STATE OF ILLINOIS
WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
JOHN C. FRYE, *Chief*
URBANA

REPORT OF INVESTIGATIONS 187

CHAR FOR METALLURGICAL COKE

BY

F. H. REED, H. W. JACKMAN, AND P. W. HENLINE

AUG. 26TH 1818

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

1955

STATE OF ILLINOIS
WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
JOHN C. FRYE, *Chief*
URBANA

REPORT OF INVESTIGATIONS 187

CHAR FOR METALLURGICAL COKE

BY

F. H. REED, H. W. JACKMAN, AND P. W. HENLINE

AUG. 26TH 1818

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

1955

ORGANIZATION

STATE OF ILLINOIS
HON. WILLIAM G. STRATTON, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION
HON. VERA M. BINKS, *Director*

BOARD OF NATURAL RESOURCES AND CONSERVATION
HON. VERA M. BINKS, *Chairman*
W. H. NEWHOUSE, Ph.D., *Geology*
ROGER ADAMS, Ph.D., D.Sc., *Chemistry*
ROBERT H. ANDERSON, B.S., *Engineering*
A. E. EMERSON, Ph.D., *Biology*
LEWIS H. TIFFANY, Ph.D., Pd.D., *Forestry*
W. L. EVERITT, E.E., Ph.D.
Representing the President of the University of Illinois
DELYTE W. MORRIS, Ph.D.
President of Southern Illinois University

GEOLOGICAL SURVEY DIVISION
JOHN C. FRYE, Ph.D., D.Sc., *Chief*

(24459—2500—10-55) 2

STATE GEOLOGICAL SURVEY DIVISION

Natural Resources Building, Urbana
JOHN C. FRYE, Ph.D., D.Sc., *Chief*
M. M. LEIGHTON, Ph.D., D.Sc., *Chief, Emeritus*
Enid Townley, M.S., *Geologist and Assistant to the Chief*
Velda A. Millard, *Junior Assistant to the Chief*
Helen E. McMorris, *Secretary to the Chief*

RESEARCH

(not including part-time personnel)

GEOLOGICAL RESOURCES

Arthur Bevan, Ph.D., D.Sc., *Principal Geologist*
Frances H. Alsterlund, A.B., *Research Assistant*

Coal

Jack A. Simon, M.S., *Geologist and Head*
G. H. Cady, Ph.D., *Senior Geologist and Head, Emeritus*
Charles E. Marshall, Ph.D., *Visiting Research Scientist*
Robert M. Kosanke, Ph.D., *Geologist*
Raymond Siever, Ph.D., *Geologist*
John A. Harrison, M.S., *Associate Geologist*
Paul Edwin Potter, Ph.D., *Associate Geologist*
Harold B. Stonehouse, Ph.D., *Associate Geologist*
Margaret A. Parker, M.S., *Assistant Geologist*
M. E. Hopkins, M.S., *Assistant Geologist*
Kenneth E. Clegg, M.S., *Assistant Geologist*

Oil and Gas

A. H. Bell, Ph.D., *Geologist and Head*
Lester L. Whiting, B.A., *Associate Geologist*
Virginia Kline, Ph.D., *Associate Geologist*
Wayne F. Meents, *Assistant Geologist*
Margaret O. Oros, B.A., *Assistant Geologist*
Kenneth R. Larson, A.B., *Research Assistant*
Jacob Van Den Berg, B.S., *Research Assistant*

Petroleum Engineering

Paul A. Witherspoon, M.S., *Petroleum Engineer and Head*
Frederick Squires, A.B., B.S., D.Sc., *Petroleum Engineer, Emeritus*

Industrial Minerals

J. E. Lamar, B.S., *Geologist and Head*
Donald L. Graf, Ph.D., *Geologist*
James C. Bradbury, A.M., *Assistant Geologist*
Meredith E. Ostrom, M.S., *Assistant Geologist*
Donald L. Biggs, M.A., *Assistant Geologist*

Clay Resources and Clay Mineral Technology

Ralph E. Grim, Ph.D., *Consulting Clay Mineralogist*
W. Arthur White, M.S., *Associate Geologist*
Herbert D. Glass, Ph.D., *Associate Geologist*
Charles W. Spencer, M.S., *Research Assistant*

Groundwater Geology and Geophysical Exploration

Arthur Bevan, Ph.D., D.Sc., *Acting Head*
Merlyn B. Buhle, M.S., *Associate Geologist*
Robert E. Bergstrom, Ph.D., *Assistant Geologist*
John W. Foster, M.S., *Assistant Geologist*
James E. Hackett, M.S., *Assistant Geologist*
Margaret J. Castle, *Assistant Geologic Draftsman* (on leave)
Wayne A. Pryor, M.S., *Assistant Geologist*
Lidia Selkregg, D.N.S., *Assistant Geologist*
Robert C. Parks, *Technical Assistant*

Engineering Geology and Topographic Mapping

George E. Ekblaw, Ph.D., *Geologist and Head*
William C. Smith, M.A., *Assistant Geologist*

Stratigraphy and Areal Geology

H. B. Willman, Ph.D., *Geologist and Head*
David H. Swann, Ph.D., *Geologist*
Elwood Atherton, Ph.D., *Geologist*
Charles W. Collinson, Ph.D., *Associate Geologist*
Donald B. Saxby, M.S., *Assistant Geologist*
T. C. Buschbach, M.S., *Assistant Geologist*
Howard R. Schwalb, B.S., *Research Assistant*
Frank B. Titus, Jr., B.S., *Research Assistant*
Charles C. Engel, *Technical Assistant*
Joseph F. Howard, *Assistant*

Physics

R. J. Piersol, Ph.D., *Physicist, Emeritus*

Topographic Mapping in Cooperation with the United States Geological Survey.

May 16, 1955

GEOCHEMISTRY

Frank H. Reed, Ph.D., *Chief Chemist*
Grace C. Johnson, B.S., *Research Assistant*

Coal Chemistry

G. R. Yohe, Ph.D., *Chemist and Head*
Earle C. Smith, B.S., *Research Assistant*
Guey H. Lee, M.S., *Research Assistant*

Physical Chemistry

J. S. Machin, Ph.D., *Chemist and Head*
Juanita Witters, M.S., *Assistant Physicist*
Tin Boo Yee, Ph.D., *Assistant Chemist*
Daniel L. Deadmore, B.S., *Research Assistant*

Fluorine Chemistry

G. C. Finger, Ph.D., *Chemist and Head*
Robert E. Oesterling, B.A., *Assistant Chemist*
Carl W. Kruse, M.S., *Special Research Assistant*
Raymond H. White, B.S., *Special Research Assistant*
Richard H. Shiley, B.S., *Special Research Assistant*

Chemical Engineering

H. W. Jackman, M.S.E., *Chemical Engineer and Head*
R. J. Helfinstine, M.S., *Mechanical Engineer and Supervisor of Physical Plant*
B. J. Greenwood, B.S., *Mechanical Engineer*
James C. McCullough, *Research Associate* (on leave)
Robert L. Eissler, B.S., *Assistant Chemical Engineer*
Walter E. Cooper, *Technical Assistant*
Edward A. Schaede, *Technical Assistant*
Cornel Marta, *Technical Assistant*

X-Ray

W. F. Bradley, Ph.D., *Chemist and Head*

Analytical Chemistry

O. W. Rees, Ph.D., *Chemist and Head*
L. D. McVicker, B.S., *Chemist*
Emile D. Pierron, M.S., *Associate Chemist*
Donald R. Dickerson, B.S., *Assistant Chemist*
Francis A. Coolican, B.S., *Assistant Chemist*
Charles T. Allbright, B.S., *Research Assistant* (on leave)
William J. Armon, B.S., *Research Assistant*
Joseph M. Harris, B.A., *Research Assistant*
JoAnne E. Kunde, B.A., *Research Assistant*
Joan M. Cederstrand, *Research Assistant*
Harold E. Winters, *Technical Assistant*
George R. James, *Technical Assistant*
Frances L. Scheidt, *Technical Assistant*

MINERAL ECONOMICS

W. H. Voskuil, Ph.D., *Mineral Economist*
W. L. Busch, A.B., *Assistant Mineral Economist*
Ethel M. King, *Research Assistant*

EDUCATIONAL EXTENSION

George M. Wilson, M.S., *Geologist and Head*
Dorothy E. Rose, B.S., *Assistant Geologist*

RESEARCH AFFILIATES IN GEOLOGY

J Harlen Bretz, Ph.D., *University of Chicago*
John A. Brophy, M.S., *Research Assistant, State Geological Survey*
Stanley E. Harris, Jr., Ph.D., *Southern Illinois University*
C. Leland Horberg, Ph.D., *University of Chicago*
M. M. Leighton, Ph.D., D.Sc., *Research Professional Scientist, State Geological Survey*
Heinz A. Lowenstam, Ph.D., *California Institute of Technology*
William E. Powers, Ph.D., *Northwestern University*
Paul R. Shaffer, Ph.D., *University of Illinois*
Harold R. Wanless, Ph.D., *University of Illinois*
J. Marvin Weller, Ph.D., *University of Chicago*

CONSULTANTS

Geology, George W. White, Ph.D., *University of Illinois*
Ralph E. Grim, Ph.D., *University of Illinois*
L. E. Workman, M.S., *Former Head, Subsurface Division*
Ceramics, Ralph K. Hursh, B.S., *University of Illinois*
Mechanical Engineering, Seichi Konzo, M.S., *University of Illinois*

GENERAL ADMINISTRATION

(not including part-time personnel)

LIBRARY

Anne E. Kovanda, B.S., B.L.S., *Librarian*
Ruby D. Frison, *Technical Assistant*

MINERAL RESOURCE RECORDS

Vivian Gordon, *Head*
Margaret B. Brophy, B.A., *Research Assistant*
Sue J. Cunningham, *Technical Assistant*
Betty Clark, B.S., *Technical Assistant*
Jeanine Climer, *Technical Assistant*
Kathryn Brown, *Technical Assistant*
Marilyn W. Thies, B.S., *Technical Assistant*
Hannah Fisher, *Technical Assistant*
LaRoy Peterson, *Technical Assistant*
Patricia L. Luedtke, B.S., *Technical Assistant*
Genevieve Van Heyningen, *Technical Assistant*

PUBLICATIONS

Barbara Zeiders, B.S., *Assistant Technical Editor*
Meredith M. Calkins, *Geologic Draftsman*
Marlene Ponshock, *Assistant Geologic Draftsman*

TECHNICAL RECORDS

Berenice Reed, *Supervisory Technical Assistant*
Marilyn DeLand, B.S., *Technical Assistant*
Mary Louise Locklin, B.A., *Technical Assistant*

GENERAL SCIENTIFIC INFORMATION

Ann P. Ostrom, B.A., *Technical Assistant*
Jill B. Cahill, *Technical Assistant*

OTHER TECHNICAL SERVICES

Wm. Dale Farris, *Research Associate*
Beulah M. Unfer, *Technical Assistant*
A. W. Gotstein, *Research Associate*
Glenn G. Poor, *Research Associate**
Gilbert L. Tinberg, *Technical Assistant*
Wayne W. Nofftz, *Supervisory Technical Assistant*
Donovon M. Watkins, *Technical Assistant*

FINANCIAL RECORDS

Velda A. Millard, *In Charge*
Leona K. Erickson, *Clerk-Typist III*
Virginia C. Sanderson, B.S., *Clerk-Typist II*
Irma E. Samson, *Clerk-Typist I*

CLERICAL SERVICES

Mary Cecil, *Clerk-Stenographer III*
Mary M. Sullivan, *Clerk-Stenographer III*
Lyla Nofftz, *Clerk-Stenographer II*
Lillian Weakley, *Clerk-Stenographer II*
Sharon Ellis, *Clerk-Stenographer I*
Barbara Barham, *Clerk-Stenographer I*
Mary Alice Jacobs, *Clerk-Stenographer I*
Irene Benson, *Clerk-Typist I*
Mary J. de Haan, *Messenger-Clerk I*

AUTOMOTIVE SERVICE

Glenn G. Poor, *In Charge**
Robert O. Ellis, *Automotive Mechanic*
Everette Edwards, *Automotive Mechanic*
David B. Cooley, *Automotive Mechanic's Helper*

May 16, 1955

*Divided time

CONTENTS

ILLUSTRATIONS

TABLES

CHAR FOR METALLURGICAL COKE

BY

F. H. REED, H. W. JACKMAN, AND P. W. HENLINE

ABSTRACT

Pilot-plant studies have been made at the Illinois State Geological Survey to determine how partially devolatilized coal, or char, may be used in place of low-volatile coal in the production of metallurgical coke. A retort was designed and built to produce chars having a wide range of volatile matter. Cokes of good quality were produced by using char made from Illinois coals. Neither the percentage nor uniformity of char volatile matter in the range studied was found critical. However, the quality of the high-volatile coals used for blending is of great importance. Comparison with chars produced in other retorts indicates that retort design and consequent operating procedure influence the properties of the product.

INTRODUCTION

THE EXTENSIVE USE by the expanding steel industry of low-volatile bituminous coals for metallurgical coke and the demand for smokeless fuels to satisfy the requirements of smoke abatement ordinances are reducing the reserves of Pocahontas and other low-volatile coals so rapidly that they will be the first coals to be exhausted. In the United States, reserves of low-volatile bituminous coal comprise about 4 percent of the total reserves of bituminous coal and 2 percent of total fuel reserves (Fieldner, 1950, p. 4). Only about one-fourth of low-volatile coal production is used for metallurgical coke, but as this is about 20 million tons annually it is desirable that a substitute be found before the supply becomes too limited. The development of such a substitute fuel should be of particular interest to those steel producers who do not own or control their own coal supplies or are distant from the low-volatile bituminous coal fields.

During and immediately following World War II, the acute shortage of low-volatile coal of high quality was felt by coke producers in many areas. In response to suggestions by members of the steel industry, the Illinois Geological Survey decided to investigate the physical and chemical properties of "char," or partially devolatilized coal, to determine how it might be used in place of low-volatile coal in production of metallurgical coke.

Although many processes have been proposed for production of a char-like material by low-temperature carbonization of coal, very few have become commercial and none is known to yield a product suitable, desirable, and economical for use in metallurgical coke. It became necessary, therefore, to design and build in our laboratory a retort in which a variety of chars could be produced under controlled conditions and their properties studied. This retort was designed for continuous operation and had a maximum capacity of about one ton of coal per day. Operation for a few hours could produce char in quantity sufficient for evaluation in blends with high-volatile coals.

The Survey's pilot coke oven, 14 inches wide, was used for the evaluation studies (Reed et al., 1947). Coke produced in this experimental oven duplicates closely that made in commercial-size ovens. Therefore, by construction of the char retort, facilities were made available for producing chars that when blended with high-volatile coals could be evaluated in the pilot oven and the results compared directly with equivalent commercial operation.

ACKNOWLEDGMENTS

We wish to acknowledge the cooperation of the many individuals and organizations who contributed to the planning and progress of this project. K. L. Storrs contributed the original concept of a vibrating re-

tort. Illinois coal producers furnished coals from the No. 2, No. 5, and No. 6 seams that were used in producing char and as coals for blending. Colorado Fuel and Iron Corp., Granite City Steel Co., Indiana Gas and Chemical Corp., Inland Steel Co., Koppers Co., Laclede Gas Co. (now the coke plant of the Great Lakes Carbon Corp.), and United States Steel Corp. contributed both Eastern and Western coals, and the members of their staffs gave valued counsel.

Various divisions of the Illinois State Geological Survey provided assistance. The Analytical Division analyzed all coals and carbonization products, the Physical Chemistry Division determined surface areas of coals and chars, and the Coal Division gave information about location and characteristics of coal deposits.

To all these organizations and individuals we express our sincere appreciation. The following individuals deserve special acknowledgment for their advice and active help: A. C. Fieldner, United States Bureau of Mines; E. J. Gardner, Inland Steel Co.; Frank F. Kolbe, The United Electric Coal Companies; Heber V. Lauer of A. J. Boynton Co.; C. E. Lesher, who prepared special chars for the project; V. F. Parry, who prepared special chars at the Bureau of Mines Experiment Station at Denver, Colo.; A. R. Powell of Koppers Co.; and J. D. Price, Colorado Fuel and Iron Corp.

HISTORICAL BACKGROUND

The United States has been fortunate throughout its industrial history in having large deposits of low-volatile coal available. South Africa, India, Japan, parts of Europe, and much of South America have been less fortunate, having little or no low-volatile indigenous coal of coking quality.

The following review of char development in certain of these countries is by no means a complete coverage of this subject. It is presented only to show the world-wide interest in char and to describe certain developments that, with others, eventually may lead to a wide-spread commercial use of this product.

Char in Japan

Only in Japan has char been developed and used commercially over an extended period of time for producing metallurgical coke. During World War II, the Wanishi Iron and Steel Co. for a period of two years operated blast furnaces of up to 700 metric tons of iron capacity per day on coke produced from high-volatile Japanese coking coal blended with 13 to 25 percent char. The coking coal used at this plant is high in vitrain and has a high Gieseler fluidity.

Japanese char, or "coalite" as it is called, is produced in rotary drum carbonizers from noncoking coal (Reid, 1948; Hisada, 1951). Each carbonizer consists of two units: an internally heated rotary drying drum, 73 feet long and 6 feet 4 inches in internal diameter, for drying and conditioning the coal; and an externally heated rotary carbonizing retort, 76 feet long and 7 feet 10 inches in diameter, into which the dried coal is discharged and partially devolatilized. The carbonizing retort is mounted in a gas-fired furnace. Combustion gases, after heating the retort, pass through the drying drum where the waste heat is utilized in conditioning the coal. To produce coalite of 18 to 20 percent volatile matter, a supplementary source of gas is required for heating in addition to the gas generated from the coal. Four carbonizers were installed at the Wanishi plant, each having a daily capacity of 100 tons of coalite. Three of these were kept in operation continuously while a fourth was being reconditioned.

Private correspondence and interviews with operating personnel disclosed that strong metallurgical coke was produced by blending 20 to 25 percent coalite with the high-volatile coal indigenous to the area. Tests showed the coke had a Japanese drum-stability index of 90 to 91, corresponding approximately to the ASTM tumbler-stability index of 53.

During the later part of the war, the coalite retorts ceased operation. In 1949 they were reconditioned and resumed production, and in November of that year a 700-ton blast furnace was fired with coke made from the indigenous coal and 25 percent coalite. Furnace operation was as good as, or better than, that of any previous operating period. Research programs were initiated in plants and laboratories throughout Japan to utilize other noncoking coals for coalite production. Economic conditions have favored the importation of low-volatile coals, however, and coalite production has not expanded.

Char in Europe

Considerable thought has been given to the production and utilization of char in Europe, but we believe that none has been used commercially for production of metallurgical coke. The late Dr. Eng. Adolph Thau of the Didier Works, Berlin, Germany, reviewed European experience with low-temperature carbonization up to World War II (Reed, 1948) and described in particular the process developed by the Didier Works. In this process, a noncoking or weakly coking coal is carbonized in a continuously operated cylindrical vertical-chamber oven at 550° to 600° C. (1022° to 1112° F.). The semicoke is crushed and blended with 5 to 8 percent of coal-tar pitch and 10 to 15 percent of coking coal. This mixture is briquetted at a pressure of 100 to 200 atm. and the briquettes carbonized in vertical-chamber ovens at 900° to 1000° C. (1652° to 1832° F.).

It is claimed that even lignite may be converted into metallurgical coke by this process after first being dried in a rotary-turbine drier of special design. A blast-furnace test on coke briquettes formed primarily from lignite indicated that coke manufactured by this two-stage process meets the conditions of normal blast-furnace operation.

In 1950 the experimental plant of the Centre d'Etudes et Recherches des Charbonnages de France at Marienau started to develop methods for producing metallurgical coke solely from the local weakly coking coals of Lorraine and the Saar (Minchin, 1953; Cheradame, 1954). The basis for this development was a low-temperature char produced in two rotating cylinders, one for drying the coal and the other for carbonization at a temperature of 550° C. Blends of 20 percent char with the Saar and Lorraine coals were heat-dried and charged into high-temperature coke ovens at a bulk density 13 percent higher than could be obtained with undried coal. Other mixtures using char blended with best-quality German coking coals and indigenous French coals have been studied. These blends were compacted by heat drying rather than by stamping before they were charged into the coke ovens. Practical problems of dust control and of oxidation at coal-drying temperatures must be solved before such a process becomes commercial. It is reported, however, that coke of good quality has been made.

Recent research at Marienau is directed toward the development of a fluidized-bed retort for char production. A pilot retort with a capacity of one ton per hour was built in 1954 and is being evaluated (Cheradame, personal communication, 1954).

The Petit char process also has been developed in France to large pilot-plant scale. A vertical retort is employed through which coal cascades and devolatilizes quickly, the amount of remaining volatile matter depending primarily, as in all such processes, on the temperature attained by the char.

American Experience with Char

Metallurgical coke plants in Far Western United States have had no near source of low-volatile coal, and until recent years have coked straight high-volatile coal or blends of this with a small percentage of coal-tar pitch. Recently, limited quantities of low-volatile coal from Arkansas and Oklahoma have been imported, but transportation charges make the cost high.

The Colorado Fuel and Iron Co. at Pueblo, Colo., and the Kaiser Steel Co. at Fontana, Calif., have sought to evaluate chars made from Colorado and Utah coals, respectively. Price and Woody (1944) reported that adding 10 to 25 percent char of 17 to 19 percent volatile matter to Colorado high-volatile coal improved the quality of the coke. When more than 30 percent char was added, the coke tended to become pebbly and lose strength. Reducing volatile matter to 15 percent caused char to have little value as a low-volatile coal substitute. The use of 25 percent char of optimum volatile-matter content produced a satisfactory coke similar to that made by using 20 percent Pocahontas coal.

Char at Pueblo was produced in a Hayes retort pilot plant (Woody, 1941). The Colorado coking coal that first was used for char production was later replaced by a noncoking coal to improve retort operation. Char from both types of coal proved to be satisfactory when carbonized in blends; however, that made from the noncoking coal produced the best final coke. A full-scale coke-oven and blast-furnace test of limited duration, using a blend of char and Colorado coal, indicated strongly that the coke was satisfactory as a blast-furnace fuel.

Extensive tests also were made at the Fontana plant by Kaiser Steel Co. on the use of char in blends with Utah high-volatile coal. Thompson (1946) reported that char made of Utah coal in a pilot retort of the Disco type (Lesher, 1941) could be blended advantageously with the same Utah coal. Blends containing 15 percent char produced the best coke. The optimum volatile-matter content of Fontana char was shown to be 16.6 percent, or 17.9 percent on the dry ash-free basis. At this plant 15 percent of char improved coke properties slightly more than did 12½ percent of Pocahontas coal. Full-scale oven tests substantiated pilot-plant results.*

METHOD OF PROCEDURE

We have studied these American and foreign developments and find that there is little uniformity in methods of char production and considerable controversy as to the kind of coal from which char should be made. There are conflicting theories regarding the use of a noncoking coal or a coking coal similar to or different from the high-volatile coal with which the char is to be blended. Little is known about the characteristics of char or the basic methods of procedure either in its production or use. Much fundamental information and experimental work is needed to solve the problems of why char acts as it does and how it should be produced and used for metallurgical coke.

Four processes for char production were investigated in our preliminary consideration of this project. First studied was the Disco process, now operating commercially, which converts Pittsburgh seam coal into "balls" of about 17 percent volatile matter suitable for smokeless domestic fuel. The process utilizes a rotary drum and, when operating on Pittsburgh seam coal, requires preoxidizing the coal and recycling a portion of the char.

Also studied was the Hayes process. Retorts of this type were operated first at Moundsville, W. Va., and a pilot plant was built later at Pueblo. This too is a rotary-drum unit, with an internal oscillating stirrer. Recycling of a portion of the char appears to be desirable for smooth retort operation except when noncoking coal is used. However, Price and Woody (1944) reported that this procedure is detrimental to the quality of the final coke.

Two other methods of char production were considered, both of which were in the pilot-plant development stage. The fluidized-bed unit (Singh, 1946) had not been perfected to a point where we felt justified in adopting the method. The Storrs process (Carter, 1947), involving the passing of a thin turbulent coal bed over a heated surface, was under development by the Coal Logs Co. of Salt Lake City, and although the pilot plant had not been operated successfully we felt that char could be produced by this principle in a small experimental unit.

Our decision to adopt the basic principle of the Storrs process, that is, to cause coal to flow through a heated retort by vibration of the retort, was based on the belief that this process offered the opportunity to control and vary operating conditions, making possible the production of uniform char over a wide range of volatile matter. It should be stated at this time that our interest was not directed toward the development of a commercial plant but, rather, toward the

---

* For a more complete review of low-temperature carbonization before World War II, refer to the report of the Utah Conservation and Research Foundation of May 1939.

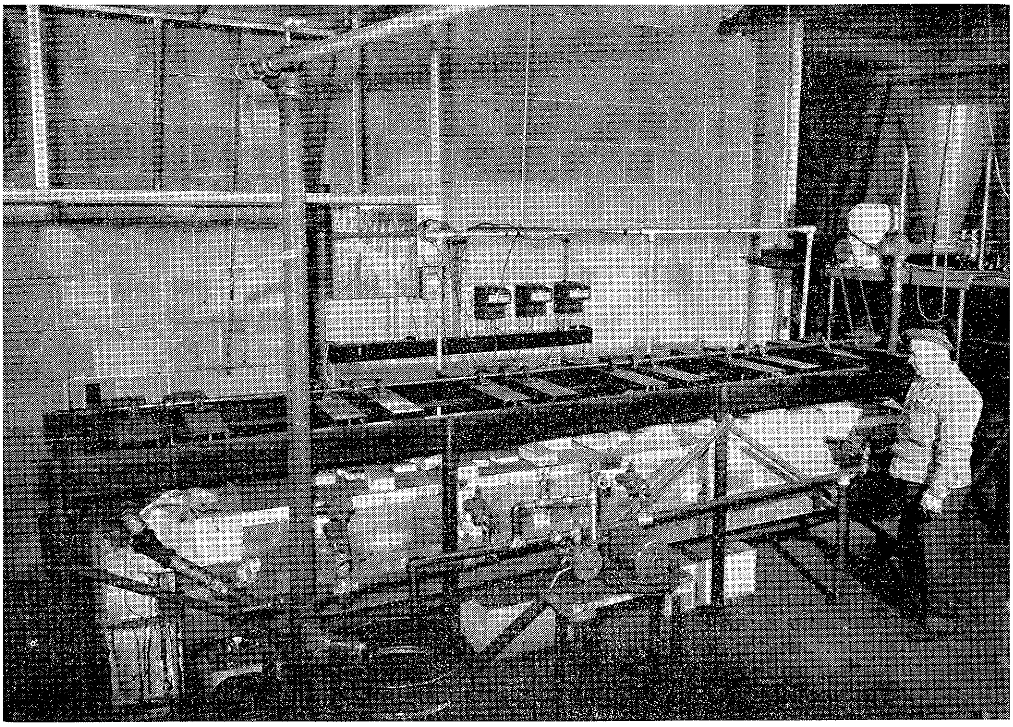

FIG. 1.—Char retort for continuous operation.

production of char in experimental quantities in a unit in which chars having a wide range of properties could be made under controlled operating conditions.

CHAR PILOT PLANT

The vibrating retort built in our laboratory for the continuous carbonization of a thin turbulent bed of coal has produced the chars required for this study. Operation has not always been smooth. Problems of control and measurement of temperatures have been encountered. Mechanical difficulties, caused in part by the wear of moving parts, sometimes made it impossible to control char volatile matter. However, most of these problems were solved as they were recognized, and a workable experimental unit was evolved that could continuously produce chars of 14 to 25 percent volatile matter, as desired.

DESIGN

General design of the pilot plant is shown in figures 1, 2, and 3. It consists essentially of a steel retort 3 inches wide by 3¼ inches high, inside dimensions, and 15 feet 5 inches long. The retort is suspended horizontally from eccentric bearings driven from a horizontal rotating shaft by a variable-speed motor. Fast rotation of the shaft causes the retort to vibrate vertically; the intensity of vibration depends on the eccentricity of the bearings. A shaft rotation of 1000 rpm is sufficient to cause a layer of fine coal in the retort to form a turbulent bed.

Horizontal travel of the bed of coal through the retort is produced by an eccentric bearing at the coal-feed end, driven at the same speed as the overhead eccentrics and synchronized with them through a gear box. Maximum coal travel is obtained when the forward thrust on the retort occurs simultaneously with the upward thrust. Coal travel may be retarded by changing the phase relation between the forward and vertical thrusts.

The entire retort is suspended in a muffle that is heated electrically by Calrod elements placed on the muffle bottom. The elements are divided into three horizontal sections. The temperature of each section is controlled separately within the limits of desired operation.

Coal is fed into one end of the vibrating retort from an overhead hopper through a screw conveyor driven by a variable-speed motor. Char drops out of the opposite end through a seal into a receiver. Gas and tar vapors enter the receiver and are piped through the usual purification train.

As a result of these design features, the following operating conditions may be controlled: 1) frequency and intensity of vibration, 2) rate of coal feed, 3) time of retention of coal in the retort, and 4) retort temperature.

OPERATION

Operation of the pilot plant has demonstrated that Illinois coals may be converted into chars of desired volatile-matter content and that the volatile matter may be maintained within close limits. Although high-Btu gas and low-temperature tar were evolved during carbonization, this study was undertaken primarily to evaluate the char in blends with high-volatile coals, and no attempt is made in this report to evaluate the other carbonization products.

PRETREATMENT OF COAL

Each coal considered for conversion into char presents a separate problem, and usually some degree of pretreatment is required before devolatilization. Coals are pretreated to remove moisture and render them essentially nonagglomerating by passing them through the retort counter-current to a flow of air. Results of pretreatment are twofold. First, dry coal is more uniform in composition, and second, oxidized coal passes through the retort at charring temperature without becoming sticky and plugging the retort.

All Illinois coal must be pretreated. Satisfactory pretreatment of No. 6 seam coal may be obtained by passing it through the retort in $1\frac{1}{2}$ minutes with the bottom-plate temperature held in the range 500° F. to 700° F. Coal is fed at a rate of 60 pounds per hour, and air is passed over the turbulent bed, counter-current to the flow of coal, at a rate of 100 cu. ft. per hour. Temperatures taken in the turbulent bed indicate that the coal attains a temperature approximately 25° F. lower than that of the retort floor plate.

Ideally, after pretreatment the coal should be passed directly into a carbonizing retort, where the temperature would be increased immediately to carbonizing conditions. As we have used the same retort for pretreatment and carbonization, the second step could not follow immediately, so the pretreated coal was cooled to room temperature in the interim.

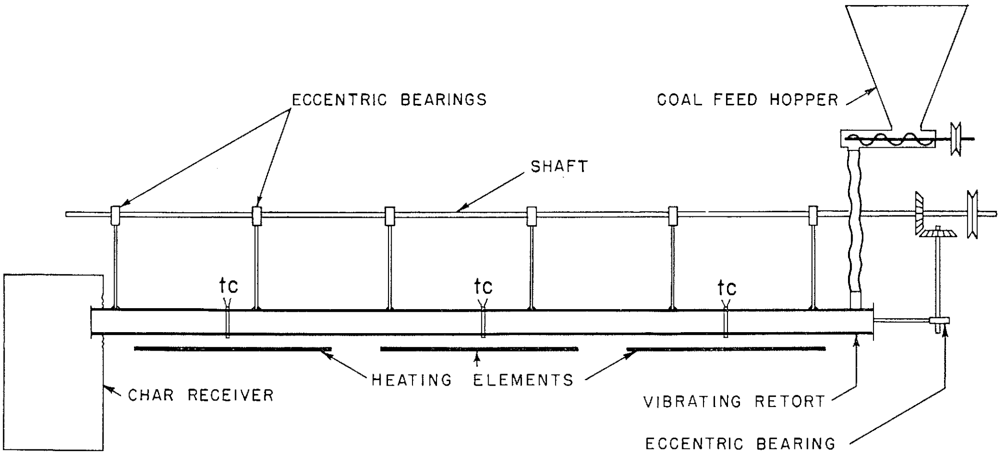

FIG. 2.—Sketch of mechanical parts of char retort.

COAL TRAVEL IN RETORT

A study was made of the flow characteristics of the turbulent coal bed through the retort. The amount of coal held in the retort, which is a measure of bed thickness, was found to be directly proportional to the rate of coal feed at a given setting of the eccentrics. The time of coal retention in the retort is independent of the coal feed, depending entirely on the eccentric gear relations.

The effect of size consist on coal travel was studied in a cold retort with the top removed to permit observation. Five samples of dried coals with the minus-100-mesh portion varying from 8.8 to 22.3 percent were observed. When coal was added to the empty retort, the larger pieces tended to reach the discharge end first. Fine coal tended to hang back after the coal feed was stopped. In no case, however, did serious segregation of sizes appear while the coal feed was maintained, the small sizes being carried along by the larger. The amount of fines within the limits mentioned above, therefore, had no significant effect on retention time of coal in the retort.

We have no proof that coal travels at the same velocity at carbonization temperatures as it does in a cold retort. Tests have shown, however, that char and dry coal travel at approximately the same rate when cold. Assuming that this velocity remains essentially the same at the higher temperatures, we compute that under normal drying and carbonizing conditions (1075 rpm vibration rate), coal remains in the retort 1½ minutes during drying and 2½ minutes during carbonization. At a feed rate of 60 pounds per hour, the thickness of the coal bed during the drying period (if quiescent) would be about 0.1 inch, and during carbonization 0.17 inch.

CARBONIZATION

When the retort was operated as a carbonizer, the temperatures of the three heating sections were set to give a gradient of 375° to 400° F. on the lower plate from coal feed to char discharge end. The maximum plate temperature normally was maintained in the range 950° to 1150° F., depending on the volatile matter desired in the char.

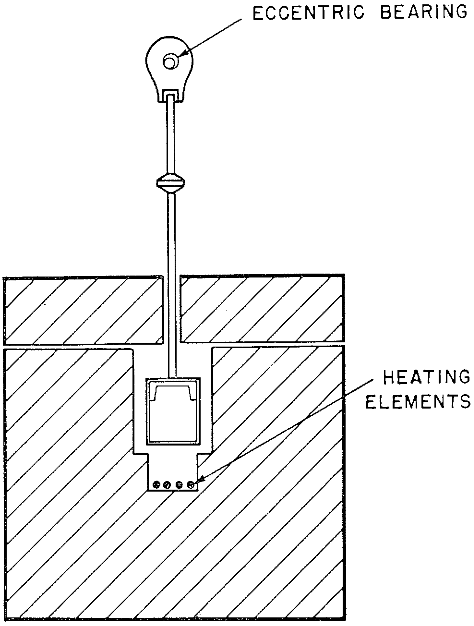

FIG. 3.—Cross section of char retort and muffle.

The vibrating equipment was standardized with ⅛-inch eccentrics producing vertical vibration and 1/32-inch eccentrics horizontal vibration. The eccentric shaft was rotated at 1075 rpm. Any wear on the horizontal eccentric was critical, but wear on the vertical eccentrics did not affect coal travel appreciably.

Char fell from the retort through a dry seal of glass and asbestos cloth into a collecting hopper from which it was removed by hand at intervals.

The heavy muffle surrounding the retort provided excellent insulation except for heat loss through the ends. Owing to the bulk and heat capacity of the retort, considerable time was required to reach temperature equilibrium, so it was not practical to obtain heat balances during the average operating time of 4 to 5 hours.

Attaching thermocouples to the vibrating retort to control and record retort temperatures proved to be a critical operating problem. The best control was obtained by clamping couples directly to the lower side

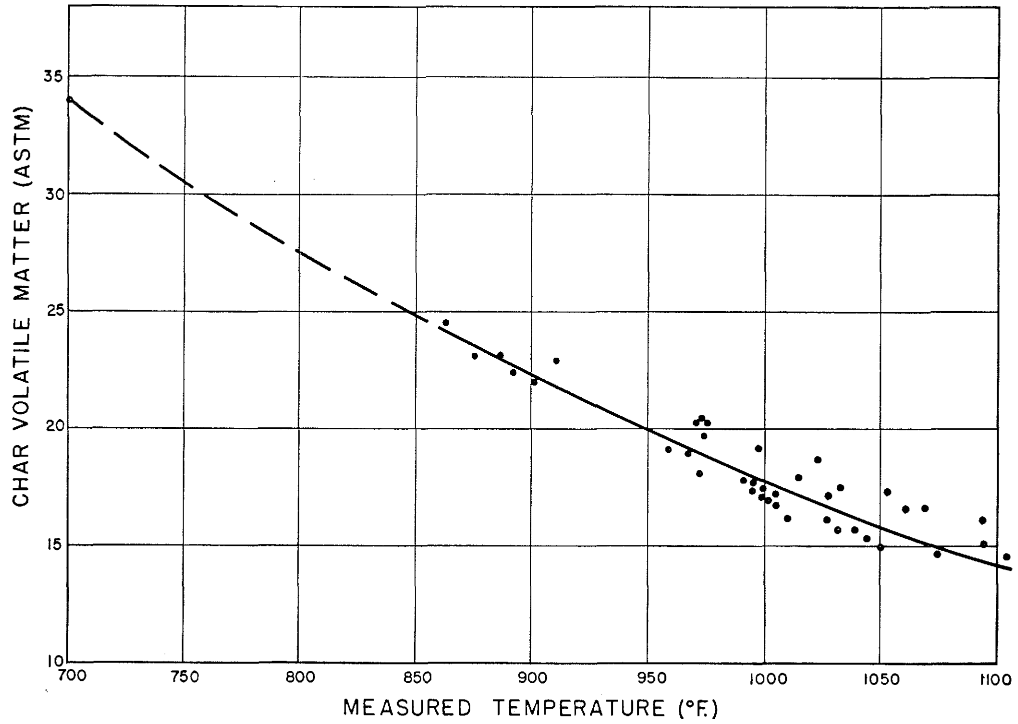

Fig. 4.—Char volatile matter vs. measured internal char temperature.

of the bottom plate. However, the best indication of actual char temperature was obtained by suspending a couple inside the retort near the discharge end just above floor level so that it would contact the thin turbulent bed of char.

FACTORS AFFECTING VOLATILE MATTER

Study of operating temperatures and char analyses indicates that the volatile matter of any char is directly dependent on the temperature attained by the char in the retort. As char does not have sufficient time to reach an equilibrium temperature with the floor plate, its attained temperature is influenced by any operating variable, i.e., feed rate, retention time, or even the agglutinating characteristics of the coal. Therefore, close regulation of all operating details is essential. Assuming proper pretreatment of coal and a sturdily built uniformly heated retort, the control of char volatile matter becomes a problem of regulating the coal feed rate and the retention time in the retort.

There is some doubt as to the accuracy of temperature measurements inside the retort owing to the thin bed of turbulent char and the effect of radiation from the retort floor. However, char temperatures taken in the turbulent bed correlate more closely with volatile matter than do temperatures taken at any exterior point. A compilation of data obtained at various feed rates over the temperature range studied has resulted in the curve shown in figure 4, relating char volatile matter and char temperature as measured inside the retort.

Coals for Char

Any coal to be charred in the retort should pass through the heating cycle with a minimum of agglomeration. There are no noncoking coals in or near Illinois, so coals from the various seams mined in the State were used in this study. No. 6 coal from southern Illinois seemed to approximate most closely ideal conditions, as its uniformly low plastic properties could be reduced sufficiently by simple oxidation. However, the No. 2 and No. 5 coals have been charred successfully after the required amount of oxidation.

Char also has been produced from a Colorado noncoking coal and from a Utah coal with plastic properties similar to Illinois No. 6. The usual pretreatment was given these coals, and both were charred without difficulty.

After some preliminary investigation, all coals processed in the pilot retort have been pulverized to pass through a ¼-inch screen. The following size analysis is representative of the prepared coal:

Plus 8 m	3.5%
8 m x 28 m	50.1%
28 m x 48 m	20.9%
48 m x 65 m	7.6%
65 m x 100 m	5.8%
Minus 100 m	12.1%

Char Yields from Illinois Coal

The yield of char from any coal depends on moisture loss during drying and on the extent of devolatilization during carbonization. Yields obtained in the pilot retort were computed on 40 experimental runs with Illinois No. 6 coal and are listed in table 1 over the range of char volatile matter studied.

Characteristics of Char

Char produced in the pilot retort from Illinois coal is free flowing and consists of particles only slightly larger than the original pulverized coal. Fine dust has agglomerated with larger particles so that there are few extreme fines, and the char does not appear to be dusty. The char particles have a semifused appearance, many having expanded into cenospheres with an impervious obsidian-like inner surface. The particles are soft and easily pulverized; they offer little resistance to breakage into fine-sized material suitable for blending with coal for coke manufacture.

Char is lighter in weight than the pulverized coal from which it is made. That produced in our pilot plant has a bulk density of about 26 pounds per cu. ft. as compared with 50 pounds for the coal.

Determinations of total surface area (Brunauer et al., 1938) of the chars made in our laboratory show them to be relatively nonporous, with less surface than the coal from which they were made. Table 2 lists the results of total surface-area determinations on a number of coals, chars, and cokes. Reduction in surface area during the charring process indicates that fusing of coal material has sealed off or destroyed much of the capillary pore structure, and may account for the fact that these chars have never heated spontaneously after their initial cooling.

METALLURGICAL COKE FROM COAL-CHAR BLENDS

The primary objective of this investigation has been to learn how char might be used in place of low-volatile coal to produce metallurgical coke. Consequently many of the chars made in the pilot retort have been coked in blends with high-volatile coals and the cokes evaluated by standard chemical and physical tests. Early results indicated that chars made from various Illinois coals were not sufficiently different in their properties to make the choice of coal a critical factor.

Table 1.—Char Yields from Illinois No. 6 Coal

Char volatile matter	Char yields	
Percent	% of pretreated coal as charged	% of original coal as received
14.0–15.9	78.7	69.3
16.0–17.9	81.4	71.1
18.0–19.9	83.1	72.8
20.0–21.9	84.6	73.5
22.0–23.9	89.4	77.8
24.0–24.5	92.7	81.3

Table 2.—Total Surface Area of Representative Coals, Chars, and Coke

	Surface area Square meters per gram
Coal	
Low-volatile bituminous	
Pocahontas No. 3	2.7
High-volatile A bituminous	
Illinois No. 5 (Gallatin Co.)	1.75
Pittsburgh seam	1.6
High-volatile B bituminous	
Illinois No. 6 (1)	9.2
Illinois No. 6 (2)	8.3
High-volatile C bituminous	
Illinois No. 6	66.3
Illinois No. 5	78.7
Char	
Vibrating retort	
From Illinois No. 6	2.58 to 3.95
From Colorado noncoking coal	3.33
From Utah Hiawatha	3.61
Disco pilot retort	
From Illinois No. 6	1.97
Bureau of Mines fluidized-bed retort	
From Illinois No. 6	2.67
Coke	
High-temperature	3.8
Breeze (V.M. = 1.2%)	7.51

No special study was made on char pulverization as it affected the coking properties of blends of coal and char. In normal operating procedure, the char to be blended was first pulverized in the hammer mill generally used for preparing coals, but a ⅛-inch cradle screen was substituted for the usual ¾-inch screen. Pulverized char was mixed with the coal and the mixture passed through the hammer mill, set to yield a coal 80 percent minus ⅛ inch. Final blending of the coal-char mixture was accomplished by hand shoveling on the laboratory floor.

CHAR VOLATILE MATTER

RANGE FOR OPTIMUM COKING PROPERTIES

Previously published investigations (Price and Woody, 1944; Thompson, 1946) of the use of char in metallurgical coke blends have been in agreement that char volatile matter must be kept within a narrow range for optimum coking results. The validity of this premise might well be the determining factor in the commercial use of char, as the expense of maintaining volatile matter in a narrow range might increase the cost of char production.

To determine the optimum volatile-matter range of chars from Illinois coals, we produced series of chars with volatile matter ranging from 15 to 24 percent. These were coked in blends with both strongly coking Eastern coals and lower-rank coking coals of Illinois. Results of representative series of these coking tests are shown in table 3 and indicate that the actual volatile-matter content of Illinois char within this range is not critical and tends to have little or no effect on the properties of the cokes produced.

In Japan it was found that char of 12 percent volatile matter was unsatisfactory. There are without doubt both upper and lower limits for volatile matter in the Illinois char, but as the range appears to be very wide the commercial production and use of this char would be simplified.

It was not considered advisable to devolatilize char to much under 15 percent in our retort, so the lower limit of volatile matter for best coke practice could not be determined. However, to prove that such a limit does exist, a test was made using coke breeze of about 1 percent volatile matter in place of char. The results shown in table 4 indi-

Table 3.—Char Volatile Matter vs. Coke Properties

Run No.	Char	Blend		Coke						
	V. M. %	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
80% Eagle—20% char										
545 . . .	14.8	47.4	swelled	50.6	70.3	61.5	82.7	69.1	3.2	.904
521 . . .	18.9	48.0	"	46.2	70.9	58.0	84.0	69.3	3.6	.961
522 . . .	19.2	47.7	"	46.1	71.5	60.1	83.0	73.7	3.2	.968
547 . . .	23.8	48.6	"	50.7	68.6	67.3	86.7	72.6	3.5	.972
58½% Ill. No. 6—21½% Eagle—20% char										
544 . . .	14.8	46.4	7.2	44.9	62.6	64.1	85.9	70.7	5.0	.816
539 . . .	16.6	45.7	4.0	45.2	62.4	63.1	86.8	69.8	4.8	.790
541 . . .	18.5	47.2	5.9	43.4	62.1	66.1	86.2	69.3	4.7	.780
526 . . .	18.7	46.5	7.2	44.8	62.4	69.5	88.5	71.5	4.3	.784
524 . . .	20.3	47.6	4.8	45.2	62.1	65.9	86.7	69.5	4.8	.796
546 . . .	23.8	48.1	5.1	43.6	63.4	69.9	87.7	72.2	4.8	.826
58½% Ill. No. 6—21½% Ill. No. 5—20% char										
514 . . .	16.1	46.2	5.1	43.5	58.4	70.4	87.6	74.7	6.5	.764
513 . . .	17.0	47.8	7.3	38.6	56.9	68.5	86.5	73.3	7.5	.775
511 . . .	17.5	47.9	3.6	40.1	57.1	69.9	86.7	74.9	7.2	.766
516 . . .	18.1	48.1	3.8	39.8	57.3	62.1	85.3	72.3	6.6	.795
520 . . .	19.2	48.1	6.1	38.1	58.7	67.2	87.3	74.4	6.0	.788
505 . . .	22.0	48.1	2.2	36.6	51.0	65.9	84.7	69.5	10.9	.792
504 . . .	22.9	48.3	3.8	39.8	57.3	61.5	85.5	70.7	8.0	.783
80% Ill. No. 5—20% char										
459 . . .	17.3	42.4	4.7	50.7	63.8	57.8	87.7	73.5	4.2	.746
463 . . .	17.8	43.7	19.1	42.9	62.4	58.7	83.3	70.3	3.7	.800
460 . . .	17.9	42.3	7.3	48.9	63.1	63.6	88.6	72.3	4.3	.719
461 . . .	18.4	46.6	8.0	46.5	63.8	54.2	84.8	65.8	4.7	.795
462 . . .	18.4	43.4	7.1	48.6	63.0	58.9	86.6	71.9	4.0	.748
464 . . .	18.5	44.7	15.0	46.9	64.2	59.5	85.6	69.4	3.8	.762
468 . . .	20.6	43.6	9.7	42.5	58.8	67.8	88.7	77.2	4.2	.779
80% Ill. No. 6—20% char										
453 . . .	15.5	41.7	1.2	43.8	60.0	68.7	87.7	71.9	6.4	.717
455 . . .	16.6	38.9	1.7	36.0	52.5	68.4	87.7	74.6	10.3	.680
465 . . .	18.4	43.1	1.7	44.4	55.6	65.7	86.9	73.5	8.1	.703
467 . . .	20.6	43.5	1.8	38.0	52.7	68.3	87.3	73.1	7.5	.715
451 . . .	22.0	42.3	1.3	35.8	51.6	66.7	87.2	72.4	8.4	.718

cate that breeze is very much inferior to any char tested. In this test the coke breeze was pulverized to approximately the same size consist as the char, and all other operating conditions remained unchanged.

Also shown in table 4 are results of coking tests in which Disco rotary-drum chars of relatively low volatile-matter content are used. These chars are made from the same Illinois coal as those produced in our retort. Indications are that the char containing only 12 percent volatile matter is of poor quality.

UNIFORMITY AS A FACTOR AFFECTING COKING PROPERTIES

Price and Woody (1944), Thompson (1946), and others have thought it necessary to have all char particles uniform in composition. To check this theory with the Illinois chars, several blends have been coked in which the char used was a half-and-half mixture of two chars having very different volatile-matter content (15 and 24 percent). Cokes were compared with those made from blends containing the individual chars, and results are shown in ta-

Table 4.—Indication of Lower Limit of Char Volatile Matter
(Blend—58½% Ill. No. 6, 21½% Eagle, 20% char)

Run No.	Char	Blend		Coke						
	V. M. %	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
546 . . .	23.8	48.1	5.1	43.6	63.4	69.9	87.7	72.2	4.8	.826
526 . . .	18.7	46.5	7.2	44.8	62.4	69.5	88.4	71.5	4.3	.784
544 . . .	14.8	46.4	7.2	44.9	62.6	64.1	85.9	70.7	5.0	.816
586 . . .	1.2*	52.6	6.3	11.5	15.1	70.8	80.0	74.8	11.5	.781
568 . . .	15.2†	50.1	5.8	40.9	65.3	60.1	84.6	65.7	3.9	.849
571 . . .	12.0†	50.3	4.9	35.0	65.5	48.2	75.7	55.6	4.4	.854

*High-temperature coke breeze.
†Char produced from Illinois No. 6 coal in Disco rotary-drum retort.

ble 5. The data presented are not entirely conclusive. However, very little or no degrading of coke properties resulted from mixing chars. This indicates that nonuniformity of char within these limits has little effect on the structure of the coke produced.

Importance of High-Volatile Coal

The quality of high-volatile coal is very important in regular coking practice, in which high- and low-volatile coals are blended. It is even more important when the low-volatile coal is replaced by char. The coking results of a number of blends of char with various high-volatile coals are shown in table 6. Blends are arranged according to the decreasing value of their Gieseler fluidities. The coke properties shown for each blend are average values of from 2 to 13 individual coking tests.

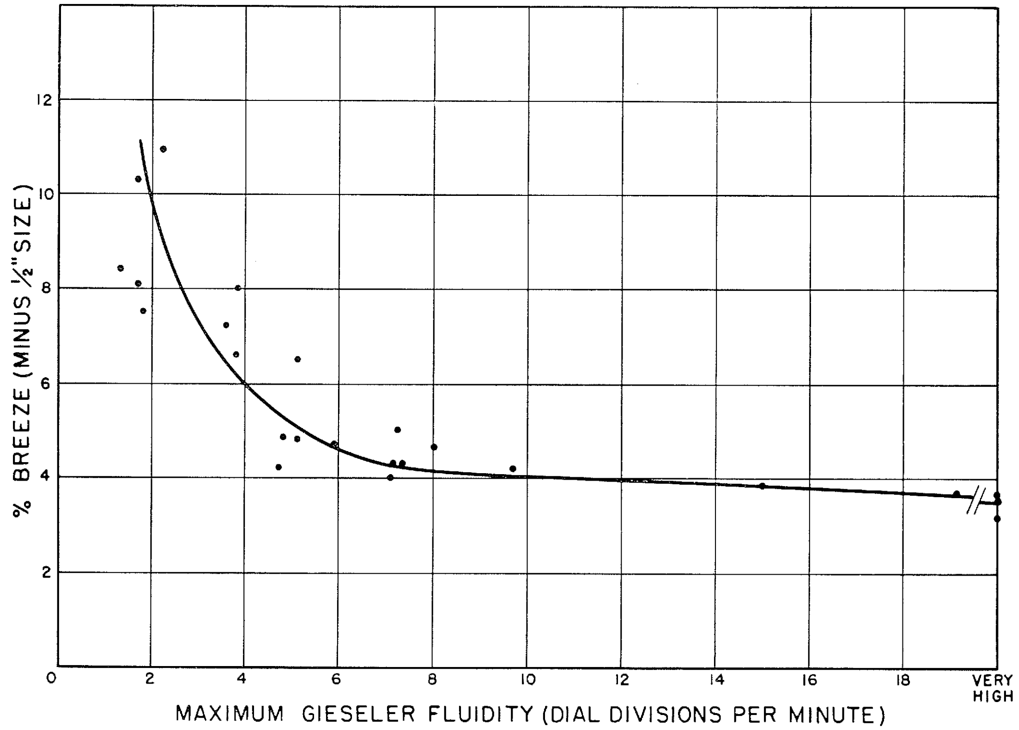

Fig. 5.—Percent breeze vs. maximum fluidity of blends.

Table 5.—Uniformity of Volatile Matter vs. Coke Quality

Run No.	Char	Blend		Coke						
	V. M. %	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
	58 ½% Ill. No. 6—21 ½% Eagle—20% char									
	Single chars									
544	14.8	46.4	7.2	44.9	62.6	64.1	85.9	70.7	5.0	.816
546	23.8	48.1	5.1	43.6	63.4	69.9	87.7	72.2	4.8	.826
Av. 6 runs	Range 14.8 to 23.8	46.9	5.7	44.5	62.5	66.4	87.0	70.5	4.7	.799
	Mixed chars									
562	50%–14.7 50%–23.0	46.8	5.7	42.4	60.7	60.9	87.6	72.5	4.7	.809
585	50%–16.6 50%–22.9	47.7	7.4	42.8	63.4	63.7	82.9	72.1	4.2	.802
	80% Eagle—20% char									
	Single chars									
545	14.8	47.4	swelled	50.6	70.3	61.5	82.7	69.1	3.2	.904
547	23.8	48.6	"	50.7	68.6	67.3	86.7	72.7	3.5	.972
Av. 4 runs	Range 14.8 to 23.8	47.9	"	48.4	70.3	61.2	84.1	71.2	3.4	.951
	Mixed chars									
548	50%–14.8 50%–23.8	48.2	"	51.2	69.3	57.9	84.0	72.3	3.2	.914
563	50%–14.7 50%–23.0	48.2	"	44.7	68.6	53.5	82.3	72.4	3.0	.930

The maximum fluidity of a blend containing borderline coking coals may be correlated with coke breeze production (Reed et al., 1952). The blends in table 6 follow this trend. Decrease in the maximum Gieseler fluidity is accompanied by increase in coke fines and lowered resistance to abrasion (indicated by the tumbler hardness factor). Figure 5, in which coke breeze (−½-inch size) is plotted against Gieseler fluidity, shows the critical fluidity to be about 5 or 6 dial divisions per minute. Any blend of these coals with a lower fluidity produces excessive breeze.

We concluded that Illinois No. 5 coal from Saline County blended with 20 percent char produces coke having satisfactory physical properties. Illinois No. 6 coal from Franklin County cannot be blended satisfactorily with this amount of char, however, unless Eastern coal of high fluidity has been added to the blend to increase the Gieseler value above the critical point.

Varying the Percentage of Char

Although 20 percent char was used in all blends shown in table 6, it is not necessarily the optimum amount for any specific coal blend. However, it is in the proper range to show trends and is near the maximum that may be used advantageously in any blend with which we have had experience. Generally speaking, an increase in the percentage of char causes the coke to be lighter in weight and to have a structure with less resistance to abrasion (lower tumbler hardness factor). Gieseler fluidity is usually reduced, and if it falls into the critical range (fig. 5), other changes in coke size and strength may be noted.

Three series of tests in which the percentage of char is varied are shown in table 7. Each blend responds differently. In the blend with Eagle coal, 25 percent char is probably near the optimum amount, and 30 percent is excessive. The blend with No. 6 and Eagle coals showed little change when char was increased from 15 to 20 percent, whereas the same increase in blends with No. 6 coal alone is definitely undesirable.

We cannot, on the basis of these results, generalize too freely, but it is evident that to obtain the best coke each blend of coal and char will require individual study. Such study is even more critical for coal-char blends than for blends of high- and low-volatile coal.

Variations in Char Retort Operation

EFFECT OF FASTER HEATING

Increasing the rate of coking in ovens of standard design improves the coke produced from borderline coals. Similarly, the fast heating rate in the vibrating char retort tends to produce a more agglomerated char than does the slower rate in retorts of the rotary-drum type. It has been thought that greater agglomeration may improve the char for use in metallurgical coke.

All our char has been made at a relatively fast rate, but we decided to reduce the retention time to about one-half normal (with a compensating increase in retort temperature) to determine whether the char could be improved. Table 8 shows coking tests on this char compared with char made at the normal rate. There is no appreciable difference in the effect of these chars on coke properties. It will be shown later, however, that charring this coal in a rotary drum with a retention time of about 2 hours produces a product with somewhat different characteristics.

EFFECT OF COAL OXIDATION TEMPERATURE

There is a theory that predrying and preoxidation of coal before it is charred is detrimental to the properties of the char. Although a certain amount of oxidation is required before Illinois coal can be charred in

Table 6.—High-Volatile Coals vs. Coke Properties

Coal Blend*			Coke						
	Bulk density	Maximum fluidity	Tumbler		Shatter		Sizing		Appar. gravity
			Stability	Hardness	+2″	+1½″	+2″	−½″	
80% Eagle 20% Char	47.9	swelled	48.4	70.3	61.2	84.1	71.2	3.4	.951
40% Ill. No. 6 40% Eagle 20% Char	47.7	54	43.8	62.4	67.4	87.3	76.1	3.7	.845
80% Ill. No. 5 20% Char	43.8	10.1	46.7	62.7	60.1	86.5	71.5	4.3	.764
58½% Ill. No. 6 21½% Eagle 20% Char	46.9	5.7	44.5	62.5	66.4	87.0	70.5	4.7	.799
58½% Ill. No. 6 21½% Ill. No. 5 20% Char	47.8	4.0	40.3	57.5	66.7	86.5	72.7	7.3	.781
80% Ill. No. 6 20% Char	41.9	1.5	39.6	54.3	66.5	87.1	73.0	8.5	.708

* Data for each blend are the average of from 2 to 7 separate coke runs.

TABLE 7.—PERCENTAGE OF CHAR VS. COKE PROPERTIES

Coal Blend			Coke						
	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
80% Eagle 20% Char	47.9	swelled	48.4	70.3	61.2	84.1	71.2	3.4	.951
75% Eagle 25% Char	45.1	2728	47.6	62.8	61.8	85.4	74.6	3.1	.865
70% Eagle 30% Char	43.2	2778	42.7	57.4	69.6	88.4	71.4	3.5	.811
62½% Ill. No. 6 22½% Eagle 15% Char	47.0	5.9	46.8	63.5	66.0	86.3	71.8	4.6	.789
58½% Ill. No. 6 21½% Eagle 20% Char	46.9	5.7	44.5	62.5	66.4	87.0	70.5	4.7	.799
85% Ill. No. 6 15% Char	42.3	1.9	44.1	59.1	60.8	86.1	71.4	7.5	.705
80% Ill. No. 6 20% Char	41.9	1.5	39.6	54.3	66.5	87.1	73.0	8.5	.708
75% Ill. No. 6 25% Char	39.2	1.2	36.5	46.2	77.6	88.0	72.2	14.2	

the vibrating retort, it was possible to vary the degree of pretreatment. Three batches of coal were oxidized in the usual manner but with retort floor temperatures held at 500° F., 600° F., and 700° F. At 700° F. there was some visible thermal decomposition, which lowered the volatile matter about 2 percent.

The oxidized coals were charred in the usual manner and the chars blended with high-volatile coals and coked. Results of the tests, shown in table 9, indicate that the different temperatures of pretreatment had no detectable effect on the quality of the coke produced.

Char Compared with Pocahontas Coal

In our experience, char in a coal blend never has been completely equivalent to Pocahontas coal. Comparisons are shown in table 10. In general, blends with char do

TABLE 8.—EFFECT OF REDUCING TIME OF RETENTION OF COAL IN THE RETORT
(Blend—58½% Ill. No. 6, 21½% Eagle, 20% char)

Run No.	Char		Blend		Coke						
	Retention time	V. M. %	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
539	Normal operation	16.6	45.7	4.0	45.2	62.4	63.1	86.8	69.8	4.8	.790
552	Approx. one-half normal	15.6	46.8	6.3	44.7	61.7	66.0	87.0	70.7	5.0	.793
553		17.8	48.4	6.7	42.8	62.4	60.5	85.1	68.0	5.0	.801

TABLE 9.—EFFECT OF RETORT TEMPERATURE DURING PERIOD OF COAL OXIDATION
(Blend—58½% Ill. No. 6, 21½% Eagle, 20% char)

Run No.	Char		Blend		Coke						
	Retort temp. (°F.) oxidizing period	V. M. %	Bulk density	Maximum fluidity	Tumbler		Shatter		Sizing		Appar. gravity
					Stability	Hardness	+2″	+1½″	+2″	−½″	
539	700	16.6	45.7	4.0	45.2	62.4	63.1	86.8	69.8	4.8	.790
549	600	16.2	47.0	4.0	44.7	62.1	64.7	86.5	72.1	4.6	.795
550	500	15.7	47.7	5.3	42.4	62.4	62.7	83.3	71.3	5.0	.807
551	500	17.1	47.5	8.5	45.6	62.4	63.1	84.5	70.5	4.5	.801

not produce coke with as high tumbler stability and hardness; an exception is the 80 percent Eagle–20 percent char blend, which consistently produced coke with an unusually high hardness factor. The coke from this blend tends to be small, but this trend is not so apparent when only Illinois high-volatile coals are used. Char generally produces more coke fines than does Pocahontas, especially when high-volatile coals of lower fluidity are used. Char tends to open the coke structure, producing a product with lower apparent gravity, the one exception again being the blend with 80 percent Eagle coal.

COMPARISON WITH CHAR RETORTS OF DIFFERENT DESIGN

Under the inherent carbonizing conditions of the vibrating retort, all chars produced from Illinois coals have had similar properties even though the range of volatile matter was wide. Regardless of minor changes in operating procedures or temperatures, the product has had a sintered structure which tended to expand and form cenospheres. Expansion of the particles has reduced the bulk density to about 26 lbs. per cu. ft. Because this char is lighter than coal, its use in blends reduces the weight of fuel that can be carbonized in a standard coke oven. Although not as much time is required to complete carbonization, the net result is a reduction in the daily capacity of a battery of ovens.

A char retort of different design might be expected to produce char inherently different in structure. For example, the Disco retort is essentially a rotary drum in which coal is heated slowly, allowing thermal decomposition to reach a state of equilibrium. The coalite plant in Japan is similar. Slow heating, which is less inducive to agglomeration and formation of cenospheres, might be expected to yield heavier char.

Distinctly different also is the method of heating in the fluidized-bed retort developed by the Bureau of Mines at Denver, Colo., for charring subbituminous coal and lignite. In this retort, retention of individual particles of coal in the fluidized bed may vary considerably, resulting in lack of uniformity of devolatilization.

These and other processes all produce char of similar volatile-matter content but different physical structure. To determine how the coking properties of these chars compare, Illinois No. 6 coal was carbonized in the Disco pilot plant at Verona, Pa., and in the fluidized-bed retort in Denver.

DISCO RETORT

Coal was charred in the Disco drum at 950° F. without pretreatment other than pulverization to minus ⅛-inch size. Seventeen to fifty percent of recycle char was added to raw coal in some batches, and raw coal alone was processed in others. The Illinois coal agglomerated fairly well with or without recycle char. The product was predominantly minus ¼-inch size; the plus ¼-inch portion, varying from 4 to 35 percent of the total weight, was greatest when only raw coal was processed. The larger char was in flat scaly pieces, probably formed from coal that had stuck to the rotating drum and broken loose later as carbonization progressed.

TABLE 10.—CHAR COMPARED WITH POCAHONTAS COAL

Run No.	Blend			Coke						
		Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
556	75% Eagle 25% Char	45.1	swelled	47.6	62.8	61.8	85.4	74.6	3.1	.865
523	75% Eagle 25% Pocahontas	51.9	"	53.5	66.4	75.3	91.5	83.6	2.7	.922
Av.	80% Eagle 20% Char	47.9	"	48.4	70.3	61.2	84.1	71.2	3.4	.951
555 567	80% Eagle 20% Pocahontas	51.4	"	53.7	65.2	77.9	92.2	84.8	2.6	.907
471	70% Hernshaw 30% Char	44.8	1667	35.7	58.6	61.4	84.3	72.3	3.9	.859
472	70% Hernshaw 30% Pocahontas	51.2	6000	39.4	63.9	66.8	87.7	77.3	3.1	.988
Av.	58½% Ill. No. 6 21½% Eagle 20% Char	46.9	5.7	44.5	62.5	66.4	87.0	70.5	4.7	.799
554 566	58½% Ill. No. 6 21½% Eagle 20% Pocahontas	51.4	13.7	49.2	65.7	70.6	89.5	80.9	3.2	.845
Av.	80% Ill. No. 5 20% Char	43.8	10.1	46.7	62.7	60.1	86.5	71.5	4.3	.764
376	80% Ill. No. 5 20% Pocahontas	50.5	7.5	49.9	66.4	66.0	87.1	71.1	3.0	.828
Av.	80% Ill. No. 6 20% Char	41.9	1.5	39.6	54.3	66.5	87.1	73.0	8.5	.708
388 438	80% Ill. No. 6 20% Pocahontas	50.6	2.1	47.4	66.4	65.7	86.5	76.9	4.0	.798

The Disco char was different in appearance from that made in the vibrating retort. The coal appeared to have fused, and total surface area was low, but the particles had not expanded appreciably and there was no indication of a cenosphere structure. The Disco char weighed 36 to 37 pounds per cu. ft. as compared with 26 to 27 pounds for the vibrating-retort char. When char was used as 20 percent of a coal blend, the bulk density of the oven charge was only about one pound per cu. ft. less than that of a similar blend of high- and low-volatile coals. Oven battery capacity would not be decreased appreciably by its use.

Results of coking tests on the Disco char are shown in table 11. The coke is relatively heavy, presumably owing to the bulk density of the oven charge. Coke strength appears to be slightly lower than when our regular char was used, but the resistance to abrasion, shown by the hardness factor, is consistently high, equal to that of similar blends with Pocahontas coal. The coke has a tendency to be small, but the percentage of fines is relatively low. There appears to be no difference in chars made from 100 percent raw coal and those from coal and recycle char.

In this series of tests, we have our first good indication of the lower limit of char volatile matter for satisfactory use in blends. The char in run 571 (table 11) was produced at 1050° F. and contained only 12

TABLE 11.—BLENDS WITH DISCO (ROTARY-DRUM) CHAR
CHAR FROM ILLINOIS NO. 6 COAL
(Blend—58½% Ill. No. 6, 21½% Eagle, 20% char)

Run No.	Char			Blend		Coke						
	Identifying batch	V. M. %	Bulk density	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2"	Shatter +1½"	Sizing +2"	Sizing −½"	Appar. gravity
568	7 and 8 no recycle	15.2	37.0	49.9	5.8	40.9	65.3	60.1	84.6	65.7	3.9	.849
569	2 and 3 50% and 23% recycle	14.9	36.0	49.4	5.0	42.3	65.3	56.6	82.6	64.7	3.8	.827
587	4 and 5 23% recycle	15.2		49.9	6.1	38.7	65.4	60.3	82.5	72.4	4.3	.837
571	9 and 10 no recycle	12.0	37.5	50.3	4.9	35.0	65.5	48.2	75.7	55.6	4.4	.854

percent volatile matter. Coking results are poor compared with those of other blends where the chars contained about 15 percent volatile matter. While not conclusive, results indicate that the lower volatile-matter limit falls between 12 and 15 percent.

FLUIDIZED-BED RETORT (DENVER)

Illinois coal sent to the Bureau of Mines Experiment Station at Denver, Colo., was pulverized to minus 1/16-inch size. It was then flash-dried and preoxidized at about 300° F. where the free-swelling index was reduced from a No. 3½ to a No. 2 button. The hot, dry coal was carried directly into the fluidized-bed retort, which was held at a temperature of 940° F. A superficial velocity of 6 to 8 feet per second was maintained in the retort by using air as the fluidizing agent. Char of 16.5 percent volatile matter was obtained. Other batches with a volatile matter range from 18.5 to 22 percent were made by reducing the retort temperature to 875° F. and carbonizing at a somewhat lower superficial velocity, using process gas and a small quantity of air for fluidizing.

The initial char produced at 940° F. expanded into an exceedingly light-weight material with a bulk density of only 18.5 pounds per cu. ft. Total surface area of

TABLE 12.—BLENDS WITH DENVER (FLUIDIZED-BED) CHAR
CHAR FROM ILLINOIS NO. 6
(Blend—58½% Ill. No. 6, 21½% Eagle, 20% char)

Run No.	Char			Blend		Coke						
	Identifying batch	V. M. %	Bulk density	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2"	Shatter +1½"	Sizing +2"	Sizing −½"	Appar. gravity
572	1 and 2 Retort temp. 940° F.	16.5	18.5	39.4	5.9	41.0	54.7	74.6	90.8	75.2	6.5	.662
573	3 Retort temp. 875° F.	18.6	27.0	46.5	5.3	44.0	62.6	69.1	87.5	71.2	4.3	.779
588	4 Retort temp. 875° F.	18.5	27.0	48.5	5.9	42.1	63.1	70.9	86.5	70.4	5.1	.876

TABLE 13.—COMPARISON OF CHARS FROM DIFFERENT RETORTS

Char			Blend		Coke						
Origin	V.M. %	Bulk density	Bulk density	Maximum fluidity	Tumbler Stability	Tumbler Hardness	Shatter +2″	Shatter +1½″	Sizing +2″	Sizing −½″	Appar. gravity
Blend 1*—58½% Ill. No. 6, 21½% Eagle, 20% char											
Vibrating retort	18.8	27	46.9	5.7	44.5	62.5	66.4	87.0	70.5	4.7	.799
Fluidized-bed retort	18.6	27	47.5	5.6	43.1	62.9	70.0	87.0	70.8	4.7	.828
Rotary-drum retort	15.0	36.5	49.8	5.6	40.6	65.3	59.0	83.2	67.6	4.0	.838
Blend 2—80% Eagle, 20% char											
Vibrating retort	14.8	27	47.4	swelled	50.6	70.3	61.5	82.7	69.1	3.2	.904
Fluidized-bed retort (batch 1 and 2)	16.5	18.5	39.3	3845	48.4	62.2	71.2	89.8	72.7	3.3	.768
Rotary-drum retort (batch 6–17% recycle)	15.0	36.5	49.7	3750	44.9	70.5	55.6	82.4	63.8	2.8	.938

* All values are averages of two or more runs.

12.76 square meters per gram was greater than that of the original coal. When pulverized as usual and carbonized in metallurgical coke blends, the mixtures of coal and char weighed less than 40 pounds per cu. ft., and the cokes produced were light in weight. A low hardness factor indicated an abraidable coke structure (table 12, run 572).

Char produced at 875° F. was similar in structure and appearance to that made in the vibrating retort. It weighed about 27 pounds per cu. ft. and had a total surface area of 2.67 square meters per gram. Coking tests with Illinois No. 6 and Eagle coals indicated that the properties of the coke produced also are similar to those obtained with char from the vibrating retort (table 12, runs 573 and 588).

COMPARISON OF CHARS FROM THE THREE RETORTS

Chars made from Illinois No. 6 coal in the Illinois vibrating retort, the Disco rotary retort, and the Bureau of Mines fluidized-bed retort are compared in table 13. Each char has been blended with the same coals and coked under identical conditions.

The most notable difference among the three chars is the greater weight of the Disco. Chars made in the other two retorts are similar in bulk density, both being produced under conditions of fast heating, whereas the Disco char was devolatilized at a much slower rate. Bulk density of the coal bed with Disco char is increased proportionally and a heavier coke is produced.

In this comparison, as well as in others not shown in the table, the coke containing Disco char has the highest hardness index and contains the least amount of fines. The size stability, however, appears to be slightly lower than that of the other cokes. Chars from the vibrating-bed and fluidized-bed retorts are shown to produce cokes having similar properties throughout.

As the Disco char was all relatively low in volatile matter (15 percent), it did not compare exactly with the other two chars. In our experience, however, the volatile matter of this char is in the range which gives coking results comparable to that of chars of 18 percent or more volatile matter.

REFERENCES

BRUNAUER, STEPHEN, et al., 1938, Adsorption of gases in multimolecular layers: Jour. Am. Chem. Soc., v. 60, p. 309-319.

CARTER, G. W., 1947, Coal Logs process for coal carbonization: Chem. Eng. Progress, Trans. Section, v. 43, no. 4, p. 180-182.

CHERADAME, R., 1954, Studies in coke formation: Coke and Gas, v. 16, no. 179, p. 143-149.

FIELDNER, A. C., 1950, Coal for coke production: U. S. Bur. Mines Inf. Circ. 7559.

HISADA, K., 1951, Coke making from Hokkaido coal for blast furnaces: Japan Sci. Rev., v. 2, no. 1.

LESHER, C. E., 1941, Disco, a smokeless fuel: Ind. Eng. Chem., v. 33, p. 858.

MINCHIN, L. T., 1953, Coke from weakly-coking coals: Coke and Gas, v. 15, no. 168, p. 167-171.

PRICE, J. D., and WOODY, G. V., 1944, Production and use of low-temperature char as a substitute for low-volatile coal in the production of high-temperature coke: A.I.M.E. Tech. Pub. 1745 (Class F, Coal Division, No. 155).

REED, F. H., 1948, Some observations on coking practice in Germany: U. S. Bur. Mines Inf. Circ. 7462.

REED, F. H., et al., 1947, Use of Illinois coal for production of metallurgical coke: Illinois Geol. Survey Bull. 71.

REED, F. H., et al., 1952, Some observations on the blending of coals for metallurgical coke: Blast Furnace and Steel Plant, v. 40, no. 3, p. 305-311, 344; reprinted as Illinois Geol. Survey Circ. 178.

REID, W. T., 1948, Low-temperature carbonization of coal in Japan: U. S. Bur. Mines Inf. Circ. 7430.

SINGH, A. D., 1946, Partial devolatilization of coal by the fluidization process: Am. Gas Assoc. Proc., v. 28, p. 400-409.

THOMPSON, J. H., 1946, Beneficiation of blast furnace coke at the Kaiser Steel Co., Fontana, California: Blast Furnace and Steel Plant, v. 34, nos. 2-5.

UTAH Conservation and Research Foundation, 1939, Low-temperature carbonization of Utah coals (a report to the Governor).

WOODY, G. V., 1941, Production of coke as a domestic fuel: Ind. Eng. Chem., v. 33, p. 841.

APPENDIX

CHEMICAL ANALYSES OF COALS AND CARBONIZATION PRODUCTS

TABLE A.—REPRESENTATIVE ANALYSES OF COALS USED IN PRODUCTION OF CHARS AND FOR BLENDING

Coal	M.	Moisture-free basis				F.S.I.	Gieseler fluidity
		V.M.	F.C.	Ash	Sulfur		
Illinois No. 6	8.5	37.8	54.4	7.8	0.90	4	8
Illinois No. 5	7.0	37.5	55.0	7.5	1.75	5½	50
Illinois No. 2	17.4	39.5	54.8	5.7	2.35	2	4
Hernshaw	2.0	37.3	56.0	6.7	0.75	—	30,000
Eagle	3.5	30.0	63.0	7.0	0.75	7½	9,000
Pocahontas No. 3	3.5	17.0	76.2	6.8	0.65	9	10

TABLE B.—EFFECT OF OXIDATION AND CHARRING ON ULTIMATE ANALYSIS OF NO. 6 COAL

	Moisture and ash-free basis				
	H	C	N	O	S
Air dried coal	5.28	81.51	2.05	10.13	1.03
Oxidized at 700° F.	5.08	81.85	1.90	10.16	1.01
Charred at 860° F. (V.M. = 25.5%)	4.46	83.29	1.99	9.38	0.88
Charred at 1100° F. (V.M. = 14.6%)	3.38	86.96	2.17	6.59	0.90

TABLE C.—ANALYTICAL DATA FOR EXPERIMENTAL COKE RUNS SHOWN IN TABLE 3

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	80% Eagle 20% char					
545	Char	1.7	14.8	75.9	9.3	0.76
	Blend	1.6	27.3	65.0	7.7	0.80
	Coke		0.7	89.4	9.9	0.64
521	Char	0.7	18.9	71.4	9.7	0.95
	Blend	1.4	27.8	64.4	7.8	0.81
	Coke		0.7	89.5	9.8	0.66
522	Char	0.8	19.2	71.2	9.6	0.95
	Blend	1.1	28.2	64.3	7.5	0.80
	Coke		0.7	89.4	9.9	0.64
547	Char	1.3	23.8	67.9	8.3	0.81
	Blend	1.8	29.1	63.5	7.4	0.83
	Coke		0.4	89.7	9.9	0.70
	58½% Ill. No. 6 21½% Eagle 20% char					
544	Char	1.7	14.8	75.9	9.3	0.76
	Blend	5.4	30.5	61.7	7.8	0.81
	Coke		1.0	88.3	10.7	0.57
539	Char	1.1	16.6	73.3	10.1	0.84
	Blend	5.9	30.9	60.7	8.4	0.83
	Coke		0.7	87.5	11.8	0.81
541	Char	1.1	18.5	72.2	9.3	0.84
	Blend	5.4	31.5	60.1	8.4	0.91
	Coke		0.8	87.7	11.5	0.71
526	Char	1.0	18.7	73.1	8.2	0.88
	Blend	5.1	31.8	60.5	7.7	0.86
	Coke		1.0	88.4	10.6	0.68
524	Char	0.5	20.3	70.9	8.8	
	Blend	5.1	32.1	60.6	7.3	0.94
	Coke		0.9	89.0	10.1	0.77
546	Char	1.3	23.8	67.9	8.3	0.81
	Blend	5.2	32.3	60.2	7.5	0.79
	Coke		0.8	88.7	10.5	0.74
	58½ Ill. No. 6 21½% Ill. No. 5 20% char					
514	Char	1.1	16.1	74.2	9.7	0.78
	Blend	6.4	32.9	58.6	8.5	1.20
	Coke		1.0	87.1	11.9	0.96
513	Char	1.3	17.0	74.0	9.0	0.76
	Blend	5.9	32.7	58.7	8.6	1.12
	Coke		1.0	87.2	11.8	0.93
511	Char	1.4	17.5	72.6	9.9	0.77
	Blend	6.8	33.1	57.9	9.0	1.14
	Coke		1.2	86.1	12.7	0.96

Table C.—(concluded)

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
516	Char	0.7	18.1	72.7	9.2	0.76
	Blend	6.2	33.0	58.9	8.1	1.17
	Coke		1.0	87.4	11.6	0.91
520	Char	0.6	20.5	70.3	9.2	0.81
	Blend	5.5	34.2	57.0	8.8	1.16
	Coke		1.0	86.3	12.7	0.92
505	Char	1.3	22.0	68.6	9.4	0.73
	Blend	6.6	34.4	56.9	8.7	1.29
	Coke		1.1	86.5	12.4	0.99
504	Char	1.2	22.9	68.5	8.6	0.72
	Blend	7.1	34.3	57.4	8.3	1.16
	Coke		1.0	87.0	12.0	0.94
	80% Ill. No. 5 20% Char					
459	Char	0.4	17.3			
	Blend	5.1	32.8	57.8	9.4	1.99
	Coke		1.0	86.8	12.2	1.57
463	Char	0.8	17.8			
	Blend	5.3	33.4	58.1	8.5	1.93
	Coke		1.3	87.4	11.3	1.50
460	Char	0.6	17.9			
	Blend	4.5	33.3			
	Coke		0.9			
461	Char	0.6	18.4			
	Blend	4.9	33.4	57.8	8.8	
	Coke		1.8	86.3	11.9	1.64
462	Char	0.6	18.4			
	Blend	4.0	33.3	57.3	9.4	2.30
	Coke		1.3	86.0	12.7	1.88
464	Char	0.6	18.5			
	Blend	4.8	32.9	57.6	9.5	1.97
	Coke		1.1			
468	Char	0.8	20.6	70.1	9.3	0.85
	Blend	4.8	33.2	58.3	8.5	1.63
	Coke		1.4	87.3	11.3	1.30
	80% Ill. No. 6 20% char					
455	Char	0.6	16.7	77.3	6.0	1.82
	Blend	6.7	33.4	60.1	6.5	1.04
	Coke		1.3	89.5	9.2	0.94
465	Char	0.6	18.4			
	Blend	6.1	33.3	57.5	9.2	1.27
	Coke		1.1	86.7	12.2	1.04
467	Char	0.8	20.6	70.1	9.3	0.85
	Blend	6.4	33.8	58.1	8.1	0.81
	Coke		1.5	87.9	10.6	0.70
451	Char	1.5	24.8	67.8	7.4	2.58
	Blend	6.8	34.7	57.9	7.4	1.13
	Coke		1.3	88.0	10.7	0.93

TABLE D.—ANALYTICAL DATA FOR EXPERIMENTAL COKE RUNS SHOWN IN TABLE 4

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% char					
546	Char	1.3	23.8	67.9	8.3	0.81
	Blend	5.2	32.3	60.2	7.5	0.79
	Coke		0.8	88.7	10.5	0.74
526	Char	1.0	18.7	73.1	8.2	0.88
	Blend	5.1	31.8	60.5	7.7	0.86
	Coke		1.0	88.4	10.6	0.68
544	Char	1.7	14.8	75.9	9.3	0.76
	Blend	5.4	30.5	61.7	7.8	0.81
	Coke		1.0	88.3	10.7	0.57
586	Breeze	1.0	1.2	88.0	10.8	0.70
	Blend	5.2	26.3	65.2	8.5	0.90
	Coke		0.7	88.2	11.1	0.72
568	Disco char	1.2	14.9	76.3	8.8	0.67
	Blend	5.2	30.6	61.7	7.7	0.86
	Coke		0.7	89.0	10.3	0.66
571	Disco char	1.4	12.0	78.3	9.7	0.62
	Blend	5.3	30.7	61.9	7.4	0.80
	Coke		0.7	89.5	9.8	0.67

Table E.—Analytical Data for Experimental Coke Runs Shown in Table 5

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% char					
544	Char	1.7	14.8	75.9	9.3	0.76
	Blend	5.4	30.5	61.7	7.8	0.81
	Coke		1.0	88.3	10.7	0.57
546	Char	1.3	23.8	67.9	8.3	0.81
	Blend	5.2	32.3	60.2	7.5	0.79
	Coke		0.8	88.7	10.5	0.74
Av. 6 runs	Char		14.8–23.8			
	Blend	5.4	31.5	60.6	7.9	0.86
	Coke		0.9	88.2	10.9	0.71
562	50% of char	0.8	14.7	75.8	9.5	0.75
	50% of char	0.6	23.0	68.3	8.7	0.72
	Blend	5.6	31.3	61.0	7.7	0.79
	Coke		1.4	87.5	11.1	0.62
585	50% of char		16.6			
	50% of char		22.9			
	Blend	5.6	31.5	60.2	8.3	0.91
	Coke		0.7	87.9	11.4	0.73
	80% Eagle 20% char					
545	Char	1.7	14.8	75.9	9.3	0.76
	Blend	1.6	27.3	65.0	7.7	0.80
	Coke		0.7	89.4	9.9	0.64
547	Char	1.3	23.8	67.9	8.3	0.81
	Blend	1.8	29.1	63.5	7.4	0.83
	Coke		0.4	89.7	9.9	0.70
Av. 4 runs	Char		14.8–23.8			
	Blend	1.5	28.1	64.3	7.6	0.82
	Coke		0.6	89.5	9.9	0.66
548	50% of char	1.7	14.8	75.9	9.3	0.76
	50% of char	1.3	23.8	67.9	8.3	0.81
	Blend	1.4	28.0	64.4	7.6	0.85
	Coke		0.6	89.4	10.0	0.69
563	50% of char	0.8	14.7	75.8	9.5	0.75
	50% of char	0.6	23.0	68.3	8.7	0.72
	Blend	1.4	28.0	63.9	8.1	0.73
	Coke		0.4	89.3	10.3	0.60

Table F.—Analytical Data for Experimental Coke Runs Shown in Table 6

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	80% Eagle 20% char					
Av. 4 runs	Char	1.1	19.2	71.6	9.2	0.87
	Blend	1.5	28.1	64.3	7.6	0.82
	Coke		0.6	89.5	9.9	0.66
	40% Ill. No. 6 40% Eagle 20% char					
Av. 2 runs	Char	0.4	19.1	72.3	8.6	
	Blend	3.9	31.2	61.3	7.5	0.85
	Coke		0.7	89.1	10.2	0.72
	80% Ill. No. 5 20% char					
Av. 7 runs	Char	0.6	18.4			
	Blend	4.8	33.2	57.8	9.0	1.96
	Coke		1.3	86.8	11.9	1.58
	58½% Ill. No. 6 21½% Eagle 20% char					
Av. 6 runs	Char	1.1	18.8	72.2	9.0	0.83
	Blend	5.4	31.5	60.6	7.9	0.86
	Coke		0.9	88.2	10.9	0.71
	58½% Ill. No. 6 21½% Ill. No. 5 20% char					
Av. 7 runs	Char	1.1	19.2	71.5	9.3	0.76
	Blend	6.4	33.5	57.9	8.6	1.18
	Coke		1.0	86.8	12.2	0.94
	80% Ill. No. 6 20% char					
Av. 4 runs	Char	0.9	20.1	72.2	7.7	1.75
	Blend	6.5	33.8	58.4	7.8	1.06
	Coke		1.3	88.0	10.7	0.90

Table G.—Analytical Data for Experimental Coke Runs Shown in Table 7

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
Av. 4 runs	80% Eagle 20% char					
	Char	1.1	19.2	71.6	9.2	0.87
	Blend	1.5	28.1	64.3	7.6	0.82
	Coke		0.6	89.5	9.9	0.66
556	75% Eagle 25% char					
	Char	0.9	17.4	73.8	8.8	0.66
	Blend	1.8	27.1	65.7	7.2	0.77
	Coke		0.5	89.9	9.6	0.65
557	70% Eagle 30% char					
	Char	0.9	17.4	73.8	8.8	0.66
	Blend	1.9	27.0	65.8	7.2	0.71
	Coke		0.5	90.2	9.3	0.61
558	62½% Ill. No. 6 22½% Eagle 15% char					
	Char	0.9	17.4	73.8	8.8	0.66
	Blend	5.6	31.5	60.8	7.7	0.81
	Coke		0.7	88.8	10.5	0.66
Av. 6 runs	58½% Ill. No. 6 21½% Eagle 20% char					
	Char	1.1	18.8	72.2	9.0	0.83
	Blend	5.4	31.5	60.6	7.9	0.86
	Coke		0.9	88.2	10.9	0.71
456	85% Ill. No. 6 15% char					
	Char	1.3	19.7	74.7	5.6	1.82
	Blend	6.5	34.6	58.3	7.1	0.94
	Coke		1.2	89.1	9.7	0.87
Av. 4 runs	80% Ill. No. 6 20% char					
	Char	0.9	20.1	72.2	7.7	1.75
	Blend	6.5	33.8	58.4	7.8	1.06
	Coke		1.3	88.0	10.7	0.90
457	75% Ill. No. 6 25% char					
	Char	1.3	19.7	74.7	5.6	1.82
	Blend	5.9	33.0	60.0	7.0	1.03
	Coke (Not analyzed)					

Table H.—Analytical Data for Experimental Coke Runs Shown in Table 8

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% char					
539	Char	1.1	16.6	73.3	10.1	0.84
	Blend	5.9	30.9	60.7	8.4	0.83
	Coke		0.7	87.5	11.8	0.81
552	Char	1.2	15.6	75.4	9.0	0.79
	Blend	5.4	31.5	61.2	7.3	0.90
	Coke		1.3	88.6	10.1	0.66
553	Char	1.1	17.8	72.8	9.4	0.74
	Blend	5.2	32.1	60.7	7.2	0.87
	Coke		0.7	89.0	10.3	0.70

Table I.—Analytical Data for Experimental Coke Runs Shown in Table 9

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% char					
539	Char	1.1	16.6	73.3	10.1	0.84
	Blend	5.9	30.9	60.7	8.4	0.83
	Coke		0.7	87.5	11.8	0.81
549	Char	1.7	16.2	74.6	9.2	0.79
	Blend	5.4	31.6	61.2	7.2	0.82
	Coke		0.8	88.8	10.4	0.75
550	Char	1.5	15.7	74.7	9.6	0.83
	Blend	5.1	31.0	61.3	7.7	0.90
	Coke		1.0	88.4	10.6	0.72
551	Char	1.5	17.1	73.8	9.1	0.80
	Blend	5.5	31.6	60.5	7.9	0.91
	Coke		0.8	88.1	11.1	0.70

TABLE J.—ANALYTICAL DATA FOR EXPERIMENTAL COKE RUNS SHOWN IN TABLE 10

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
556	75% Eagle 25% char Blend	1.8	27.1	65.7	7.2	0.77
	Coke		0.5	89.9	9.6	0.65
523	75% Eagle 25% Pocahontas Blend	1.5	27.5	65.4	7.1	0.70
	Coke		0.6	90.3	9.1	0.63
Av. 4 runs	80% Eagle 20% char Blend	1.5	28.1	64.3	7.6	0.82
	Coke		0.6	89.5	9.9	0.66
555 567	80% Eagle 20% Pocahontas Blend	1.5	27.5	65.5	7.0	0.74
	Coke		0.5	90.2	9.3	0.63
471	70% Hernshaw 30% char Blend	1.0	30.9	61.5	7.6	1.20
	Coke		0.6	90.0	9.4	1.04
472	70% Hernshaw 30% Pocahontas Blend	1.1	31.6	61.9	6.5	0.70
	Coke		0.7	92.0	7.3	0.62
Av. 6 runs	58½% Ill. No. 6 21½% Eagle 20% char Blend	5.4	31.5	60.6	7.9	0.86
	Coke		0.9	88.2	10.9	0.71
554 566	58½% Ill. No. 6 21½% Eagle 20% Pocahontas Blend	5.3	31.5	61.4	7.1	0.80
	Coke		0.7	89.5	9.8	0.62
Av. 7 runs	80% Ill. No. 5 20% char Blend	4.8	33.2	57.8	9.0	1.96
	Coke		1.3	86.8	11.9	1.58
376	80% Ill. No. 5 20% Pocahontas Blend	5.0	34.4	58.2	7.4	1.86
	Coke		1.4	88.1	10.5	1.41
Av. 4 runs	80% Ill. No. 6 20% char Blend	6.5	33.8	58.4	7.8	1.06
	Coke		1.3	88.0	10.7	0.90
388 438	80% Ill. No. 6 20% Pocahontas Blend	6.9	34.1	58.7	7.2	0.80
	Coke		1.3	88.6	10.1	0.63

Table K.—Disco Pilot Plant Chars*
(Ill. No. 6 Coal)

Batch No.	Composition	Retort temp. (°F.)	Product		Analyses		
			%-¼″	%+¼″	V.M.	F.C.	Ash
1	100% oxidized coal (for recycling)	950	100		14.9	77.0	8.1
2	50% raw coal	950	92.0		15.1	75.4	9.5
	50% recycle			8.0	14.7	79.3	6.0
3	77% raw coal	950	91.3		14.8	76.2	9.0
	23% recycle			8.7	13.3	80.2	6.5
4	77% raw coal	950	95.7		15.4	74.9	9.7
	23% recycle			4.3	13.8	80.0	6.2
5	77% raw coal	950	87.4		15.1	75.5	9.4
	23% recycle			12.6	14.2	79.1	6.7
6	83% raw coal	950	79.5		15.1	75.8	9.1
	17% recycle			20.5	14.7	78.2	7.1
7	100% raw coal	950	67.6		14.9	75.0	10.1
				32.4	14.7	77.8	7.5
8	100% raw coal	950	64.5		14.5	75.2	10.3
				35.5	15.7	76.8	7.5
9	100% raw coal	1050	79.2		11.6	78.5	9.9
				20.8	11.8	80.5	7.7
10	100% raw coal	1050	73.5		10.8	78.2	11.0
				26.5	11.4	80.7	7.9

* As originally sampled upon receipt of char.

Table L.—Analytical Data for Experimental Coke Runs Shown in Table 11

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% Disco char					
568	Disco char (batch 7–8)*	1.2	14.9	76.3	8.8	0.67
	Blend	5.2	30.6	61.7	7.7	0.86
	Coke		0.7	89.0	10.3	0.66
569	Disco char (batch 2–3)*	1.2	15.8	75.0	9.2	0.70
	Blend	5.6	31.4	61.2	7.4	0.78
	Coke		0.8	88.8	10.4	0.65
587	Disco char (batch 4–5)*	1.8	(15.2)†	(75.4)†	9.4	0.67
	Blend	5.4	29.3	62.4	8.3	0.90
	Coke		1.0	88.1	10.9	0.75
571	Disco char (batch 9–10)*	1.4	12.0	78.3	9.7	0.62
	Blend	5.3	30.7	61.9	7.4	0.80
	Coke		0.7	89.5	9.8	0.67

* As sampled for individual coking tests.
† Computed from original samples.

Table M.—Chars from Denver Fluidized-Bed Retort*
(Ill. No. 6 Coal)

Identifying batch no.	Temp. of carbonization	M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
1—Total char	940° F.	0.7	16.7			
2—Total char	940° F.	0.6	16.2			
Minus 48 mesh		0.7	18.5			
3—Total char	875° F.	0.5	18.7	71.4	9.9	0.73
Minus 48 mesh		0.8	21.3			
4—Total char	875° F.	0.5	18.5			
Minus 48 mesh		0.5	21.2			
5—Total char	875° F.	0.6	22.2			
Minus 48 mesh		0.7	23.7			

* As originally sampled upon receipt of char.

Table N.—Analytical Data for Experimental Coke Runs Shown in Table 12

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% Denver char					
572	Denver char (batch 1–2)*	1.0	16.5	74.0	9.5	0.82
	Blend	5.1	31.0	60.1	8.9	1.03
	Coke		1.3	86.3	12.4	0.86
573	Denver char (batch 3)*	0.5	18.7	71.4	9.9	0.73
	Blend	4.9	31.6	59.8	8.6	1.01
	Coke		0.8	87.2	12.0	0.80
588	Denver char (batch 4)*	1.4	19.2	73.2	7.6	0.71
	Blend	5.1	30.5	61.3	8.2	0.92
	Coke		0.8	88.7	10.5	0.74

* As sampled for individual coking tests.

Table O.—Analytical Data for Experimental Coke Runs Shown in Table 13

Run No.		M.	Moisture-free basis			
			V.M.	F.C.	Ash	Sulfur
	58½% Ill. No. 6 21½% Eagle 20% char					
Av. 6 runs	Char (vibrating retort)	1.1	18.8	72.2	9.0	0.83
	Blend	5.4	31.5	60.6	7.9	0.86
	Coke		0.9	88.2	10.9	0.71
573 588	Char (fluidized bed)	1.0	19.0	72.3	8.7	0.72
	Blend	5.0	31.1	60.5	8.4	0.97
	Coke		0.8	88.0	11.2	0.77
568 569 587	Char (rotary drum)	1.4	15.3	75.6	9.1	0.68
	Blend	5.4	30.4	61.8	7.8	0.85
	Coke		0.8	88.6	10.5	0.69
	80% Eagle 20% char					
545	Char (vibrating retort)	1.7	14.8	75.9	9.3	0.76
	Blend	1.6	27.3	65.0	7.7	0.80
	Coke		0.7	89.4	9.9	0.64
576	Char (fluidized bed)	1.0	16.5	74.0	9.5	0.82
	Blend	1.8	28.1	64.7	7.2	0.71
	Coke		0.7	89.7	9.6	0.62
577	Char (rotary drum)	0.9	15.0	76.3	8.7	
	Blend	1.8	26.1	66.5	7.4	0.70
	Coke		0.6	90.1	9.3	0.60

Illinois State Geological Survey, Report of Investigations 187
38 p., 5 figs., 13 tables, 1955