

"SELECTION OF COALS FOR COKE MAKING"

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Abstract

This report has been prepared to describe coal properties and their relative importance in formulating blends for producing high-quality metallurgical coke.

To qualify as coking coal, the coal must be classified bituminous and subclassified between high-volatile B and low volatile in rank. It must also be agglomerating and have the capability to melt when heated. For prime quality, the coal should be strongly coking and have a minimum amount of noncarbon impurities such as silica, alumina, iron, calcium, sulfur, phosphorus, chlorine, sodium, and potassium. To obtain high-strength coke, the individual coals must be blended to produce blends that range in volatile-matter content between 25 and 32 percent (daf) and in vitrinoid reflectance between 1.1 and 1.3 percent. Although coke strength improves as the rank of the blend increases (as volatile matter decreases and reflectance increases), the amount of improvement is controlled by the inert-maceral content of the blend and is limited by carbonization pressure and contraction obtained during coking.

Few coals have all the properties desirable for coke making. However, a deficiency in one property of a coal in a blend can be offset by an excess of that property in another

coal, and as a result, trade-offs can be made in coal selection to formulate satisfactory blends. In addition, the strength of coke from a particular coal blend can be improved by coal-preparation and coke-oven-operating practices, such as pulverizing the coal to a smaller particle size, decreasing the coking rate, or increasing the coal-charge bulk density.

Introduction

Coal is an energy resource composed of a mixture of organically derived macerals and associated minerals. Macerals are the plant remains that have undergone chemical and physical changes in response to geologic processes. The kinds and amount of each maceral present determine the coal type. The degree of metamorphism or alteration of the macerals establishes the coal rank, and the amount and type of minerals associated with the organic constituent determine the coal grade.

Industrial coal petrography deals with the microscopic determination of how coals differ in type, rank, and grade and how these differences affect the utilization of coal. Laboratory carbonization testing deals with quantitatively measuring the effect of rank, type, and grade on expansion/contraction, pressure, and coke strength. In this report, the ranges for the coal properties that determine coking characteristics are presented for use as a guide in assessing the quality and utilization of metallurgical coals. In addition, their relative importance in establishing the criteria for selecting coals in the formulation of blends for the production of high-quality metallurgical coke is discussed.

Blast-Furnace-Coke Specifications

The important coke properties that affect blast-furnace performance are chemical composition, size, strength,

and reactivity. Coke composition is generally measured in terms of volatile-matter, ash, sulfur, alkali, and phosphorus contents. A good coke has a volatile-matter content of less than 1 percent, an ash content of 9.0 percent or less, and a sulfur content of 0.8 percent or less. The optimum size of blast-furnace coke should be 3 inches by 1 inch (76 by 25 mm).

Coke strength is measured by determining the amount of degradation induced by shatter (ASTM D3038)¹⁾* or by tumbling (ASTM D3402).²⁾ The indexes of coke strength from the tumbler test are called the stability and hardness factors. The stability factor is the most commonly used strength criterion employed in the United States and indicates the tendency of the coke to break upon handling and impact. The hardness factor indicates the tendency of the coke to abrade into fines upon handling. Other strength tests (Micum, Irsid, JIS, Sundgren) used throughout the world have been related to the ASTM tumbler test. In general, blast-furnace performance improves with increased coke stability. This is particularly true for large-diameter blast furnaces.

Coke reactivity tests indicate the rate at which carbon is converted to carbon monoxide by reaction with carbon dioxide under specified conditions of temperature and gas

* See References.

flow. Generally, the higher the rank of the coal blend and the higher the final coking temperature, the lower the reactivity of the coke.

Few coals meet all the requirements to produce a high-quality coke, so coals must be blended to meet these requirements. Thus, to evaluate a specific coal for coke making, it is important to know what other coals are to be used in the blend and how much of each is to be used. Frequently, in commercial blends it is economically attractive to include coals that do not meet normal metallurgical-coal specifications. In these cases, it is necessary that the other coals in the blend be correspondingly higher in quality or have properties that compensate for deficiencies in the poorer coal.

Coal Properties

Coal Rank

All coking coals possess the unique property of softening, agglomerating or fusing, and resolidifying to form a coherent, porous coke structure during carbonization. The class of coals referred to as bituminous are the only coals in the lignite-to-anthracite rank series that possess these properties. In addition, it is only the agglomerating bituminous coals that are considered coking and caking.

Coals are classified (ASTM D388) according to rank, and rank is the most important parameter relating to the

coking potential of coals. Figure 1 compares the rank group, names, and boundary lines of the ASTM system with class names and boundary lines of the international system.³⁾ Bituminous coals are subdivided by rank into high-, medium-, and low-volatile coals, with the high-volatile bituminous coals subdivided into high-volatile A, B, and C. In general, high-volatile C coals are noncoking, high-volatile B coals are marginal coking, and high-volatile A coals are coking. The medium-volatile bituminous coals and some of the high-volatile A-rank coals that are nearer the medium-volatile coals in rank are good coking coals and, like medium-volatile coals, can be used individually to make strong coke. Although low-volatile and high-rank medium-volatile coals produce strong cokes, they exert excessive wall pressure during carbonization and cannot be coked alone in by-product ovens since they can cause oven damage. In addition, these coals do not contract sufficiently during coking to permit easy removal from the coke ovens.

Table I gives a range of coking properties of the ranks of coals (high, medium, and low volatile) that are used to produce a coking-coal blend with an acceptable coke strength. These coals are classified by rank according to dry, mineral-matter-free volatile matter (ASTM D388).⁴⁾ Although volatile matter (Property 1, Table I) is a convenient and universally accepted indicator of coal rank, it is one of the least

reproducible chemical properties determined on coal and is affected by the presence of carbonates and changes in petrographic composition. The rank of a coal is also determined in petrographic analysis⁵⁾ by measuring the mean maximum reflectance of the vitrinoid maceral, the major reactive component in coal (Property 2, Table I). The relationship between these two rank parameters, vitrinoid reflectance and volatile matter, is shown in Figure 2.⁶⁾ Since the reflectance of vitrinoids is not influenced by other coal properties as volatile matter is, reflectance is a more accurate measure of the relative rank difference between coals.

Reflectance measurements on individual vitrinoid macerals in bituminous coal may range from about 0.5 to 2.00 percent reflectance. Vitrinoid-reflectance measurements are classified into types, each type representing a reflectance range of 0.10 percent. For example, V8 contains all the vitrinoids with a reflectance of 0.80 through 0.89 percent.

Coal Type

In addition to rank, coking coals are also selected by type or the petrographic reactive- and inert-maceral content. The maceral composition is determined microscopically (ASTM D2799).⁷⁾ Coals are commonly classified in terms of bright or dull types. Bright coals are generally considered superior to dull coals for coke making. Bright-banded bituminous coals

macroscopically consist of an abundance of clarain and vitrain, and microscopically the clarain and vitrain contain a predominance of the reactive maceral vitrinoid and may have significant amounts of resinoid and exinoid macerals. The vitrinoid macerals soften and resolidify to form the continuous-bond phase during carbonization. The exinoids and resinoids produce mostly by-products but also contribute to the bond phase in coke. Dull-banded bituminous coals macroscopically consist of an abundance of durain, and microscopically the durain commonly contains a greater abundance of the inert macerals. The inert macerals do not soften during carbonization and act as inert filler in the coke structure. Dull coals can be used to a limited extent in blends, particularly when the dull coals have good chemistry or price or some other advantage that would give an incentive for including them in blends.

The organic inert macerals are composed of micrinoids, fusinoids, and semifusinoids. In North American coals, 2/3 of the semifusinoids are categorized as inert macerals in high-volatile coal and 4/5 are classed as inert macerals in low-volatile coal. The organic inerts will burn in the blast furnace. Their inorganic inerts are the ash-forming materials or mineral matter composed largely of silicon, aluminum, iron, calcium, and alkalies such as sodium and potassium. The inorganic inerts will not burn in the blast furnace.

It has been found by laboratory experimentation that each rank of coal (measured by the reflectance of the vitrinite) has an optimum inert content for best coke strength. The relation of vitrinoid type to the optimum inert content is shown in Figure 3.⁸⁾ The ratio of the actual inert content of a coal to its optimum inert content is called the composition-balance index. Thus, by definition, a composition-balance index of 1.0 would give the optimum coke strength for that coal. Either an excess or a deficiency of inerts would result in decreased strength of coke from a coal of a given rank. However, in the case of coal blends, a deficiency of inerts in one coal can be at least partly offset by a surplus of inerts in another coal, assuming high pulverization levels and proper proportioning and mixing.

The rank of a coal affects to some degree the amount of inerts that result in optimum coke strength. As the coal rank increases from high volatile to medium and low volatile, the optimum inert content decreases because the vitrinite (principal coke-producing maceral) of the higher rank coals cannot assimilate the inerts as well as the lower rank fluid-type vitrinite. The optimum amount of inerts for most coking-coal blends with a vitrinoid reflectance of 1.3 percent is about 15 percent, whereas the optimum amount of inerts for blends with a vitrinoid reflectance of 1.2 percent is about

25 percent. In general, blends with lower reflectance and higher Gieseler fluidity can tolerate and incorporate more inert materials.

Coal Fluidity

Various tests have been proposed to measure the ability of coking coals to incorporate inerts. Two of the most commonly used tests are the Gray King Test (150/R505)⁹⁾ and the Roga Test (United Nations Publ. 1956 11.E.4, E/ECE/247, E/ECE/Coal/110).¹⁰⁾ In the United States, the Gieseler plastometer test (ASTM D2639)¹¹⁾ is commonly used to measure the plastic properties of coal during heating (Property 3, Table I). Coking coals soften, then become very fluid, and finally solidify. Strongly coking high- and medium-volatile coals become very fluid and have a wide fluid range. The fluid range is defined as the difference between the solidification and softening temperature. Poor-coking high- and low-volatile coals have low fluidity and a narrow plastic range.

In selecting coking coals for blends, the coals should have widely overlapping plastic ranges to assure the production of homogeneous coke structure, Figure 4.¹²⁾ In addition, many workers in the field insist that the blend fluidity should exceed 2000 dial divisions per minute. In addition, some workers believe the coke contraction relates to coal fluidity in addition to rank. The Arnu or Ruhr dilatometer is used widely in Europe to measure plastic properties of

coals (ISO/TC/27, Doc. 221,^{13,14}) AFNOR and DIN 51739,¹⁵) respectively). These tests are becoming more popular in the United States.

The free-swelling index (FSI) test (ASTM D720)¹⁶) is used to determine the agglomerating or swelling properties of coal (Property 4, Table I). In this test, the coke-button height is used to judge the caking and swelling properties of a coal. In general, the FSI of coking coals should exceed a coke-button size of 4; however, the better coking coals have a button size in excess of 7. Australian workers have shown that changes in the coke-button size are a function of rank and the proportion of vitrite and clarite present in a coal.¹⁷)

Hardgrove Grindability Index

The Hardgrove grindability index (HGI) (ASTM D409-71)¹⁸) measures the hardness, strength, and fracture characteristics of coal. It is used to determine the relative grindability or ease of pulverization of coals in comparison with coals chosen as standards. In this method, a prepared sample of known size-consist receives a definite amount of grinding energy in a miniature pulverizer and the change in size-consist is determined by sieving. The higher the index, the easier the coal is to pulverize.

The ease or difficulty of pulverizing coal is mostly a function of the coal rank (Property 5, Table I). High-volatile coals are difficult to pulverize and the indexes vary

between about 32 and 75. The lower rank high-volatile coals have indexes between about 32 and 70 and the higher rank coals, between 48 and 75. The lower rank medium-volatile coals have indexes between about 60 and 90 and the higher rank coals, between about 80 and 135. The lower rank low-volatile coals have indexes between about 90 and 120 and the higher rank coals, between about 85 and 105. At the upper limit of medium-volatile coking-coal rank, the indexes start to decrease until low values are obtained on noncoking anthracites (20 to 45 range).

Other properties of coal such as type of ash and petrographic-maceral content also affect the grindability index, although to a lesser extent than rank. The relation of HGI to coal rank (volatile matter) and type (maceral content) is shown in Figure 5.¹⁹⁾ A higher ash content can increase or decrease the HGI, depending on the rank of coal and type of ash; a higher micrinoid, exinoid, and/or resinoid content will reduce the HGI.

The breakage of coal and the ease or difficulty of pulverizing coal is of considerable importance in coal-washing plants and in the preparation of coal for charging to the coke ovens. Coke plants utilize high-volatile, low-volatile, and/or medium-volatile coals in the coal blends to obtain acceptable coke strength. Because of the great difference in

the HGI, it is most desirable to pulverize each coal rank and type separately. One scheme has been proposed in which HGI and volatile matter of the coal are used to predict coke stability.²⁰⁾

Coal Grade

Coking coals are also selected by grade, in addition to rank and type (Table II). Coal grade principally relates to the chemistry such as ash, sulfur, alkali, chloride, and phosphorus contents. In addition, the chemistry of the ash and the ash-fusion characteristics are often determined. In general, the ash content should not exceed 8 percent, and the better coals have an ash content of 6 percent or less. The sulfur content should not exceed about 1 percent, and the better coals should have a sulfur content of less than 0.7 percent. The phosphorus limitations relate to the other burden materials and, for normal blast-furnace operation, the phosphorus in the hot metal should not exceed 0.1 percent. U. S. Steel's limits for various chemical components of blast-furnace burdens are shown in Table III.²¹⁾

If any of the chemical components of a prospective material exceed these limits, the material may still be satisfactory for specific applications because it might be possible to blend it with other materials to keep the composition of the entire burden within the specified limits.

The limits for the components in Group I are based on the chemical specifications for residual elements for many grades of steel. In plants where these steels are not produced, some exceptions to these limits would be permitted.

The limits for the components in Group II are based on the maximum amounts that can be tolerated without encountering severe operating difficulties or serious environmental pollution problems.

The limits for the components in Group III are based on amounts in excess of which higher than normal operating cost would be encountered because of additional fuel requirements or refining times. No limit is set for manganese because the requirements for manganese differ greatly from plant to plant. In general, all the components in Group III should be as low as possible.

The alkalis attack and break the coke, and also cause scabs and other operating problems in the blast furnace. Therefore, the alkali content should be kept as low as possible. Chlorides pass into the coke-plant by-product system and require considerable water to remove them from the tars. In addition, chlorides cause maintenance problems both in the coal-preparation plants and coke works because of the corrosive nature of the compounds containing chlorine.

The ash-softening temperature for coking coals should be relatively high (+2300°F) so that the coal ash does not fuse to the refractory coke-oven lining during carbonization. Although coal grade is an inherent property of the coal, the grade can be and is established by exploration property evaluations and improved to various degrees by beneficiation plants.

Coal Oxidation

In addition to coal rank, type, and grade, particular emphasis is also placed on detecting oxidized coal since it can adversely affect coal-charge bulk-density control, coal flow, coke strength, and coking characteristics.²²⁾ The extent of coal oxidation can be measured by heating a minus-100-mesh sample in a caustic solution (NaOH) and recording the light transmission of the filtered solute with a spectrophotometer. Since oxidized coal is soluble in caustic, the light transmittance of a coal is lowered when oxidized coal is present. Certain blends containing coals with less than 80 percent transmittance have proved difficult to handle, and control of bulk density has been a problem. In addition, some success has been achieved in correlating the percent and degree of oxidized particles in different ranks and types of coal, as determined microscopically, with their light-transmittance values. A test for detecting oxidized coal is outlined in Table IV.

Calculated Coke-Stability Factor

Based on data obtained from more than 300 laboratory carbonization tests on all ranks of coals and coal blends, an excellent correlation was established between the coke-stability factors determined on coke produced in laboratory carbonization tests and those calculated from petrographic composition and reflectance analyses on the individual coals used in testing. These tests were conducted with standard conditions of pulverization of the coals to 80 percent minus 1/8 inch (3.2 mm), a coking rate of 1.03 inches (26.2 mm) per hour, and a bulk density of about 53.5 pounds per cubic foot (857 kg/m³).

Two indexes are required to calculate the coke-stability factor of a coal. First, the composition-balance index which, as discussed earlier, is the ratio of the actual determined total inert content of the coal to the optimum inert content for best coke strength for the particular rank of the coal as determined by reflectance (Property 6, Table I). Second, the rank index, which represents the relative effect of coal rank on coke strength as measured on a scale from 2 to 8 (Property 7, Table I). The rank index is determined by proportionally combining the coking strength of the individual vitrinoids at a given inert level that make up the coal.

The relation between vitrinoid reflectance types is plotted with reference to inert content and rank index on

Figure 6. In general, the rank index increases as the reflectance of the vitrinoids increases up to 1.99 percent (Vitrinoid 19), after which the rank index decreases. However, for any given vitrinoid, the rank index is highest at the optimum inert level, and decreases with an excess or deficiency of inerts. The composition balance index and rank index are used to predict the calculated coke-stability factor from a graph, (Property 1, Table V), Figure 7. The isostability curves are curves of equal stability and are based on the laboratory coke tests on blends and individual coals.^{5,23)}

To obtain the coke-stability factor expected from a given coal or coal blend carbonized under plant operating conditions, corrections must be made, taking into account those operating factors that were different from the standard conditions for which the original correlations were obtained; that is, pulverization level, coking rate, and charge bulk density. Because the effects of these three operating variables on coke stability are not the same for all coal blends, laboratory carbonization tests must be conducted to establish general relationships for adjusting to plant conditions.

Generally, coke strength is increased as the pulverization level and bulk density are increased and as coking rate is decreased (Figures 8, 9, 10). In addition, the lower the rank of the blend the larger the increase in coke strength for each of these operating variables.

Coal Blends

Only about 10 percent of the coking-coal reserves are of medium-volatile rank, 8 percent are low-volatile, and the remaining 82 percent are high volatile.²⁴⁾ Because there are insufficient reserves of medium-volatile coals to permit their exclusive use in coke making, and because these coals exert high pressure and have low contraction and cannot be coked in slot-type ovens, industry has resorted to blending of high-, medium-, and low-volatile coals. The blends commonly consist of 60 to 85 percent high-volatile coal with 15 to 40 percent low- and/or medium-volatile coals.

The rank of the coal blend is generally controlled to a volatile matter of 25 to 32 percent (daf), which corresponds to a vitrinoid reflectance of 1.1 to 1.3 percent. Some experts prefer a blend reflectance between 1.1 and 1.2 percent. When a blend is on the lower volatile end of the range (higher reflectance), it is necessary to operate at lower bulk densities and possibly lower coking rates than when the blend contains higher volatile matter. This precaution is taken to avoid high pressure and insufficient contraction during carbonization. The relation of reflectance of vitrinoids to coke stability, expansion/contraction, and pressure for individual coals is shown in Figure 11.

Volume Change During Carbonization

To assure easy pushing of the coke from the ovens at the end of the coking cycle, the coke must contract away from the oven walls.

The volume-change characteristics of coals and coal blends are determined quantitatively in the sole-heated oven (ASTM D2014).²⁵⁾ In this method, a known weight and thickness of coal is heated from the bottom surface of the charge while a specified force is applied to the top by a piston. At the end of the test, the thickness of the coke is measured by recording the final position of the piston.

Experience has shown that the rank of the coal blend, coal-charge bulk density, plastic properties, and total inert content of the coal charge control the volume-change characteristics of coals. Table V, Property 2, shows the expansion/contraction characteristics of individual high-A, medium-, and low-volatile rank coals. High-volatile coking coals contract significantly when carbonized alone. Medium-volatile coals at the low end of the rank scale contract sufficiently, but at the upper end of the scale they exhibit expansion and normally cannot be used alone to produce coke. Low-volatile coals are normally expanding and cannot be used alone to produce coke because they cannot be pushed from the ovens. The general relation of volume change to individual

coal reflectance (rank) is shown in Figure 12²⁶⁾ and the general relation of blend-coal reflectance to volume change is shown in Figure 13. To make acceptable-strength (stability) coke, medium- and/or low-volatile coals that can be used are limited by both the expansion/contraction and the coking-pressure properties of the blend.

In addition to the coals used in a blend, the bulk density of the coal charge in the oven has a significant effect on the expansion/contraction properties of coals during coking. As bulk density is increased, contracting coals become less contracting and expanding coals become more expanding. Therefore, a slightly expanding coal at a higher bulk density can be made to contract within limits by reducing bulk density.

The expansion/contraction properties of coals are also affected by their fluidity and total inert content. With coals of a given rank (reflectance), those with higher inert content or lower fluidity will contract less or expand less than coals with lower inerts or higher fluidity in somewhat the same manner.

In establishing the required contraction of coal blends for the various coke plants, several factors have to be considered. Among these factors are (1) the condition of the coke ovens and the amount of carbon on the walls, (2) the amount of oven taper from pusher side to coke side, (3) the

coal segregation experienced during handling and charging the oven, (4) the capability of the facilities to accurately proportion the various coals used in the blends, (5) the capability of the facilities to control bulk density by either oil or water addition to the coal charge, and (6) the variability in rank of the coals used, especially the low-volatile coals. Where most of the above factors are favorable, a smaller safety factor is used. In plants where most of the factors are unfavorable, larger safety factors are used which result in the necessity to use lower coal bulk densities with a resulting loss of coke production. The actual contraction required for each plant is based mostly on past experience with hard pushes and stickers. Most plants require between 5 and 12 percent contraction of the charge for easy pushing of the coke.

Coking Pressure

Coking pressure results from the gas pressure developed in the coal plastic layer and on the coal side of the plastic layer during carbonization. This gas pressure is related to the permeability of the plastic layer and the evolution of gases. The pressure is exerted from the plastic layer through the coke to the oven walls. Coking pressures are determined in 30- or 500-pound experimental pilot-scale test ovens containing a movable wall on which the total force is measured.

These coking pressures have been related to commercial ovens through the gas pressures developed in both types of ovens.

After the coal has been charged to the ovens, the heat front generated by the walls on each side of the ovens at temperatures of about 2400°F moves into the coal mass which starts to become plastic. At the same time, gases are being driven out of the coal between the plastic fronts coming from both sides of the oven. The gases are partly prevented from escaping through the plastic fronts, and pressure starts to build up in the envelope between the two plastic fronts, exerting pressure on the oven walls. A peak pressure occurs as the two plastic fronts meet, which occurs after about 12 hours through an 18-hour coking time. The pressure then decreases because the plastic mass has solidified, permitting the gases to escape through the cracks and fissures. A peak pressure does not occur if a plastic envelope does not form or if the plastic layer is very permeable.

The rank of the coal primarily determines the coking-pressure characteristics of the coal, as shown in Table V, Property 3.

The bulk density of the coal charge has a significant effect on the coking pressure because, as the bulk density increases there is more coal per cubic foot of oven volume, which means the coal is packed tighter in the oven. The

plastic mass is then less permeable to gas flow, and the pressure builds up to a greater degree than at lower bulk densities. Figure 14 shows the general relation of bulk density to pressure.

Total inert content of the coal has an effect on pressure. The general relation of pressure to vitrinoid reflectance (rank) and inert level of the coal is shown in Figures 15²⁷⁾ and 16.²⁸⁾ With coal of a given rank, the pressure exerted is less with a high inert content than with a low inert content at the same coal bulk density. This can be explained by the fact that the inerts do not become plastic and an increase in inerts simply reduces the amount of material in the coal that becomes plastic during coking. In addition, the inert content affects the coal plastic properties which have a great influence on coking pressure.

The coking rate used with a given coal blend will affect the coking pressure; however, various coals and blends respond differently and the relationship between coking rate and coking pressure must be determined from laboratory carbonization tests.

Most coke ovens are designed to withstand lateral pressure of 2 pound per square inch (psi) (14.06 kN/m^2) or more. To assure that ovens are not damaged by excessive pressure, the same factors listed for contraction of coal

blends must be considered. Most coal blends are designed to exert no more than about 0.5 to 1.5 psi (3.515 to 10.55 kN/m²) at the normal operating conditions.

Conclusions

In conclusion, to qualify as coking coal, the coal must be classified bituminous and subclassified between high-volatile B and low volatile in rank. It must also be agglomerating, and have the capability of melting when heated. For prime quality, the coal should have a minimum amount of noncarbon impurities such as silica, alumina, iron, calcium, sulfur, phosphorus, chlorine, sodium, and potassium. To obtain high-strength coke, the individual coals must be blended to produce blends that range in volatile-matter content between 25 and 32 percent (daf) and in vitrinoid reflectance between 1.1 and 1.3 percent. Although coke strength improves as the rank of the blend increases (as volatile matter decreases and reflectance increases), the amount of improvement is affected by the inert-maceral content of the blend and is limited by carbonization pressure and contraction obtained during coking.

Few coals have all the properties desirable for coke making. However, a deficiency in one property of a coal in a blend can be offset by an excess of that property in another coal, and as a result, trade-offs can be made in coal selection to formulate satisfactory blends. In addition, the strength

of coke from a particular coal blend can be improved by coal preparation and coke-oven operating practices such as pulverizing the coal to a smaller particle size, decreasing the coking rate, or increasing the coal-charge bulk density.

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Table I
Rating of Coking Coals for Blending

Property	Coal Classification								
	High Volatile-A			Medium Volatile*			Low Volatile		
	Rating			Rating			Rating		
	Good	Medium	Poor	Good	Medium	Poor	Good	Medium	Poor
1 Volatile Matter, %	31.0-33.0	33.0-36.0	>36.0	21.0-24.0	24.0-27.0	27.0-31.0	18.0-21.0	15.0-18.0	<15.0
2 Vitrinoid Reflectance, % ²	0.92-1.09	0.85-0.95	0.68-0.85	1.40-1.50	1.20-1.40	1.10-1.20	1.51-1.70	1.70-1.85	>1.85
3 Fluidity, ddp ³	>20,000	5000-20,000	<5000	500-8000	300-20,000	<300->20,000	100-300	30-1000	<30->1000
4 Free-Swelling Index	9	6-8	<6	9	7-8	<7	9	7-8	<7
5 Hardgrove Grindability Index	48-75		32-70	80-135		60-90	90-120		85-105
6 Composition-Balance Index ²	0.40-0.80	0.80-1.40	>1.4	1.0-1.50	1.50-2.00	>2.0	2.00-3.50	3.50-5.00	>5.00
7 Rank Index ²	3.4-4.3	3.0-3.4	2.2-3.0	6.0-6.5	4.3-5.5	<4.3	>6.8	6.0-7.5	<7.5

* These properties such as volatile-matter content, reflectance in oil, and rank index have little bearing in the ranking of medium-volatile coals because the rank required for a medium-volatile coal is dependent upon the rank and amount of the other coals used in the blend.

** Determined petrographically

*** Dial divisions per minute

Table II

Chemistry of Coking-Coal Blends

	<u>Good</u>	<u>Acceptable</u>
Ash, %	<6.0	~8.0
Sulfur, %	<0.7	~1.0
Potassium and Sodium Oxides, % of ash	<1.0	<3.0
Ash-Fusion Temperature, °F	>2500	2300
Phosphorus*, %	<0.01	<0.03

Table III

Proposed Limits for Various Chemical Components of
Blast-Furnace Burdens Including Ore, Stone, and Coke

	<u>Component</u>	<u>Maximum Ratio of Component to Fe</u>	<u>Maximum Amount of Component Expressed as lb per ton Fe</u>
Group I	Cu	0.0001	0.2
	Ni + Co	0.0004	0.8
	Mo	0.0003	0.6
	Sn	0.00015	0.3
	Cr	0.0004	0.8
	V	0.0001	0.2
Group II	Zn	0.0004	0.8
	Pb	0.0008	1.6
	TiO ₂	0.01	20.0
	Na ₂ O + K ₂ O	0.002	4.0
	As	0.0001	0.2
	Sb	0.0001	0.2
	P	0.002	4.0
	S	0.001	2.0
	Cl	0.0001	0.2
	F	0.0002	0.4
Group III	SiO ₂	0.1	200.0
	Al ₂ O ₃	0.04	80.0
	Mn	(Each application must be considered separately)	

Group I - Limits for the components are based on the chemical specifications for residual elements for many grades of steel.

Group II - Limits for the components are based on the maximum amounts that can be tolerated without encountering severe operating difficulties or serious environmental pollution problems.

Group III - Limits for the components are based on amounts in excess of which higher than normal operating cost would be encountered because of additional fuel requirements or refining times.

Table IV

Determination of Oxidized Coal

SCOPE:

This test is used as a quick method to determine the amount of oxidized coal present in a sample. Oxidized coal is soluble in caustic, and results in a brown solution. This discoloration is proportional to the amount of oxidized coal. It should be noted that according to coal petrography, this method will detect oxidized coal that is greater than 2 to 5 percent, depending upon the coal type. It has been Clairton's experience that coals with less than 80 percent transmittance will present coal handling problems.

REAGENTS AND MATERIALS:

1. 1 N NaOH
2. 20 percent solution of Tergitol TMN in ethanol
3. 250 ml beakers
4. #40 and #42 Whatman filter paper
5. 60° glass funnels
6. Spectrophotometer (Bausch & Lomb Spectronic 20) (Fisher Scientific #7-143-1)
7. Hot plate
8. 3/4-inch test-tube-type cells
9. 100 ml graduate cylinder
10. Thermometer

PROCEDURE:

1. Add 1 gram of coal sample that has been prepared to 100 percent minus 60 mesh to 100 ml of 1 normal NaOH.
2. Add 1 drop of Tergitol
3. Stir the coal and caustic; then heat on a hot plate at $85 \pm 2^\circ\text{C}$ for 1 hour. Periodically stir the slurry as the solution is heating.
4. Filter the slurry through #40 and 589 filter papers. This double filtration is done in one operation with the #40 paper on top of the 589 paper
5. Bring the volume of the filtrate to 80 ml, using distilled water.
6. Measure the percent transmittance at 520 nm, using a blank of 1 N NaOH that has had the same treatment as the samples to set 100 percent transmittance.
7. Report results in percent transmittance.

Table V

Coking Characteristics of Different Ranks of Coal

Property	Coal Classification					
	High Volatile-A		Medium Volatile		Low Volatile	
	Rank		Rank		Rank	
	Low	High	Low	High	Low	High
1 Calculated Stability Factor	<35	35 to 58	40 to 65	50 to 65	50 to 65	20 to 60
2 Volume Change (+ expansion, - contraction) at 52 lb/ft ³ (833 Kg/m ³) dry oven bulk density	-5 to -30	-10 to -25	0 to -14	-5 to +10	-2 to +10	+4 to +30
3 Coking Pressure, psi @ 52 lb/ft ³ (833 Kg/m ³) dry oven bulk density	<1.0	0.5 to 2.2	1.0 to 5.0	2.0 to 10.0	5.0 to 15.0	10 to 30

International classification class number	0	1	2	3	4	5	6	7	8	9		
		5	10	15	20	25	30	b/ 14 000	13 500	17 000	11 000	10 000
		Volatile-matter parameter ^{a/} 70						Calorific value parameter ^{a/} 11 000				
ASTM classification group name	Subbituminous C coal	Anthracite	Semi-anthracite	Low-volatile bituminous coal	Medium-volatile bituminous coal	High-volatile A bituminous coal	High-volatile B bituminous coal	High-volatile C bituminous coal and subbituminous A coal	Subbituminous B coal			

^{a/} Parameters in international system are on ash-free basis. In ASTM system, they are on mineral-matter free basis.

^{b/} No upper limit of calorific value for class 6 and high-volatile A bituminous coals.

Figure 1. Comparison of Class Numbers and Boundary Lines of International System with Group Names and Boundary Lines of ASTM System

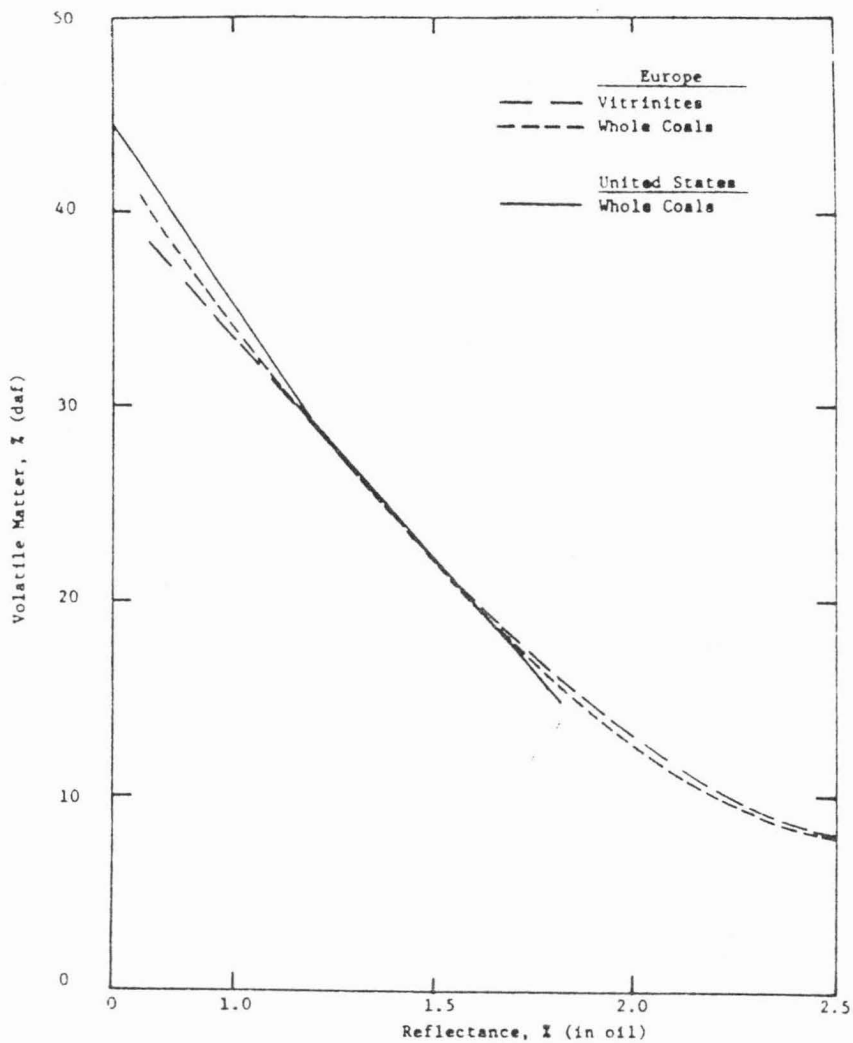


Figure 2. Reflectance-Volatile Matter Relations for European and United States Vitrinites or Whole Coals in the Bituminous Semi-Anthracite Range (After McCartney).

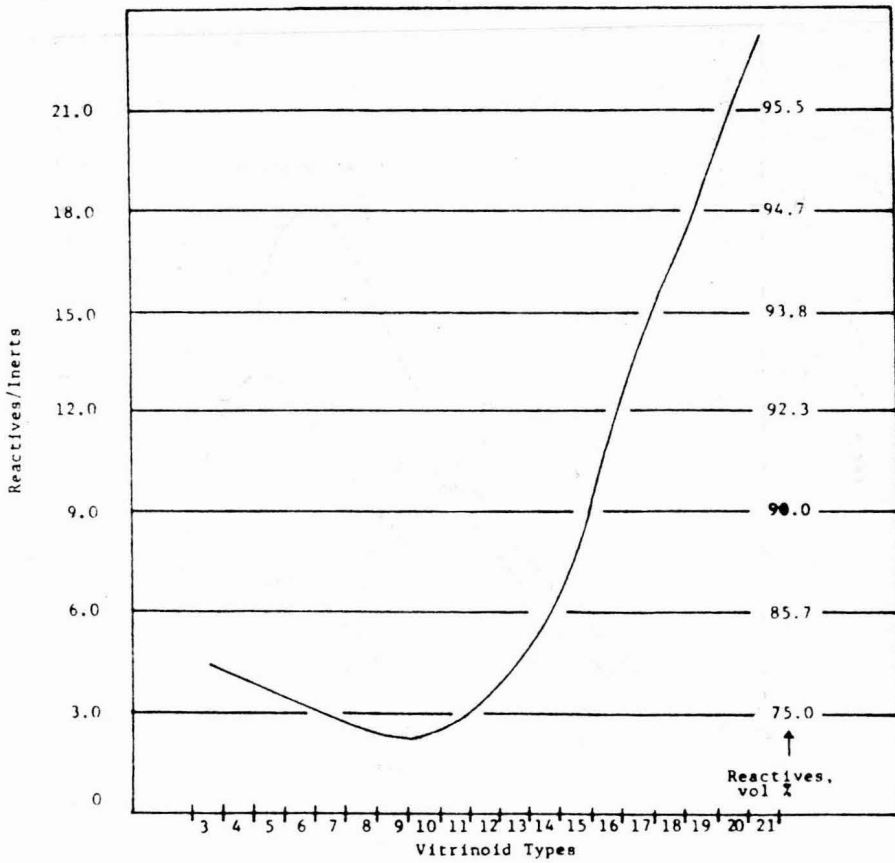


Figure 3. Optimum Ratio of Reactives to Inerts for Each Vitrinoid Type

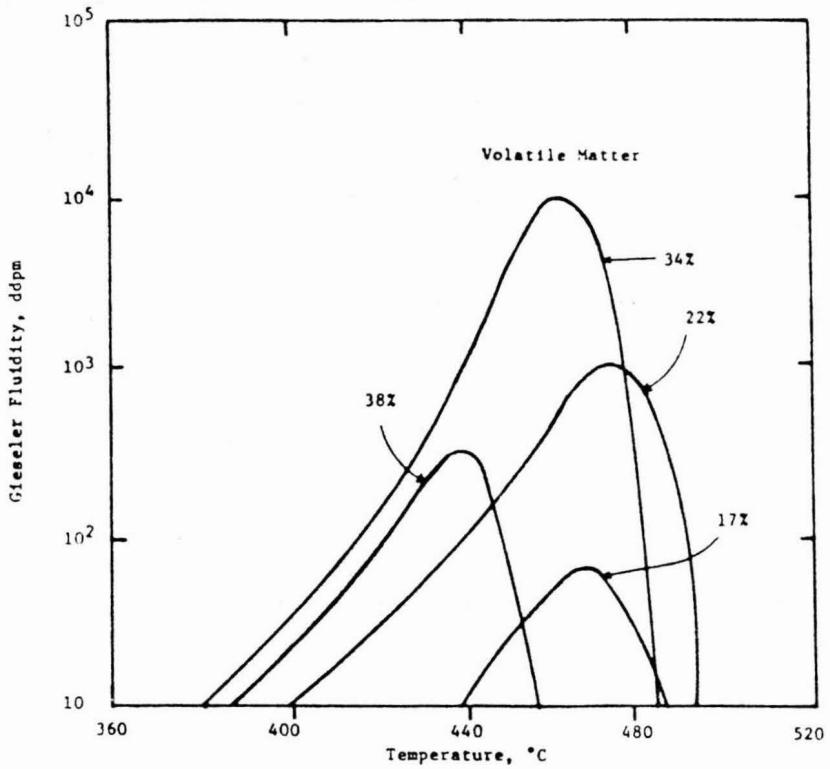


Figure 4. Gieseler Plastometer Curves for Coals of Different Rank
(Compatible coals for blending for coke making should have overlapping plastic ranges.)

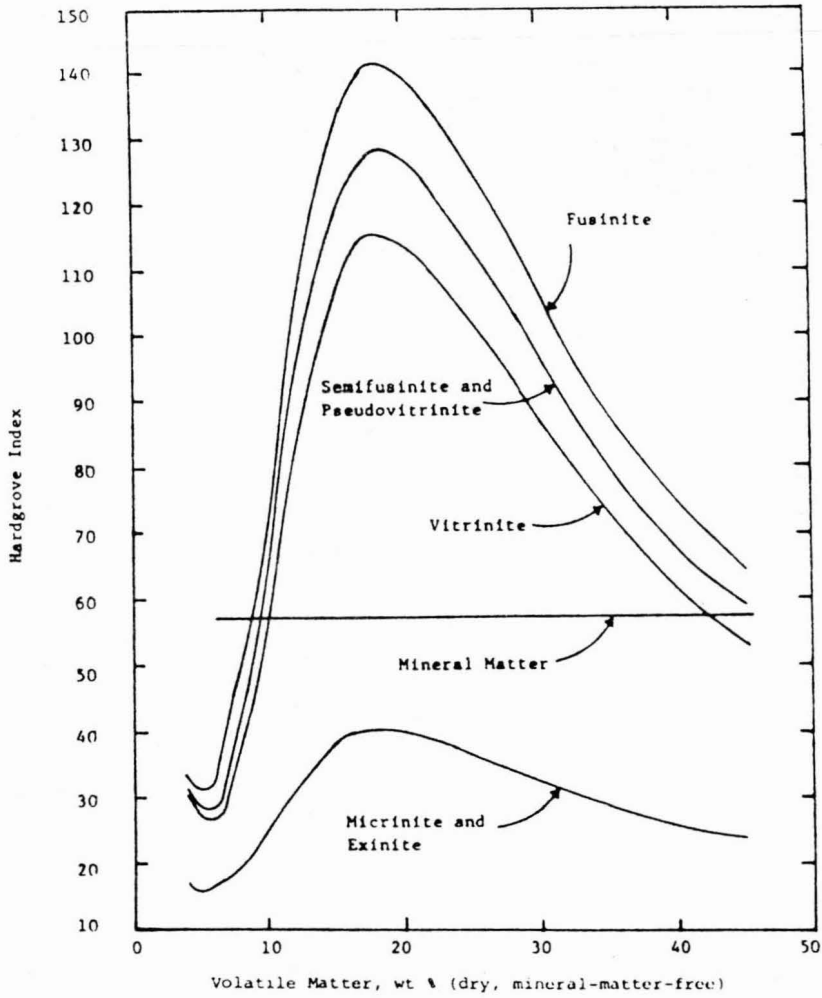


Figure 5. Hypothetical Grindabilities of Different Macerals and Total Mineral Matter Calculated from Coal Sample Assumed to Contain 100 Percent of a Particular Maceral or of Mineral Matter (After Shaung-Shii Hsieh)

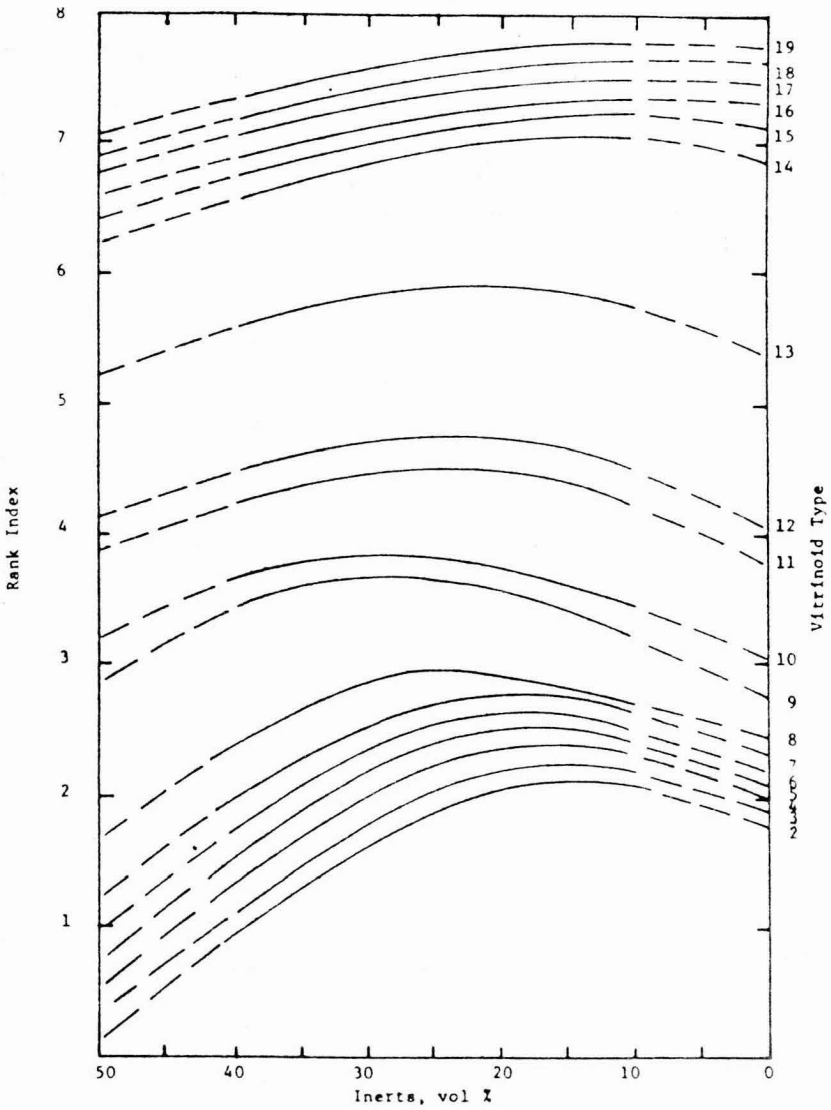


Figure 6. Relationship of Rank Index, Vitrinoid Type, and Inerts of Coal

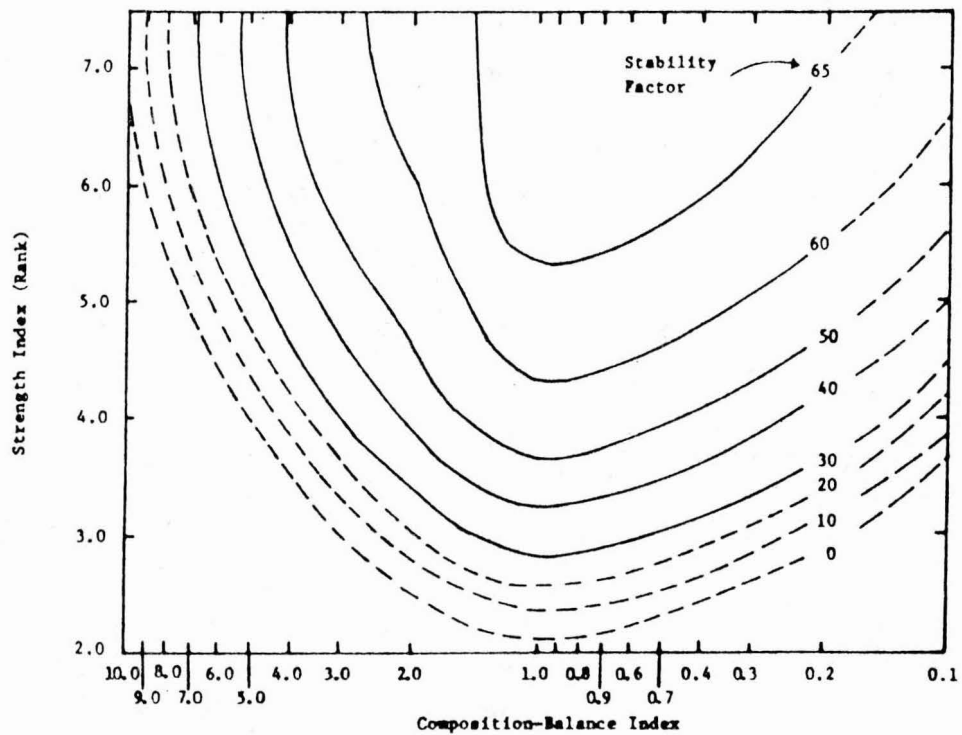


Figure 7. Correlation Graph for Predicting ASTM Tumbler Stability and Bleeding Potential From Basic Petrographic Data

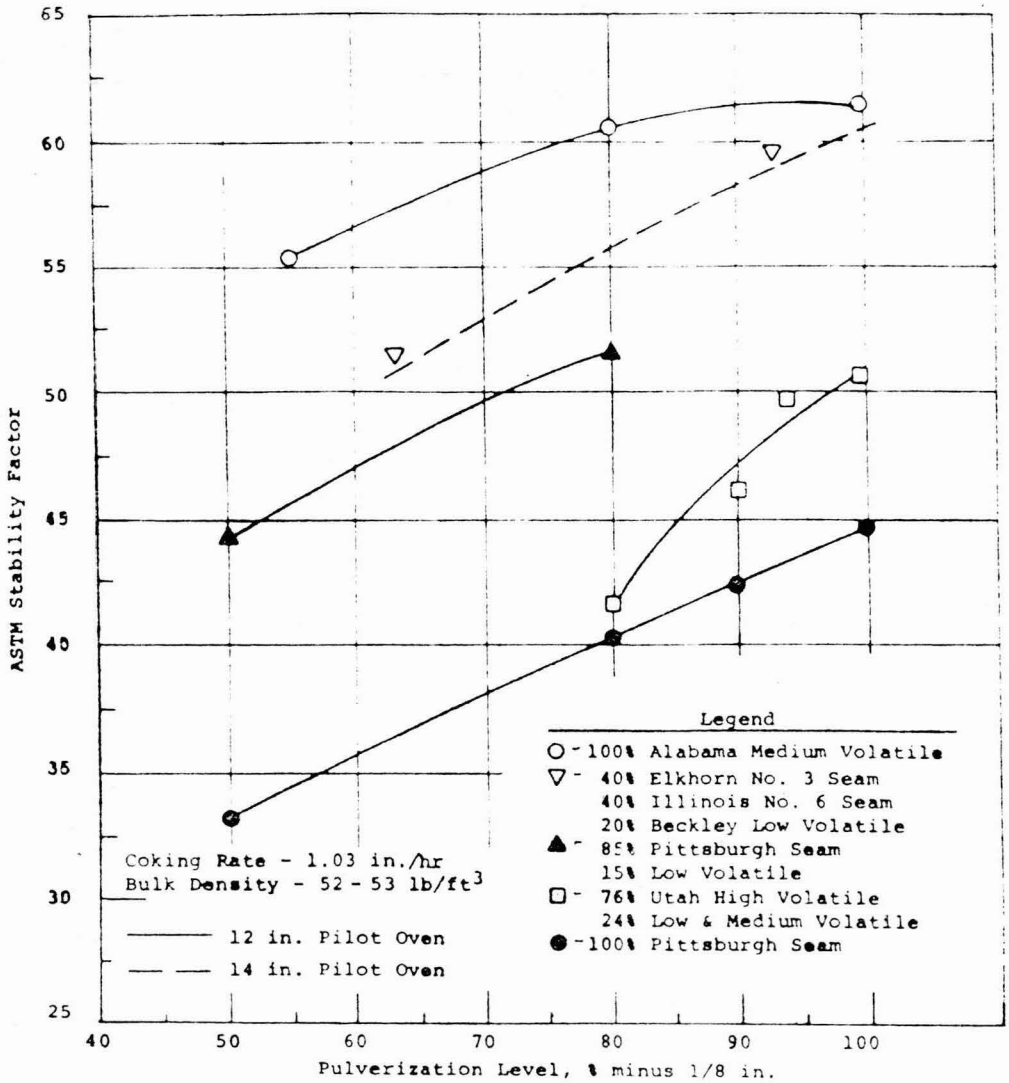


Figure 8. Effect of Coal Pulverization Level on the Strength of the Resultant Coke

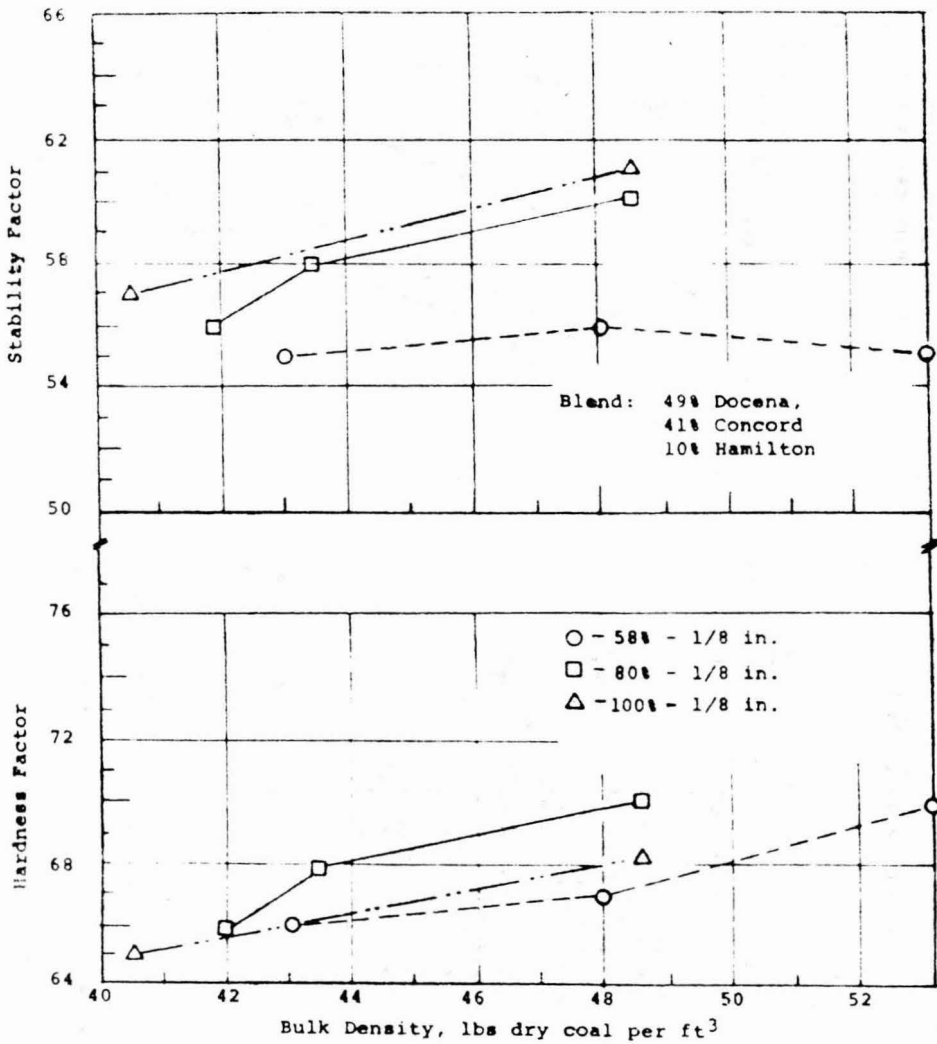


Figure 3. Effect of Bulk Density on Stability and Hardness Factors of Resultant Cokes.

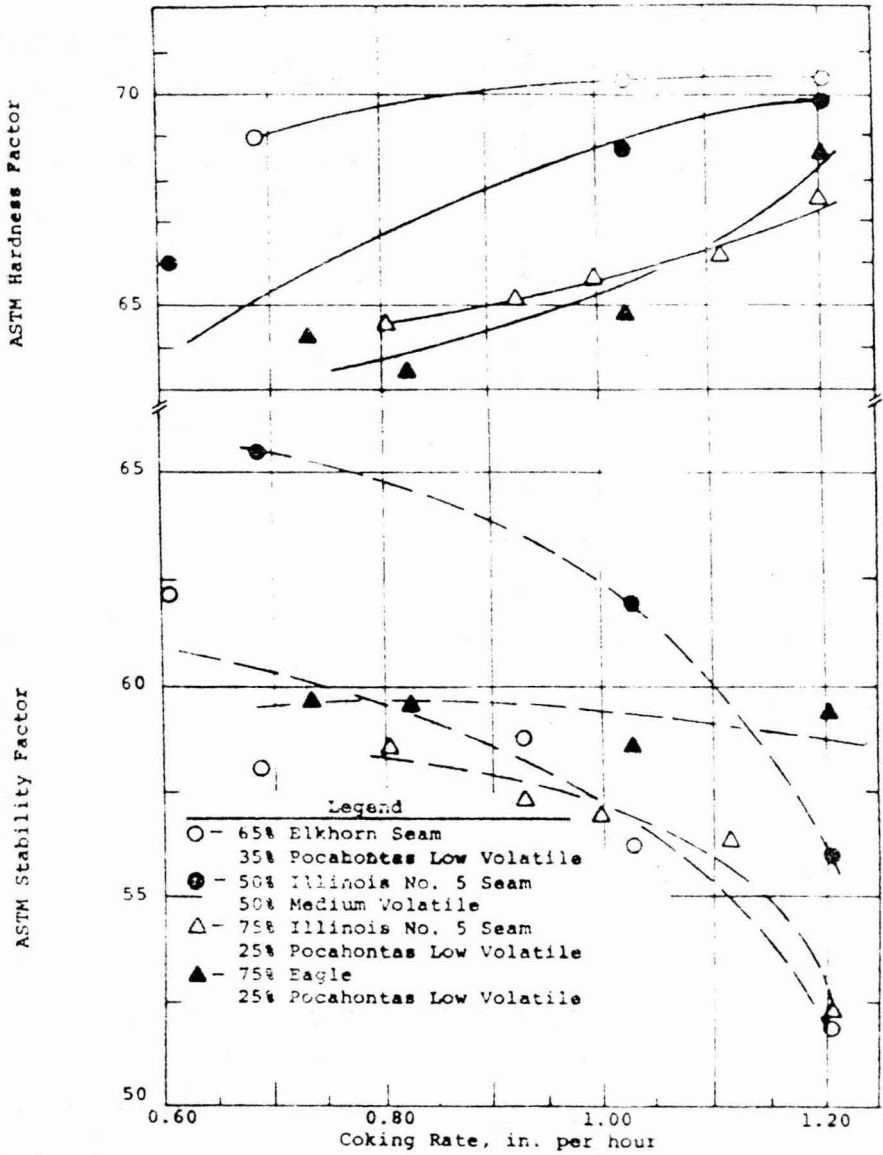


Figure 10. Effect of Coking Rate on the Strength of the Resultant Coke

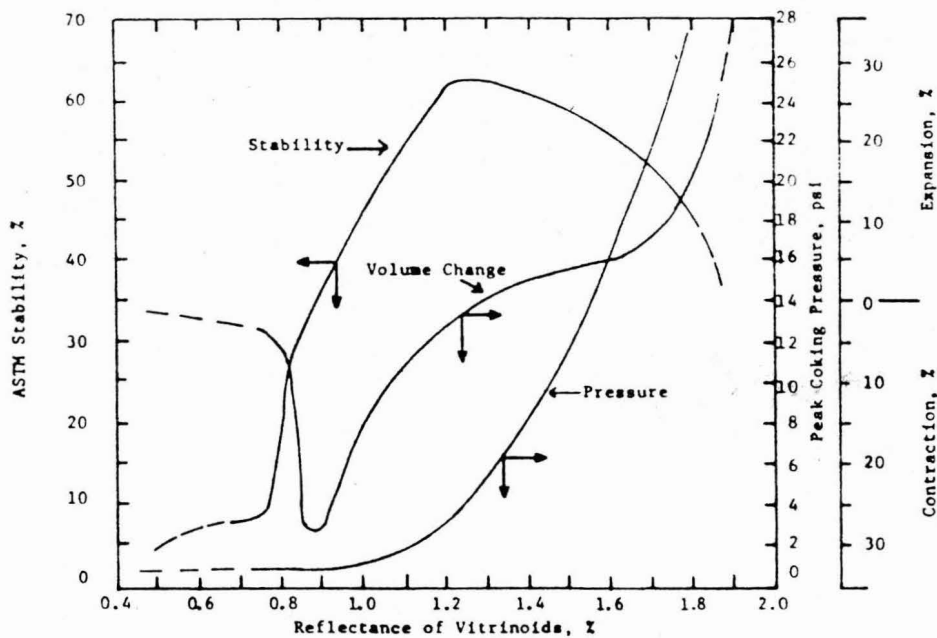


Figure 11. Relation of Reflectance of Vitrinoids to Coke Stability, Volume Change (Expansion and Contraction), and Pressure for Individual Coals

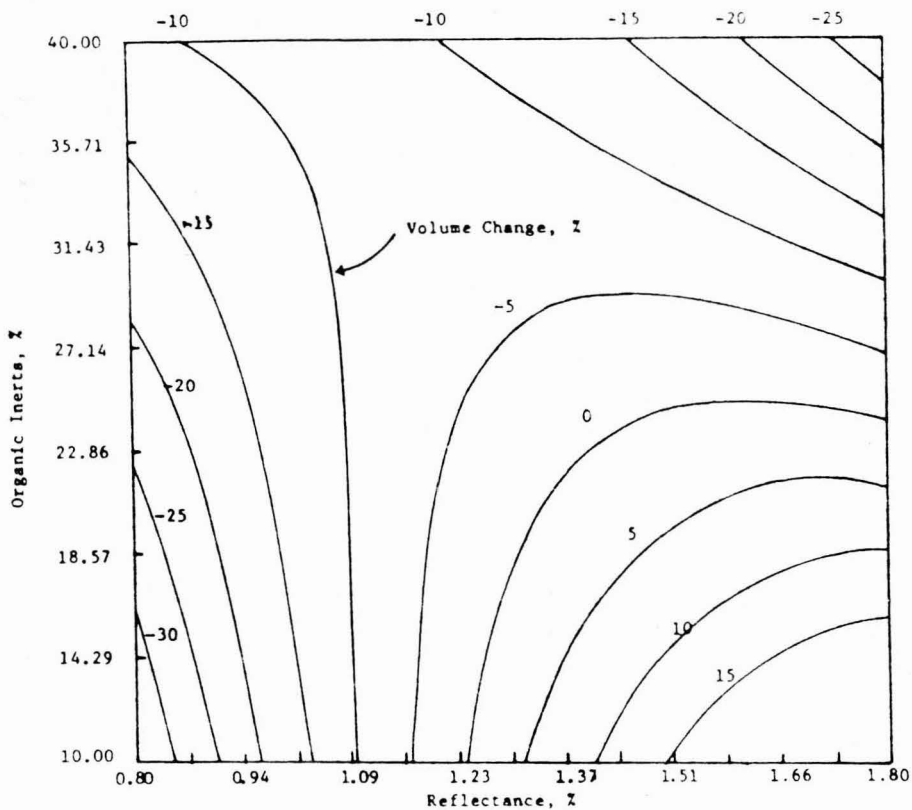


Figure 17. Relation of Vitrinoid Reflectance and Coal Organic Inerts to Volume Change in a Sole-Heated Oven for Individual Coals (52 lb/ft³, 833 kg/m³ bulk density)

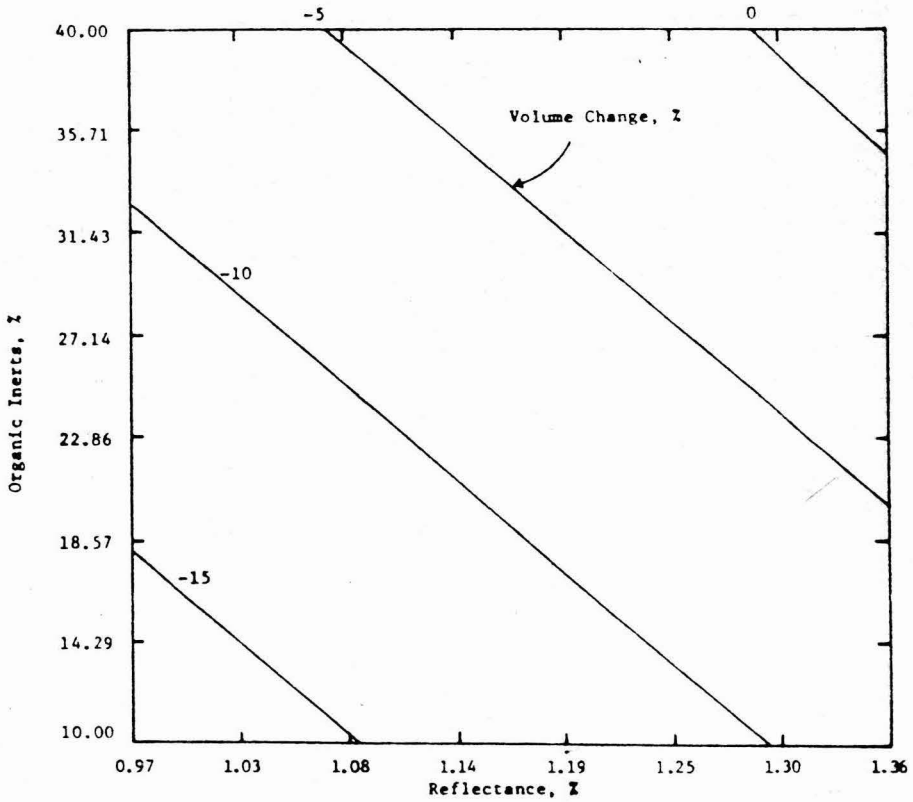


Figure 23. Relation of Vitrinoid Reflectance and Coal Organic Inerts to Volume Change in a Sole-Heated Oven for a Coal Blend (52 lb/ft³, 833 kg/m³ bulk density)

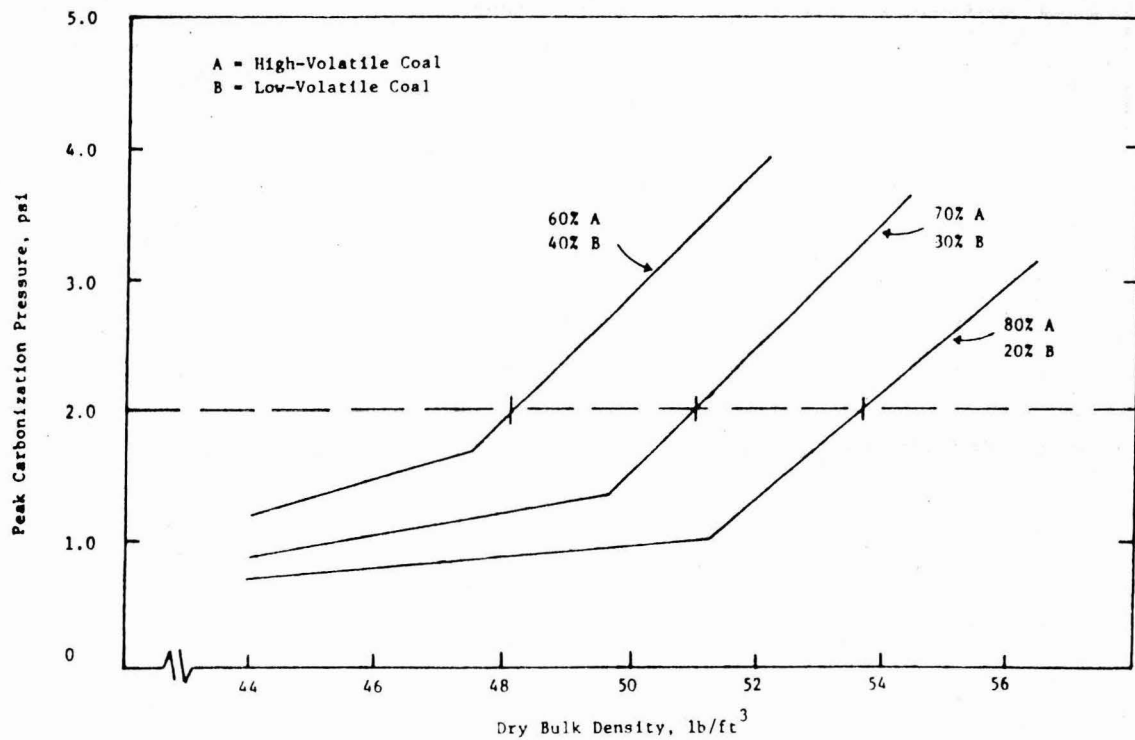


Figure 14. Effect of Bulk Density on Coking Pressure for "AB" 2-Coal Blends (Coking Rate 1.0 inch, 25.4 mm per hour)

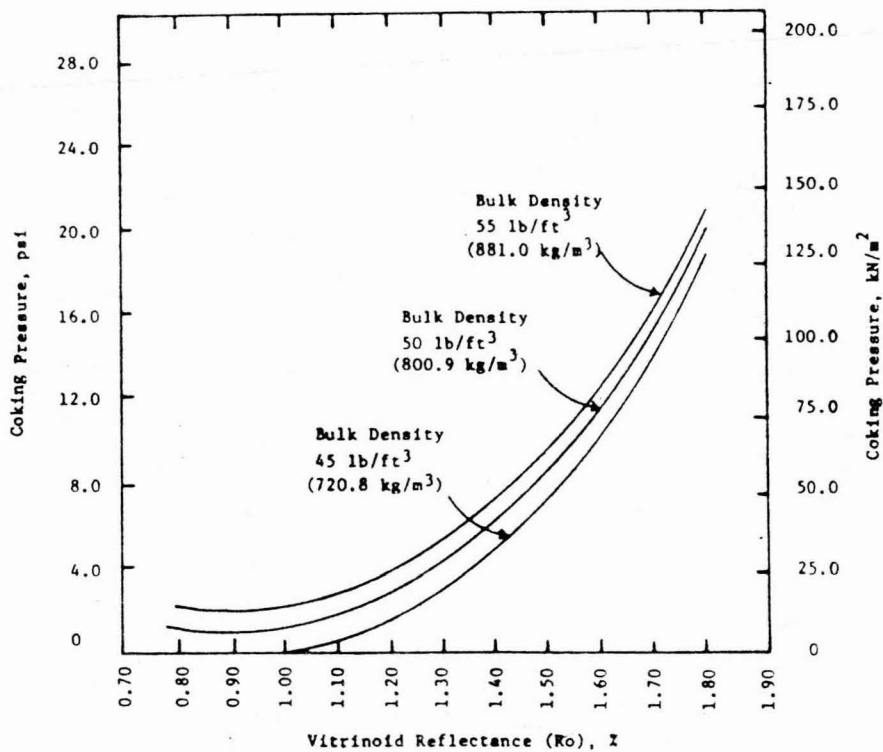


Figure 15. Relationship of Coking Pressure and Average Reflectance of Vitrioids at Indicated Bulk Density

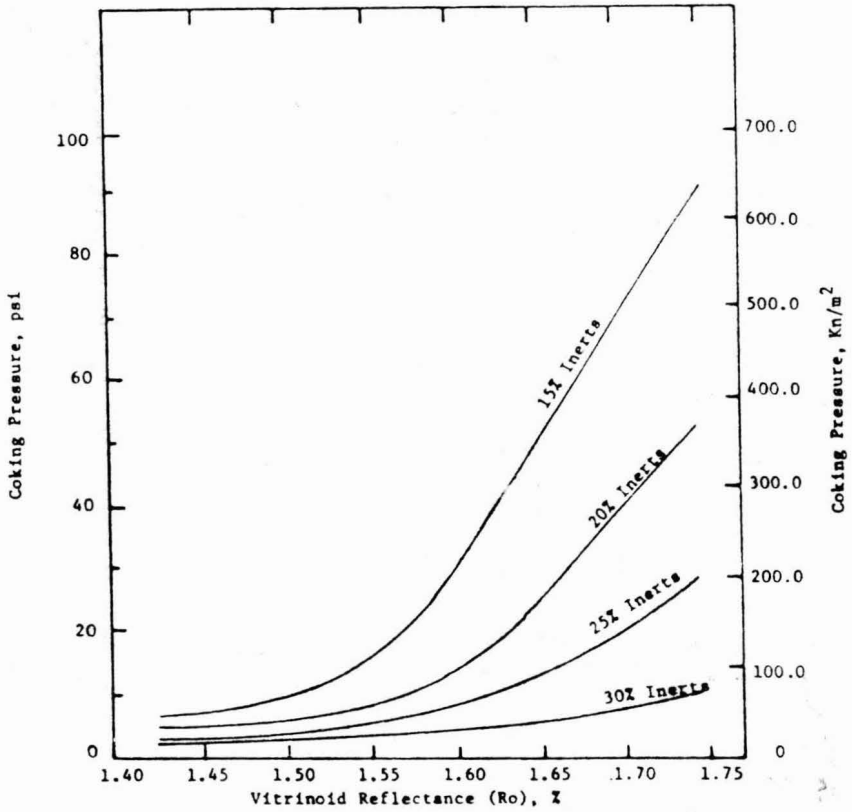


Figure 16. Relationship Between Coking Pressure and Petrographic Composition of Low-Volatile Coal (Bulk Density 51 lb/ft³, 817 kg/m³) (after Thompson et al)