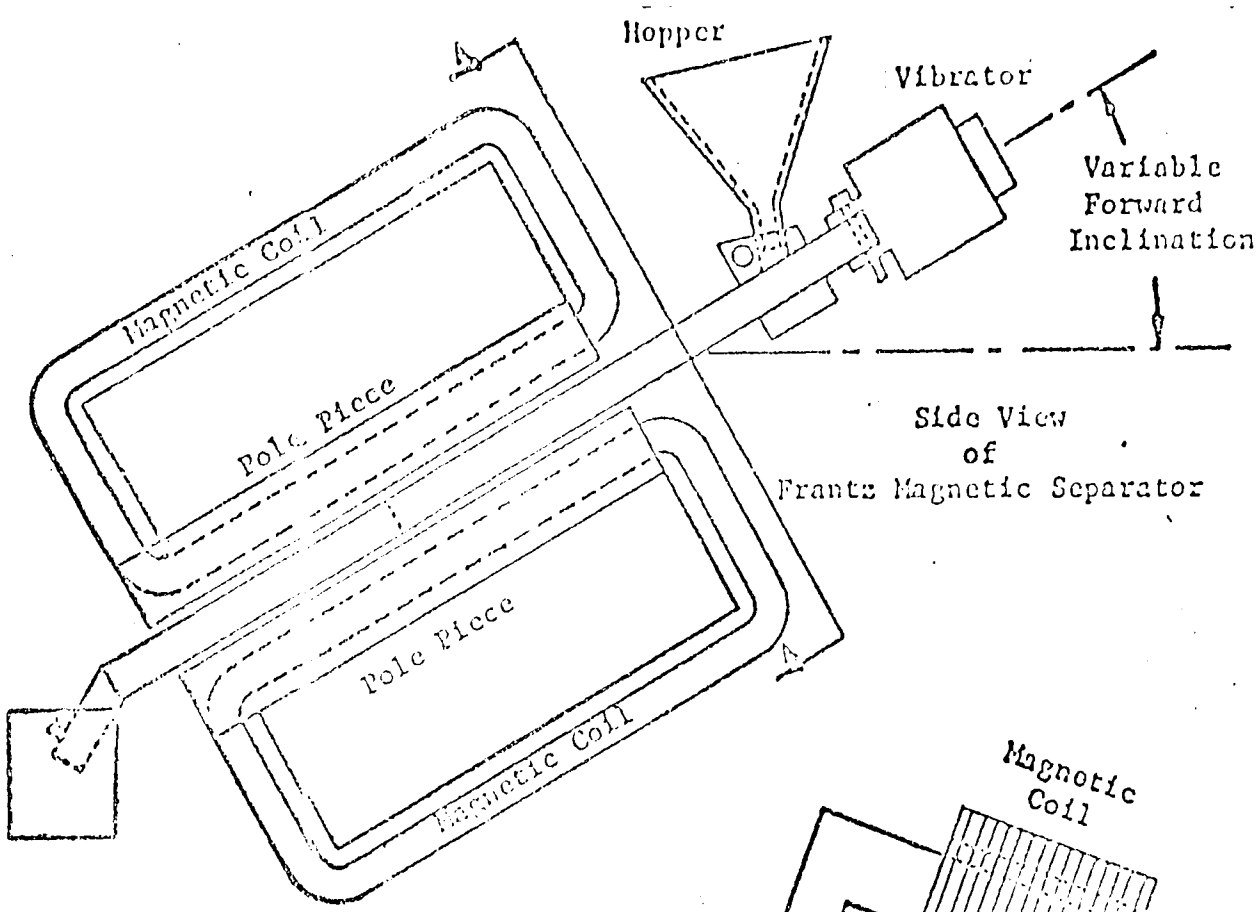
LABORATORY FLOTATION SAMPLES

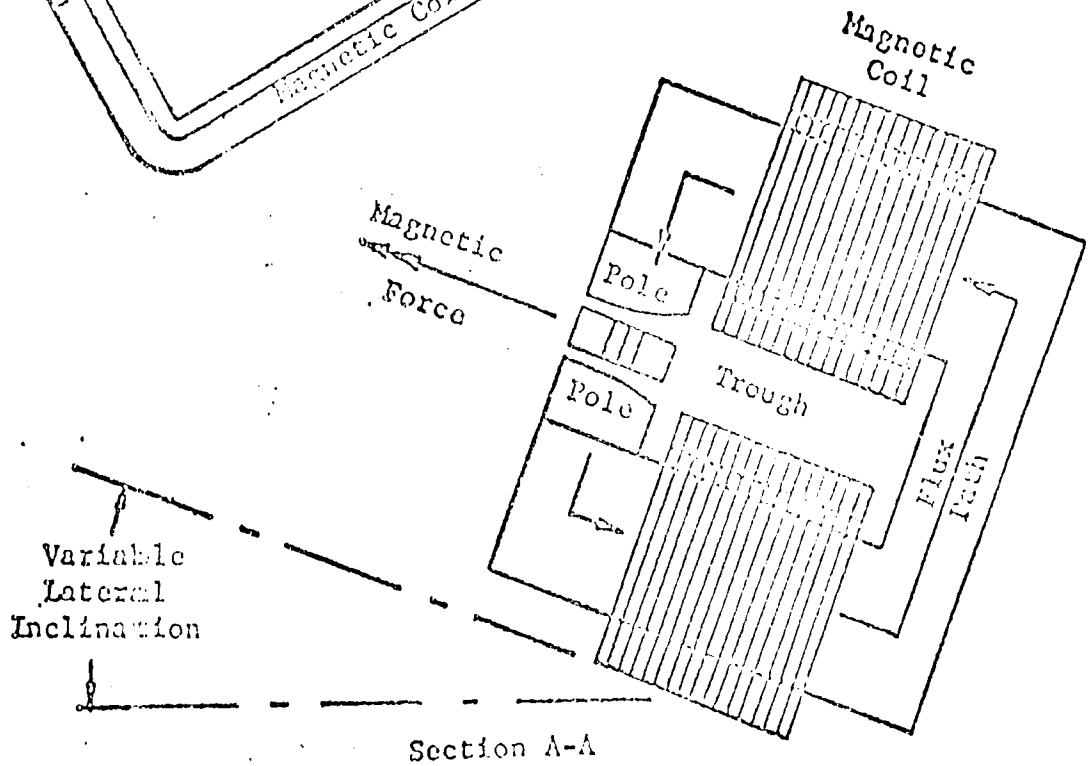
Sharigh Coal - Middle Seam

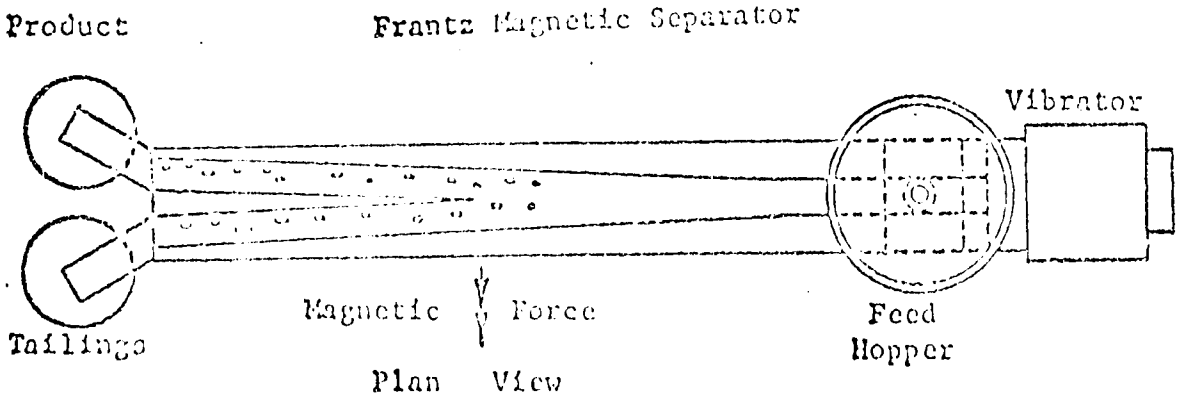
Percent	28 mesh x 48 mesh Head	Product	Reject	48 mesh x 100 mesh Head	Product	Reject	-100 mesh Head	Product	Reject
Ash	28.30	19.10	50.20	29.80	23.00	50.00	36.50	36.30	37.00
Sulfur	8.24	8.32	7.43	8.13	8.23	7.89	8.13	8.04	8.15
Yield		70.40			74.80			71.40	

Sharigh Coal - Top Seam

Percent	28 mesh x 48 mesh Head	Product	Reject	48 mesh x 100 mesh Head	Product	Reject	-100 mesh Head	Product	Reject
Ash	23.80	15.70	53.20	22.40	12.10	61.80	28.30	21.60	40.20
Sulfur	7.37	7.34	7.80	7.66	8.40	8.01	7.22	7.16	8.13
Yield		78.40			79.30			64.00	







SCHEMATIC OF FRANTZ MAGNETIC SEPARATOR
USED TO BENEFICIATE FINE COALS MAGNETICALLY

30

DEASHING & DESULFURIZATION

INTRODUCTION

Coal is a very heterogeneous material. It is composed of a mixture of combustible metamorphosed plant remains, sedimentary rock, and various minerals. These coal components are generally evident at a coal face as a banding or layering effect and in some cases as a mineral filling of fractures. During mining, these components are broken up and mixed. The purpose of coal cleaning or preparation is to unmix the raw coal to produce a product for utilization and a reject for disposal. Coal cleaning is frequently directed at the lowering of ash and/or the lowering of sulfur, which is a major detriment in Pakistan coals. In some cases, coal cleaning is also undertaken to improve coking properties.

Coal preparation techniques exploit some difference in physical or chemical properties between the various coal components to effect a separation. The properties which are exploited in conventional coal preparation are specific gravity, surface chemistry, and friability. Specific gravity is the primary coal property which is exploited by common separation equipment such as dense medium vessels, dense medium cyclones, water only cyclones, wet concentrating tables and jigs. Because specific gravity concentration is commonly used in coal preparation, extensive laboratory

specific gravity separations were performed on the Sharigh and Lakhra coals. These tests were done in the manner of a washability study in which a coal sample was exposed to successively higher specific gravity solutions. The float material was analyzed at each step and the sink material passed on to the next higher specific gravity solution. The float and sink were both analyzed after separation at the highest gravity used in the test.

The property of surface chemistry is utilized for separation with various types of flotation equipment. Flotation was not evaluated as a separation technique for the Sharigh and Lakhra coals because it is the least commonly used of the conventional systems and the costs involved to grind and clean the entire run-of-mine coal is considered prohibitive. There are two basic problems involved in the use of flotation as a separation mechanism: pyrite cannot be removed except under highly controlled laboratory conditions and a very fine (generally minus 28 mesh) size coal is required as feed. In modern practice, only the naturally occurring fines are ever considered for treatment by flotation and then only for washing and clarification purposes. The general use of flotation for sulfur removal is not considered commercially practical because of the grinding requirements.

METHODS, PROCEDURES AND EQUIPMENT

Washability

The coal (after grinding and screening as required) was placed in a container holding an organic liquid of 1.25 specific gravity, mixed with the fluid and allowed to stand until the separation was complete. The sink was passed on to a second container holding an organic liquid with a specific gravity of 1.30 and the float was collected and stored. This cycle was continued through liquids with gravities of 1.40, 1.50, and 1.60. After the separation at gravity 1.60, both the float and sink were collected.

All of the coal samples (5 float and 1 sink for each test coal) were placed in an air sweep drying oven set at 15°C above ambient temperature. After drying, the samples were crushed in a jaw crusher (this step was omitted for the finer mesh sizes) and pulverized to minus 60 mesh for analysis.

RESULTS AND DISCUSSION

Washability

The primary dependent criteria of coal separation based on specific gravity are the amount of yield, and the ash and sulfur content of the yield. A general rule is that for a given single-pass gravity separation, the reduction of ash and sulfur content results in a reduction in yield. However, for a given coal, one type of gravity process may be much more efficient than another, especially at low separation gravities. This fact illustrates the importance of determining the washability characteristics of the coal to be separated. However, it must be realized that the sink-float information gathered in a laboratory washability study cannot be completely duplicated by commercial gravity separation equipment. The failure in duplication may range from slight when cleaning plus 48 mesh coal in heavy media cyclones, to intermediate when cleaning a full size range in a jig, to great when cleaning minus 48 mesh in hydrocyclones or on concentration tables.

Figures 1 through 25 display the results of extensive washability studies on the Lakhra and Sharigh coals. Each figure contains four curves labeled either A, B, C, or D. Curve A is the cumulative float (or yield) ash versus the percent yield. This curve can be used either to determine the amount of ash at a given yield or vice versa. Curve B

is the cumulative float sulfur versus percent yield and can be utilized in a similar manner to Curve A. Curve C is the specific gravity of separation versus the percent yield and denotes the percent float for a separation at a given gravity. Curve D is a plot of the percent of the raw coal which is within ± 0.10 specific gravity of the gravity of separation (near gravity material).

The amount of near gravity material at the gravity of separation is very important in designing a preparation facility because this parameter indicates the difficulty of separation at a given gravity. For example, less than seven percent of near gravity material at the gravity of separation indicates a simple separation. In such a case it is not necessary to utilize a process which provides a sharp separation (such as heavy media) and all water processing may be indicated. Most all water processes, where applicable, are generally less expensive than heavy media processes in terms of cost per ton of coal processed. A general rule which may be applied is that when dealing with conditions where there is seven percent or less near gravity material, straight water processes (jigs or tables) are indicated, if water processing can provide a sufficiently low ash and sulfur content in the yield and if the yield is satisfactory. This arbitrary limit of seven percent near gravity material is sometimes increased to ten percent or

in rare cases stretched even higher, but the seven percent limit is consistent with prudent engineering practice.

A second consideration in the use of all water processing is the desired gravity of separation. Generally all water processes begin to fail below a gravity in the range of 1.50 to 1.55 and if a lower gravity of separation is required, heavy media is again indicated.

When heavy media is utilized, consideration should be given to the possibility of reprocessing the middling or sink portion of the feed coal. Reprocessing the middlings may be especially attractive if the first gravity of separation was very low, causing a low yield. In such a case, the middlings can be reprocessed at a higher gravity to produce a second fuel product of a lower grade, but quite suitable for certain purposes. Such practice is common and assures a very high recovery.

The following table titled "Potential for All Water Processing" is a summation of the projected effects of all water processing on the test coals. In a few cases a realistic projection was not permible and these tests are not included in the table. In general, if the yield, ash, and sulfur values on the table are acceptable for a given coal sample, then all water processing should be considered providing that the gravity of separation is above (in the instance of Pakistan coals) 1.65. If the ash or sulfur values

TABLE 1

Potential for All Water Processing*
(Seven Percent Near Gravity Material)

Coal Sample	Tyler Mesh Size	Separation Gravity	Percent Yield	Percent Ash	Percent Sulfur
Lakhra WMI	Combined	1.63	84	13.1	5.9
Lakhra HIM3	Combined	1.71	93	12.8	8.7
Sharigh Middle	Combined	1.58	62	12.4	8.4
Sharigh Top & Middle	Combined	1.72	78	14.3	7.2
Lakhra WMI	+3	1.69	86	15.4	6.1
Lakhra WMI	3 x 14	1.64	87	11.7	6.1
Lakhra WMI	14 x 28	1.91	93	17.6	7.0
Lakhra WMI	28 x 48	1.58	72	11.9	5.6
Lakhra WMI	48 x 100	1.63	64	10.8	5.4
Lakhra HIM3	+3	1.58	94	20.0	5.6
Lakhra HIM3	3 x 14	1.62	91	20.0	5.7
Lakhra HIM3	14 x 28	1.82	96	25.3	5.8
Lakhra HIM3	28 x 48	1.58	76	19.1	5.2
Sharigh Middle	3 x 14	1.68	62	15.4	8.6
Sharigh Middle	14 x 28	1.57	69	10.4	8.2
Sharigh Middle	28 x 48	1.72	74	12.7	8.3
Sharigh Top	+3	1.61	69	6.4	5.2
Sharigh Top	3 x 14	1.60	72	7.0	5.4
Sharigh Top	14 x 28	1.69	83	8.9	5.6
Sharigh Top	28 x 48	1.65	87	12.0	6.1
Sharigh Top	48 x 100	1.55	72	5.8	5.5

*Note: Estimates of results for sizes finer than approximately 48 mesh should be regarded as extremely general.

found on the table are too high or if the gravity is below 1.65, then heavy media processing may be indicated. A more detailed evaluation of the results of this washability study indicate the permissible parameters of the cleaning process. The necessary information is included in this report to allow a selection of the goals and limitations of the proposed plant to make the desired separations.

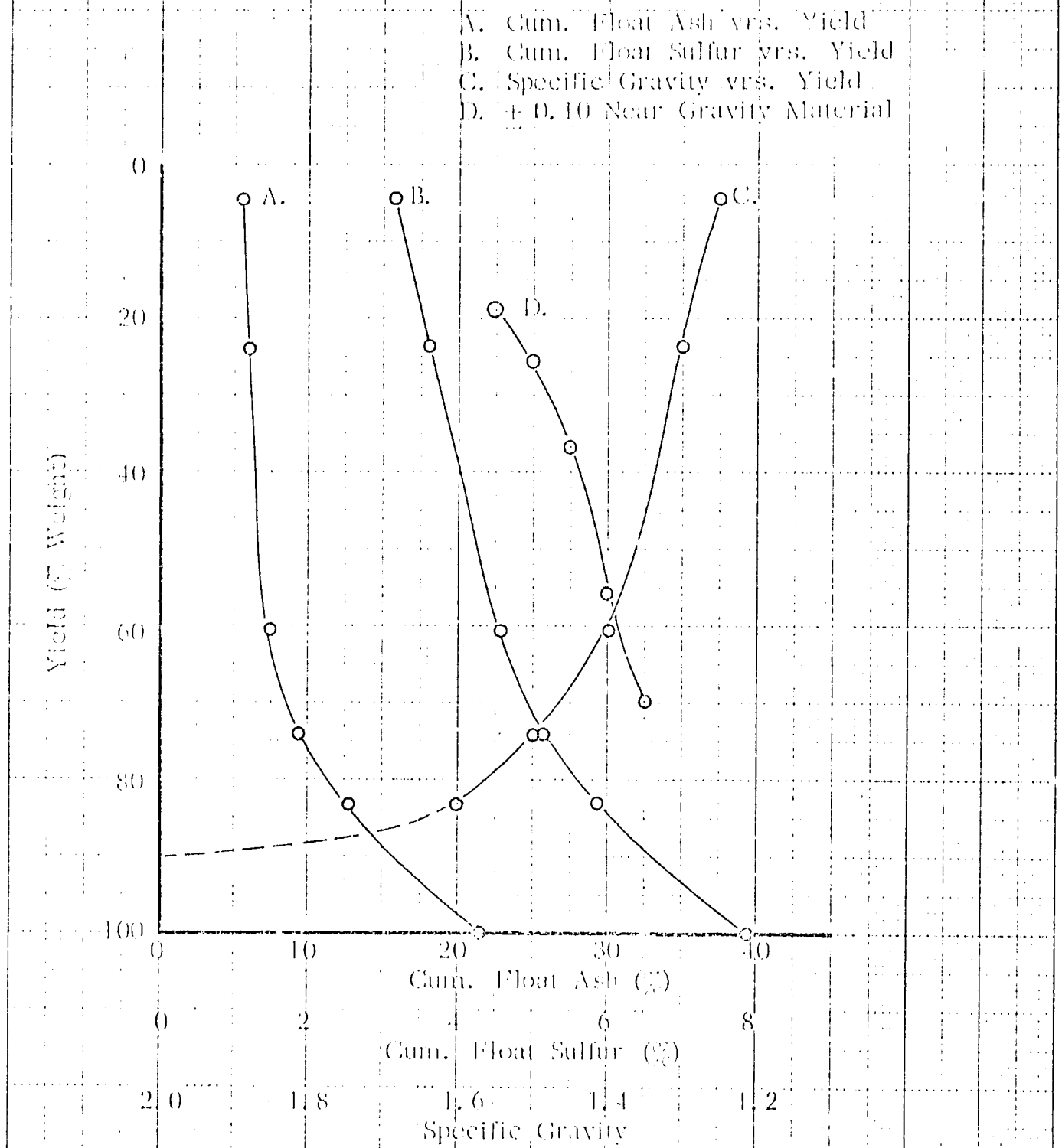
RECOMMENDATIONS AND CONCLUSIONS

Washability

A discussion of the results of the washability study is included in the section titled "Results and Discussion." Sufficient specific data is presented to define the limits of ash and sulfur as a function of yield for the washability of Sharigh and Lakhra coals. Once the selection is made for recovery, then the permissible sulfur and ash can be determined as well as the difficulty of separation.

FIGURE 1

LAKHRA WMI COMBINED TOTALS OF SIZED FRACTIONS



Washability Curve

WEF VPI
4/28/76

FIGURE 2

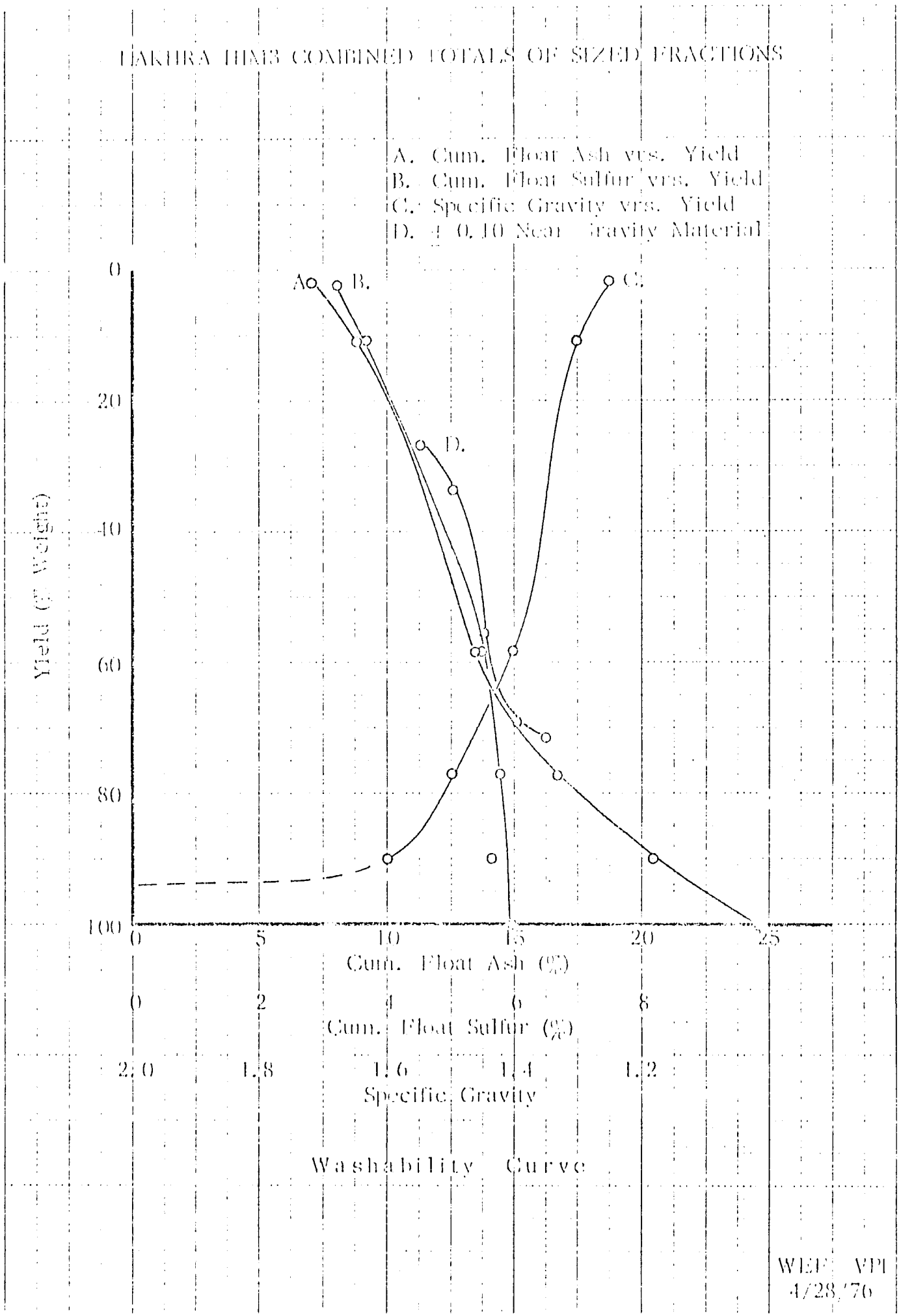

HAKHRA HMB COMBINED TOTALS OF SIZED FRACTIONS
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 3

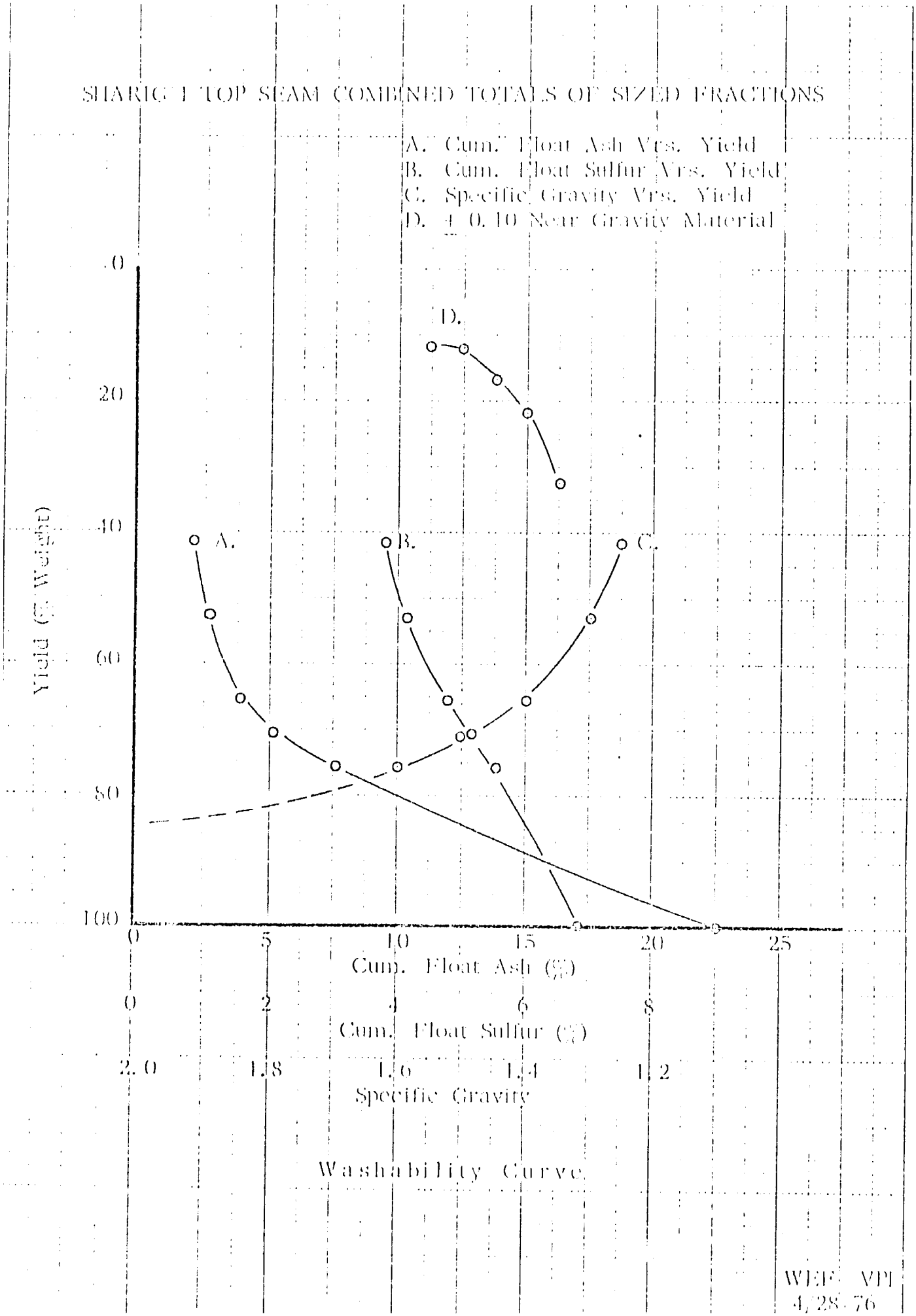
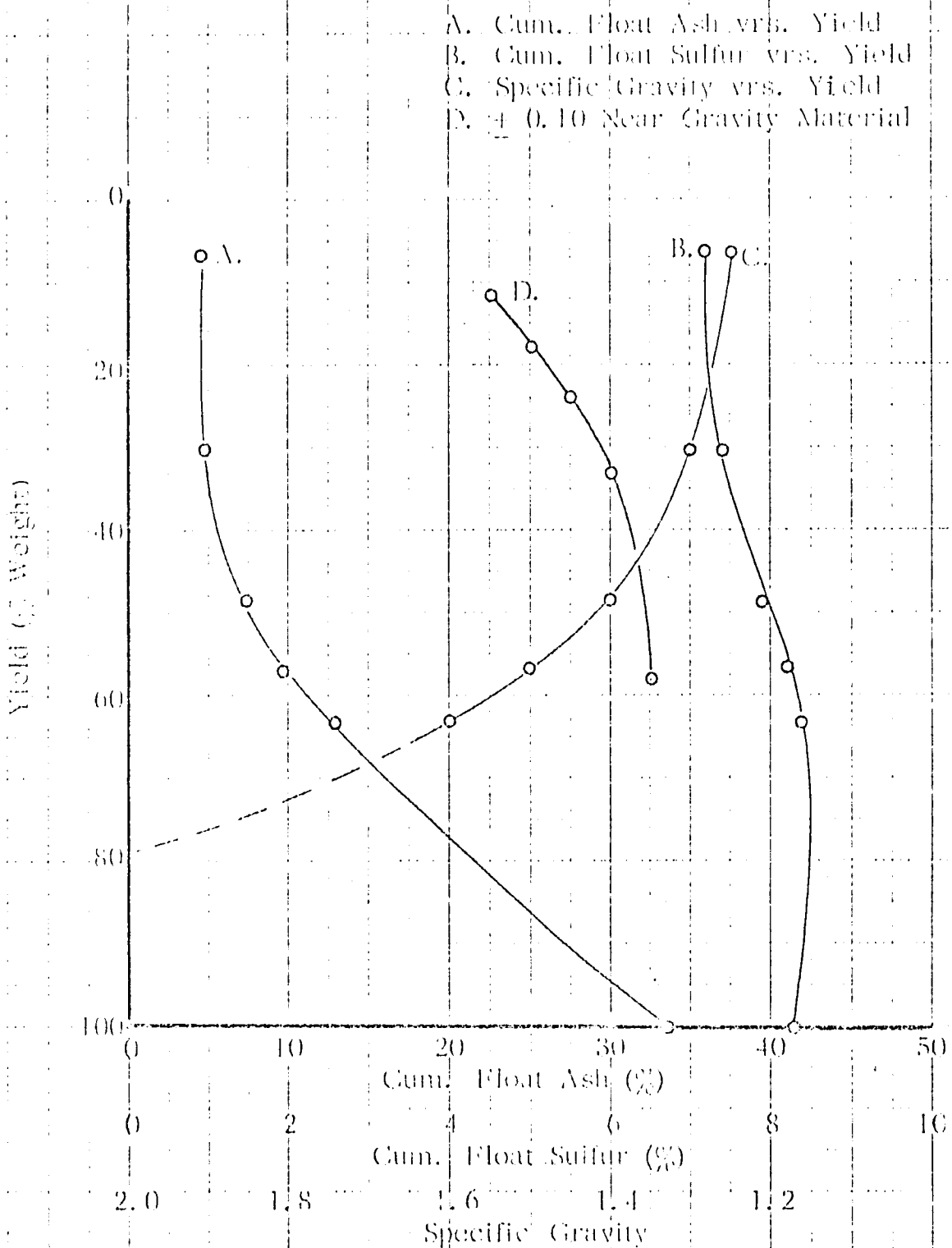

SHARIGI TOP SEAM COMBINED TOTALS OF SIZED FRACTIONS
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 4

SHARIGH MIDDLE SEAM COMBINED TOTALS OF SIZED FRACTIONS



Washability Curve

WEF VPI
4/28/76

FIGURE 5

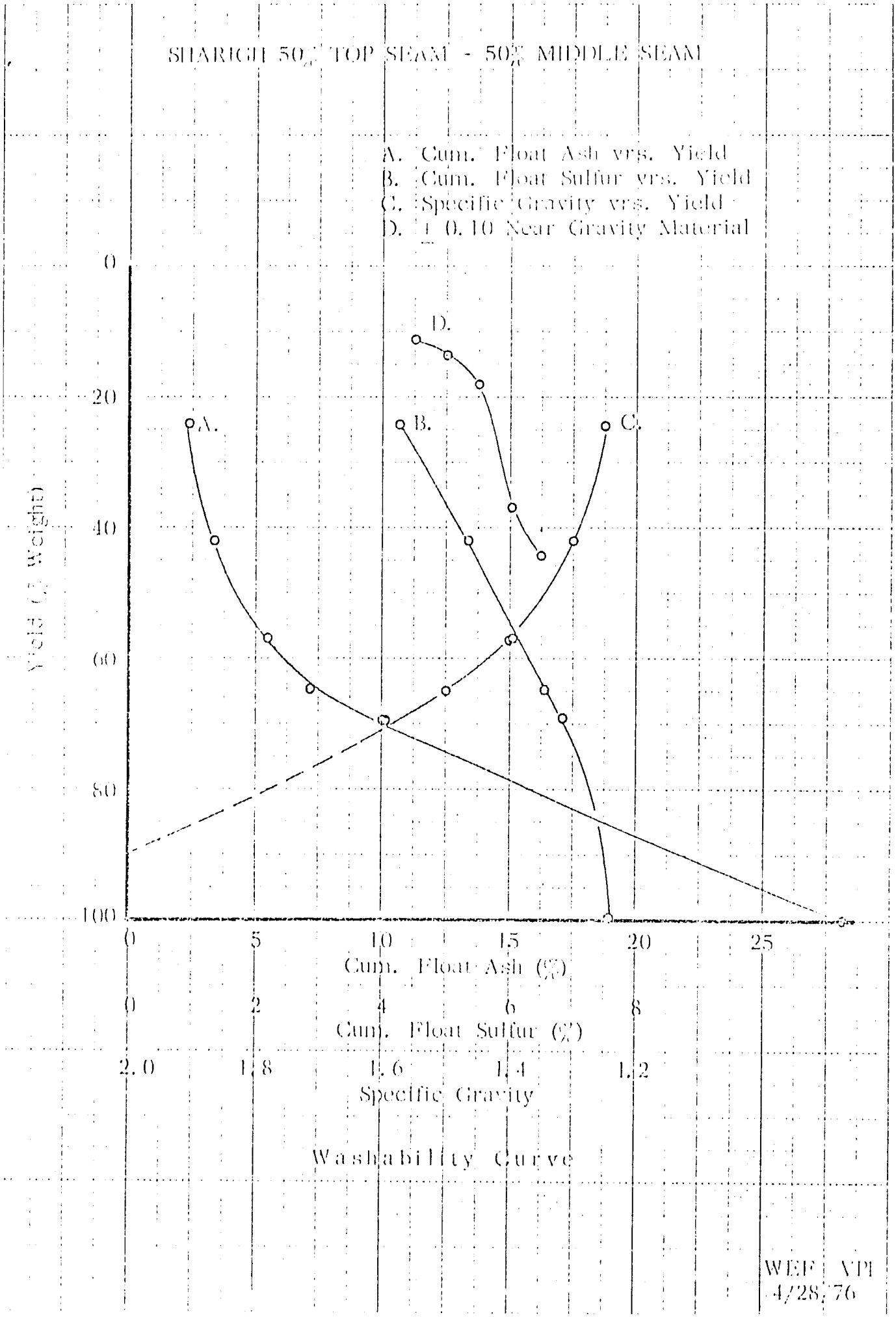

SHARIGH 50% TOP SEAM - 50% MIDDLE SEAM
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 6

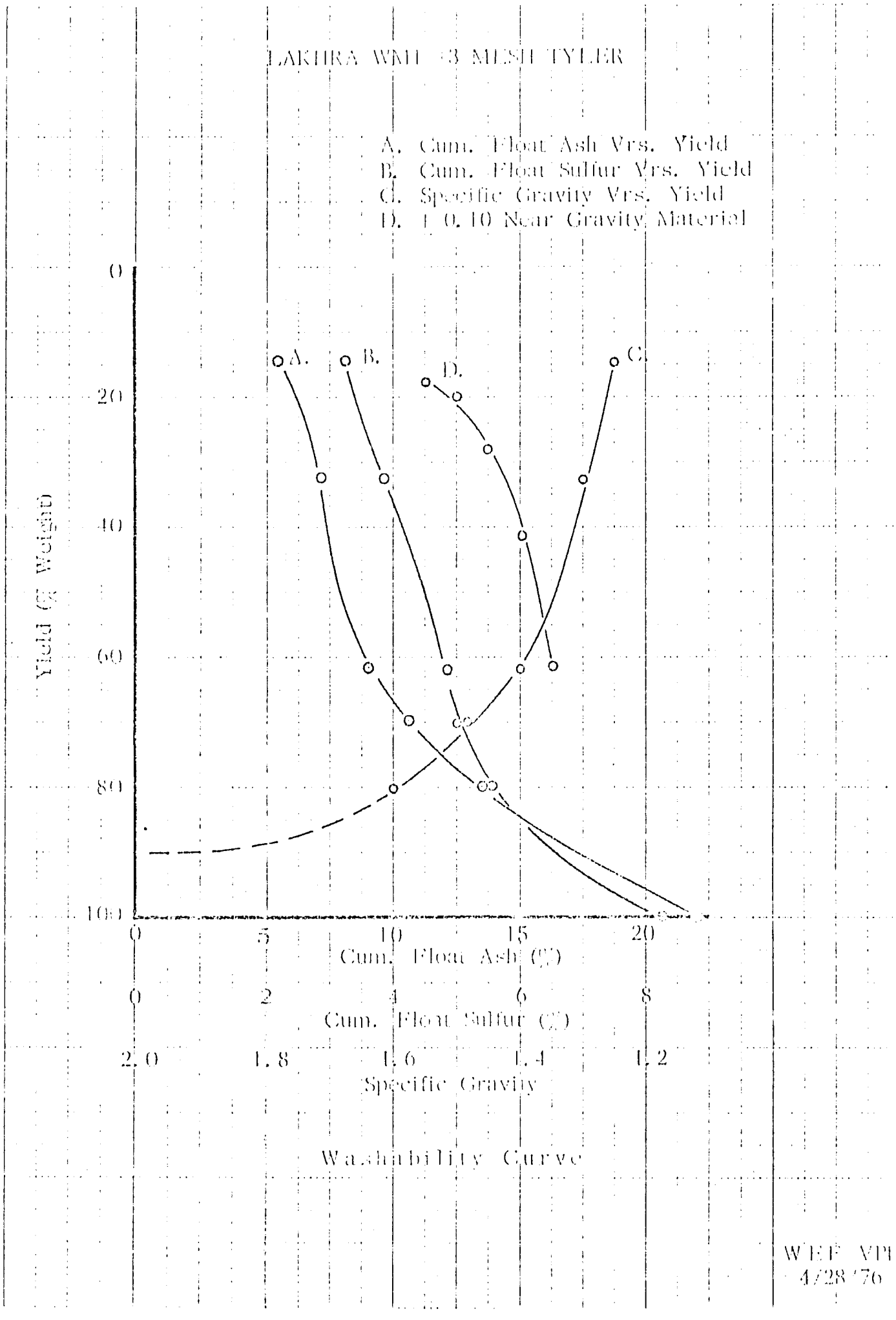

LAKHRA WMH -3 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. + 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 7

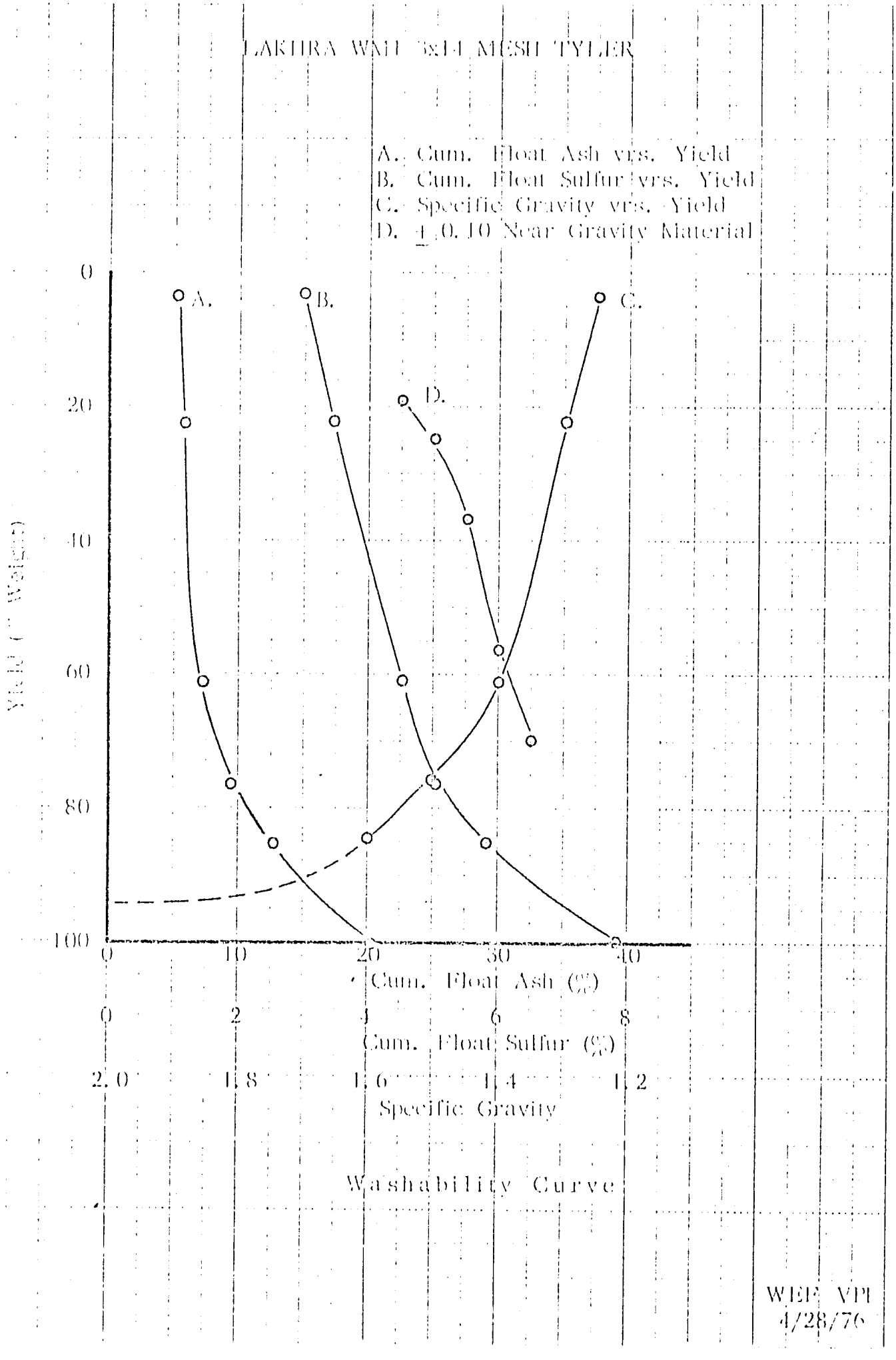
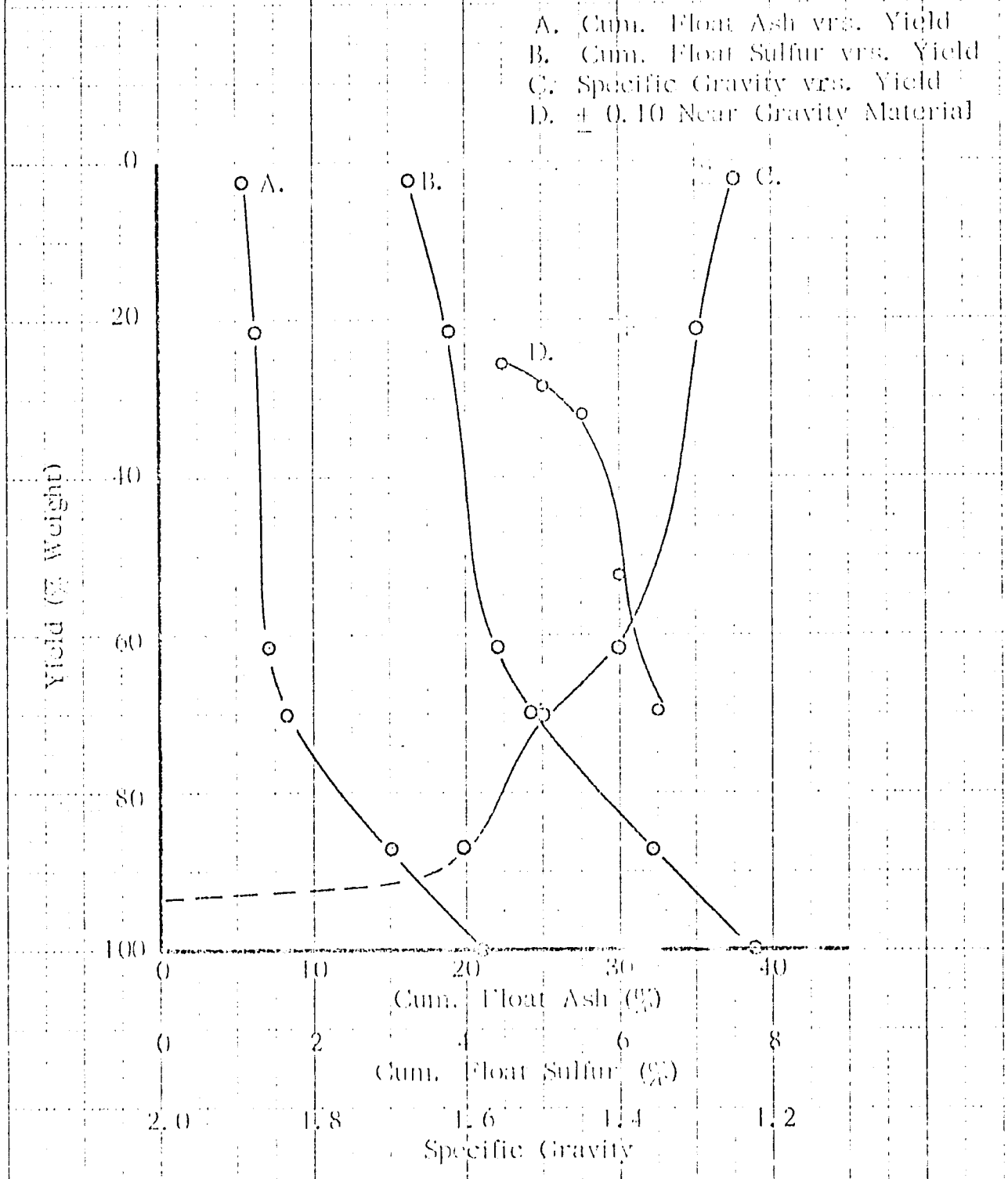

LAKHRA WMH 3x14 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
10
20
30
40
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 8

LAKHRA WMH 14x28 MESH TYLER

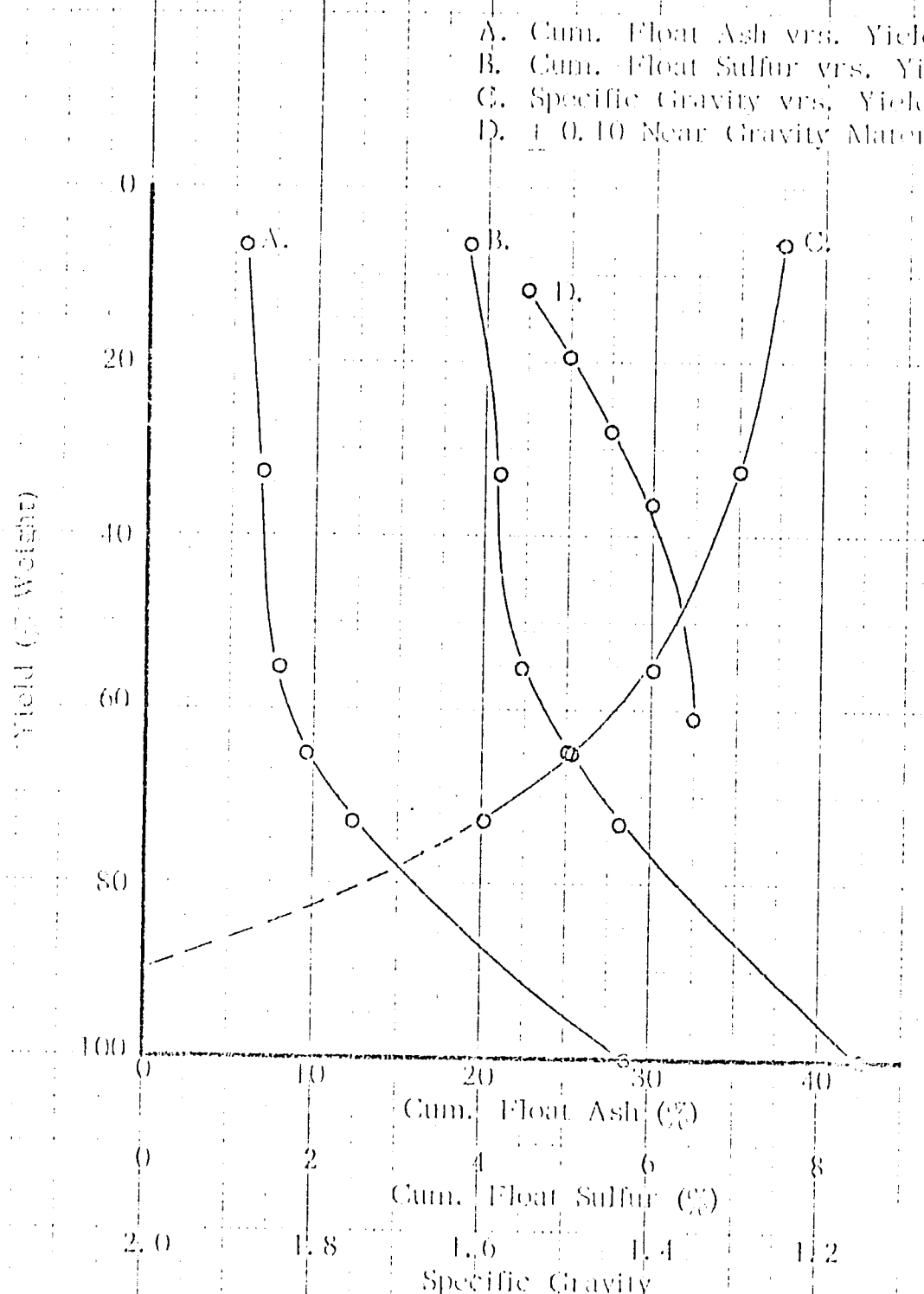


Washability Curve

WEF, VPI
4/28/76

FIGURE 9

LAKHRA WMI 28x48 MESH TYLER



Washability Curve

WEF VPI
4/28/76

FIGURE 10

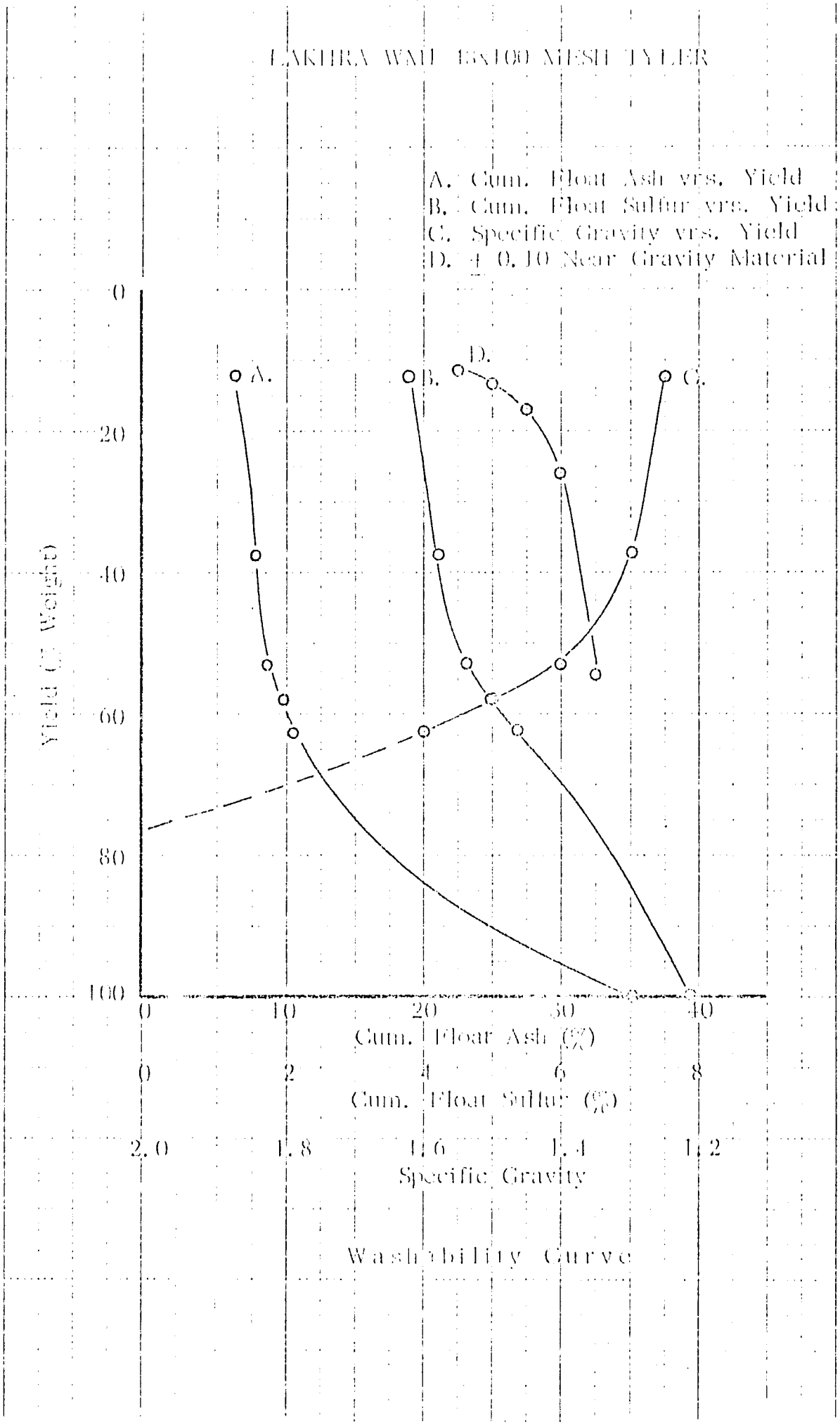

LAKHRA WMU 6X100 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
10
20
30
40
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 11

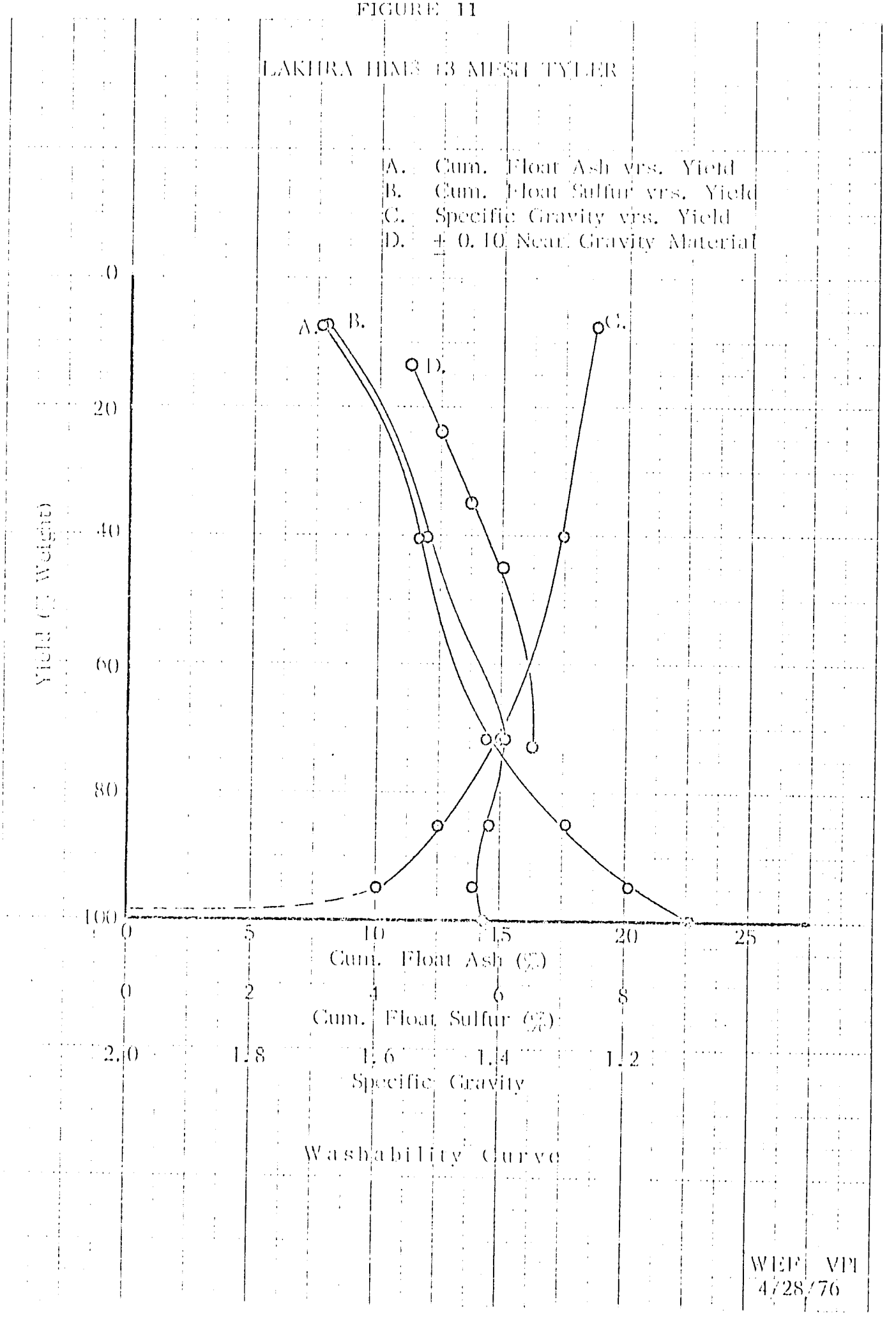

LAKHRA HIMS 13 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 12

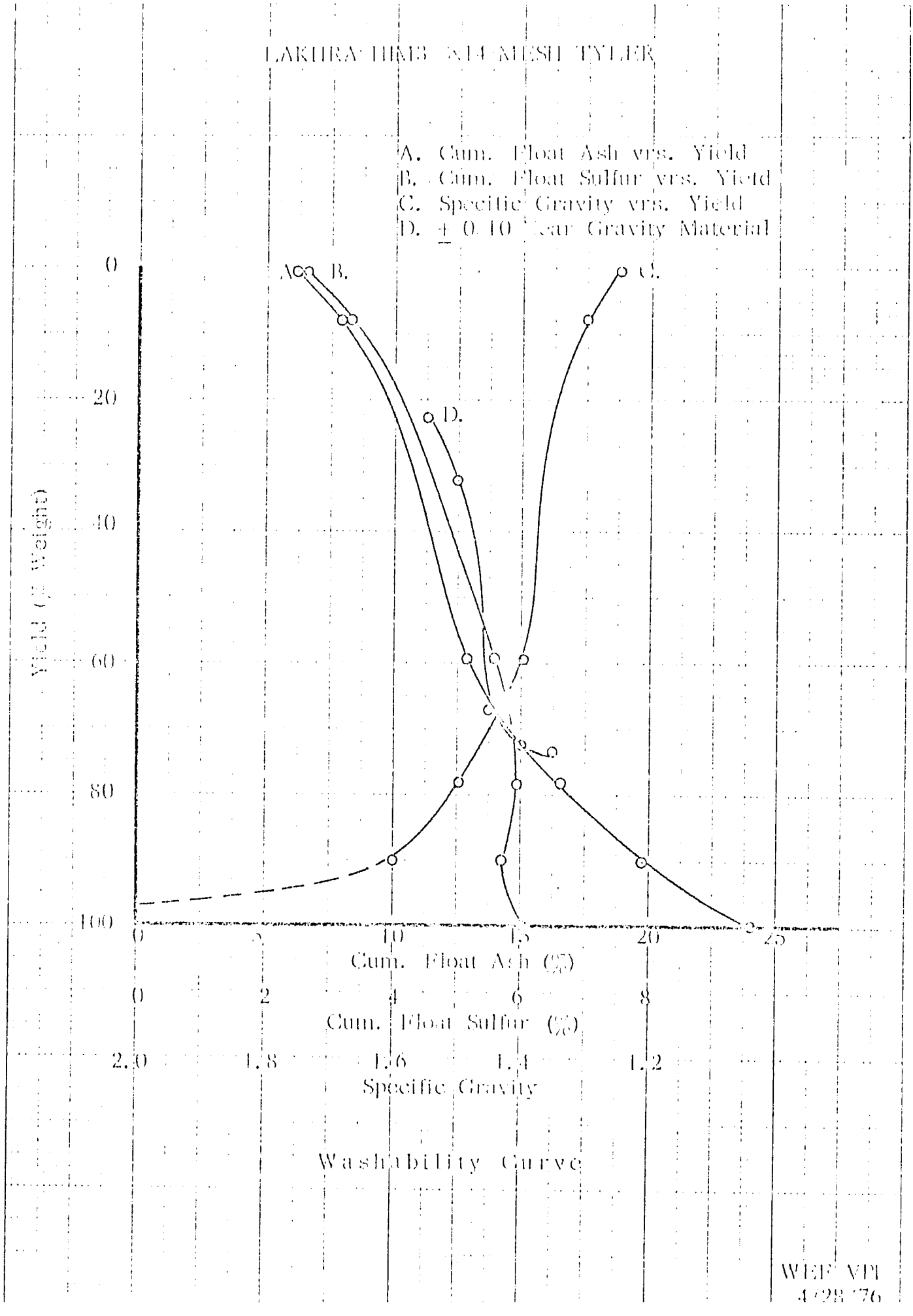
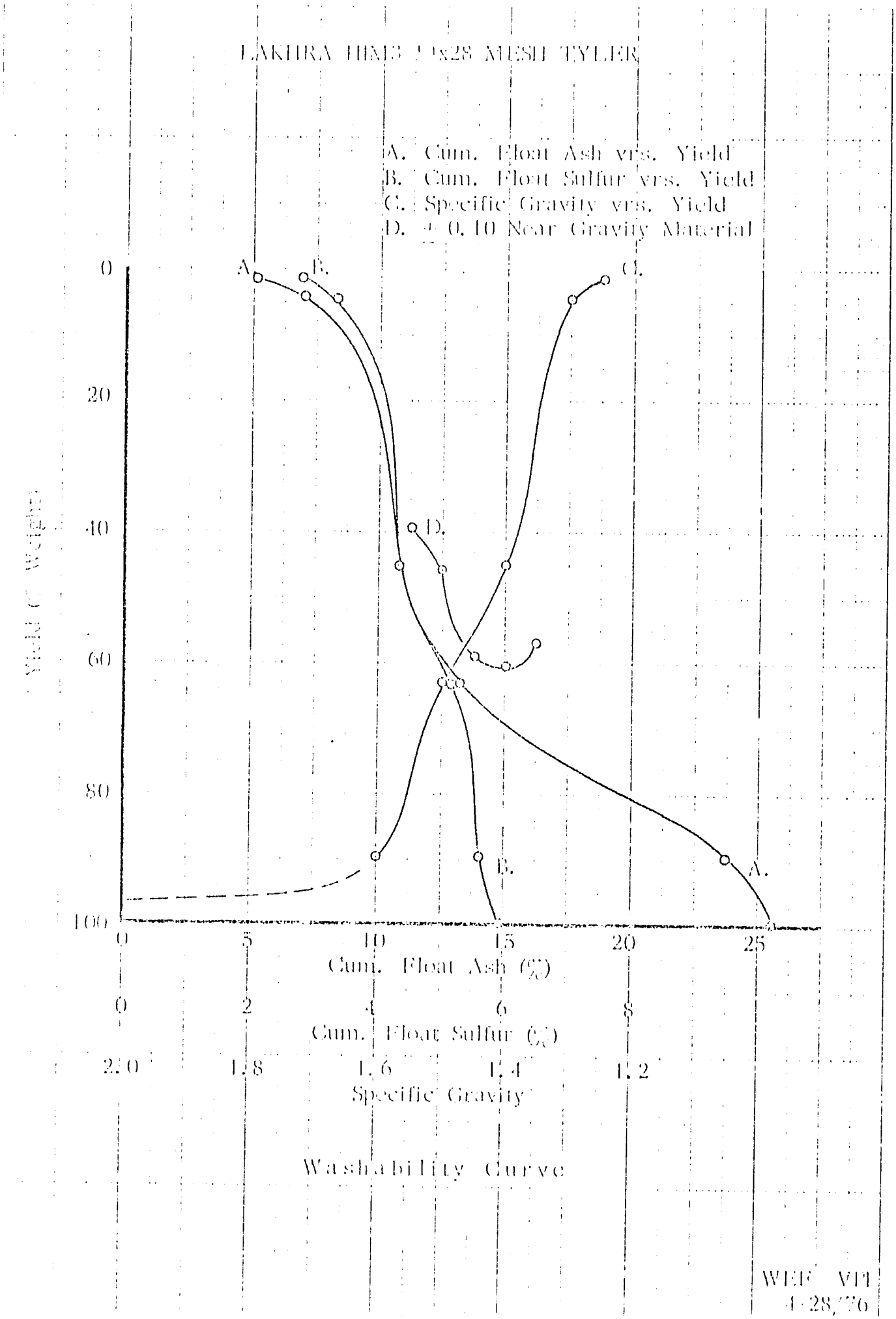

LAKHRA THAB 14 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 13



Washability Curve

FIGURE 14

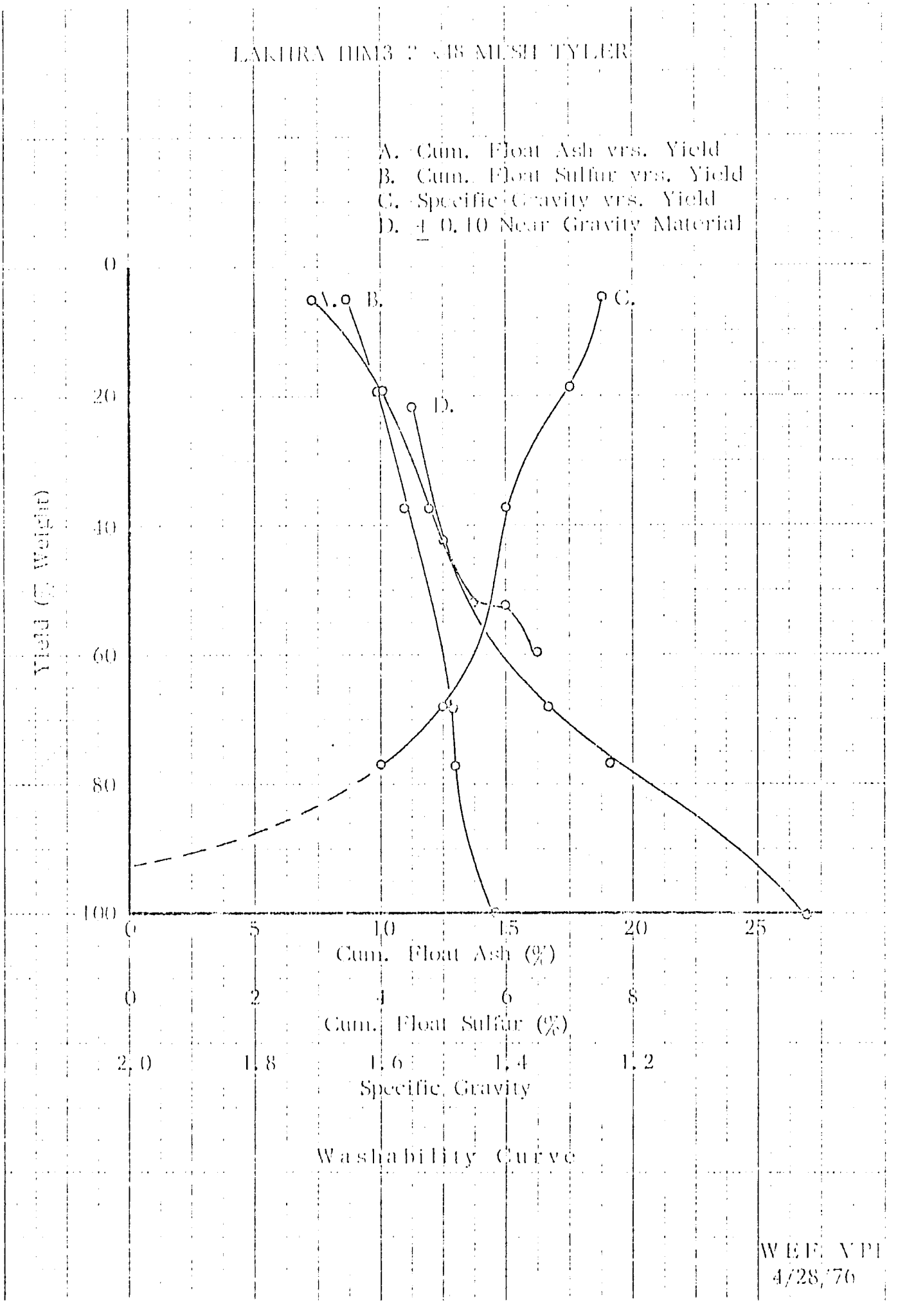

LAKHRA HM3 2" x48 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 15

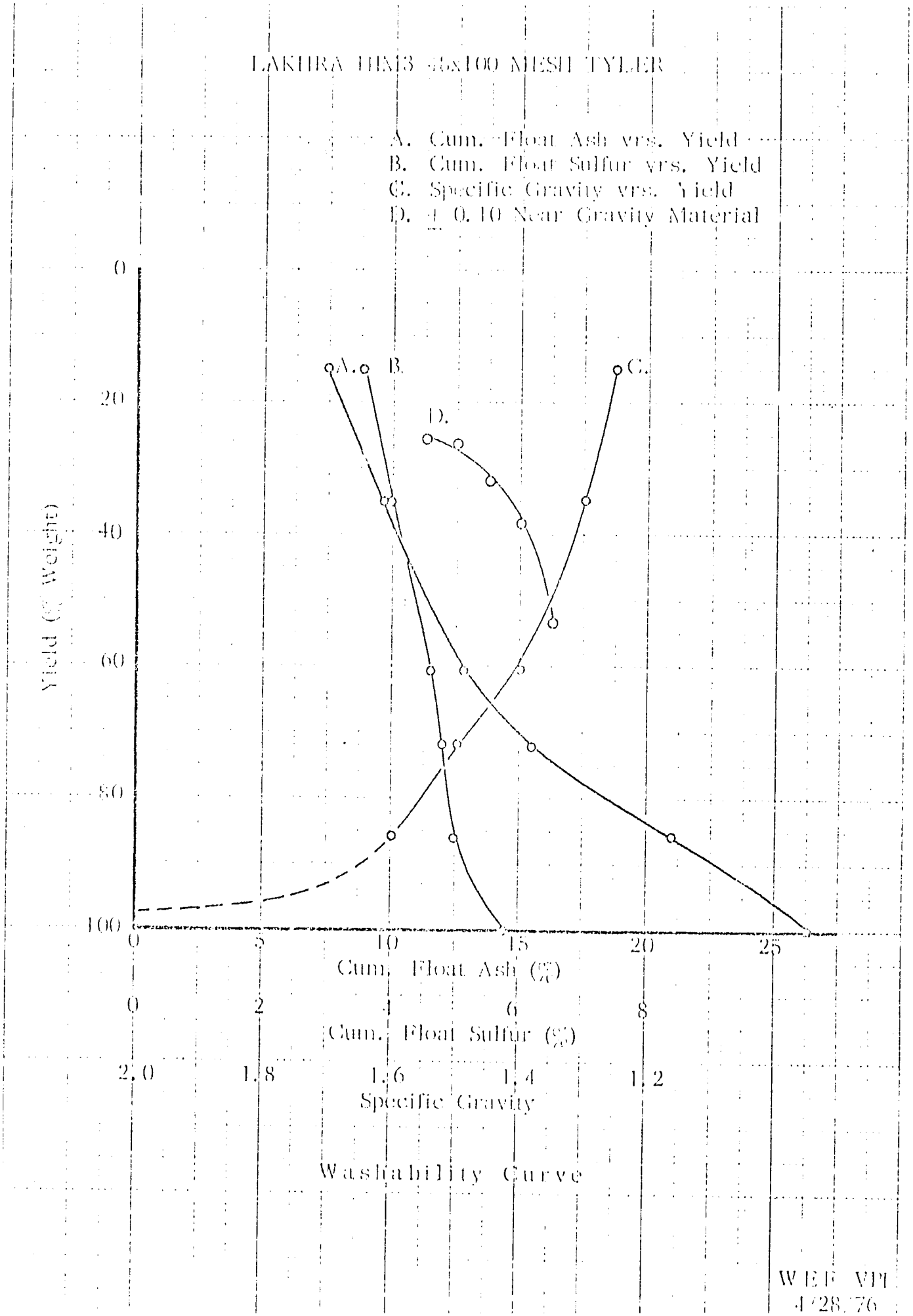

LAKHRA HM3 -6x100 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 16

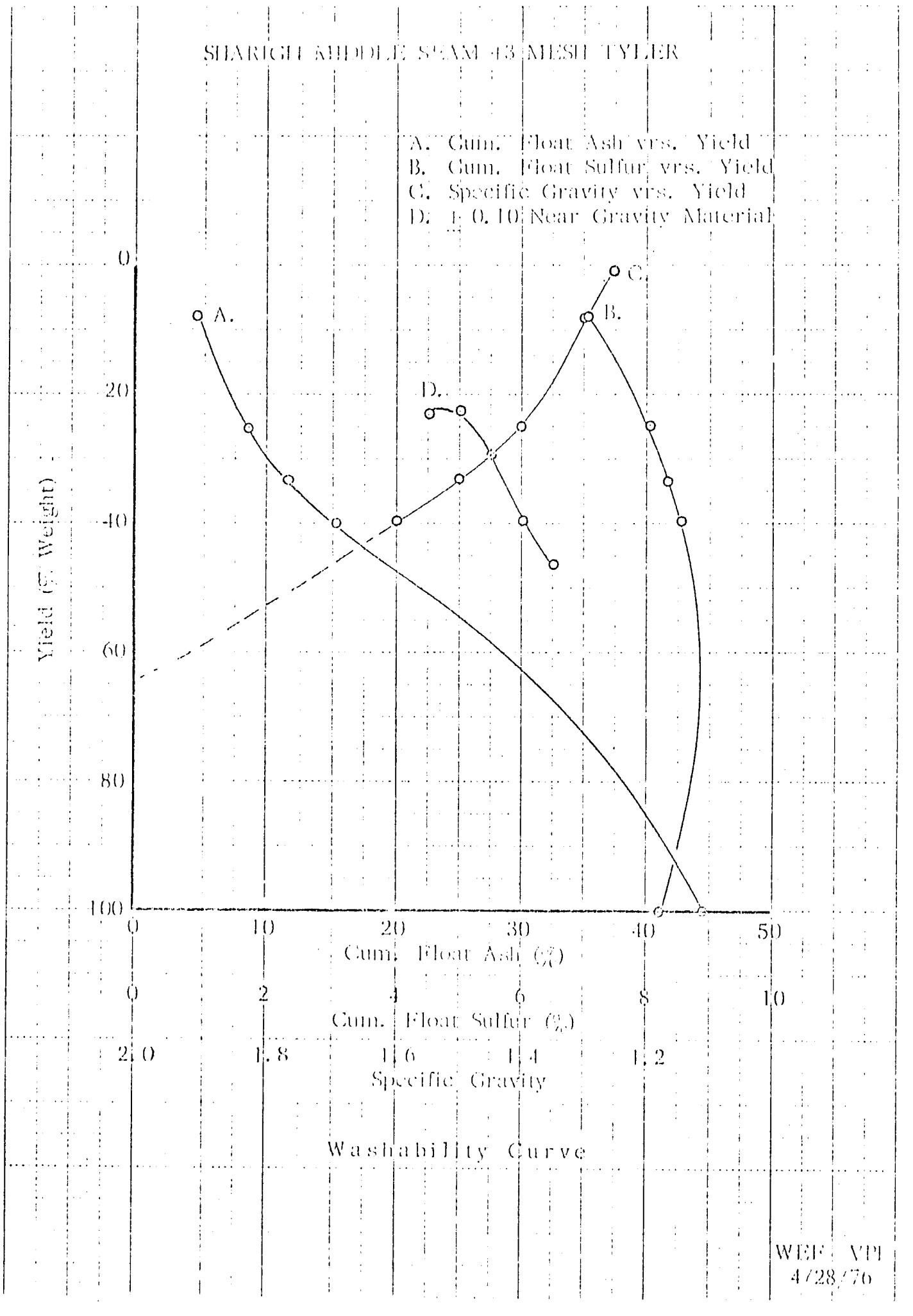

SHARIGH MIDDLE SEAM -43 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
10
20
30
40
50
Cum. Float Ash (%)
0
2
4
6
8
10
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 17

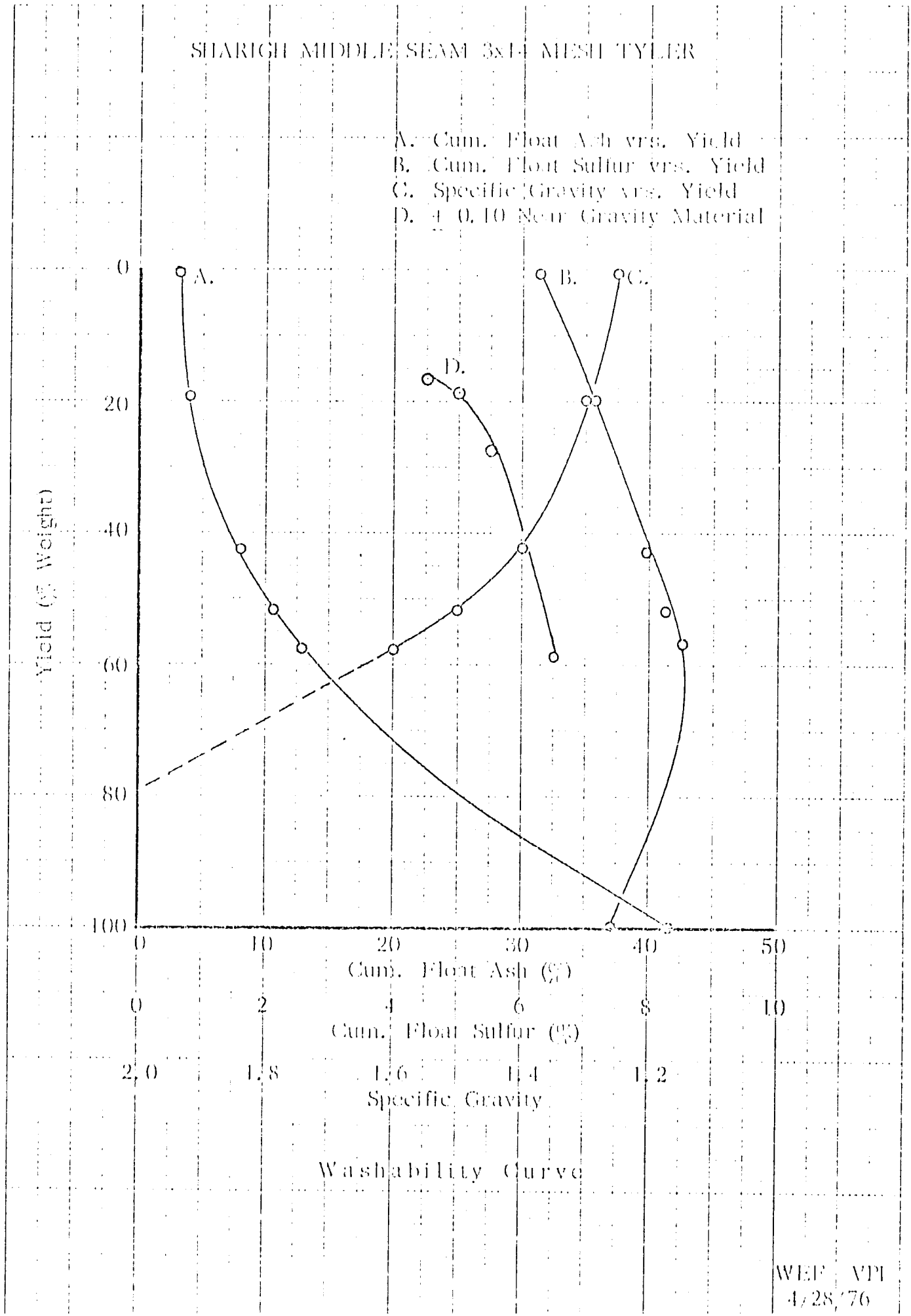

SHARIGH MIDDLE SEAM 3x14 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
10
20
30
40
50
Cum. Float Ash (%)
0
2
4
6
8
10
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 18

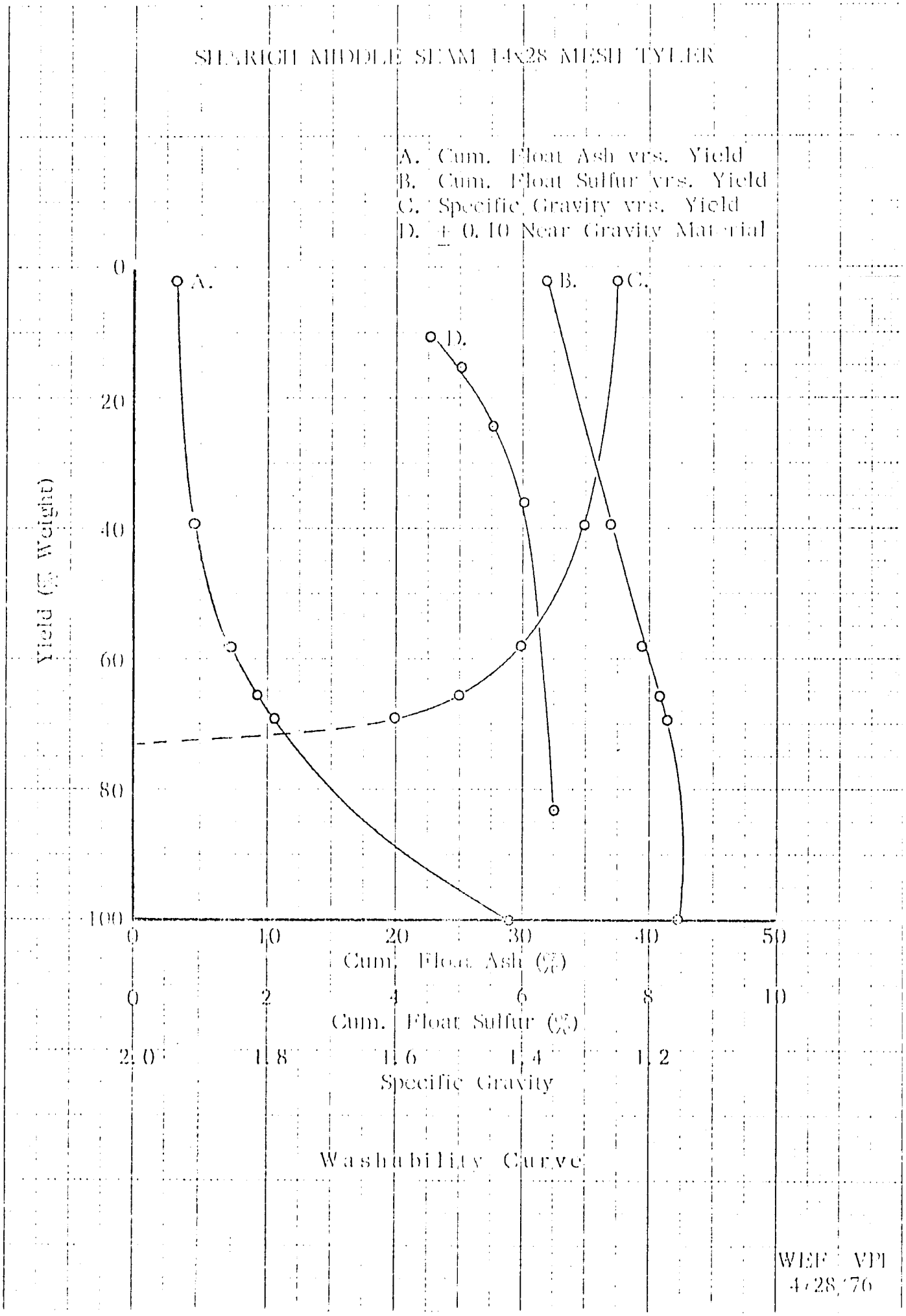

SEAGRIGH MIDDLE SEAM 14x28 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
A.
B.
C.
D.
Yield (% Weight)
0
20
40
60
80
100
0
10
20
30
40
50
Cum. Float Ash (%)
0
2
4
6
8
10
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WIEF VPI
4/28/76

FIGURE 19

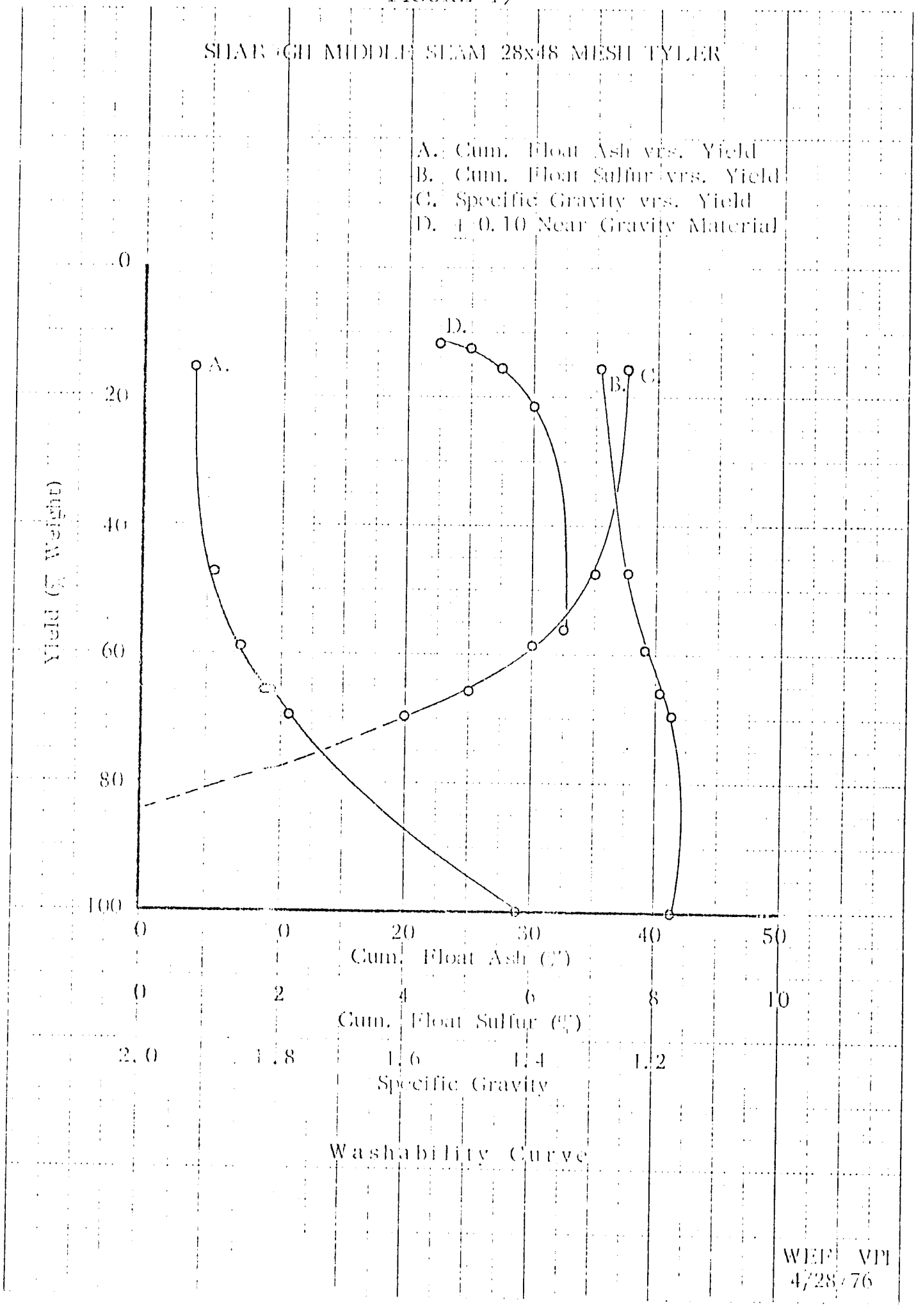

SHAR GH MIDDLE SEAM 28x48 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
0
20
30
40
50
Cum. Float Ash (%)
0
2
4
6
8
10
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 20

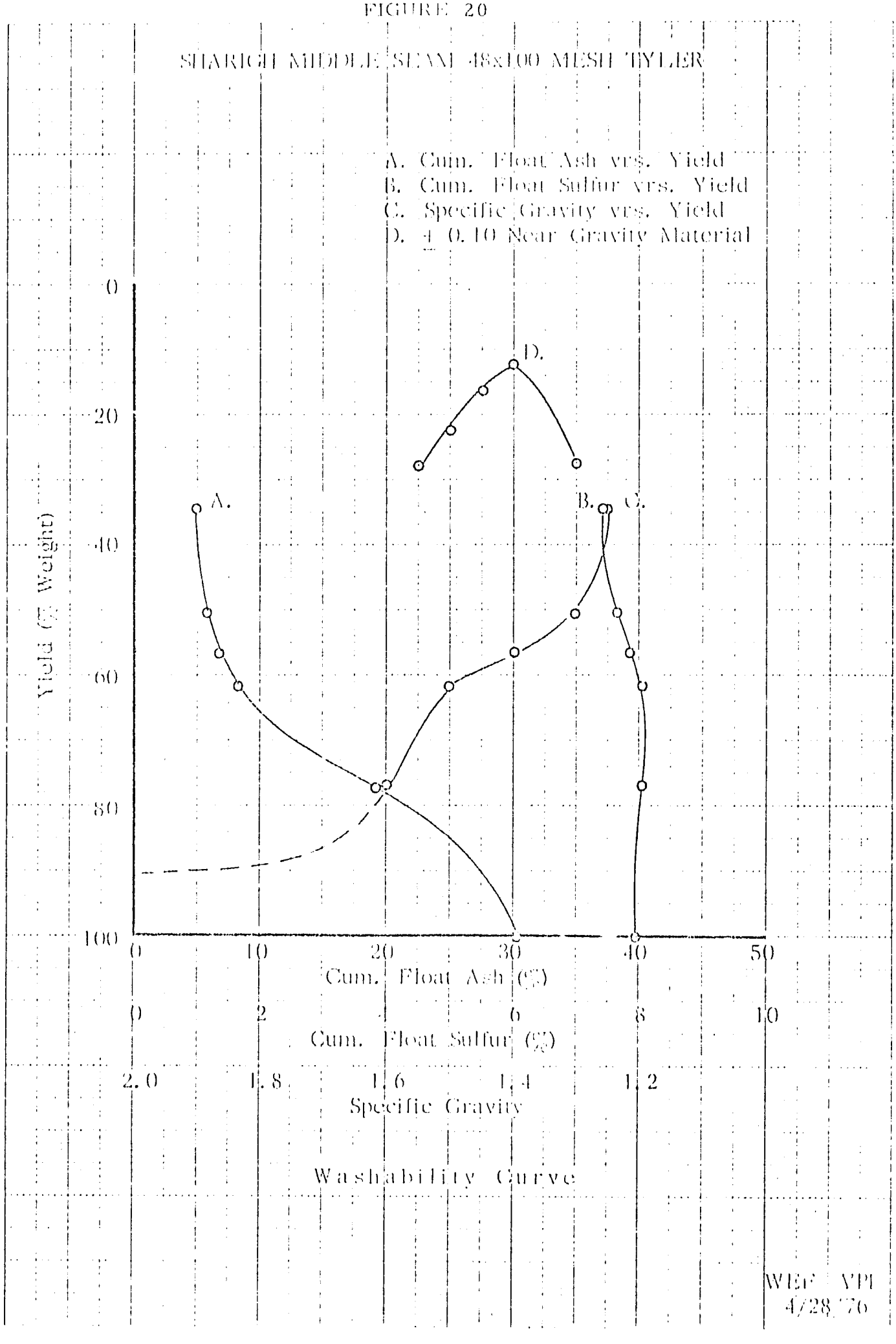

SHARIGH MIDDLE SEAM 48x100 MESH TYLER
A. Cum. Float Ash vrs. Yield
B. Cum. Float Sulfur vrs. Yield
C. Specific Gravity vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
10
20
30
40
50
Cum. Float Ash (%)
0
2
4
6
8
10
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 21

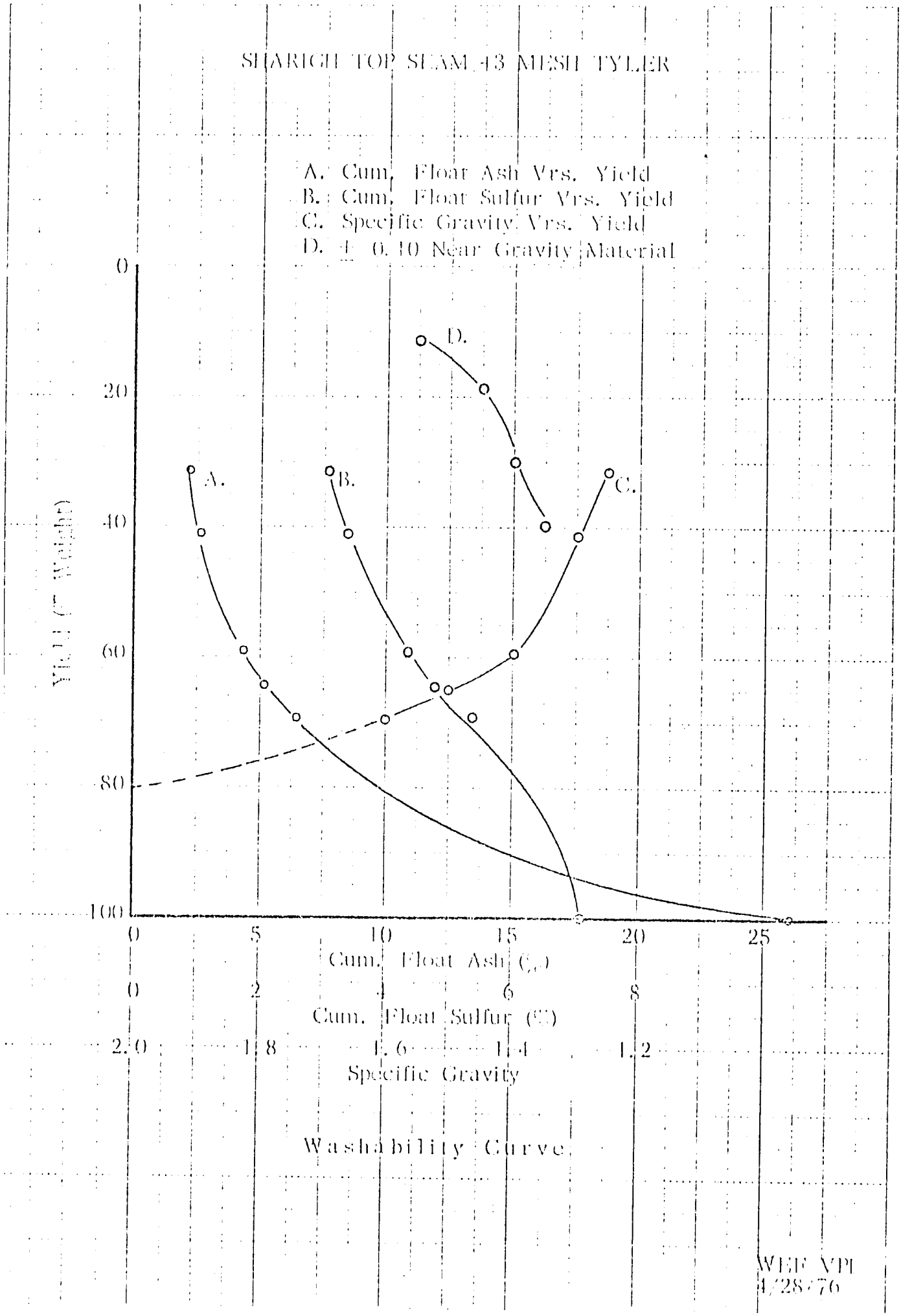

SHARIGH TOP SEAM 43 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 22

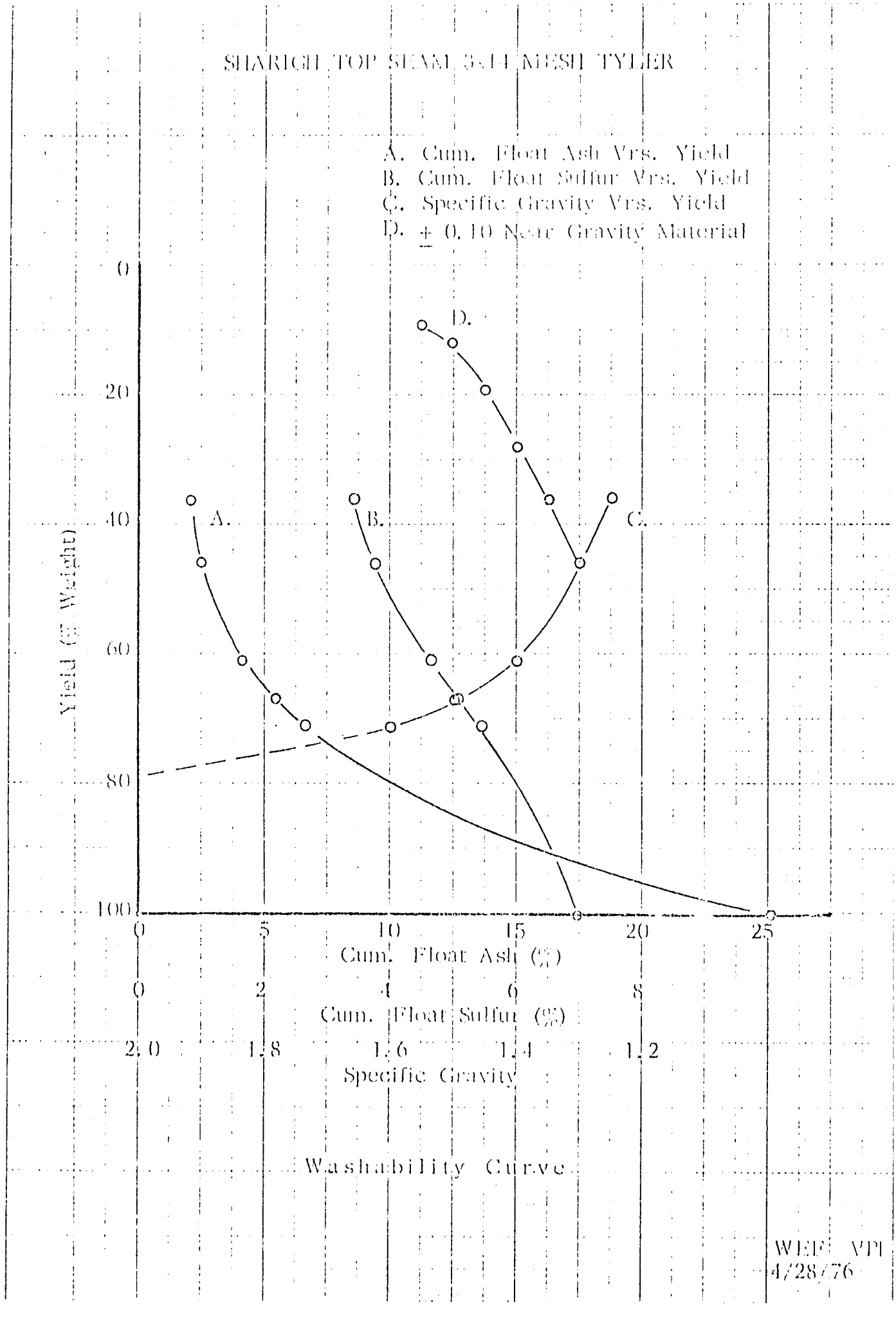

STARIGHT TOP SEAM 3x14 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

FIGURE 23

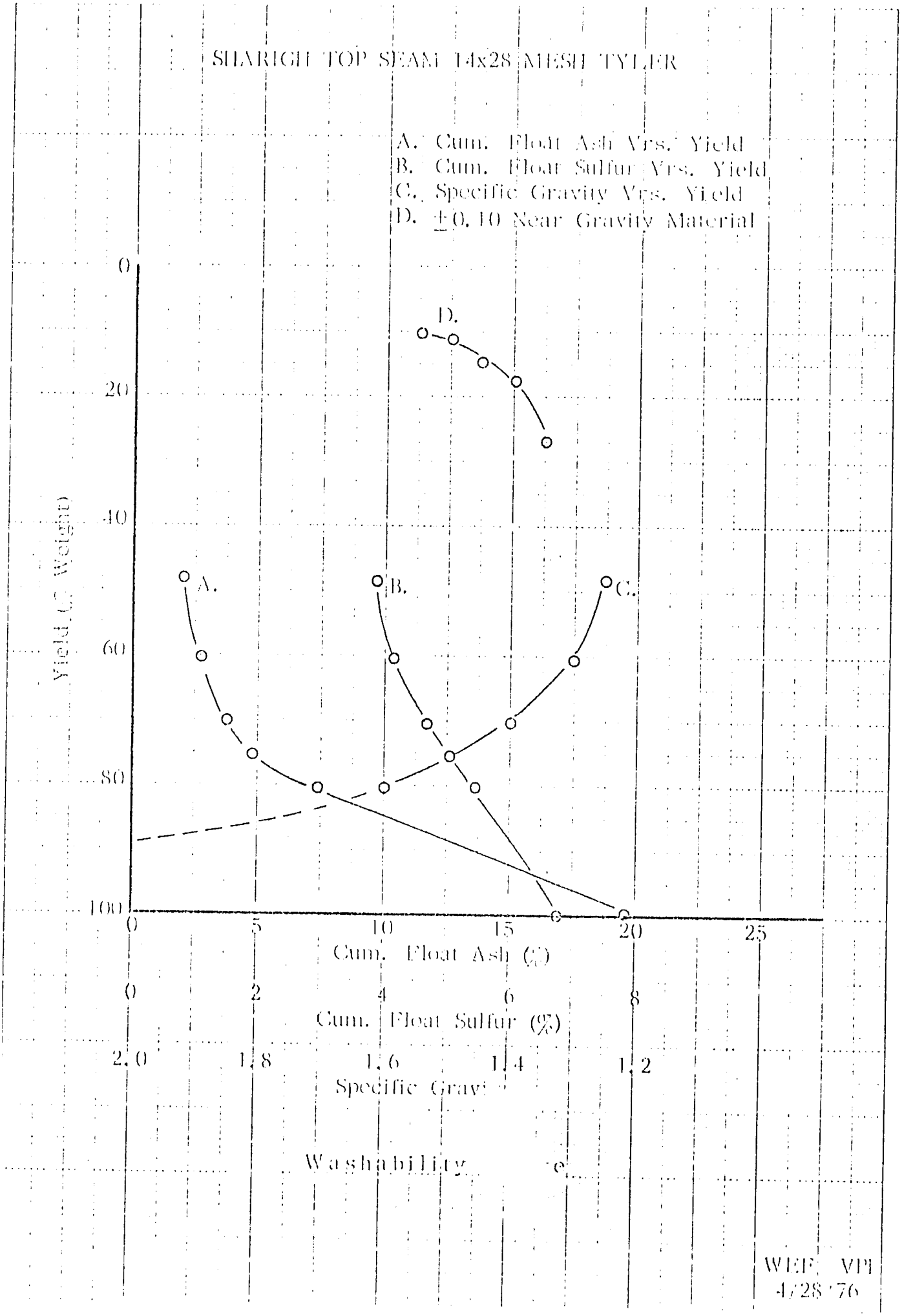

SHARIGH TOP SEAM 14x28 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ±0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Grav
Washability
WEF VPI
4/28/76

FIGURE 24

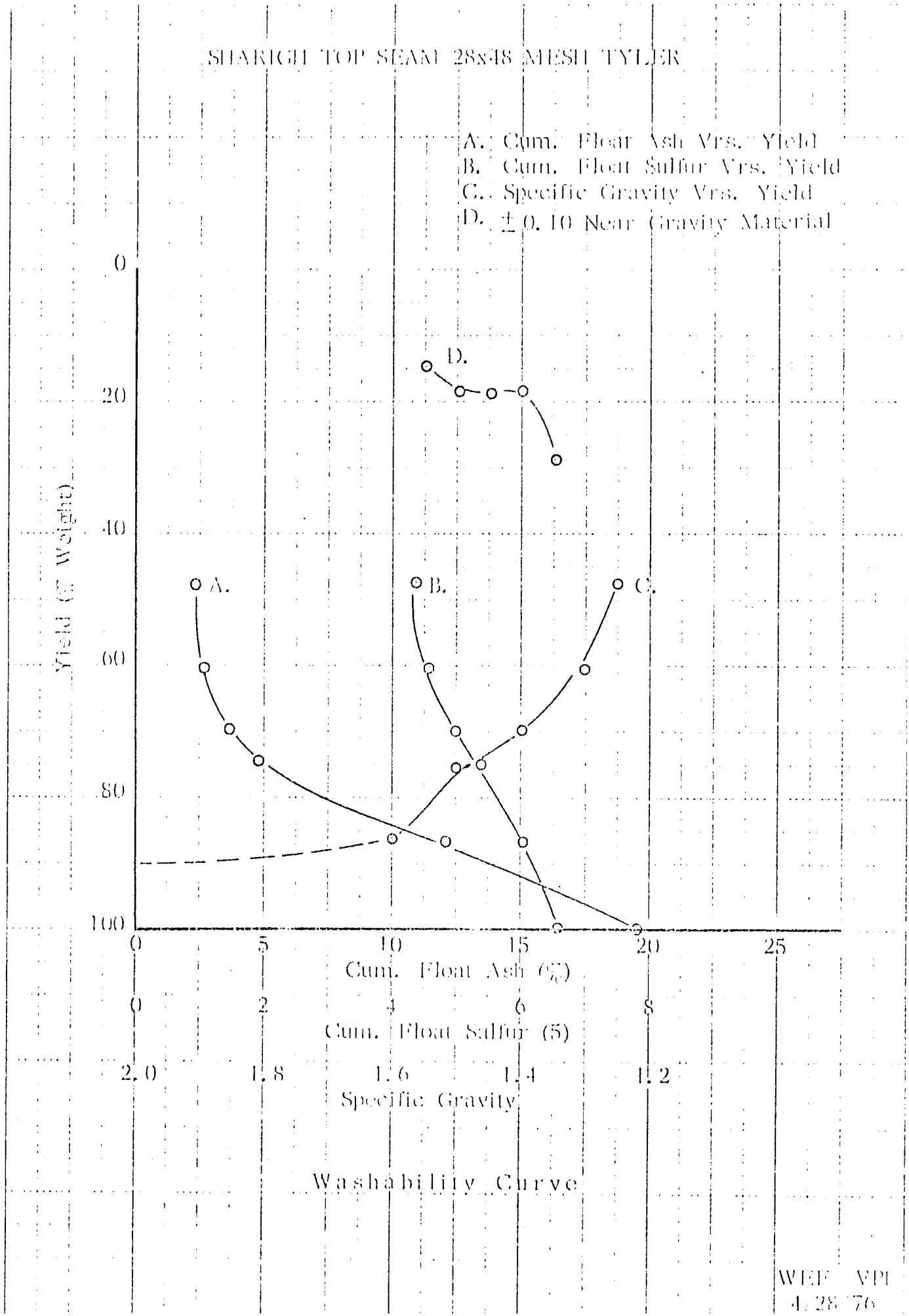

SHARIGH TOP SEAM 28x48 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4-28-76

FIGURE 25

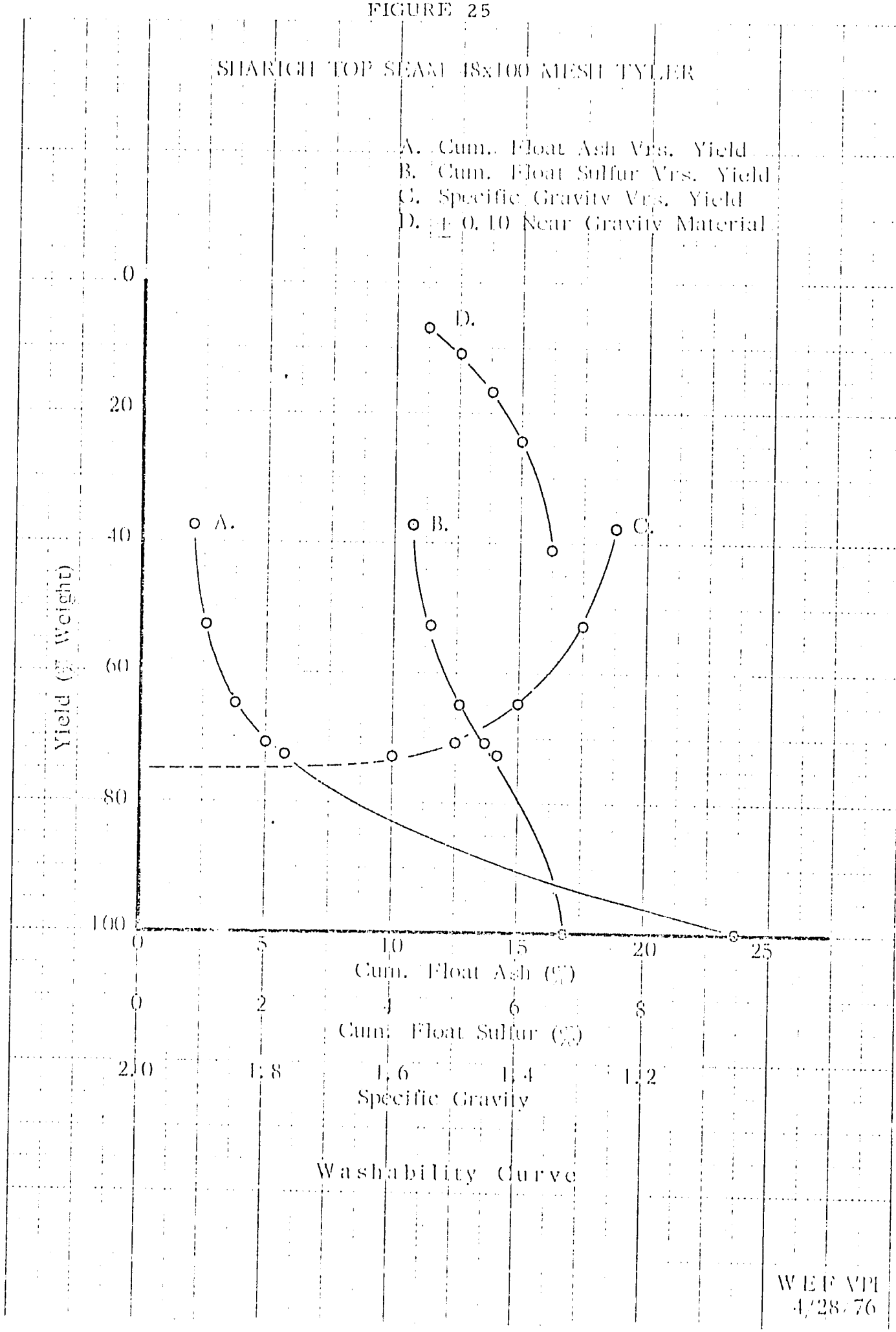

SHARIGH TOP SEAM 18x100 MESH TYLER
A. Cum. Float Ash Vrs. Yield
B. Cum. Float Sulfur Vrs. Yield
C. Specific Gravity Vrs. Yield
D. ± 0.10 Near Gravity Material
Yield (% Weight)
0
20
40
60
80
100
A.
B.
C.
D.
0
5
10
15
20
25
Cum. Float Ash (%)
0
2
4
6
8
Cum. Float Sulfur (%)
2.0
1.8
1.6
1.4
1.2
Specific Gravity
Washability Curve
WEF VPI
4/28/76

TABLE 2

FINELY GROUND SAMPLES

Sharig Coal - Top Seam

1.60 Float

	I		II		III	
	+100 Mesh	-100 Mesh	+200 Mesh	-200 Mesh	+325 Mesh	-325 Me
Ash =	7.9	9.7	7.7	10.0	8.1	11.4
Total S =	4.79	5.56	4.72	5.95	5.37	6.17
Sulfate S =	0.04	0.09	0.04	0.10	0.07	0.11
Pyrite S =	1.31	1.83	1.19	1.95	1.56	1.99
Total Inorganic S =	1.35	1.92	1.23	2.05	1.63	2.12
Organic S =	3.44	3.74	3.49	3.90	3.74	4.05

Lakra Coal - Sample HIM3

1.60 Float

	I		II		III	
	+100 Mesh	-100 Mesh	+200 Mesh	-200 Mesh	+325 Mesh	-325 Me
Ash =	20.8	23.6	19.4	24.5	20.1	25.0
Total S =	5.42	6.32	5.27	6.45	5.43	6.50
Sulfate S =	0.23	0.13	0.26	0.27	0.27	0.28
Pyrite S =	2.51	3.21	2.29	3.56	2.51	3.50
Total Inorganic S =	2.74	3.52	2.55	3.83	2.78	3.78
Organic S =	2.68	2.80	2.72	2.62	2.65	2.72

Note: Samples, I, II, III were gound so that 80% passed the 100, 200, and 325 mesh screens respectively.

TABLE 3

COMBINED TOTALS OF SIZED FRACTIONS FROM WASHABILITY DATA

Description	Specific Gravity	Weight Grams	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Ash Percent	Cumulative Sulfur Percent
WM1 Lakhra	1.25 Ft.	184	4.5	5.3	3.15	4.5	5.3	3.15
	1.25-1.30 Ft.	778	19.2	6.0	3.72	23.7	5.9	3.61
	1.30-1.40 Ft.	1491	36.8	8.4	5.13	60.5	7.4	4.53
	1.40-1.50 Ft.	545	13.5	17.9	7.85	74.0	9.3	5.13
	1.50-1.60 Ft.	369	9.1	40.1	11.93	83.1	12.7	5.88
	1.60 Sink	683	16.9	63.2	17.47	100.0	21.2	7.34
HIM3 Lakhra	1.25 Ft.	52	1.8	7.1	3.24	1.8	7.1	3.24
	1.25-1.30 Ft.	253	8.9	9.2	3.77	10.7	8.8	3.68
	1.30-1.40 Ft.	1343	47.3	14.5	5.88	58.0	13.5	5.47
	1.40-1.50 Ft.	526	18.5	26.9	6.79	76.5	16.7	5.79
	1.50-1.60 Ft.	370	13.1	41.7	4.81	89.6	20.4	5.65
	1.60 Sink	294	10.4	61.4	8.75	100.0	24.6	5.97
Sharigh Top Seam	1.25 Ft.	3109	41.1	2.1	3.82	41.1	2.1	3.82
	1.25-1.30 Ft.	874	11.5	4.4	5.15	52.6	2.6	4.11
	1.30-1.40 Ft.	946	12.5	9.5	7.30	65.1	3.9	4.72
	1.40-1.50 Ft.	406	5.4	18.8	10.50	70.5	5.1	5.17
	1.50-1.60 Ft.	400	5.3	41.8	10.86	75.8	7.6	5.56
	1.60 Sink	1833	24.2	69.2	10.73	100.0	22.5	6.81
Sharigh Middle Seam	1.25 Ft.	526	6.7	4.4	7.19	6.7	4.4	7.19
	1.25-1.30 Ft.	1858	23.7	4.8	7.46	30.4	4.7	7.40
	1.30-1.40 Ft.	1452	18.5	12.1	8.71	48.9	7.5	7.90
	1.40-1.50 Ft.	606	7.7	23.9	9.91	56.6	9.7	8.17
	1.50-1.60 Ft.	499	6.4	41.7	9.95	63.0	13.0	8.35
	1.60 Sink	2894	37.0	68.8	8.20	100.0	33.6	8.29

TABLE 4

SHARIG: 50% TOP SEAM - 50% MIDDLE SEAM WASHABILITY DATA

Description	Specific Gravity	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Weight Percent	Cumulative Weight Percent
Combined	1.23 Ft.	23.9	2.4	4.29	23.9	2.4	4.29
50% Top Seam	1.23-1.30 Ft.	17.6	4.7	6.71	41.5	3.4	5.32
-	1.30-1.40 Ft.	15.5	11.1	8.14	57.0	5.5	6.08
50% Middle	1.40-1.50 Ft.	6.6	21.8	10.15	63.6	7.2	6.51
Seam	1.50-1.60 Ft.	5.8	41.7	10.36	69.4	10.1	6.83
	1.60 Sink	30.6	69.0	9.20	100.0	28.1	7.55

TABLE 5

WMI LAKHRA WASHABILITY DATA

Description	Specific Gravity	Weight Grams	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Ash Percent	Cumulative Sulfur Percent
WMI Lakhra +8 Mesh	1.25 Ft.	17	14.0	5.5	3.23	14.0	5.5	3.23
	1.25-1.30 Ft.	22	18.0	7.4	4.39	32.0	6.6	3.88
	1.30-1.40 Ft.	36	29.5	11.6	5.92	61.5	9.0	4.86
	1.40-1.50 Ft.	10	8.2	22.8	7.33	69.7	10.6	5.15
	1.50-1.60 Ft.	12	9.8	33.5	8.01	79.5	13.4	5.50
	1.60 Sink	25	20.5	55.3	16.84	100.0	22.0	8.23
WMI Lakhra 3x14 Mesh	1.25 Ft.	126	3.9	5.0	2.97	3.9	5.0	2.97
	1.25-1.30 Ft.	595	18.6	5.7	3.39	22.5	5.6	3.48
	1.30-1.40 Ft.	1240	38.7	8.3	5.14	61.2	7.3	4.53
	1.40-1.50 Ft.	472	14.8	18.0	7.87	76.0	9.4	5.18
	1.50-1.60 Ft.	272	8.5	39.8	11.92	84.5	12.4	5.85
	1.60 Sink	497	15.5	62.1	18.30	100.0	20.1	7.79
WMI Lakhra 14x28 Mesh	1.25 Ft.	8	2.1	5.5	3.28	2.1	5.5	3.28
	1.25-1.30 Ft.	73	19.0	6.3	3.85	21.1	6.2	3.79
	1.30-1.40 Ft.	152	39.6	7.7	4.72	60.7	7.2	4.40
	1.40-1.50 Ft.	36	9.4	14.8	7.57	70.1	8.2	4.82
	1.50-1.60 Ft.	65	16.9	43.7	12.99	87.0	15.1	6.41
	1.60 Sink	50	13.0	60.4	16.92	100.0	21.0	7.75
WMI Lakhra 28x48 Mesh	1.25 Ft.	11	6.7	5.5	3.79	6.7	5.5	3.79
	1.25-1.30 Ft.	43	26.1	7.1	4.22	32.8	6.8	4.13
	1.30-1.40 Ft.	37	22.4	9.0	4.97	55.2	7.7	4.47
	1.40-1.50 Ft.	17	10.3	18.7	7.99	65.5	9.4	5.03
	1.50-1.60 Ft.	12	7.3	38.4	11.32	72.8	12.3	5.65
	1.60 Sink	45	27.2	66.3	15.96	100.0	27.0	8.46
WMI Lakhra 48x100 Mesh	1.25 Ft.	22	12.5	6.3	3.79	12.5	6.3	3.79
	1.25-1.30 Ft.	45	25.4	8.4	4.42	37.9	7.7	4.21
	1.30-1.40 Ft.	26	14.7	11.3	5.63	52.6	8.7	4.61
	1.40-1.50 Ft.	10	5.6	18.6	8.08	58.2	9.7	4.94
	1.50-1.60 Ft.	8	4.5	34.5	10.60	62.7	11.4	5.35
	1.60 Sink	6[illegible]	37.3	74.9	12.16	100.0	35.1	7.89

TABLE 6

HIM 3 LAKHRA WASHABILITY DATA

Description	Specific Gravity	Weight Grams	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Ash Percent	Cumulative Sulfur Percent
HIM 3 Lakhra +3 Mesh	1.25 Ft.	8	7.7	7.7	3.22	7.7	7.7	3.22
	1.25-1.30 Ft.	34	32.7	12.5	5.19	40.4	11.6	4.81
	1.30-1.40 Ft.	32	30.7	18.0	7.69	71.1	14.4	6.06
	1.40-1.50 Ft.	14	13.5	31.8	4.82	84.6	17.1	5.86
	1.50-1.60 Ft.	10	9.6	45.0	3.20	94.2	20.2	5.59
	1.60 Sink	6	5.8	60.0	8.34	100.0	22.5	5.75
HIM 3 Lakhra 3x14 Mesh	1.25 Ft.	11	0.5	6.2	2.66	0.5	6.2	2.66
	1.25-1.30 Ft.	169	7.5	8.0	3.36	8.0	7.9	3.32
	1.30-1.40 Ft.	1157	51.0	13.7	5.98	59.0	12.9	5.62
	1.40-1.50 Ft.	435	19.2	27.5	7.02	78.0	16.5	5.98
	1.50-1.60 Ft.	267	11.8	40.7	4.31	90.0	19.7	5.75
	1.60 Sink	226	10.0	62.8	8.63	100.0	24.0	6.03
HIM 3 Lakhra 14x28 Mesh	1.25 Ft.	3	1.3	5.1	2.78	1.3	5.1	2.78
	1.25-1.30 Ft.	7	2.9	7.7	3.57	4.2	6.9	3.33
	1.30-1.40 Ft.	98	41.2	11.2	4.43	45.4	10.8	4.33
	1.40-1.50 Ft.	42	17.6	18.9	7.43	63.0	13.1	5.19
	1.50-1.60 Ft.	63	26.5	42.6	6.61	89.5	23.7	5.61
	1.60 Sink	25	10.5	55.8	8.62	100.0	25.4	5.93
HIM 3 Lakhra 28x48 Mesh	1.25 Ft.	2	4.7	7.2	3.43	4.7	7.2	3.43
	1.25-1.30 Ft.	6	14.0	11.1	4.18	18.7	10.2	3.99
	1.30-1.40 Ft.	8	18.6	13.6	4.77	37.3	11.9	4.38
	1.40-1.50 Ft.	13	30.2	22.4	6.08	67.5	16.6	5.14
	1.50-1.60 Ft.	4	9.3	36.4	5.60	76.8	19.0	5.20
	1.60 Sink	10	23.2	53.3	7.86	100.0	26.9	5.81
HIM 3 Lakhra 48x100 Mesh	1.25 Ft.	28	14.9	7.4	3.51	14.9	7.4	3.51
	1.25-1.30 Ft.	37	19.7	11.4	4.29	34.6	9.7	3.95
	1.30-1.40 Ft.	48	25.5	16.9	5.47	60.1	12.7	4.60
	1.40-1.50 Ft.	22	11.7	29.5	5.67	71.8	15.5	4.77
	1.50-1.60 Ft.	26	13.8	49.2	6.11	85.6	20.9	4.99
	1.60 Sink	27	14.4	58.3	10.30	100.0	26.3	5.75

TABLE 8

SHARIGH TOP SEAM WASHABILITY DATA

Description	Specific Gravity	Weight Grams	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Ash Percent	Cumulative Sulfur Percent
	1.25 Ft.	110	30.9	2.2	3.04	30.9	2.2	3.04
Sharigh	1.25-1.30 Ft.	35	9.8	3.8	4.43	40.7	2.6	3.37
Top	1.30-1.40 Ft.	64	18.0	8.1	6.42	58.7	4.3	4.31
Seam	1.40-1.50 Ft.	19	5.3	14.3	9.97	64.0	5.1	4.79
-4 Mesh	1.50-1.60 Ft.	19	5.3	22.4	12.05	69.3	6.4	5.33
	1.60 Sink	109	30.7	70.0	10.98	100.0	25.9	7.07
	-1.25 Ft	1112	36.6	2.1	3.46	36.6	2.1	3.46
Sharigh	1.25-1.30 Ft.	295	9.7	3.9	5.08	46.3	2.5	3.79
Top	1.30-1.40 Ft.	460	15.1	9.4	7.15	61.4	4.2	4.62
Seam	1.40-1.50 Ft.	171	5.6	18.2	10.30	67.0	5.4	5.09
3x14 Mesh	1.50-1.60 Ft.	120	4.0	27.7	11.38	71.0	6.6	5.45
	1.60 Sink	880	29.0	70.3	10.60	100.0	25.1	6.94
	1.25 Ft.	939	48.2	2.0	3.87	48.2	2.0	3.87
Sharigh	1.25-1.30 Ft.	235	12.1	5.3	5.05	60.3	2.7	4.11
Top	1.30-1.40 Ft.	184	9.5	10.5	7.97	69.8	3.7	4.63
Seam	1.40-1.50 Ft.	97	5.0	20.1	10.58	74.8	4.8	5.03
14x28 Mesh	1.50-1.60 Ft.	104	5.3	43.0	11.12	80.1	7.3	5.43
	1.60 Sink	387	19.9	68.4	11.96	100.0	19.5	6.73
	1.25 Ft	543	47.6	2.3	4.34	47.6	2.3	4.34
Sharigh	1.25-1.30 Ft.	144	12.6	4.3	5.41	60.2	2.7	4.56
Top	1.30-1.40 Ft.	104	9.1	10.2	7.81	69.3	3.7	4.99
Seam	1.40-1.50 Ft.	58	5.1	19.7	10.55	74.4	4.8	5.37
28x48 Mesh	1.50-1.60 Ft.	136	11.9	57.5	10.08	86.3	12.1	6.02
	1.60 Sink	157	13.7	65.4	10.19	100.0	19.4	6.59
	1.25 Ft.	405	37.3	2.0	4.27	37.3	2.0	4.27
Sharigh	1.25-1.30 Ft.	165	15.2	4.3	5.34	52.5	2.6	4.58
Top	1.30-1.40 Ft.	134	12.3	8.4	6.90	64.8	3.8	5.02
Seam	1.40-1.50 Ft.	61	5.6	18.9	10.90	70.4	5.0	5.49
48x100 Mesh	1.50-1.60 Ft.	21	1.9	31.9	10.66	72.3	5.7	5.62
	1.60 Sink	300	27.7	68.6	9.73	100.0	23.1	6.76

TABLE 7

SHARIGH MIDDLE SEAM WASHABILITY DATA

Description	Specific Gravity	Weight Grams	Weight Percent	Ash Percent	Sulfur Percent	Cumulative Weight Percent	Cumulative Ash Percent	Cumulative Sulfur Percent
	1.25 Ft.	3	0.7	-	-	0.7	-	-
Sharigh	1.25-1.30 Ft.	30	6.8	4.5	7.10	7.5	4.5	7.10
Middle	1.30-1.40 Ft.	77	17.5	10.5	8.42	25.0	8.6	8.02
Seam	1.40-1.50 Ft.	35	8.0	21.6	9.28	33.0	11.8	8.32
-3 Mesh	1.50-1.60 Ft.	28	6.4	33.2	9.77	39.4	15.3	8.56
	1.60 Sink	267	60.6	63.7	8.05	100.0	44.6	8.25
	1.25 Ft.	16	0.4	3.1	6.27	0.4	3.1	6.27
Sharigh	1.25-1.30 Ft.	708	19.1	3.9	7.20	19.5	3.9	7.18
Middle	1.30-1.40 Ft.	862	23.3	11.4	8.55	42.8	8.0	7.93
Seam	1.40-1.50 Ft.	331	8.9	23.2	9.70	51.7	10.6	8.23
3x14 Mesh	1.50-1.60 Ft.	228	6.1	32.6	10.66	57.8	12.9	8.49
	1.60 Sink	1563	42.2	69.1	8.08	100.0	36.6	8.32
	1.25 Ft.	38	2.2	3.2	6.40	2.2	3.2	6.40
Sharigh	1.25-1.30 Ft.	656	37.1	4.5	7.46	39.3	4.4	7.40
Middle	1.30-1.40 Ft.	335	19.0	13.1	8.93	58.3	7.3	7.90
Seam	1.40-1.50 Ft.	129	7.3	25.0	10.34	65.6	9.2	8.17
14x28 Mesh	1.50-1.60 Ft.	66	3.7	34.4	10.84	69.3	10.6	8.31
	1.60 Sink	542	30.7	70.5	8.79	100.0	29.0	8.45
	1.25 Ft.	160	15.8	3.8	7.03	15.8	3.8	7.03
Sharigh	1.25-1.30 Ft.	318	31.3	6.2	7.77	47.1	5.4	7.52
Middle	1.30-1.50 Ft.	119	11.7	14.7	9.13	58.8	7.3	7.84
Seam	1.40-1.50 Ft.	66	6.5	26.0	10.26	65.3	9.1	8.08
28x48 Mesh	1.50-1.60 Ft.	39	3.8	36.0	10.73	69.1	10.7	8.22
	1.60 Sink	313	30.9	70.0	8.22	100.0	28.9	8.23
	1.25 Ft.	309	34.1	4.9	7.41	34.1	4.9	7.41
Sharigh	1.25-1.30 Ft.	146	16.1	7.9	8.14	50.2	5.9	7.64
Middle	1.30-1.40 Ft.	59	6.5	14.7	9.23	56.7	6.9	7.83
Seam	1.40-1.50 Ft.	45	5.0	24.4	10.17	61.7	8.3	8.02
48x100 Mesh	1.50-1.60 Ft.	138	15.2	63.4	8.17	76.9	19.2	8.05
	1.60 Sink	209	23.1	67.0	7.75	100.0	30.2	7.98

CONVERSION PROCESSES

This portion of the work is concerned with the possible economic upgrading of the Sharigh and Lakhra coals.

Two processes which have been previously commercialized were investigated, i.e. carbonization and hydroliquefaction.

Research and development effort at present has resulted in coal conversion processes of a variety of techniques. The state-of-the-art indicates that the proposed methods all require substantial funds for commercialization and each presents formidable technical problems. These are discussed elsewhere in this report.

The carbonization of coal is an old art which has been in commercial production for many years. It presents no unusual developmental problems.

Presently plans are being formalized to mine one million tons of Lakhra coal as fuel to a thermal unit to generate 250 MW of electricity.

If the generating facility were located at the mine shaft, it would

(1) Partly alleviate the problem of spontaneous combustion.

(2) Save in hauling and capital cost for a railroad. Water pipelines and power lines cost less than a coal transport system.

(3) Coal could be devolatilized and the offgas and hot char fed to the furnaces at the powerhouse.

(4) Proper limestone conditioning of coal would present the most economical method of high sulfur disposal in the ash.

(5) Limestone additive to the coal would condition the ash as a possible feed development to a cement kiln.

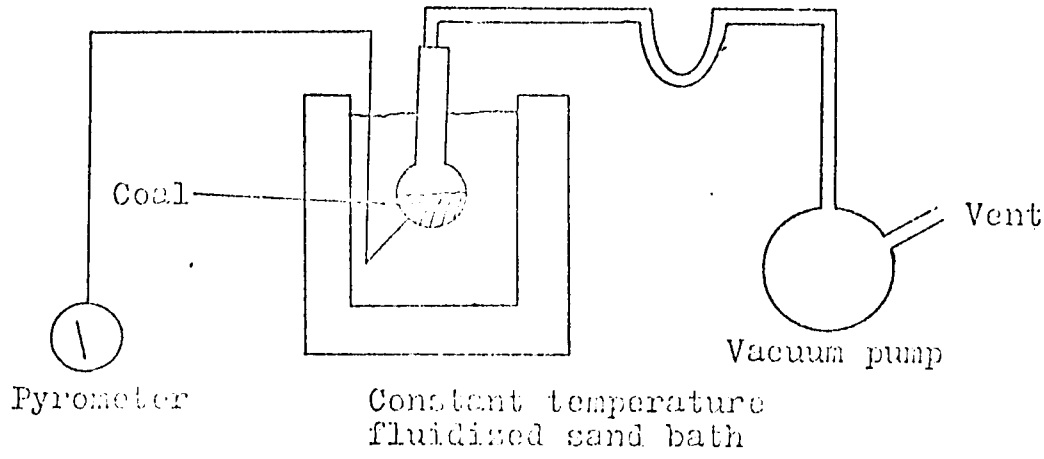
(6) The liquid and low temperature tars can be processed to benzene, toluene, xylene, naphthalene, wax, etc. to increase the economic recovery of values from the Lakhra coal.

(7) The planned disposal of products to the powerhouse furnace adds an important degree of flexibility for balancing the product streams from a carbonizer.

It is with this purpose that carbonization studies were undertaken. In considering a potential carbonization process for Lakhra coal it is important to take into consideration the production of tar products which will be generated from the coke plant to be installed in conjunction with the steel mill operation in Pakistan. The by-products of the coke plant may produce all of the tar products required for Pakistan.

Carbonization - This phase of the research program involved investigating the potential for partial devolatilization of each of the four coals. Each coal was first examined using thermogravimetric analysis to determine the optimum temperature of devolatilization for carbonization.

Next, an apparatus was devised (illustrated below) to determine to what extent these coals could be devolatilized and if the resultant coal-char could be briquetted as fuel.



For these tests, ten grams of the 1.60 float fraction of each coal was weighed and placed in a vacuum retort immersed in a constant temperature fluidized sand bath. The vacuum served two purposes: first, to remove oxygen from the coal to prevent combustion and second, to remove volatiles as they were given off. For each coal, the temperature was increased gradually until volatiles began to come off as evidenced by the odor from the pump vent and in some cases from the visible smoke emitted. When the production of volatiles seemed to be finished, the temperature was increased slightly to encourage further release. This procedure was followed until no additional gases could be removed. The retort was then removed from the bath and the weight loss determined. Results are given in the table below:

Partial Devolatilization of 1.60 Float
Lahkra and Sharigh Coals

Coal	Weight Loss Percent	Original Vol. Matter of 1.60 Float	Volatile Loss Percent
WMI	17.71	43.3	40.9
HIM3	15.29	42.1	36.3
STS	16.70	46.3	36.1
SMS	19.12	48.7	39.3

Devolatilization temperatures were 380°C for the Lahkra coals WMI and HIM3 and 410°C for the Sharigh coals. The char remaining from the devolatilization test for each coal was then mixed with calcium hydroxide in the same proportions chosen for the large scale briquettes on the basis of compressive strength, i.e. 100% stoichiometric calcium hydroxide for the Lahkra coals and 200% stoichiometric calcium hydroxide for the Sharigh coals. The mixtures were prepared in a mortar and pestel and hand pressed into pellets using the same technique as was utilized in the preliminary briquetting studies.

Pellets were made for each devolatilized coal but were much weaker than those made with regular coal. These four pellets were then burned and an odor emission evaluation made. Volatile matter odor was still apparent although the sweet lime smell could also be discerned. No sulfur dioxide odor was detected. It was noted during this work that all coals, if exposed to air at 300°C, would combust spontaneously and that the Sharigh coals had a tendency to lose volatile matter by coking over a very narrow temperature range.

The following is a general example to the low-temperature tars composition to be expected from the Lakhra coal:

Specific Gravity crude tar 60/60	1.019
Benzene insoluble matter	2.0
Distillation pressure	40 mm
Distillate	65
Pitch	33
Loss	2
Temp. of decomposition °C	294
Specific gravity distillate	0.963
Yield Distillate, Vol. %	68

Analysis of Distillate	%	Sp. Gr.
170°C	1.5	.84
170 - 200	5.4	.918
200 - 210	4.1	.930
210 - 240	9.5	.940
240 - 275	17.8	.952
275 - 350	50	.970
Residue	9	
Loss	2.2	

The composition and quantity of tar and fixed gases will vary depending on rate of heating, temperature and extent of devolatilization. It can be anticipated for preliminary estimates that the char yield would be about 70% of the charge (ash and moisture-free basis); the gallons (U.S.) of tar per ton of char would be about 37-38 per long ton (MAF) or 26-27 based on MAF coal.

The idea of carbonizing subbituminous coals prior to combustion in a power plant is not new. In Germany, power plants have operated on brown coal and lignites for many years. The carbonization process with noncoking coals has been investigated extensively by the U.S. Bureau of Mines employing fluidized beds about twenty years ago.

Bed temperatures of 500°C are employed with a lignite feed of minus 840 mesh to yield primary tar, gas and char. It has been found that a small processing plant to handle up to 50 tons of subbituminous noncoking coal per hour can be built at relatively low cost.

Pioneering work was done by the Aluminum Company of America and Texas Power & Light Co. at Rockdale, Texas in order to solve many of the engineering and operational problems.

Each proposal for a carbonizing plant must be evaluated on its particular circumstances and economics. Many factors affecting such recommendationare unknown at present and are outside of the scope of this project.

The work at the Fuel and Leather Research Centre under the Pakistan Council of Scientific & Industrial Reasearch (PCSIR) should be encouraged, particularly their studies of low-temperature tars and to provide additional data.

Economic Parameters

The incentive for carbonizing coals at a power plant is to produce a fuel and a tar by-product. The value of the tar must pay for its generation, the loss of heating values, amortization of capital assets, and an acceptable profit incentive.

The relative ratio of costs between tar and coal indicate the degree of economic incentive for this type of process. As the cost of coal advances, the margins of profit decrease. The following formula applies:

$$P = VT - C(- R)$$

Where P = Net cost of processing and handling fuel to the burner - Includes crushing, drying, carbonization, tar condensing and material handling minus the total estimated cost of burning raw coal including crushing, pulverizing and handling.

C = Cost of coal delivered to the processing plant.

R = heat ratio, char/coal = $\frac{\text{net heat in char produced}}{\text{net heat in coal processed.}}$

T = tar yield, gallons per ton.

V = break-even value of the tar, costs per gallon.

Estimates for Lakhra coal are indicated to be as follows:

$R = \frac{9850}{11.000}$ (MAF basis) (Estimated)

C = 200 R$/ per long ton

T = 27 (U.S.) gallons/ton of coal.

V = R$/ 2.5 minimum value of tar.

then $P = VT - C(- R) = 2.5 \times 27 - 200 (1 - \frac{9850}{11.000})$

P = R$/ 47/ton.

The net cost of processing should not be higher than R$/ 47 based on the assumptions made. The price of tar is expected to be much higher than R$/ 2.5 per U.S. gallon. This indicates the pocitive preliminary economic fasibility of the process; however, a considerable amount of testing must be done to verify these preliminary concepts.

Furthermore, consideration should be given to the effect of this type process on socio-economic factors, balance of payments, etc. for Pakistan.

We therefore recommend that this work be continued by PMDC.

LIQUEFACTION

A large number of coal types in the bituminous class lend themselves to treatment with coal tar solvents. Such treatment at elevated temperatures results in both solution of volatile fractions as well as the depolymerization of vitrines and inertites to particles of colloidal size.

Where such reaction occurs it is possible to filter the ash and pyrite impurities from the coal sols and thus produce a stock for delayed coking which provides midvolatile cokes, solvents and recycle tars for the solution process.

This process has been practiced in Germany (Pott-Brosch) many years ago; however, its application is limited by the nature of the coal and the filterability and yield of sols resulting from the digestion of the fine coal with recycle tars.

Modifications of these solution processes have been reported from time to time. (See Exhibit 1 on the following page.)

The liquefaction potential of the two Sharigh coals was examined in order to evaluate their possible use as an organic chemical feedstock. During the preliminary stages of this work, no pressure equipment was available. In order to gain some information, a refluxing

EXHIBIT 1

Technology

ADL develops coal liquefaction process

With oil and gas production in the U.S. slowly decreasing, coal is seen by many as the obvious fossil fuel alternative. The problem is that coal suffers from a number of handicaps.

Coal, for example, contains sulfur that is difficult to remove, and that can make it environmentally undesirable. At the same time, a lump of coal can't be used to fuel an automobile, or conveniently be converted into, say, polyethylene.

The answer is to convert coal into sulfur-free liquid fuels and chemical feedstocks, a process known as coal liquefaction. Several projects are under way toward this end, including a new version from Arthur D. Little Inc., the big Boston-based research and consulting firm.

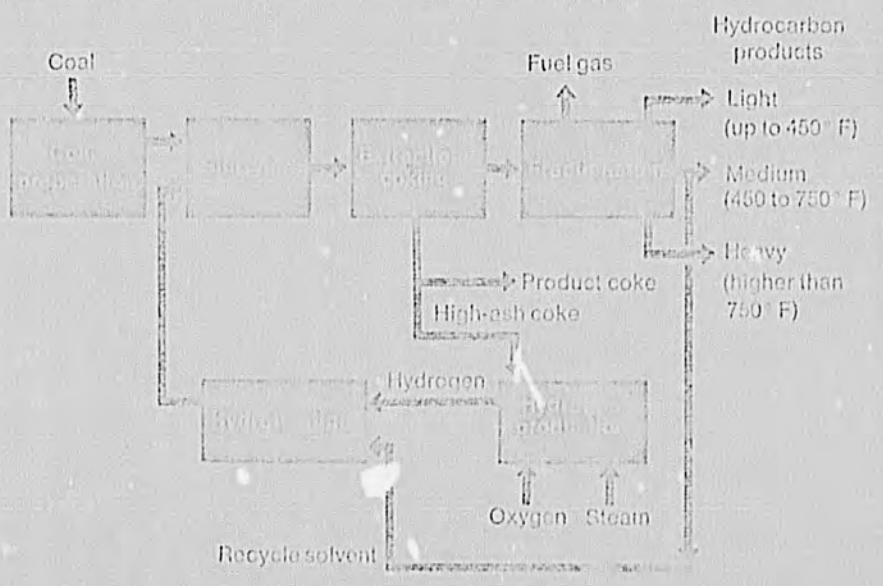
Although similar to several existing processes, such as H-Coal and Synthoil, ADL researchers claim their process overcomes some of the major difficulties with coal liquefaction, not the least of which is separation of undissolved coal and ash from liquid extracts. According to ADL chemical engineer Stephen A. Reber, the liquefaction process gets around this problem by using extractive coking to achieve a clean separation of liquids and solids. At the same time, coking has a number of other advantages, says Reber, including more efficient hydrogen utilization, relatively easy extraction of liquids, the use of commercially available equipment, and no need for an extraction catalyst. The Energy Research & Development Administration is funding the work, and Foster Wheeler Energy Corp., Livingston, N.J., is supplying a pilot plant and manpower to test the process.

Extractive coking uses a hydrogen donor solvent under mild conditions to perform the liquefaction, and then cracking and coking to separate the product as a vapor from coal and ash. It starts when a mixture of crushed coal and a mildly hydrogenated aromatic solvent (boiling range 450 to 750° F) is added to the coking drum as a slurry. The coal and solvent are allowed to react in the drum for about one hour at about 100 psi to keep the solvent in liquid form. During the extraction, hot solvent is passed continuously through the coking drum to supply heat and mixing action. When the extraction is complete, the drum pressure is reduced to remove the solvent and light hydrocarbon fractions.

Heating with solvent is continued, and the drum content is allowed to coke at about 850° F. This results in complete separation of ash and unreacted coal, which, according to Reber, is a distinct advantage over the usual mechanical separation. Hydrocarbon vapors produced by extractive coking are continuously fractionated to separate the solvent from products. Fractionation also separates products into gases and light-, middle-, and heavy-boiling-range products. Light- and middle-boiling-range products can be hydrotreated and hydrocracked to a low-sulfur distillate that can be processed into products such as gasoline and jet fuel.

Since the liquefaction process hasn't yet been run in a commercial-scale plant, says Reber, its economics aren't clear. But he believes it will "definitely" offer significant advantages over existing processes. He cites a number of factors, but lower capital investment is the biggest one. For example, extraction takes place at a much lower pressure (100 psi) than in other processes (2000 to 4000 psi), eliminating the need for much high-pressure hardware. □

Extraction-coking step is key to ADL process



experiment using coal and anthracene oil was carried out to see if any coal could be solubilized or any sulfur removed without destroying the coking properties of the coal. Each coal in turn was added to a fresh amount of anthracene oil in the proportions of 20 grams of coal to 120 grams of oil and placed in the reflux apparatus. The cold slurry was heated to 170°C at atmospheric pressure and held at temperature for 15 minutes. At the end of this time the slurry was cooled to 100°C and vacuum filtered while still hot. The filter cake was washed and dried over night and analyzed for percent sulfur and FSI. It should be pointed out that this data was obtained using raw coal and not the 1.60 float fraction. The following is a tabulation of the data obtained:

Coal	% S in Raw Coal	% S in Treated Filter Cake	FSI Untreated	FSI Treated
WMI	7.84	7.13	0	0
HIM3	5.97	5.40	0	0
STS	6.81	5.72	4	1
SMS	3.29	8.00	4	1

This data indicated that very little sulfur reduction could be achieved and that any coking properties would be essentially destroyed. The filtrate portion of the reflux operation was analyzed by infrared spectroscopy in order to determine if any volatile material was dissolved by the anthracene oil solvent. The infrared spectrum of the Lakhra WMI and HIM3 samples in the 4000 to 1500 cm^{-1} region

together with a spectrum of anthracene oil which was processed through the reflux operation as a blank are included as Figures 8, 9, and 10, pages 7-15,16, and 17. Unfortunately, the anthracene oil solvent contains too many infrared bands to allow any meaningful comparisons between it and the WMI and HIM3 bands. However, no new bands were noted. This would seem to indicate that no volatine material was removed from the coal during this experiment. The most useful piece of information gained from this work was that the temperature for the devolatilization of these coals must exceed 170°C at atmospheric pressure.

A Parr pressure vessel was used in a second series of tests. Seventy-five grams of anthracene oil was added to 25 grams of STS coal and the slurry placed in the vessel. A mechanical stirrer kept the coal in suspension during the test. Heat was applied to the pressure vessel until a pressure of 150 psig was achieved where the pressure was held for approximately 10 minutes. The heat was then turned off and the pressure allowed to drop naturally to about 90 psig. At this time, a release valve was cracked to hasten the pressure drop while maintaining temperature. This was done in an effort to keep the viscosity sufficiently low to permit the removal of ash particles from the dissolved coal and oil solution by filtering through a pre-heated porcelain buchner funnel. When the contents of the vessel were poured into the funnel, however, only a few drops of filtrate was extracted before the molasses-like coal and oil mixture solidified into a tar like sub-

stance. Scraping of the filter cake revealed undissolved particles of coal and the test was aborted. In a second test using SMS coal the pressure was raised to 170 psig and the pressure bled off after cooling to 100 psi in an effort to overcome the viscosity problem, but the results were essentially the same.

For the next two tests, a special hot vacuum metal filter apparatus was devised and fabricated in an attempt to solve the problem. The device consisted of a 325 mesh brass cloth supported by a 40 mesh 8 inch brass testing sieve. This was placed over and sealed to a vacuum canister below. The apparatus was heated to approximately 500°F prior to use. The final pressure reached in the last two tests (STS and SMS) was 190 and 210 psig respectively. In spite of the higher filtering temperatures achieved with the metal filter only slightly improved results were achieved as evidenced by the absence of undissolved coal granules in the tar. The slurry remained too viscous to filter however, and these tests were also aborted. The vapor pressure curve for anthracene oil, included as Figure 4, page 7-14 indicates a breakdown of molecular structure at temperatures approaching those obtained in the final test. The results indicate that a different solvent and/or the addition of hydrogen gas and higher pressure would probably be necessary for complete liquefaction of these coals. It was noted during this work that a paraffin-like substance condensed from the vapors which escaped when bleeding off excess pressure prior to filtering. The quantity of this material increased to an estimated quarter gram in the final test.

CONCLUSIONS - The following conclusions relative to their portion of the investigation are in order.

(1) The depolymerized miscelles in the sols formed from Sharigh coals are of such size as to make filtration impractical.

(2) The use of cutter stocks such as recycle neutral oil results in the precipitation of soluble fractions of the vitrines making the sols "gummy" and impossible to filter.

(3) The high viscosity of the sols is not reduced appreciably with increase in temperature.

(4) Sharigh coals are not candidates for solution processes on a practical economically sound basis due to the high telinite content of the vitrinite.

We recommend no further effort be expended in this direction for the present and forseeable future, or until new techniques are discovered.

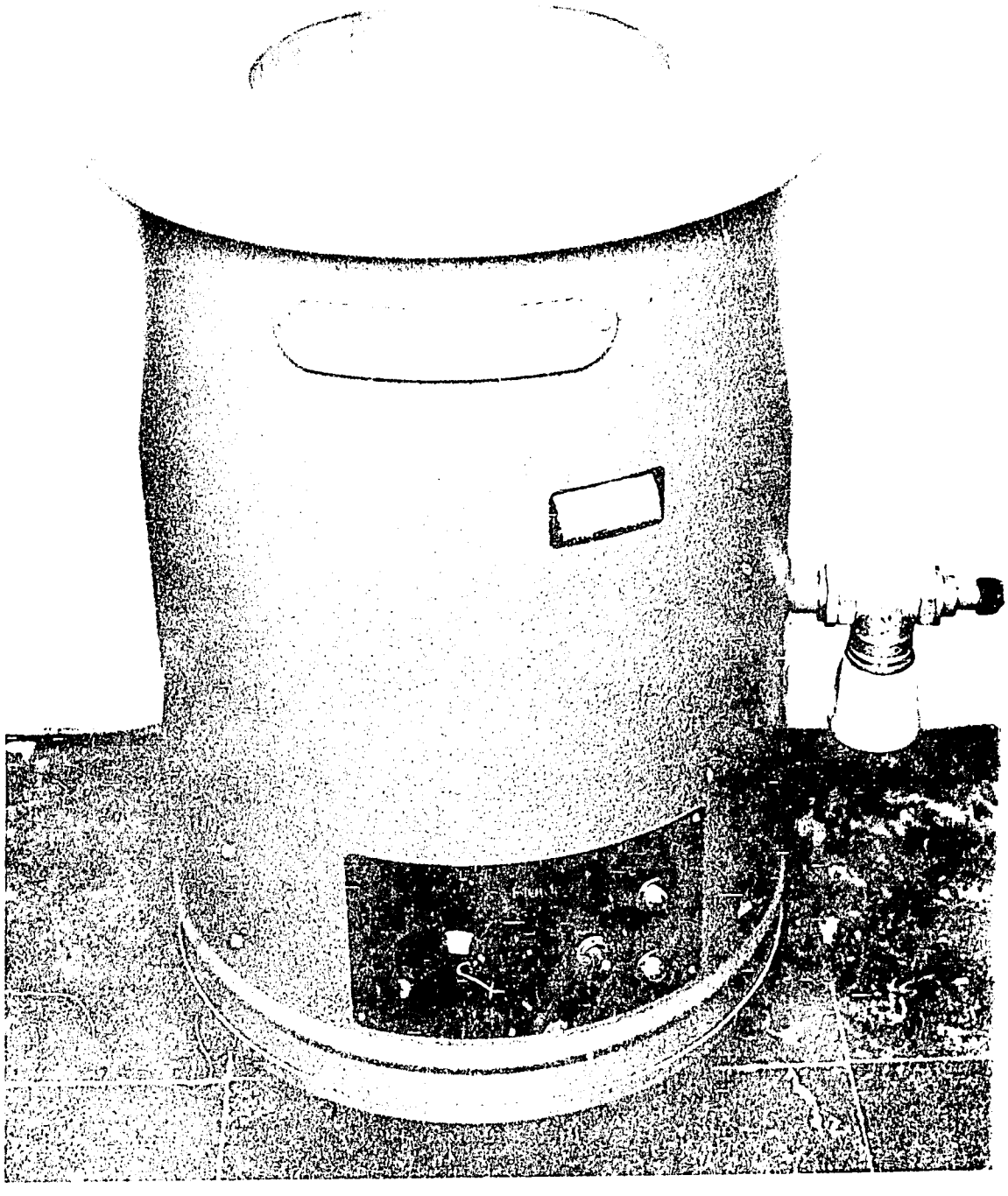


FIGURE 1. FLUIDIZED BED REACTOR

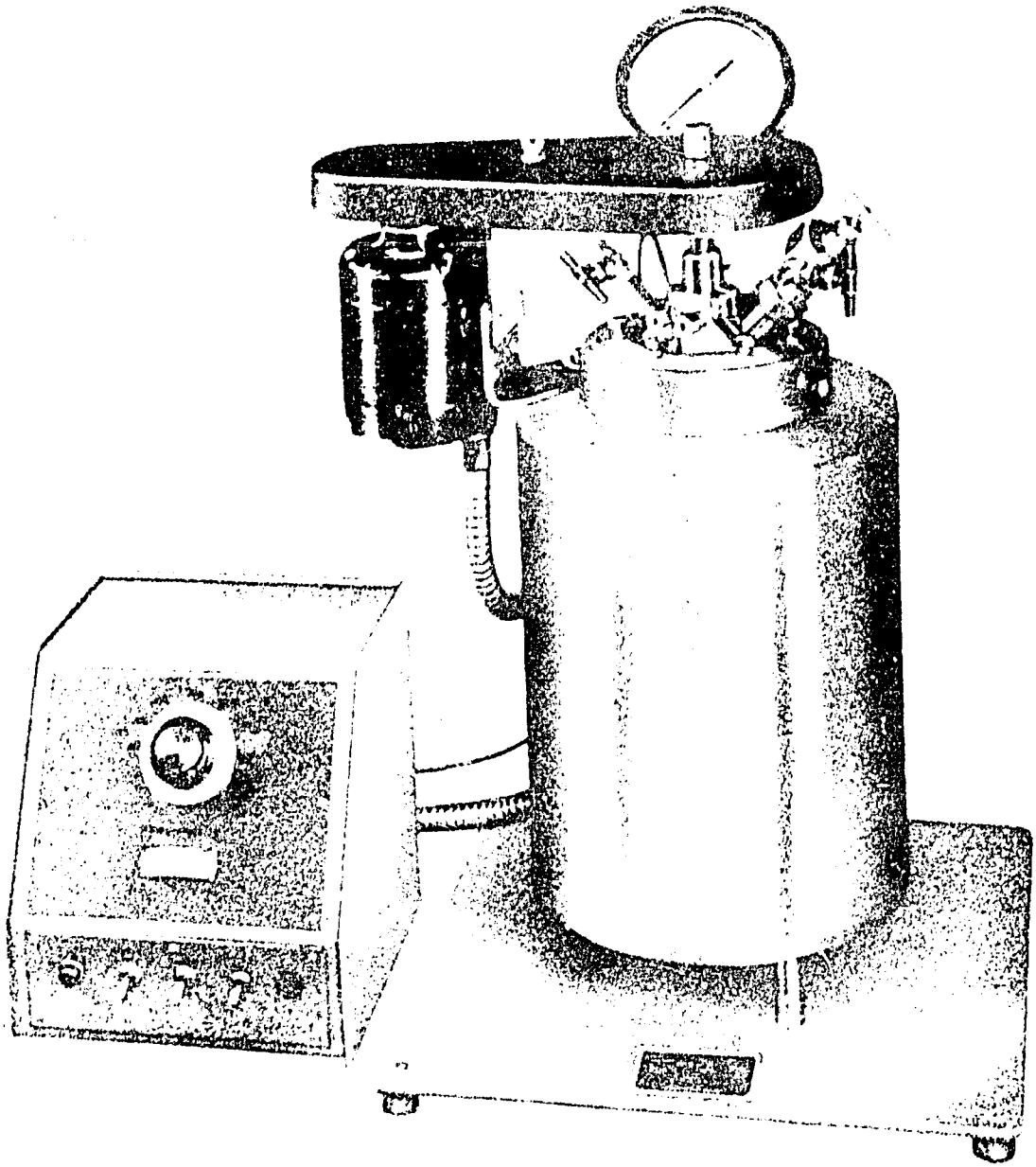


FIGURE 2. PARR PRESSURE REACTION APPARATUS

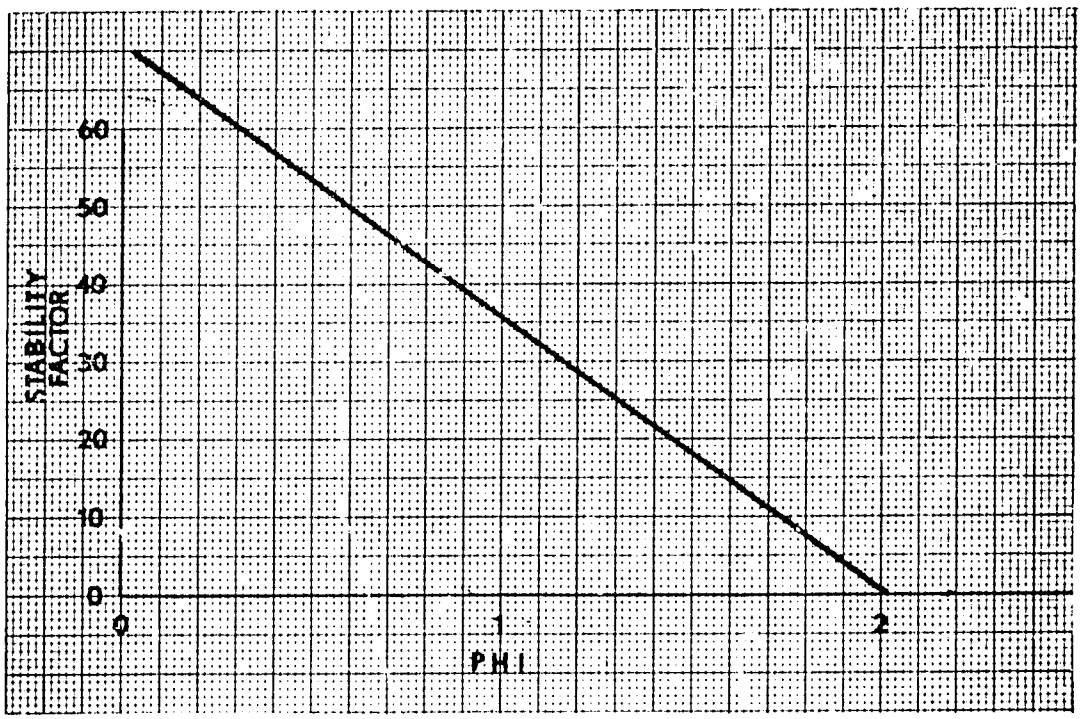


Figure 8. Stability Factor Standard Curve. PHI (Ø) units of the 30th percentile from the probability graph are transformed to Stability Factors.

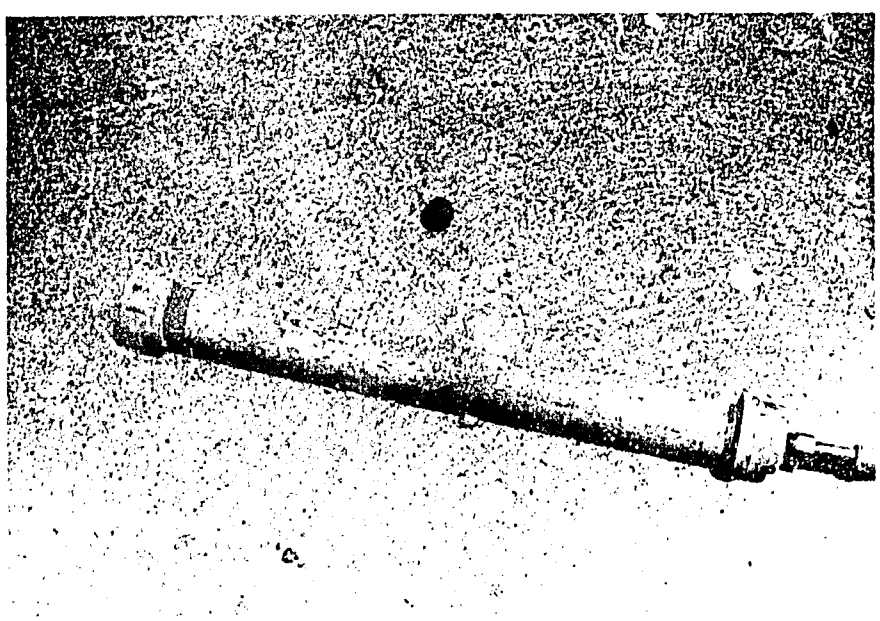
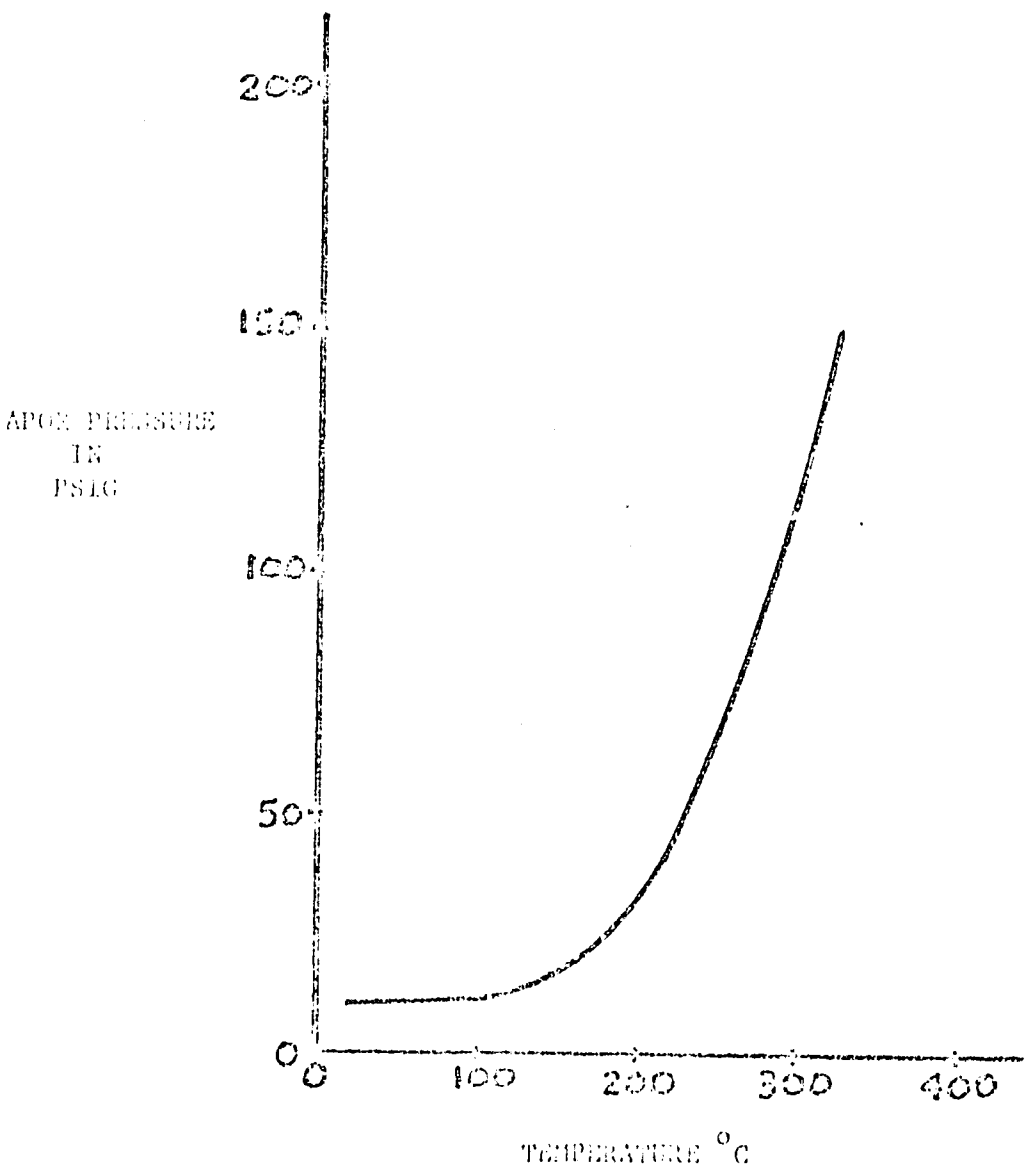


Figure 3. Devolatilizing cylinder. 50 grams c is placed in the cylinder and nitrogen fed into the cylinder through the pipe attached. The steel ball is placed inside with the coal. The cylinder is placed into a 700°C oven for 1 hour and agitated every 5 minutes.

FIGURE 4

THE RELATIONSHIP OF VAPOR PRESSURE OF ANTHRACENE OIL (COMMERCIAL) TO TEMPERATURE



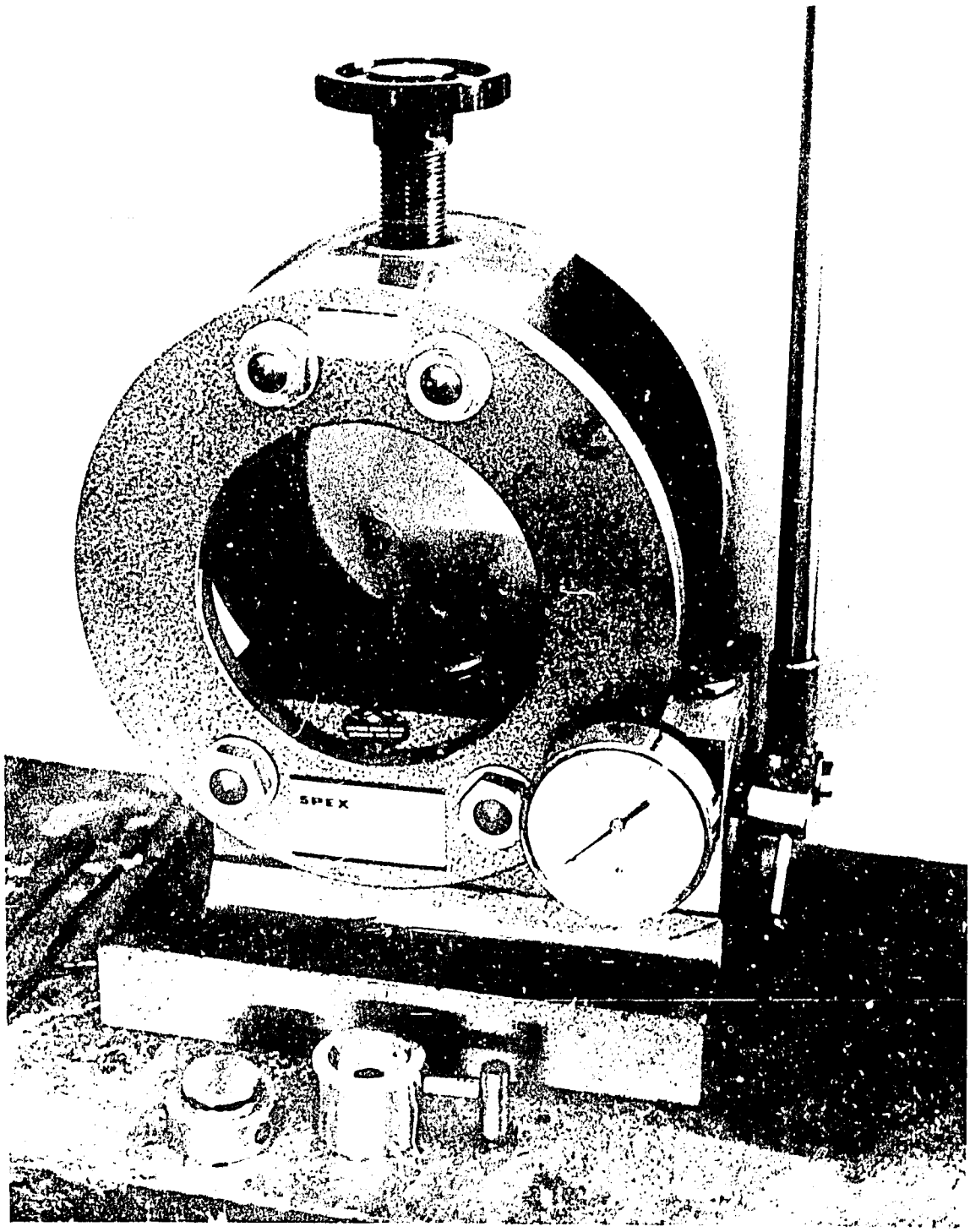


FIGURE 5. PELLET PRESS

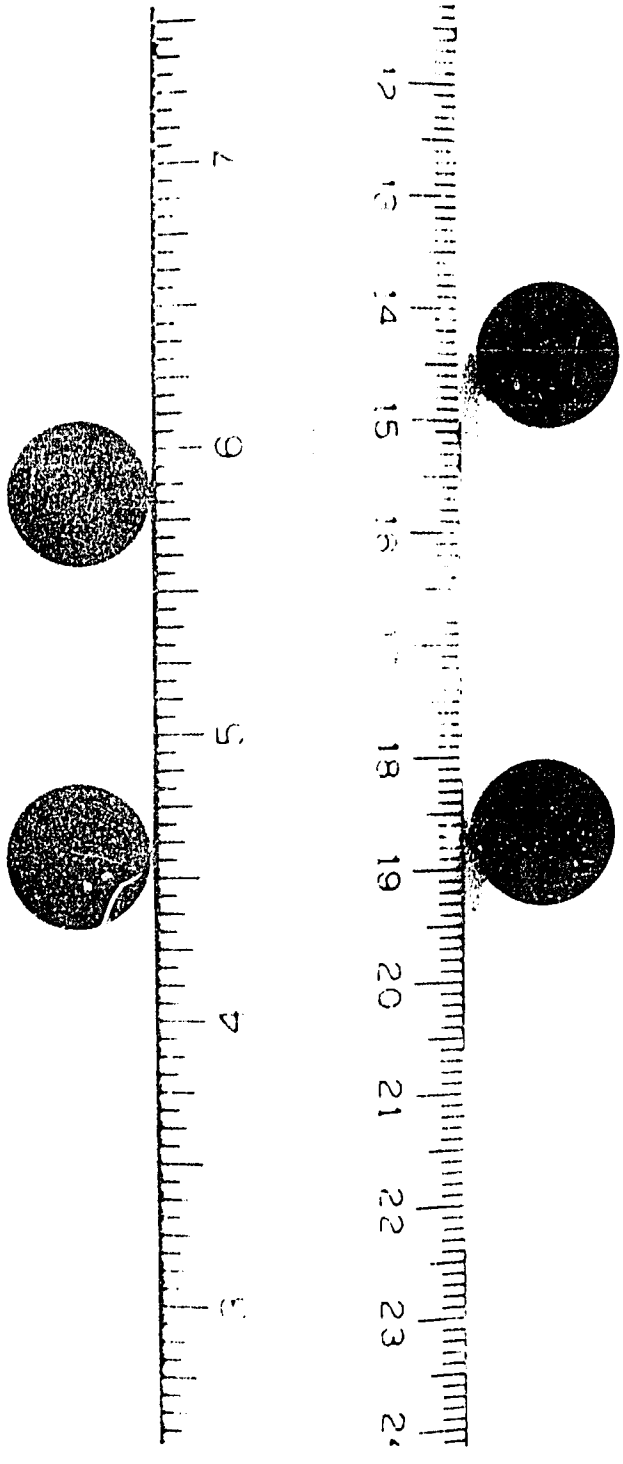


FIGURE 6. COAL PELLETS

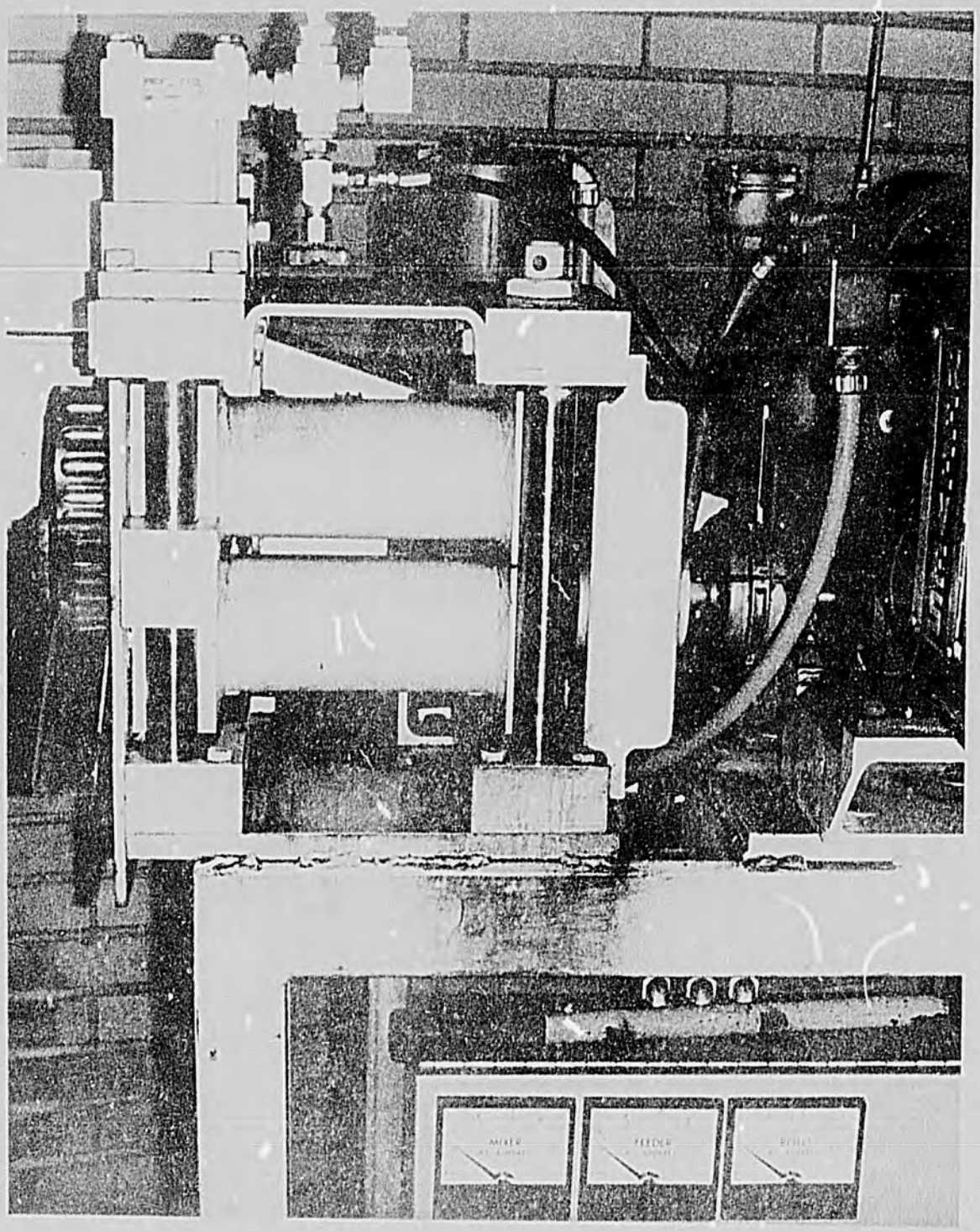


FIGURE 7. BRIQUETTING MACHINE

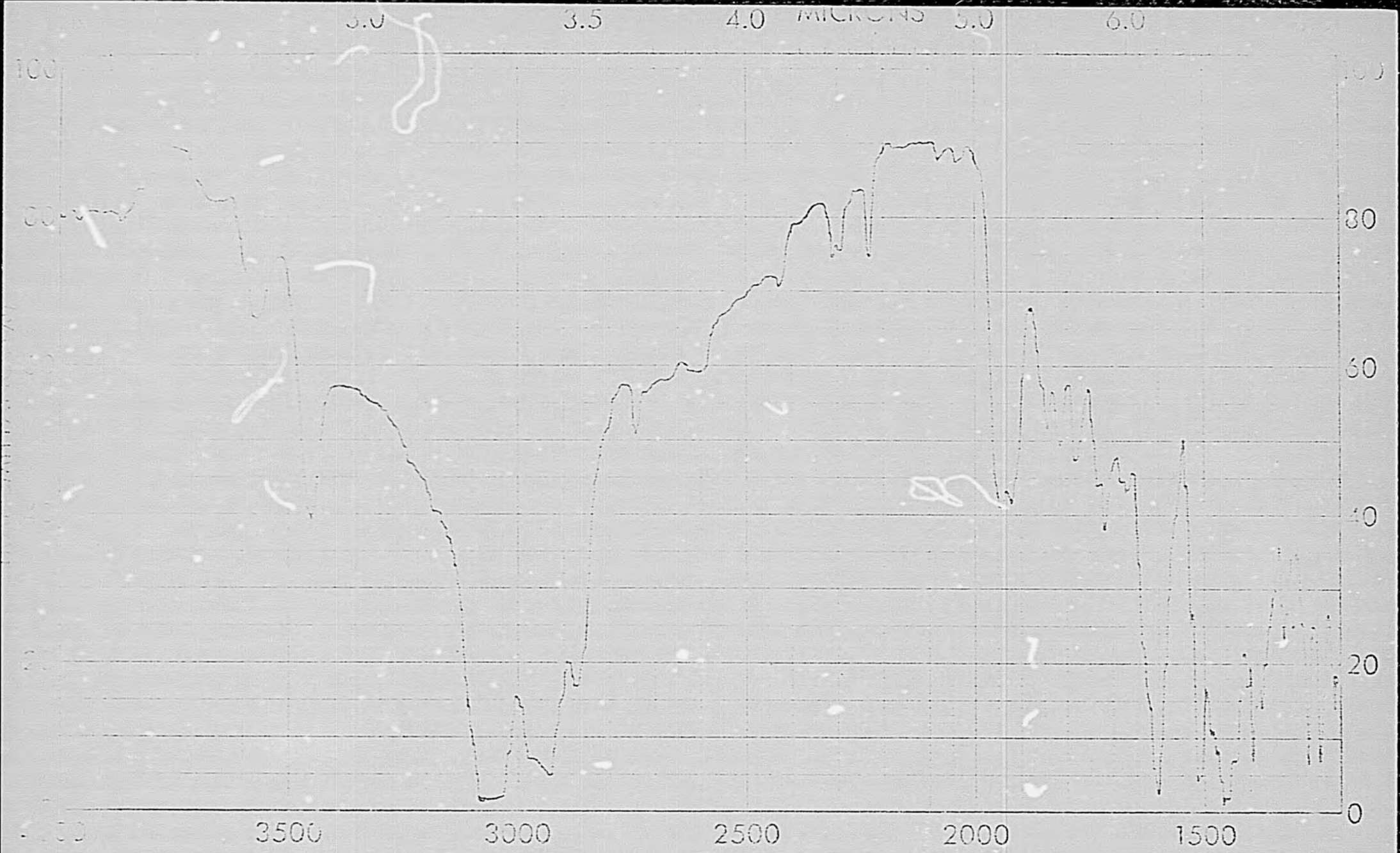


FIGURE 9

FREQUENCY (CM

LOCHRA Extract-VIII I	CURVE NO.	SCAN SPEED S/CW
	CONC. Neat	SLIT N
	CELL PATH 0.1 mm.	REMARKS

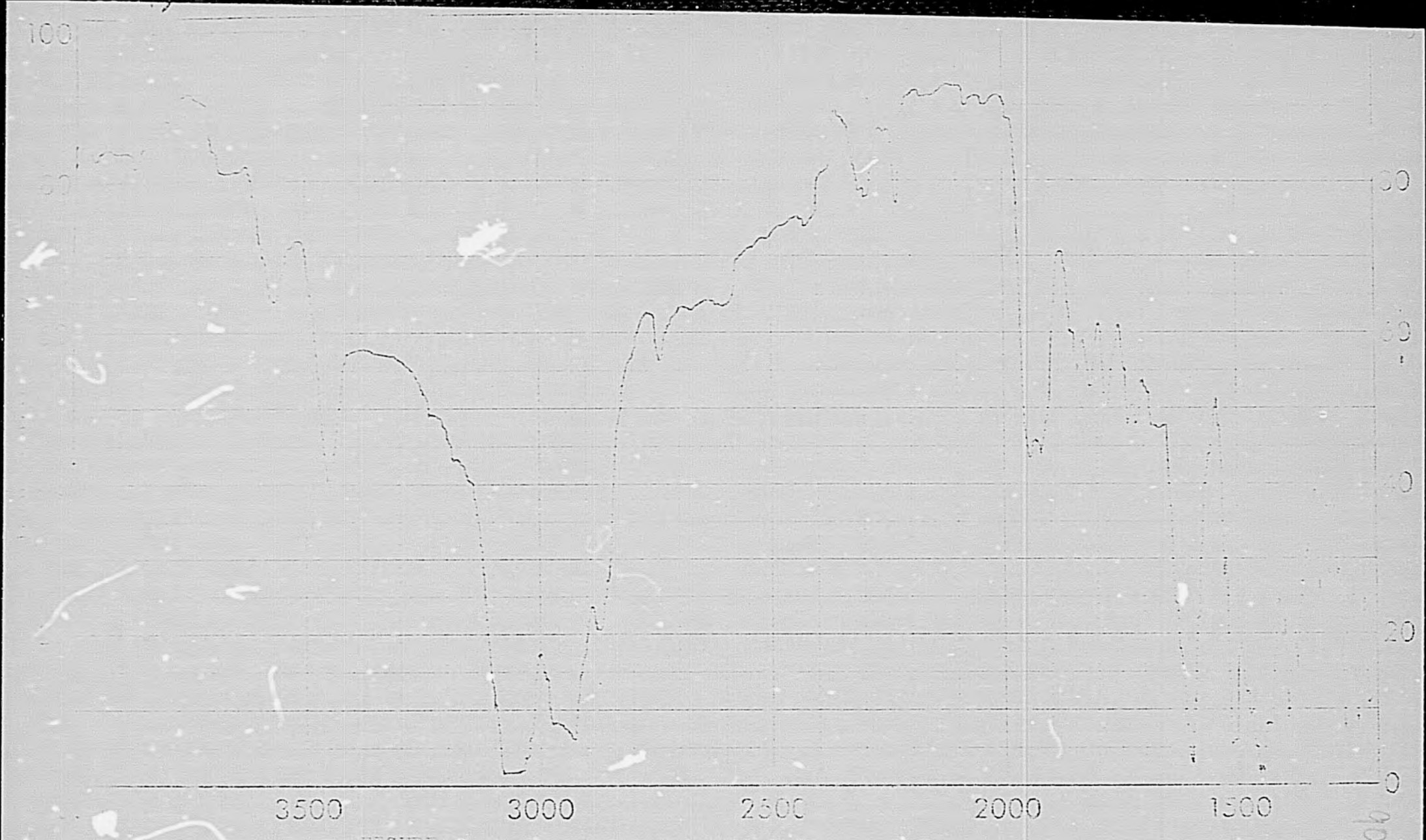


FIGURE 8

FREQUENCY CM⁻¹

LOCHRA Extract HIN-3	CURVE NO.	SCAN SPEED slow
	CONC. neat	SLIT N
	CELL PATH 0.1 mm	REMARKS
	REFERENCE	

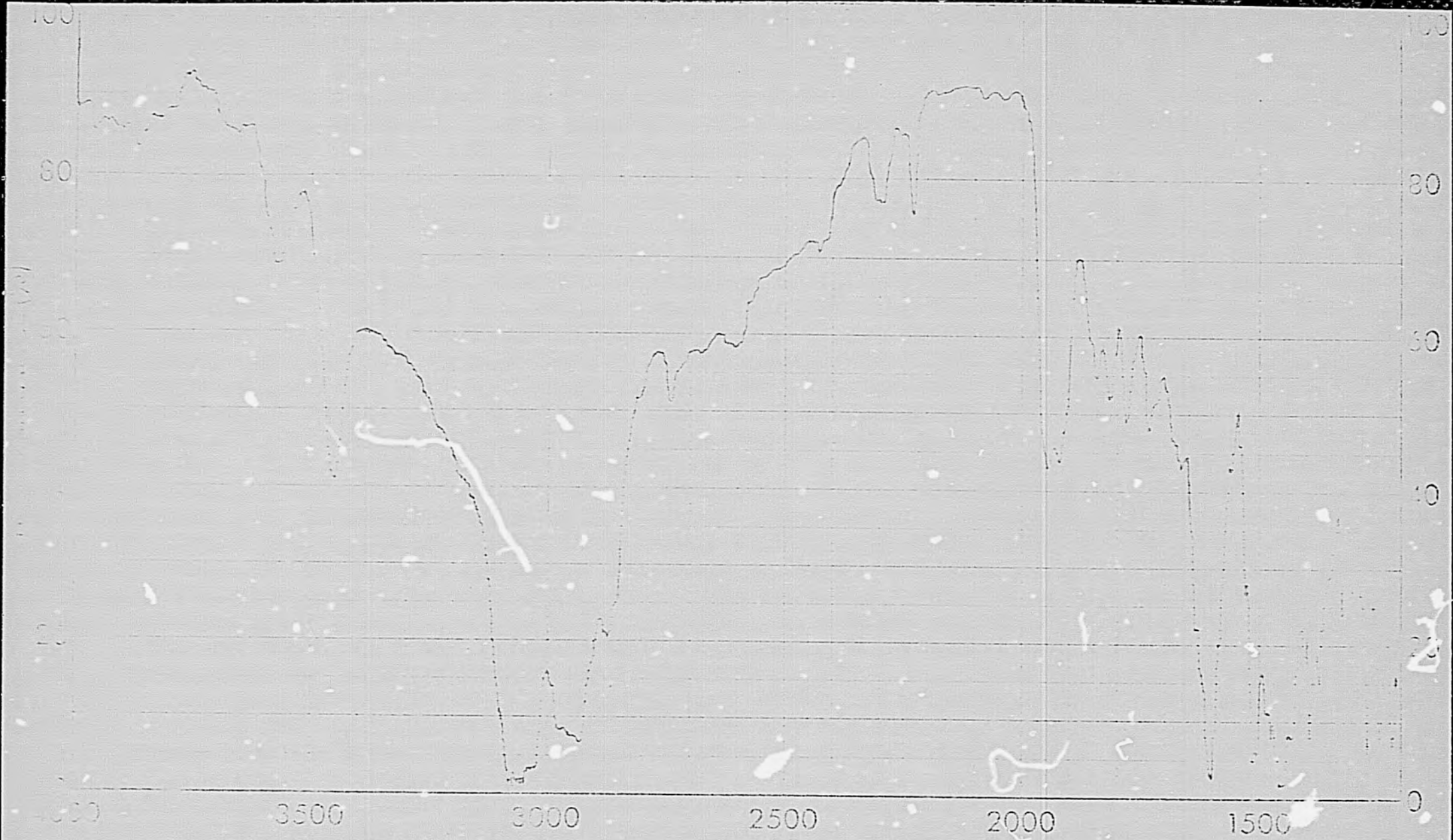


FIGURE 10

SAMPLE Anthracene Oil - Heated	CURVE NO.	SCAN SPEED slow
	CONC. Neat	SLIT N
ORIGIN	CELL PATH 0.1 mm	REMARKS
	THICKNESS	

PRODUCTION OF COKE

COKING TESTS FOR SLOT & BEEHIVE OVENS

Coking Tests

The properties within the coal which effect coking quality are vitrinite rank and composition. Reflectance measurements of the middle and top seams indicate that both are of high volatile bituminous rank. Vitrinites of this low rank have a very viscous plastic stage during coking. Little material flows within the coke during the plastic stage, preventing the formation of strong coke. Exinite mixed intimately with the vitrinite increases the formation and size of pores within the plastic vitrinite. Very few inertinite particles in the coal reduce coke strength, because of the absence of aggregate material which strengthens pore walls and reduces fissuring. All of these factors working in combination: (1) viscous non-flowing plastic state, (2) numerous small pores, and (3) lack of aggregate material to form pore walls, produce weak coke. The high pyrite and clay percentages further reduce the quality of coke produced from these coals.

Small scale coking tests were performed on coals and coal blends listed in Table 2, page 8-19. Megascopic descriptions of the cokes are given in Table 1, pages 8-17 and 18, and photographs in Figure 8. The following discussions will evaluate the effects of Pocahontas No. 3 blends, and devolatilization blends, on coke strengths.

Modifications to the stability factors of the STS and SMS coals by blending Pocahontas coal were very similar (Figure 9, page 8-20). Stability factors of both cokes increased nearly linearly with the addition of Pocahontas coal. From examining Figure 9, it appears that to achieve a coke with stability factors in excess of 50 for either coal, only 20% or less of SMS or STS coal could be blended with Pocahontas No. 3 coal.

Blending devolatilized STS coal (47.2% of the volatile matter removed) with STS coal resulted in total loss of stability. The stability of cokes produced with 25% and 50% devolatilized coal had a stability factor of 0. Blending 25% devolatilized SMS coal (61.2% of the volatile matter removed) resulted in a slight decrease in the stability factor, but the addition of 50% devolatilized coal increased the stability factor to 38. It appears that the addition of coal with greater than 60% volatile matter removed may add strength to the SMS, and probably STS, cokes, but it appears doubtful that this procedure would produce a coke with a favorable stability factor in excess of 50.

Physical appearances of cokes made from both minus 20 mesh and minus 8 mesh coals are very similar. The stability factor of the STS minus 8 mesh coke is slightly lower than the minus 20 mesh coke, Table 2, page 8-19, but within the probable range of error of this test. The stability

factor of the minus 8 mesh SMS coke is higher than the minus 20 mesh coke, and may indicate that this coal could produce stronger cokes with larger size consist.

The addition of 3% agricultural lime to the coal significantly increased the stability factors of both Sharigh cokes. The increase could be caused by the addition of inerts to the coke, but this cannot be confirmed at the level of effort commited to this exploratory study.

Petrographic Coke Analysis

In order to more fully understand the coking problems of the Sharigh coals, polished sections of top and middle seam cokes, and their blends were examined.

Cokes are either isotropic or anisotropic. The Pocahontas No. 3 coke (Figures 11 and 12) is anisotropic, as is the Pittsburgh coke (Figures 13 and 14). Both Sharigh cokes are isotropic (Figures 15 and 16. The viscosity of isotropic coke, during the plastic state, is very high, and as a result very little flowage takes place throughout the plastic stage. Strong evidence for the high viscosity is found in these cokes. Angular coal fragments are represented by subangular coke in which very little coalescence or deformation of the grains has taken place (Figure 17). Virtually undisturbed bedding in clay fragments within the coke, even though the vitrinite between these bands has passe through

the plastic stage, is another item of evidence (Figures 18 and 19). Pyrite lineations within the coke representing their original orientation in the coal is also noted (Figure 20).

In addition to the plastic stage of the coke being very viscous, clay laminations within the coke deforms pores and prevents coalescence of small pores to form larger ones (Figure 21). Pores within the portions of the coke which are free of clay are small and spherical (Figure 22) as opposed to the irregular pores of the more fluid Pocahontas coke (Figure 23).

Blending Pocahontas coal with either Sharigh coal does not result in the modification of the plastic properties of either coke type, nor is there a mixing of the coke types. The high viscosity of the Sharigh cokes does not allow them to blend with the Pocahontas coke, and both remain as separate entities within the coke (Figures 24 through 27).

Petrographic analysis of the devolatilized coals revealed that these were actually isotropic coke grains which were rounded, but not bound together (Figure 28).

Cokes containing the devolatilized coal display very slight anisotropism around the devolatilized grains.

In the cokes containing the agricultural lime no particles could be positively identified as the lime or a product of the heated lime. Petrographic examination did not reveal the reasons for the higher stability factors of these cokes.

Pyrite remains in the cokes of both Sharigh seams in high concentrations. Clay also is not altered by the coking process, and remains in the coke. These two factors result in the Sharigh cokes being high in both sulfur and ash. The pyrite is as intimately mixed with the coke as it was in the coal, and probably cannot easily be removed.

Petrography and Coking

Sample selection - From each canister containing the Sharigh top and middle seams, four random samples were removed. These are referred to as STS-1 through STS-4, and SMS-1 through SMS-4, and represent the Sharigh top and middle seams respectively. These samples were used for variability studies. These eight samples were stage ground to minus 20 mesh for petrographic analysis. Each cannister was then riffled to obtain another split representative of the entire sample. These splits were riffled to obtain approximately four pounds of each sample to be ground in stages to minus 20 mesh, cleaned in a 1.60 specific gravity solution, and coked in the small scale coking tests. A small portion of the original riffled split was ground in stages to minus 8 mesh, cleaned in a 1.60 specific gravity solution, and used in one coking test. A small portion of the cleaned, minus 20 mesh, coal was removed for petrographic analysis.

Petrographic analytical methods - All petrographic analysis was done by reflected light utilizing polished microblocks of particulate coal. Microblocks were cast in 1 1/4 inch diameter molds by mixing 5 grams of riffled minus 20 mesh coal with 6 grams of epoxy and cured at room temperature and pressure. Five microblocks were constructed from each sample. Grinding and polishing of the microblocks was achieved by following ASTM procedure D2797-69T section 7, using 120, 240, 400, and 600 grit silicon carbide papers for grinding; and 5 micron and 0.05 micron polishing compounds for rough and final polishing respectively.

Petrographic analysis consisted of a point count approximation of maceral composition and a point count approximation of pyrite content and type.

The maceral content was determined using a 1 x 1 mm. grid spacing, resulting in approximately 200 counts per microblock, or 1000 counts per sample. The average maceral composition of the sample was determined by averaging the maceral counts of all five microblocks.

A single microblock was randomly selected from each sample for pyrite analysis. The pyrite analysis consisted of first determining the percentage of coal exposed on the polished face of the microblock. To achieve this, 1000 points (0.5 x 1 mm grid) were counted as either coal or epoxy. The percent coal exposed was calculated from

this. The same microblock was then counted for pyrite types using a .2 x .2 mm grid spacing until 100 pyrite grains were encountered.

Pyrite content, on a volume basis, was calculated from the percent of the polished face which was coal, and the number of counts required to achieve 100 pyrite counts. With 100 pyrite grains counted, the percent of any pyrite type is equal to the number of times the type was encountered.

Small scale coking tests

Small scale coking tests were carried out on samples of the Sharigh top and middle seams, blends of these coals with devolatilized Sharigh coals and Pocahontas No. 3 coal, and Pocahontas No. 3 and Pittsburgh coals of known stability factor.

The coking tests were carried out in a coking apparatus which held three cylinders into which the coal charge was placed (Figure 1). The cylinders are 1 7/8 inches (4.5 cm) in diameter, and 1 1/2 inches (3.7 cm) high. They are covered, on top and bottom, by a 3/16 inch (1 cm) thick asbestos plate and a 1/16 inch (0.5 cm) thick steel plate. The asbestos and steel plates are 3 inches (7.5 cm) wide and 3 1/2 inches (8.7 cm) long. The three coking cylinders, with plates in place, are bolted between two 3/16 (1 cm) thick by 11 1/2 inch (29.2 cm) long additional steel plates to control the swelling pressure exerted by the coal (Figure 2).

With the bottom plates and cylinders in place, the coal charge was poured into the cylinders. The cylinder sides were gently tapped to assure compaction of the charge, and more coal added as needed. The weight of the coal charge was determined by weighing the coal before and after the cylinders were charged; the difference being the weight of the coal in the cylinder. The top plates were then positioned and the bolts tightened so that the cylinders were held tightly in place. The coking apparatus, containing the three coking cylinders, was then placed into a vacuum chamber (V in Figure 3). Air was evacuated from the chamber, and replaced by nitrogen from a compressed cylinder (N in Figure 3). The removal of air, and replacement by nitrogen was repeated three times to assure the removal of all oxygen from the coking cylinders. The coking apparatus was then quickly placed into a 1010°C, nitrogen filled, preheated oven (O in Figure 3). The oven used was a Lindberg Hevi-Duty with programmable temperature control (P in Figure 4). Inside this oven, a smaller coking chamber was constructed of firebrick (Figure 5). The inner dimensions of the chamber were just large enough to accommodate the coking apparatus. Nitrogen was fed into the chamber, under slight pressure, through a 1/4 inch copper pipe (N in Figure 5).

A thermocouple, connected to a chart recorder was also placed inside the coking chamber. The temperature inside the chamber was monitored on a chart recorder (C in Figure 4).

The coking apparatus remained in the oven for an additional two hours after the chamber returned to 1010°C. Usually the total time in the oven was 4 1/2 hours. After the prescribed coking time, the apparatus, now at 1010°C, was quickly removed from the oven, and again placed in the vacuum chamber to cool. The same air removal procedure was followed to insure that nitrogen filled the chamber as the apparatus cooled. Cooling generally took six hours, after which the bolts were loosened and the cylinders carefully removed from the apparatus. The coke was immediately removed from the cylinders and weighed before absorbing moisture. The cylindrical coke was then cut vertically on a dry diamond blade saw. One half was photographed and details of zonations and pores noted. Both halves were then recombined for the strength test.

The coke strength (Stability Factor) is determined by a modified Hardgrove Grindability method. The coke is first crushed in stages in a grinding machine to 10 x 60 mesh size range, being careful not to over crush and create large amounts of fines. To assure the removal of all fines, the 10 x 60 mesh fraction was placed on a 60 mesh screen in a Roto-Tap mechanical shaker for 5 minutes. Ten grams (± 0.0005 gm) of 10 x 60 mesh coke was then weighed for the grindability test.

The modified Hardgrove-machine method of coke strength measurement was based on ASTM test D409-71, and consisted of grinding the coke with a ring of eight 1 inch diameter steel balls under a 64 pound (29 kg) load for 60±.25 revolutions at 20 r.p.m. (Figure 6).

The crushed coke, removed from the machine, was placed on a series of 60, 100, and 200 mesh sieves, and sieved for 10 minutes on the Roto-Tap mechanical shaker. The weight of the coke in the +60, 60 x 100, 100 x 200, and minus 200 mesh fractions were very carefully measured, and the weight percent of the original 10 grams in each size fraction calculated. The sieve sizes were converted to phi (Ø) units (Table 1, page 5-34) and the cumulative weight percents (excluding the minus 200 mesh fraction) were plotted on probability paper as in Figure 7, page 8-15. A straight line was drawn through the three points. The size at which the line crossed the 30th percentile was determined, and this value was transferred to the standard curve (Figure 29, page 8-21) to determine the stability factor of the coke. The 30th percentile was chosen because of the low slope of the resulting standard curve which minimizes error from inaccurate measurements, and because the line need not be extrapolated far beyond the three measured points.

Blends of coal containing devolatilized STS and SMS coals were examined to determine if this procedure could produce better STS and SMS cokes. Devolatilized coals were produced in a 1 inch inner diameter (2.5 cm) 14 inch (35.6 cm) long cylinder, with caps screwed to each end (Figure 3, Chapter 7). The caps contained 3/8 inch (1 cm) threaded openings covered with screen. One cap was fitted with a 3/8 inch (1 cm) pipe which in turn was connected to a 1/4 inch (0.6 cm) copper tube connected to a compressed nitrogen cylinder. Approximately 50 grams of coal were placed into the cylinder, and a 3/4 inch (2 cm) diameter steel ball was added. The caps were tightly fitted, and nitrogen was pumped through the cylinder to remove all air. The entire apparatus was then placed in a 700°C, nitrogen filled, preheated oven for 1 hour. The cylinder was removed at 5 minute intervals and very vigorously shaken such that the steel ball broke up any agglomeration which was beginning to form, and to redistribute the coal in the cylinder so that no coal was continuously exposed to the hot walls of the cylinder. The time and temperature of this experiment was determined by trial and error. After 1 hour the cylinder was removed from the oven and quenched with water. Nitrogen flowed through the cylinder throughout the entire process until the cylinder was cool. After

cooling, the coal was removed from the cylinder and weighed. The percent volatile matter removed was based on the weight loss during a 4 1/2 hour coking cycle. STS coal had 47.2% of the volatile matter removed, and SMS had 61.2% of the volatile matter removed by the process. The coal was re-ground to pass a 20 mesh sieve before being blended with the STS and SMS coals.

Petrography and Coking

Petrographic analysis of the Sharigh top (STS) and middle seams (SMS), small scale coking tests of these coals, and petrographic analysis of the cokes of these coals revealed the following list of conclusions:

(1) Petrographic composition of each seam varies within wide limits within the single sample received, indicating possible wide variation of the petrographic composition of these seams both perpendicular and parallel to bedding.

(2) Vitrinite in both seams has a reflectance of approximately 1.1% indicating that both seams are of approximately high volatile bituminous rank, insofar as reflectance measurements are concerned.

(3) The petrographic composition of these coals is poor for coking purposes because:

a. of the low quality of the vitrinite,
b. the high amounts of impurities (cutinite and clay) within the vitrinite, causing small pore formation in the coke,
c. the very low amounts of inert macerals to provide aggregate material in the coke,
d. high amounts of clay and pyrite, even in the cleaned coals.

(4) Clays in the STS coal occur as grains, probably representing large partings, and can be cleaned from the coal relatively easily and thoroughly, but the clays in the SMS coal are slightly more intimately mixed with the coal.

(5) Pyrite in both seams is very intimately mixed with the coal, and of such very small size, indicating that removal will be very difficult by normal means.

(6) Estimated stability factors for the STS and SMS cokes are 13 and 14 respectively.

(7) Blending STS or SMS coals with Pocahontas No. 3 coal produces an estimated stability factor in excess of 53 if less than 20% of either Sharigh coal is utilized.

(8) It may be possible to increase the stability factor of Sharigh cokes by blending Sharigh coals, which have been highly devolatilized, with the normal Sharigh coals, but much work needs to be done to substantiate this possibility.

(9) The addition of 3% agricultural lime to both Sharigh coals before coking increases the stability factor.

(10) Isotropic cokes produced from the Sharigh coals suggest that the plastic stage of coke formation was very viscous, and did not allow the flowage to produce intimate bonding of particles.

(11) Blending Pocahontas coal with the Sharigh coals prior to coking increases the coke strength by simply adding small grains of Pocahontas coke within the matrix of Sharigh coke, and not by modification of the coking and fluidity properties of the Sharigh coal itself.

(12) Pyrite and clay are not volatilized during the coking process, but remain within the coke, producing a coke very high in sulfur and ash.

Relationships of Maceral Composition and Coking Properties

The properties within the coal which affect coking quality are rank and composition. Reflectance measurements of the middle and top seams indicate that both are of High Volatile Bituminous rank. Vitrinite of this low rank have a very viscous plastic stage during coking. Little material flows within the coke during the plastic stage, preventing the formation of strong coke. Exinite mixed intimately with the vitrinite increase the formation and size of pores within the plastic vitrinite. Very few inertinite particles in the coal reduce coke strength, because of the absence of aggregate material which strengthens pore walls. All of these factors working in combination: (1) viscous non-flowing plastic stage, (2) numerous small pores, and (3) lack of aggregate material to form pore walls, produce very weak coke. The high pyrite and clay percentages further reduce the usefulness of coke produced from these coals.

A possibility exists that the strength of the cokes derived from Sharigh coals may be improved through the addition of a "blocking agent" to the coking charge.

An effective "blocking agent" can result from the admixture of small quantities of coke breeze to the coal charge.

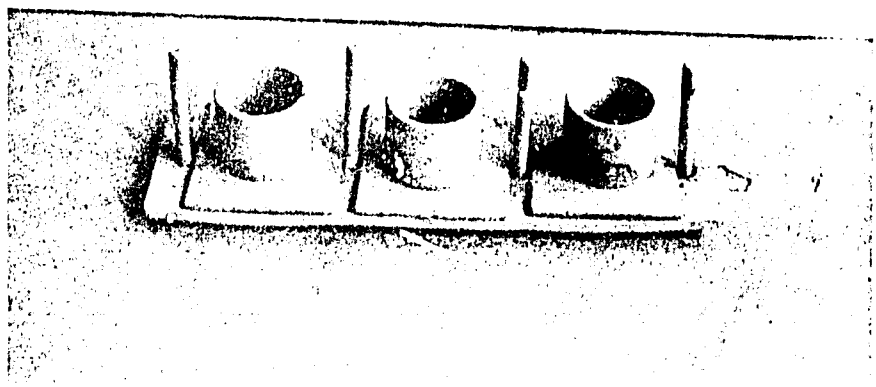


Figure 1. The small scale coking apparatus with the top plate removed to show the three cylinders into which the coal is charged.

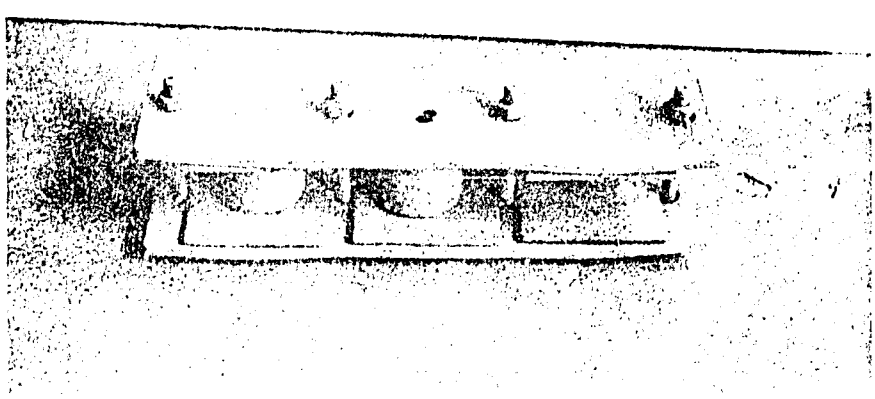


Figure 2. The small scale coking apparatus with the top plate bolted in place, and ready to be placed in the oven.

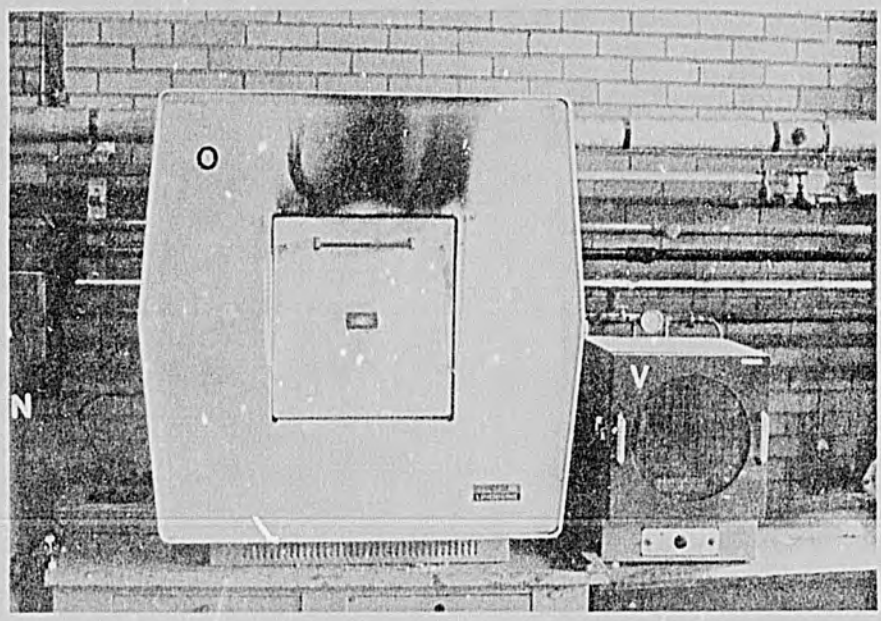


Figure 3. The small scale coking test oven (O), nitrogen cylinder (N), and vacuum chamber (V) used in the small scale coking tests.

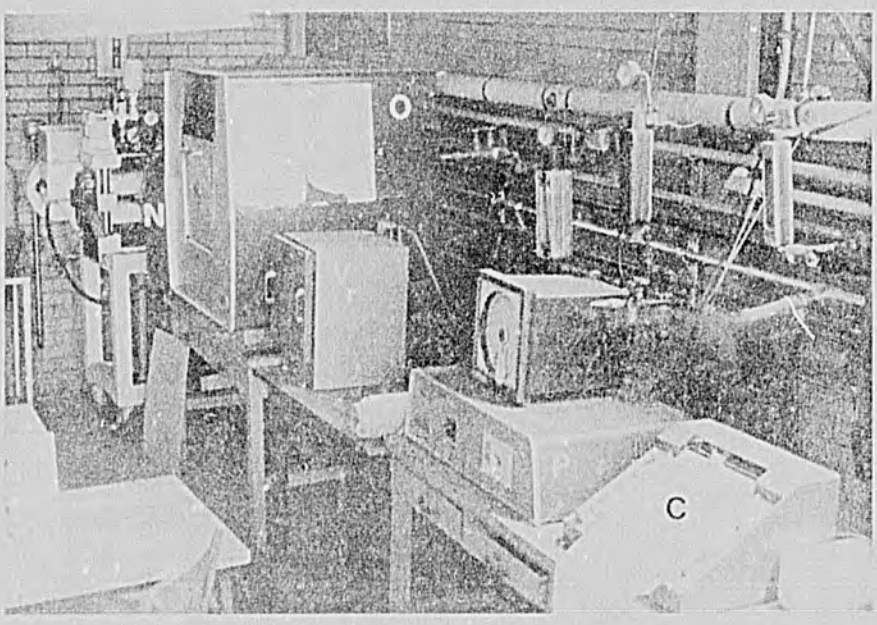


Figure 4. The small scale coking test area with the coking oven (O), nitrogen cylinder (N), vacuum chamber (V) for oxygen removal prior to coking and cooling, programmable temperature controller for the oven (P), and a chart recorder attached to the thermocouple inside the coking chamber inside the oven (C).

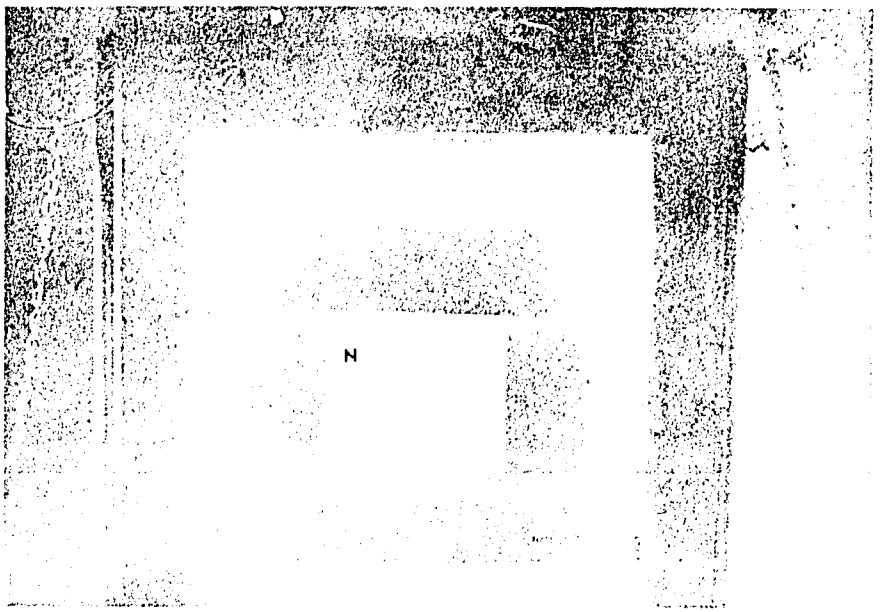


Figure 5. Coking chamber built inside the Lindberg Hevi-Duty oven. Nitrogen enters the chamber under slight pressure through a 1/4 inch copper pipe (N). A thermocouple is in the top of the chamber (hidden from view). The chamber is constructed of firebrick.

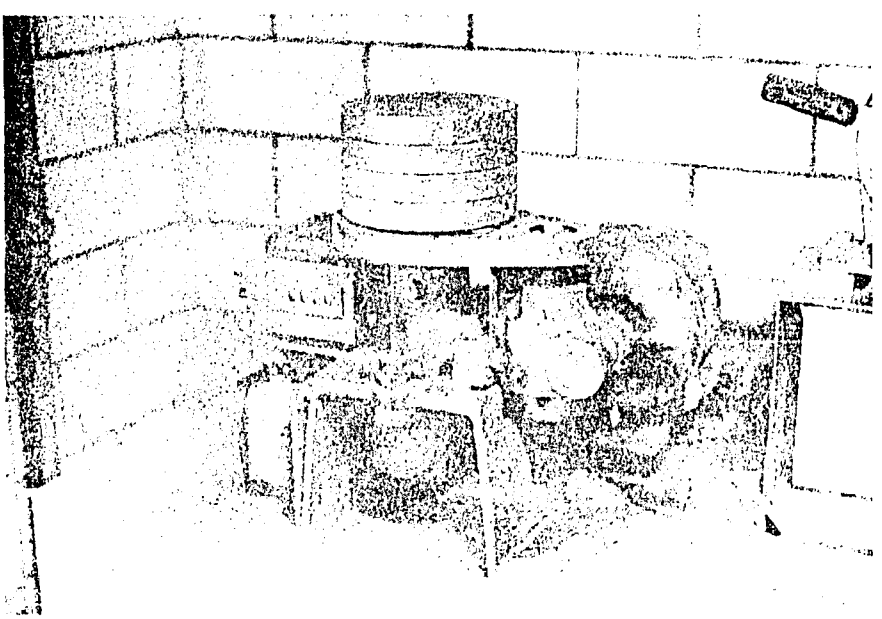
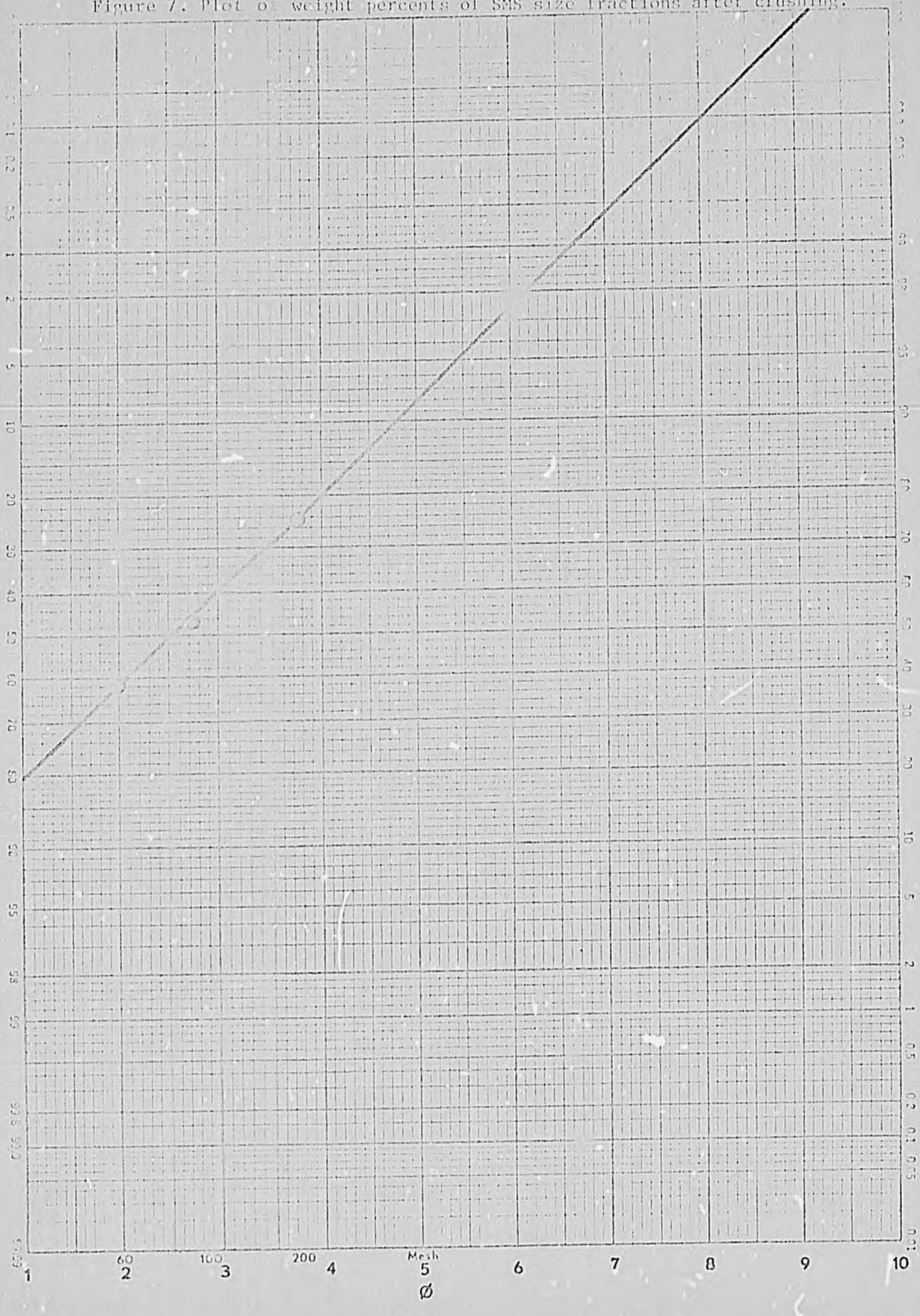


Figure 6. The Hardgrove Grindability machine used to crush the 10X60 mesh coke in the test of coke strength (Stability Factor).

Figure 7. Plot of weight percents of SMS size fractions after crushing.



COKE ANALYSIS

Sharigh Coal - Top Seam
160 Float

Ash = 16.2
Sulfur = 4.71

Sharigh Coal - Middle Seam
160 Float

Ash = 24.3
Sulfur = 6.53

Table 1. Megascopic descriptions of the small scale cokes illustrated in Figures 8 A through 8 .

COAL OR COAL BLEND	Fig. 8 location	Megascopic Characteristics
Pittsburgh	A	Fragile, large central cavity, thin fragile pore walls, outer envelope 3mm thick of dense coke.
Pocahontas No.3	B	Strong, thick dense outer envelope of coke (10mm.), central zone of thin walled pores, very few fractures, rounded outline.
Pocahontas 25%-Pittsburgh 75%	C	Strong, uniform pore size and wall thickness, small central cavity, radial fractures, sharp outline of coking chamber.
Sharightop seam (STS)	D & E	Strong, dense, moderately fractured, pore size increases inward to small central cavity, thin pore walls.
STS 90% - Pocahontas No.3 10%	F	Strong, dense, moderately fractured, pore size increases inward to small central cavity, thin pore walls.
STS 75% - Pocahontas No.3 25%	G	Strong, dense, very few fractures, pore size increases inward to small central cavity, thin walled pores.
STS 75% - STS devolatilized 25%	H	Strong, dense, very few fractures, small pores which increase slightly in size inward to small central cavity, thin pore walls.
STS 50% - STS devolatilized 50%	I	Strong, dense, very few fractures, small pores which increase very slightly in size to very small central cavity, thin walled pores.
STS 70% - STS devolatilized 20% - Pocahontas No.3 10%	J	Strong, dense, few fractures, small pores which increase in size inward to small central cavity, thin walled pores.
STS 97% - Agricultural lime 3%	K	Strong, dense, fractured, 2mm. thick dense coke envelope, moderate pore size increasing inward to moderately large central cavity, thin pore walls.

Table 1. (continued)

Sharigh top seam 1/8X0	L	Strong, dense, fractured, 2mm. thick outer coke envelope, large pore size (1mm.) increasing inward to large central cavity with very thin pore walls.
Sharigh middle seam (SMS)	M	Fragile, very large pores (1-3mm.), very thin fragile pore walls, very irregular fractures, very light weight, expanded to fill cylinder.
SMS 90% - Pocahontas No.3 10%	N	Very fragile, very large pores (1-3mm.), very thin fragile pore walls, large central cavity, very irregular fractures, expanded to fill coking cylinder.
SMS 75% - Pocahontas No.3 25%	O	Fragile, light weight, large pores (1mm.), very thin pore walls, pore size increases inward to large central cavity, did not fill cylinder.
SMS 75% - SMS devolatilized 25%	P	Very fragile, many irregular fractures, large pore size (1-2mm.), very fragile pore walls, very light weight, did not expand to fill cylinder.
SMS 50% - SMS devolatilized 50%	Q	Strong, dense, large pore size (1-2mm.), pore size increases inward to a zone of large pores, thin pore walls, did not expand to fill cylinder.
SMS 97% - Agricultural lime 3%	R	Very fragile, light weight, very large fragile pores (1-3mm.), very thin fragile pore walls, many irregular fractures, expanded to fill coking cylinder.
Sharigh middle seam 1/8X0	S	Very fragile, light weight, very large pores (1-3mm.), very fragile pore walls, many irregular fractures, expanded to fill cylinder.

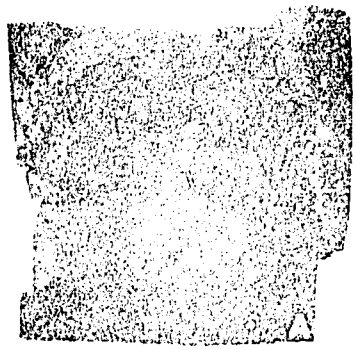
Table 2. Stability factors and yields of small scale cokes.

COAL OR COAL BLEND	STABILITY FACTOR	YIELD
Pittsburgh	34	58.7%
Pocahontas No.3	64	80.4%
Pittsburgh 75% Pocahontas No.3 25%	14#	47.4%
Sharig top seam	14	44.5%
Sharig top seam	14	48.6%
Sharig top seam (STS)	6	54.3%
STS 90% Pocahontas No.3 10%	13	58.1%
STS 75% Pocahontas No.3 25%	18	62.7%
STS 75% STSD* 25%	0	59.3%
STS 50% STSD* 50%	0	66.7%
STS 70% STSD* 20% Pocahontas No.3 10%	53	60.0%
STS 97% Agricultural lime 3%	39	59.7%
STS (-8 mesh)	9	59.3%
Sharig middle seam (SMS)	14	40.1%
SMS 90% Pocahontas No.3 10%	18	45.1%
SMS 75% Pocahontas No.3 25%	24	51.2%
SMS 75% SMSD* 25%	10	50.4%
SMS 50% SMSD* 50%	39	65.2%
SMS 97% Agricultural lime 3%	43	45.0%
SMS (-8 mesh)	22	52.1%

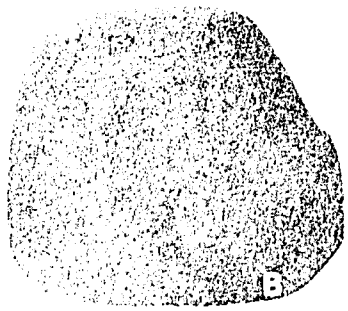
* STSD = Sharig top seam devolatilized coal
SMSD = Sharig middle seam devolatilized coal

\# Only 8 grams of this sample were available to measure the stability factor. This seems to have significantly reduced the strength measured. To acheive consistent results the recommended 10 grams must be used.

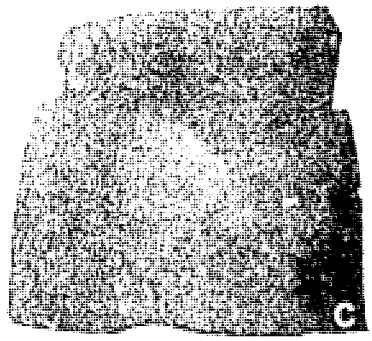
NOTE: Predictions made with substances other than natural coal, such as agricultural lime and devolatilized coal, should be viewed with caution since results with them are outside the prediction accuracy known to be feasible with coal itself in this type of procedure.



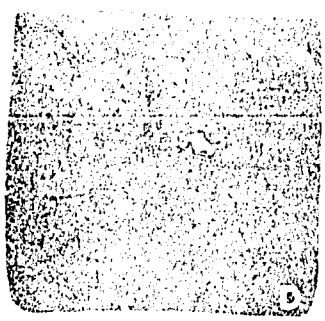
Pittsburgh



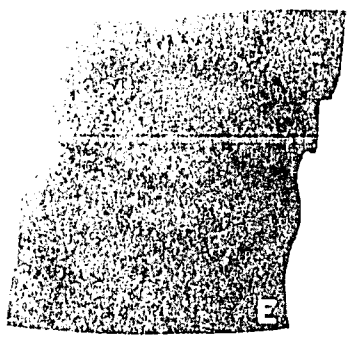
Pocahontas No.3



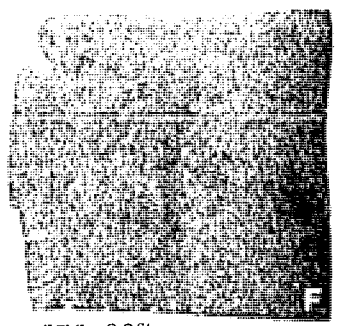
Pittsburgh 75%
Pocahontas No.3 25%



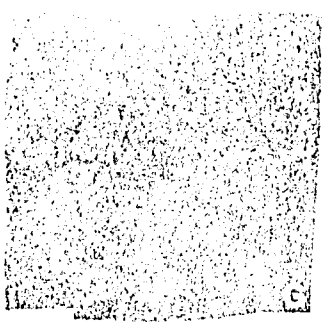
Sharightop seam



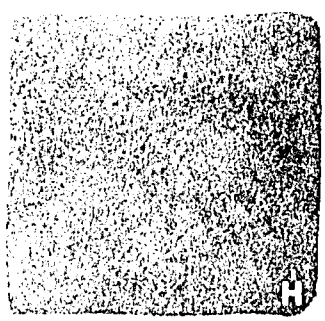
Sharightop seam



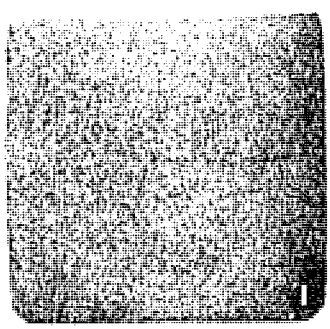
STS 90%
Pocahontas No.3 10%



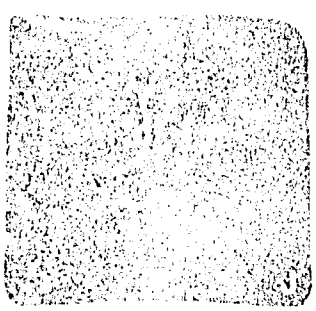
STS 75%
Pocahontas No.3 25%



STS 75%
STSD 25%

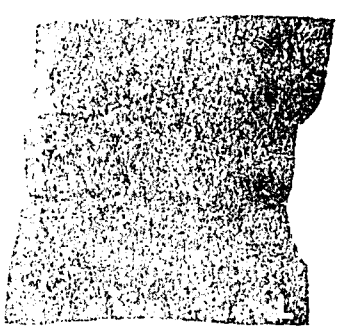


STS 50%
STSD 50%



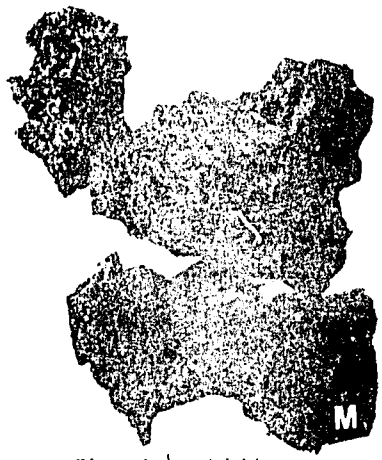
STS 70%
STSD 20%
Pocahontas No.3 10%

STS 97%
Agricultural
Lime 3%

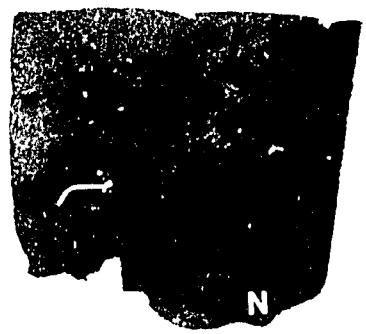


Sharightop seam
1/8 inch X 0

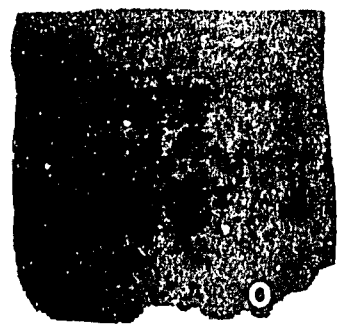
Figure 8. Megascopic photographs of small scale cokes. Actual Size. These cross sections were produced by cutting the coke cylinders vertically.



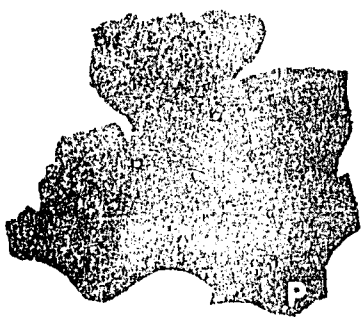
Sharigh middle seam



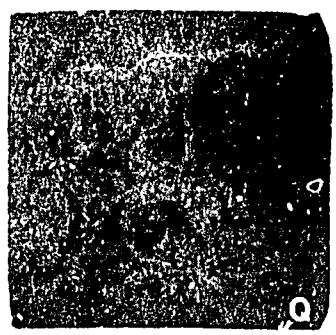
SMS 90%
Pocahontas No.3 10%



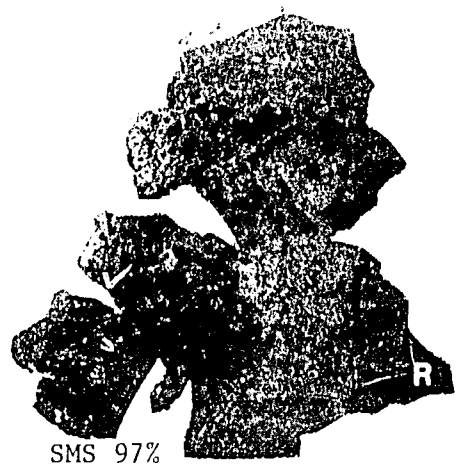
SMS 75%
Pocahontas No.3 25%



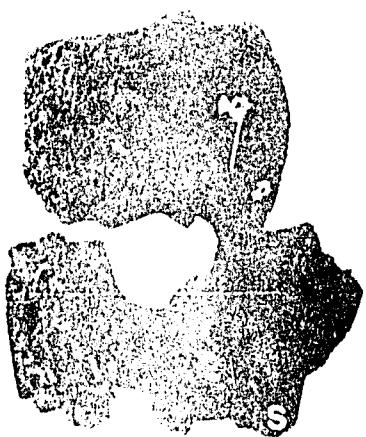
SMS 75%
SMSD 25%



SMS 50%
SMSD 50%



SMS 97%
Agricultural lime
3%



Sharigh middle seam
1/8 inch X 0

Figure 8 continued. Actual size.

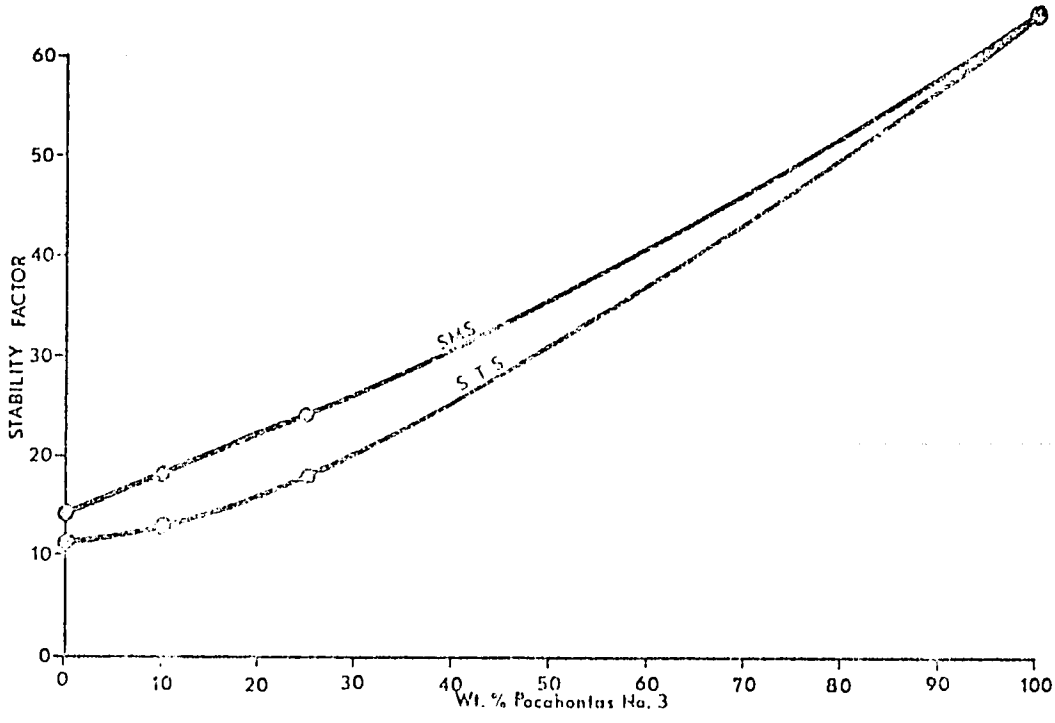


Figure 9. Stability factors of blends of Sharigh coals and Pocahontas No.3 coal.

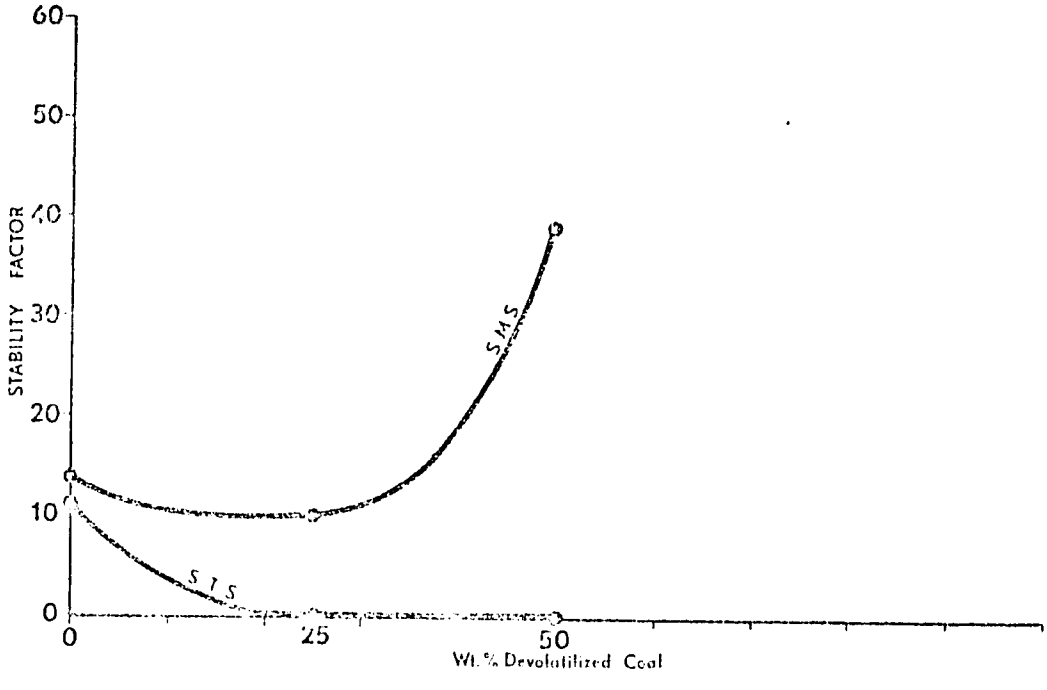


Figure 10. Stability factors of blends of Sharigh coals with their devolatilized coals. The Sharigh top seam loses all of its strength by blending, but the middle seam increases when 50% devolatilized coal is added. This increase is probably due to increased density of the coke.

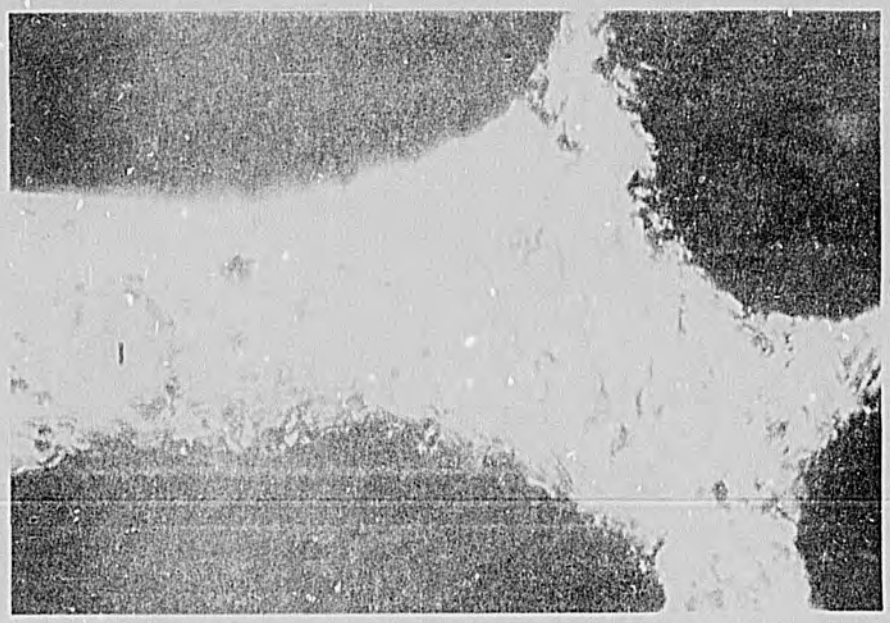


Figure 11. Pocahontas No.3 coke examined with plane (polarized in one direction) light. This coke clearly shows patterns of flow during the plastic stage. Note the sphere of micrinite (inertinite) in the pore wall (I).

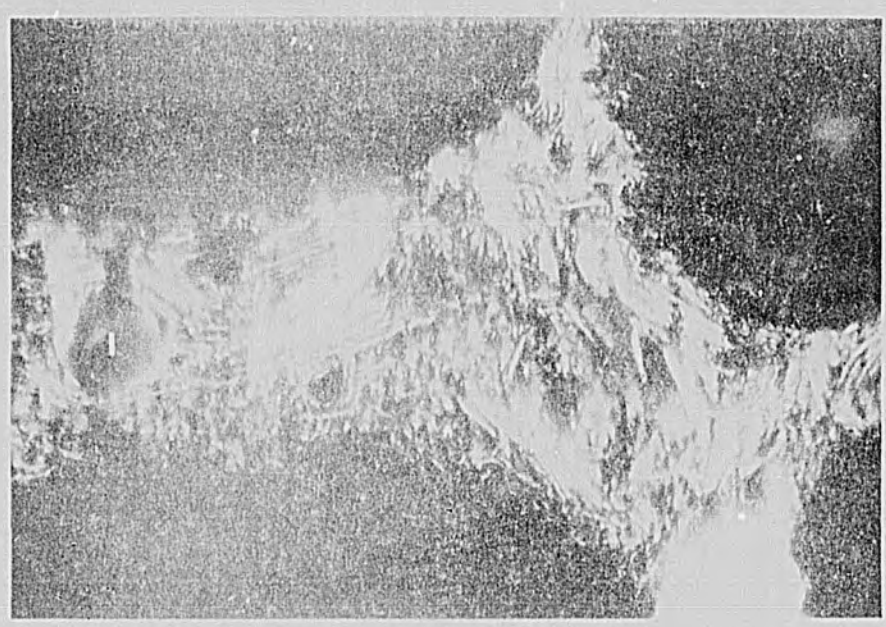


Figure 12. The same coke as above examined with crossed polarizing filters (crossed nicols). Examining the coke in this way shows the anisotropism of this coke. Note the isotropic (dark under crossed nicols) nature of the inertinite (I) in the pore wall. Also note the large pore size of this coke.

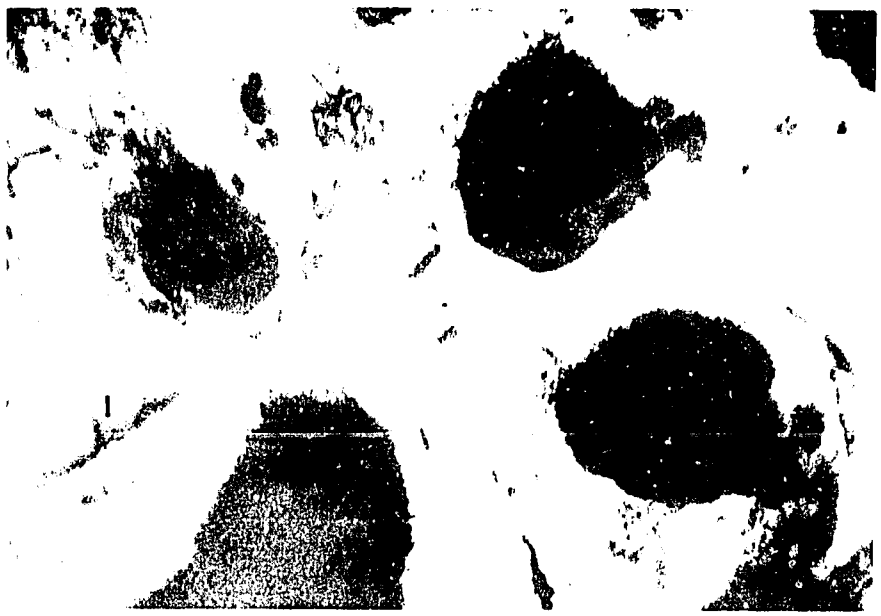


Figure 13. Pittsburgh coke examined with plane light showing thick walls and small pores. Inertinite is in the left part of the photograph (I).

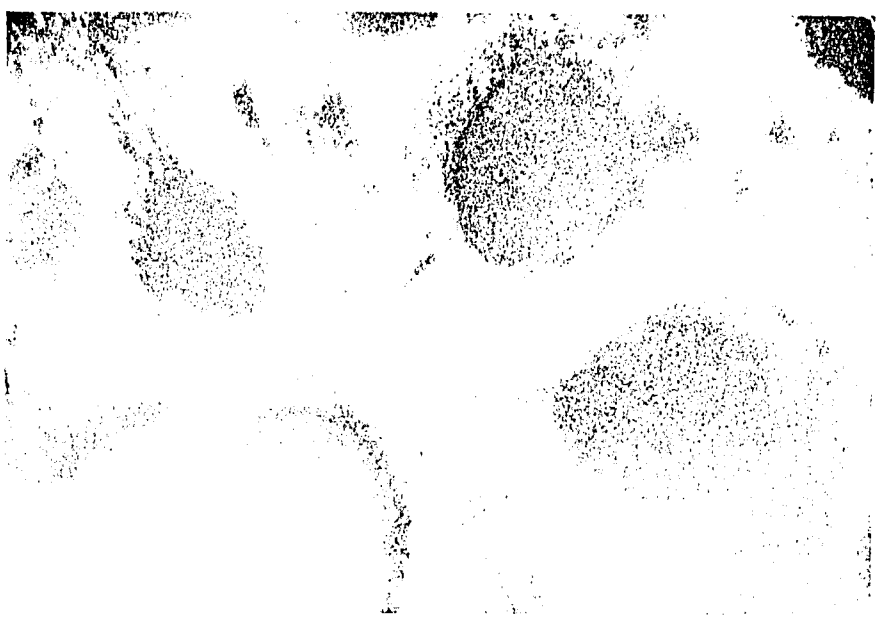


Figure 14. Pittsburgh coke examined with crossed nicols. Note the much smaller anisotropic texture, as compared to the Pocahontas coke.

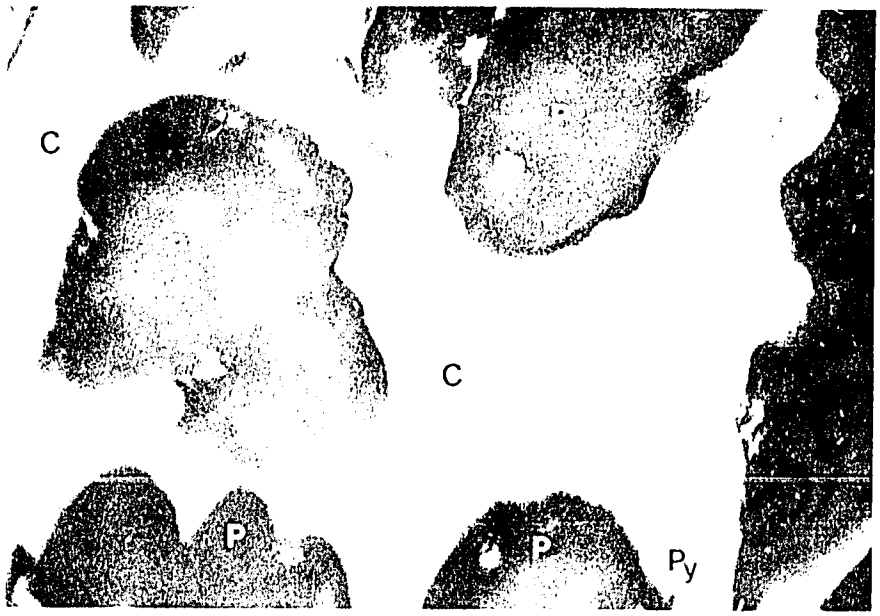


Figure 15. Sharightop seam coke examined with plane light. The coke (C) is lacking in internal structure except for occasional pyrite (Py) and clay. Pores (P) are small, and pore walls are thin.

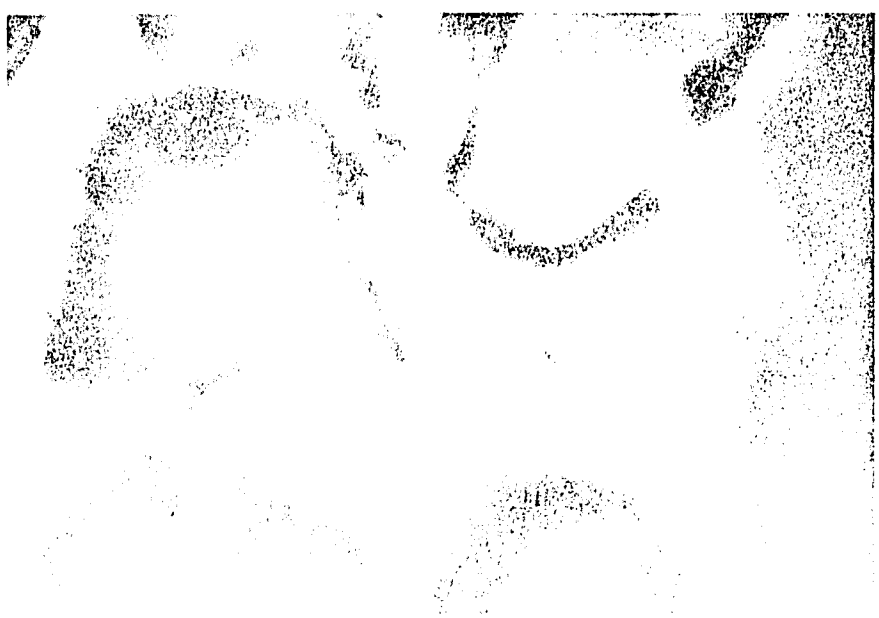


Figure 16. Sharightop seam coke examined with crossed nicols. The coke appears dark because of its isotropic nature.

Figure 17. Sharigh top seam coke with angular coke grains only slightly coalesced. These grains probably were angular grains of coal before coking, and the viscous nature of the Sharigh coal plastic stage did not allow flowage. This is one indication of the viscous nature of the Sharigh coal plastic stage.

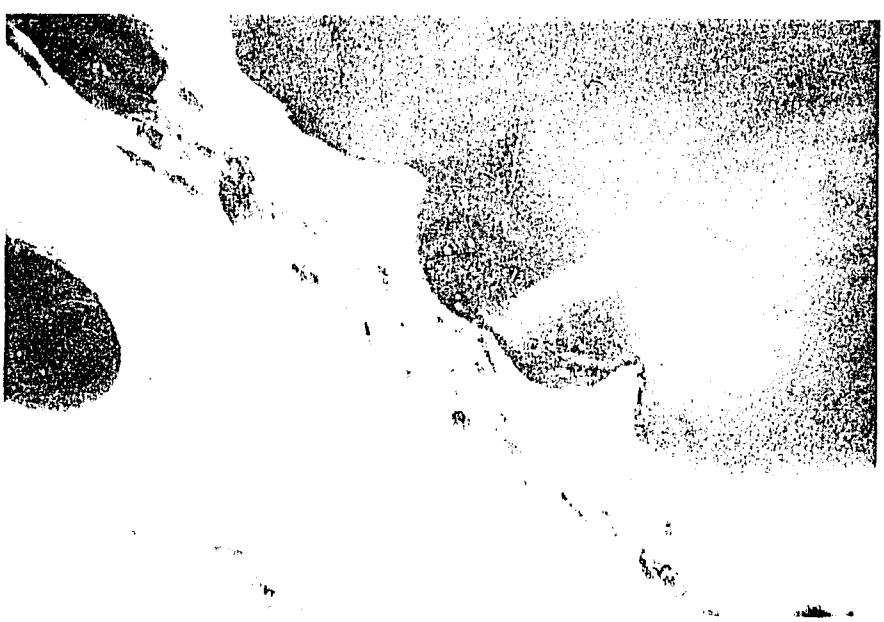


Figure 18. Clay bands in the Sharigh coke. These bands have not been distorted, even though the vitrinite between bands has passed through the plastic stage. This is also evidence of the highly viscous nature of the Sharigh coal plastic stage.

Figure 19. Clay bands in Sharigheoke. The bands outline the shape of the original coal grain. Coke bands occur within the clay, and represent vitrinite in the original coal. The clay has not been deformed by flowage during the plastic stage.

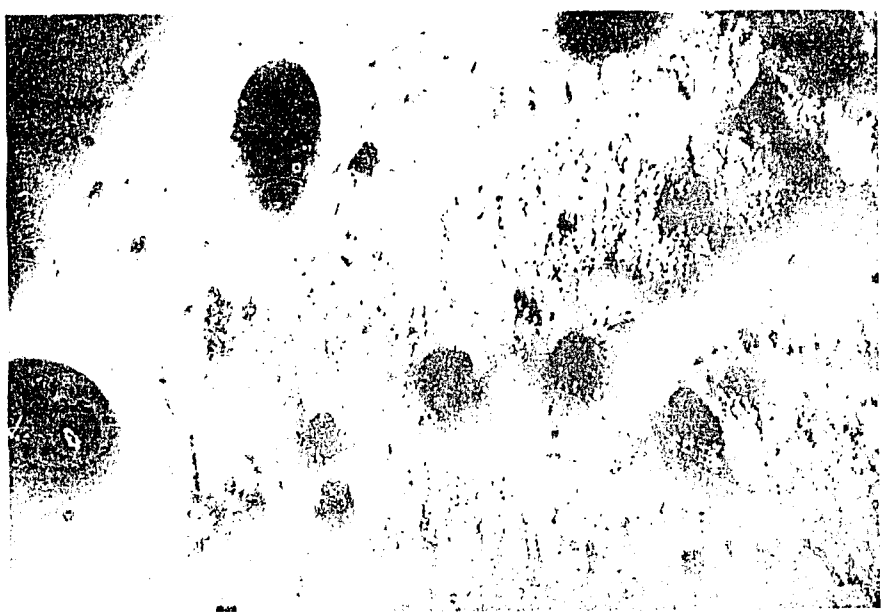


Figure 20. Pyrite lenses within the Sharigheoke. There has been little deformation of these lenses due to flowage. Note also the small pores within the restricted area between the pyrite lenses.

Figure 21. Lenticular pores in portions of the Sharigh cokes which contain thin clay laminae.

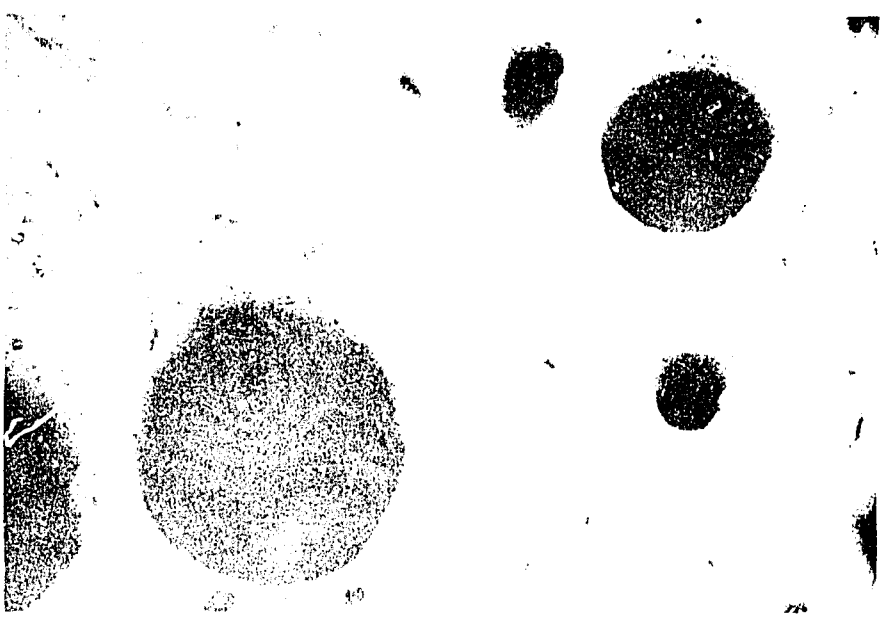


Figure 22. Small spherical pores within Sharigh coke which is free of clay laminations. The coal which formed this coke was probably vitrinite interspersed with cuticles and isolated pyrite.

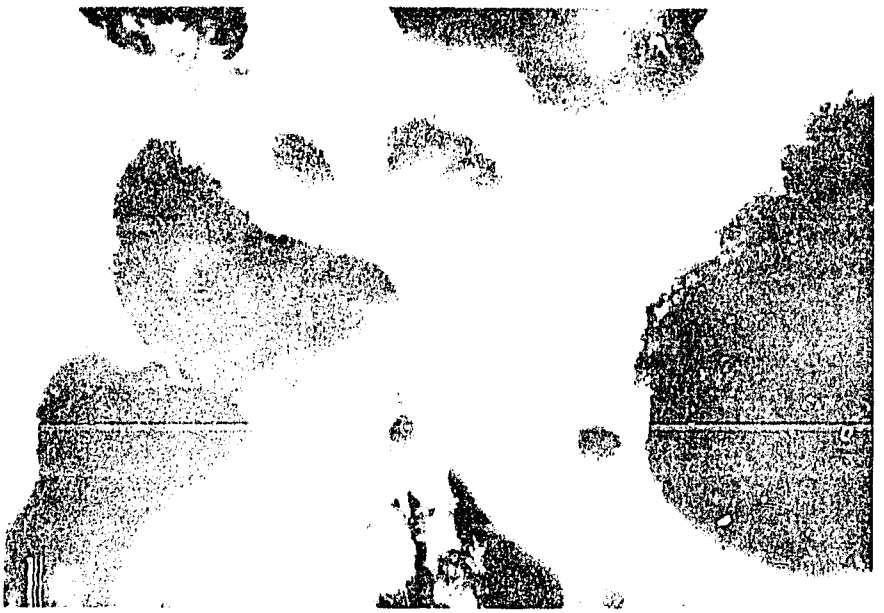


Figure 23. Pores in Pocahontas No. 3 coke. These pores are more irregular, larger, and have thinner walls than the Sharightcokes (Figure 75).

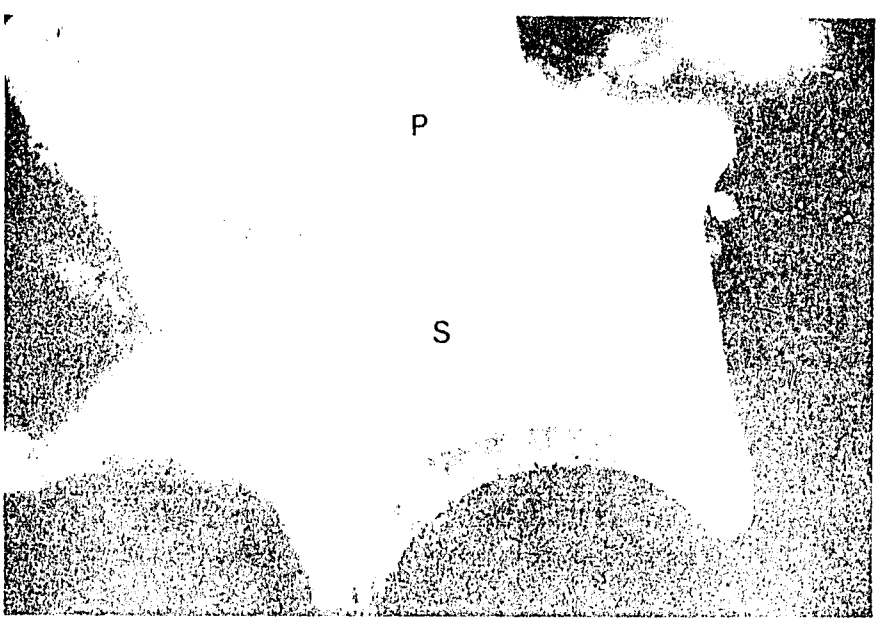


Figure 24. The contact between Sharightcoke (S) and Pocahontas coke (P) in a blend. This photograph, taken in plane light, shows the difference in structures of the two coke types.

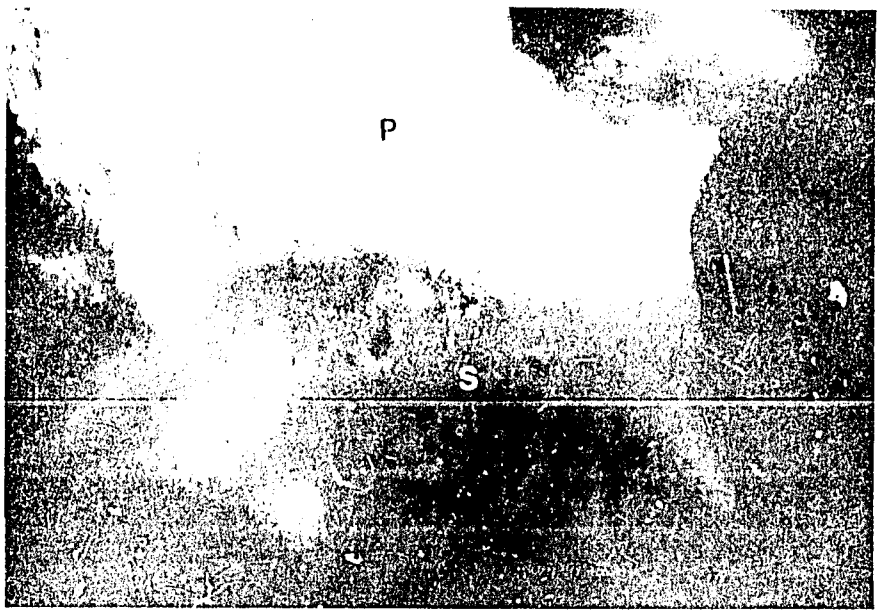


Figure 25. The contact between Sharighcoke (S) and Pocahontas coke (P) in a blend. This photograph covers the same area as figure 77. Note the sharp transition from Sharighcoke to Pocahontas coke. No intermixing is evident at all, but there does appear to be a thin (2-5 micron) zone in which an anisotropic coke with very small texture is present.

Figure 26. A grain of Pocahontas coke (P) imbedded in a mass of Sharighcoke (S). There is no intermixing, but the Sharighcoke does seem to have flowed around the Pocahontas coke. No evidence is available to determine if the plastic stage for the Sharighcoal occured at the same temperature (therefore time) as the plastic stage for the Pocahontas coal.

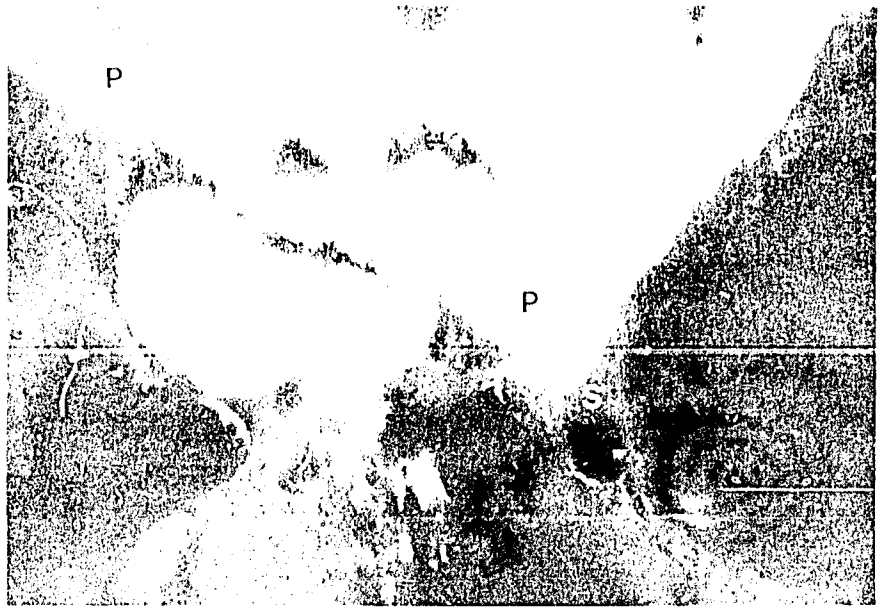


Figure 27. An angular grain of Pocahontas coke (P) bound to a grain of Sharightcoke (S) as revealed with crossed nicols. The boundary between the two coke types is extremely sharp.

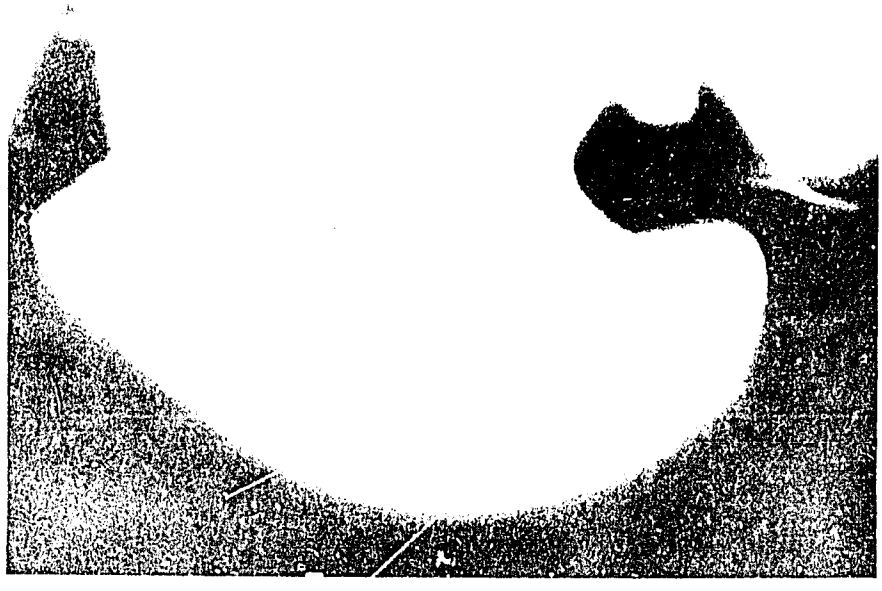


Figure 28. Devolatilized Sharightop seam coal. The grain is greatly rounded, but not coalesced with other grains, as it would be in coke. The grain is isotropic, and very bright. More like coke than coal.

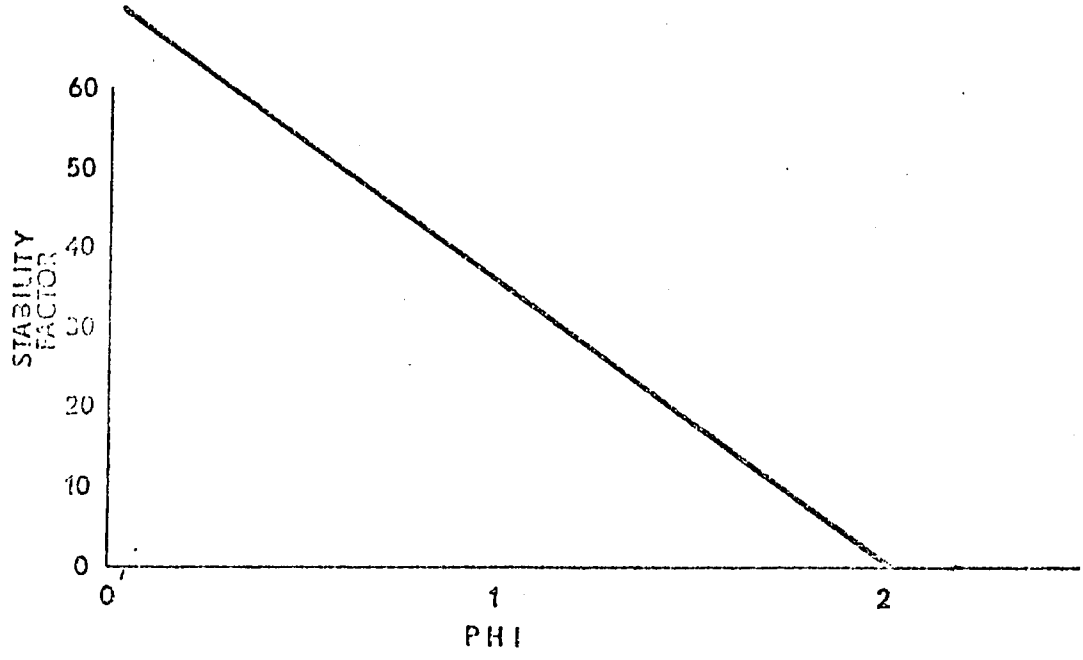


Figure 29. Stability Factor Standard Curve. PHI (Ø) units of the 30th percentile from the probability graph are transformed to Stability Factors.

TABLE 3

GIESLER PLASTICITY

Random Samples

Coal	Sample	Maximum Fluidity (D.D.P.M.)	°C @ Max. Fluidity	°C Start (1 D.D.P.M.)	°C Final (1 D.D.P.M.)	°C Range
Sharig Middle Seam	1	123	393	357	420	63
Sharig Middle Seam	2	100	393	354	414	60
Sharig Middle Seam	3	87	396	360	414	54
Sharig Middle Seam	4	123	390	354	414	60
Sharig Top Seam	1	3	396	369	405	36
Sharig Top Seam	2	2.5	396	369	411	42
Sharig Top Seam	3	2.5	399	378	414	36
Sharig Top Seam	4	2.5	399	378	411	33

Screen Samples

Coal	Size Fraction	Maximum Fluidity (D.D.P.M.)	°C @ Max. Fluidity	°C Start (1 D.D.P.M.)	°C Final (1 D.D.P.M.)	°C Range
Sharig Middle Seam	+3M	5	384	363	399	36
Sharig Middle Seam	3Mx14M	14	396	360	411	51
Sharig Middle Seam	14Mx28M	700	387	333	399	66
Sharig Middle Seam	28Mx48M	260	393	357	420	63
Sharig Middle Seam	48Mx100M	235	396	357	426	69
Sharig Middle Seam	-100M	82	393	354	417	63
Sharig Top Seam	+3M	2	405	369	414	45
Sharig Top Seam	3Mx14M	2	402	378	411	33
Sharig Top Seam	14Mx28M	3	405	369	414	45
Sharig Top Seam	28Mx48M	3.5	399	372	411	39
Sharig Top Seam	48Mx100M	4	399	381	411	30
Sharig Top Seam	-100M	3	399	366	408	42

PROPOSED SHARIGH COKE

The review of the work done on the Sharigh coal showed that, in either the raw coal form or as a clean coal, it was not entirely suitable for coke because of its high sulfur content and a weak coke produced. Cleaning of this coal can give a significant sulfur reduction if lowered recoveries are acceptable.

The weak coking characteristics of the Sharigh coal indicate that blending with a suitable blending coal would be necessary to produce a satisfactory product for use in either steel mills or sugar mills.

A project to convert the Sharigh coals to beehive coke was observed at Sharigh and is shown in Photo 6. The coke which was observed near the beehive ovens was weak. Indications were also that it had a high sulfur content. Even with the addition of a significant amount of low-sulfur blending coal, this approach could not achieve a sufficiently low sulfur in the final product to meet market requirements. This statement is based on our studies on the Sharigh coal.

Another possibility that may have merit is Dr. Chotani's work at the PCSI using the fixed bed reactor. During our review of this work in Karachi, Dr. Chotani indicated that he had had success in reducing the sulfur content by 40 percent. The coke produced, however, while lower in sulfur than that from a beehive oven, appeared to be weak. It is, therefore, suggested that if his investigations are to continue, he should investigate blending the Sharigh coals with low-sulfur coals to achieve a suitable coke product with adequate strength for utilization in the steel mill and sugar mills. Blending of the charge with coke breeze is suggested.

To this end, two schemes are offered in Exhibit A which follows. Case I assumes that the coal is cleaned at 1.7 specific gravity; Case II shows an optimum case with a significant sulfur reduction, and the coal cleaned at 1.5 specific gravity. Case II indicates that

if the strength characteristics are met, the sulfur content might be within an acceptable range so that it could be marketed to the sugar mills.

At this point we would add that on our agenda, for our work here in the United States, is to attempt to identify a coal which might meet these specifications for blending with the Sharigh coals to make a marketable coke, hence the blending with Pocahontas No. 3.

The specifications for beehive and metallurgical coke used in Pakistan are shown in Exhibit A. Specifications for the iron ore and coking coal are shown in Exhibit B.

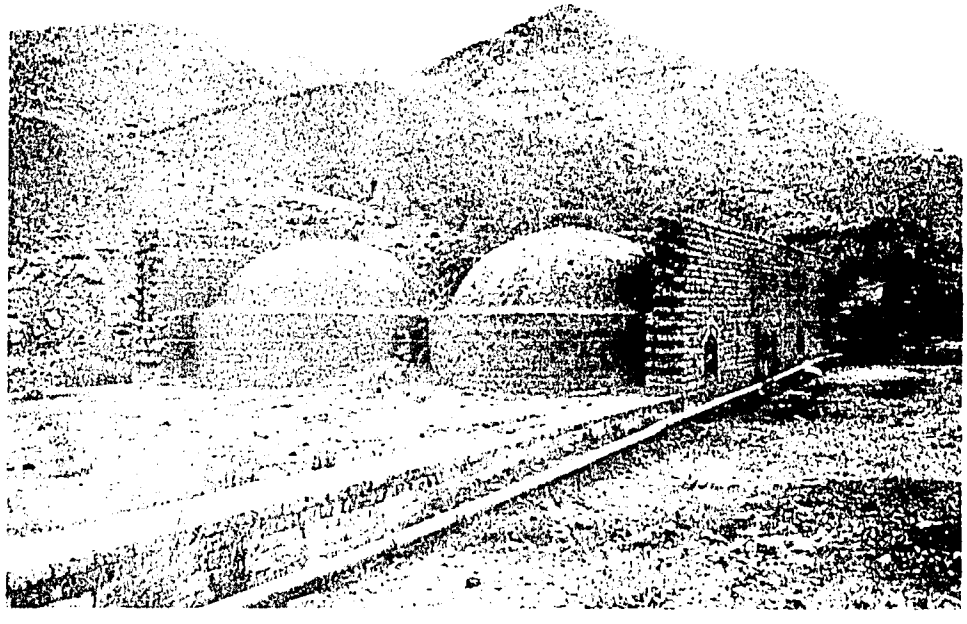
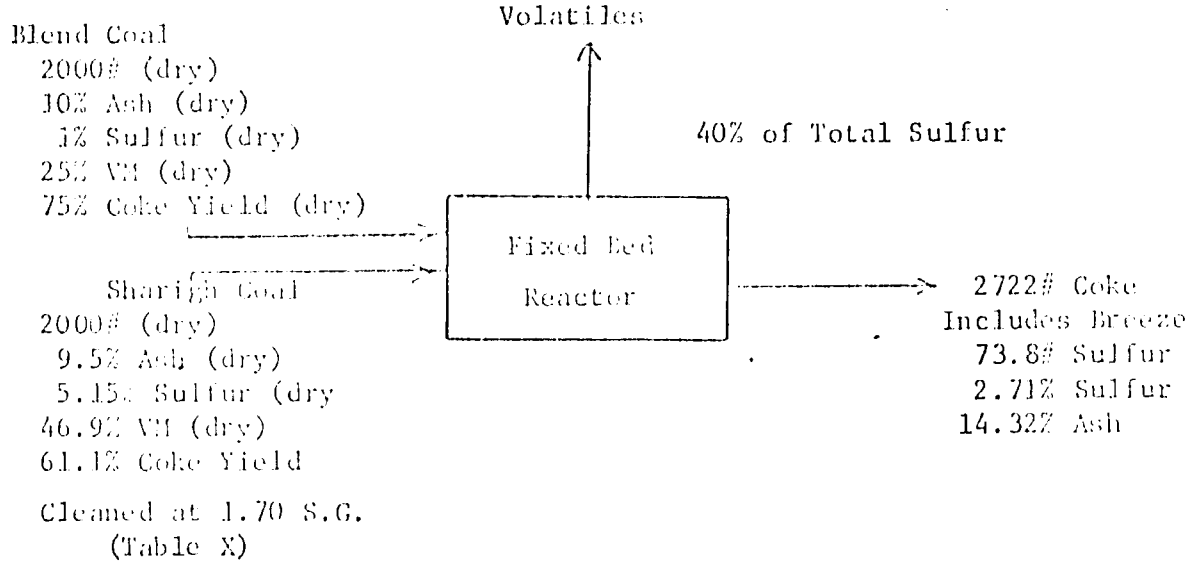
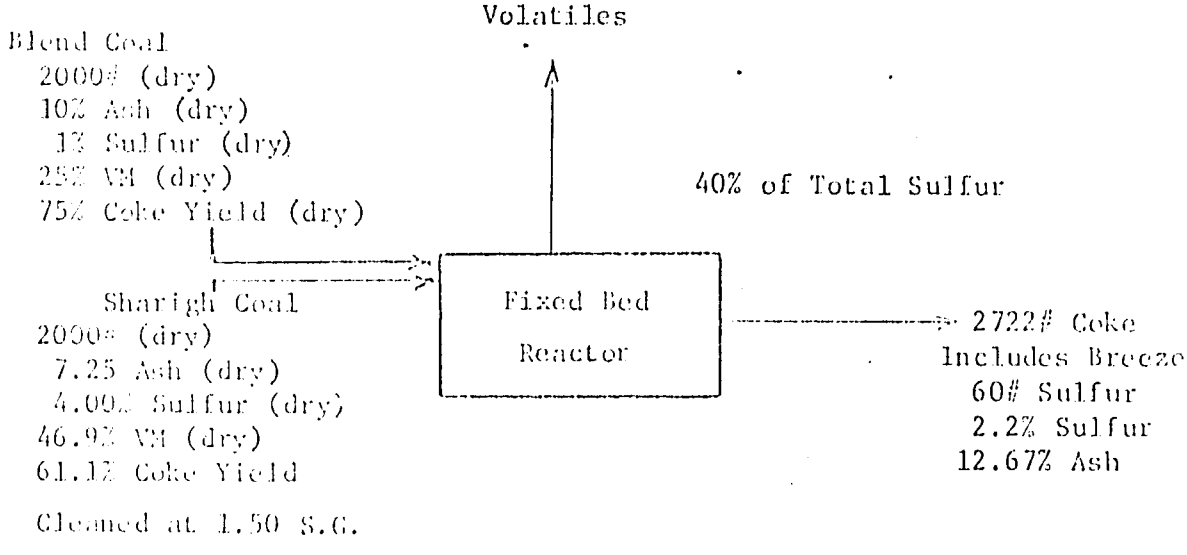


Photo 6. Photograph of Beehive Coke Oven at Sharigh.

EXHIBIT A
FIXED BED REACTOR USED TO PRODUCE COKE AND REDUCE SULFUR IN SHARIGH COAL



CASE I



CASE II

From Data in Washability and Coking Characteristics of Sharigh Top Seam and Middle Seam Coals by Heinrich and Malik, November 1973.

EXHIBIT B
SPECIFICATIONS FOR BEEHIVE AND METALLURGICAL COKE

	Beehive Coke (Indian Region)	Metallurgical Coke Polish	Metallurgical Coke Chinese
Ash	28%	9-11% (dry basis)	15% maximum
Moisture	2-3%	3-6%	5% and below (if it exceeds 5%, excessive proportion will be deducted from the weight.
Volatile	2-3%	1-1.5%	0.80% maximum in average
Sulfur	1% maximum	0.9-1.05% (air dried basis)	0.80% in average
Fixed carbon (by difference)	. 65%	87% minimum (dried basis)	79% minimum
Shatter test	---	81-84%	---
B.T.U	8500/9000	Not less than 12500 C	---
Size-grading		Screened over 60mm not more than 10% between 40-60mm and 5% below 40mm with dust proportion not exceeding 2%	40mm and up will amount to 85% minimum

The landed cost and the selling prices during the last 5 years were:

Years	Beehive Coke Selling Price Per Ton	Polish Coke Selling Price Per L/Ton	Chinese Coke Selling Price Per L/Ton
7/70	Rs. 242/-	Rs. 520/-	Rs. 333/-
6/71	No imports	---	390/-
5/72	-do-	413/-	413/-
7/73	-do-	671/-(on account of revision as a sequel to devaluation)	---
3/74	-do-	---	1278/20
8/74	-do-	1712/-	---
2/75	-do-	---	1760/-

* Information from the Pakistan Mineral Development Corporation.

EXHIBIT C
SPECIFICATIONS FOR PASMIC IRON ORE

- Size of Sinter = Below 6 mm
- Size of lump ore = 30 mm - 6 mm
- Desirable limit on content of various constituents:

	Percent	
Total Iron	60.0	(min.)
Phosphorous	0.1	(max.)
Sulphur	0.05	(max.)
Arsenic	0.005	(max.)
Copper	0.01	(max.)
Manganese	2.0	(max.)
Silica	8.0	(max.)
Titanium dioxide	0.1	(max.)

SPECIFICATIONS FOR PASMIC COKING COAL

- Size of coal = Below 50 mm
- Desirable limit on content of various constituents:

	Percent	
Moisture	5.0	(around)
Volatiles	28.0	(max.)
Ash Content	10.0	(max.)
Sulphur	0.8	(max.)

BRIQUETTING FOR SMOKELESS FUEL

Agglomeration

A final coal preparation system which was evaluated involved both conventional and unconventional aspects. The purpose of this system was to produce a sweet-smelling, smokeless, briquetted fuel. Briquetting of coal is a well developed process involving crushing the coal, mixing it with a binder and pressing it into briquettes. However, simple briquetting alone will not reduce smoke and odor emissions. In order to reduce emissions, the sulfur content of the coal was lowered by gravity separation and lime was added before briquetting to retain the remaining sulfur.

The primary purpose of this study is to reduce the ash and sulfur content of the Lakhra and Sharigh coals enough to produce a high grade fuel such as would be required for power plant, commercial and metallurgical applications. However, some attention was given to the possibility of using these coals as an organic chemical feedstock. This work involved both devolatilization studies using a fluidized bed and liquifaction studies in a Parr pressure vessel. Successful devolatilization would produce a char which could be briquetted to produce an acceptable fuel. Liquifaction is a conversion process which also has a good potential for producing an acceptable fuel.

Briquetting and Smokeless Fuel

The possibility of producing a sweet (eg. non-acid) smelling, smokeless and easily briquetted fuel from two samples of Lakhra coal (WMI and HIM-3) and two samples of Sharigh coal (STS and SMS) was examined. It was found by mixing either lime or calcium carbonate with each of the coals that the desired product could be obtained. A 100 percent stoichiometric addition of lime based on the sulfur content of the Lakhra coals and 200 percent stoichiometric addition of lime based on the sulfur content of the Sharigh coals was found to be the optimum mix proportions.

A partial devolatilization of each of the coals was also carried out in order to determine the potential of each of these coals for organic chemical feedstocks with the resultant residue being used in the production of a sweet (eg. non-acid) smelling, smokeless and easily briquetted fuel. It was found that all four samples could be partially devolatilized to 50 percent of the original or less volatile matter and the resultant residue briquetted into the desired fuel. The same mix proportions of 100 percent stoichiometric for the Lakhra and 200 percent for the Sharigh was used. The resultant pellets were considerably weaker in strength than the non-devolatilized coals but still acceptable as an article of commerce.

BRIQUETTING - In order to determine what addition of lime or limestone might produce the desired sweet-smelling, easily briquetted fuel, stoichiometric calculations were performed using the sulfur content of the 1.60 float fraction of each coal as the basis for computation. The following reaction is assumed:

$$CaO + SO_2 + 1/2\ O_2 \longrightarrow CaSO_4$$

Sulfur values are given below:

Lakhra Coal		Sharigh Coal	
Sulfur % @ 1.60 float			
WMI	5.88	STS	5.56
HIM3	5.65	SMS	8.35

Due to the high sulfur and ash content of these coals, it was determined that additions of hydrated lime ($Ca(OH)_2$) and limestone ($CaCO_3$) should be kept to a minimum as increased ash content directly results from such additions. As an example, adding limestone to Sharigh coal (SMS, 8.35% sulfur) in double the quantity theoretically needed to convert all the sulfur to sulfates, i.e., 200% stoichiometric, results in an ash increase of at least 540 pounds per ton, effecting an increase from 13% ash to nearly 40%. It should be pointed out that SMS coal at 8.35% sulfur is the highest sulfur coal of those tested and therefore requires the most limestone. This example represents the maximum amount of limestone actually added for this testing program.

Since the coals to be tested were all high in ash (see table below), it was determined that a specific gravity separation at 1.60 would yield much lower ash values

Lakhra Coal		Sharigh Coal	
Ash content % as received			
WMI	21.1	STS	22.5
HIM3	24.6	SMS	33.6

at reasonable recovery rates (See Washability Section). Ash values were reduced as shown below:

Lakhra Coal		Sharigh Coal	
Ash content % 1.60 float			
WMI	12.7	STS	7.6
HIM3	20.4	SMS	13.0

Experience has shown that 100% stoichiometric additions of sulfur sorbents seldom follow the theoretical postulates and that most coals, depending on firing conditions, sulfur breakdown and other parameters, often require twice or more of the theoretical quantity of lime or limestone to achieve the desired level of sulfur capture. For these reasons, stoichiometric levels of addition for both lime and limestone of 100, 150 and 200% were chosen for the initial study using a press and die to make individual pellets. The desired proportions of coal and either limestone or lime were mixed, placed in the die, and pressure applied to form the pellet.

In order to determine how strong the compacted pellets were and as a guideline in selecting optimum lime or limestone contents for full size briquettes, compressive crush strengths were determined for one pellet from each mixture using a universal testing machine.

The table below gives the results of this test:

Coal	Percent Stoichiometric Level	Crush Strength in PSI for Hydrated Lime ($Ca(OH)_2$) Additive	Crush Strength in PSI for Limestone ($CaCO_3$) Additive
Lakhra WKI	100	1740	1090
	150	600	960
	200	1130	630
HLM3	100	1400	1350
	150	1210	1210
	200	1300	1210
Sharigh STS	100	1040	720
	150	1060	920
	200	1300	870
SMS	100	1620	1740
	150	1570	1210
	200	1690	1880

Calcium hydroxide additions as shown in the table resulted in pellet strengths exceeding 1000 psi in every case but one. A crush strength of 750 psi generally indicates sufficient strength to be handled and transported normally without excessive breakage or dusting.

Odor emission tests were performed by placing crushed pellets of the twenty-four coal mixtures on a nichrome

screen one at a time and igniting the coal with a fisher burner. Even though two people participated in the test, no smell of sulfur dioxide was specifically noted for any of the twenty-four mixtures. A volatile matter odor was discerned for all coals, however, and was noticeably stronger in the Sharigh coals. A sweet smell, characteristic of heated lime was noticed to varying degrees for all of the mixtures. As a rule, the Lakhra pellets were harder to ignite, as were those of increasing lime or limestone content, although all pellets ignited. When untreated coals were burned, a sulfurous odor was discerned. The subjective nature of such a test does not accurately allow for the degree of odor or quantity of sulfur dioxide released upon combustion. To better determine to what degree a "sweet smelling" fuel could be produced, a test was devised in which sulfur analyses were performed on the pellets before, and the ash after, the carbon was burned off in a furnace. Using this approach, the percent of sulfur retained and that which indirectly evolved (probably as sulfur dioxide) can be accurately determined.

After combustion, the ash residues were carefully weighed, then analyzed for sulfur content. By comparing the weight of sulfur in the unburned pellet with the weight of sulfur in the ash, the percentage of sulfur retained in the ash can be determined.

Sulfur retention values for all four coals are given in the table below:

Sulfur Retention

Coal	Stoichiometric Addition %	Sulfur Retention % Calcium Hydroxide	Sulfur Retention % Calcium Carbonate
WMI	100	48.06	53.27
	150	71.40	77.41
	200	101.50	85.26
HIM3	100	36.96	41.10
	150	69.28	68.18
	200	98.78	84.36
STS	100	51.59	33.15
	150	71.63	46.56
	200	80.00	53.71
SMS	100	51.69	43.28
	150	70.37	46.15
	200	69.08	46.06

As can be seen from the table, in nearly every case, the percent sulfur retained varies as the amount of sulfur sorbent added. In the case of the Lakhra coals, all or nearly all of the sulfur present was retained in the ash when 200% stoichiometric calcium hydroxide was added, 101.5% for WMI and 98.78% for HIM3. In most cases calcium hydroxide was more effective in retaining sulfur. Exceptions are noted with lower stoichiometric levels of addition in the Lakhra coals where calcium carbonate was slightly more reactive.

Ash percentages were also determined during the pellet combustion tests and are given below:

Percent Ash

Coal	Stoichiometric Addition %	Ash % Calcium Hydroxide	Ash % Calcium Carbonate
WMI	0	12.70	12.70
	100	23.20	23.03
	150	28.26	28.21
	200	33.66	30.65
HIM3	0	20.40	20.40
	100	29.11	28.94
	150	34.98	33.69
	200	39.72	36.55
STS	0	7.60	7.60
	100	19.54	19.85
	150	24.93	21.10
	200	28.48	23.52
SMS	0	13.00	13.00
	100	30.31	27.31
	150	36.36	30.56
	200	38.93	32.61

As can be seen from the table, the percentage of ash increases as the amount of sorbent added increases. Also, calcium carbonate, in almost every case produced less residue than calcium hydroxide at the same stoichiometric level of addition.

The primary consideration in attempting to produce briquettes from treated mixtures of the four coals examined was strength. It was determined from the compressive strength data gathered on the pellets that the 100% stoichiometric calcium hydroxide mixtures would give the best results for the Lakhra coals while 200% stoichiometric calcium hydroxide mixtures were chosen for the Sharigh coals. The production of briquettes from all stoichiometric mixtures

was precluded by the insufficient quantity of sample available.

For the briquetting tests, additional samples of each coal in larger (15-20 pound) quantities were obtained as before by riffling, crushing, washing at 1.60 gravity in perchloroethylene, drying and pulverizing. Preparation of the briquetting mixtures, however, required the use of a muller type mixer. This type of mixer gives complete, thorough mixing by a grinding, smearing and spatulating action.

Nearly all of the briquettes produced exhibited cracking along the midline. This occurs as a moisture release subsequent to briquetting and if more sample were available could most likely be eliminated by varying water content, roll speed, and pressure release parameters. The briquettes produced appear to have good structural integrity and moderate strength. Samples of briquettes produced are available for inspection. It was noted during the briquetting runs that the slightly coarser Sharigh coals (which were troublesome on the hand pellet press) actually made briquettes more readily than the Lakhra coals.

The special steel drums containing the four coals were opened and the entire contents of each

(approximately 40 pounds) were riffled through a sample splitting device until approximately two pound samples of each coal were obtained. A coating of fine white precipitate was noted on the coal particles as the Lakhra coal containers were opened; in addition, some rusting of the Lakhra containers was noted. The containers of Sharigh coal appeared normal. The relatively high moisture content of the Lakhra samples was apparently the cause of the oxidation. Moisture values for the four coals are reported below:

Lakhra Coal		Sharigh Coal	
WMI	26.08	STS	3.93
HIM3	27.50	SMS	3.20

Following riffling, the samples were crushed in a jaw crusher (top size 1/2 inch) then in a roll crusher (top size 1/4 inch) before being placed in a drying oven at 110°F overnight.

The roll crushed, oven dried samples were separated at 1.60 using perchlorethylene as the heavy media. The float fraction for each coal was then dried and pulverized to approximately minus 200 mesh U.S.S. (United State Sieve). During pulverization, it was noted that the Sharigh coals produced a coarser product than the Lakhra coals, were considerably harder to grind and left a slight woody fiber residue in the pulverizer (as if a wooden matchstick had

fallen into the sample). However, no such contamination had been observed.

While crushing the two pound sample of Sharigh middle seam coal, a sulfur ball measuring about 1 inch in diameter was encountered when it jammed the roll crusher. It was removed from the sample. Upon crushing the SMS coal a distinct odor of hydrogen sulfide was noted. The odor seemed strongest when coarser fractions of the coal were crushed and much less noticeable during pulverization.

During the preparation of the Lakhra coals it was noted that (although the coals seemed dry to the touch and, in a 1/4 inch by zero size were pourable and dusting) when pulverized they released water causing mild caking of the product. Care was taken with these coals that complete water removal was achieved. This was done by drying the samples for 24 hours at 115°F.

Reagent grades of calcium hydroxide and calcium carbonate were used in treating the coals to reduce the possibility of interference or decreased reactivity caused by impurities. Ten gram mixtures of pulverized coal and sulfur sorbent (calcium carbonate or hydroxide) were prepared, six mixes for each coal, a total of 24 mixes. An analytical balance accurate to 0.0001 gram was used to assure accuracy and mixing was performed using an automatic mortar and pestel. Each sample was mixed for 20

minutes to insure even distribution of the lime or limestone and the coal. Then, five one gram portions of each mixture were placed in a die and hand pressed into a pellet using a hydraulic pellet press (Figure 5, Chapter 7). Forming loads of one ton, maintained for approximately thirty seconds, were used on mixtures of Lakhra coals while Sharigh coals required a load of approximately 1.6 ton to produce a "good" pellet. The size of the pellets produced were about 1/2 inch in diameter (surface area 0.204 in^2) as indicated in Figure 6, Chapter 7. Forming pressure for the Lakhra coal pellets was approximately 9800 psi; for the Sharigh, 15,680 psi.

The addition of some quantity of water is generally needed to produce a good strong briquette. For these small pellets, however, it was found that a dry mixture gave better results. The Lakhra coals formed pellets quite readily, were easy to remove from the die and smooth textured. The Sharigh coals, however, in addition to requiring the higher forming pressure mentioned earlier, were very difficult to press free the die and had a more coarse texture. This is, perhaps, a result of the larger particle size of the Sharigh coals caused by the difference in hardness and grindability mentioned previously.

One of the five pellets for each of the twenty-four mixtures was analyzed for sulfur content using a LECO

sulfur analyzer and another placed in an electric muffle furnace at 1850°F for approximately one hour. Each pellet was carefully weighed and then placed on a nichrome wire screen over a platinum bowl to catch any ash particles which might fall through the screen. An oxidizing atmosphere was maintained in the furnace by circulating air to insure complete carbon burnoff. The Lakhra pellets burned evenly and produced a hard fired ash pellet. Although without structural strength, these pellets produced no fine ash and could be picked cleanly off the screen without breakage or dusting. The Sharigh pellets, however, burned violently for the first few moments after being placed in the hot furnace. The rapid escape of volatiles from these coals was in some cases violent enough to lift the pellet completely off the screen requiring additional tests to insure that all the ash remained on the screen or in the bowl. In contrast to the Lakhra coal pellets, the fired pellets of the STS coal were extremely powdery and friable. The bloated shape of one fired pellet (100% stoichiometric limestone SMS) indicated very well the effect of rapid volatile matter release. For the SMS coal, calcium hydroxide was more effective in dampening the swelling effect.

In the briquetting tests, calcium hydroxide was first dry mixed for fifteen minutes with the coal, then water

was added and mixing continued for an additional twenty minutes. The quantity of water necessary was determined by adding small quantities of water and mixing until the desired consistency (determined by squeezing the mixture in the hand) was achieved. Variations in the rate of feed and the roll speed of the briquetting machine (pictured in Figure 7, Chapter 7, and Figure 1, this chapter) were then made order to produce good briquettes. Briquettes produced are illustrated as Figures 2 through 5).

TABLE 1

PERCENT SULFUR RETENTION, ASH AND CRUSH STRENGTH ON FIRED PELLETS OF LAKHRA AND SHARIGH COALS

›al	% Stoichiometric Addition		% Sulfur Retention		% Ash		Crush Strength psi	
	Lime,	Limestone	Lime,	Limestone	Lime,	Limestone	Lime,	Limestone
ıI	100	100	48.06	53.27	23.20	23.03	1740	1090
	150	150	71.40	77.41	28.26	28.21	600	960
	200	200	101.5	85.26	33.66	30.65	1130	630
.M-3	100	100	36.96	41.10	29.11	28.94	1400	1350
	150	150	69.28	68.18	34.98	33.69	1210	1210
	200	200	98.78	84.36	39.72	36.55	1300	1210
'S	100	100	51.59	33.15	19.54	19.85	1040	720
	150	150	71.63	46.56	24.93	21.10	1060	920
	200	200	80.00	53.71	28.48	23.52	1300	870
S	100	100	51.69	43.28	30.31	27.31	1620	1740
	150	150	70.37	46.	36.36	30.56	1570	1210
	200	200	69.08	46.66	38.93	32.61	1690	1880

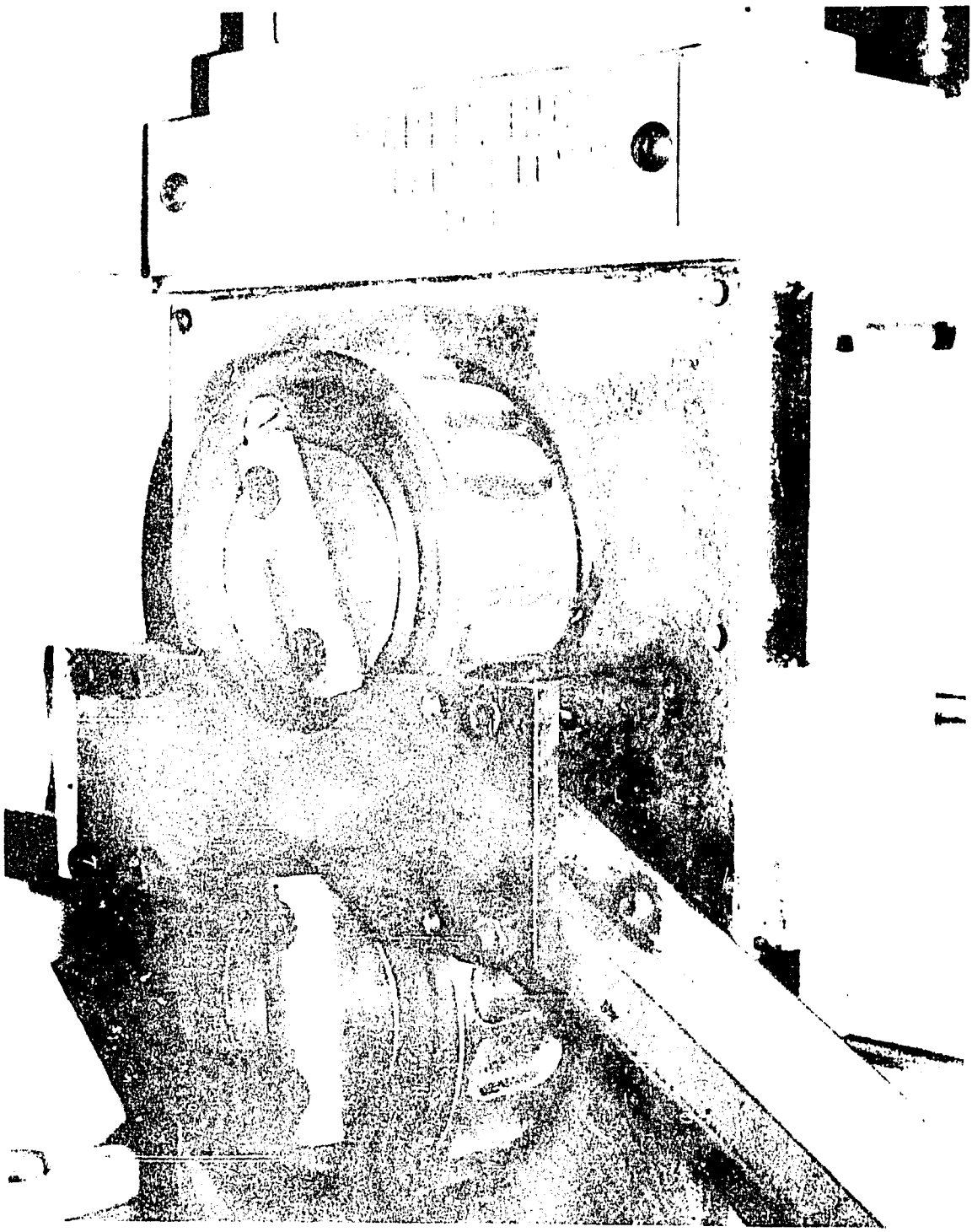


FIGURE 1. BRIQUETTING ROLLERS

FIGURE 2. LAKHRA WMI BRIQUETTES

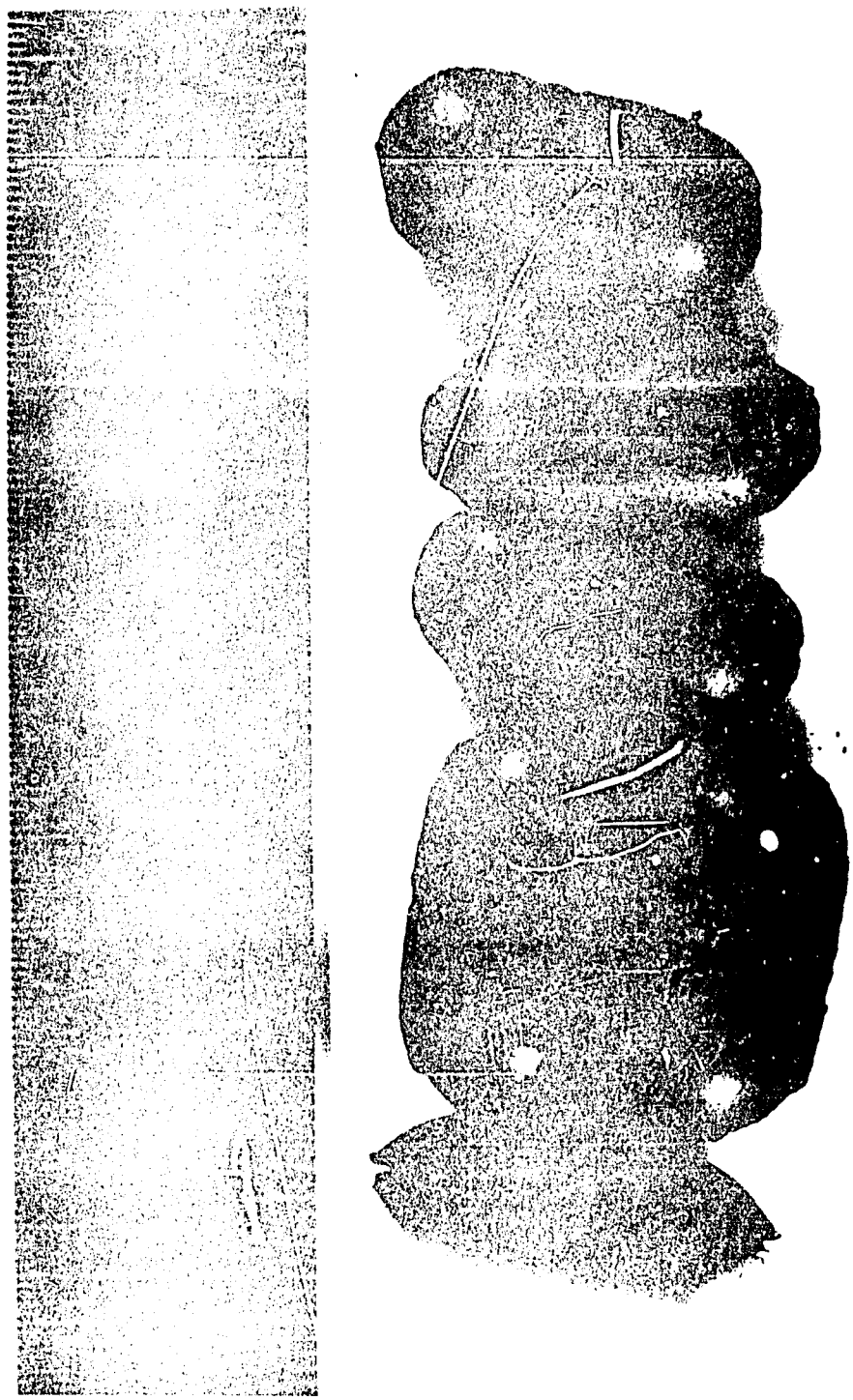


FIGURE 3. LAKHRA HIM3 BRIQUETTES

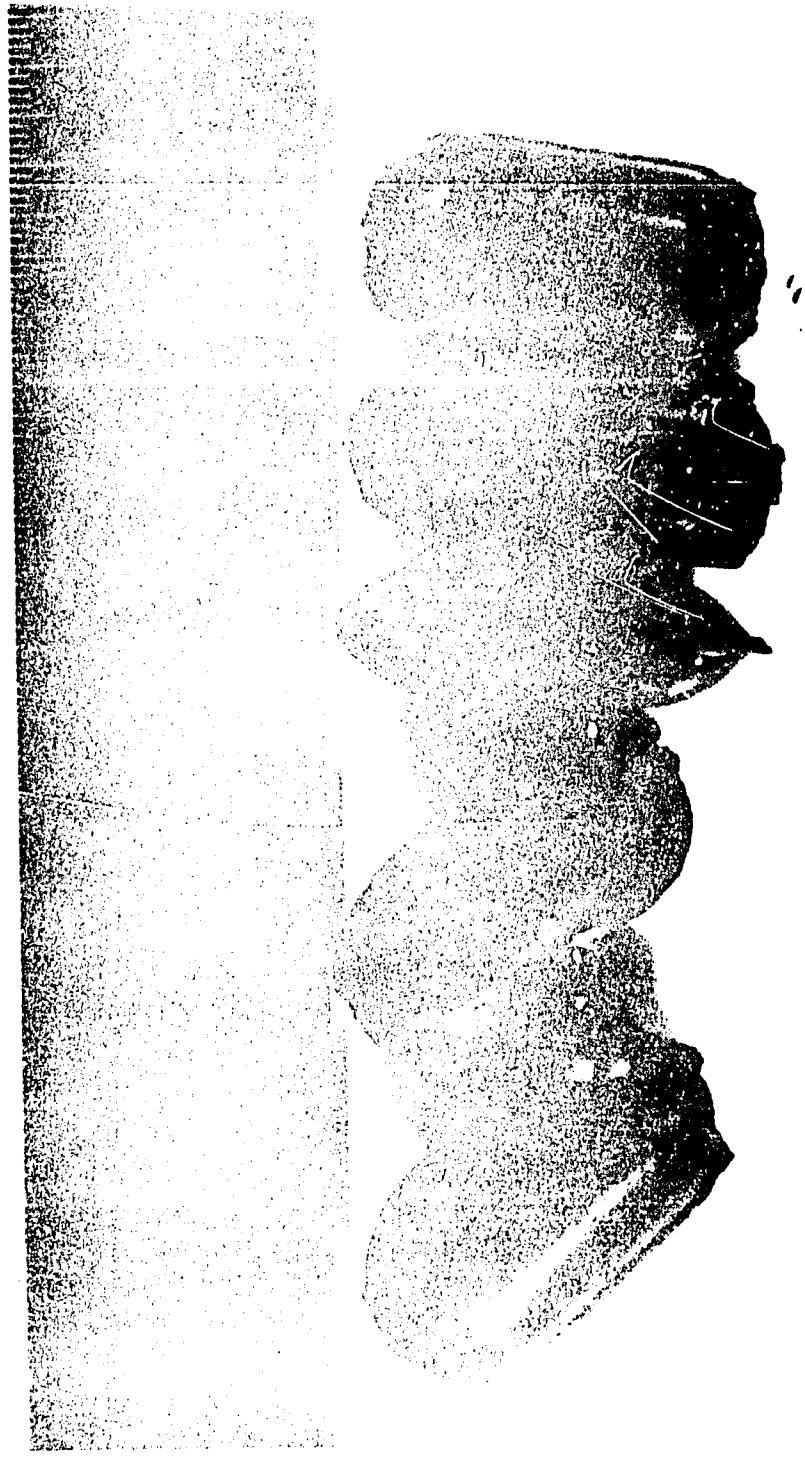


FIGURE 4 [illegible] MIDDLE SEAM BRIQUETTES

FIGURE 5. SHARIGH TOP SEAM BRIQUETTES

FLOW DIAGRAM - A block flow diagram for a briquetting plant is shown in Figure 6. It is applicable to both Sharigh and Lakhra coals.

ESTIMATED CAPITAL COSTS - The estimated guideline to capital costs for a briquetting plant to produce 100,000 long tons per year of briquettes is estimated to be as follows.

Item	Description	U.S. Dollars	Pakistan Rupees
1	Flotation	$ 250,000	R₹ 2,500,000
2	Drier & Conveyors		500,000
3	Mill & Screening Plant	200,000	200,000
4	Limestone Mill & Screen	150,000	150,000
5	Mix Muller	100,000	200,000
6	Presses & Conveyors	100,000	500,000
7	Packer	25,000	100,000
8	Site Preparation & R.R.		1,500,000
9	Buildings		2,000,000
	Total	$ 825,000	R₹ 7,650,000
	Engineering & Contingency	200,000	1,191,000
		$1,000,000	R₹ 8,841,000

Total cost would approximate U.S. $1,000,000 and R₹ 8.8 million.

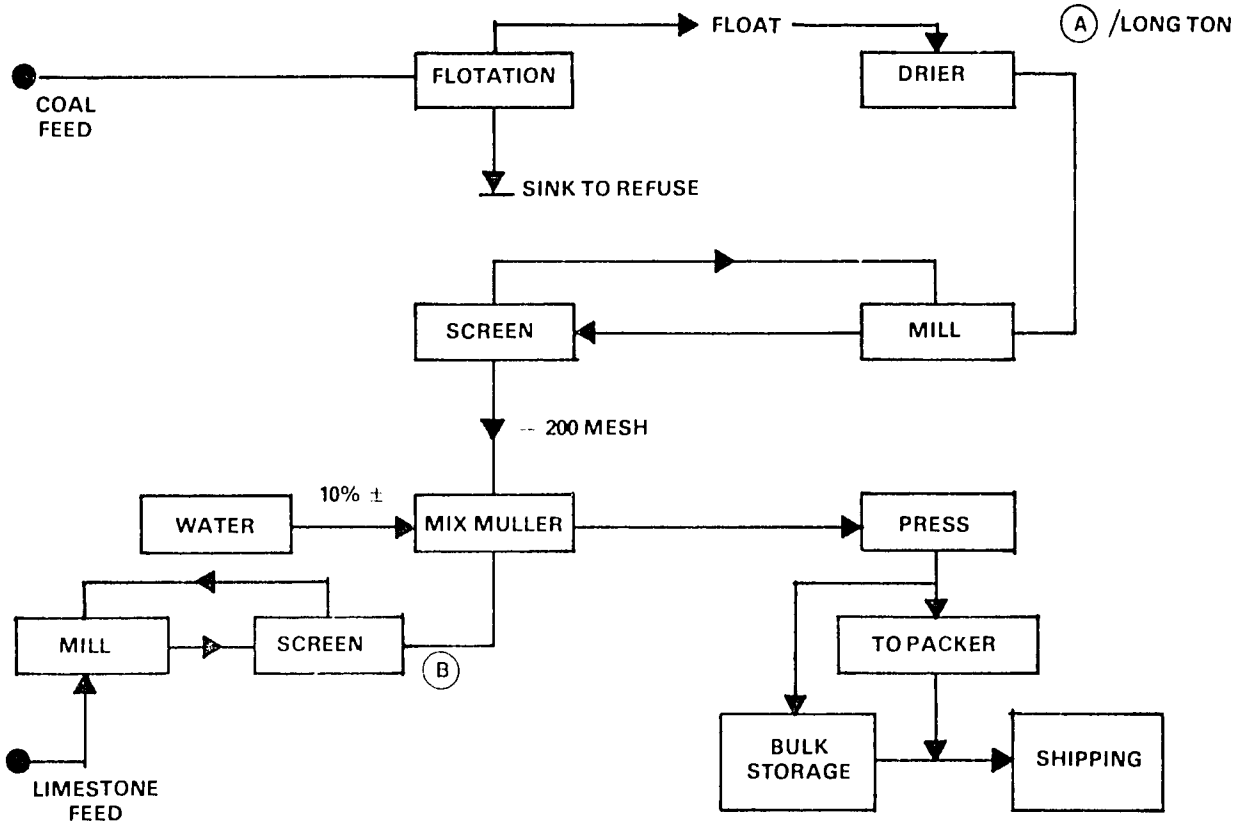
Depreciation on a straight-line basis over 15 Years would thus be about: U.S. $ .67/ton and R₹ 5.87/ton.

Direct Operation costs per ton of briquettes would be approximately as follows.

Raw Materials:		@100% R₹/ton	@200% R₹/ton
Coal:	R₹ 2.00/.6 =	334	
less Credit:	R₹ 200 x $\frac{7000}{11000}$ x .4 =	51	
	Subtotal	283	283
Limestone:	R₹ 40/ton x $\frac{400}{2240}$ =	7.2	14.4
	Subtotal - Raw Materials	290.	297.

Figure 6

FLOW DIAGRAM



(A)	Lakhra WMI	HM3	Sharigh Top Seam	Middle Seam
Ash	8.0	13	5.0	15
% Reeving	60.0	60	70.0	69
Sulfur	4.5	6.0	5.0	8.5
Specific Gravity	1.40	1.40	1.50	1.7
(B) @ 100%				
Limestone (lbs.) -200 mesh	316 *	420	350	595
Ash (lbs.)	343.5	509.4	294	645.4
% Ash *	15.3	22.74	13.1	29
@ 200%				
Limestone (lbs.)	632	840	700	1190
Ash (lbs.)	507	728	476	955
% Ash *	22.6	32.5	21.25	42.6

* Based on coal feed.

	@100% R$/ton	@200% R$/ton
Direct Labor	50	50
Maintenance & Repair	10	10
Supervision	50	50
Power & Fuel	100	100
Subtotal - Conversion	210	210
Total Cost	500	500
Depreciation & Overhead:		
Depreciation - portion of U.S.	6.7	6.7
	6.0	6.0
Subtotal - Depreciation	12.7	12.7
Finance Cost Average:		
R$ 18.8×10^6 @6% = 1.128×10^6 per year		
per ton =	11.3	11.3
Administration	10	10
Subtotal - Overhead	34	34

@100% - Total Cost Each Plant: R$ 534/ton x $\frac{2240}{2640}$ = R$ 453

@200% - " " " " 541/ton x $\frac{2240}{3040}$ = R$ 398

These range figures serve to illustrate the cost of this product.

It is our recommendation that a pilot plant operation be initiated to extract the reliability of the data; to supply market samples and to train personnel.

A range of products is possible depending on the sulfur and ash content of the coal and the desired stabilization.

CONCLUSIONS - Experimental work was completed on briquetting, through a "mini" pilot plant stage with both Sharigh and Lakhra coals. The logistics of shipping large amounts of coal did not permit a larger production. However, past experience has indicated the reproducibility of the process in commercial equipment.

A satisfactor briquette can be produced with an amount of limestone addition (or lime) to neutralize all or as much of the sulfur in the coal as desired.

The effects of slow ignition of the high limestone-bearing briquettes can be improved, if desired, by the addition of about 0.5% of soda ash to the mix.

The briquetting of devolatilized coal chars is not recommended because of low strength, higher ash content, and poor burning characteristics resulting from the limestone additions.

RECOMMENDATIONS - It is recommended that trial runs of these briquettes be made in the Quetta briquette plant if the presses are suitable. If this is not possible, then a pilot plant operation be established, using a commercial-sized press. This can later be enlarged to a commercial plant. This will permit market penetration, establishment of prices, training of personnel, etc.

STATE OF ART - COAL PROCESSES

CANDIDATE PROCESSES FOR IMPROVEMENT OF COAL PURITY

Presently, reports are received of a variety of processes said to be effective for the removal of sulfur, ash, etc. Some of these processes are discussed herein for completeness of our evaluation.

These processes are all of a proprietary nature and are not now, or may never be, ready for commercial application; therefore, testing of the Sharigh and Lakhra coals was not considered to be productive of meaningful results.

TRW-Meyers Process

This process utilizes a chemical leach with aqueous ferric sulfate at temperatures of between 50 and 130°C. The leach is reported to only affect the pyrite in the coal. The products of the reaction are dissolved ferrous sulfate, sulfuric acid and precipitated free sulfur. The leach solution is regenerated by oxidation with air and precipitated free sulfur is either washed out with a solvent or removed by distillation.

Questions such as reagent losses, effect on coking properties, and capacity are yet to be answered. Moreover, this process only attacks pyrite, which for the Pakistan coals studied, would not be sufficient for the removal of sulfur because much sulfur occurs in the difficult to remove organic form.

Battelle Process

This process also involves leaching. Raw coal is ground and mixed with an aqueous solution of up to 10% sodium hydroxide and about 2% calcium hydroxide. The slurry is pumped into pressure vessels, where it is held for about 30 minutes at pressures between 350 and 2500 psi and temperatures between 225° and 350°C. The liquid is then removed by filtration and the coal is washed and dried.

This process is limited by the same factors which limit the TRW process for application to the test coals except that it is reported to be capable of removing organic sulfur. However, it is believed that this is achieved as a tradeoff to a substantial loss in coking properties and cost.

Miscellaneous Chemical

A number of chemical agents have been considered for the desulfurization of coal. Aqueous solutions containing dissolved oxygen, nitric acid, chlorine, hydrofluoric acid, caustic, or molten caustic have all been reported as successful coal leaching agents for sulfur removal. These processes are all still experimental, generally involve the use of expensive chemicals and in some cases destroy the coal's coking properties and in general cannot be justified economical

Oxidizing Agents

Chlorine gas, nitrogen oxides, and hydrogen peroxide have all been considered as sulfur removal agents. Treatment with chlorine gas involves suspending coal particles in water and then bubbling gas through the mixture. This treatment does reduce the sulfur content of the coal, but has an unfavorable effect on coking properties. The nitrogen oxide treatment is carried out on a fluidized bed reactor at atmospheric pressure, followed by a sodium hydroxide leach. The treatment with hydrogen peroxide involves suspending the coal in a 3 percent hydrogen peroxide solution. All inorganic sulfur can be removed by this treatment without affecting the coking properties of the coal. These processes are primarily effective only on pyritic sulfur and require the use of expensive chemicals. A great deal of further research, especially in recycling systems, is required before any of these systems can be considered for commercial application.

Thermal

Thermal processes generally remove sulfur by their high temperatures; however, chemical agents may be used. Steam-air treatment has also been considered and appears to be the least expensive of the thermal processes. These processes are still experimental and may prove too costly for commercial application.

Bacterial Action

Iron oxidizing bacteria have been found to aid in sulfur removal. Ferric ions oxidize pyrite (allowing it to go into solution) and are themselves reduced to the ferrous state (Meyers Process). The bacteria catalyze the reaction by oxidizing the ferrous iron back to ferric iron by taking on an electron as an energy source. The present stage of development of this process requires too long an exposure time of the coal to the bacteria to be practical. Also, this process only removes pyritic sulfur.

Chemical Comminution

This process involves chemically induced breakage of coal. The chemical compounds or comminution agents (such as liquid ammonia and methanol) induce breakage selectively along boundaries previously weakened by the infiltration of mineral constituents such as pyrite. This results in fragmented coal which has been liberated from entrained pyrites and ash. The pyrites could then be removed by conventional gravity separation.

This process is in effect a substitute for the crushing and grinding step in conventional coal cleaning. Because a conventional plant must still be operated when using this process, the net effect of this treatment is to approximately double the cost of coal treatment (compared to conventional treatment alone) in order to obtain an as yet undemonstrated improvement in ash and sulfur removal.

Two-Stage Flotation

This process consists of a first-stage coal flotation step to remove coarse pyrite and other refuse. The cleaned coal is then passed into a second-stage flotation step (after treatment with a coal depressant, a pyrite collector and a frother) to selectively float the remaining pyrite. This process can only be applied for pyrite removal, and would require that the entire run of mine coal be finely ground.

COAL LIQUEFACTION & HYDROGENATION - The hydrogenation of Sharigh and Lakhra coals presents some problems associated with the high organic sulfur contents of these coals. The life of any applicable catalyst would be severely affected by these constituents.

The past economic prospectus of coal hydrogenation processes has been poor. The only successful processes were practiced in Germany during World War II to produce liquid fuels. The economic factors under those conditions were immaterial.

The most noteworthy attempt at hydrogenation was made by Union Carbide Corp. during 1950-60 decade in the United States. Reports show economic operating losses of multimillions of dollars until the abandonment of the project.

The present State of the Art covers many processes which can be classified as:

(1)	Hydroliquefaction	Solvent refined coal
	(a) Noncatalytic	Coke
	(b) Catalytic	Synthoil, H-Coal
(2)	Extraction: Donor Solvent	CSF, Exxon
(3)	Pyrolysis	
	(a) Direct	COED, Garrett
	(b) Hydropyrolysis	Coalcon, Clean Coke
(4)	Indirect Liquefaction	Fischer Tropsch

A brief description of each process follows. Our comments re the applicability to PMDC coals is also included.

(1) Hydroliquefaction (Figure 1) - Ground coal is slurred into a recycle tar-derived solvent and mixed with a hydrogen containing gas. The mix is subject to elevated temperatures and pressures.

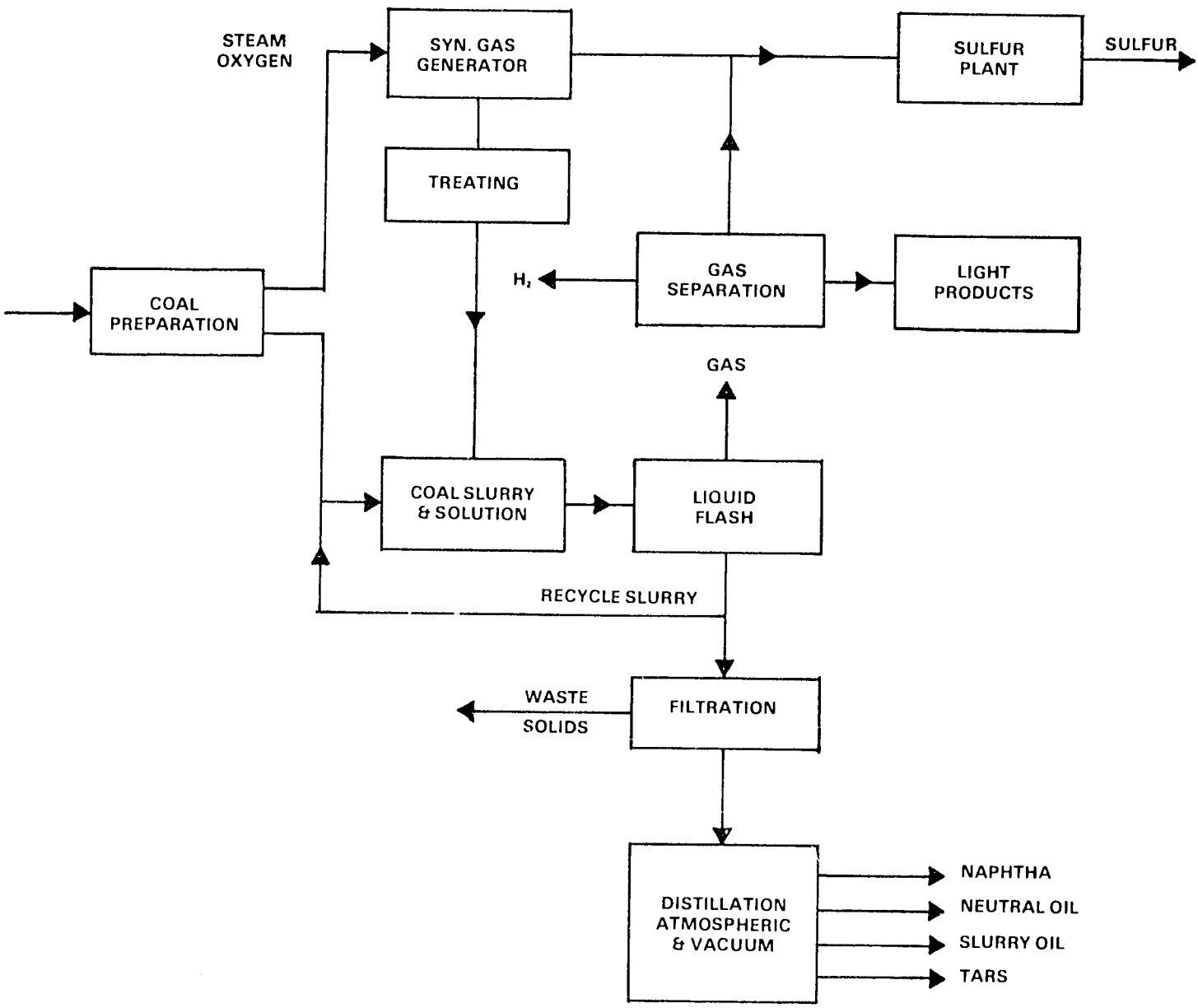
The reaction can be noncatalytic for certain coals will react with hydrogen at pressures which are feasible. Generally, most coals require a catalyst of some kind, be it an ash constituent or a true catalyst.

Products are recovered flash sulfuration at lowered pressures, followed by filtration for ash and unreacted coal fractions.

These processes are not readily applicable to Sharigh or Lakhra coals since treated liquid slurries containing fusains, etc. are not readily filtered. These fractions are not amenable to reaction with hydrogen nor can they be colloidized.

Figure 1

HYDROLIQUEFACTION



In general the economics of this process are not favorable, unless the size of the operation can produce liquid and gaseous fuels at competitive costs. This criterion cannot be met in Pakistan. In summary, coal can be liquefied on an industrial scale; however, the process is not considered economically feasible until such times as petroleum costs are elevated considerably over today's levels, and plants of large integrated capacity are required.

Hydrogenation is not recommended as a viable process for Pakistan at this time.

(2) Extraction - Donor Solvent Processes - This process resembles the hydroliquefaction processes in all ways except that a hydrogen donor solvent is used in place of elemental hydrogen. The recycle solvent is hydrogenated and used to slurry the incoming coal.

The process is not applicable to the Sharigh or Lakhra coals for reasons stated above.

(3) Pyrolysis - This process carbonizes coal to produce char, fixed gases, and tar liquids. The tars are hydrotreated to produce low sulfur liquids. The char is reacted with steam and oxygen or air to produce a synthesis gas.

The synthesis gas can be used for power generation, SNG, for production of liquids via Fischer-Tropsch technology or for production of ammonia or methanol.

The possibility for tar liquids recovery by decarbonization of Lakhra coal has been discussed previously in this report.

(4) Indirect Liquefaction - These processes are based on the production of a synthesis gas from coal by reaction with steam and oxygen or air, purification of the syn gas and conversion to a liquid in a catalytic converter. The Fischer-Tropsch process characterizes these processes. Improvements currently permit operation of the converter at 25 - 30 atmospheres.

Installations of this type require large capacities before they can become economically feasible.

Recent estimates of costs for a Fischer-Tropsch plant consuming 4200 mtpd of high sulfur coal to produce SNG, fuel oils, fuel gas, wax and sulfur indicate a capital cost of U.S. $260 (basis 1973 values) and a production cost of U.S. $ 4.85 per MM BTU basis 65/35 debt equity at 9% interest. These values do not include the part of the mine.

CURRENT DEVELOPMENTS - A summary of current developments in the U.S. follows:

Hydroliquefaction

SRC - Pilot plant for solvent refined coals at Fort Lewis, Washington to treat 45 tpd in operation since 1974 by Pittsburgh & Midway Mining Co. (division of Gulf Oil Co.)

Now being updated to recycle ash for pseudo-catalytic effects. Will produce 2750 metric tons of product for functional testing in a 22 MW boiler.

SRC - Electric Power Research Institute is operating a 5 ton per day SRC plant for ERDA at Wilsonville, Alabama.

In a related program Project Lignite is operating an SRC unit to process $\frac{1}{2}$ mtpd of lignite at the University of North Dakota.

U.S. Steel is operating a similar unit at Monroeville, Pennsylvania as part of their clean coke project.

A catalytic hydrogenation unit is being operated at ERDA Pittsburgh Energy Research Center at Bruceton, Pa.

Extraction

CSF Donor Solvent Extraction pilot plant at Cresap, West Virginia was designed to process 25 mtpd of coal. It operated between 1966 to 1970. Mechanical and materials of construction problems have been solved and the pilot plant is now being reactivated.

Pyrolysis

The COED Process, a multistep pyrolysis process pilot plant has been operated successfully by FMC Corp. at Princeton, New Jersey from 1970 through the first half of 1975. It was designed to process 33 tons per day. A conceptual design of a commercial plant has been made employing this technology to produce a syncrude and fuel for a power plant.

Other pyrolysis processes are under development by ERDA employing a variety of techniques such as fluidization, pressure pyrolysis, flock pyrolysis, etc. These may be identified as Coalcon process, Garrett flock pyrolysis process, etc.

Presently there are also numerous Conseptual Designs based on a wide variety of adoptions of the above processes.

It will be many years before these conceptual designs and processes will become commercially proven, and large amounts of funding will be required to arrive at this point.