EVALUATION OF THE COKING QUALITY OF COAL SUPPLIES

by

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EVALUATION OF COKING QUALITY IN COAL MINE PLANNING

ABSTRACT

Coal mine planning is employed on a continuous basis by Bethlehem Steel's mining divisions, and the evaluation of the coking potential of the coal is an integral part of that program. The petrographic analysis is the major tool employed for coal-quality evaluation, because it is the only reliable method that can be applied to small-scale samples such as drill cores. In Bethlehem Steel's coal reserve evaluation program, all of the coal cores obtained from the mining divisions are subjected first to washability analyses in the Mining Department laboratory. The simulated clean-coal fractions resulting from the washability analyses are then evaluated for quality by the Research Department. The quality evaluations include consideration of the use of the coal in particular steel plant situations. The significant coal-quality properties and the techniques used for evaluating them are outlined. Some examples of the application of these techniques are described.

INTRODUCTION

Coal mine planning is employed on a continuous basis by Bethlehem Steel's mining divisions, and the evaluation of the coking potential of the coal is an integral part of that program. Petrographic analysis is the major tool employed for coal-quality evaluation, because it is the only reliable method that can be applied to small scale samples such as drill cores. The objectives of this presentation are to:

- Outline the Bethlehem coal evaluation program, as it applies to cokemaking.
- Detail the significant coal-quality techniques and properties used in making these evaluations.
- Describe by some selected examples the application of this property evaluation information by Bethlehem's Mining, Purchasing and Steel Operations Departments.

In this first slide we can follow the steps in Bethlehem Steel's coal reserve evaluation program.

1. The coal cores obtained from the drilling programs at all of our mining divisions are subjected first to washability analyses in the Mining Department laboratory.
2. Various coal fractions obtained in these analyses are treated by the Mining Department to obtain information on the coals recoverable and actual reserves and on the chemistry that can be expected when the coal is cleaned. This information is required to determine how much coal of acceptable chemistry can be produced from a given coal reserve.
3. Applying coal petrographic techniques and also incorporating data from the Mining Department, the Research Department's Coal Petrography group determines the cokeability of the coals and which particular coal mixes are suitable for Bethlehem's various cokemaking operations.

As noted in Slide 1, all gravity fractions produced in the treatment of drill core samples are available for petrographic analyses. However, for the actual determination of coke and coking properties we deliberately select those clean coal fractions that are in line with the requirements of the respective coal preparation plants. The example in this slide is for the 1.45 specific gravity float fractions from the washability analyses which happen to be one of the more common gravity fractions in Bethlehem's coal preparation plants. It is the coking properties of these selected fractions that are needed in formulating plans for distributing and using the coal mixes at our coke plants.

The petrographic analysis of a particular clean-coal fraction makes use of the following measurements in determining the kind of coke that a coal will produce. As shown in Slide 2, these petrographic measurements are: (1) coal reflectance, which is a direct measure of coal rank, and (2) inert content, which is an inverse measure of the components in coal that form coke. These two measurements, together with empirical relationships we developed make it possible to describe the coke and coking properties of coal that are significant to our coke plant operations. Although there are a number of coke and coking properties, the most important to our coke plant operators are (Slide 3):

- <u>Coke Stability</u> - This property is expressed as a standard measure of the physical strength of coke. Bethlehem's aim is to produce the strongest coke possible to insure that a high percentage of the coke produced withstands the rigors of handling and reaches the blast furnace with sufficient size and strength to support the blast furnace burden.

- <u>Coking Pressure</u> - This term refers to a relative measure of the amount of pressure that a mix of coals will exert on coke oven walls during coking. To minimize damage to coke oven refractories and to eliminate "stickers" at the completion of coking, Bethlehem's operators use coal mixes that produce low coking pressure.

- <u>Coke Reactivity</u> - This property is determined by measuring the weight loss of a given coke after it has been heated at a given temperature for a given period of time in CO_2. Bethlehem's target is to produce coke that is characterized by a low and uniform reactivity, because this type of reactivity is considered by many to be conducive to good blast furnace operation. Also, low and uniform values mean that the coal supplies and coking conditions at the coke plants are under tight control.

Thus, these coke and coking properties are the yardsticks by which all captive and purchased coal products and coal reserves are evaluated. Prediction of these properties by coal petrographic analysis is the basis for determing the compatibility of a coal or coals with those currently being used in coal mixes and the correct proportions for their incorporation into the coal mixes. On the basis of coal petrographic properties, coal mixes are formulated that:

1. Will generate acceptable coking pressures during coking, less than 2 psi.

2. Will produce coke with two major properties:

    - Good strength, i.e., above 55 stability
    - Low reactivity, i.e., below 12%

The coals selected for coal mixes must meet corporate specifications for coal chemistry, and the resulting coke must have acceptable chemistry.

Having dealt briefly with the techniques and quality parameters for evaluating coals for cokemaking, I will now give actual examples of how our evaluations have been applied to both captive and purchased coals.

CAPTIVE COAL RESERVES

As mentioned earlier, the evaluation of coal properties is done on the washed fractions of drill cores. These fractions are petrographically analyzed for reflectance, i.e., coal rank, and inert properties, and these measurements are used to make predictions of the coke and coking properties in Slide 3. These predictions are then entered on mine maps to show the coking properties of the coal in the reserve. The mine map in Slide 4 shows: (1) a primary contouring based on coal-reflectance properties for a low-volatile coal reserve, and (2) subdivisions based on the coking properties as predicted from the coal reflectance and inert measurements. To simplify this map for our discussion purposes, the inert content measurements are omitted in this example, but they were of course considered in determining the coking property subdivisions shown for the reserve. As the reflectance contours in Slide 4 show, the coal seam in this reserve varies significantly in rank from north to south, ranging from 1.35% to 1.80% reflectance. These variations in rank are not only major determinants of the quality of coke that will be produced from coal across the reserve but also tell us how the coal should be used in our mixes. This coal is low-volatile in rank and the intent would be to project its usage at about 25-30% of plant coal mixes, which is Bethlehem's standard usage for low-volatile coal in mixes. The subdivisions in terms of the coking properties were keyed in with this intended level of usage and refinements of subdivisions were eliminated to make it easier for our mine operating personnel to make use of the map in developing the best mine plan for this particular reserve (Slide 4). As the slide shows, the coal toward the center of the reserve (between 1.40 and 1.65% reflectance) is described as ideal reflectance low-volatile coal, i.e., it could be used in up to 30% of coal mixes and not produce excessive coke oven pressures and would produce coke that is of acceptable strength (>55 stability) and reactivity (<12%). If we were purchasing or exploring for low-volatile coal reserves, it would be coal of this description that we would welcome because it could be used directly in our coal mixes in percentages up to 30 and at most coke oven operation conditions. In the lower right half of the reserve, the coal has a reflectance above 1.65% and is low-volatile coal that would, if used in coal mixes, produce coke of good strength and reactivity properties. However, the use of this high-reflectance coal in amounts of 25-30% of coal mixes would generate excessive oven pressures during coking and would also lead to delays in coke oven operations because of coke-mass stickers. Therefore, the percentage of this coal in a mix would have to be reduced to less than 20%, in order to eliminate the threat of high coking pressures. On the other hand, since the reduction of the percentage of low-volatile coal to this level would lower coke yields and result in a coke of inferior strength properties, this type of coal would not be suitable for standard coke plant operating conditions but could be used in limited amounts under special conditions.

The coal in the upper portion of Slide 4, although still in the same seam, is ranked as medium-volatile, i.e., exhibits less than 1.40% reflectance. Its use in coal mixes would adversely affect coke stability, because low-volatile coal is the component in mixes that controls the strength of coke to be produced. Thus, even though the coal of this area of the reserve could produce good coke by itself in coke ovens, it will not produce satisfactorily strong coke if it is included in mixes of the type used by Bethlehem. However, there are two reasons that this coal is not used by itself: (1) There is not enough coal of this rank available to support a coke oven facility. (2) The use of this coal would result in a substantial loss in coke yield even though strong coke could be produced. The Mining Division, having incorporated Research's evaluations into its planning, is now mining and metering the high-reflectance low-volatile coal in this reserve at fixed percentages with the ideal low-volatile coal and is reserving the medium-volatile coal mining until future market conditions warrant.

To sum up the discussion of coal-property evaluations:

- Coals are analyzed petrographically
- Coke properties are predicted
- Based on these predictions the reserve is mapped for use by our Mining Personnel

One last point: Since the institution of our system for evaluating the properties and coking potential of a coal, the required knowledge about the coal in a reserve is available at the very outset of mining planning and not - as sometimes used to be the case - after mining is well under way and the coal is already being used in cokemaking.

COAL SOURCES

Research's responsibilities are not over when it has provided Mining personnel with a description of a coal reserve in terms of the variations of quality and rank of the coal in the ground. After mining, Research also evaluates the products of the coal-preparation plants to define these products in terms of what the customers, i.e., the coke plants, needs. For this purpose, Research applies to coal-preparation plant products the same coal petrography-based techniques it employs to evaluate drill-core samples from reserves.

Another important reason for monitoring source samples, i.e., the products from our various coal-preparation plants, is to keep tabs on the amount of weathered coal being mined. As all of you know, surface mining has gained in prominence in the industry because of economics, and this form of mining can result in more and more weathered coal ending up in coal-preparation plant products if nothing is done to minimize the problem during actual mining.

Weathered coal must be minimized or eliminated because its inclusion in coal mixes adversely affects the coking properties of coal and the resulting coke. Slide 5 shows the effect of increasing amounts of weathered coal on the FSI properties of the coal products from one of our coal reserves. The rapid decrease of the FSI as the percent weathering increases is a good rule of thumb for the adverse effects that weathered coal can have on the thermal behavior of coal. On the basis of our experience with weathered coal and its effects on coking and coke properties, we have set a 2% upper limit on the amount of weathered coal in coals going to our coke plants, i.e., the level at which coke properties will be affected. Based on this limit, the weathered coal-FSI relationship in Slide 5 serves as a broad tool for screening out weathered coal.

Reading vertically from the 2% weathered coal value in this slide, we note that the FSI level should be greater than 8 to be acceptable. The FSI-weathered coal relationship is now routinely used as a rapid field test to screen out zones of weathered coal in surface mining operations. These weathered zones are identified and marked in exposed outcrops by this field technique so that the weathered coal can be left for markets other than coking. The FSI test for weathering is, of course, spot-checked periodically by means of petrographic analyses to insure that it is effectively screening out the weathered coal and, conversely, to make certain that unweathered coal of good quality is not being lost.

PURCHASED COALS

Bethlehem purchases about 10% of the total coal used annually in our coke ovens and, to satisfy this purchased coal requirement, probably looks at as many as 200 potential coal sources over a year's time. To provide Purchasing personnel with the data they need when selecting outside sources, we perform the same type of studies on outside sources that we provide for evaluating Bethlehem's own coal reserves. To recap, we describe each coal's coking properties from petrographic analyses of small samples, screen out those coals that have the best potential for coking, decide on this information in which plant the coal should be used, and suggest how it should be used in combination with existing coals.

Because the available supply of high quality coking coals has diminished significantly over the past several years, Bethlehem has had to develop an effective procedure for evaluating potential purchased coals to insure that the highest quality coals are obtained in any given market situation. The procedure that has been worked out by Bethlehem is shown in Slide 6.

When a prospective coal supply is spotted by the Purchasing Department, arrangements are made for our Mining Division that is nearest to that area to visit the mine site to examine the facilities and to make a judgement as to whether production and quality claims can be met.

If it appears that these can be met, Mining obtains a representative product sample of the coal from that source and then evaluates it for chemistry and FSI properties.

Samples that do not meet Bethlehem's specifications for chemistry and FSI are rejected at this point, whereas those that meet the specifications are forwarded to the Research Department for petrographic analyses.

Upon the completion of our petrographic analyses, which include measurements of coal reflectance and inert content and screening for weathering, reports are made to the Purchasing and Steel Plant Operations Departments advising whether or not the prospective coal should be purchased and detailing how the coals to be purchased should be used in coal mixes.

Prior to the development of coal petrographic techniques for evaluating the coking properties of coal, each prospective coal was shipped in to Bethlehem for testing in an 18" Test Oven. This test oven method of evaluating coals is highly accurate but requires about 1000# of coal and is time-consuming and costly. In today's market, we cannot afford the time to routinely evaluate coals by this technique because by the time a decision could be made on a prospective coal, somebody else would probably be buying it on speculation. In contrast, coal petrography enables Bethlehem to make accurate and rapid decisions on the quality of coals offered by outside sources and thus remain competitive.

AUTOMATED COAL PETROGRAPHY

Bethlehem has accepted coal petrographic analyses as the method for evaluating coke and coking properties, because it is the only proven method available for making such determinations rapidly on small coal samples. However, the Corporate acceptance of coal petrography for this use has resulted in an interesting problem, namely, that it is not possible for us to keep up with the increasing volume of requests for petrographic information from our Mining and Purchasing Departments. Consequently, a large backlog of samples is developing, particularly in connection with the reserve evaluations at our five mining divisions. As quick as petrographic analysis is, it will need to be even quicker if we are to continue to provide the kind of service that the Corporation has come to expect from us. Since one cannot simply continually increase staff personnel to accommodate the increased work, the logical solution to the problem is to develop automated coal petrographic techniques. We have been seriously exploring this approach, and automated petrographic methods will be developed for routine use, possibly before 1980. Our industry as a whole will have an ever greater need for such methods, and everyone is welcome to try his hand at developing them. If some of you in this audience have an idea or a system that you're developing for this purpose, I'm sure that Bethlehem and other corporations would be interested in talking with you about them.

Slide #1

PROCEDURE FOR DRILL CORE EVALUATION

CORE

PHOTOGRAPHED, MEASURED, DESCRIBED

THICK PARTINGS REMOVED

CORE CRUSHED TO -1/4"

5 LB SAMPLE RIFFLED OUT

RAW COAL SAMPLE
FOR REFERENCE

SAMPLE SIZED FOR
SPECIFIC GRAVITY TESTS

-100 MESH COAL REMOVED

-100 MESH SAMPLE FOR
CHEMISTRY, PETROGRAPHY

+100 MESH COAL SEPARATED
AT 1.45 GRAVITY

1.45 SINK SAMPLE
FOR CHEMISTRY

1.45 FLOAT COAL FOR
CHEMISTRY, PETROGRAPHY,
FSI, FLUIDITY

SIGNIFICANT PETROGRAPHIC MEASUREMENTS

COAL REFLECTANCE

- Coal Rank

COAL COMPOSITION

- Coal Inert Content

Slide #3

SIGNIFICANT COKE AND COKING PROPERTIES

1) COKE STABILITY

   > 55

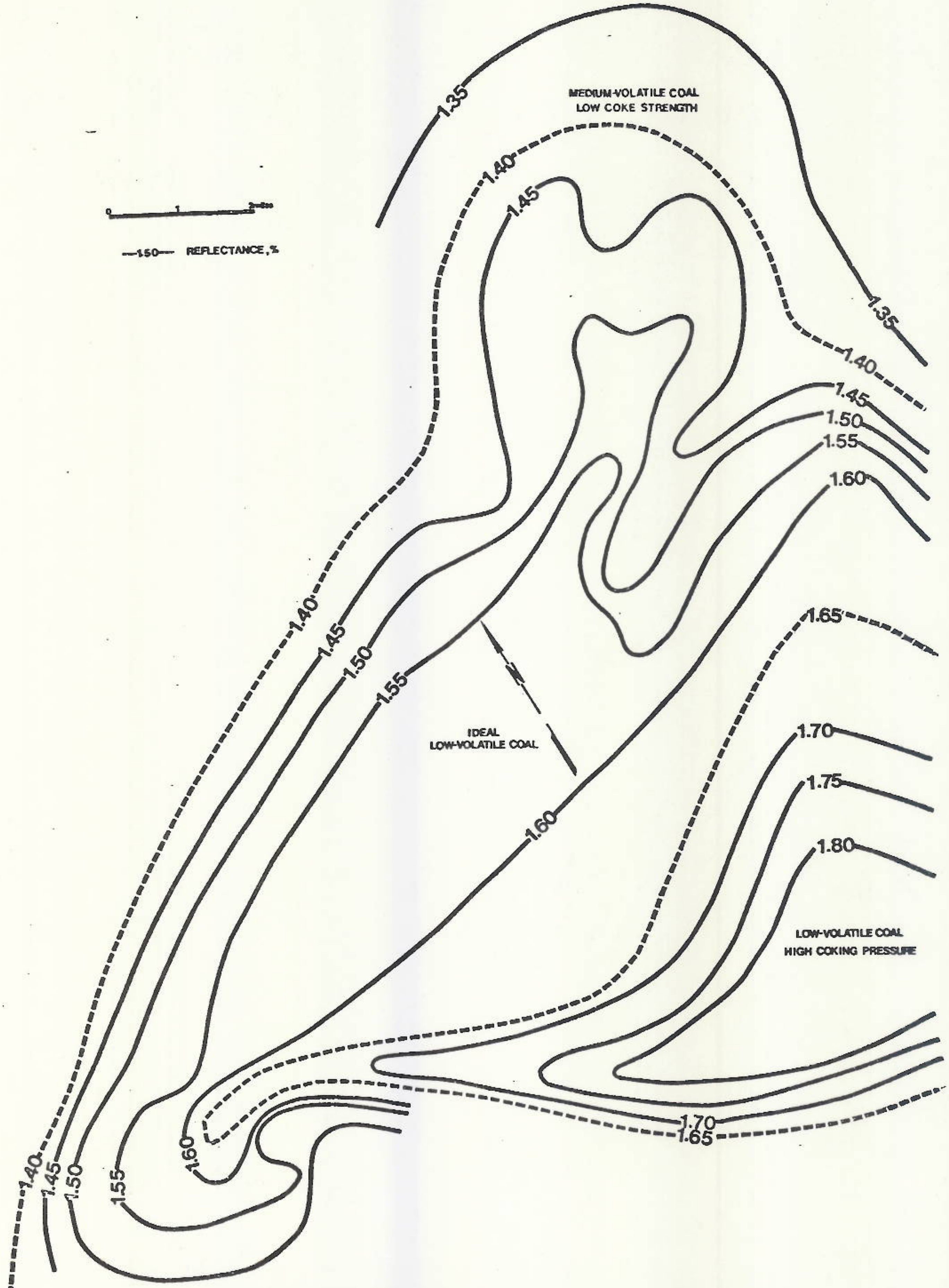
2) COKING PRESSURE

   < 2 psi

3) COKE REACTIVITY

   $< 12\%$

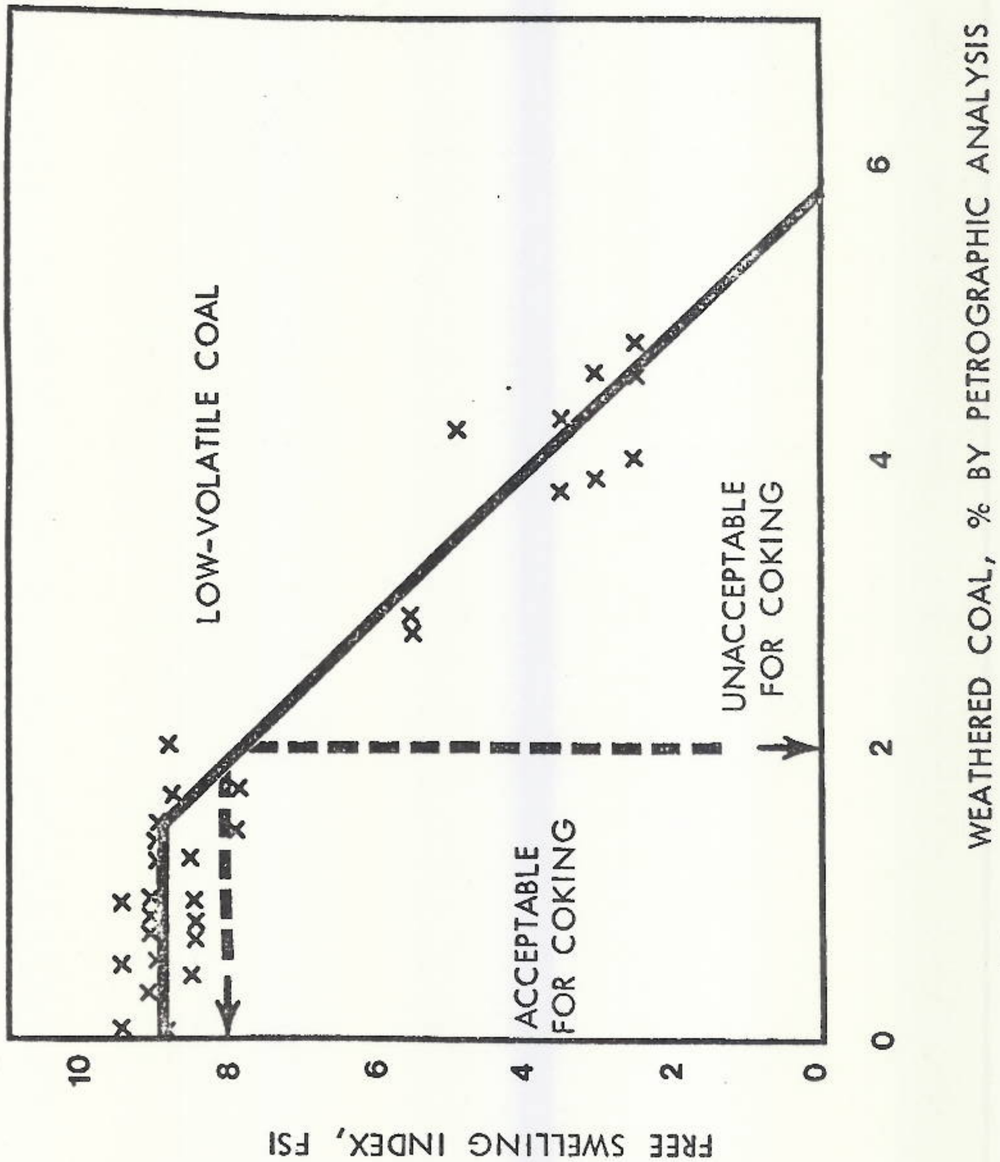
Slide #4



REFLECTANCE AND COKING PROPERTIES,

LOW VOLATILE COAL

Slide #5



LOW-VOLATILE COAL
UNACCEPTABLE FOR COKING
ACCEPTABLE FOR COKING
FREE SWELLING INDEX, FSI
10
8
6
4
2
0
0
2
4
6
WEATHERED COAL, % BY PETROGRAPHIC ANALYSIS

Slide #6

BETHLEHEM'S PROCEDURE FOR EVALUATING PURCHASED COALS

- CONTACT MADE BETWEEN SUPPLIER AND BETHLEHEM PURCHASING DEPT.

- BETHLEHEM MINING PERSONNEL VISITS PROSPECT

    - Facilities and production capabilities evaluated

    - Mining obtains product sample

    - Mining evaluates Chem. and FSI of Coal

    - Coals of poor Chem. and FSI are rejected at this point

    - Coals meeting specs. are sent to Research

- PETROGRAPHIC ANALYSES DONE BY RESEARCH

    - Results reported to Purchasing Dept. and Steel Plant Operations