INSTITUTE OF GAS TECHNOLOGY
IIT CENTER
CHICAGO, ILLINOIS 60616

# PREPARATION OF A COAL CONVERSION SYSTEMS TECHNICAL DATA BOOK

ERDA Contract No. E(49-18)-1730
Report No. 6
April 1975

Project 8964 Status Report

for

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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## I. Project Objective

The objective of this work is to provide a single, comprehensive source of data on coal conversion systems. This compilation shall be entitled The Coal Conversion Systems Technical Data Book and shall provide up-to-date data and information for the research, development, design, engineering, and construction of coal conversion processes and/or plants. Other concurrent objectives are to identify those areas where data are required and to suggest research programs that will provide the required data.

## II. Summary

### Liquefaction

A number of people were contacted regarding the data book project during the Pittsburgh Symposium on "Catalytic Conversion of Coal." Some data, obtained from Conoco, are being studied.

### Gasification

A method is presented for estimating the relative reactivity of coal. Some typical relative reactivities are presented for different ranks of coal.

An example is given, which demonstrates the use of the various steam-oxygen gasification charts presented in previous reports.

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Fluidization

The proposed correlation for estimating the minimum fluidization velocity for coal and related materials is presented in graphical form. Two other correlations are also evaluated; they show no improvement over the proposed correlation.

Three other correlations for estimating bed expansion were evaluated by comparison with the available data.

Combustion

Low-Temperature (Fluidized-bed)

A kinetic model is described for sulfur removal from the fluidized-bed combustors.

High-Temperature (MHD)

A meeting was arranged with Mr. Bomkamp of Argonne National Laboratory to coordinate its efforts on MHD data collection and evaluation with our plans.

Coal, Char, and Oil Shale Properties

We have received analytical and other data on 50 large coal deposits from Penn State. It is being prepared for inclusion in the coal properties compilation table.

A list of large deposits in the United States, which are capable of supplying at least 150 million tons of coal over a 20-year period, has been compiled and is presented in this report.

Additional papers on the specific heat of coal and related materials were obtained and are reviewed herein.

Notice to Readers of Open File

Any comments about the material presented in this report or suggestions about the format and the content of the data book as well as the priorities of the needed data are most welcome. Please direct any communications to Mr. Bipin Almaula of ERDA (202/634-6643) or to Dr. Al Talwalkar of the Institute of Gas Technology (312/225-9600, Ext. 869).

## III. Work Accomplished

### A. LIQUEFACTION

While attending the "Catalytic Conversion of Coal" symposium in Pittsburgh, we took the opportunity of contacting Dr. E. Donath, consultant, Mr. Willard Bull of Gulf, and personnel from Conoco in Library, Pa. Mr. Walter Lobo, our consultant on the project, accompanied us on the visit to Conoco.

Dr. Donath is not available for evaluating and correlating the coal liquefaction data for the data book, but he may be available for its review and for any consultation. We also tried to enlist the services of Dr. R. Hiteshue in correlating the liquefaction data, but he also is not available at this time.

Mr. Bull indicated that the data from the S. R. C. pilot plant will become available in 1975-76. They are trying to collect information on corrosion, heat transfer, and physical properties. He suggested that correlations between coal liquids and petroleum fractions be included in the data book.

We received some information on properties of solvents, tars, coal, and char from Conoco's data book, which includes the following items:

a. Estimated density of solvents versus temperature

b. Estimated viscosities of various cuts versus temperature

c. Extract-solvent viscosities versus temperature

d. Heat content of coal and char

e. Heat content of low-temperature tar fractions

f. Heating value of coal tar and char

g. A chart of mean specific heat versus temperature for coke

h. Latent heats and molecular weights for coal-tar fractions

i. Specific gravity of tar versus ultimate analysis.

We also received a copy of Design Criteria for Scale-Up of CSF Slurry Preheater developed by Dr. Rutledge of Conoco. This report, as well as other data received from Conoco, is being studied now.

## B. GASIFICATION

### 1. Relative Reactivity Factor for Low-Rate Gasification, $f_o$

The mathematical correlation describing the char gasification kinetics in the low-rate gasification stage, which has been presented in detail in previous monthly reports, is —

$$\frac{dx}{dt} = f_L k_T (1-X)^{2/3} \exp(-\alpha X^2) \quad (1)$$

The parameter, $f_L$, is further defined as —

$$f_L = f_o \exp(8467/T_o) \quad (2)$$

where —

- $X$ = base carbon conversion fraction
- $k_T$ = rate constant which is a function of the gasification temperature T and the gas composition
- $T_o$ = maximum temperature to which char has been exposed prior to gasification, °R (if $T_o < T$, then a value of $T_o = T$ is used)
- $f_o$ = relative reactivity factor for low-rate gasification which is a property of the particular coal.

The value of $f_o$ for different types of coals is based on the definition $f_o = 1$ for a specific batch of air-pretreated Ireland mine coal. The exponential term in Equation 2 accounts for the effect of the temperature history of the coal being gasified on the gasification reactivity.

The reactivity of a particular coal is a function of the chemical properties of its organic and mineral constituents and of the physical structure of the coal particle. It has been observed in general that the coal reactivity for gasification increases with decreasing coal rank. Efforts are under way to predict the coal gasification reactivity based on the physical and chemical properties of the particular coal.

A standard experimental procedure has been set up to determine both the rapid-rate and low-rate gasification reactivities of coal. At this time, only the procedure for the determination of low-rate gasification reactivity will be outlined.

For constant temperature, pressure, and gas composition, the rate equation (Equation 1) can be integrated with time to yield —

$$M(X) = \int_{X_o}^{X_F} \frac{\exp(\alpha X^2)}{(1-X)^{2/3}} \, dX = f_L k_T t \qquad (3)$$

where

$X_F$ = base carbon conversion fraction at final time, t

$X_o$ = base carbon conversion fraction at time t = 0, this value for devolatilized coal = 0

A plot of M(X) versus t yields a straight line with a slope of $f_L k_T$. To obtain the quantitative information needed to plot M(X) versus t, the test coal sample is gasified in an apparatus known as a thermobalance at the standard conditions — gasification with hydrogen at a temperature of 1700 °F and a pressure of 35 atm.

The thermobalance is an apparatus capable of continuously weighing a coal sample that is undergoing reaction in a gaseous environment of desired composition and at a constant pressure. The temperature can either be kept constant or varied; 10° F/min is the maximum rate for the apparatus used at IGT. A schematic of the thermobalance apparatus is shown in Figure 1. The coal sample is contained in the annular space of a wire-mesh basket bounded on the inside by a hollow, stainless-steel tube and on the outside by a wire-mesh screen. To facilitate mass and heat transfer between the bed and its environment, the thickness of the bed is only 2 to 3 particle diameters when using −20+40 U. S. sieve-size particles. Gas flow rates used with this system are sufficiently large relative to gasification rates so that gas conversion is limited to less than 1% for devolatilized coal char.

The following is a typical test procedure: The wire-mesh basket is initially in an upper, cooled portion of the reactor in which a downward, inert gas flow is maintained. During this time the desired temperature and pressure conditions are established in a lower heated portion of the reactor in the presence of a flowing gas. A test is initiated by lowering the basket into the heated reaction zone, a procedure which takes 5 to 6 seconds. Theoretical computation indicates that about 1 to 2 minutes are required for the sample to achieve reactor temperature, as measured by several thermocouples surrounding the basket in the reaction zone. This computation is reasonably

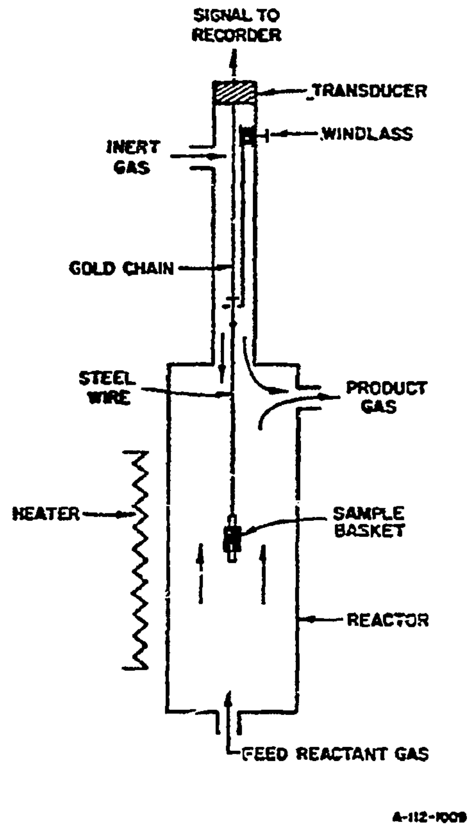



Figure 1. DIAGRAM OF THERMOBALANCE REACTOR

corroborated by various kinetic indications and by the behavior of the thermocouples in reattaining their preset temperatures. The sample is kept in the heated portion of the reactor for the specified time while its weight is continuously recorded. The test is terminated by raising the basket back to the upper, cooled portion of the reactor.

During a test, the dry feed gas flow rates are measured by an orifice meter and the dry product gas flow rates by a wet-test meter. Periodic samples of product gas are taken to determine the dry gas' composition by mass spectrography.

For determining the low-rate gasification reactivity, the coal sample is initially exposed to a nitrogen atmosphere at a temperature of 1700°F prior to exposure to a hydrogen atmosphere. During this period, the volatile matter in the coal sample is essentially removed and at the same time the tendency to undergo rapid-rate methane formation is destroyed. The resulting devolatilized coal is then exposed to hydrogen at 1700° F and 35 atm for a desired period of time during which the low-volatile carbon reacts with hydrogen.

The value of the slope of the plot of M(X) versus t for the standard Ireland mine pretreated coal can be calculated at the standard test conditions of 1700° F and a hydrogen gas pressure of 35 atm. ($k_T$ is calculated from the rate constant equations given in the February 1975 Report, exp $8467/T_o$ is equal to 50.4, and $f_o = 1$ by definition.) The thermobalance yields the weight loss information from which the M(X) versus t plot can be constructed and the slope of the straight line obtained. Dividing the experimental value of the slope for the test coal by the calculated value of the slope for the standard coal yields the value of $f_o$ for the test coal.

Table 1 shows the approximate ranges of the relative low-rate gasification reactivity factors for different ranks of coal. These values are from previous work that has been performed at IGT and may be used in conjunction with the design charts presented in previous monthly reports. These results do not, however, generally apply to lignites, which show a wide variability in reactivity due to inherent catalytic effects of certain mineral components which predominate at this level of rank. With lignites, therefore, experimental determination of reactivity factors is usually necessary.

Table 1. RELATIVE LOW-RATE GASIFICATION REACTIVITY FACTORS

| Carbon Content of Raw Coals (Dry, Ash-Free), wt% | Low-Rate Gasification Reactivity Factor, $f_o$ |
|---|---|
| 65-70 | 1.4-1.3 |
| 70-75 | 1.3-1.2 |
| 75-80 | 1.2-1.0 |
| 80-85 | 1.0-0.8 |
| 85-90 | 0.8-0.6 |
| 90-95 | 0.6-0.3 |

2. <u>Example</u>

This example shows the use of the design charts presented up to now for the fluidized-bed steam-oxygen gasification of char.

A fluidized-bed gasifier must be designed to produce synthesis gas from a char feed that has been devolatilized and partially gasified. The appropriate conditions of operation are taken to be 1850°F, 70 atm, and a steam-to-carbon feed ratio of 1.2. Ninety percent of the feed carbon has to be gasified, with the heat for gasification being supplied by burning part of the coal with oxygen. Assume that the coal is in plug flow and the gases are backmixed.

The following information on the coal feed is available:

a. Ultimate and proximate analysis of fresh coal before partial gasification is —

| | wt %, dry |
|---|---|
| C | 67.5 |
| $H_2$ | 4.6 |
| O | 18.5 |
| $N_2$ | 0.9 |
| S | 0.7 |
| Ash | 7.8 |
| | 100.0 |

| | wt % |
|---|---|
| Volatile Matter | 36.9 |
| Fixed Carbon | 52.1 |
| Ash | 7.5 |
| Moisture | 3.5 |
| | 100.0 |

b. The ultimate analysis of the partially gasified char to the steam-oxygen gasifier is —

| | wt % |
|---|---|
| C | 78.0 |
| $H_2$ | 1.2 |
| O | -- |
| $N_2$ | 1.1 |
| S | 0.6 |
| Ash | 19.1 |
| | 100.0 |

c. The rate of char feed to the gasifier is 500 lb/hr.

Solution

Because the feed to the gasifier is a partially gasified char, the initial base carbon conversion fraction, $X_o$, is not equal to zero but has some value, which is calculated as follows:

$C_b°$ (base carbon), the carbon in the fixed carbon fraction = 0.96 X fixed carbon fraction of feed coal

$$= 0.96 \times \frac{0.521}{1.000-0.035}$$

= 0.518 lb carbon/lb raw coal (dry)

This approximation is used when an estimate of the organic coal components present in the fixed carbon fraction is not available.

The fraction of base carbon, $C_b$, in the partially gasified char, may be obtained by an ash balance.

$$C_b = 0.78 \frac{\text{lb ash}}{\text{lb raw coal}} \times \frac{1}{0.191} \frac{\text{lb partially gasified char}}{\text{lb ash}}$$

$$\times\ 0.78 \frac{\text{lb carbon}}{\text{lb partially gasified char}}$$

$$= 0.318 \text{ lb carbon/lb raw coal}$$

Thus, the initial base carbon conversion fraction is —

$$X_o = \frac{C_b^o - C_b}{C_b^o}$$

$$= \frac{0.518 - 0.318}{0.518} = 0.39$$

Note: These calculations are shown with a block diagram in Figure 2 for convenience. Charts presented in previous monthly reports are reproduced here as Figures 3 to 6; an open circle on each of them indicates the values read for this example.

Using the graph in Figure 3 for 1850°F, 90% feed carbon conversion, and a steam-carbon ratio of 1.2, the following are read:

$\theta_b$, the base case char residence time = 80 min.
Oxygen feed requirements = 0.23 lb-mole/lb-mole feed carbon.

Three corrections must be applied to the base case residence time:

1. Reactivity Correction: The relative low-rate gasification reactivity for the feed coal is read from Table 1 to be 1.2. The char residence time is inversely proportional to $f_o$ and, therefore —

   $M_{f_o}$, correction factor for reactivity $= 1/f_o = 1/1.2 = 0.833$

2. Partially gasified char feed correction: To use the chart in Figure 4, a corrected carbon conversion fraction, Y, must be calculated:

   $$Y = \left(\frac{\text{total carbon gasified}}{\text{carbon in feed}} - \frac{\text{oxygen}}{\text{carbon in feed}}\right), \text{ in mole/mole} = 0.9 - 0.23 = 0.67$$

   From Figure 4, $M_{X_o} = 1.22$.

3. Solids plug-flow model correction: Using Figure 5, for initial carbon conversion fraction $X_o = 0.39$, and the "corrected" final carbon conversion fraction Y = 0.67, R = 0.63.

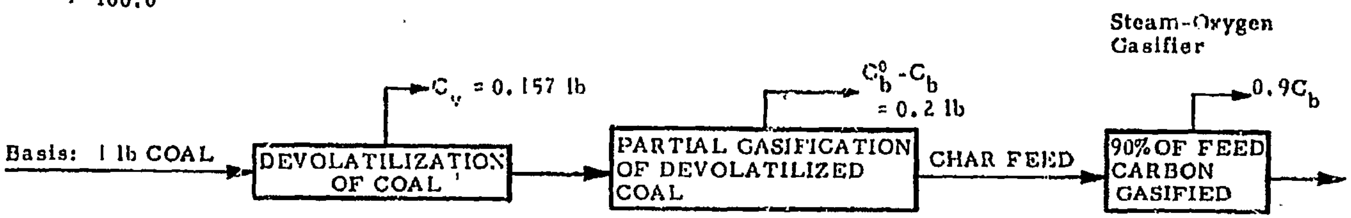
COAL

| ULTIMATE ANALYSIS wt% | |
|---|---|
| C | = 67.5 |
| $H_2$ | = 4.6 |
| O | = 18.5 |
| $N_2$ | = 0.9 |
| S | = 0.7 |
| Ash | = 7.8 |
| | 100.0 |

| PROXIMATE ANALYSIS wt% | |
|---|---|
| Volatile matter | = 36.9 |
| Fixed carbon | = 52.1 |
| Ash | = 7.5 |
| Moisture | = 3.5 |
| | 100.0 |

CHAR FEED TO STEAM-$O_2$ GASIFIER

| ULTIMATE ANALYSIS OF CHAR | |
|---|---|
| C | = 78.0 wt% |
| $H_2$ | = 1.2 |
| $N_2$ | = 1.1 |
| S | = 0.6 |
| Ash | = 19.1 |
| | 100.0 |




$C_t$ = 0.675 lb

$C_b^0$ = 0.96 X 0.521/(1 − 0.035) = 0.518 lb

$C_v = C_t - C_b^0$ = 0.157 lb

$C_b^0$ = 0.518 lb

$X_o$ = 0.0

$C_b$ = 0.318 lb

$X_o$ = 0.39

$C_b$ = 0.032 lb

By Ash Balance:

$C_b$ = 0.078/0.191 X 0.78 = 0.318

Then,

$$X_o = \frac{C_b^0 - C_b}{C_b^0} = 0.39$$

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Figure 2. BLOCK DIAGRAM OF HISTORY OF THE CHAR FEED USED IN THE STEAM-OXYGEN GASIFIER



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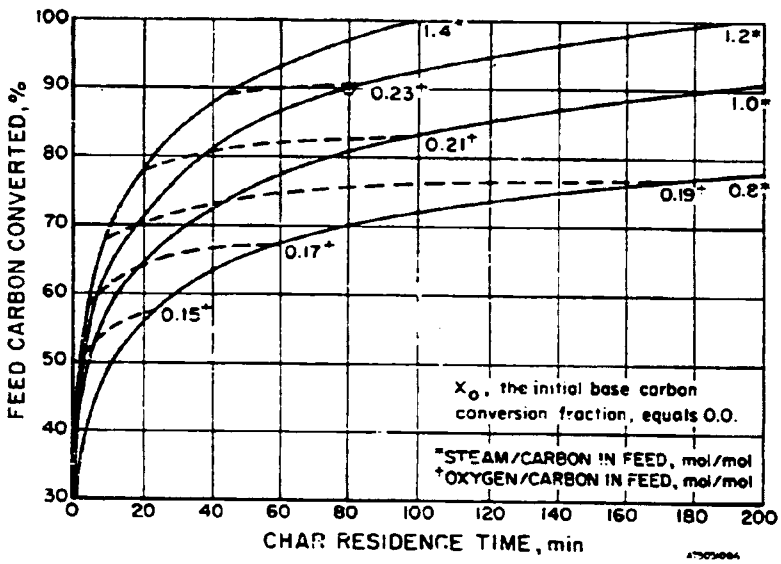


Figure 3. STEAM-OXYGEN GASIFICATION OF DEVOLATILIZED IRELAND MINE BITUMINOUS CHAR AT 1850° F AND 70-atm PRESSURE

The corrected char residence time,

$$\theta = \theta_b \times M_{f_o} \times M_{X_o} \times R$$

$$= 80 \times 0.833 \times 1.22 \times 0.63$$

$$= 51 \text{ min}$$

The total product gas moles and the product gas composition is obtained from Figure 6.

$$\text{Total moles of product gas} = 1.88 \frac{\text{moles gas}}{\text{moles C feed}} \times \frac{500(0.78)}{12.01} \frac{\text{moles C feed}}{\text{hr}}$$

$$= 61.05 \text{ lb-moles/hr}$$

Product gas composition —

| | mol % |
|---|---|
| $CH_4$ | 4.5 |
| $CO$ | 26.0 |
| $CO_2$ | 15.0 |
| $H_2$ | 26.5 |
| $H_2O$ | 28.0 |
| | 100.0 |

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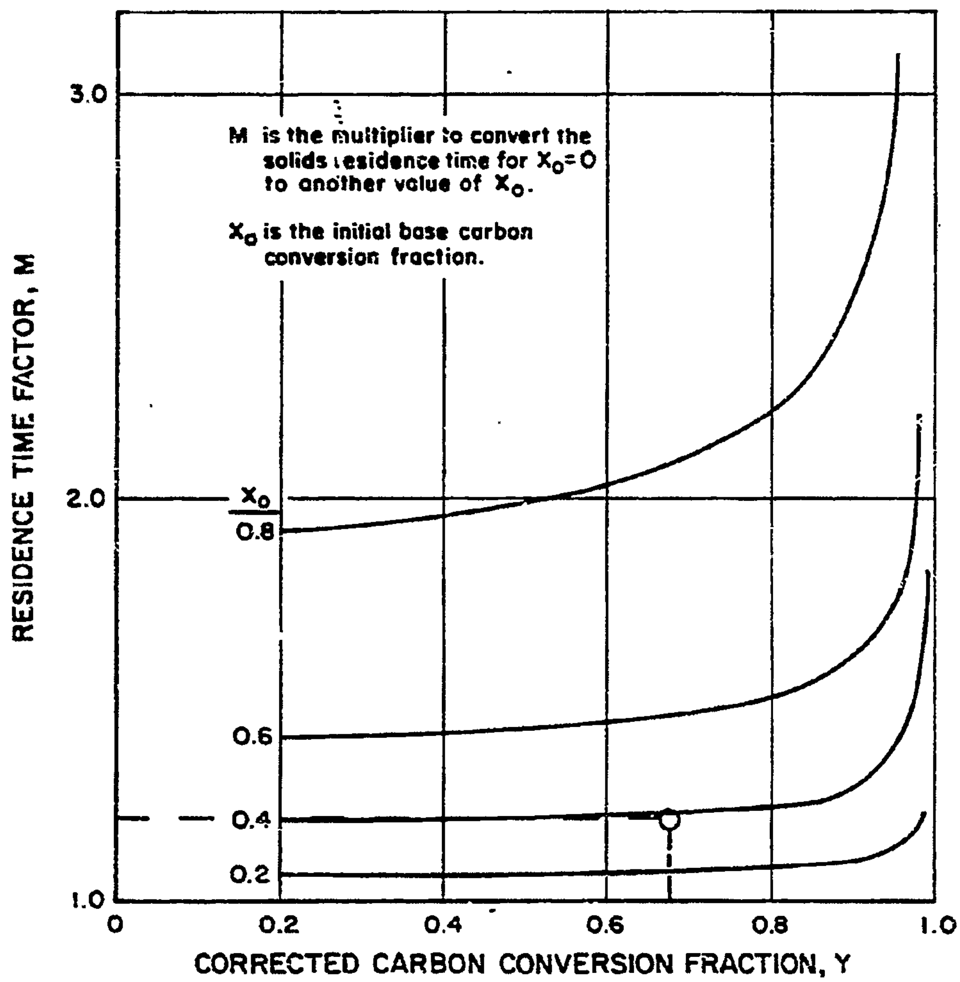


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Figure 4. CONVERSION FACTOR FOR PARTIALLY GASIFIED CHAR FEED

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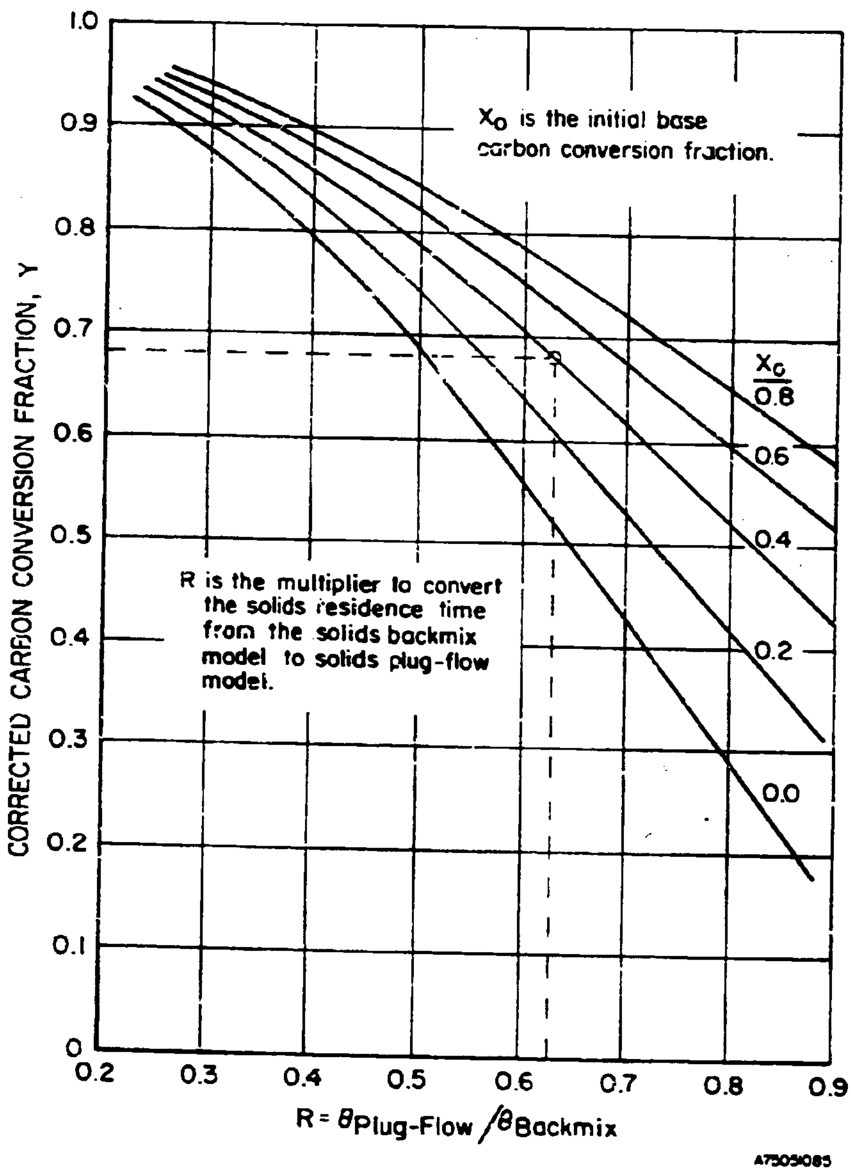


Figure 5. CONVERSION FACTOR FOR PLUG-FLOW MODEL

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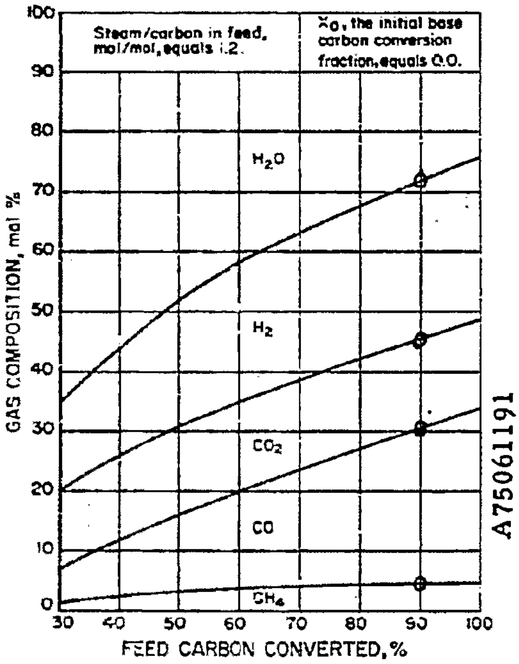
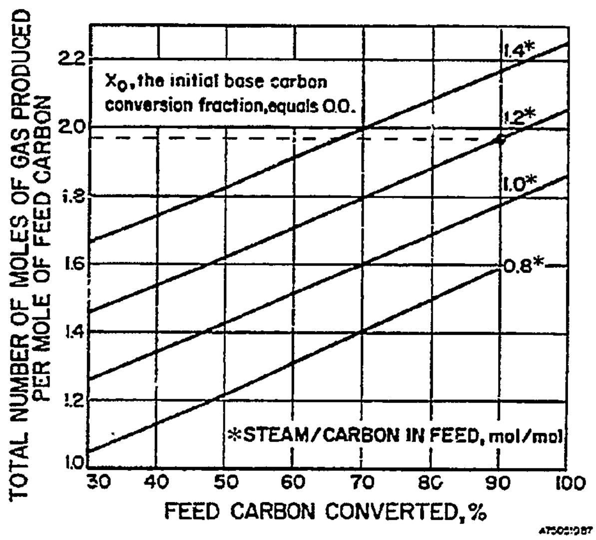



A. Gas Composition




B. Total Moles of Gas Produced

Figure 6. STEAM-OXYGEN GASIFICATION — PRODUCT GAS COMPOSITIONS AT 1850° F AND 70-atm PRESSURE

$$\text{Total oxygen required} = 0.23 \frac{\text{mole } O_2}{\text{mole C feed}} \times \frac{500(0.78)}{12.01} \frac{\text{moles C feed}}{\text{hr}}$$

$$= 7.47 \text{ moles/hr}$$

$$\text{Total steam required} = 1.2 \frac{\text{moles steam}}{\text{mole C feed}} \times \frac{500(0.78)}{12.01} \frac{\text{mole C feed}}{\text{hr}}$$

$$= 38.97 \text{ moles/hr}$$

$$\text{Total carbon gasified} = \frac{500(0.78)}{12.01} \times 0.9$$

$$= 29.23 \text{ moles/hr}$$

$$\text{Residue from the gasifier} = \text{lb char feed} - \text{lb carbon gasified}$$

$$= 500 - 500(0.78) \times 0.9$$

$$= 149 \text{ lb/hr}$$

Knowing the required char residence time in the gasifier, the fluidized-bed height may be obtained as follows:

$$\text{Fluidized-bed height} = \frac{W_{avg} X \theta}{\rho_b X A}$$

where —

$\theta$ = char residence time, hr

$\rho_b$ = density of the fluidized bed, lb/ft$^3$ (may be obtained from known correlations)

A = fluidized-bed cross-sectional area, ft$^2$ (fixed by the design gas velocity in the fluidized bed)

$W_{avg}$ = the average-weight flow rate of char, lb/hr

This last component, $W_{avg}$, may be approximated, for moderate conversions, for the plug-flow model as —

$$W_{avg} = \frac{\text{char feed rate + corrected residue rate}}{2}$$

where the corrected residue rate is the residue entering the combustion zone of the fluidized bed, that is —

$$\text{Corrected residue rate} = \text{residue out of gasifier + C combusted by } O_2 \text{ feed}$$

$$= 149 + 7.47 X 12.01$$

$$= 239 \text{ lb/hr}$$

Therefore,

$$W_{avg} = \frac{500 + 239}{2} = 369.5 \text{ lb/hr}$$

If it had been assumed that the solids were in backmixed flow, the solids plug-flow model correction would not have been required and the residence time would have been

$$\theta = \theta_b X M_{f_o} X M_{X_o}$$

$$= 80 X 0.833 X 1.22$$

$$= 81.3 \text{ min}$$

$$\text{and fluidized-bed height} = \frac{W_{out} X \theta}{\rho_b X A}$$

$$= \frac{239 X 81.3}{\rho_b A}$$

## C. FLUIDIZATION

### 1. Evaluation of Minimum Fluidization Correlations

#### a. Broadhurst-Becker Correlation

The following empirical correlation developed by Broadhurst and Becker[2] was evaluated in a manner similar to the procedure reported in the previous monthly reports.

$$U_{mf}^2 = \frac{D_p g\,(\rho_s - \rho_g)}{\rho_g} \cdot \frac{1}{2.42 \times 10^5 \left[\frac{\mu^2}{D_p^3 g(\rho_s - \rho_g)\rho_g}\right]^{0.85} + (\frac{\rho_s}{\rho_g})^{0.13} + 37.7} \qquad (1)$$

for

$$0.01 < Re_{mf} < 1000$$

$$500 < \frac{\rho_s}{\rho_g} < 50{,}000$$

and

$$1 < D_p^3 \rho_g \cdot \frac{g(\rho_s - \rho_g)}{\mu^2} < 10^7$$

A graphical comparison of the calculated minimum fluidization velocity values from Equation 1 with published experimental data on coal and related materials is shown in Figure 7. It is seen from this figure that the calculated values are generally lower than the measured minimum fluidization velocity values.

#### b. Zenz Correlation

A similar comparison was also made by solving for the minimum fluidization velocity from the following empirical equation,[16] fitted to the graphical correlation developed by Zenz.[17]

$$\epsilon_{mf} = 1.4673081 + 0.0147726\,(\beta) - 0.26864208\,(\ln \alpha) + 0.18601248\,(\ln \beta) + 0.00814086\,(\ln \beta)^2 \qquad (2)$$

where

$$\alpha = \frac{D_p}{\left[\frac{3}{4} \cdot \frac{\mu^2}{\rho_g(\rho_s - \rho_g)g}\right]^{1/3}} \qquad (3)$$

$$\beta = \frac{U_{mf}}{\left[\frac{4}{3} \cdot \frac{\mu(\rho_s - \rho_g)g}{\rho_g^2}\right]^{1/3}} \qquad (4)$$

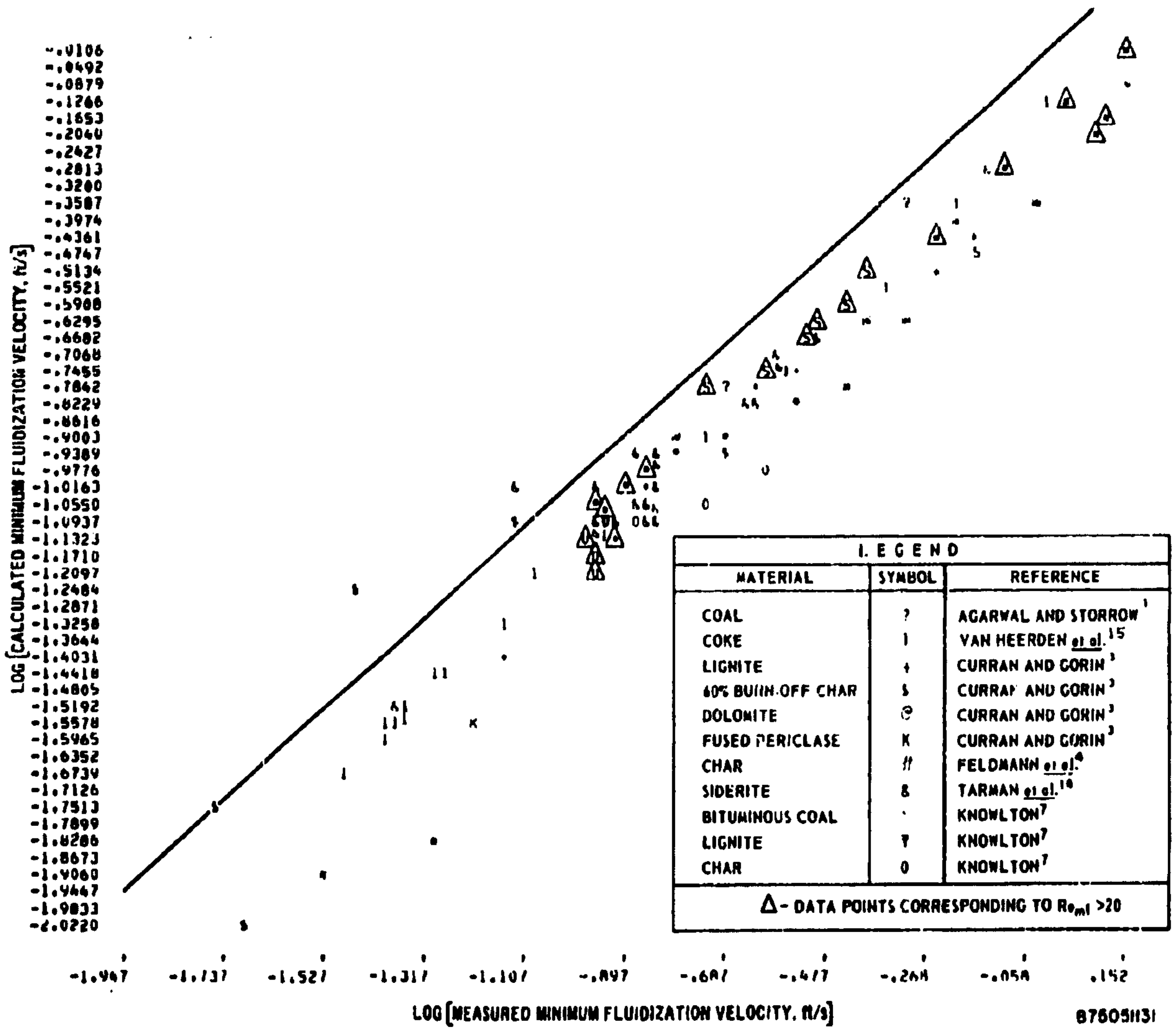



Figure 7. COMPARISON OF BROADHURST-BECKER'S CORRELATION WITH MEASURED MINIMUM FLUIDIZATION DATA

The comparison of the calculated values using Equation 2 with the published data used in this investigation is shown in Figure 8.

The calculated standard relative deviations for the correlations given by Equations 1 and 2 are —

a. Broadhurst-Becker,[2] 36.04
b. Zenz,[16] 113.29%

It must be recognized that even though Broadhurst and Becker [2] used the data of particles ranging in density from 81 to about 463 lb/cu ft, the particles were usually spherical; conceivably, therefore, the empirical constants in Equation 1 may not be fully descriptive of the physical characteristics of coal and the related types of material used in this investigation.

It is apparent that by employing the empirical equation (Equation 2), the percent standard relative deviation is lower than when the values are calculated by the graphical readout procedure reported earlier.[6] The magnitude of the standard relative deviation is still a reminder that Zenz's graphical correlation [17] is sensitive to the bed voidage at minimum fluidization velocity and was developed primarily for the particulate fluidization of particles that are generally sperical in shape.

Studies similar to this will be made and reported whenever new correlations become available.

c. Proposed Correlation

The proposed correlation given in last month's report is plotted in Figure 9, where $Re_{mf}$ is given as a function of Galileo's number. It should be recalled that this correlation was developed by determining the parameters $1/\varphi \cdot \epsilon_{mf}^3$ and $(1 - \epsilon_{mf})/\varphi^2 \cdot \epsilon_{mf}^3$ from the available data by nonlinear regression analysis.

However, if the shape factor, $\varphi$, and the minimum fluidization voidage, $\epsilon_{mf}$, can be precisely determined for the system under study, a better estimation of the minimum fluidization velocity can presumably be obtained by substituting these values in the original Kunii-Levenspiel equation:[8]

$$\frac{1.75}{\varphi \cdot \epsilon_{mf}^3} (Re_{mf})^2 + \frac{150(1 - \epsilon_{mf})}{\varphi^2 \cdot \epsilon_{mf}^3} \cdot Re_{mf} - Ga = 0 \qquad (5)$$

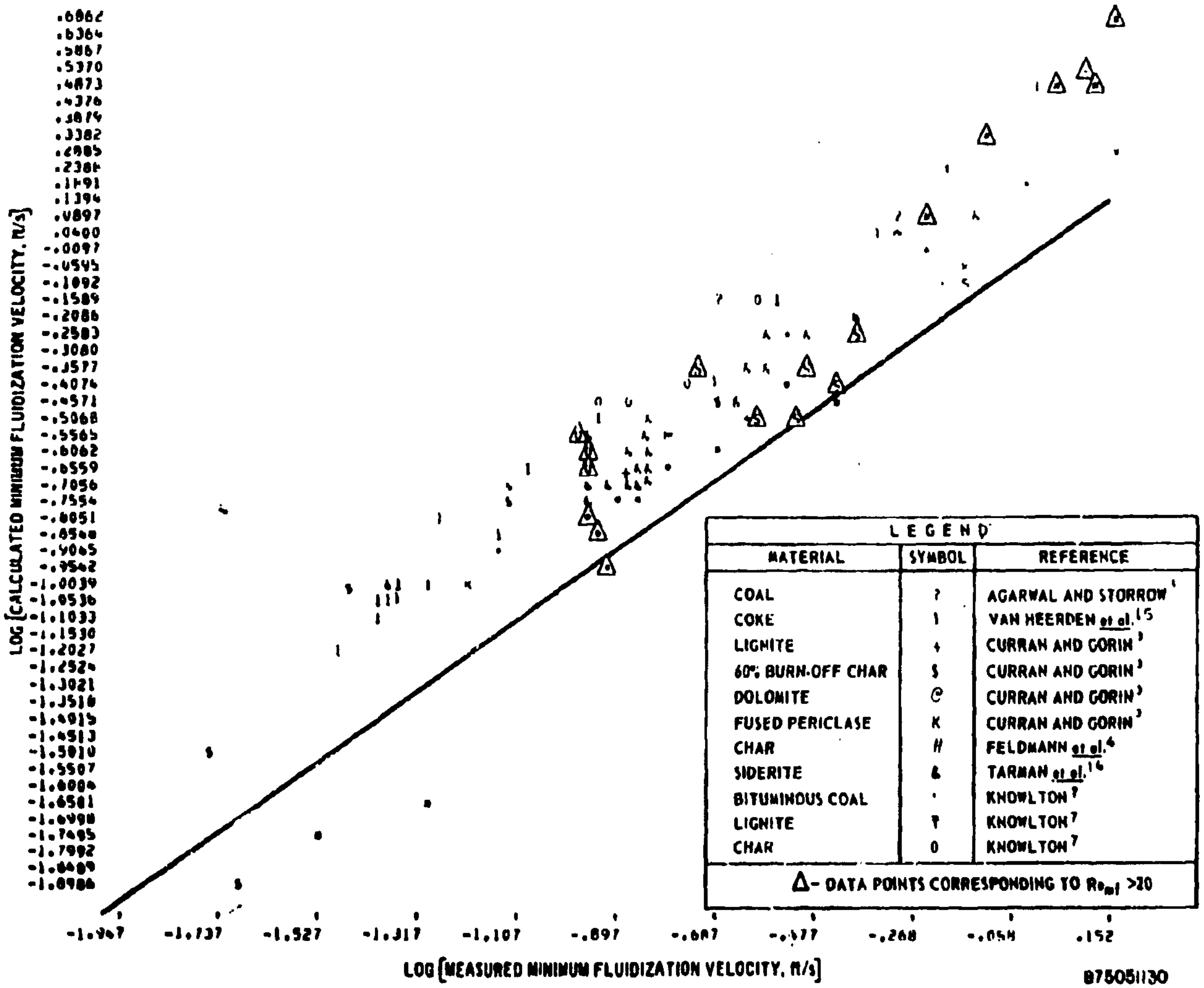



Figure 8. COMPARISON OF ZENZ'S CORRELATION WITH MEASURED MINIMUM FLUIDIZATION DATA

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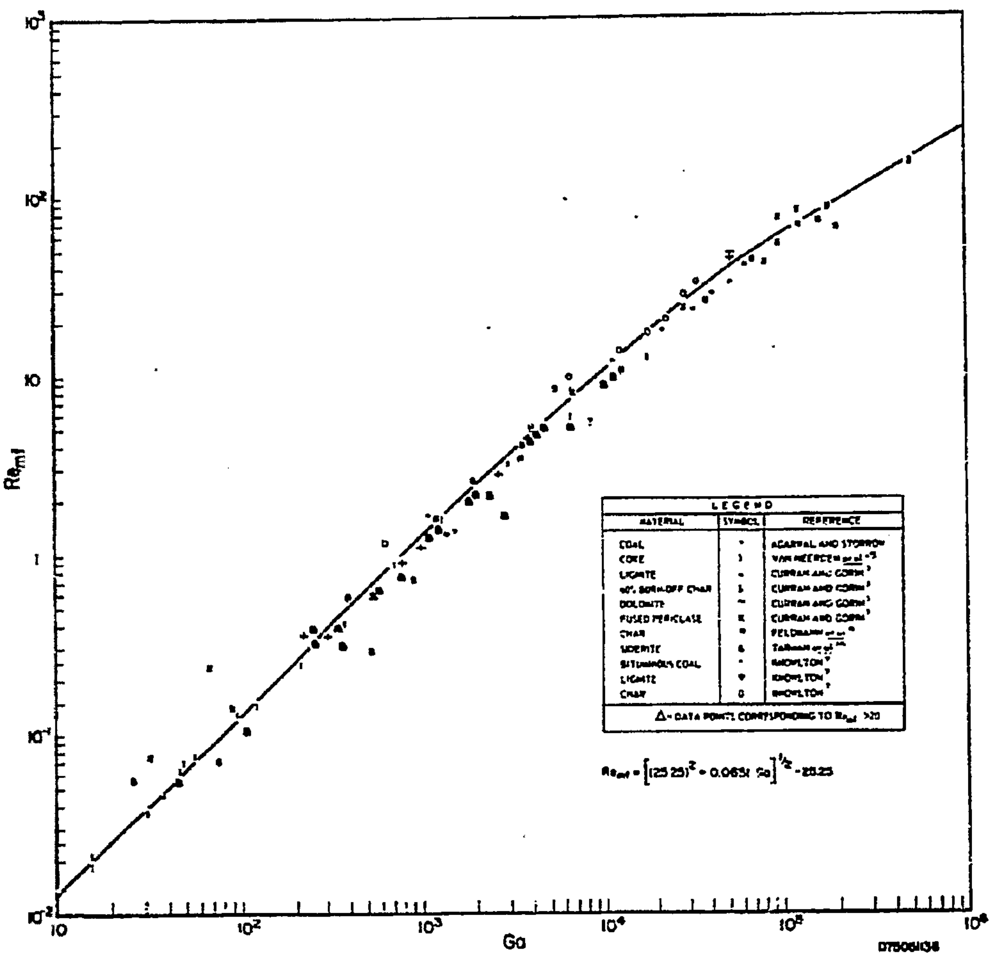


Figure 9. PROPOSED CORRELATION FOR THE PREDICTION OF MINIMUM FLUIDIZATION VELOCITY

But the values of $\varphi$ and $\epsilon_{mf}$ are generally not available with any acceptable degree of precision, and hence it is recommended that the proposed correlation be used to estimate the minimum fluidization velocity for coal and related materials.

2. Bed Expansion on Fluidization

The two-phase theory[8] postulates that the gas in excess of the minimum fluidization velocity will traverse the bed height in the form of gas bubbles. The literature published on fluidization during the last decade can be broadly divided into two groups: those in support of the two-phase theory and those against the generalization of the two-phase theory principles. However, from a theoretical point of view, it is conceivable that the bed expansion ratio is related to the gas flow in excess of the minimum fluidization velocity.

a. Lewis et al. Correlation

The correlation developed by Lewis et al.[12] was one of the first to relate the bed expansion ratio ($L_f/L_{mf}$) to the difference in superficial gas velocity at the fluidizing and minimum fluidizing conditions. The empirical relationship developed by these investigators is given by —

$$\frac{L_{mf}}{L_f} = 1 - \frac{0.0188}{D_p^{0.5}} (U - U_{mf}) \qquad (6)$$

A graphical comparison of the calculated fluidized-bed expansion ratio from Equation 6 with the measured bed expansion data is shown in Figure 10. It is seen that about 90% of the published data are within $\pm$ 20% of the values calculated from Equation 6.

The data by Tarman et al.[14] show a uniquely different trend compared with the rest of the data in Figure 10. Their measured bed expansion ratios are lower than those calculated from Equation 6, indicating the generally accepted effect of the column diameter. Clearly, the Lewis et al. correlation predicts a lower bed expansion for most of the cases except for the Tarman et al. system. The reasons for this discrepancy are not clear because no definite and physically pertinent trends could be rationalized by grouping the data in Figure 10 into different density groups, particle sizes, or operating pressures or into fluidizing columns of the same diameters.

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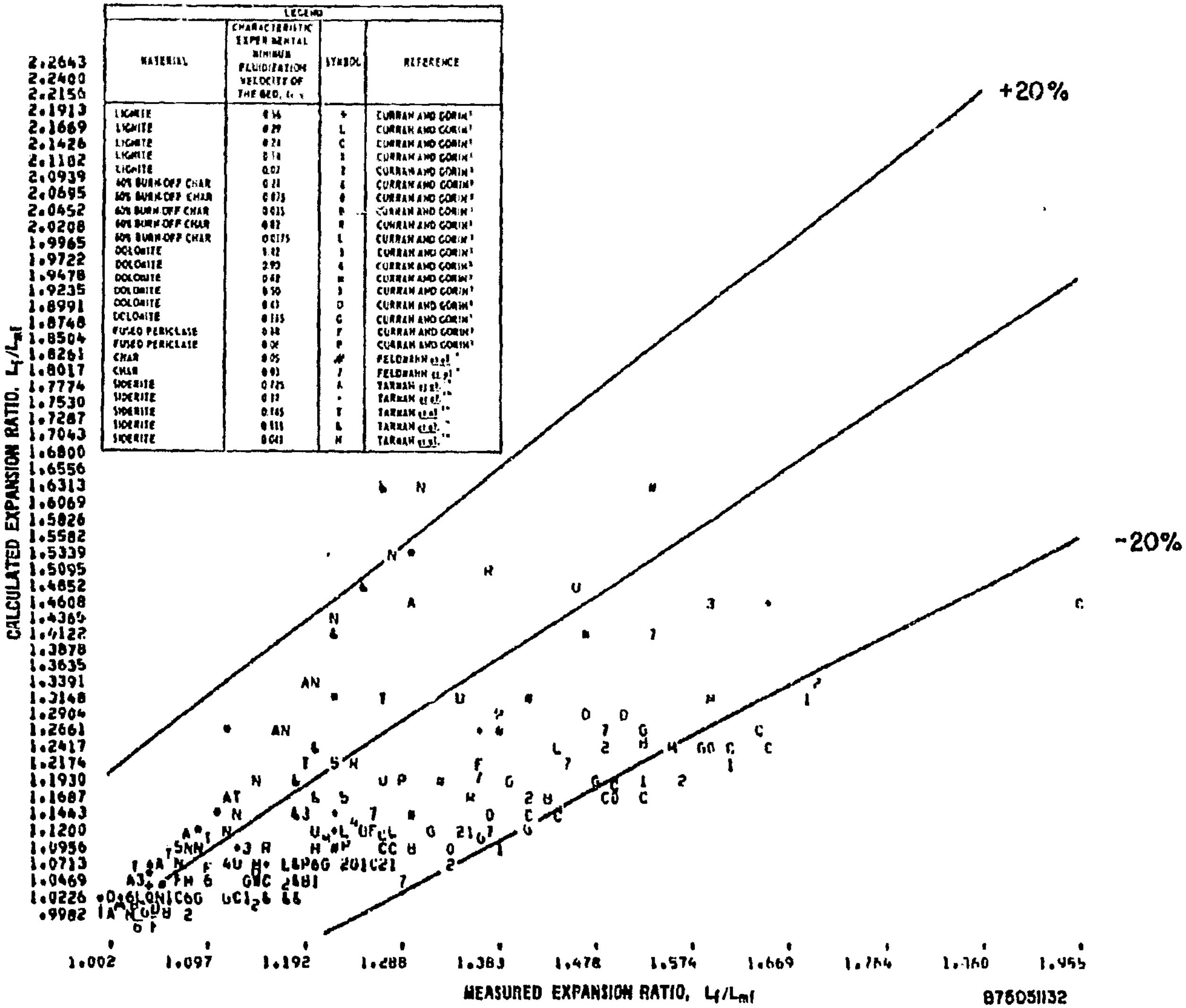


Figure 10. COMPARISON OF LEWIS et al. CORRELATION WITH MEASURED BED EXPANSION DATA

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b. Shen-Johnstone Correlation

A modification of the Lewis et al. correlation for the bed expansion ratio was published by Shen and Johnstone[13] in the following form:

$$\frac{L_f}{L_{mf}} = 1 + \frac{0.0188}{D_p^{0.5}} (U - U_{mf}) \qquad (7)$$

This modification was developed to describe their experiments with a cracking catalyst in a fluidized bed, 3.75 inches in diameter.

A comparison of the calculated bed expansion characteristics with the measured values as a function of the gas velocity, taken from the literature, is shown in Figure 11. About 90% of the measured data is within ± 20% of the calculated values from the Shen-Johnstone correlation. As seen in Figure 10, the data reported by Tarman et al.[14] show a trend different from the majority of the data in Figure 11. Also, the values calculated by the Shen-Johnstone correlation for the lighter materials (such as lignite and some chars) are less than 80% of the measured values.

c. Leva et al. Correlation

Using the empirical correlation for minimum fluidization and assuming uniform particles and therefore uniform voidage in the fluidized bed, Leva et al.[9,11] related the mass velocity of the fluidizing medium to the fractional volume of voids by the following equation:

$$G \propto \left(\frac{1-\delta}{\delta^3}\right)^m \qquad (8)$$

Frantz[5] later summarized the following procedure to predict the fluidized-bed expansion characteristics using Leva's derivations:

Step 1. Predict $G_{mf}$ from the Leva et al. correlation.[10]

Step 2. Estimate $\epsilon_{mf}$ from Figure 12.

Step 3. Obtain slope m from Figure 13.

Step 4. Plot $G_{mf}$ and $(1 - \epsilon_{mf})/\epsilon_{mf}^3$ on logarithmic coordinates.

Step 5. Draw line of slope m through $G_{mf}$, $(1 - \epsilon_{mf})/\epsilon_{mf}^3$, as shown in Figure 14. (Note: $\epsilon_{mf} = \delta$ at incipient fluidization conditions.)

Step 6. Estimate the fluidized-bed expansion characteristics from Figure 14.

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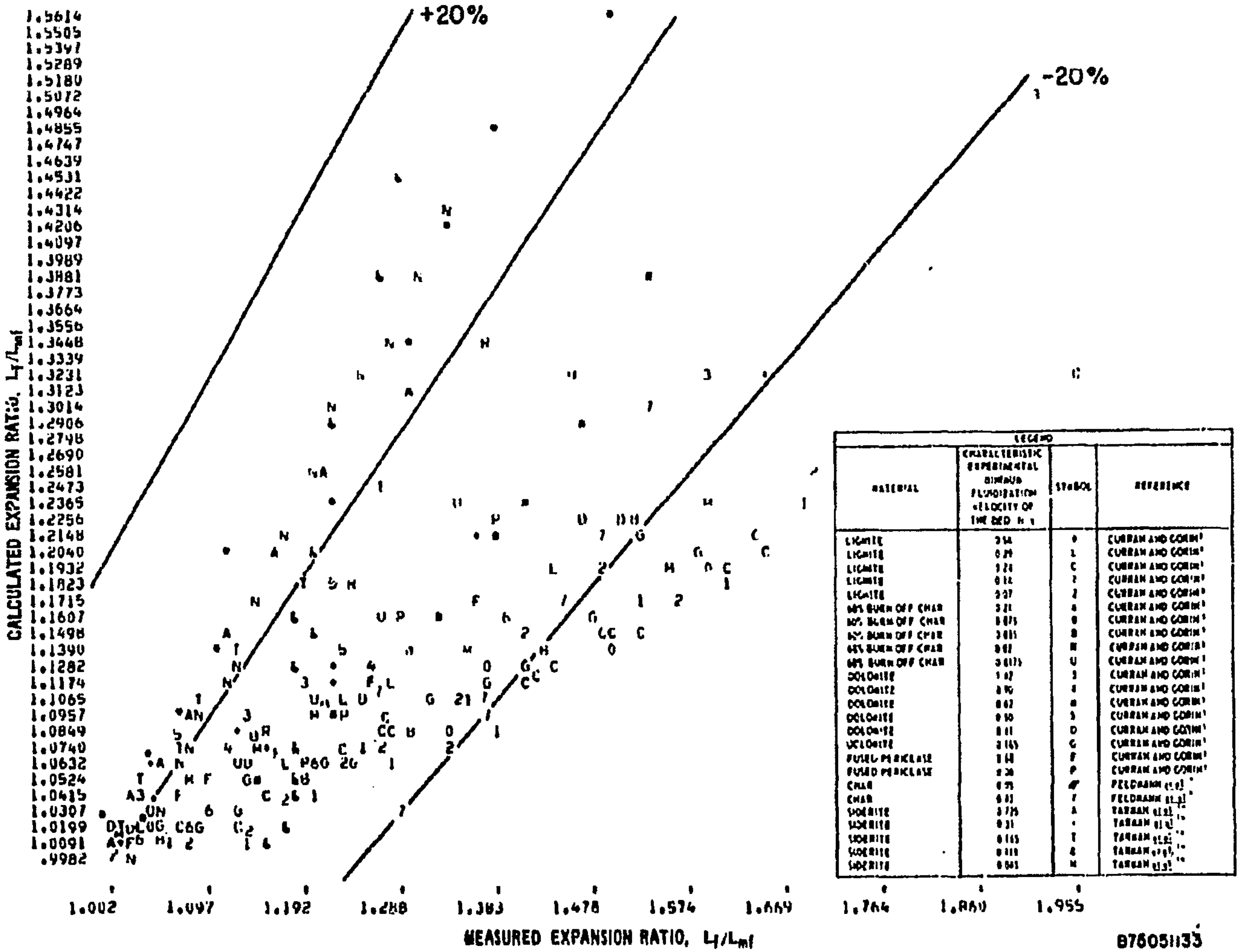


Figure 11. COMPARISON OF SHEN-JOHNSTONE CORRELATION WITH MEASURED BED EXPANSION DATA

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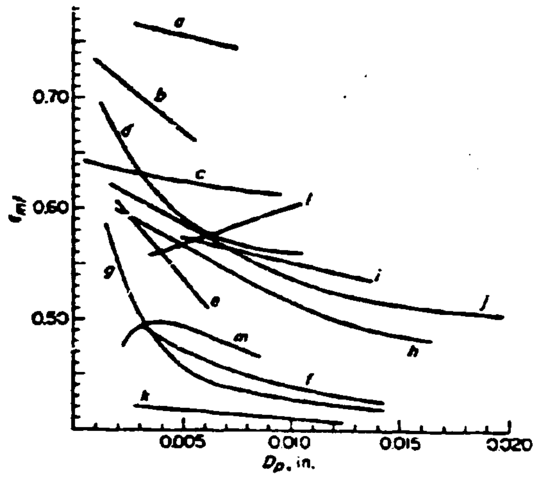



| LEGEND | | | |
|---|---|---|---|
| MATERIAL | | SYMBOL | REFERENCE |
| SOFT BRICK | | A | AGARWAL AND STORROW |
| ABSORPTION CARBON | | B | AGARWAL AND STORROW |
| BROKEN RASCHIG RINGS | | C | AGARWAL AND STORROW |
| COAL AND GLASS POWDER | | D | AGARWAL AND STORROW |
| CARBORUNDUM | | E | AGARWAL AND STORROW |
| SAND | | F | AGARWAL AND STORROW |
| ROUND SAND | φ = 0.86 | G | LEVA et al |
| SHARP SAND | φ = 0.67 | H | LEVA et al |
| FISCHER-TROPSCH CATALYST | φ = 0.58 | I | LEVA et al |
| ANTHRACITE COAL | φ = 0.63 | J | LEVA et al |
| MIXED ROUND SAND | φ = 0.86 | K | LEVA et al |
| COKE | | L | VAN HEERDEN et al |
| CARBORUNDUM | | M | VAN HEERDEN et al |



Figure 12. RELATION OF INCIPIENTLY FLUIDIZED-BED VOIDAGE TO THE AVERAGE PARTICLE DIAMETER

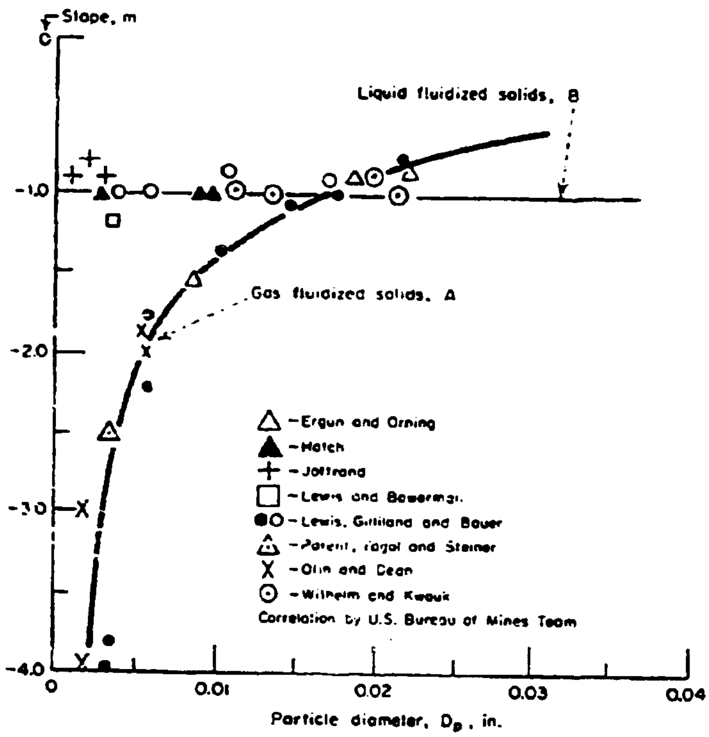



Figure 13. VALUES OF m IN RELATION TO $D_p$.

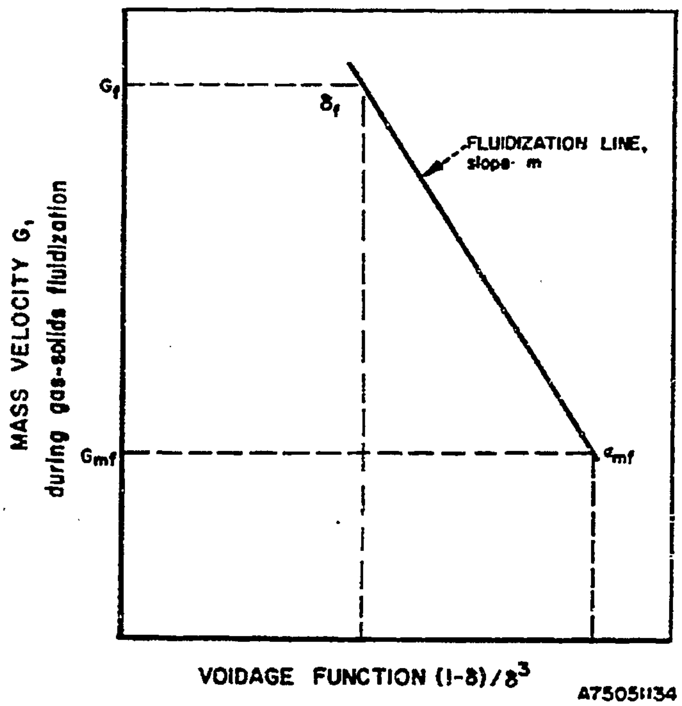



Figure 14. BEHAVIOR OF EXPANDED BED[9]

Frantz[5] also notes that the Leva et al. correlation can predict the expansion characteristics as long as the voids are uniformly distributed in fluidized beds. He estimates that beyond a fractional volume of voids equal to 0.65, the fluidized bed becomes heterogeneous, and therefore the Leva et al. correlation may not result in adequately reliable values.

A comparison of the calculated fluidized-bed expansion characteristics using Leva's procedure with the published data used in this investigation is shown in Figure 15. Leva's procedure of calculating bed expansion ratio produces values that compare with 90% of the data within ± 20% deviation. No definite trend descriptive of density, particle size, or the diameter of the fluidizing column is noticed in Figure 15.

It can be visualized that the fluidized-bed expansion characteristics are not only related to the physical properties of the solids and gases but also to the fluidized-bed diameter in some complex manner. The evaluation of these correlations gives no insight into the phenomena of fluidized-bed expansion. We anticipate that the analysis of correlations incorporating bubble properties and bubble inventory will produce a better description of the published data. However, such an analysis will not be attempted until we complete work on the section on bubble properties in gas-solid fluidized beds.

Specific recommendations regarding the use of published correlations to estimate the fluidized-bed expansion characteristics in coal conversion will be proposed in the future monthly reports.

3. Nomenclature

$D_f$ = particle diameter of a sieved fraction, ft

$D_p$ = average particle diameter, ft = $\frac{1}{\Sigma(X/D_f)}$

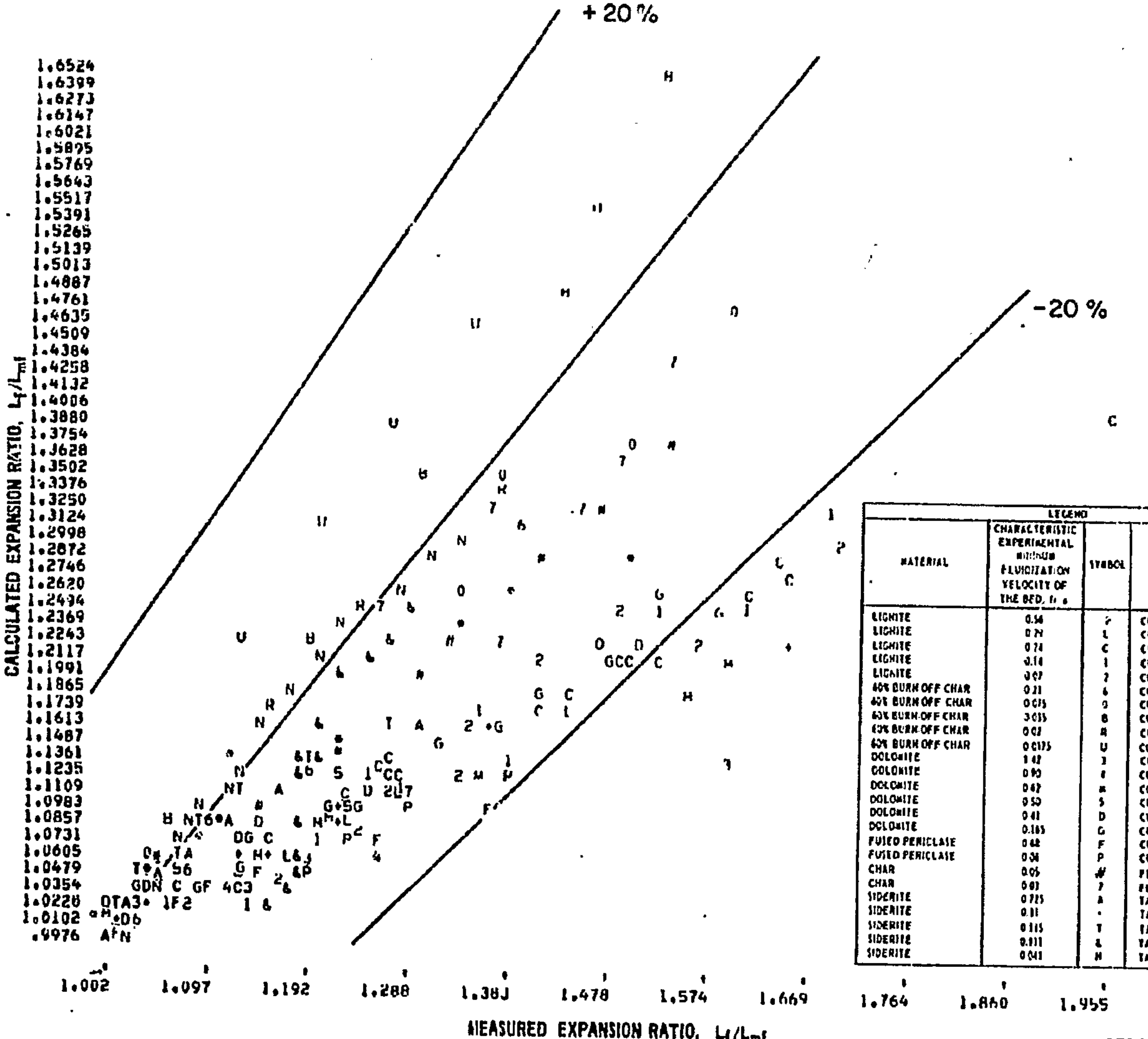
$g$ = gravitational constant, $ft/s^2$

$G$ = superficial mass velocity, $lb/ft^2 \cdot s$

$Ga$ = Galileo number = $g \frac{D_p^3(\rho_s - \rho_g)\rho_g}{\mu^2}$

$L_f$ = height of fluidized bed, ft

$L_{mf}$ = height of minimum fluidized bed, ft




| LEGEND | | | |
|---|---|---|---|
| MATERIAL | CHARACTERISTIC EXPERIMENTAL MINIMUM FLUIDIZATION VELOCITY OF THE BED, ft/s | SYMBOL | REFERENCE |
| LIGNITE | 0.56 | ? | CURRAN AND GORIN[1] |
| LIGNITE | 0.74 | L | CURRAN AND GORIN[1] |
| LIGNITE | 0.74 | C | CURRAN AND GORIN[1] |
| LIGNITE | 0.14 | 1 | CURRAN AND GORIN[1] |
| LIGNITE | 0.07 | 7 | CURRAN AND GORIN[1] |
| 60% BURN OFF CHAR | 0.21 | 6 | CURRAN AND GORIN[1] |
| 60% BURN OFF CHAR | 0.075 | 0 | CURRAN AND GORIN[1] |
| 60% BURN-OFF CHAR | 0.035 | B | CURRAN AND GORIN[1] |
| 60% BURN-OFF CHAR | 0.03 | R | CURRAN AND GORIN[1] |
| 60% BURN OFF CHAR | 0.0175 | U | CURRAN AND GORIN[1] |
| DOLOMITE | 1.42 | 3 | CURRAN AND GORIN[1] |
| DOLOMITE | 0.90 | ' | CURRAN AND GORIN[1] |
| DOLOMITE | 0.67 | K | CURRAN AND GORIN[1] |
| DOLOMITE | 0.50 | S | CURRAN AND GORIN[1] |
| DOLOMITE | 0.41 | D | CURRAN AND GORIN[1] |
| DOLOMITE | 0.165 | G | CURRAN AND GORIN[1] |
| FUSED PERICLASE | 0.62 | F | CURRAN AND GORIN[1] |
| FUSED PERICLASE | 0.36 | P | CURRAN AND GORIN[1] |
| CHAR | 0.05 | # | FELDMANN *et al.* |
| CHAR | 0.03 | 7 | FELDMANN *et al.* |
| SIDERITE | 0.725 | A | TARMAN *et al.* |
| SIDERITE | 0.11 | • | TARMAN *et al.* |
| SIDERITE | 0.115 | T | TARMAN *et al.* |
| SIDERITE | 0.111 | & | TARMAN *et al.* |
| SIDERITE | 0.041 | H | TARMAN *et al.* |

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Figure 15. COMPARISON OF THE LEVA et al. CORRELATION WITH MEASURED BED EXPANSION DATA

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m = constant

$Re_{mf}$ = particle Reynold's number = $(D_p \cdot U_{mf} \cdot \rho_g/\mu)$

$U_{mf}$ = minimum fluidization velocity, ft/s

V = superficial velocity, ft/s

X = weight fraction of sieved particles

$\delta$ = fractional volume occupied by bubbles and voids in a fluidized bed

$\epsilon_{mf}$ = voidage of minimum fluidized bed

$\varphi$ = shape factor

$\rho_g$ = density of fluidizing gas, lb/CF

$\rho_s$ = particle density of fluidizing solids, lb/cu ft

$\mu$ = viscosity of fluidizing gas, lb/ft-s

## 4. References Cited


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16. Zenz, F. A., Private Communication, April 1975.

17. Zenz, F. A., "Calculate Fluidization Rates," Pet. Refiner 36, No. 8, 147-55 (1957).

## 5. Errata

In the Project 8964 February 1975 Status Report, the following correction is to be noted. In Table 3 (page 36), the bed diameter for Feldmann et al.'s data is 2 and 3.69 inches instead of 3.69 inches.

In the Project 8964 March 1975 Status Report, the following corrections are to be noted.

In Table 3 (page 26), the bed diameter for Feldmann et al.'s data is 2 inches instead of 3.69 inches.

In Section 4, References Cited, Reference 14 of Leva et al. should be numbered as 13 and Reference 14 should be —

14. Lewis, W. K., Gilliland, E. R. and Bauer, W. C., "Characteristics of Fluidized Particles," Ind. Eng. Chem. 41, 1104 (1949).

## D. COMBUSTION

### Low-Temperature Combustion (Fluidized-Bed Combustion)

A major factor in the design of fluidized-bed combustors is the recovery of sulfur through reaction of $SO_2$ with CaO according to the following reaction:

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

The source of CaO can be natural limestone or dolomite, or a regenerated CaO or $CaCO_3$.

As discussed by Archer et al.,[1] the results of the kinetics studies of the above reaction based on flue products or $SO_2$-air mixtures cannot be directly used in fluidized-bed coal combustion systems. An obvious difference is in the temperature effect. In several studies of the combustion of a wide range of coal in the presence of a wide range of additives, a maximum rate of sulfur recovery was observed between 1500° and 1600° F. There is no counterpart of this phenomenon in the $SO_2$-CaO kinetics. It also may be peculiar to low-pressure operation[3] because it was not observed in a system operating at 8 atm. Until the detailed structure of the fluidized-bed combustion (FBC) process is known, we cannot apply the kinetics of other contacting systems. We presumably must derive them from FBC systems studies.

As must be expected in gas-solid reactions, the reaction rates depend strongly on the source of the CaO. To a lesser but still significant extent, the apparent rate depends on the coal characteristics.

To calculate the sulfur retention in a combustor, therefore, we need reactivity factors for the additive (the source of CaO), and for the coal. To establish these factors from FBC data, we must assume a mixing model and a kinetic model and assign reference materials. In the present state-of-the-art, the gas phase can be considered completely mixed or in plug flow and the solid phase uniformly distributed. The kinetics with respect to $SO_2$ and CaO also can be expected to be some simple, approximately first, order.

To describe the sulfur recovery system, we define the following symbols:

$S_{feed}$ = feed rate of coal sulfur (moles/time)

F = product (flue) gas rate (moles/time)

$X_{SO_2}$ = $SO_2$ mole fraction in product gas

$r$ = mole ratio of CaO or equivalent in additive feed to coal sulfur

$R_S$ = fraction of feed coal sulfur recovered as $CaSO_4$

$W_{bed}$ = bed mass (mass)

$Ca_{bed}$ = calcium mass fraction in bed

$X_{Ca}$ = fraction of feed CaO or equivalent converted to $CaSO_4$

Some relationships among these are—

$$X_{SO_2} = (1-R_S)\, S_{feed}/F \quad (1)$$

$$X_{Ca} = R_S/r \quad (2)$$

If the elutriation is or assumed to be nonselective with respect to the different calcium compounds, the conversion, $X_{Ca}$, would apply to the fluidized bed. If the elutriation is nonselective with respect to the coal and additive residues, then we have the following relation:

$$Ca_{bed} = 1.25r/\left[\left(\frac{ash}{S}\right)_{coal} + 2.5R_S + 1.25r\left(\frac{ash}{Ca}\right)_{additive}\right] \quad (3)$$

where the numerator is the amount of calcium in the bed and the terms in the denominator give the contributions to the bed weight by the residue from coal, retained $SO_2$, and the additive residue, respectively.

For a simple completely mixed reactor model, if we assume the bed weight is proportional to the bed volume, the rate of reaction should be calculated from

$$\text{rate (moles of S/time/mass of bed)} = R_S \cdot S_{feed}/W_{bed} \quad (4)$$

If we assume a rate law that is first order in the $SO_2$ in the bed, and is some function of the unreacted CaO,

$$\text{rate} = k\, X_{SO_2} \quad (5)$$

where k is some function of temperature, pressure, and unreacted CaO. In this simple representation, k is, for now, determined from FBC data and therefore, as long as it works, is a means of summarizing or coordinating the data and is not implied to be a correct physical model.

Keppel in the ANL report of 1971[2] presented a model based on plug flow of the gas and different possible patterns of $SO_2$ generation. The ability to describe the experimental results apparently was not sensitive to these patterns. If one were to use the Koppel model with uniform generation of $SO_2$, then instead of Equation 5 one would need the implicit equation

$$\ln\left[1 - \frac{k\ X_{SO_2}}{(R_s \cdot S_{feed}/W_{bed})}\right] = -\frac{R_s}{1 - R_s}\left[\frac{k\ X_{SO_2}}{(R_s \cdot S_{feed}/W_{bed})}\right] \qquad (6)$$

For sulfur recoveries greater than 40%, Equation 6 can be replaced by the approximation –

$$\text{rate} = R_s \cdot S_{feed}/W_{bed} = \frac{k\ X_{SO_2}}{1 + 1.2\,(1 - R_s)} \qquad (7)$$

Because the models are different, the rate constants derived from the data will be different and they must be used only in their respective models.

Koppel also introduced a dependence on the CaO in the bed assuming first-order dependence on an effective fraction of the CaO. He concluded, for the materials and conditions of that study,[2] that the additive (a limestone) had only 50% effective CaO. This cannot be considered the general case and probably implies the need of at least two parameters to describe the reactivity of the additive.

For choice of reference materials, the work of Argonne National Laboratories[3] using Tymochtee Dolomite as an additive and a highly volatile bituminous Pittsburgh seam coal from the Consolidation Coal Company Arkwright Mine is one of the more extensive studies and permits examination of the effects of some major variables. The variables considered are velocity, temperature, and CaO-to-sulfur ratio. The data are constrained to relatively constant air-fuel ratio, feed particle size, bed weight, and system pressure. The air-fuel ratio must be expected to be a significant factor, but in practice, may not have a wide range. The effect of bed volume or weight can be anticipated from simple kinetics considerations. Feed particle size, if necessary, will show up in the proposed simple formulation, in the reactivity factors. The pressure effects are apparently very temperature sensitive and must ultimately appear in the chemical kinetic expression However, here too, probable practice may limit the pressures of interest to a few distinct ranges. This study[3] also reports the bed compositions and conversions, thereby avoiding the dependence on Equations 2 and 3 and their unproved assumptions.

In Table 2, the characteristics of the coal and additive are shown. In Table 3, the operating conditions are summarized.

Table 2. CHARACTERISTICS OF REFERENCE MATERIALS[3]

| Analysis, wt % | Arkwright Coal | | Tymochtee Dolomite |
|---|---|---|---|
| Moisture | 2.89 | Ca | 20.0 |
| Ash | 7.68 | $CO_2$ | 38.5 |
| Sulfur | 2.32 | Ash | 59.7 |
| Carbon | 74.91 | | |
| Hydrogen | 5.08 | | |
| Oxygen | 4.83 | | |
| Sieve Range, U.S. sieve No. | −14+170 | | −14+170 |
| Mean Particle size, μm | 323 | | 750 |

Table 3. OPERATING RANGES OF REFERENCE SYSTEM[3]

| | |
|---|---|
| Temperature | 1445° - 1665° F |
| Pressure | 8 atm |
| Dry Flue Gas/Coal | 153 SCF/lb |
| Bed Diameter | 0.5 ft |
| Bed Weight | 22-36 lb |
| Ca/S Mole Ratio | 1.0-3.3 |
| Ca Conversion | 0.32-0.83 |
| Ca Bed Wt Fraction | 0.17-0.24 |
| Sulfur Recovery Fraction | 0.62-0.95 |

The validity of Equations 2 and 3 for bed compositions was examined. As an estimate of the calcium weight fraction, Equation 3 gives values, on the average, 0.01 less than the measured value with a standard deviation of about 0.01. This accuracy, if generally true, makes Equation 3 a useful equation. Equation 2 for the conversion, $X_{Ca}$, gives values that are 20% low with a standard error of 12%. At higher conversions, the calculated value of $(1 - X_{Ca})$ which appears in the rate expression, could have a high uncertainty, and prevent reasonable interpretation of data. However, if generally true, the use of the factor of 1.2 to correct the calculated conversion would serve adequately for the range of probable operation in which conversions of less than 0.5 will be necessary to maintain low $SO_2$ levels.

In the following calculations, the reported rather than calculated values are used.

Following Koppel's line, we assume that the rate constant k is proportional to the effective CaO, that is –

$$k = k_o (X_{Ca,m} - X_{Ca}) \, Ca_{bed} \qquad (8)$$

where $X_{Ca,m}$ is the maximum possible conversion. The ANL data were used to calculate the values of k based on the completely mixed reactor model (Equations 4 and 5), and they were plotted to test Equation 8 in Figure 16. The completely mixed model and the plug flow (uniform generation) model seem to reasonably represent the data of this system with the assumption that maximum possible conversion is complete conversion. Also (again, for this system) there is no major temperature effect. (Since mole fraction of $SO_2$ rather than concentration was used, one may assume the rate is proportional to the absolute temperature, but such a low dependence is lost in the random deviations.) The line drawn in Figure 16 is based on the completely mixed model and is such that $k_o$ = 0.61 lb-moles of sulfur/lb of calcium/minute. We have no rationalization of the point with apparently unusually high rate of reaction.

With the system discussed above for reference, other sets of data on the performance of FBC systems are being evaluated.

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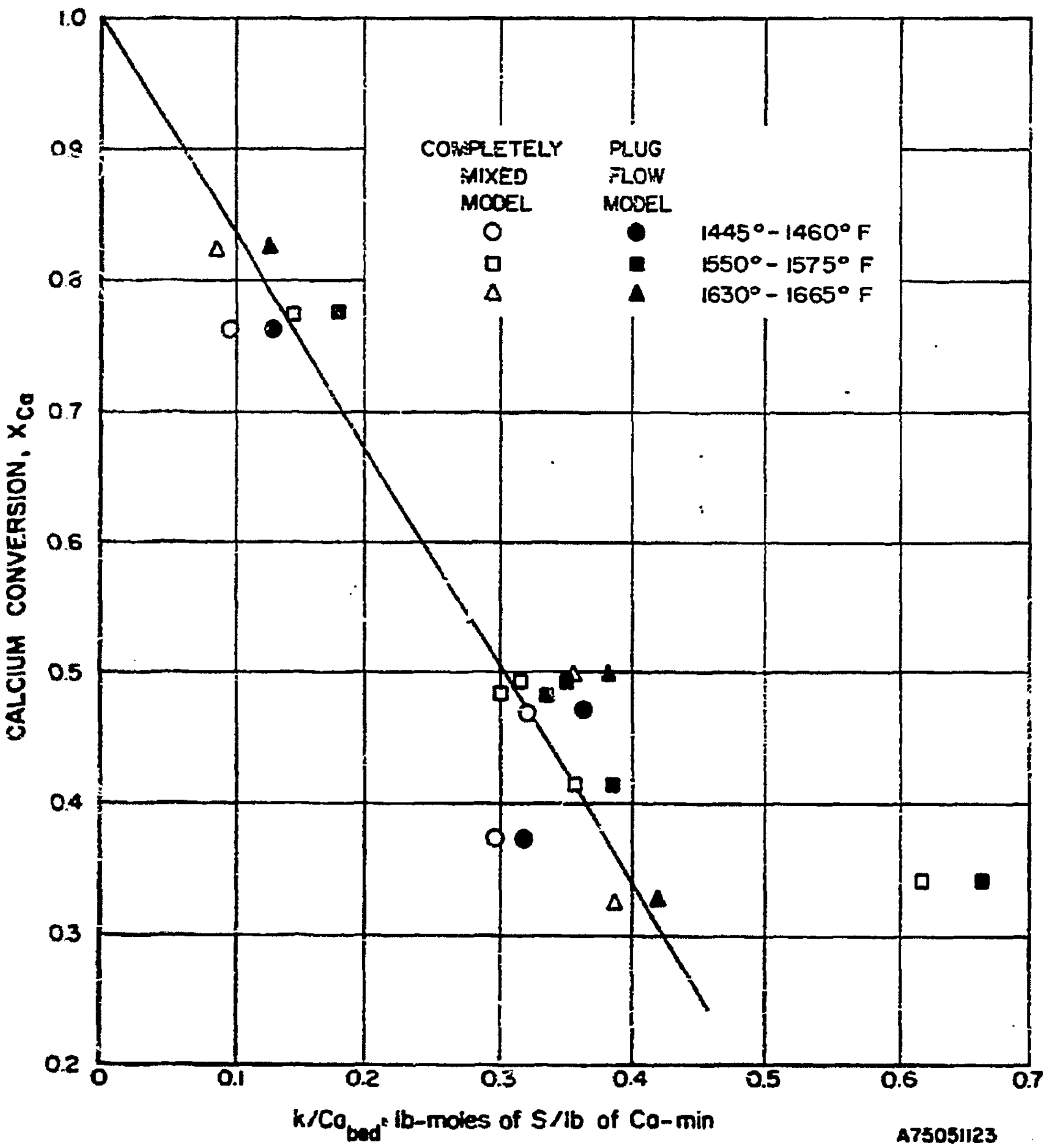


Figure 16. DEPENDENCE OF FBC SULFUR RECOVERY RATE CONSTANT ON CONVERSION [ANL Data[3] for Arkwright Mine Coal with Tymochtee Dolomite at 8 atm.]

2. High-Temperature Combustion (MHD)

A meeting was held with Mr. Daryl Bomkamp of Argonne National Laboratory to determine the type of data being collected by ANL on MHD and the best means of coordinating ANL's work on MHD data collection with the Data Book project. He indicated that the data on electrical properties of the gases at high temperature will be available before the end of the year.

It was decided to prepare an outline of the MHD data section so that information can be collected in an orderly manner.

3. References Cited

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E. COAL, CHAR, AND OIL SHALE PROPERTIES

1. Coal Data Compilation

The Bureau of Mines has recently published a compilation of coal reserve data for underground mining in states east of the Mississippi River,[18] and another for strippable coal in the whole of the United States.[17] With data from these and other publications we have prepared a table with region-by-seam entries of deposits seemingly large enough to support coal conversion plants (Table 4). The purpose of the table is to provide a basis for choosing the coal samples that will be included in our final compilation of data.

Terms used in the estimation of the amount of coal in the deposits are defined in the cited publications as follows:[17,18]

"Coal resource and coal reserve classification is presently based upon three criteria — (1) thickness of the coalbed, (2) depth of the coalbed, and (3) the reliability of the data upon which the estimate was based. The criteria for each category are described in the following paragraphs.

"Identified Resources — Include beds of bituminous coal and anthracite 14 inches or more thick and beds of subbituminous coal and lignite 30 inches or more thick that occur at depths to 3,000 feet, the existence and quantity of which have been delineated within specified degrees of geologic assurance as measured, indicated, or inferred. Include also thinner and/or deeper beds that presently are being mined or for which there is evidence that they could be mined commercially.

"Undiscovered Resources — Include beds of bituminous coal and anthracite 14 inches or more thick and beds of subbituminous coal and lignite 30 inches or more thick that are presumed to occur in unmapped and unexplored areas reasonably near the surface (to depths of 3,000 feet) or in deeper structural basins of depths between 3,000 feet and 6,000 feet. All undiscovered coal resources in the United States are considered to be in the hypothetical category.

"Total Resources — Include in this category the sum of the identified and undiscovered resources.

"Reserve Base — Include in-place beds of bituminous coal and anthracite 28 inches or more thick and beds of subbituminous coal 60 inches or more thick that occur at depths to 1,000 feet. Include also thinner and/or deeper beds that presently are being mined or for which there is evidence that they could be mined commercially at this time. Include beds of lignite 60 inches or more thick that can be surface mined — generally those that occur at depths no greater than 120 feet. Also, it includes only coal from measured and indicated categories of reliability.

"Reserve or Recoverable Reserve — Include that portion of the reserve base that can be mined legally and economically at the time of classification.

"Subeconomic Resources — Include all identified resources that do not fall into the reserve category. Include in this category beds of bituminous coal and anthracite 14 inches to 28 inches thick and beds of subbituminous coal 30 inches to 60 inches thick that occur at depths to 1,000 feet. Include also beds of bituminous coal and anthracite 14 inches or more thick and beds of subbituminous coal 30 inches or more thick that occur at depths between 1,000 and 3,000 feet. Include lignite beds 30 inches or more thick that cannot be surface mined, generally those that occur at depths greater than 120 feet, and lignite beds 30 inches to 60 inches thick that can be surface mined. Include the nonrecoverable portion of the reserve base.

"The following criteria for measured, indicated, and inferred are applicable to both the reserve and subeconomic resource components:

"Measured — Tonnage is computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coalbeds, the points of observation are, in general, no greater than one-half mile apart. Generally, measured reserves are synonymous with proved reserves of other reports.

"Indicated — Tonnage is computed partly from specified measurements and partly from projections of visible data for a reasonable distance on the basis of geologic evidence. In general, the points of observation are about 1 mile apart, but they may be as much as 1-1/2 miles apart for beds of known continuity. Generally, indicated reserves are equivalent to probable reserves of other reports.

"Inferred — Quantitative estimates are based largely on broad knowledge of the geological character of the bed or region, and few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation for which there is geologic evidence. In general, inferred coal lies more than 1-1/2 miles from the outcrop or from points for which mining or drilling information is available, but usually does not exceed 4 miles, modified in practice by geological considerations.

"Demonstrated Reserves — Include in this category the sum of the measured and indicated reserves."

Terms applicable to strip mining are —

"Recoverable strippable resource — The remaining strippable resource multiplied by a mining recovery factor.

"Recovery factor — The proportion of the resource that is technically capable of being produced, usually expressed as a percent.

"Reserves — The measured portion of the resource that is recoverable (minable coal) with the technology and equipment presently available or that may be made available in the foreseeable future.

"Remaining strippable resource — The total original coal resource under a specified maximum depth of overburden and reduced by depletion computed from past strip and auger mining production.

"Resource — The estimated total quantity of all coal in place, having a specified minimum coalbed thickness and under a specified maximum depth of overburden.

"Strippable reserves — The recoverable strippable resource adjusted to conform to the stripping ratio, which varies by area. Coal that cannot be mined because of the proximity of natural or manmade features is also excluded. These reserves are the actual raw tons of coal that can be removed from the ground. They are also assumed to be all 'available' tonnages and are not divided into 'measured', indicated', and 'inferred' reserves."

For underground mining, the reserve base, including measured and indicated deposits, is reported in the cited publications by county and seam.

In the Eastern United States, counties rarely extend more than about 30 miles. A reserve base of 300 million tons of coal in a county, from which 150 million tons is usually estimated to be producible, was taken as sufficient to support a conversion plant for 20 years. This criterion was applied for the inclusion of a county in our list. Seams contributing 10% or more to the county total were then listed under each county. Run-of-mine samples may occasionally consist of coal from more than one seam being simultaneously mined, but channel samples are always taken from a single seam. This necessitates the listing of seams in our table.

In the Western States, counties often extend 60 miles or more, and we consider listing by deposit or field to be necessary.

In the Bureau of Mines publication on coal resources for strip-mining,[17] amounts of measured and indicated strippable reserve (estimated producible amounts) are given for counties and for seams, but usually not by seam in each county or field. Breakdown of each county or field by seams (when available) was obtained from state geological survey publications; these amounts may include inferred deposits, as indicated in the table. A criterion of 150 million tons of strippable reserve (SR) for counties in Eastern States and counties or fields (where applicable) in Western States was adopted for the table. When data were available (Illinois and Montana), inferred deposits were included for application of the criterion. In other states, the criterion was applied to the strippable reserve values of the Bureau of Mines publication.[17]

No Bureau of Mines or similar publication is available for underground mining in the Western States. However, such a compilation is not needed at present because additional mining for lignite and subbituminous coal in the west is likely to be limited to stripping. However, underground mining may have to be considered for liquefaction, for which bituminous coal is preferable.

2. <u>Penn State Data</u>

We have received analytical and other data on 50 coal deposits from Penn State. The data are being tabulated in a suitable form for presentation in the Data Book. We will check the deposits analyzed by Penn State against the list of deposits presented in Table 4. The coal properties data will be presented in next month's report.

Table 4. Part 1. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| | | ARIZONA | | |
| Navajo County[b] | SR | MI | 387 | 17 |
| Black Mesa Field | RSR | MI | 400 | 17 |
| Wepo Group (8 Seams) | SR | MI | 387 | 17 |
| | | COLORADO | | |
| Routt County | SR | MI | 330 | 17 |
| Yampa Field, 20-mile deposit | RSR | MI | 330 | 17 |
| E | | | | 2 |
| D | | | | 2 |
| C, Webber, Butcher Knife, Rice Mine | | | | 2 |
| No. 3, B, Bear River, Sun Mine | | | | 2 |
| No. 2, A, Pinnacle | | | | 2 |
| No. 1, Brooks, Curtis | | | | 2 |
| | | ILLINOIS | | |
| Adams County | SR | MII | 619.275 | 10 |
| | SR | MI | 54.5 | 17 |
| Colchester (No. 2) | SR | MII | 619.275 | 10 |

Note: Bases of the amounts of coal reported in the table are indicated by the following symbols:

URB — underground reserve base

SR — strippable reserve

RSR — recoverable strippable resource

MI — value includes coal of measured and indicated reliability of estimate

MII — value includes coal of measured, indicated, and inferred reliability of estimate.

[a] All undesignated coal is bituminous.

[b] Subbituminous.

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Table 4, Part 2. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Bond County | URB | MI | 1831.5 | 18 |
| Herrin (No. 6) | URB | MI | 1752.1 | 18 |
| Brown County | SR | MII | 386.496 | 10 |
| | SR | MI | 37.1 | 17 |
| Colchester (No. 2) | SR | MII | 386.496 | 10 |
| Bureau County | URB | MI | 1029.44 | 18 |
| | SR | MI | 73.90 | 17 |
| | SR | MII | 452.4 | 16 |
| Danville (No. 7) | URB | MI | 186.30 | 18 |
| | SR | MII | 183.223 | 16 |
| Herrin (No. 6) | URB | MI | 250.18 | 18 |
| | SR | MII | 262.115 | 16 |
| Colchester (No. 2) | URB | MI | 592.96 | 18 |
| Christian County | URB | MI | 3347.44 | 18 |
| Herrin (No. 6) | URB | MI | 2651.30 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 617.21 | 18 |
| Clinton County | URB | MI | 1322.46 | 18 |
| Herrin (No. 6) | URB | MI | 1320.34 | 18 |
| Crawford County | URB | MI | 442.62 | 18 |
| Danivlle (No. 7) | URB | MI | 70.58 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 105.29 | 18 |
| James Town | URB | MI | 80.66 | 18 |
| Seelyville | URB | MI | 151.24 | 18 |
| Douglas County | URB | MI | 411.68 | 18 |
| Herrin (No. 6) | URB | MI | 390.61 | 18 |
| Edgar County | URB | MI | 1749.89 | 18 |
| Danville (No. 7) | URB | MI | 511.39 | 18 |
| Herrin (No. 6) | URB | MI | 333.50 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 332.01 | 18 |
| Seelyville | URB | MI | 572.99 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 3. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Fayette County | URB | MI | 1173.72 | 18 |
| Danville (No. 7) | URB | MI | 296.02 | 18 |
| Herrin (No. 6) | URB | MI | 877.70 | 18 |
| Franklin County | URB | MI | 3038.43 | 18 |
| Herrin (No. 6) | URB | MI | 1875.68 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 831.79 | 18 |
| Fulton County | SR | MII | 2120.797 | 16 |
| | SR | MI | 330.2 | 17 |
| Herrin (No. 6) | SR | MII | 249.286 | 17 |
| Harrisburg-Springfield (No. 5) | SR | MII | 702.386 | 17 |
| Colchester (No. 2) | SR | MII | 1104.785 | 17 |
| Gallatin County | URB | MI | 1761.08 | 18 |
| | SR | MI | 48.300 | 17 |
| | SR | MII | 237.754 | 12 |
| Herrin (No. 6) | URB | MI | 557.13 | 18 |
| | SR | MII | 121.905 | 12 |
| Harrisburg-Springfield (No. 5) | URB | MI | 582.38 | 18 |
| | SR | MII | 115.849 | 12 |
| DeKoven | URB | MI | 266.05 | 18 |
| Davis | URB | MI | 348.63 | 18 |
| Greene County | SR | MII | 597.922 | 14 |
| | SR | MI | 74.1 | 17 |
| Herrin (No. 6) | SR | MII | 97.274 | 14 |
| Colchester (No. 2) | SR | MII | 500.648 | 14 |
| Grundy County | SR | MII | 356.077 | 15 |
| | SR | MI | 46.3 | 17 |
| Summum (No. 4) | SR | MII | 43.558 | 15 |
| Colchester (No. 2) | SR | MII | 312.519 | 15 |
| Hamilton County | URB | MI | 2440.16 | 18 |
| Herrin (No. 6) | URB | MI | 1489.80 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 950.36 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 4. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Henry County | SR | MII | 577.265 | 16 |
| | SR | MI | 112.1 | 17 |
| Danville (No. 7) | SR | MII | 58.878 | 16 |
| Herrin (No. 6) | SR | MII | 255.435 | 16 |
| Colchester (No. 2) | SR | MII | 242.952 | 16 |
| Jackson County | SR | MII | 391.321 | 13 |
| | SR | MI | 96.400 | 17 |
| Herrin (No. 6) | SR | MII | 149.318 | 13 |
| Harrisburg-Springfield (No. 5) | SR | MII | 99.843 | 13 |
| Murphysboro | SR | MII | 130.278 | 13 |
| Jefferson County | URB | MI | 1800.56 | 18 |
| Herrin ( No. 6) | URB | MI | 1305.60 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 494.96 | 18 |
| Jersey County | SR | MII | 220.461 | 14 |
| | SR | MI | 28.10 | 17 |
| Herrin (No. 6) | SR | MII | 57.336 | 14 |
| Colchester (No. 2) | SR | MII | 163.125 | 14 |
| Knox County | SR | MII | 1583.379 | 16 |
| | SR | MI | 188.4 | 17 |
| Herrin ( No. 6) | SR | MII | 257.066 | 16 |
| Harrisburg-Springfield (No. 5) | SR | MII | 626.509 | 16 |
| Colchester (No. 2) | SR | MII | 697.281 | 16 |
| LaSalle County | URB | MI | 1082.96 | 18 |
| | SR | MI | 39.300 | 17 |
| | SR | MII | 280.420 | 15 |
| Danville (No. 7) | URB | MI | 370.77 | 18 |
| Herrin (No. 6) | SR | MII | 70.204 | 15 |
| Colchester (No. 2) | URB | MI | 620.16 | 18 |
| | SR | MII | 209.712 | 15 |
| Lawrence County | URB | MI | 893.64 | 18 |
| Danville ( No. 7) | URB | MI | 143.44 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 5. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Harrisburg-Springfield (No. 5) | URB | MI | 272.52 | 18 |
| James Town | URB | MI | 152.85 | 18 |
| Livingston County | URB | MI | 586.49 | 18 |
| Danville (No. 7) | URB | MI | 272.05 | 18 |
| Colchester (No. 2) | URB | MI | 265.50 | 18 |
| Logan County | URB | MI | 813.68 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 813.68 | 18 |
| McLean County | URB | MI | 420.95 | 18 |
| Danville (No. 7) | URB | MI | 231.68 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 107.12 | 18 |
| Colchester (No. 2) | URB | MI | 82.15 | 18 |
| Macon County | URB | MI | 439.31 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 420.39 | 18 |
| Macoupin County | URB | MI | 3421.12 | 18 |
| | SR | MI | 46.10 | 17 |
| | SR | MII | 275.605 | 14 |
| Herrin (No. 6) | URB | MI | 3006.52 | 18 |
| | SR | MII | 250.810 | 14 |
| Colchester (No. 2) | URB | MI | 259.26 | 18 |
| | SR | MII | 24.795 | 14 |
| Madison County | SR | MI | 134 | 17 |
| | SR | MII | 615.35 | 14 |
| Herrin (No. 6) | SR | MII | 449.283 | 14 |
| Colchester (No. 2) | SR | MII | 166.067 | 14 |
| Marion County | URB | MI | 421 | 18 |
| Herrin (No. 6) | URB | MI | 319.35 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 101.65 | 18 |
| McDonough County | SR | MI | 58.400 | 18 |
| | SR | MII | 584.320 | 10 |
| Colchester (No. 2) | SR | MII | 584.320 | 10 |

[a] All undesignated coal is bituminous.

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Table 4, Part 6. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Marshall County | URB | MI | 357.98 | 18 |
| Danville (No. 7) | URB | MI | 77.62 | 18 |
| Colchester (No. 2) | URB | MI | 270.61 | 18 |
| Montgomery County | URB | MI | 3966.5 | 18 |
| Herrin (No. 6) | URB | MI | 3272.28 | 18 |
| Rock Island (No. 1) | URB | MI | 208.20 | 18 |
| Menard County | URB | MI | 1460.0 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 1460.0 | 18 |
| Morgan County | SR | MI | 111 | 17 |
| | SR | MII | 827.615 | 14 |
| Herrin (No. 6) | SR | MII | 485.880 | 14 |
| Colchester (No. 2) | SR | MII | 341.735 | 14 |
| Peoria County | SR | MI | 355.1 | 17 |
| | SR | MII | 2174.236 | 16 |
| Danville (No. 7) | SR | MII | 282.537 | 16 |
| Herrin ( No. 6) | SR | MII | 1058.371 | 16 |
| Harrisburg-Springfield (No. 5) | SR | MII | 725.549 | 16 |
| Colchester (No. 2) | SR | MII | 107.779 | 16 |
| Perry County | URB | MI | 1201.02 | 18 |
| | SR | MI | 291.7 | 17 |
| | SR | MII | 1106.041 | 13 |
| Herrin (No. 6) | URB | MI | 1025.37 | 18 |
| | SR | MII | 896.767 | 13 |
| Harrisburg-Springfield (No. 5) | URB | MI | 175.65 | 18 |
| Harrisburg-Springfield (No. 5) | SR | MII | 209.274 | 13 |
| Putnam County | URB | MI | 588.89 | 18 |
| Danville ( No. 7) | URB | MI | 181.01 | 18 |
| Herrin (No. 6) | URB | MI | 78.88 | 18 |
| Colchester (No. 2) | URB | MI | 329.0 | 18 |
| St. Clair County | URB | MI | 951.35 | 18 |
| | SR | MI | 395 | 17 |

[a] All undesignated coal is bituminous.

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Table 4, Part 7. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| | SR | MII | 1249.123 | 13 |
| Herrin (No. 6) | URB | MI | 932.07 | 18 |
| | SR | MII | 1249.123 | 13 |
| Randolph County | SR | MI | 108.50 | 17 |
| | SR | MII | 455.029 | 13 |
| Herrin (No. 6) | SR | MII | 279.139 | 13 |
| Harrisburg-Springfield (No. 5) | SR | MII | 175.890 | 13 |
| Saline County | URB | MI | 2553.37 | 18 |
| | SR | MI | 78 | 17 |
| | SR | MII | 545.410 | 12 |
| Herrin (No. 6) | URB | MI | 1076.77 | 18 |
| Herrin (No. 5) | SR | MII | 284.572 | 12 |
| Harrisburg-Springfield (No. 5) | URB | MI | 814.92 | 18 |
| | SR | MII | 93.442 | 12 |
| DeKoven | URB | MI | 215.82 | 18 |
| Davis | URB | MI | 428.02 | 18 |
| Cutler | SR | MII | 78.44 | 12 |
| Sangamon County | URB | MI | 3540.03 | 18 |
| Herrin (No. 6) | URB | MI | 1559.11 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 1955.33 | 18 |
| Schuyler County | SR | MI | 91.6 | 17 |
| | SR | MII | 719.544 | 10 |
| Harrisburg-Springfield (No. 5) | SR | MII | 113.394 | 10 |
| Colchester (No. 2) | SR | MII | 606.150 | 10 |
| Shelby County | URB | MI | 712.47 | 18 |
| Danville (No. 7) | URB | MI | 125.27 | 18 |
| Herrin (No. 6) | URB | MI | 534.09 | 18 |
| Stark County | SR | MI | 94.0 | 17 |
| | SR | MII | 525.951 | 16 |
| Danville (No. 7) | SR | MII | 57.703 | 16 |
| Herrin (No. 6) | SR | MII | 442.467 | 16 |

[a] All undesignated coal is bituminous.

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Table 4, Part 8. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Tazewell County | SR | MI | 24.3 | 17 |
| | SR | MII | 150.005 | 16 |
| Herrin (No. 6) | SR | MII | 69.680 | 16 |
| Harrisburg-Springfield (No. 5) | SR | MII | 37.05 | 16 |
| Colchester (No. 2) | SR | MII | 39.092 | 16 |
| Vermilion County | URB | MI | 1544.28 | 18 |
| Danville (No. 7) | URB | MI | 963.12 | 18 |
| Herrin (No. 6) | URB | MI | 536.64 | 18 |
| Warren County | SR | MI | 39.30 | 17 |
| | SR | MII | 159.758 | 16 |
| Colchester (No. 2) | SR | MII | 158.951 | 16 |
| Washington County | URB | MI | 1555.21 | 18 |
| Herrin (No. 6) | URB | MI | 1543.1 | 18 |
| White County | URB | MI | 992.47 | 18 |
| Herrin (No. 6) | URB | MI | 360.64 | 18 |
| Harrisburg-Springfield (No. 5) | URB | MI | 626 | 18 |
| Williamson County | URB | MI | 1573.10 | 18 |
| | SR | MI | 161.1 | 17 |
| | SR | MII | 651.820 | 12 |
| Herrin (No. 6) | URB | MI | 398.30 | 18 |
| Herrin (No. 6) | SR | MII | 290.718 | 12 |
| Harrisburg-Springfield (No. 5) | URB | MI | 690.5 | 18 |
| Harrisburg-Springfield (No. 5) | SR | MII | 200.268 | 12 |
| DeKoven | URB | MI | 316.71 | 18 |
| Davis | URB | MI | 109.37 | 18 |
| INDIANA | | | | |
| Gibson County | URB | MI | 1301.54 | 18 |
| Danville (VII) | URB | MI | 165.47 | 18 |
| Hymera (VI) | URB | MI | 252.68 | 18 |
| Springfield (V) | URB | MI | 883.39 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 9. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Knox County | URB | MI | 1453.48 | 18 |
| Danville (VII) | URB | MI | 145.55 | 18 |
| Hymera (VI) | URB | MI | 473.80 | 18 |
| Springfield (V) | URB | MI | 652.49 | 18 |
| Survant (IV) | URB | MI | 156.60 | 18 |
| Posey County | URB | MI | 720.90 | 18 |
| Danville (VII) | URB | MI | 95.89 | 18 |
| Hymera (VI) | URB | MI | 213.50 | 18 |
| Springfield (V) | URB | MI | 292.30 | 18 |
| Seelyville (III) | URB | MI | 119.21 | 18 |
| Sullivan County | URB | MI | 1922.31 | 18 |
| | SR | | 154.622 | 17 |
| Danville (VII) | URB | MI | 259.36 | 17 |
| Danville (VII) | SR | | | |
| Hymera (VI) | URB | MI | 539.43 | 17 |
| | SR | | | |
| Springfield (V) | URB | MI | 532.58 | 17 |
| | SR | | | |
| Survant (IV) | SR | MI | 264.53 | 17 |
| Seelyville (III) | SR | MI | 326.41 | 17 |
| Vanderburgh County | URB | MI | 451.36 | 18 |
| Springfield (V) | URB | MI | 233.80 | 18 |
| Seelyville (III) | URB | MI | 202.51 | 18 |
| Vermillion County | URB | MI | 497.63 | 18 |
| Springfield (V) | URB | MI | 99.53 | 18 |
| Survant (IV) | URB | MI | 106.90 | 18 |
| Seelyville (III) | URB | MI | 269.35 | 18 |
| Vigo County | URB | MI | 1212.14 | 18 |
| Danville (VII) | URB | MI | 320.43 | 16 |
| Springfield (V) | URB | MI | 452.04 | 18 |
| Survant (IV) | URB | MI | 110.02 | 18 |
| Seelyville (III) | URB | MI | 269.02 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 10. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Warrick County | URB | MI | 532.57 | 18 |
| | SR | MI | 152.554 | 17 |
| Danville (VII) | URB | MI | 90.49 | 18 |
| Hymera (VI) | URB | MI | 81.15 | 18 |
| | SR | | | |
| Springfield (V) | URB | MI | 332.97 | 18 |
| | SR | | | |
| **IOWA** | | | | |
| Unnamed County | SR | MI | 180 | 17 |
| Unnamed Seam | SR | MI | 180 | 17 |
| **KENTUCKY (EAST)** | | | | |
| Floyd County | URB | MI | 952.57 | 18 |
| Upper Elkhorn (No. 3) | URB | MI | 334.80 | 18 |
| Upper Elkhorn (No. 2) | URB | MI | 226.93 | 18 |
| Upper Elkhorn (No. 1) | URB | MI | 296.22 | 18 |
| Harlan County | URB | MI | 1408.51 | 18 |
| Hazard (No. 5A) | URB | MI | 154.05 | 18 |
| Upper Elkhorn (No. 3) | URB | MI | 206.77 | 18 |
| Upper Elkhorn (No. 2) | URB | MI | 239.13 | 18 |
| Upper Elkhorn (No. 1) | URB | MI | 362.74 | 18 |
| Lower Elkhorn | URB | MI | 132.73 | 18 |
| Knott County | URB | MI | 1248.37 | 18 |
| Hazard (No. 7) | URB | MI | 264.67 | 18 |
| No. 7 | URB | MI | 258.94 | 18 |
| Upper Elkhorn (No. 3) | URB | MI | 424.58 | 18 |
| Upper Elkhorn (No. 2) | URB | MI | 88.49 | 18 |
| Lesie County | URB | MI | 619.50 | 18 |
| Hazard (No. 5A) | URB | MI | 187.82 | 18 |
| Fire Clay | URB | MI | 125.37 | 18 |
| No. 7 | URB | MI | 197.92 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part II. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Letcher County | URB | MI | 730.36 | 18 |
| No. 7 | URB | MI | 180.73 | 18 |
| Mason (Mingo) | URB | MI | 75.36 | 18 |
| Upper Elkhorn (No. 3) | URB | MI | 244.04 | 18 |
| Lower Elkhorn | URB | MI | 82.84 | 18 |
| Perry County | URB | MI | 560.22 | 18 |
| Hazard (No. 7) | URB | MI | 148.42 | 18 |
| No. 7 | URB | MI | 263.01 | 18 |
| Mason (Mingo) | URB | MI | 62.35 | 18 |
| Pike County | URB | MI | 2170.01 | 18 |
| Upper Elkhorn (No. 3) | URB | MI | 194.01 | 18 |
| Upper Elkhorn (No. 2) | URB | MI | 438.59 | 18 |
| Upper Elkhorn (No. 1) | URB | MI | 194.94 | 18 |
| Lower Elkhorn | URB | MI | 668.00 | 18 |
| KENTUCKY (WEST) | | | | |
| Henderson County | URB | MI | 1503.64 | 18 |
| | SR | MI | 165 | 17 |
| No. 9 | URB | MI | 1411.14 | 18 |
| Hopkins County | URB | MI | 1805.67 | 18 |
| | SR | MI | 165 | 17 |
| No. 14 | SR | | | |
| No. 12 | URB | MI | 170.53 | 18 |
| No. 12 | SR | | | |
| No. 11 | URB | MI | 154.88 | 18 |
| No. 11 | SR | | | |
| No. 9 | URB | MI | 1145.34 | 18 |
| No. 9 | SR | | | |
| McLean County | URB | MI | 723.65 | 18 |
| No. 9 | URB | MI | 627.25 | 18 |
| No. 6 | URB | MI | 84.34 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 12. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Muhlenberg County | URB | MI | 898.37 | 18 |
| | SR | MI | 258 | 17 |
| No. 12 | URB | MI | 158.24 | 18 |
| No. 12 | SR | | | |
| No. 11 | URB | MI | 176.08 | 18 |
| No. 11 | SR | | | |
| No. 9 | URB | MI | 535.81 | 17 |
| Ohio County | SR | MI | 161 | 17 |
| No. 14 | SR | | | |
| No. 11 | SR | | | |
| Union County | URB | MI | 1926.29 | 18 |
| No. 11 | URB | MI | 338.74 | 18 |
| No. 9 | URB | MI | 1286.43 | 18 |
| No. 6 | URB | MI | 182.64 | 18 |
| Webster County | URB | MI | 1436.44 | 18 |
| No. 9 | URB | MI | 1194.42 | 18 |
| | | MARYLAND | | |
| Allegany County | URB | MI | 378.58 | 18 |
| Freeport | URB | MI | 135.41 | 18 |
| Lower Bakers Town | URB | MI | 82.27 | 18 |
| Upper Freeport | URB | MI | 102.63 | 18 |
| Garrett County | URB | MI | 523.33 | 18 |
| Lower Bakerstown | URB | MI | 132.79 | 18 |
| Upper Freeport | URB | MI | 312.99 | 18 |
| Upper Kittanning | URB | MI | 55.98 | 18 |
| | | MONTANA | | |
| Bighorn County[b] | SR | MI | 1009 | 17 |
| Deckerfield | RSR | MI | 816 | 17 |
| Dietz | SR | MI | 540 | 17 |
| Rolandfield | RSR | MI | 251 | 17 |
| Roland | SR | MI | 126 | 17 |
| Hangingwoman Creek Field | RSR | MI | 265 | 17 |
| Dietz 1 | ST | MI | 132 | 17 |

[a] All undesignated coal is bituminous.
[b] Subbituminous.

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Table 4, Part 13. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Sarpy Creek Field | RSR | MI | 1500 | 5 |
| Wolf Mountains (Indian Reservation) | RSR | MII | 1922 | 5 |
| Powder River County[b] | SR | MI | 1405 | 17 |
| Moorhead Field | RSR | MI | 1200 | 17 |
| Canyonbed | SR | MI | 100 | 17 |
| Dietz | SR | MI | 100 | 17 |
| Anderson | SR | MI | 400 | 17 |
| Otter Creek Field | RSR | MI | 915 | 17 |
| Knoblock | SR | MI | 608 | 17 |
| Ashland (Knoblock) | RSR | MI | 2595 | 5 |
| Powder River County[c] | SR | MI | 1245 | 17 |
| Broadus Field | RSR | MI | 378 | 17 |
| Broadus | SR | MI | 240 | 17 |
| Sonnette Field | RSR | MI | 165 | 17 |
| Pawnee | SR | MI | 95 | 17 |
| Pumpkin Creek Field | RSR | MI | 1520 | 17 |
| Sawyer | SR | MI | 910 | 17 |
| Rosebud County[b] | SR | MI | 922 | 17 |
| Birney Coal Field | RSR | MI | 160 | 17 |
| Brewster-Arnold | SR | MI | 28 | 17 |
| Poker Jim O'Dell Field | RSR | MI | 200 | 17 |
| Knoblock | SR | MI | 100 | 17 |
| Rosebud Creek Field[c] | RSR | MI | 168 | 17 |
| Terret | SR | MI | 80 | 17 |
| Colstrip Field[b] | RSR | MI | 1057 | 17 |
| Rosebud | SR | MI | 718 | 17 |
| McCone County[c] | SR | MI | 410 | 17 |
| Weldon-Timber Creek | RSR | MI | 579 | 17 |
| S-Bed | SR | MI | 290 | 17 |
| Redwater Field | RSR | MI | 240 | 17 |
| S-Bed | SR | MI | 120 | 17 |
| Powder River County[b] | | | | |
| Foster Creek Field | RSR | MI | 472 | 17 |
| Knoblock | SR | MI | 224 | 17 |

[a] All undesignated coal is bituminous.

[b] Subbituminous.

[c] Lignite.

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Table 4, Part 14. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Dawson County[c] | SR | MI | 180 | 17 |
| Thirteen Mile Creek Field | RSR | MI | 180 | 17 |
| Pust | SR | MI | 180 | 17 |
| Richland County[c] | SR | MI | 109 | 17 |
| Breezy Flat Field | RSR | MI | 160 | 17 |
| Pust | SR | MI | 80 | 17 |
| O'Brian-Alkalie Creek | RSR | MII | 150 | 5 |
| Fox Lake Field | RSR | MI | 46 | 5 |
| Pust | SR | MI | 29 | 5 |
| Roosevelt County[c] | SR | MI | 204 | 17 |
| Fort Kipp Field | RSR | MI | 265 | 17 |
| Fort Peck | SR | MI | 73 | 17 |
| Fort Kipp | SR | MI | 131 | 17 |
| Sheridan County[c] | SR | MI | 460 | 17 |
| Reserve Field | RSR | MI | 197 | 17 |
| Reserve | SR | MI | 100 | 17 |
| Coalridge Field | RSR | MI | 480 | 17 |
| Coalridge | SR | MI | 360 | 17 |
| Wibaux County[c] | SR | MI | 462 | 17 |
| Wibaux Field | RSR | MI | 603 | 17 |
| C | SR | MI | 426 | 17 |
| Four Buttes Field | RSR | MI | 730 | 17 |
| C | SR | MI | 636 | 17 |
| | NEW MEXICO | | | |
| San Juan County[b] | SR | MI | 2370 | 17 |
| Navajo Field | RSR | MI | 2400 | 8 |
| Fruitland Field | RSR | MI | 158 | 8 |
| Bisti and Star Lake Areas | RSR | MI | 635 | 8 |

[a] All undesignated coal is bituminous.

[b] Subbituminous.

[c] Lignite.

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Table 4, Part 15. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| | | NORTH DAKOTA | | |
| Bowman County[c] | SR | MI | 2130 | 17 |
| Bowman Field | RSR | MI | 182 | 17 |
| Harmon | SR | MI | 101 | 17 |
| Gascogne Field | RSR | MI | 218 | 17 |
| Harmon | SR | MI | 112 | 17 |
| Golden Valley County[c] | SR | MI | 224 | 17 |
| Beach Field | RSR | MI | 368 | 17 |
| C | SR | MI | 224 | 17 |
| Mercer County[c] | SR | MI | 312 | 17 |
| Renner's Cove Deposit | RSR | MI | 77.7 | 9 |
| Zap | RSR | MI | 77.7 | 9 |
| Hazen Deposit (9) | RSR | MI | | |
| Hazen | RSR | MI | 71.1 | 9 |
| Knife River Deposit | RSR | MI | 624 | 17 |
| Beulah-Zap | SR | MI | 295 | 17 |
| Slope County[c] | SR | MI | 594 | 17 |
| Harmon Deposit | RSR | MI | 777 | 17 |
| Harmon | SR | MI | 263 | 17 |
| Slope I Deposit | RSR | MI | 136 | 17 |
| Harmon | SR | MI | 102 | 17 |
| Slope II Deposit | RSR | MI | 112 | 17 |
| Harmon | SR | MI | 56 | 17 |
| Slope III Deposit | RSR | MI | 120 | 17 |
| T-Cross | SR | MI | 40 | 17 |
| Slope IV Deposit | RSR | MI | 160 | 17 |
| Hansen | SR | MI | 133 | 17 |
| Stark County[c] | SR | MI | 286 | 17 |
| Dickenson Deposit | RSR | MI | 640 | 17 |
| D | SR | MI | 210 | 17 |
| E | SR | MI | 160 | 17 |

[a] All undesignated coal is bituminous.

[b] Subbituminous.

[c] Lignite.

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Table 4, Part 16. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| | | OHIO | | |
| Athens County | URB | MI | 1326.97 | 18 |
| Pittsburgh (No. 8) | URB | MI | 135.52 | 18 |
| No. 7 | URB | MI | 216.00 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 962.58 | 18 |
| Belmont County | URB | MI | 3927.08 | 18 |
| No. 9 | URB | MI | 1081.96 | 18 |
| Pittsburgh (No. 8) | URB | MI | 2431.25 | 18 |
| Carroll County | URB | MI | 757.73 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 353.14 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 157.77 | 18 |
| Columbiana County | URB | MI | 747.93 | 18 |
| No. 7 | URB | MI | 561.80 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 115.72 | 18 |
| Gallia County | URB | MI | 339.63 | 18 |
| Pittsburgh (No. 8) | URB | MI | 122.88 | 18 |
| No. 7 | URB | MI | 36.47 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 87.37 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 48.77 | 18 |
| Guernsey County | URB | MI | 1184.43 | 18 |
| No. 7 | URB | MI | 597.40 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 422.85 | 18 |
| Harrison County | URB | MI | 1523.27 | 18 |
| Pittsburgh (No. 8) | URB | MI | 258.90 | 18 |
| No. 7 | URB | MI | 267.74 | 18 |
| No. 6A | URB | MI | 391.05 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 507.92 | 18 |

[a] All undesignated coal is bituminous.

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Table 4. Part 17. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Jefferson County | URB | MI | 1356.24 | 18 |
| Pittsburgh (No. 8) | URB | MI | 327.72 | 18 |
| No. 7 | URB | MI | 168.79 | 18 |
| No. 6A | URB | MI | 729.13 | 18 |
| Lawrence County | URB | MI | 477.03 | 18 |
| No. 7 | URB | MI | 99.21 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 166.95 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 164.98 | 18 |
| Mahoning County | URB | MI | 308.15 | 18 |
| Lower Kittanning (No. 6) | URB | MI | 285.48 | 18 |
| Meigs County | URB | MI | 396.32 | 18 |
| No. 8A | URB | MI | 376.94 | 18 |
| Monroe County | URB | MI | 468.36 | 18 |
| Pittsburgh (No. 8) | URB | MI | 413.33 | 18 |
| Morgan County | URB | MI | 435.12 | 18 |
| No. 9 | URB | MI | 173.00 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 208.21 | 18 |
| Muskingum County | URB | MI | 720.78 | 18 |
| No. 7 | URB | MI | 83.68 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 536.99 | 18 |
| Noble County | URB | MI | 570.02 | 18 |
| No. 9 | URB | MI | 387.22 | 18 |
| No. 7 | URB | MI | 168.17 | 18 |
| Perry County | URB | MI | 644.97 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 515.41 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 101.26 | 18 |
| Stark County | URB | MI | 376.61 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 162.15 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 109.71 | 18 |
| No. 4 | URB | MI | 99.27 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 18. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Tuscarawas County | URB | MI | 841.20 | 18 |
| No. 7 | URB | MI | 101.89 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 523.18 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 187.85 | 18 |
| Vinton County | URB | MI | 301.20 | 18 |
| Middle Kittanning (No. 6) | URB | MI | 85.35 | 18 |
| Lower Kittanning (No. 5) | URB | MI | 55.06 | 18 |
| No. 4A | URB | MI | 107.80 | 18 |
| | | PENNSYLVANIA | | |
| Allegheny County | URB | MI | 881.41 | 18 |
| Upper Freeport (E) | URB | MI | 356.61 | 18 |
| Lower Freeport (D) | URB | MI | 425.46 | 18 |
| Armstrong County | URB | MI | 1092.87 | 18 |
| Upper Freeport (E) | URB | MI | 359.10 | 18 |
| Lower Freeport (D) | URB | MI | 172.58 | 18 |
| Lower Kittanning (B) | URB | MI | 463.69 | 18 |
| Beaver County | URB | MI | 435.29 | 18 |
| Upper Freeport (E) | URB | MI | 255.62 | 18 |
| Lower Kittanning (B) | URB | MI | 76.09 | 18 |
| Butler County | URB | MI | 863.85 | 18 |
| Upper Freeport (E) | URB | MI | 292.86 | 18 |
| Lower Freeport (D) | URB | MI | 117.07 | 18 |
| Middle Kittanning (C) | URB | MI | 290.23 | 18 |
| Clarion (A) | URB | MI | 125.91 | 18 |
| Cambria County | URB | MI | 1[illegible]54.17 | 18 |
| Upper Freeport (E) | URB | MI | 263.14 | 18 |
| Lower Freeport (D) | URB | MI | 426.43 | 18 |
| Upper Kittanning (C) | URB | MI | 359.01 | 18 |
| Lower Kittanning (B) | URB | MI | 352.04 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 19. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Clarion County | URB | MI | 640.12 | 18 |
| Lower Kittanning (C) | URB | MI | 209.73 | 18 |
| Clarion (A) | URB | MI | 336.34 | 18 |
| Clearfield County | URB | MI | 1102.48 | 18 |
| Lower Freeport (D) | URB | MI | 170.21 | 18 |
| Upper Kittanning (C) | URB | MI | 118.45 | 18 |
| Lower Kittanning (B) | URB | MI | 372.74 | 18 |
| Clarion (A) | URB | MI | 116.51 | 18 |
| Brookville (A) | URB | MI | 195.35 | 18 |
| Fayette County | URB | MI | 1023.70 | 18 |
| Waynesburg | URB | MI | 172.43 | 18 |
| Pittsburgh | URB | MI | 217.83 | 18 |
| Upper Freeport (E) | URB | MI | 229.12 | 18 |
| Lower Freeport (D) | URB | MI | 125.14 | 18 |
| Lower Kittanning (B) | URB | MI | 120.80 | 18 |
| Greene County | URB | MI | 6515.66 | 18 |
| Waynesburg | URB | MI | 1178.31 | 18 |
| Sewickley | URB | MI | 785.45 | 18 |
| Pittsburgh | URB | MI | 3540.07 | 18 |
| Upper Freeport (E) | URB | MI | 1011.83 | 18 |
| Indiana County | URB | MI | 1716.93 | 18 |
| Upper Freeport (E) | URB | MI | 568.30 | 18 |
| Lower Freeport (D) | URB | MI | 423.95 | 18 |
| Lower Kittanning (B) | URB | MI | 694.12 | 18 |
| Jefferson County | URB | MI | 407.37 | 18 |
| Upper Freeport (E) | URB | MI | 91.25 | 18 |
| Lower Freeport (D) | URB | MI | 67.29 | 18 |
| Lower Kittanning (B) | URB | MI | 149.39 | 18 |
| Brookville (A) | URB | MI | 72.33 | 18 |
| Somerset County | URB | MI | 1240.55 | 18 |
| Upper Freeport (E) | URB | MI | 209.34 | 18 |
| Lower Freeport (D) | URB | MI | 121.07 | 18 |
| Upper Kittanning (C) | URB | MI | 444.87 | 18 |
| Lower Kittanning (B) | URB | MI | 294.43 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 20. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Washington County | URB | MI | 3604.21 | 18 |
| Waynesburg | URB | MI | 316.19 | 18 |
| Pittsburgh | URB | MI | 2995.61 | 18 |
| Upper Freeport (E) | URB | MI | 187.23 | 18 |
| Westmoreland County | URB | MI | 747.54 | 18 |
| Pittsburgh | URB | MI | 95.13 | 18 |
| Upper Freeport (E) | URB | MI | 528.58 | 18 |
| | | SOUTH DAKOTA | | |
| Unnamed County[c] | SR | MI | 160 | 17 |
| Unnamed Seam | SR | MI | 160 | 17 |
| | | TEXAS | | |
| Milam County[c] | SR | MI | 167 | 17 |
| Wilcox Formation | RSR | MI | 813 | 3 |
| | | VIRGINIA | | |
| Buchanan County | URB | MI | 819.98 | 18 |
| Hagy | URB | MI | 109.40 | 18 |
| Splashdam | URB | MI | 250.54 | 18 |
| Kennedy | URB | MI | 197.01 | 18 |
| No. 5 | URB | MI | 134.77 | 18 |
| Dickenson County | URB | MI | 515.54 | 18 |
| Splashdam | URB | MI | 50.25 | 18 |
| Upper Banner | URB | MI | 122.14 | 18 |
| Kennedy | URB | MI | 78.60 | 18 |
| Jewell | URB | MI | 92.14 | 18 |
| No. 5 | URB | MI | 82.66 | 18 |
| Russell County | URB | MI | 403.02 | 18 |
| Kennedy | URB | MI | 85.54 | 18 |
| No. 5 | URB | MI | 185.31 | 18 |
| Tiller | URB | MI | 84.66 | 18 |
| Wise County | URB | MI | 716.60 | 18 |
| Norton (No. 2) | URB | MI | 62.10 | 18 |
| Upper Banner | URB | MI | 57.11 | 18 |
| No. 5 | URB | MI | 62.83 | 18 |

[a] All undesignated coal is bituminous.

[c] Lignite.

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Table 4, Part 21. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| | | WEST VIRGINIA | | |
| Barbour County | URB | MI | 948.76 | 18 |
| Upper Freeport | URB | MI | 104.64 | 18 |
| Upper Kittanning | URB | MI | 165.17 | 18 |
| Upper Mercer | URB | MI | 159.70 | 18 |
| Bed No. 928 | URB | MI | 347.34 | 18 |
| Boone County | URB | MI | 1868.85 | 18 |
| Winifrede | URB | MI | 347.79 | 18 |
| | SR | MI | | |
| Chilton | URB | MI | 187.40 | 19 |
| | SR | MI | | |
| Hernshaw | URB | MI | 289.70 | 18 |
| Cedar Grove | URB | MI | 241.89 | 18 |
| | SR | MI | | |
| Alma | URB | MI | 317.181 | 18 |
| | SR | MI | | |
| Campbell Creek | URB | MI | 332.97 | 18 |
| Braxton County | URB | MI | 467.73 | 18 |
| Lower Kittanning | URB | MI | 203.68 | 18 |
| Sockton | URB | MI | 61.82 | 18 |
| Clay County | URB | MI | 695.02 | 18 |
| Upper Kittanning | URB | MI | 77.54 | 18 |
| Middle Kittanning | URB | MI | 73.72 | 18 |
| Lower Kittanning | URB | MI | 227.16 | 18 |
| Sockton | URB | MI | 101.75 | 18 |
| Coal Burg | URB | MI | 157.10 | 18 |
| Fayette County | URB | MI | 796.26 | 18 |
| | SR | MI | 148.7 | 18 |
| Campbell Creek | URB | MI | 220.80 | 18 |
| Eagle | URB | MI | 94.92 | 18 |
| Sewell | URB | MI | 171.47 | 18 |
| Grant County | URB | MI | 313.23 | 18 |
| Bakers Town | URB | MI | 72.31 | 18 |
| Upper Freeport | URB | MI | 228.20 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 22. LARGE-SIZE U. S. STRIPPABLE AND EASTERN U. S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Harrison County | URB | MI | 380.89 | 18 |
| Pittsburgh | URB | MI | 335.06 | 18 |
| Upper Kittanning | URB | MI | 40.33 | 18 |
| Kanawha County | URB | MI | 1120.62 | 18 |
| | SR | MI | 284.1 | 17 |
| Sockton | URB | MI | 321.77 | 18 |
| Campbell Creek | URB | MI | 298.76 | 18 |
| Bed Code 928 | URB | MI | 193.45 | 18 |
| Lewis County | URB | MI | 730.30 | 18 |
| Redstone | URB | MI | 221.55 | 18 |
| Pittsburgh | URB | MI | 254.05 | 18 |
| Elklick | URB | MI | 94.46 | 18 |
| Lincoln County | URB | MI | 360.43 | 18 |
| Lower Kittanning | URB | MI | 105.97 | 18 |
| Sockton | URB | MI | 129.03 | 18 |
| Campbell Creek | URB | MI | 113.44 | 18 |
| Logan County | URB | MI | 3076.26 | 18 |
| | SR | MI | 142.4 | 18 |
| Cedar Grove | URB | MI | 503.27 | 18 |
| Alma | URB | MI | 732.29 | 18 |
| Campbell Creek | URB | MI | 800.85 | 18 |
| McDowell County | URB | MI | 912.35 | 18 |
| Beckley | URB | MI | 123.72 | 18 |
| Pocahontas No. 2 | URB | MI | 236.54 | 18 |
| Pocahontas No. 3 | URB | MI | 241.10 | 18 |
| Marion County | URB | MI | 2599.46 | 18 |
| Waynesburg | URB | MI | 313.25 | 18 |
| Swickley | URB | MI | 989.71 | 18 |
| Pittsburgh | URB | MI | 1022.93 | 18 |
| Marshall County | URB | MI | 3043.77 | 18 |
| Sewickley | URB | MI | 916.06 | 18 |
| Pittsburgh | URB | MI | 1924.67 | 18 |

[a] All undesignated coal is bituminous.

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Table 4, Part 23. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Mingo County | URB | MI | 1887.45 | 18 |
| | SR | MI | 165.800 | 17 |
| Coalburg | URB | MI | 199.05 | 18 |
| Cedar Grove | URB | MI | 592.92 | 18 |
| Alma | URB | MI | 332.50 | 18 |
| Monongalia County | URB | MI | 3008.81 | 18 |
| Waynesburgh | URB | MI | 544.90 | 18 |
| Sewickley | URB | MI | 848.90 | 18 |
| Pittsburgh | URB | MI | 1342.14 | 18 |
| Nicholas County | URB | MI | 1433.69 | 18 |
| Coalburg | URB | MI | 155.95 | 18 |
| Eagle | URB | MI | 194.99 | 18 |
| Sewell | URB | MI | 236.86 | 18 |
| Ohio County | URB | MI | 379.05 | 18 |
| Sewickley | URB | MI | 54.27 | 18 |
| Pittsburgh | URB | MI | 273.29 | 18 |
| Preston County | URB | MI | 837.48 | 18 |
| Upper Freeport | URB | MI | 221.05 | 18 |
| Upper Kittanning | URB | MI | 141.79 | 18 |
| Raleigh County | URB | MI | 1656.34 | 18 |
| Eagle | URB | MI | 196.13 | 18 |
| Beckley | URB | MI | 334.13 | 18 |
| Pocahontas No. 3 | URB | MI | 261.40 | 18 |
| Randolph County | URB | MI | 757.19 | 18 |
| Sewell | URB | MI | 308.12 | 18 |
| Taylor County | URB | MI | 388.24 | 18 |
| Upper Kittanning | URB | MI | 130.95 | 18 |
| Lower Kittanning | URB | MI | 201.10 | 18 |
| Upshur County | URB | MI | 876.87 | 18 |
| Upper Kittanning | URB | MI | 83.24 | 18 |
| Upper Mercer | URB | MI | 143.92 | 18 |
| Bed Code 928 | URB | MI | 300.38 | 18 |

[a] All undesignated coal is bituminous.

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Table 4. Part 24. LARGE-SIZE U.S. STRIPPABLE AND EASTERN U.S. UNDERGROUND COAL DEPOSITS[a]

| Location and Seam | Basis | Estimate Class | Amount of Coal, $10^6$ tons | Reference No. |
|---|---|---|---|---|
| Wayne County | URB | MI | 403.55 | 18 |
| Lower Kittanning | URB | MI | 141.96 | 18 |
| Campbell Creek | URB | MI | 224.29 | 18 |
| Webester County | URB | MI | 1098.91 | 18 |
| Eagle | URB | MI | 160.78 | 18 |
| Sewell | URB | MI | 119.74 | 18 |
| Pocahontas No. 13 | URB | MI | 130.18 | 18 |
| Wetzel County | URB | MI | 846.09 | 18 |
| Sewickley | URB | MI | 158.15 | 18 |
| Pittsburgh | URB | MI | 585.65 | 18 |
| Wyoming County | URB | MI | 1642.10 | 18 |
| Beckley | URB | MI | 168.03 | 18 |
| Pocahontas No. 3 | URB | MI | 647.08 | 18 |
| Pocahontas No. 2 | URB | MI | 150.30 | 18 |
| | | WYOMING | | |
| Campbell County | SR | MI | 12160 | 17 |
| Wyodak Deposit | RSR | MI | 19000 | 11 |
| Felix Deposit | RSR | MI | 480 | 11 |
| Smith Local Deposit | RSR | MI | 236 | 11 |
| Canyon Deposit[d] | RSR | MI | 185 | 18 |
| Converse County | SR | MI | 253 | 17 |
| Dry Cheyenne Deposit | RSR | MI | 179 | 11 |
| Johnson County | SR | MI | 800 | 17 |
| Healy Deposit | RSR | MI | 1000 | 11 |
| Lincoln County | SR | MI | 140 | 17 |
| Adaville Deposit | RSR | | 1000 | 11 |
| Sweetwater County | SR | MI | 403 | 17 |
| Red Desert Deposit | RSR | MI | 733 | 11 |
| Jim Bridger Deposit | RSR | MI | 200 | 11 |
| Cherokee Deposit[e] | RSR | MI | 200 | 11 |

[a] All undesignated coal is bituminous.

[d] Partly in Sheridan County.

[e] Partly in Carbon County.

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3. Specific Heat of Coal, Char, and Ash

Work on the specific heat of coal, chars, and related materials was continued. The literature on the specific heat of clay (a major constituent of the mineral matter of most coals) was reviewed. Its specific heat ranges from about 0.4 to 0.5 cal/g-°C, or about twice that of typical ash from coal.[6,7] The difference is attributed to the presence of water of constitution in clay. Consideration of methods of correction is being deferred until recent Australian and Russian papers on the subject can be obtained.

Kirov's correlation[4] for the specific heat of coal, char, and coke was presented last month with data showing its good agreement with experimental data for temperatures up to 100°C. The literature has been searched for data published since Kirov's 1965 survey. It appears that measurements have been made, all told, on less than a dozen North American bituminous and lower rank coals, and on only about four of these have measurements been made at temperatures higher than 200°C. Work in this field is being pursued more actively in the Soviet Union and Japan.[1,19] Investigators in both countries use differential scanning calorimeters in which a sample is heated at a constant rate (2° to 10°C per minute) in a stream of inert gas. Results such as those shown in Figure 17 are obtained; an endothermic heat of reaction is found at temperatures from about 300° to 700°C, and

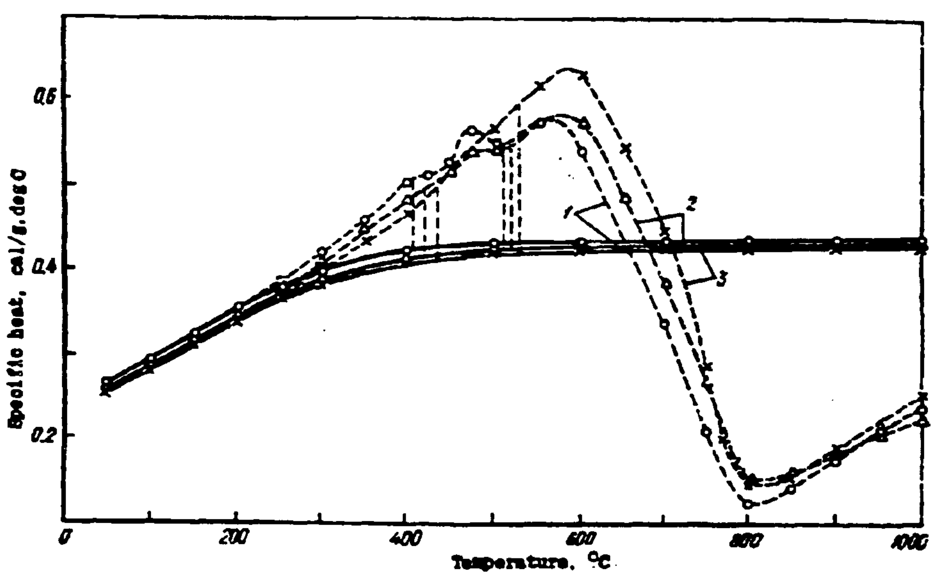


Figure 17. SPECIFIC HEAT OF COALS[1] (1) KZh14, (2) K13, AND (3) $K_2$ (Dashed Line Is the Apparent Value; Solid Line Is the True Value After Heat Soaking for 4 Hours)

an exothermic heat of reaction at higher temperatures. Measurements of this kind have begun at the Pennsylvania State University under a project funded by RANN.

For future work on this topic we plan to a) consult the principal investigator(s) at Penn State, b) obtain all the Japanese and Russian papers of interest and obtain translations as required, and c) test Kirov's correlation at elevated temperature by plotting calculated and observed specific heats against volatile matter, at selected constant temperatures.

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## IV. Patent Status

The work performed during April is not considered patentable.

## V. Future Work

The data collection and evaluation work will be continued in the selected areas of coal conversion technology.

Approved W.W. Bodle
W. W. Bodle, Director
Process Analysis

Signed A. Talwalkar
A. Talwalkar, Coordinator
Process Data

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