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Integrated Mild Gasification Processing at the Homer City Electric Power Generating Station Site

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TABLES

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FIGURES

INTEGRATED MILD GASIFICATION PROCESS

Introduction

A new process for the production of commercial grade coke, char, and carbon products has been evaluated by Penelec/NYSEG. The process, developed by Coal Technology Corporation, CTC, utilizes a unique screw reactor to produce a devolatilized char from a wide variety of coals for the production of commercial grade coke for use in blast furnaces, foundries, and other processes requiring high quality coke. This process is called the CTC Mild Gasification Process(MGP).

The process economics are significantly enhanced by integrating the new technology into an existing power generating complex. Cost savings are realized by the coke producer, the coke user, and the electric utility company. Site specific economic studies involving the Homer City Generating Station site in Western Pennsylvania, confirmed that an integrated MGP at the Homer City site, using coal fines produced at the Homer City Coal Preparation Plant, would reduce capital and operating costs significantly and would enable the HC Owners to eliminate thermal dryers, obtain low cost fuel in the form of combustible gases and liquids, and obtain lower cost replacement coal on the spot market.

A previous report, identified as the Interim Report on the Project, details the technical and economic studies conducted by Penelec, NYSEG, Bechtel, CTC, Management and Technical Systems, and the University of North Dakota Energy and Environmental Research Center.

This report provides background information on the new technology and the opportunity to build a new industry in the Homer City area. This report also details the technical evaluation of the MGP processing of the Homer City coal fines. Work completed includes fine coal cleaning in the fine coal cleaning pilot plant located at Homer City, coal drying and processing in the static and continuous CTC reactors, coke production in the CTC electrically heated oven, chemical and physical testing of the coke and by-products, petrographic analysis of the feed, char, and coke, and comparison of CTC, lab movable wall oven, and commercial grade cokes.

Principal participants in this study include Coal Technology Corporation, Ralph Gray and Associates, Management and Technical Systems, CLI Corporation, Penelec and NYSEG. The entire project was cofunded by the Morgantown Energy Technical Center, U. S. Department of Energy and the Homer City Owners.

Background Information

In 1980, the United States produced approximately 67 million tons per year of high quality carbon in the form of reactive coke for use in ferrosilicon production, steel making, activated carbon, specialty steel and foundry use. Since that time, over 60 percent of the U.S. production has ceased operation, and an additional 10 to 15% of capacity are expected to close in the near future. The closings are due to age of facilities, environmental and economic factors, not the least of which is the current abundance of carbon worldwide. This loss of basic production capability can have significant long term effects on our Nation's ability to rapidly respond to national defense needs based on steel production. Heavy reliance on foreign sources of carbon, in the form of high quality coke, are not in the national interest.

The United States has abundant supplies of the raw materials required for the production of the highest quality coke. Comparison of CTC/MGP coke with coke which meets steel industry specifications is shown below in Table 1. The CTC coke meets all standard specifications.
These data indicate that, within narrow ranges, the CTC coke and coke made from CTC green briquettes in a conventional test expansion coke oven are nearly identical. The comparison with the commercial coke, which uses a significant percentage of Pittsburgh seam coal, indicates close comparison on many parameters but demonstrates a need to improve the blending recipe to achieve parody. These results are further discussed in the coal petrography section.

Table 1. Analytical Data on CTC Products
Base Coal - Homer City Fines

	Proximate and Sulfur			
Identification	Vol. Matter,%	Fixed Carbon,%	Ash,%	Sulfur,%
Green Briquettes	19.32	74.19	6.49	0.87
Coke:				
a. Expansion Oven	0.81	90.85	8.34	0.96
b. CTC Oven	2.42	90.06	7.94	0.83
c. Commercial Oven	0.36	90.72	8.92	0.83

	Physical Properties					
				Sp. Grav.		
	Porosity	Stability	Hardness	App.	True	Density
Coke:						
a. E.O.	38.3	77.2	82.1	1.21	1.96	1.06
b. CTC O	34.7	77.9	78.7	1.25	1.90	1.15
c. Comm.	54.9	79.0	85.0	0.93	2.06	0.98

Coke making technology began with the beehive ovens which emitted coke gases to the atmosphere. The slot oven process was developed to capture these coke gases for by-product recovery. The conventional by-product coking process involves the heating of coal in narrow, silica brick-lined slot ovens in the absence of air. Volatiles are driven off, collected, and sent to the by-product recovery plant.

By-product liquids are recovered for reuse, sale, or disposal. These may include ammonia or ammonium sulfate, an aromatic-rich light oil consisting primarily of benzene, toluene, xylene, naphthalene, phenols, and tars or tar oils.

Control of pollutants from a conventional coking plant is a difficult problem, and environmental compliance problems have caused a number of coke plants to shut down. Sources of air emissions include continuous emissions from doors and lids and from the oven heating combustion stacks; intermittent emissions resulting from oven charging, coke pushing, and quenching operations; particulate emissions from coal storage, handling, and preparation; and fugitive emissions from the by-product recovery operations. Pollutants of concern include particulates, volatile organic compounds (VOC), carbon monoxide, and sulfur dioxide. A number of organic and inorganic air toxics may also be emitted.

The U.S. coking industry using the 40-year old slot oven technology is now being gradually shut down because many plants cannot meet the new clean air requirements. As a result, the U.S. will import over two million tons of coke from abroad in 1993 from foreign suppliers using the same slot oven technology.

The CTC/MGP Process (coal liquids, char and coke) developed by Coal Technology Corporation (CTC) is a continuous process with all the process equipment fully enclosed and sealed to prevent leakage. The CTC/MGP Process makes coke 10 times faster than the slot oven design used by the industry today.

The final products from the CTC/MGP Process are similar to the by-product coke oven products except the CTC/MGP Process produces high quality coal liquid instead of heavy coal tar and a uniform size of formed coke instead of irregular size coke. An intermediate product of char is produced which has an independent and developing world market in the ferroalloy and ferrosilicon industries.

The CTC/MGP Process approach is a two-stage carbonization with a low temperature stage, followed by a high temperature stage while conventional coke ovens are a one-stage, high temperature carbonization. In addition, CTC/MGP technology is a totally enclosed, continuous system, while the conventional coke oven is essentially an open batch system.

The totally enclosed continuous system, the sealed continuous coker and the enclosed indirect coke quenching system eliminate the processes that create pollution problems in the conventional coke ovens.

Environmental Regulations

The coke oven environmental standards would establish visible emission limitations, equipment and performance standards, and work practice requirements for new and existing coke oven batteries.

In this country, the conversion of coal to coke is performed primarily in by-product coke oven batteries. In this process, coal undergoes destructive distillation under positive pressure to produce coke and coke oven gas, from which by-products (e.g., tar, benzene, toluene, xylene, light oil) are recovered downstream in the by-product plant.

During the coking process, coke oven emissions escape from different emission points on the coke oven battery as leaks that can change in size and location over time. Raw coke oven gas is also emitted from bypass/bleeder stacks for by-product coke oven batteries when gases are vented directly to the atmosphere to relieve excess pressure. Nationwide coke oven emissions from coke oven batteries and bypass/bleeder stacks are estimated at 1,700 mt/yr. at the current level of control. This estimate includes benzene soluble organics (BSO), which is a measure of organic particulate matter, as well as benzene, toluene, xylene, and hydrogen sulfide.

Of the 10 states currently regulating by-product coke oven emissions, limits on charging operations range from an average of 11 to about 60 seconds of visible emissions per charge. Limits for percent leaking doors, topside port lids, and offtake system(s) are standards that are not to be exceeded based on any single observation. Coke oven emissions are also subject to regulation by U.S. Occupational Safety and Health Administration. Unregulated releases of coke oven emissions exceeding one pound also are subject to EPA hazardous substance release notification requirements under the Comprehensive Environmental Response, Compensation and Liability Act.

The oily, yellow-brown smoke characteristic of coke oven emissions contains organic particulate matter such as benzo(a)pyrene and other polycyclic organic compounds as well as hazardous pollutants that are volatile organics, including benzene and toluene. Other components include toxic gases, such as hydrogen sulfide (H_2S) and carbon monoxide (CO), and metals (arsenic, beryllium, cadmium, chromium, lead and nickel).

The Clean Air Act Amendments of 1990 establish specific requirements for the development of regulations governing coke oven emissions. EPA must promulgate standards based on maximum achievable control technology (MACT) for coke oven batteries by December 31, 1992. MACT standards for existing sources can be no less stringent than the best performing 12 percent of existing sources and standards for new sources cannot be less stringent than the limit achieved in practice by the best controlled existing source. In addition, the MACT standards for coke oven batteries must require at a minimum that coke oven emissions from each battery not exceed the following short-term limits: 8 percent leaking doors, 1 percent leaking topside port lids, 5 percent leaking offtake system(s), and 16 seconds of visible emissions per charge. EPA must evaluate the use of compounds to prevent door leaks. The EPA also must evaluate use of Thompson non-recovery coke oven batteries and other non-recovery technologies as the basis of standards for new batteries.

Existing coke oven batteries must comply with the MACT standards by December 31, 1995. The Act provides an extension of the residual risk standards for coke oven batteries until January 1, 2020, provided the owner or operator of a coke oven battery complies with technology-based standards on an accelerated basis, and that these technology-based standards become more stringent over time.

Under this so-called extension track, the owner or operator must achieve short-term emission limitations by November 15, 1993. In addition, by January 1, 1998, the battery must meet an emission limitation that reflects the lowest achievable emission rate (LAER). The LAER regulations may be no less stringent than the following short-term limits: 3 percent leaking doors on batteries with doors less than 6 meters(m) in height (i.e., a "short" coke oven battery) and 5 percent leaking doors on batteries with doors 6 m or more in height (i.e., a "tall" coke oven battery); 1 percent leaking topside port lids; 4 percent leaking offtake systems; and 16 seconds of visible emissions per charge.

The standards also would require the installation, operation, and maintenance of a flare (or equivalent alternative control device or system) by March 1, 1994, on the bypass/bleeder stack for each existing by-product coke oven battery in operation as of December 31, 1995. To qualify for an exemption from the flare installation requirement, the owner or operator must submit, by December 31, 1992, a formal commitment to permanent closure of the battery. In no case may a battery, for which the owner or operator has submitted such a closure notification, operate past December 31, 1995.

The standards would apply to new and existing coke oven batteries. All types of coke oven batteries would be subject to the new regulations, including by-product coke oven batteries (using current or new technology) and non-recovery coke oven batteries.

U.S. Coke Production Facilities

The carbon production facilities in the United States have reduced in significant number during the last 10 years. Coke production facilities have been reduced to 37% of 1980 production capabilities. At the same time, however, we are currently importing coke at a rate of 2,500,000 TPY. The shortfall between U.S. demand and production capabilities will continue to increase. The short-term shortfall is projected to increase dramatically as more U.S. coking facilities are closed.

Other carbon end users continue to look for foreign supplies to augment current production capability. Activated carbon users, for example, increased imports from 18.6 million kilograms (First Quarter 1991) to 34 million kilogram (First Quarter 1992).
Domestic production of this basic commodity cannot meet current or future demands.

Coal Technology Corporation has developed CTC/MGP Process to produce coke for steel industry blast furnaces that:

is a non-polluting process
is less expensive to operate
requires less capital to build
produces top quality metallurgical coke
can process many types of coal ranging from non-coking to metallurgical coking coals

Table 2. U.S. Carbon Production Facilities

State	Production, 1980	Production, 1993
Alabama	5,850,000	2,830,000
California	1,800,000	0
Colorado	700,000	0
Illinois	2,500,000	1,350,000
Indiana	9,800,000	7,800,000
Kentucky	600,000	600,000
Maryland	3,760,000	0
Michigan	3,600,000	800,000
Missouri	400,000	0
Minnesota	850,000	0
New York	2,800,000	1,500,000
Ohio	8,300,000	3,880,000
Pennsylvania	16,950,000	3,600,000
Tennessee	200,000	200,000
Texas	800,000	0
Utah	1,300,000	0
West Virginia	6,600,000	2,400,000
Wisconsin	200,000	180,000
Total	67,010,000	25,140,000

The process is now well developed in a 12 ton per day pilot plant. It is ready for scale-up to a 500 ton per day commercial demonstration plant which is estimated to cost $37,000,000.

The process is ready just at the time that there is urgent need for a new and better coke making process. Unfortunately, the steel industry in the United States has had two decades of decline due to foreign steel imports, aging facilities, environmental problems, lighter and smaller automobiles, and less automobile production in the U.S. due to foreign competition. This has put many of the major steel companies into bankruptcy and too poor to handle situations where capital investments are essential. Since the start of research work eight years ago, the objective has been to develop a continuous coking process that would be financially feasible. The work completed under this contract, and reported previously, confirms that this objective has been achieved. The quality of the coke product is as good or better than any now commercially available.

The proposed schedule for implementing stringent environmental controls on U.S. coke producers during a period of excess world coke supply forces steel producers to rely more and more on imported coke as the economic alternative to rebuilding or modification of our domestic coke industry to meet environmental needs. The American Coke and Coal Chemicals Institute reports that coke imports, mostly from Japan, more than doubled between 1990 and 1992 with resultant job losses and increased economic pressures on domestic coke makers.

The total enclosure of the materials (coal-char-coke) being processed in the continuous CTC/MGP Process assures the complete recovery of those compounds that escape as harmful, even dangerous, emissions from existing coke ovens. The more efficient recovery of these compounds for processing into beneficial by-products, i.e., fuels, tars, chemicals versus their losses as harmful emissions would in itself be justification of the CTC/MGP Process.

There are about 79 coke batteries operating in the U.S., employing over 10,000 people, who are daily facing unacceptable hazards of health, safety and environment in their jobs. This may be one of the largest "at risk" groups in the U.S. due to their daily exposure to a toxic environment. The CTC/MGP Process provides an acceptable and economic answer. The 27,000,000 ton/year coke market is the major product objective.

There are other important products, however. These are:

Char for use in electric furnaces to produce ferrosilicon for the steel industry and silicon for computer chips. This is a world market of 400,000 tons/year.

Coal liquids which can be used as a blending agent in motor fuels. If the CTC/MGP Process becomes widely used, this could produce coal liquids that would augment petroleum motor fuels.

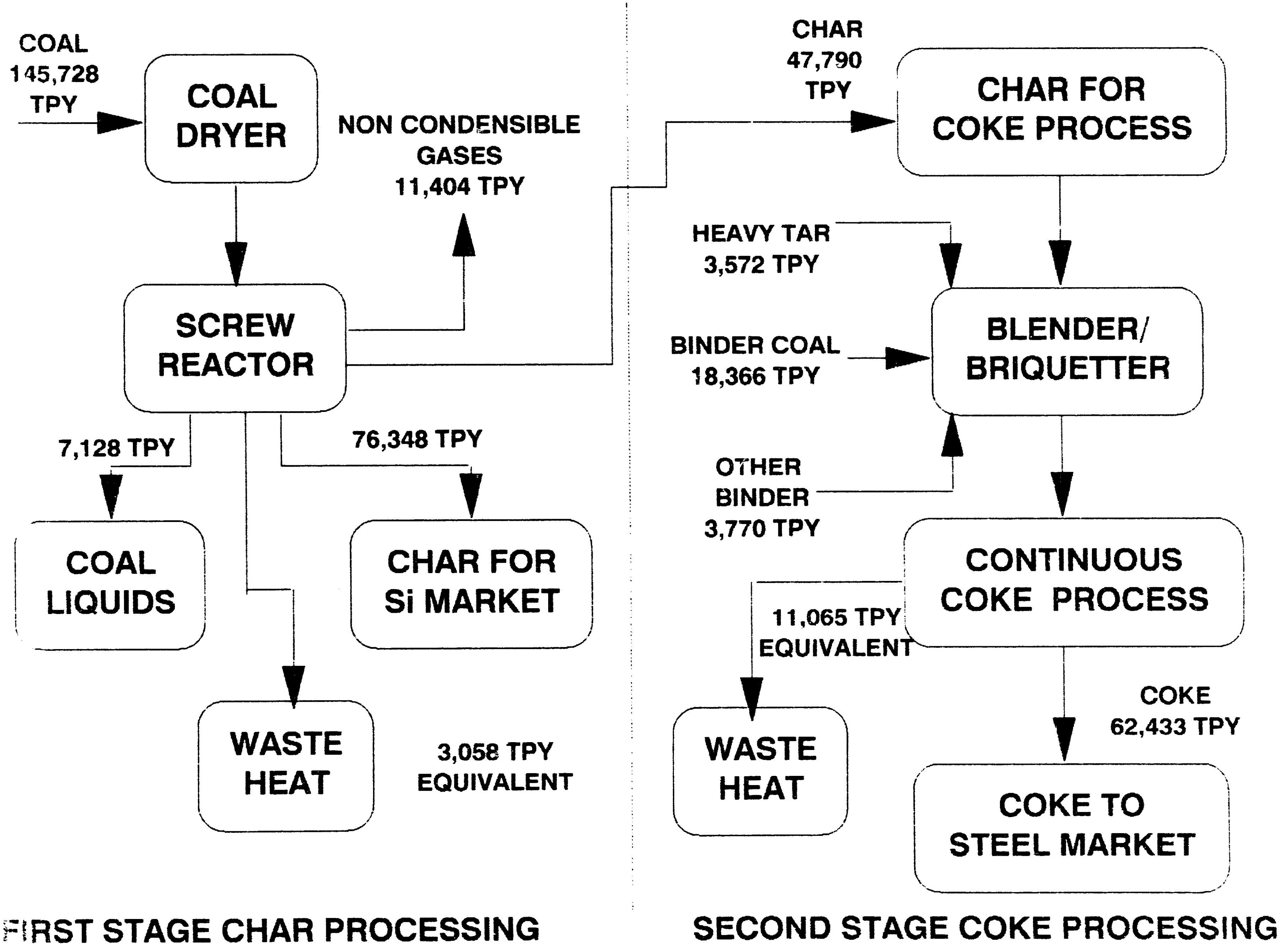
CTC Process Description

CTC operates a semi-continuous MGP process. In the current version of the pilot plant, coal can be dried, fed to a bunker, then fed to the continuous screw reactor, the resulting char after cooling, is fed to a hopper, then batches are ground and blended with tar and binder coal. This mixture is fed to a heated blender which feeds a briquetting machine. The warm briquettes are collected and manually placed in a single layer into an electrically heated oven for coking. The coke oven is purged with nitrogen to minimize oxidation of the briquettes. After the coke is formed, the coke briquettes are tested for stability and reactivity as well as for chemical composition.

The processing is shown schematically in Figure 1. In its commercial form, the CTC-MGP process would operate as follows:

Bituminous coal, in the first stage of the CTC/MGP Process, is heated in the absence of air to 800°F-1000°F in a pyrolysis reactor. The yield is about 4-5% crude coal

Figure 1. FLOW DIAGRAM AND MATERIAL BALANCE OF CTC DEMONSTRATION PROCESS



liquid which is similar in appearance to light crude oil, 70% to 80% char and about 8% hydrocarbon gases with a calorific value of 550 Btu per cubic foot. After most of its volatile content has been removed, the char is essentially carbon. The hydrocarbon gases provide the process heat required for the pyrolysis reactor.

In the second stage of the CTC/MGP Process, the char is mixed with suitable binder materials which include metallurgical coal, coal tar and asphalt in a proprietary formulation. After heating and thorough mixing, the char and binder materials are discharged from the mixer at 300°F and are formed into "green" briquettes in a briquette machine. The green briquettes are heated in a reducing atmosphere through a carefully controlled time/temperature pattern up to 1800°F, allowed to remain for a specified period of time at that calcining temperature and then cooled indirectly to a temperature below the ignition point. By this method the char briquettes are converted to coke briquettes for use in steel industry blast furnaces.

The crude coal liquids are upgraded to produce coal tar and refined coal liquids. The refined coal liquids can be blended with conventional transportation fuels to enhance automobile and diesel engine fuels. The coal tar can be used as one of the binder materials to make coke briquettes.

The key to the CTC/MGP Process is the pyrolysis reactor. This consists of a pair of interfolded screw conveyors enclosed in a heated and insulated chamber which operates at atmospheric pressure and is sealed to prevent the entrance of outside air. The shell which houses the interfolded screw conveyors is heated by radiant gas burners within the insulated chamber. The hollow shafts of the screws are heated by pulse jet gas combustors. In the 1000 lb./hr. pilot plant at Bristol each screw is 15-3/4 in. outside diameter by 16 ft. long built on a 10-in. diameter hollow shaft. The counter-rotating screws operate at 17 RPM. The process produces no waste or objectionable by-products.

The char which is produced in the first stage of the CTC/MGP Process (see Figure 1) not only is planned for use in making coke, as previously described, but also to be sold as a carbon source in the ferrosilicon industry. Char for this purpose is a worldwide market estimated at 500,000 tons/year. It is estimated that the U.S. market for char in just the silicon metal and ferrosilicon industry is more than 100,000 tons/year. The CTC/MGP Plant aims to supply the U.S. market and also expand into the world market.

Description of the Raw Materials

The process can utilize U.S. coals from the Appalachian coal fields of Pennsylvania, Southwest Virginia, Southern West Virginia and Eastern Kentucky.

The CTC/MGP Process is not restricted to a limited type of coal but has the flexibility to utilize a wide range of coals.

Typical characteristics of the raw material selected as the principal coal to be used for this process are shown in Table 3. These coal characteristics are easily attainable from hundreds of millions of tons of coal reserves readily available in the southern Pennsylvania, West Virginia, Virginia and Kentucky coal fields.

Table 3. Typical CTC/MGP Feed Coal Characteristics

Size:	1-1/2" x 0
Moisture:	<9.0%
Volatile Matter(Dry):	<20-35%
Ash (Dry):	<10.0%
Sulfur (Dry):	<1.0%
Heating Value (dry):	13,500-15,200 Btu/lb.
FSI:	≤9.0
Grindability:	<100.0
Fixed Carbon:	60-80%

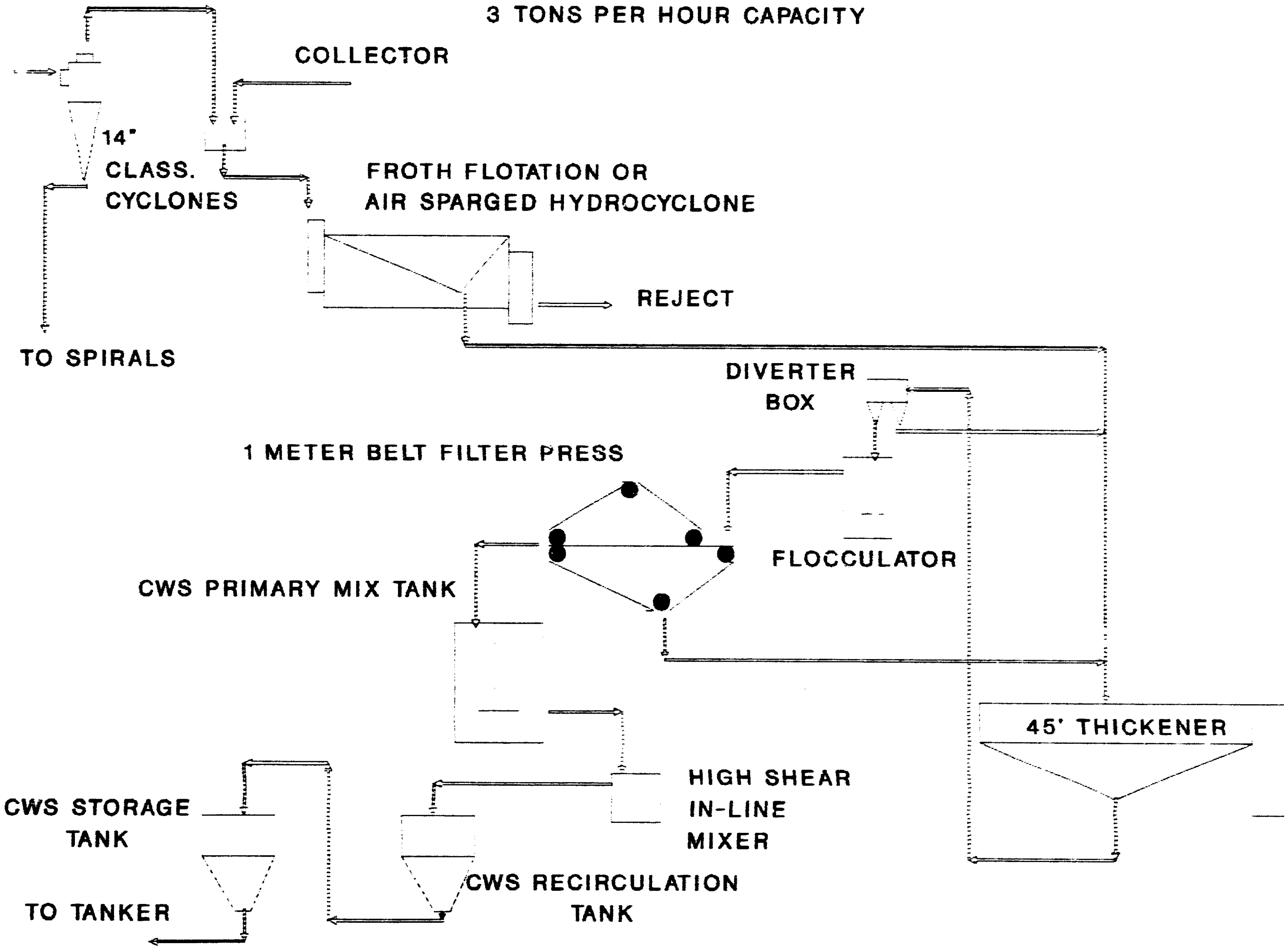
Homer City Fine Coal Cleaning

For this test program, Homer City fine coal was cleaned in a fine coal cleaning pilot plant located at the Homer City Coal Preparation Plant. The pilot plant has the capability of cleaning -28 mesh coal using classifying cyclones, spirals and froth flotation. Clean products can be produced as filter cake or as coal water slurry.
Figure 2 is a schematic flow sheet of the fine coal cleaning circuit. Raw minus 28 mesh coal(Upper Freeport seam) is classified in 14 inch diameter classifying cyclones. The cyclones partition the coal at 100 mesh. A significant amount of pyritic sulfur is removed from the minus 100 mesh fraction during the classification process. The sulfur in the feed coal to the classifying cyclones ranges from 2 to 3 percent. The classified minus 100 mesh contains 0.9 to 1.3 percent sulfur. The plus 100 mesh fraction is then cleaned in spirals. The spirals clean coal contains less than 10 percent ash and about 1 to 1.25 percent sulfur.

Minus 100 mesh is further cleaned in froth flotation equipment. Froth flotation processing includes both

Figure 2. Fine Coal Cleaning and CWS Pilot Plant

3 TONS PER HOUR CAPACITY



conventional flotation cells and a new froth technology which uses an air sparged hydrocyclone. The clean fine coal typically contains 1 to 1.3 percent sulfur and 5 to 10 percent ash. Lower ash levels can be produced from the Upper Freeport coal using froth flotation technology however this level of cleaning is typically not required.

The clean minus 100 mesh coal is then thickened in a 45 foot diameter Enviroclear thickener. The thickener underflow is pumped to a 1 meter Parkson filter press. The clean filter cake can be recovered or further processed into coal water slurry fuel. The Coal Water Slurry produced in this plant contains up to 50% solids. This slurry is stable and requires no additives to control slurry rheology or stability.

Inherent Advantages of the Process

The CTC/MGP Process has these important inherent advantages:

CTC/MGP plant will have a lower capital cost and a lower operating cost than present conventional coke ovens.

The CTC/MGP screw reactor can process various blends and types of coal.

The CTC/MGP screw reactor operates with air locks that permit coal to be charged to the screw reactor and char to be discharged from the screw reactor without the escape of any coal vapors. By comparison, the conventional coke oven releases coal vapors during charging, operation, and discharging of the ovens.

The CTC/MGP Process is a continuous operation producing coke within two hours compared to the batch processes of today requiring 18 hours of operation per batch.

The CTC/MGP screw reactor can be started and put into production in less than two hours and then shut down whenever desired. Conventional coke ovens require a first time heat up of three months and then must be kept hot for their useful life, whether operating or not.

The CTC/MGP process produces liquid in the first stage of devolatilization that is similar to petroleum crude oil which readily blends with petroleum diesel oil.

Target Market Size

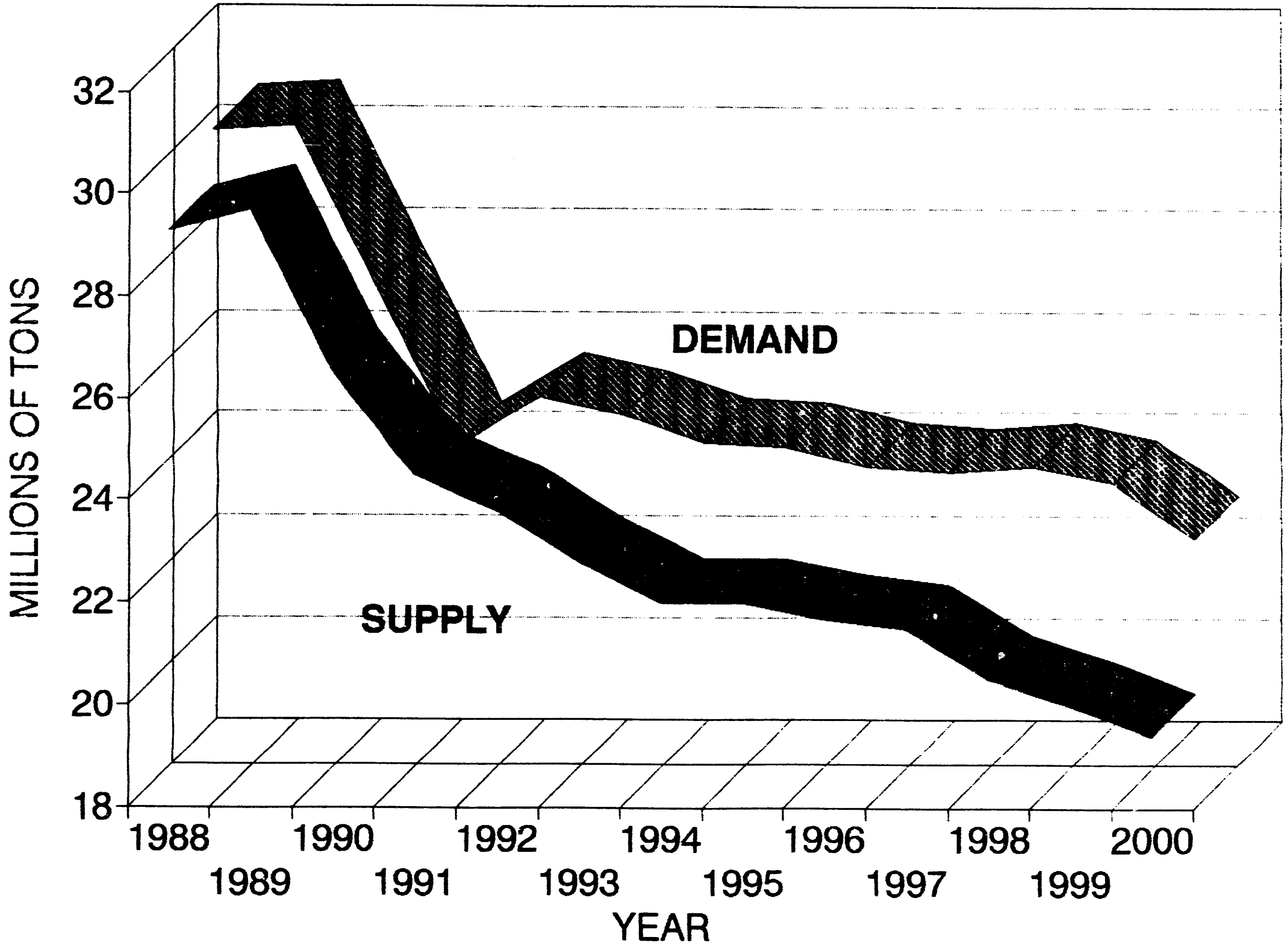
Numerous studies have been conducted by government and private agencies on the potential coke shortage faced by the U.S. in the near term. One study conducted by a large U.S. steel maker is summarized in Figure 3.

Domestic coke production is projected to be short of demand by three million tons by the year 2000. The current domestic shortfall is already 2,500,000 tons and growing which is now requiring coke imports from Asia and Europe. Successful commercialization of the CTC process could readily meet 5,000,000 tons of production reversing the supply demand curve and even providing carbon for export. A demonstration plant is needed to be able to convince the end users of carbon, primarily the steel industry, of the technical viability of the process on a large scale.

Description of the Products

The coal liquids, char, and coke (CTC/MGP) mild gasification technology to be demonstrated in this project involves the production of three new marketable products from bituminous caking type coals: (1) coal liquids for further refining into transportation fuels; (2) char used as a carbon source in the production of silicon metal, ferrosilicon, and other

Figure 3. DOMESTIC COKE SUPPLY & DEMAND



ferroalloys, and (3) briquetted coke for foundry or blast furnace application in the steel industry. The CTC/MGP Process will be the first process ever demonstrated at a commercially viable scale to continuously produce char within a 20-minute process time and produce blast furnace quality coke within a two-hour duration in a completely enclosed environmentally clean system. The coal liquids produced at less than 1000°F will be of sufficiently high quality to be acceptable for further refining into transportation fuel blend stock.

Test Results

Petrographic Analysis

The steel industry has developed technology to evaluate coke characteristics on the basis of raw material composition and coke characteristics measured microscopically. This technology is called coal petrography. It examines coal compositional variations by examining the maceral content of the coal. Macerals are the residue from the original coal forming materials e.g. plants, stems. leaves, etc. The relationship between reactive and non reactive macerals can predict coke quality parameters. Ralph Gray Associates are world experts in the application of this technology. They were engaged to evaluate coke produced from the Homer City clean fine coal stream. The results of this analysis are reported in their entirety as follows:

Ralph J. Gray
Consultant - Coal, Coke & Carbons
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Monroeville, PA 15146
(412) 327-5019

May 12, 1993.

PENELEC
Mr. Joseph J. Battista
Senior Engineer Research and Development
Pennsylvania Electric Company
1001 Broad Street
Johnstown, Pa. 15907

Dear Mr. Battista;

As part of our work covered in Agreement No. 396645, October 7, 1992, we have completed the planned work on coked briquettes that were carbonized at Coal Technology Corporation (CTC) and at UEC Coal and Coke Laboratory. In addition, a very good commercial coke from USX's Clairton Coke Works was tested for comparison.

The various samples involved with this portion of the test work were analyized for proximate analysis and total sulfur content. Coked briquettes were prepared at CTC and UEC. The cokes were tested for strength by a modified tumbler test. The reactivity to CO_2 at elevated temperatures was determined at CTC.

One or more samples from each of the green and coked briquettes as well as the Clairton coke and the residues from the coke reactivity testing were prepared for microscopic examination and described and photographed.

The proximate analysis and sulfur content of the current samples of green briquettes and cokes are listed in Table I. The volatile matter of 19.32% by weight on a dry basis for the green briquettes reflects the composition of the char, binder coal and tar blend used to produce the briquettes. The binder coal is Knox Creek with 31.5% volatile matter. The coke made in the thirty-pound test oven at CTC has 2.42% volatile matter while UEC coke has 0.81% volatiles. The CTC coke is less carbonized due to a lower final temperature or a shorter coking time than the UEC coke. The commercial coke has 0.36% volatile matter. Commercial cokes are generally less than 1% volatile matter and commonly are less than 0.5% volatile matter. The CTC cokes volatile matter should be lower to satisfy commercial users. The ash and sulfur values for the three cokes are all within the acceptable range for commercial cokes.

CTC prepared sufficient green briquettes (about 100 lbs.) for carbonization testing in a thirty-pound test oven at UEC. The green briquettes were carbonized at UEC on April 1, 1993 in Monroeville, Pa. The small coke oven takes a charge of about 30 pounds and uses a programmed (slow) heating cycle (1350° to 1850°F in 3½ hours) to produce a coke for strength testing. A modified tumbler test has been adapted to provide a measure of coke strength for 30-lb.-oven cokes that correlates with the ASTM stability and hardness tests. A publication describing the use of the thirty-pound test oven is included in Appendix A. In this test a 10-lb. sample of 2 in. by 1 in. coke is tumbled for 500 revolutions at 24 rpms in a standard ASTM drum tumbler. The tumbled coke is screened on 1-in., 3/4-in., 1/2-in., and 1/4-in. screens. The cumulative percent retained on 3/4-in. is the Modified Tumbler Index. This index has been correlated with the ASTM Stability Factor as shown in Figure I. The cumulative percent plus 1/4-in. coke from the modified tumbler has been correlated with the ASTM Hardness Factor as shown in Figure II. The correlations are between the cokes produced in a 30-lb. oven and those produced in a 500-lb. oven.

The modified stability and hardness for the subject cokes are listed in Table II. The commercial coke has the highest modified stability of 79.0 and also has the highest modified hardness. The CTC coked material has a modified stability only slightly less than the commercial coke but a lower hardness. The UEC coked sample has the lowest modified stability and an intermediate hardness.

If the modified stability factors are plotted against ASTM predicted stabilities the commercial coke has a stability of 55 while the CTC coke stability is 54 and that for the UEC coked briquettes is 47. We know the commercial coke for Clairton No. 1 Unit taken on March 22, 1993 has a stability of 60 or higher based on this knowledge the CTC coke should have a stability of 58 which is good and the UEC coked material should be about 53 in stability which may be acceptable but can be easily improved.

If the modified hardness factors are plotted against ASTM predicted hardnesses the commercial coke has a predicted hardness of 74 while that of the CTC coke is 68 and the UC coke is 72. All of the hardness values are good. In general, the hardness factor reflects interparticle fusion.

The apparent and true specific gravities of the cokes were determined and the results are shown in Table II. These data were used to calculate the coke porosity. In general, the coke stability of byproduct-oven cokes increase as the porosity decreases. In the current samples of coke the commercial coke has the highest porosity of 54.9% while the CTC coke has a porosity of 34.7% and that of the UEC coke is 38.3%, Table II. The weight and volume of coke was determined at Coal Petrographic Associates for calculating the apparent density, Table II for comparison with the ASTM apparent densities.

It is generally agreed that blast furnace coke should be low in ash and sulfur and relatively coarse and uniform in size and physically strong. The CTC and UEC coke meet these requirements with the exception that a coarser size may be desirable. Recently cokes have been required to meet the requirement of low reactivity to CO_2. It is believed that increased coke reactivity will result in more coke consumed in solution loss reaction in the blast furnace which will increase coke rate and result in poor furnace performance. Excessive coke reactivity will result in coke breaking down higher in the furnace stack and the fines that are generated reduce furnace permeability.

In the current work CTC tested the cokes in a Japanese "I" test. The name refers to the shape of the tumbler drum which is used to measure coke strength after reaction (CSR). In the Nippon Steel procedure 200 grams of 20 ±1mm. coke is heated at 1,100 ±5°C in an atmosphere of CO_2 with a flow rate of 5 LPM for 2 hours. The reacted residue is weighed and the Coke Reactivity Index (CRI) is calculated as follows:

$$\text{CRI} = \frac{\text{Wt. in} - \text{Wt. out}}{\text{Wt. in}} \text{ X } 100$$

The reacted coke is tested for strength by tumbling 600 times in 30 minutes in a cylindrical tumbler. The tumbled coke is screened on a 10 mm. sieve and the Coke Strength after Reaction (CSR) is calculated as follows:

$$\text{CSR} = \frac{\text{Wt. of + 10mm.}}{\text{Initial Weight tumbled}} \text{ X } 100$$

The CRI and CSR values for the subject cokes are listed in Table III. The UEC and commercial cokes have CSR's of slightly over 55 while the CTC coke has a value of 51.9. CSR's of at least 55 are satisfactory but higher values are preferred in the rang ef 58 or higher. The CTC coke has the lowest CSR since it has 2.42% volatile matter and will react more readily than the completely carbonized products.

The green CTC briquettes and cokes, as well as the UEC coked briquettes and commercial coke, were cut on a diamond saw and impregnated with plastic and ground and polished for microscopic examination.

The CTC green briquettes measure about 2-3/4 inches long by 2 inches wide by 1 inch high and consist of char from Penelec 28 X 100 mesh coal carbonized in the CTC twin screw reactor and briquetted with Knox Creek high volatile bituminous coal and tar additions. The green briquettes are illustrated in Figures 3, 4 and 5. The photomicrographs in Figure 3 show the edge and center areas of a cut green briquette at 82 X. Figure 4 also shows the edge and center areas of briquettes but the magnification is 165 X dry. Figure 5 shows the char and coal in the green briquette at 330 X in polarized light and at 450 X with an oil immersion objective that is used to improve resolution and contrast. Some of the coal is too coarse and mixing could be improved, Figure 3. The tar occurred in patches where it formed agglomerates with fine particles, Figure 5.

The CTC coked briquettes are illustrated in Figures 6, 7 and 8. Figure 6 shows the edge and center areas of cut and polished coke at 82 X dry while Figure 7 shows similar areas at 165 X dry. Figure 8 shows the coke in polarized light at 330 X dry and at 450 X in oil with polarized light and a gypsum tint plate. The coke structure is dense and generally has small pores that are relatively uniformly distributed, except near the surface, Figures 5 and 6, and near the cracks in the land areas. The various carbon forms from char and binder and oxidized areas are partially distinguishable in polarized light, particularly when oil immersion and a gypsum tint plate are used, Figure 8.

The UEC cokes prepared from CTC's green briquettes are illustrated in Figures 9, 10 and 11. The microscopic appearance of cut and polished edge and center areas are shown in Figure 9 at 82 X dry and in Figure 10 at 165 X dry. The photomicrographs in Figure 11 show the UEC coked briquettes in polarized light at 330 X dry and 450 X in oil. The UEC coked briquettes that were sampled are distinctly more porous than the CTC coke but much less porous than the commercial coke. The pore configurations in the UEC coke appear to be more like byproduct oven coke. The edges of the coke are partially burnt, Figures 9 and 10 and many of the pores are connected. The carbon forms (anisotropic domains) in the UEC coke appear slightly larger than those in the CTC coked briquettes.

The polished surface of the commercial coke is shown in Figures 12 and 13. Figure 12 shows the thick walls and coarse-round pores characteristic of byproduct oven cokes made with blends of high and lower volatile coals. The photomicrographs in Figure 13 show carbon forms from high and low volatile bituminous coals in polarized light. Coal inerts are also illustrated. The carbon forms from the high volatile coal are smaller than those in the coke briquettes from Penelec coal. The carbon forms from the low volatile coal have the largest anisotropic domains.

The residues from the reactivity tests were mounted in plastic and ground and polished for microscopic examination and preparation of photomicrographs. The residues supplied by CTC were submitted as plus 1/2 inch and minus 1/2 inch from each of the three cokes tested.

The photomicrographs in Figure 14 show the + 1/2 and - 1/2 inch residues from the CTC coked briquettes. The + 1/2 inch material appears mostly unattacked while the - 1/2 inch residue shows extensive breakdown, Figure 14. The + 1/2 inch residue was photographed in polarized light with a gypsum tint plate to show that there is no distinct evidance of a selective reaction between the binder carbon and char charbon, Figure 15.

The + 1/2 and - 1/2 inch residue samples from the reactivity testing of the UEC coke briquettes are shown in Figure 16. The - 1/2 inch residue from the UEC coked briquettes appears, Figure 16, much coarser than a similar fraction from the CTC coked briquettes, Figure 14. The polarized light photomicrographs in Figure 17 show that the pore surfaces and inerts are preferentially reacted. The mineral matter rich areas also appear to be preferred sites for reactivity.

The reactivity residues from the + 1/2 and - 1/2 fractions of the commercial coke are illustrated in Figure 18. The - 1/2 inch residue appears much coarser than the - 1/2 residues from the CTC and UEC coked briquettes. The reactivity with CO_2 produces distinct reacted surfaces around pores and exposed surfaces of carbons from high volatile coals, Figure 17. The reactions appear to proceed along parallel fissures in carbons from low volatile rank coals.

This report concludes the work that was planned with Penelec to determine an alternate use for fine size (28 X 100, 100 X 0 and/or 28 X 0) coal. This size coal contributes to a decrease in pulverized throughput at utility sites. It can definately be used to produce coke briquettes that meets the requirements of quality metallurgical grade coke.

Even though the coke test and analysis have been completed you might want to work up a presentation for CTC and AISI.

Please contact me at (412) 327-5019 if you have any questions concerning this work.

Sincerely,
Ralph J. Gray
Ralph J. Gray

RJG:mrb

enclosures

TABLE I

PROXIMATE ANALYSIS AND SULFUR CONTENT OF THE INDICATED GREEN BRIQUETTES AND COKES

	PROXIMATE ANALYSIS, WT. % (DRY)			
SAMPLE I.D.	VOLATILE MATTER	FIXED CARBON	ASH	TOTAL SULFUR, WT. % (DRY)
GREEN BRIQUETTES RJG# 16351	19.32	74.19	6.49	0.87
CTC COKED RJG# 16452	2.42	90.06	7.94	0.83
UEC COKED RJG# 16480	0.81	90.85	8.34	0.96
COMMERCIAL COKE RJG# 16357	0.36	90.72	8.92	0.83

TABLE II

PHYSICAL PROPERTIES OF THE INDICATED COKES AND BRIQUETTES

	MODIFIED STABILITY	MODIFIED HARDNESS	APP. SP. GRAVITY	TRUE SP. GR.	POROSITY	CPA* AVG. WT. GMS.	CPA* DENSITY G/CC
CTC COKED RJG# 16452	77.9	78.7	1.25	1.90	34.7	46.4	1.15
COKE BY UEC RJG# 16480	72.2	82.1	1.21	1.96	38.3	42.6	1.02/1.09
COMMERCIAL COKE RJG# 16357	79.0	85.0	0.93	2.06	54.9	- -	0.98
GREEN BRIQUETTES	- -	- -	- -	- -	- -	56.0	1.24

* COAL PETROGRAPHIC ASSOCIATES

TABLE III

COKE REACTIVITY TEST RESULTS FROM THE JAPANESE "I" TEST FOR COKE STRENGTH AFTER REACTION (CSR) AND COKE REACTIVITY INDEX (CRI) FOR INDICATED COKE SAMPLES

SAMPLE I.D.	COKE REACTIVITY INDEX (CRI)	COKE STRENGTH AFTER REACTION (CRI)
CTC COKED RJG# 16452	33.3	51.9
UEC COKED RJG# 16451	32.8	55.1
COMMERCIAL COKE RJG# 16357	28.4	55.6

Appendix A

Use of a Thirty Pound Test Oven
for
Rapidly Assaying the Coking Strength of Coals

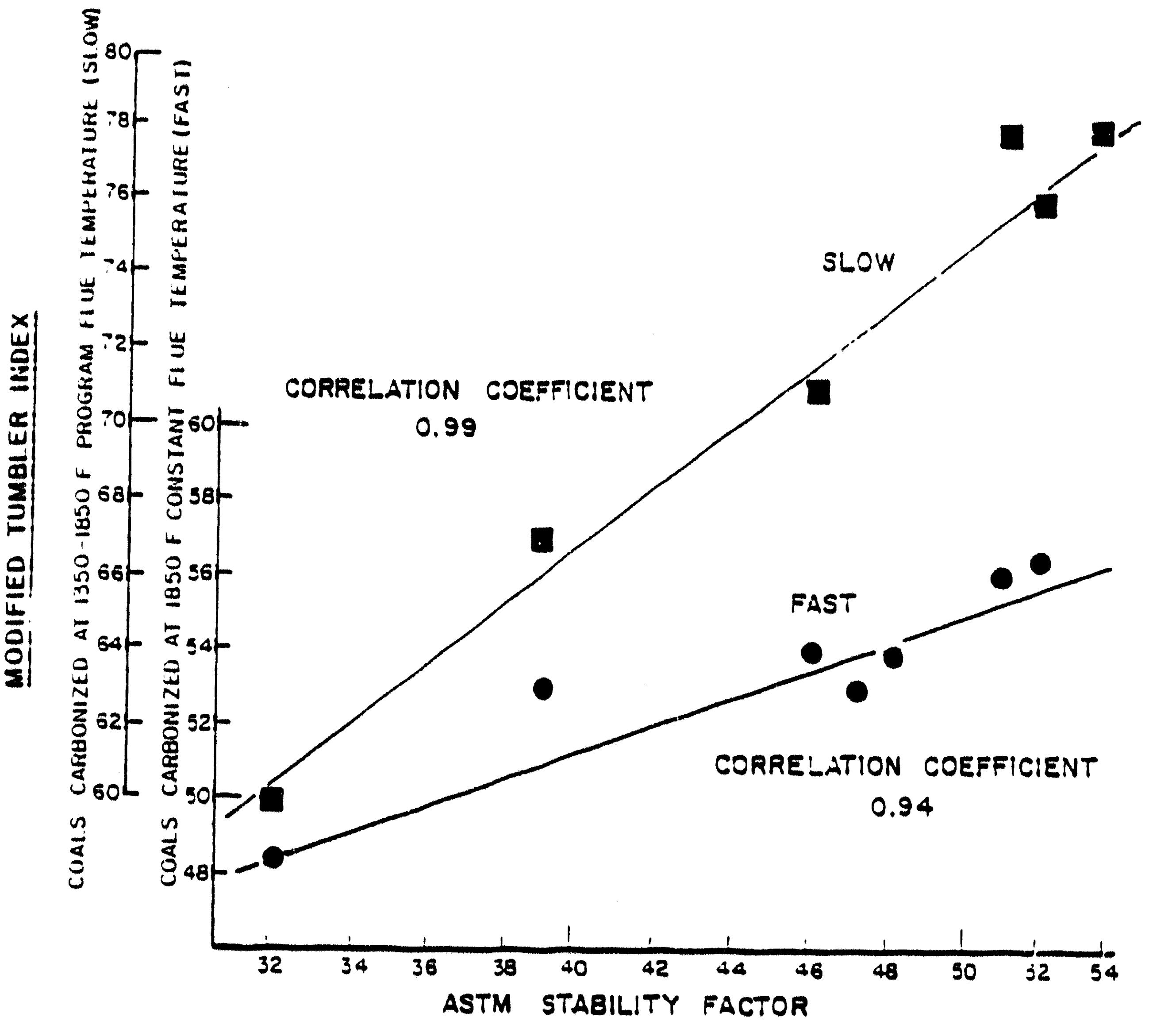


FIGURE 1: RELATION BETWEEN MODIFIED TUMBLER INDEX, DETERMINED ON COKES PRODUCED UNDER DIFFERENT CARBONIZING CONDITIONS, AND ASTM STABILITY FACTOR.

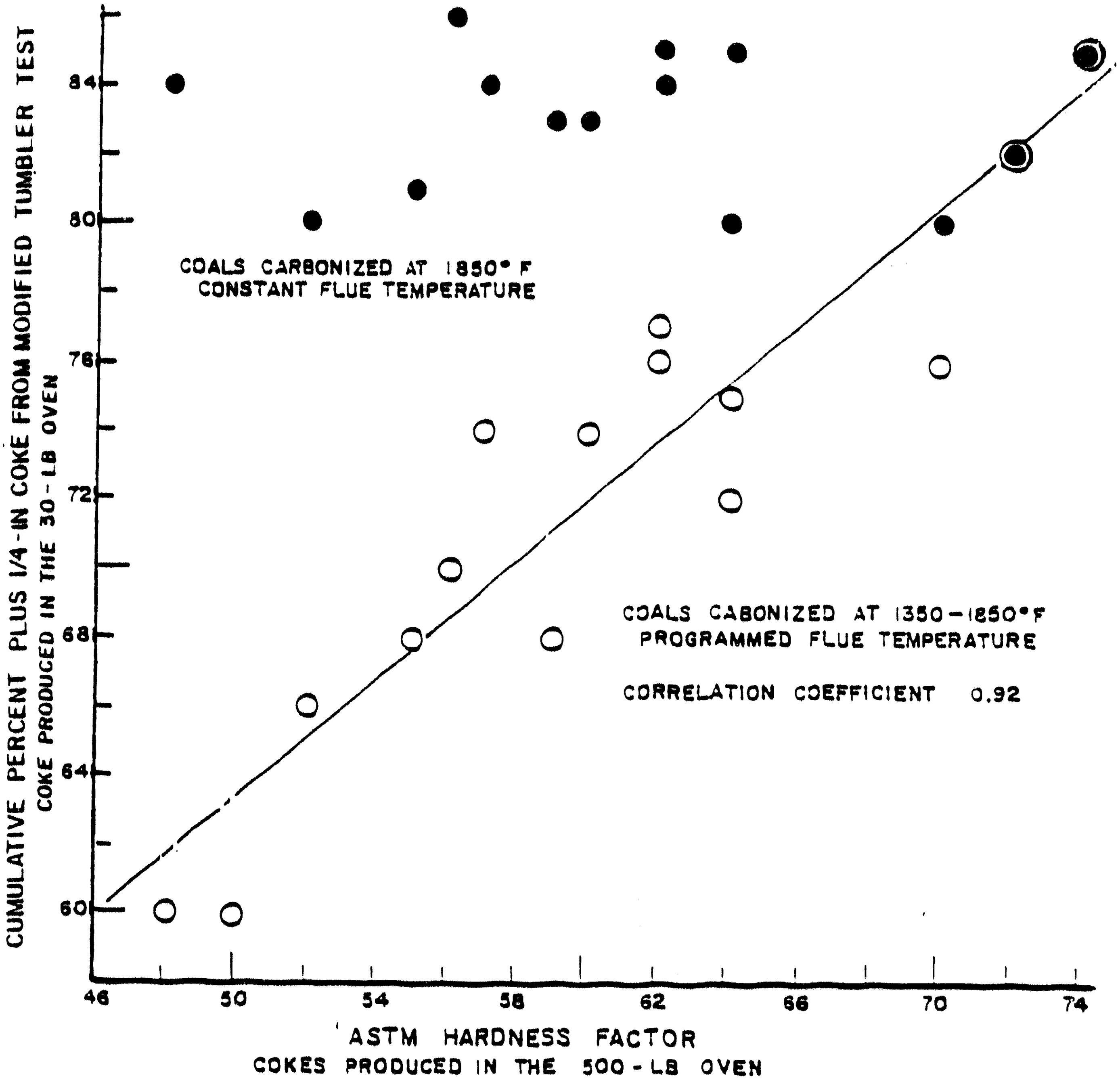


FIGURE 2: RELATION BETWEEN PLUS 1/4-INCH INDEX FROM MODIFIED TUMBLER TEST AND ASTM HARDNESS FACTOR AS INFLUENCED BY DIFFERENT COKING CONDITIONS IN 30-POUND OVEN.

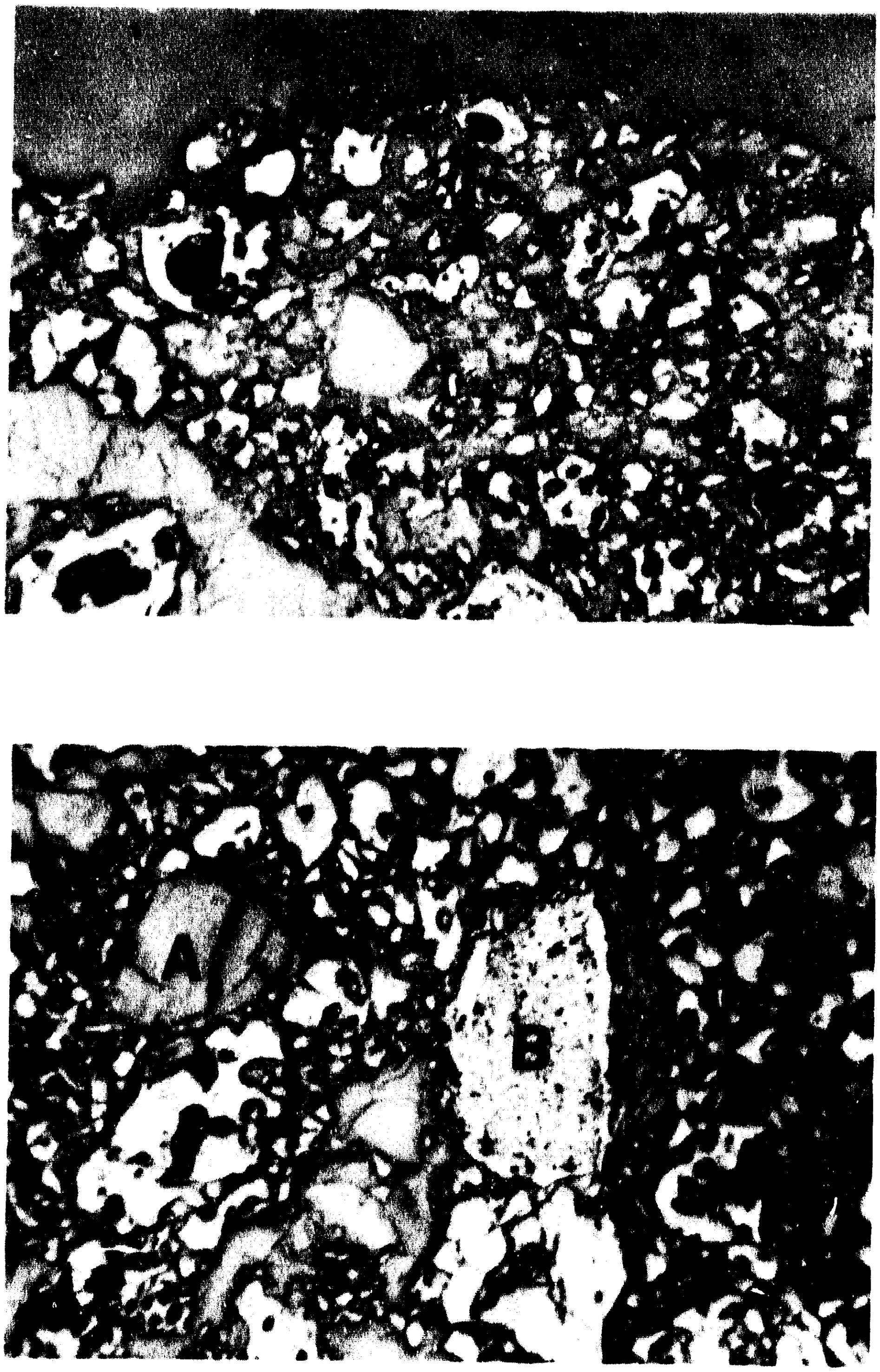


FIGURE 3: PHOTOMICROGRAPHS OF CTC GREEN BRIQUETTES SHOWING: A=COAL, B=CHAR AND C= PLASTIC MOUNTING MEDIA. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE.
REFLECTED LIGHT IN AIR, X 82.

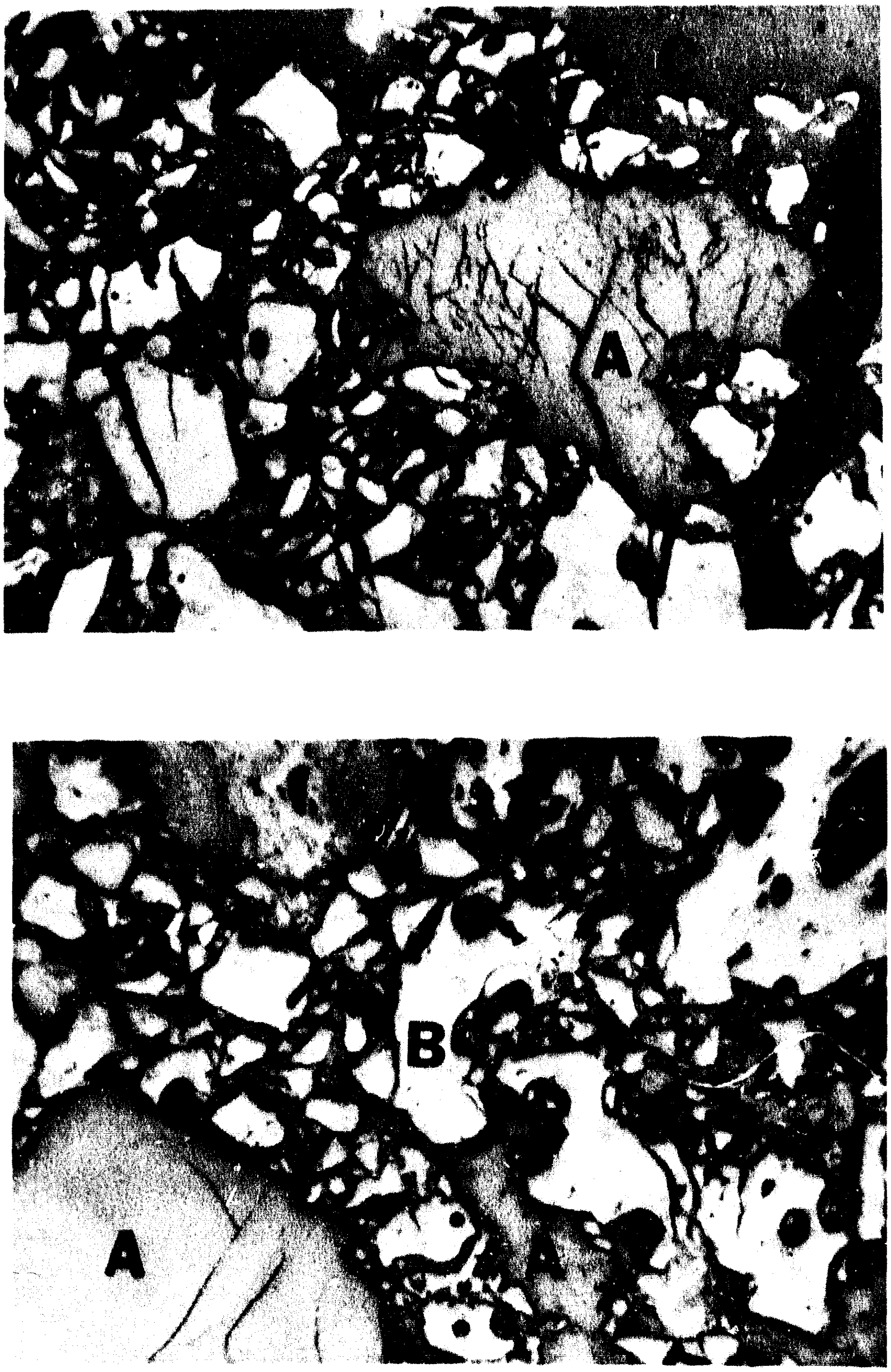


FIGURE 4: PHOTOMICROGRAPHS OF CTC GREEN BRIQUETTES SHOWING: A=COAL, B=CHAR AND C= PLASTIC MOUNTING MEDIA. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE.
REFLECTED LIGHT IN AIR, X 165.

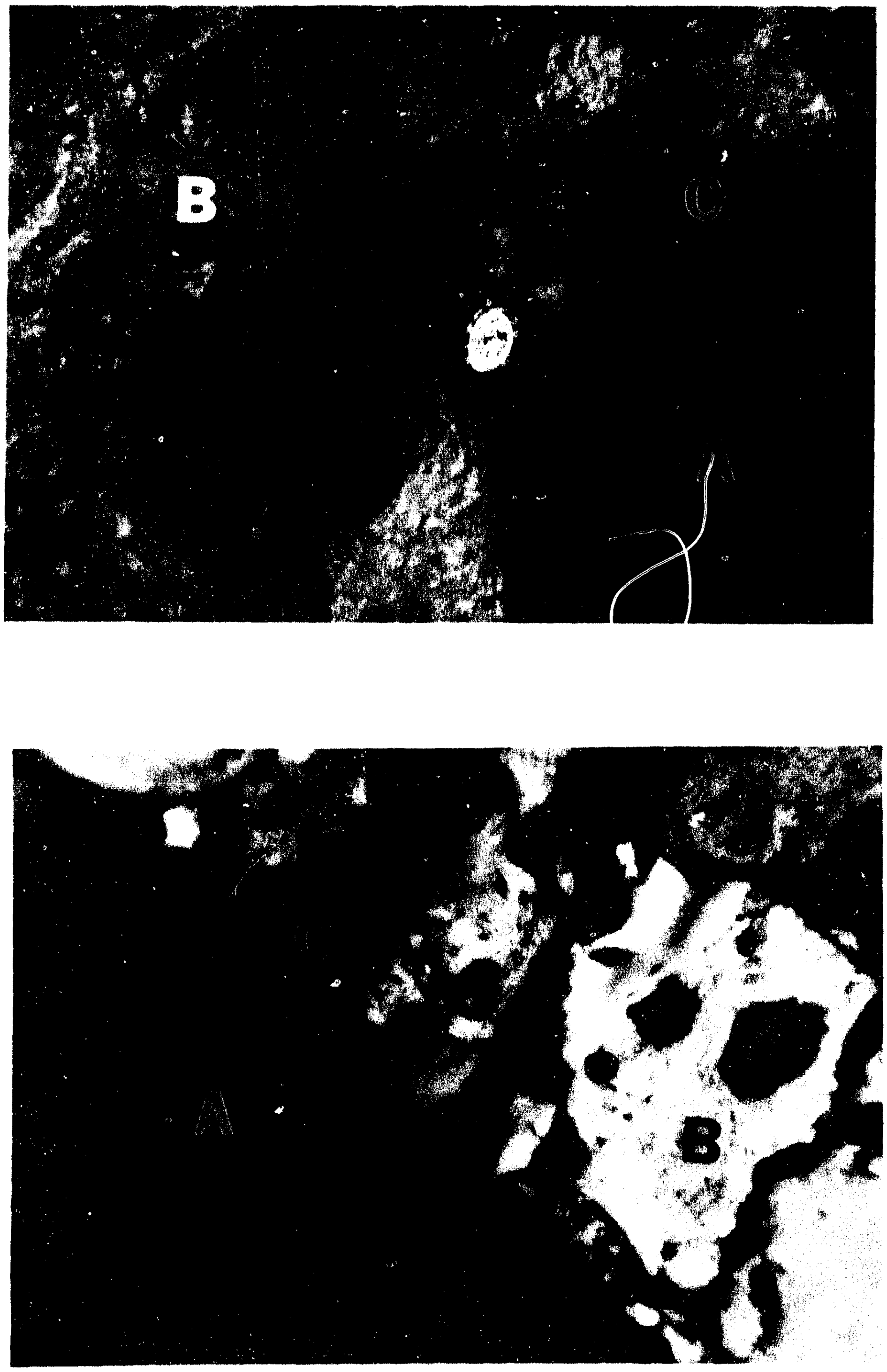


FIGURE 5: PHOTOMICROGRAPHS OF CTC GREEN BRIQUETTES SHOWING: A=COAL, B=CHAR AND C= PLASTIC MOUNTING MEDIA. TOP PHOTO IN REFLECTED POLARIZED LIGHT IN AIR X 330 AND BOTTOM PHOTO IN REFLECTED POLARIZED LIGHT IN OIL WITH A GYPSUM TINT PLATE, X 450.

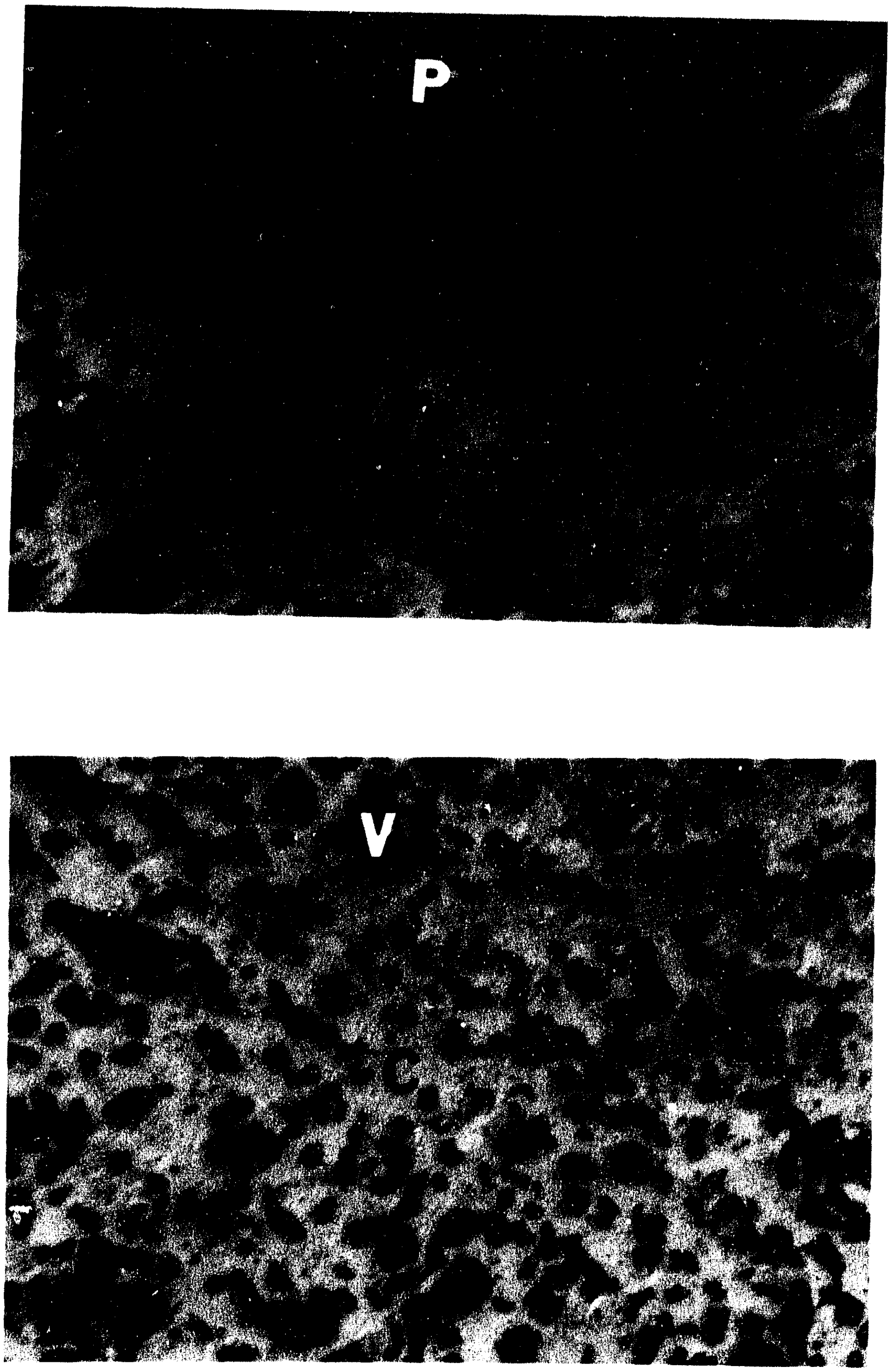


FIGURE 6: PHOTOMICROGRAPHS OF CTC COKED BRIQUETTES SHOWING: C=COKE, P=PLASTIC MOUNTING MEDIA AND V=UNFILLED VOIDS. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE.
REFLECTED LIGHT IN AIR, X 82.

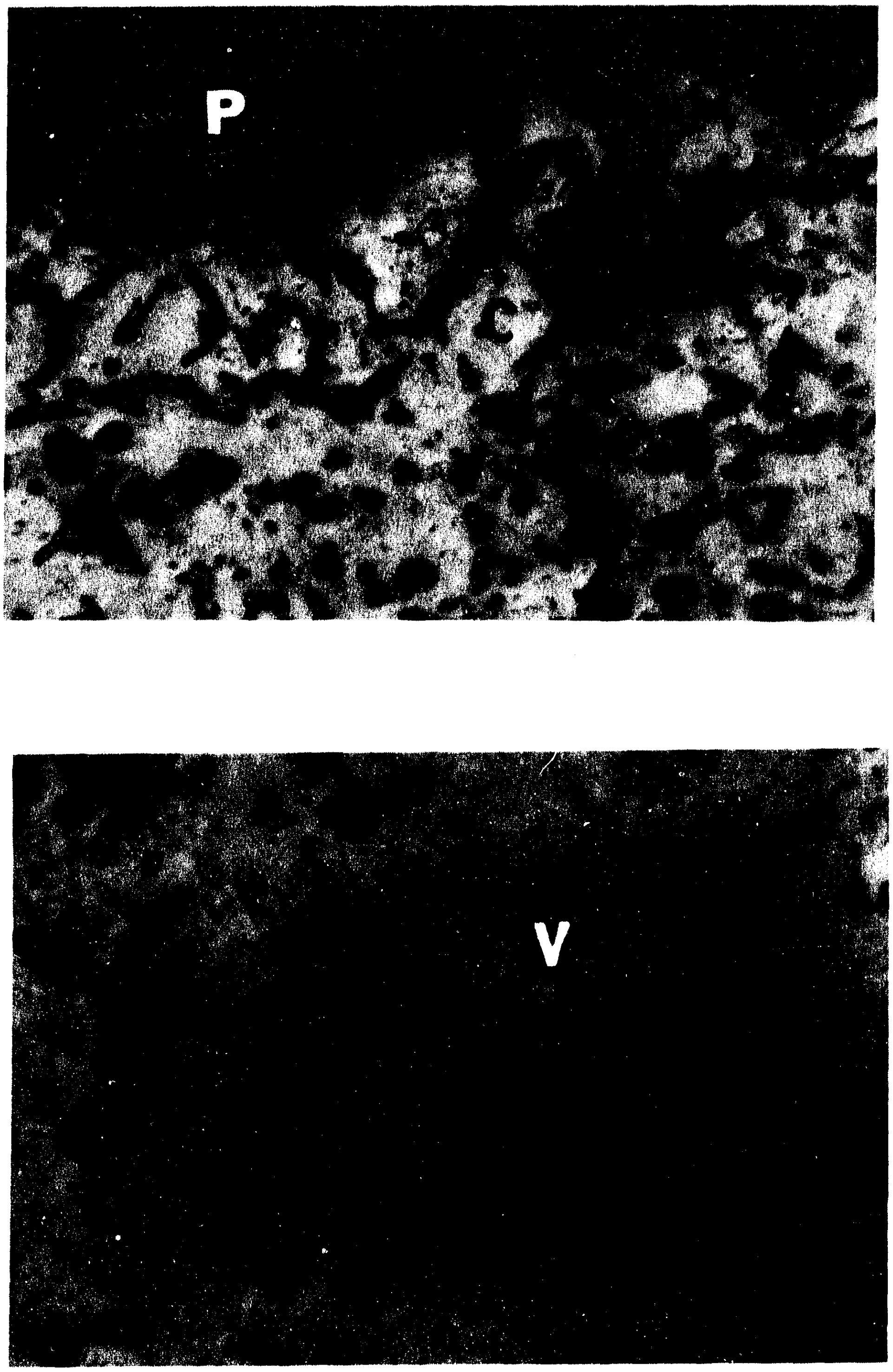


FIGURE 7: PHOTOMICROGRAPHS OF CTC COKED BRIQUETTES SHOWING: C=COKE, P=PLASTIC MOUNTING MEDIA AND V=UNFILLED VOIDS. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE.
REFLECTED LIGHT IN AIR, X 165.

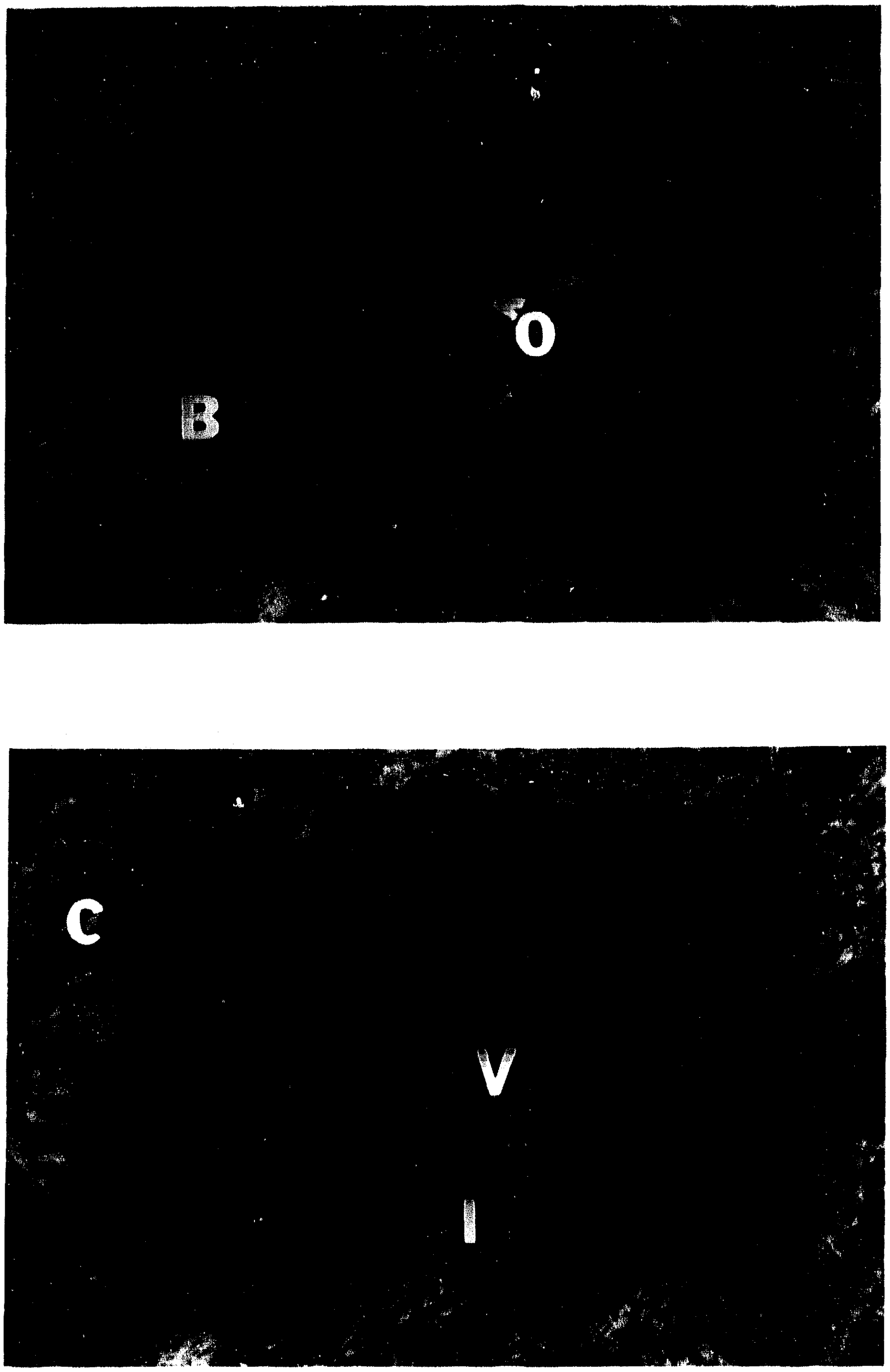


FIGURE 8: PHOTOMICROGRAPHS OF CTC COKED BRIQUETTES SHOWING: B-BINDER CARBON, C=CHAR OR COKE, T=INERTS?, O=OXIDIZED AREAS AND V=PORES OR VOIDS.
TOP PHOTO IN REFLECTED POLARIZED LIGHT IN OIL WITH A GYPSUM TINT PLATE, X 450.

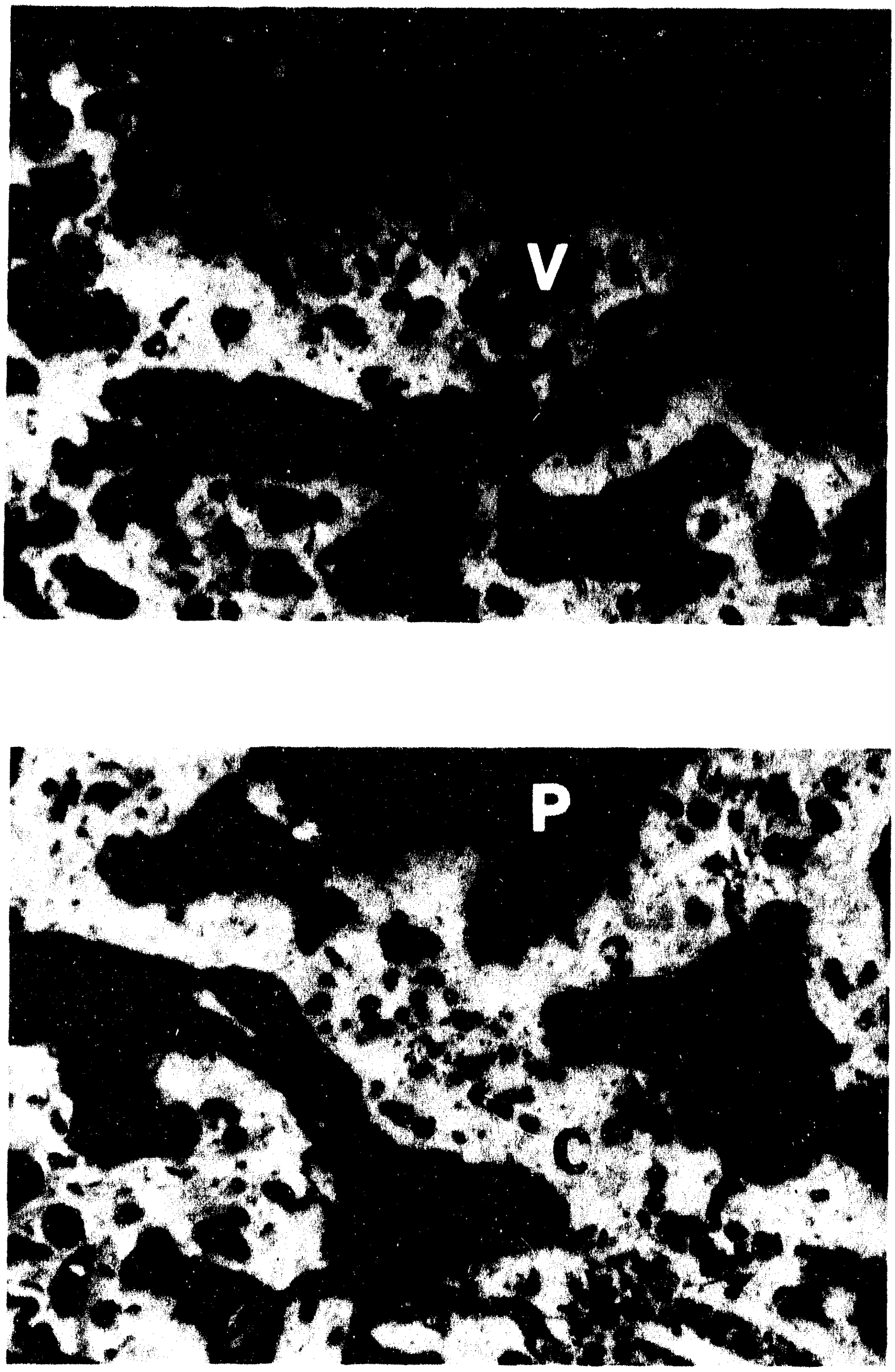
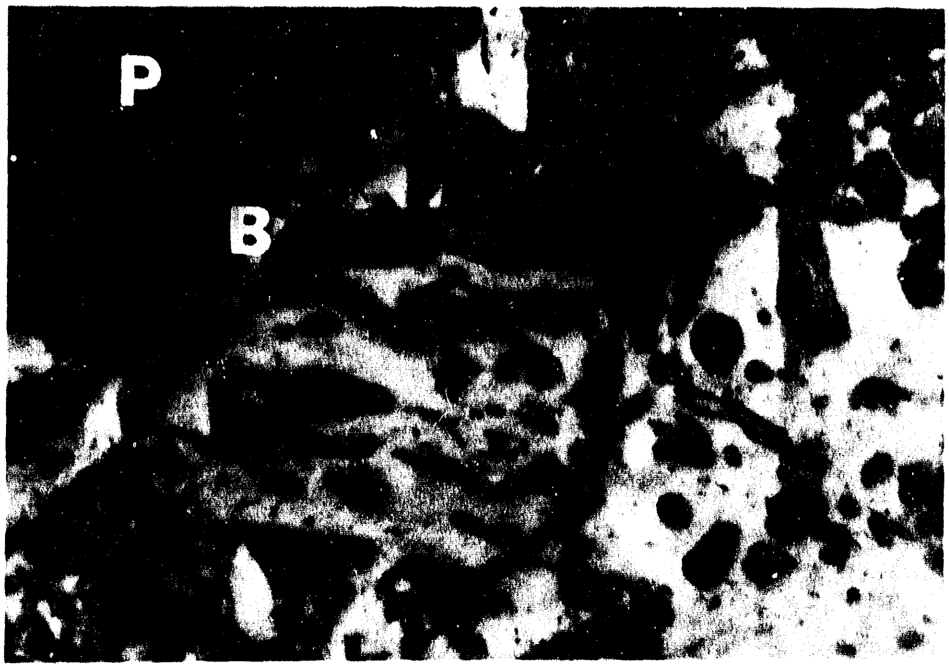


FIGURE 9: PHOTOMICROGRAPHS OF UEC COKED BRIQUETTES SHOWING: C=COKE, P=PLASTIC MOUNTING MEDIA AND V=UNFILLED VOIDS. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE.
REFLECTED LIGHT IN AIR, X 82.



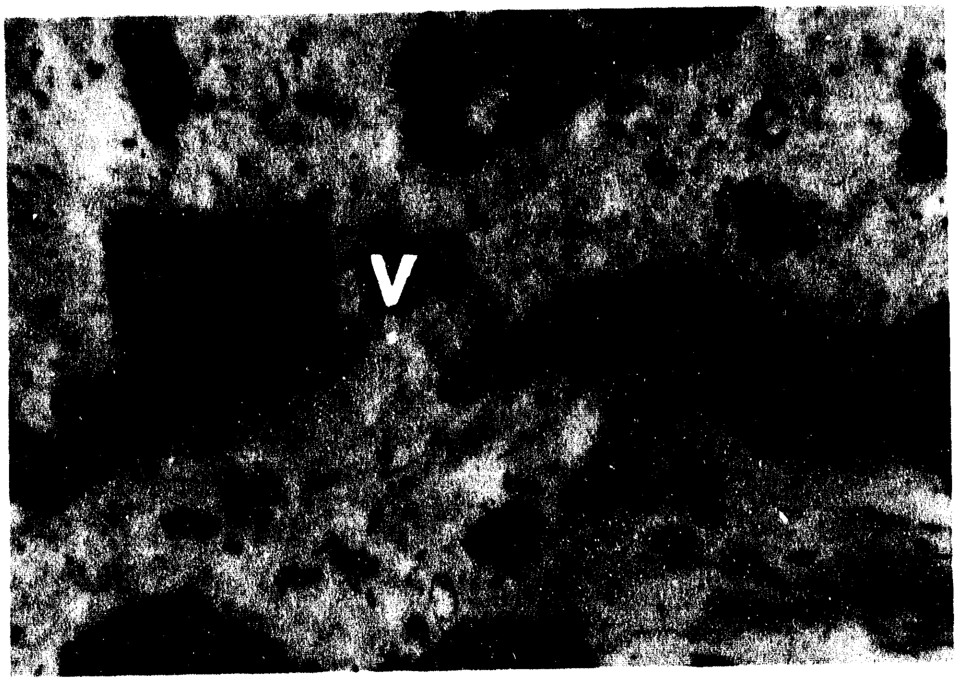
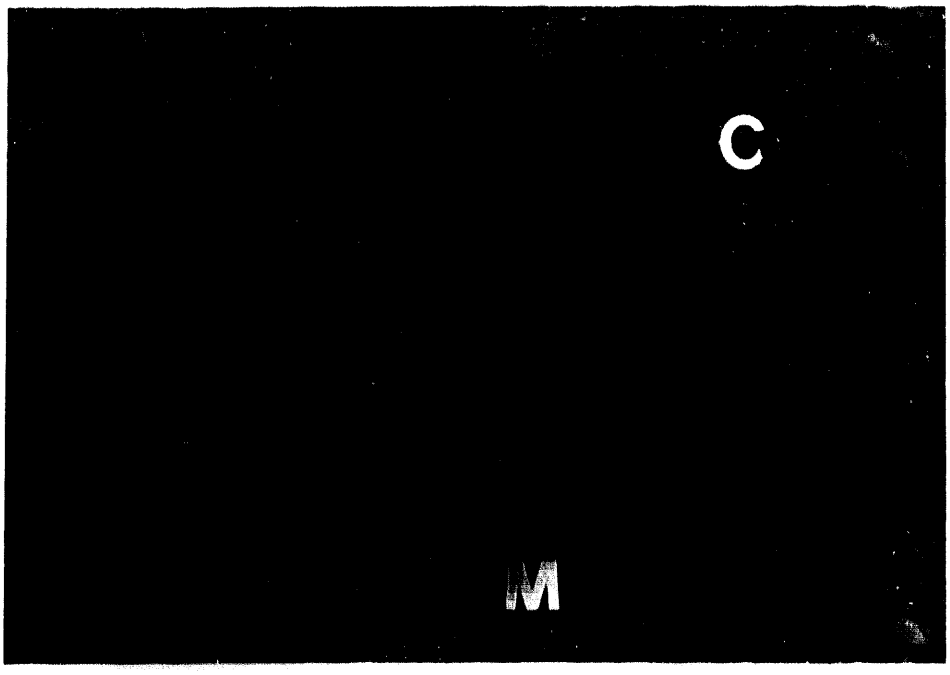
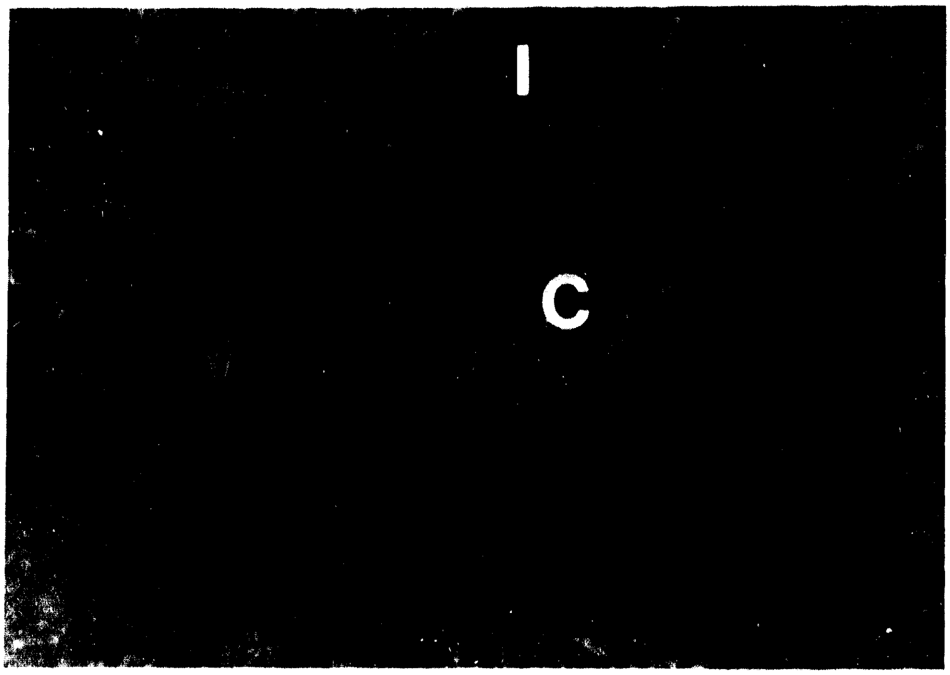


FIGURE 10: PHOTOMICROGRAPHS OF UEC COKE D BRIQUETTES SHOWING: C=COKE, B=BURNED AREAS, P=PLASTIC MOUNTING MEDIA AND V=UNFILLED VOIDS. TOP PHOTO SHOWS THE BRIQUETTE EDGE AND BOTTOM PHOTO SHOWS THE CENTER OF BRIQUETTE. REFLECTED LIGHT IN AIR, X 165.





<ins>FIGURE 11;</ins> PHOTOMICROGRAPHS OF UEC COKED BRIQUETTES SHOWING: C=COKE FROM CHAR AND BINDER CARBON, I=INERT OR OXIDIZED MATERIAL, M=MINERAL MATTER AND V=PORES OR VOIDS. TOP PHOTO IN REFLECTED POLARIZED LIGHT IN AIR, X 330 AND BOTTOM PHOTO IN REFLECTED POLARIZED LIGHT IN OIL WITH A GYPSUM TINT PLATE, X 450.

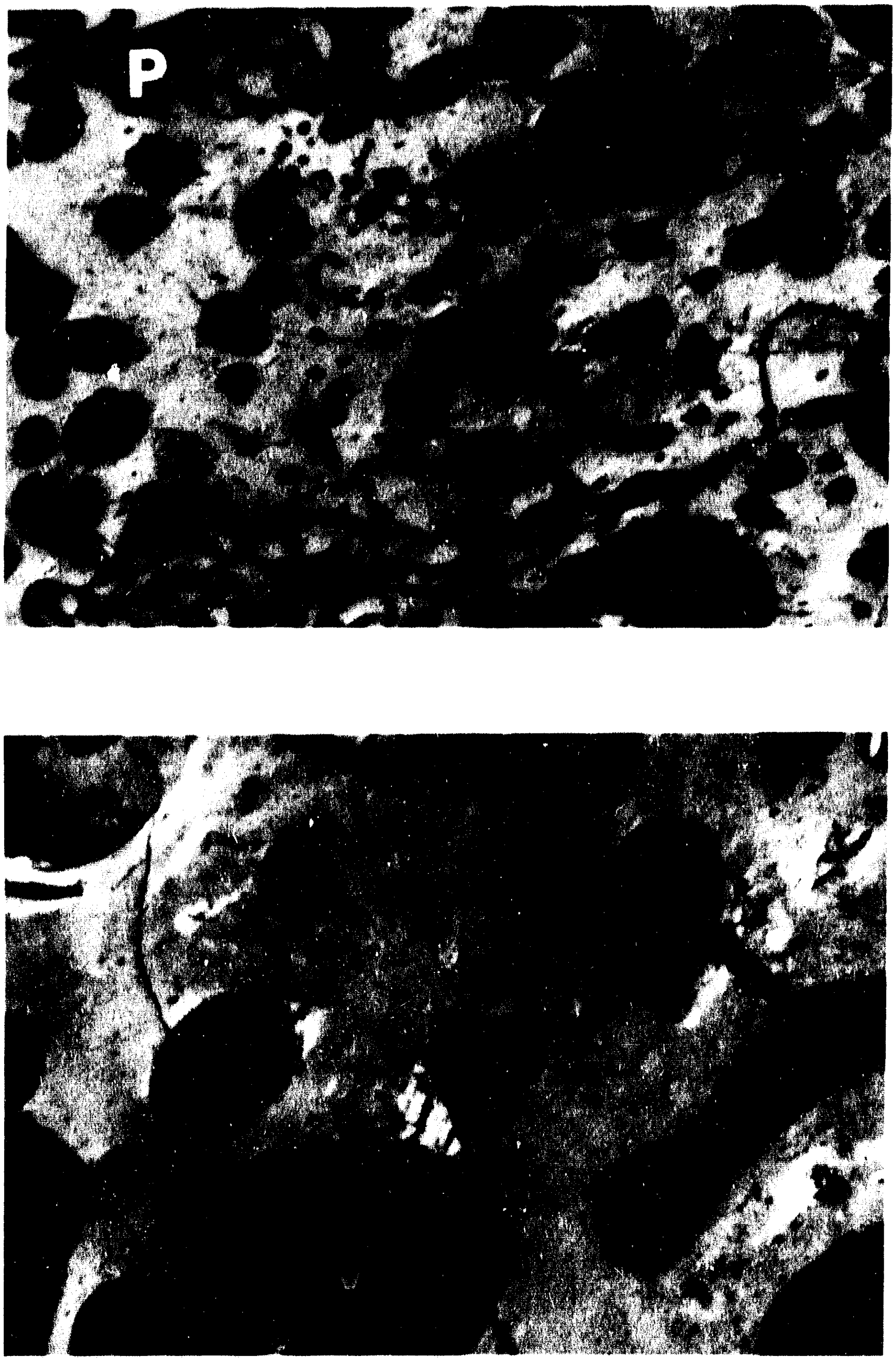


FIGURE 12: PHOTOMICROGRAPHS OF COMMERCIAL COKE SHOWING: C=COKE CARBON, P=PLASTIC MOUNTING MEDIA AND V=UNFILLED VOIDS.
REFLECTED LIGH TIN AIR, TOP PHOTO X 82 AND BOTTOM PHOTO X 165.

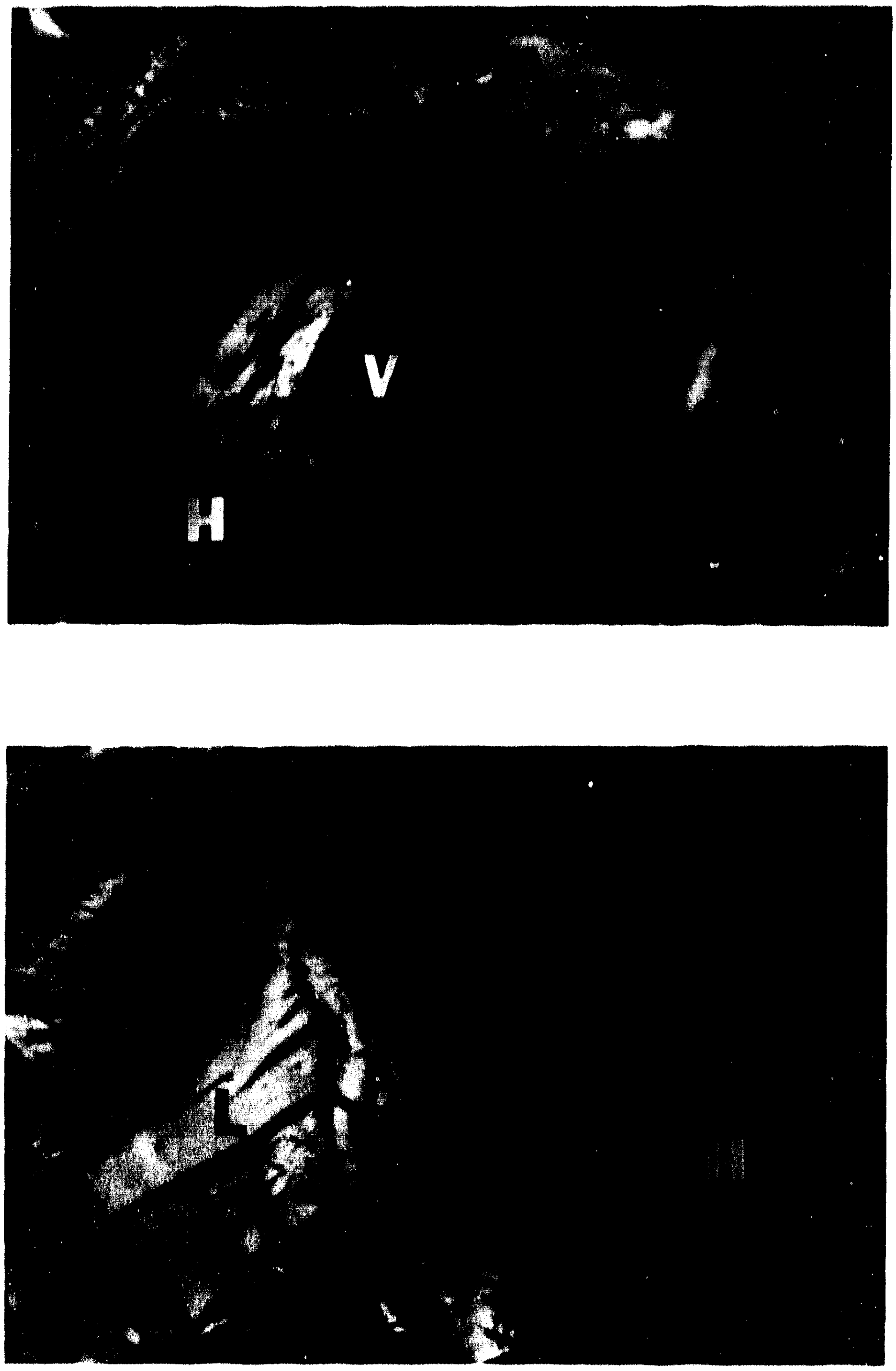


FIGURE 13: PHOTOMICROGRAPHS OF COMMERCIAL COKE SHOWING: H=CARBON FROM HIGH VOLATILE COAL, L=CARBON FROM LOW VOLAITLE COAL, I=INERTS AND V=UNFILLED VOIDS. TOP PHOTO IN REFLECTED POLARIZED LIGHT IN AIR, X 330 AND BOTTOM PHOTO IN REFLECTED POLARIZED LIGHT IN OIL WITH A GYPSUM TINT PLATE, X 450.

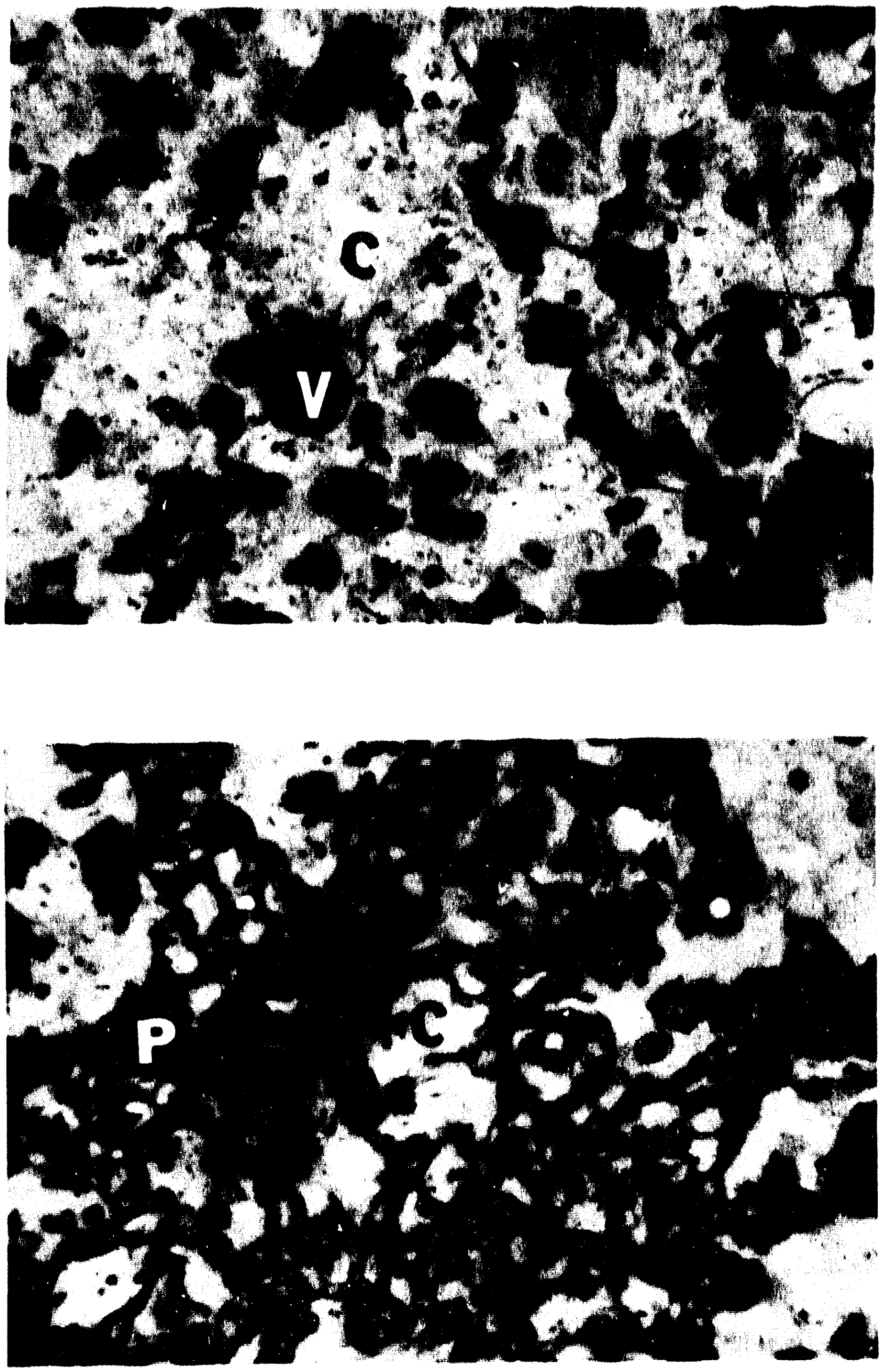


FIGURE 14: PHOTOMICROGRAPHS OF REACTIVITY RESIDUES FROM CTC COKED BRIQUETTES SHOWING: C=COKE, P=PLASTIC MOUNTING MEDIA AND V=VOIDS. TOP PHOTO OF + ½ INCH RESIDUE AND BOTTOM PHOTO OF - ½ INCH RESIDUE. REFLECTED LIGHT IN AIR, X 165.

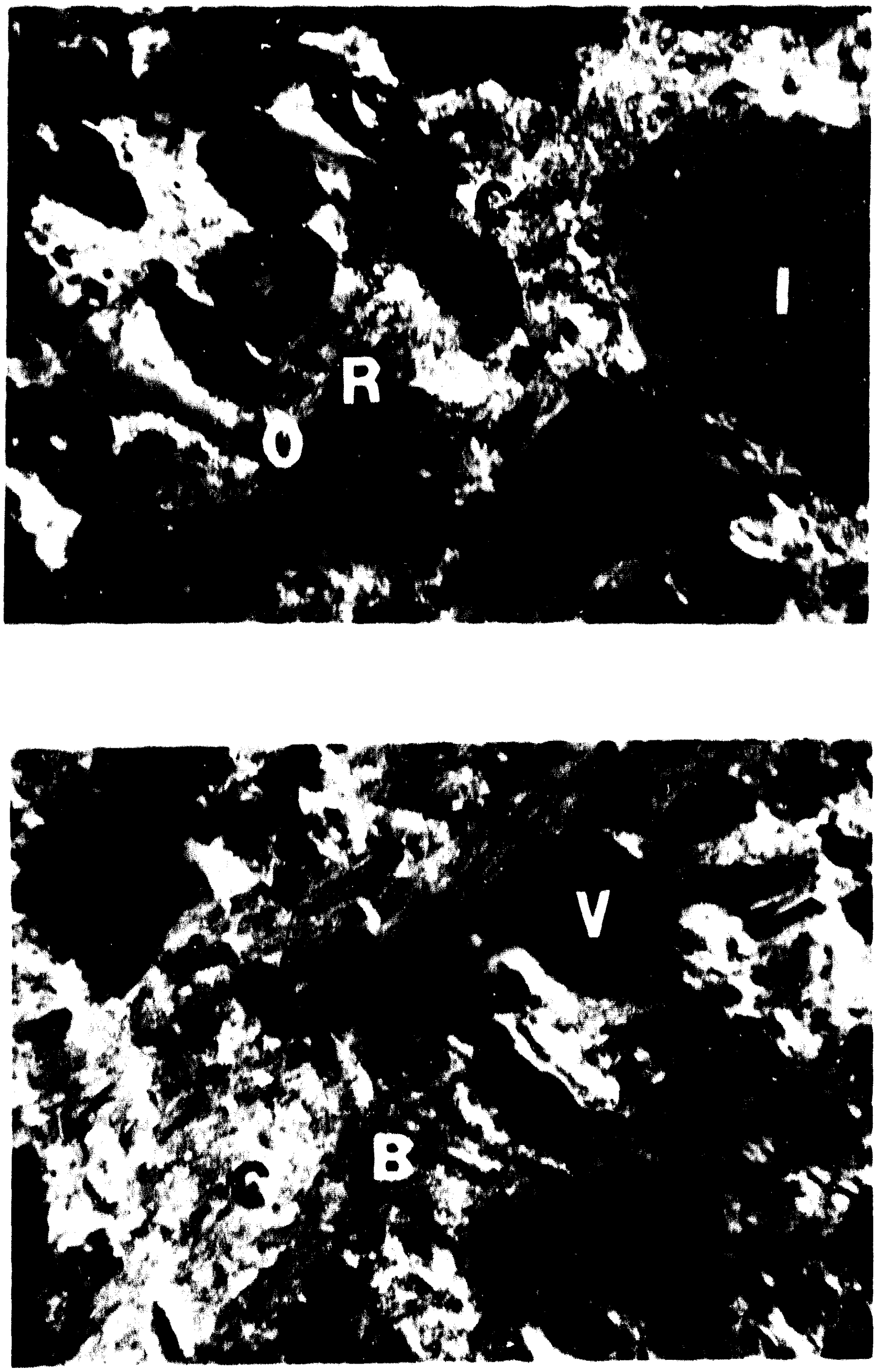


FIGURE 15: PHOTOMICROGRAPHS OF + ½ INCH REACTIVITY RESIDUES FROM CTC COKED BRIQUETTES SHOWING: B=BINDER CARBON, C=CARBON FROM CHAR, I=INERTS, O=OXIDIZED CARBON RESIDUE, R=REACTED AREA AND V=VOIDS.
REFLECTED POLARIZED LIGHT WITH GYPSUM TINT PLATE, IN OIL X 450.

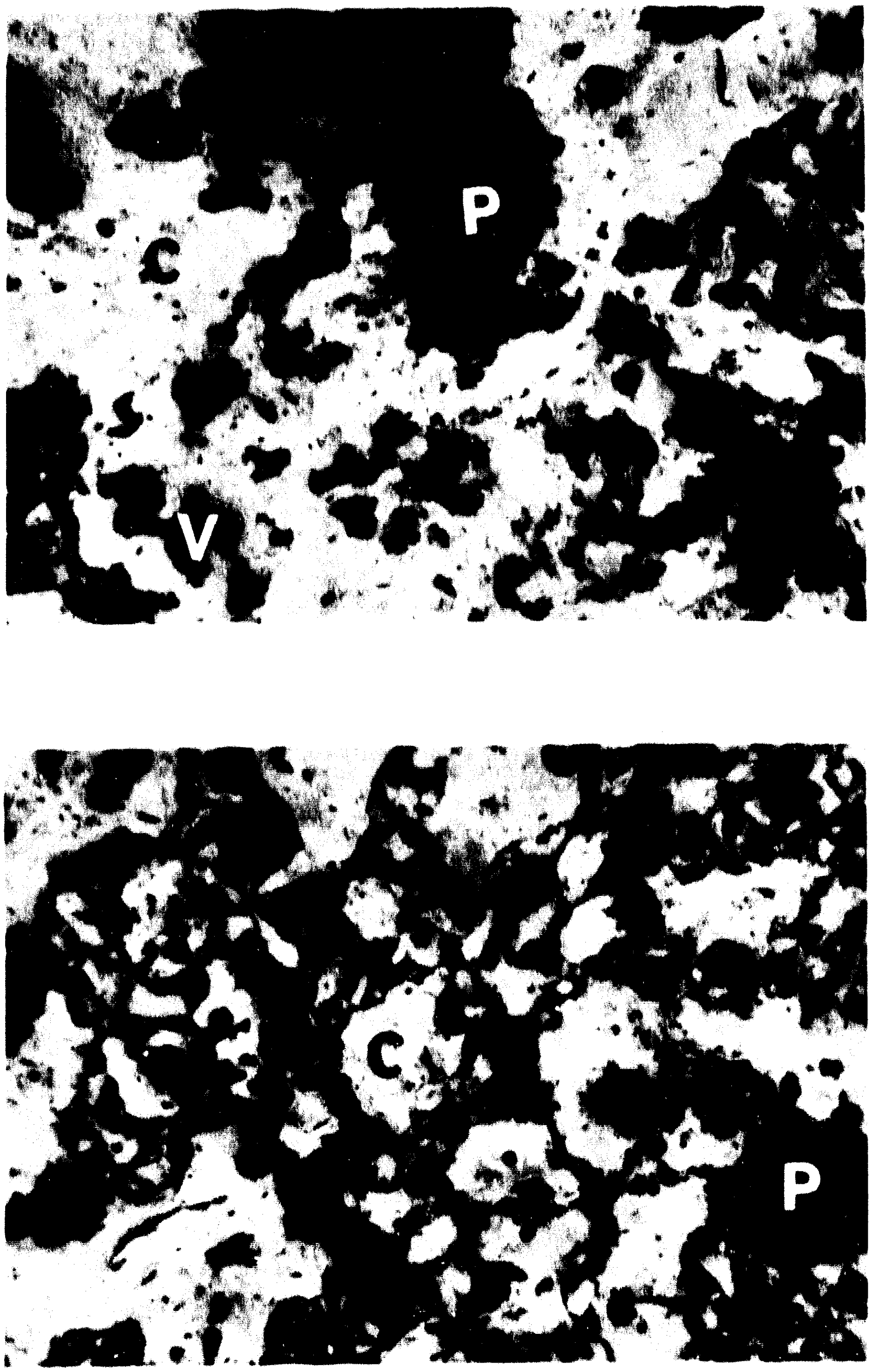


FIGURE 16: PHOTOMICROGRAPHS OF REACTIVITY RESIDUES FROM UEC COKE BRIQUETTES SHOWING; C=COKE, P=PLASTIC MOUNTING MEDIA AND V=VOIDS.
TOP PHOTO OF + ½ INCH RESIDUE AND BOTTOM PHOTO OF - ½ INCH RESIDUE.
REFLECTED LIGHT IN AIR, X 165.

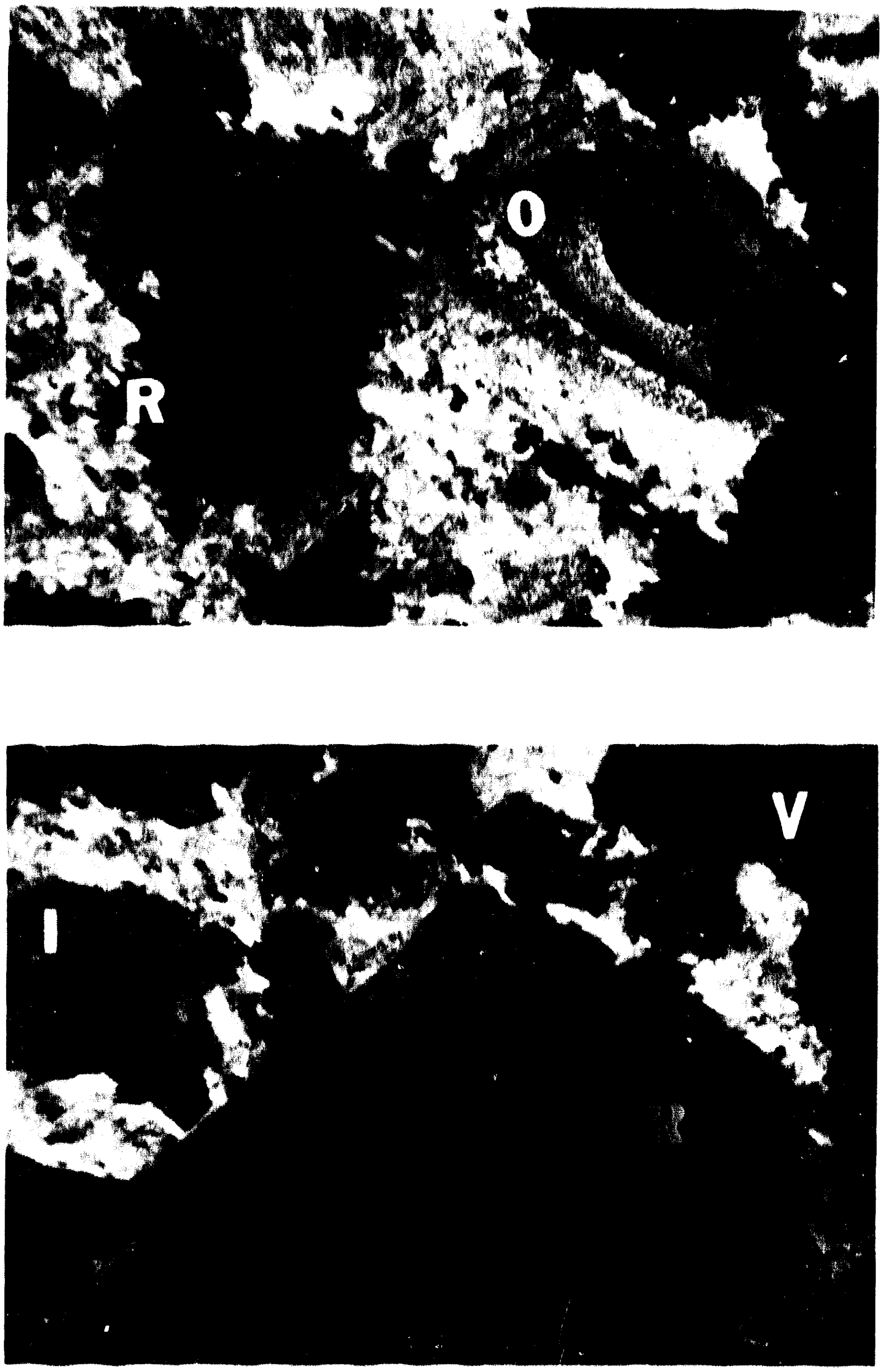


FIGURE 17: PHOTOMICROGRAPHS OF + ½ INCH REACTIVITY RESIDUE FROM UEC COKE BRIQUETTES SHOWING; C=COKE CONTINUOUS PHASE, I=INERTS, O=OXIDIZED AREA, R=REACTED AREA, AND V=VOIDS.
REFLECTED POLARIZED LIGHT WITH GYPSUM TINT PLATE IN OIL, X 450.

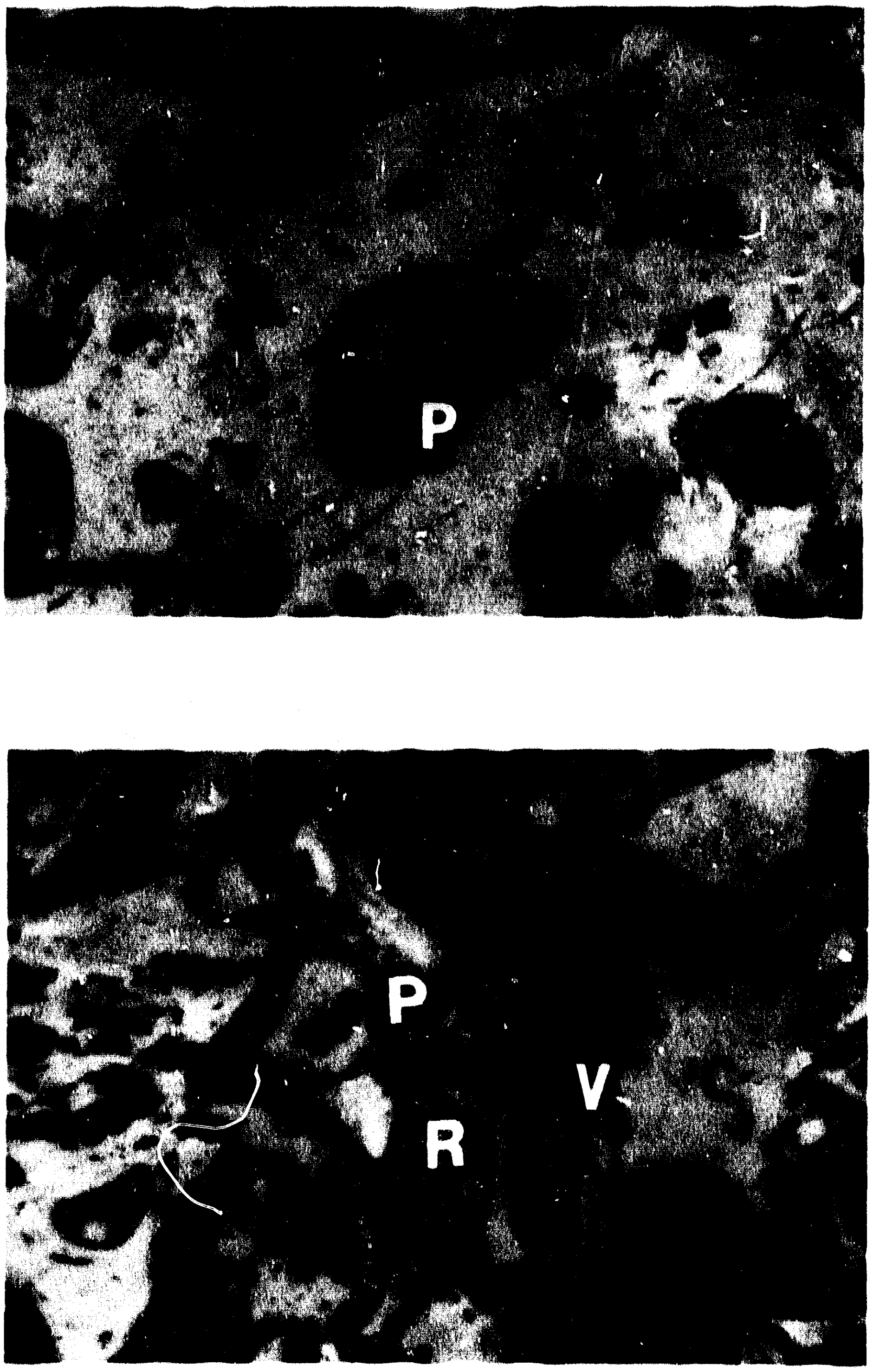


FIGURE 18: PHOTOMICROGRAPHS OF REACTIVITY RESIDUE FROM COMMERCIAL COKE SHOWING; C= COKE, R=REACTED AREA, P=PLASTIC MOUNTING MEDIA AND V=VOIDS. TOP PHOTO OF + ½ INCH RESIDUE AND BOTTOM PHOT OF - ½ INCH RESIDUE.
REFLECTED LIGHT IN AIR, X 165.

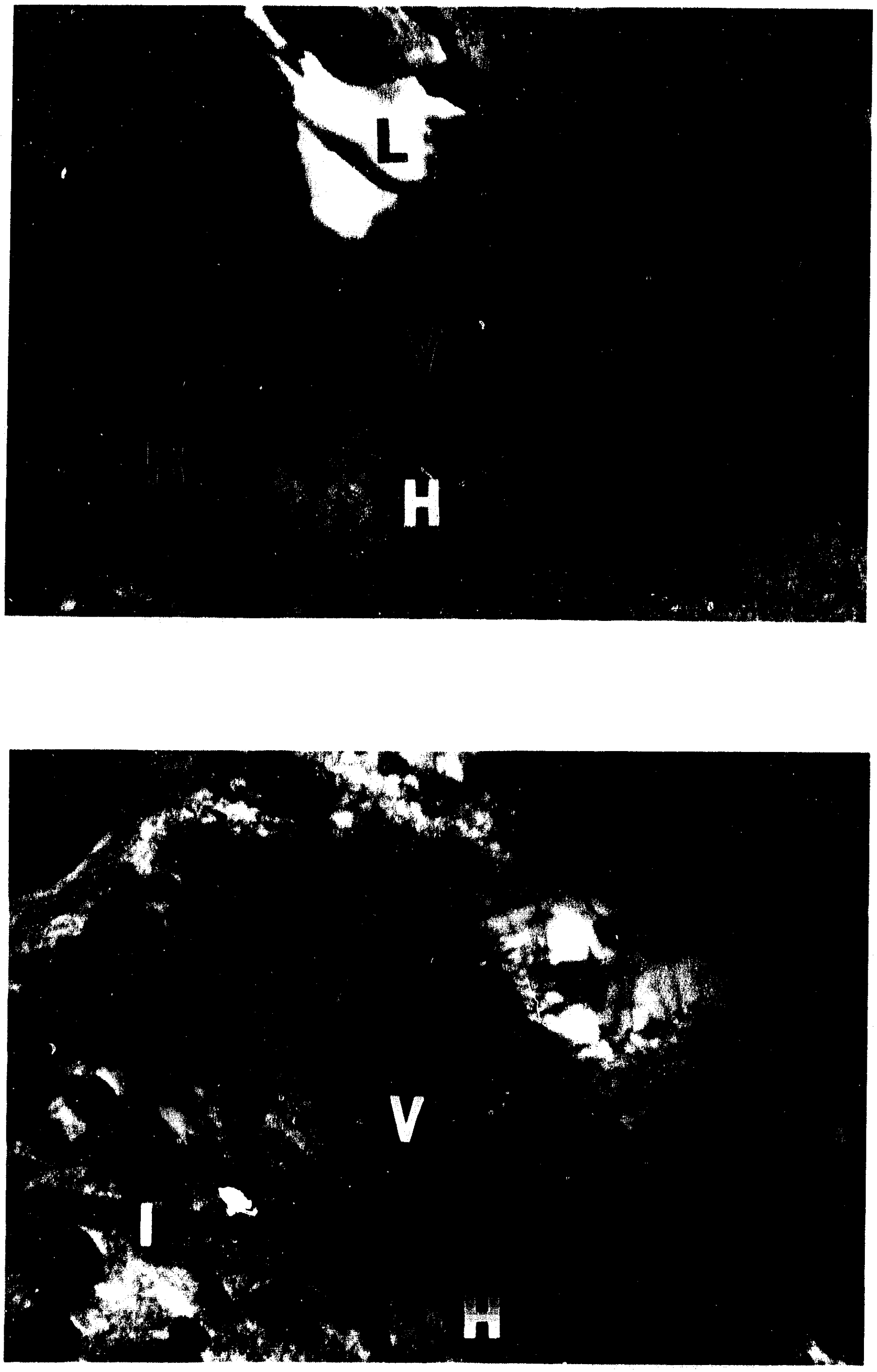


FIGURE 19: PHOTOMICROGRAPHS OF + ½ INCH REACTIVITY RESIDUES FROM COMMERCIAL COKE SHOWING; H=CARBON FROM HIGH VOLATILE COAL, L=CARBON FROM LOW VOLATILE COAL, I=INERTS, R=REACTED AREA, Y=PYROLYTIC CARBON AND V=VOIDS. REFLECTED POLARIZED LIGHT WITH GYPSUM TINT PLATE IN OIL, X 450.

Conclusions and Recommendations

1. A technical and economic study was conducted in which a new technology for producing coke for metallurgical and other industrial uses was evaluated. In particular, the integration of this technology into a power generating complex was studied to identify potential capital and operating cost benefits to the coke producer and the utility. The results of the economic study, presented in an Interim Report, showed that a significant economic incentive exists for integrating the new coke making technology into a facility which can be integrated into a utility site.

2. This report continues the economic evaluation by examining the status of the market for the coke and the factors affecting the marketing of the product. These factors include, the impact of the new environmental regulations on the "old/existing" coke making technology, the status of the steel industry, and the status of the new technology. The results show that while currently an excess of world wide coke production exists, the U.S. steel industry is exporting more coke each year as U. S. coke making facilities close. This situation weakens one of our basic industries and like our oil consumption, places the United States in the position of being reliant on foreign raw material supplies.

3. The results of the current study confirm the original assumption that commercial grade coke can be made using the new technology. In particular, commercial grade coke can be produced from the clean fines fraction of the Homer City coal supply. The coke meets industry standards for blast furnace use with minor but correctable differences. The analysis of the coke produced in this study from Homer City

coal included detailed petrographic analysis of the raw materials and intermediate and final products form the COal Technology Corporation process. This analysis also supported the conclusion that commercial grade coke was and can be made using the CTC technology.

Recommendations

1. Optimization of the coke making process will be required to produce coke of uniform quality. In particular, improved blending of char, pitch and blending coal will be necessary. The petrographic analysis identified the effect of the current blending operation. Microscopic analysis showed variations in coke pore size and wall thickness. This shortcoming of the product is easily remedied by using an improved blending unit operation.

2. The next phase in the commercialization of this process is to construct a demonstration plant. This is necessary for two reasons: first, to validate the engineering assumptions made in the scaling up of the process, in particular the capacity of the full scale screw reactor and second, to produce sufficient quantities of char and coke for full scale end user evaluation. Steel industry acceptance of the coke requires large tonnages for full scale evaluation. A demonstration size facility is required. The quantities of product needed for evaluation are as follows:

    a. Steel Industry tests - 50,000 tons of coke will be produced for actual blast furnace tests in which the CTC coke will replace increasing percentages of conventional coke. Candidate steel companies who have already expressed an interest in these test are National Steel and Wheeling Pittsburgh Steel Company. Smaller tests, using " raceway simulators" located in Canada and Australia may also be performed. These require 20 to 40 tons per test and may be used to study pertinent coke reactivity properties. The full scale tests will be supported by lab scale tests involving reactivity, strength, and quality. Petrographic analysis of the coals and cokes produced will be used to optimize the preparation of coals used in the process.

b. Ferrosilicon and silicon production - 2,000 tons of char, specially prepared to meet end user specifications, will be tested in full scale tests. Elkem Inc., a U.S. producer of ferrosilicon and silicon, has indicated interest in participating in these test. Non U.S. producers will also be contacted for participation.

c. Electric furnace carbons - 100 ton quantities will be tested in industrial electric furnaces for use as an electrode augmentation carbon.

d. Electrode Carbon manufacturing - Pitch and certain low ash chars will be produced in 50 to 100 ton quantities for evaluation by others for the production of electrode grade carbon.

e. Activated carbon - chars will be produced to meet specification for activated carbon feed stock material.

f. Coal Liquids - production of high density fuel for high altitude military aircraft has been under investigation by others. Coal derived liquids have been found to be a particular source of raw material for formulating these fuels. Quantities of coal liquids fractionated to meet the specifications for high density aviation fuel will be produced and cooperative programs will be developed to pursue this technology.

Coal liquids can currently be utilized as additives for gasoline and can thereby reduce the quantity of petroleum derived liquids. This technology is well developed and can be pursued. The demonstration plant can assist in developing pilot programs of sufficient size to demonstrate the techno economic potential of this process.

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