PLASTIC PROPERTIES OF SUNNYSIDE COAL. CLEANING PLANT PRODUCTS, OXIDATION AND STORAGE BLENDS WITH OTHER COALS AND WITH OTHER MATERIALS

Glenn C. Soth

Kaiser Steel Corporation, Fontana, California

Coal from the Kaiser Steel Corporation's Sunnyside, Utah, Mines has been the principal source of coal for making blast furnace coke at Fontana since the start of operations in 1943. Requirements have increased from two batteries of coke ovens supplying one blast furnace to seven batteries of ovens making coke for four blast furnaces. There have been many changes in mining methods, in coal preparation, and in the use of the Sunnyside coal, but this coal still remains the major source of coking coal for the Fontana plant. Experience in use during the years, as well as laboratory investigations, has provided considerable information on the properties of the Sunnyside coal and its behavior during carbonization, both alone and in blends with other materials. These investigations are continuing, to provide better coke, both with respect to chemical properties such as ash and sulfur content, as well as for the physical properties. Better coke gives increased iron production, lower coke rate, and the ultimate object, reduced cost of hot metal.

Early operations at Fontana showed that satisfactory blast furnace coke could not be produced from straight Sunnyside coal.(1) It was necessary to obtain other better coking coals or other materials for improving the size and strength of the coke and to reduce breeze. Changes in coal supply have included purchase of extensive properties in the Raton field in northern New Mexico and use of Koehler mine coal from there. Sources of supply have been developed of purchased medium and low volatile coals for blending with the Sunnyside coal to improve the size and strength of the coke.

It is common practice to blend low volatile coal with high volatile coal for increasing the size and strength of the coke.(2) However, there is no production of low or medium volatile coal nearer to Fontana than the Crested Butte field in Colorado or the interior province coals of the Arkansas-Oklahoma region. Coals from these areas must be shipped by rail; thus the freight cost becomes a very important factor in the economy of operations. Details of the coal handling practice at Fontana have been described recently.(3)

MINING AND COAL PREPARATION

The Sunnyside coal is produced from three separate adjoining mines. Raw coal from all three mines goes to mixing bins to provide a feed as uniform as possible for the coal cleaning plant. The combined coal is crushed to a top size of six inches and the 6 x 0 coal passes through jigs for cleaning. The treatment of the float coal from these jigs for dewatering results in several sizes of products. The 28 mesh x 0 fines from the screens are further treated by flotation and the cleaned coal product is recombined with the coarse clean coal for shipment to Fontana. Details of the flotation cleaning plant have been published.(4)

All of the cleaned coal is shipped immediately and in normal operation no coal is stocked at the mine. Because of the practice of recombining all size fractions of cleaned coal as well as no stocking at the mine for dewatering or drying, the coal arrives at Fontana with 6 to 7% total moisture, the flotation product itself containing 20 to 25% moisture. At Fontana all of the coal received goes to stock and stock coal, 45 - 60 days old, is used in the blend. Fears that Sunnyside coal could not be held in stock even for this length of time without serious decrease in the already poor coking properties has not proven true in practice.

LABORATORY TESTS OF COKING PROPERTIES

Full-scale testing of possible blends is both difficult and expensive, so that laboratory tests to permit selection of the more suitable coals for blending is highly desirable. A variety of laboratory methods have been described in the literature[5] for assessing the coking properties of coals, ranging from tests on usual laboratory samples as small as one gram to various pilot scale test ovens using 500 lbs. or more per test.[6][7] In general, laboratory methods, using rapid rates of heating, are unsatisfactory for application to poorly coking western coals. Often such tests yield cokes, whereas testing at usual rates of carbonization does not yield a coherent cellular coke residue. The Gieseler plastometer test, generally following the proposed ASTM method,[8] has been found most useful for western coals. An illustration of Gieseler plastometer test results is given in Chart I for three different types or ranks of coal. This illustration shows differences in maximum fluidities attained during the test as well as differences in the temperature ranges during which plastic properties were indicated.

Besides the Gieseler plastometer test, both the free swelling and the agglutination tests[9] have been used at times. Results for these tests, compared to values for the maximum fluidity shown in the Gieseler test, are given in Table I and shown graphically in Charts II-A and II-B. The tests for these comparisons at various levels of plasticity were done on 300 g samples of -35 mesh coal. The original sample was tested in the plastometer and portions taken for further grinding to -60 mesh and -200 mesh for the free swelling and the agglutinating test. The remaining gross portion of the sample was placed in a gravity convection drying oven at 105°C. After a selected time interval the sample was removed, cooled, and a portion taken for plastometer testing and other portions for grinding and testing by the other methods. This was repeated until the extent of oxidation was such that no coherent residue was obtained in the Gieseler plastometer test.

The results showed different relationships for different ranks of coal. For purposes of comparison it was found that, if the maximum fluidity in the Gieseler test was less than 2 dial divisions per minute, the residue remaining after the test was only a sintered button and did not exhibit the cellular structure associated with coke. Thus,it was concluded that neither the agglutinating test nor the free swelling test are satisfactory for assessing the coking properties of coals, but could be used possibly to indicate major changes in the coking properties of a coal if the general properties were known from Gieseler plastometer and other testing.

PLASTIC PROPERTIES OF VARIOUS SIZES OF SUNNYSIDE COAL

Plastometer tests were run on each of the sizes of coal obtained at the cleaning plant. The samples were taken at Sunnyside and were 10 to 15 days old when tested at Fontana. The data obtained, Table II, showed the expected increase in moisture with decrease in particle size. Other trends included decrease in volatile matter and increase in ash. The Gieseler plastometer results showed decidedly lower plastic properties for the finer sizes.

Petrographic analyses of the Sunnyside coal had indicated that the coal was over 90% clarain or Type III vitrinite. There were no appreciable percentages of harder or softer constituents such as durain or fusain that might be expected to segregate in the larger or finer sizes and to cause different coking properties by segregation. Therefore, it was indicated that the finer sizes of coal produced at the mine had already undergone considerable weathering between mining and delivery and testing at Fontana.

OXIDATION TESTS

Results at this time were somewhat confusing. Although preliminary studies had indicated that the Sunnyside coal was susceptible to rapid weathering in stock, actual plant practice had shown little change in the coal in 60 days or often a longer period of time. Gieseler tests of stock coal had shown considerable variation in maximum fluidity, Table III, but no apparent trends; average values were not particularly lower than averages for fresh incoming coal. Plastometer testing also was giving confusing results. Duplicate testing, both to check individual samples and to check the results obtained by different operators, did not show good agreement. Further, tests of a series of samples such as blends of Sunnyside with other coals did not show consistent results. Normal fresh Sunnyside coal had been found to give maximum fluidities of the order of 40 to 80 divisions per minute. In the test data shown in Table I the original sample had a maximum fluidity value of only 19 and two hours at 105°C had decreased this value to only 5.7 divisions per minute, indicating rapid oxidation.

It was decided to make a careful examination of the change in plastic properties with time for -35 mesh Sunnyside coal at room temperature. A sample of about 150 grams of -35 mesh Sunnyside coal was prepared as rapidly as possible and then tested immediately. The sample was then set aside in a rubber stoppered glass bottle and tested weekly. The results of this test work are shown in Chart III. As shown in this chart, only one week in this condition had decreased the maximum fluidity from 60 to only 21 divisions per minute. Subsequent testing showed further considerable decline in maximum fluidity but at a decreasing rate. In view of these results a second sample was prepared and tested daily. The results showed a decrease in maximum fluidity from 60 to 33 with only 24 hours standing at room temperature, and further decrease to about 20 after one week. These results explained the lack of agreement in duplicate testing and may explain in part the considerable variation shown in the maximum fluidity of plant control samples. In view of these results a standard time program of sample preparation and of testing was formed.

A variety of methods have been described in the literature for preserving samples of coal for future study. These include storage under an inert atmosphere such as natural gas, filling the air space in the container with water, and freezing the samples. Except for the use of an inert atmosphere, these methods often would require further treatment of the sample that may produce changes as great as would have occurred during storage under air. Also, as shown in Chart II, storage under natural gas served only partially to deter the oxidation and the decrease in the plastic properties.

Because six samples is about the maximum number that can be tested by one operator in one plastometer in an 8-hour work day, and because of the various difficulties of preserving samples, a group of tests was run to study the change in plastic properties with respect to particle size of the coal being preserved. The results are shown in Chart IV. The data obtained indicated that 1/4" was the minimum particle size for a sample that was to be held even for the few days of a testing program.

It may be noted at this point that some of these same difficulties were experienced in coking tests with a 500-lb. test oven. It is customary to obtain a relatively large sample of coal for use in a series of tests in order to eliminate variations that might occur in separate samples. It was found that Sunnyside coal, ground in the laboratory hammermill to approximately 75% -1/8" and preserved in covered steel drums, showed decided changes in coking properties within two weeks storage.

PLASTIC PROPERTIES OF BLENDS OF SUNNYSIDE WITH LOW VOLATILE COALS

Only after the rapid change in plastic properties of -35 mesh Sunnyside coal at room temperature was understood was it possible to obtain satisfactory results for plastic properties of blends of Sunnyside coal with other materials. As shown previously in Chart I, the plastic temperature range for Sunnyside coal extends from about 335° to 460°C. Many true low volatile coals, on the other hand, show plastic properties in the Gieseler test in the range 440 to 505°C. Only a small temperature interval of perhaps 20° is common to these two types of coal.

The change in maximum fluidity with change in composition of blends of Sunnyside with two different low volatile coals is shown in Chart V. The maximum fluidity shown for the Sunnyside coal and low volatile coal "A" was approximately the same at 50 to 60 divisions per minute. However, adding this low volatile coal to Sunnyside coal produced a rapid decrease in the maximum fluidity with increase in the percent of the low volatile coal used to a minimum of approximately 2½ divisions per minute at a composition of about 75% Sunnyside and 25% low volatile coal. The second series of tests was run using low volatile coal "B" of much lower maximum fluidity. The same type of curve resulted except that the change in maximum fluidity with increase in percent coal "B" was greater than when the more fluid low volatile coal "A" was used.

A minimum value for the fluidity of a blend of coking coals cannot be given because the quality of the coke is influenced by many other factors besides fluidity. However, plant practice had shown that at times during the year, particularly in the fall, the coke quality decreased. This decrease in quality with increase in breeze was found to be related to the decrease in the maximum fluidity shown by the mixed coal being carbonized. Attempts to improve the coke quality by increasing the percentage of the low volatile coal were not very successful and the reason for this is shown by the course of the curves given in Chart V. Increase in the percent low volatile coal decreases the fluidity of the mixed coal.

PLASTIC PROPERTIES OF BLENDS OF SUNNYSIDE WITH MEDIUM VOLATILE COALS

Medium volatile coals are less desirable from the economic standpoint for blending with Sunnyside coal. Higher percentages of medium volatile coal are required to obtain a given increase in the size and strength of the resulting coke. The carbon return in carbonization is lower than obtained from low volatile coals. Nevertheless, the generally excellent coking properties of medium volatile coals have been found to be desirable for use at Fontana for obtaining better fused cokes and reduction in breeze.

The results of Gieseler plastometer tests of blends of Sunnyside coal with two different medium volatile coals are shown in Chart VI. It may be seen that the change of maximum fluidity with change in composition is not linear. For practical purposes only the parts of the curves from 0 to 20% medium volatile coal additions have been of practical interest. Additions of medium volatile coal in this range cause little increase in the maximum fluidity of blends with Sunnyside coal. However, in comparison with the use of low volatile coal, it is significant that the maximum fluidity actually increased or remained the same and did not show the very marked decrease of Sunnyside-low volatile coal blends.

PLASTICITY RELATIONSHIPS USING KOEHLER COAL

The Koehler coal from the Raton, New Mexico, field had been used at various times even before purchase of the property by the Kaiser Steel Corporation in 1957. The Koehler coal shows considerably better plastic properties than the Sunnyside coal although the proximate analysis indicates approximately the same rank of coal, Table IV. Also, coke produced from straight Koehler coal is appreciably larger and stronger than is obtained from Sunnyside coal. The Gieseler plastometer test shows approximately the same temperature range of occurrence of plastic properties. Blends of Sunnyside and Koehler coal showed a linear change in maximum fluidity with change in composition, as illustrated in Chart VII. Blends of Koehler coal with low volatile or with medium volatile coals showed the same general changes in maximum fluidity with change in composition as described for the blends using Sunnyside coal. Thus, in general, Koehler coal can be substituted for Sunnyside coal.

PLASTIC PROPERTIES OF BLENDS OF LOW AND MEDIUM VOLATILE COALS

Tests were made of blends of medium volatile and low volatile coals for basic information of blending. The results are shown in Chart VIII. As would be expected, due to the great variety of both low and medium volatile coals, a great number of combinations are possible. The results shown in Chart VIII represent only two series of possibilities. These results indicated that addition of medium volatile coal to low volatile coal produced appreciable increases in the maximum fluidity when only 20% medium volatile coal was present. This result might be expected from the greater coincidence of the temperature ranges of plasticity compared to blends of Sunnyside with either low or medium volatile coal. Above 20% addition of medium volatile coal very great increases in maximum fluidity were shown although it is probable that these increases are due to a considerable extent to the swelling that occurs during the testing of such blends.

THREE-COMPONENT BLENDS OF SUNNYSIDE, LOW, AND MEDIUM VOLATILE COALS

Plant practice had shown that blends of Sunnyside and low volatile coals were satisfactory only part of the time; at other times the fusion of the blend became poor resulting in excess breeze production and decrease in the tumbler test hardness factor. Use of only medium volatile coal with Sunnyside is not desirable because greater percentages are required for a given level of size and strength. These two considerations resulted in the practice of using both low and medium volatile coals for blending with Sunnyside coal. The relative percentages of low and medium volatile coal are changed, depending upon the economic considerations and the coke requirements at a given time.

Actually, three-component blends of Sunnyside, low, and medium volatile coals result in a variety of curves between the individual two-component series of Sunnyside-medium volatile and Sunnyside-low volatile. Two relationships are shown in Chart IX. When equal quantities of the low and medium volatile coals used were blended with Sunnyside coal, the change in maximum fluidity with change in percent blending coal added showed a decline in maximum fluidity but at a much slower rate than shown by using low volatile coal alone. When the relative percentages were changed to 1/3 low volatile and 2/3 medium volatile coal, the maximum fluidity shown by the blend with Sunnyside coal showed essentially no change in maximum fluidity over the practical range of addition of the blending coal.

OTHER COALS AND MATERIALS FOR INCREASING THE FLUIDITY OF BLENDS

Except for a relatively few areas in Colorado there are no known operating mines in southwestern United States producing high fluidity coking coals. The use of such coals, of course, would be essentially substitution of the high fluidity, probably high volatile, coal for Sunnyside rather than replacement of the expensive medium and low volatile coals being used. Exploration in the Kaiser Steel Corporation's Raton properties has shown extensive deposits of both high volatile coking coal of excellent plastic properties as well as deposits of medium volatile coals also of excellent plastic properties. Use of these sources awaits future development.

Besides other coals, some natural asphalts or bituminous materials are available western raw materials. A number of these materials have been tested. Although such materials become highly fluid during carbonization, not all of them show the same ability to improve the coke quality. It is probable that the differences in effects on plastic properties are related to differences in the plastic ranges of these bituminous materials together with variations in the rate and manner of decomposition and devolatilization.

One such natural bituminous material that has been used in emergency on the plant scale basis is Gilsonite[10] obtained from northeastern Utah. It was found in plant practice during periods when the coals on hand did not possess sufficient fluidity, that 3½ to 5% Gilsonite could be blended with the coking mix successfully to reduce the plant coke breeze yield. Chart X shows the increase in the maximum fluidity obtained by blending Gilsonite either with Sunnyside coal or with low volatile coal, and comparative results are indicated for the benefits in increasing fluidity obtained using medium volatile coal. It is evident that small percentages of Gilsonite cause decided increases in the maximum fluidity shown by coals in the Gieseler plastometer test.

Chart XI illustrates the application of Gilsonite to a plant coal mix. Addition of 17½% low volatile coal to Sunnyside decreased the maximum fluidity from 42 divisions per minute for straight Sunnyside down to only 20 divisions per minute. Additions of Gilsonite to this 82½% - 17½% blend caused rapid increase in maximum fluidity with increase in percent Gilsonite. Only 4% Gilsonite was required to raise the fluidity of the coal blend up to the value shown by the Sunnyside coal itself. Further small increases in Gilsonite brought the maximum fluidity to over 100 divisions per minute. Carbon return is very low for Gilsonite and the delivered cost is high so that Gilsonite has not been used on a continuing basis.

USE OF INERT MATERIALS FOR IMPROVING THE QUALITY OF COKE OBTAINED FROM SUNNYSIDE COAL

There has always been active interest at Fontana in finding substitutes for the expensive low and medium volatile coals that have been required to improve the coke quality for satisfactory blast furnace performance. It has also been recognized that the possibilities for success were small because Sunnyside coal, coked alone, does not yield completely fused coke. Pebbly seam and, at times, considerable portions of poorly fused agglomerate rather than true coke are found. Thus, this coal could hardly be expected to absorb inert or non-coking carbonaceous materials without further considerable increase in breeze. Even with excellent coking coals such inert materials have been found to give variable results depending on source and composition. For example, some varieties of anthracite have been used successfully for incorporation into coking blends for increasing coke size and foundry coke production at fast coking rates[11], but only certain anthracites have been found suitable for this application. At Fontana many varieties of char, anthracite, petroleum coke, and other inert materials have been tested, generally with poor results.

An example of the effects on the plastic properties is the use of petroleum coke as a blending material for increasing the coke size and strength. Chart XII shows the relationships between maximum fluidity of the blend and the percent petroleum coke. As might be expected, increase in percent petroleum coke caused decrease in the maximum fluidity of the blend. However, it is interesting to note that the rate of decrease of the maximum fluidity is less than shown by equivalent additions of low volatile coal. Test work is under way at present to examine the plastic properties of blends of Sunnyside and Koehler coals with inert materials, but using Gilsonite and other natural high fluidity materials for increasing the plastic characteristics of the blends.

CONCLUSION

A knowledge of the plastic properties of the Sunnyside coal has been found useful in explaining experiences in the use of the coal both alone and in blends with other materials. This information has also been beneficial in the selection of other coals for blending and in the determination of suitable blends. However, it is recognized that plasticity is only one factor in the selection and use of coals for carbonization. The Gieseler plastometer test has been found most useful for the determination of the plastic properties of coals and blends of coals and for the detection of changes in the plastic properties. The understanding of the susceptibility of the Sunnyside coal to rapid changes in plastic properties at room temperature, for fine particle sizes, has been very important for obtaining satisfactory results for duplicate tests and for series of samples. Such rapid change in plastic properties at room temperature may be of importance for other laboratories to consider where difficulties have been experienced in obtaining duplicate results or consistent values for plastometer testing. These effects may become increasingly important in the estimation and use of other higher rank coals because of the increased mechanization of mining and finer coal production, cleaning of finer sizes, the use of heat drying to reduce the moisture content of coking coals before shipment, and the stocking of finer coking coals.

ACKNOWLEDGMENT

The author is indebted to the management of Kaiser Steel Corporation for permission to prepare and to present this paper; he wishes to express appreciation to other employees of Kaiser Steel Corporation for assistance and suggestions in the preparation of the paper.

BIBLIOGRAPHY

(1) Thompson, J.H., Blast Furnace and Steel Plant 34 225 (1946).
(2) Russell, C.C., and Perch, M., A.I.M.E. Tech. Publ. No. 1520 (1942).
(3) Schulze, W.G., and Soth, G.C., A.I.M.E. Blast Furnace, Coke Oven, and Raw Materials Conference, April 4-6 (1960).
(4) Denver Equipment Co., Deco Trefoil 21 No. 3 11 May-June 1957.
(5) Brewer, R.E., U.S. Bur. Mines Bulletin 445 (1942).
(6) Harris, H.E., Glowacki, W.L., and Mitchel, J., see ref. 3.
(7) Lee, G.W., see ref. 3.
(8) ASTM Standards on Coal and Coke, Appendix III p 129, 1954.
(9) ibid. Standard D 720-57; ibid. Sept. 1948, p 151.
(10) Bond, R.K., Chem. Eng. 64 249 (1957).
(11) Roberts, I.M., A.I.M.E. Tech. Pub. No. 1612 (1942).

TABLE I

COMPARISON OF GIESELER PLASTOMETER MAXIMUM, FREE SWELLING INDEX, AND AGGLUTINATION TEST INDEX

SUNNYSIDE COAL: V.M. 40%, ASH 7%, SULFUR 1.2%

SAMPLE	P.MAX.	FSI	A.I.
Original	19	3½	9.1
2 hours at 105°C	5.7	-	-
4 " " "	4.5	3½	6.9
8 " " "	2.9	3½	6.7
16 " " "	1.3	2½	5.5
24 " " "	1.0	2	5.3
36 " " "	.5	1+	3.9
48 " " "	No fusion	1	2.7

LOW VOLATILE COAL: V.M. 18%, ASH 8%, SULFUR .9%

SAMPLE	P.MAX.	FSI	A.I.
Original	13	9+	19.1
4 hours at 105°C	2.8	9	18.5
8 " " "	2.2	9	18.1
16 " " "	1.3	8	15.3
24 " " "	1.2	8	14.3
36 " " "	.8	5½	7.8
48 " " "	.6	4½	4.8
96 " " "	No fusion	3	2.5

TABLE II

ANALYSES AND PLASTIC PROPERTIES OF VARIOUS SIZES OF SUNNYSIDE COAL FROM THE CLEANING PLANT

SIZE	H_2O	ANALYSIS (DRY BASIS)				GIESELER PLASTOMETER TEST				
	%	V.M. %	F.C. %	ASH %	SUL. %	F.M. °C	.1 D/M °C	MAX. °C	SOLID. °C	MAX. D/M
6" x 1-5/8"	3.4	42.1	52.4	5.5	1.12	339	370	429	459	55
1-5/8" x 1/2"	4.8	40.3	52.9	6.8	1.18	339	367	429	459	46
1/2" x 3/16"	7.9	40.1	52.9	7.0	1.11	347	369	428	459	19
3/16"x 28 mesh	8.4	39.5	52.9	7.6	1.14	344	372	426	459	14
28 mesh x 0	22.2	39.2	52.6	8.2	1.27	366	387	427	455	8

TABLE III

SUNNYSIDE COAL RECOVERED FROM STOCKPILE
COAL APPROXIMATELY 60 DAYS IN STOCK

SAMPLE NO.	SIZE CONSIST +28 MESH	SIZE CONSIST -28 MESH	P.MAX. +28 MESH	P.MAX. -28 MESH
1	88	12	38	9
2	84	16	45	9
3	84	16	25	4.8
4	74	26	35	3.3
5	78	22	37	4.9
6	82	18	65	9
7	84	16	35	5.0
8	85	15	45	11
9	82	18	50	7
10	88	12	57	10
11	83	17	32	11
12	81	19	40	10

TABLE IV

PROXIMATE ANALYSES, SULFUR, AND GIESELER TEST DATA

CONSTITUENT	ANALYSIS (DRY BASIS)				GIESELER PLASTOMETER TEST				
	V.M. %	F.C. %	ASH %	SUL. %	F.M. °C	.1 D/M °C	MAX. °C	SOLID. °C	MAX. D/M
COALS:									
Sunnyside	40.4	52.9	6.7	1.21	333	368	426	458	60
Koehler	37.7	49.8	12.5	.71	330	365	427	462	200
Med.Vol.(Okla.)	26.1	66.9	7.0	1.07	377	383	453	504	2700
Med.Vol.(W.Va.)	23.9	69.9	6.2	.58	384	391	467	504	1900
Med.Vol.(Colo.)	23.4	69.1	7.5	.68	386	395	462	507	2000
Low Vol.(Okla.)	19.6	72.3	8.1	.73	425	430	474	511	160
Low Vol.(W.Va.)	18.4	75.6	6.0	.72	425	427	476	510	65
Low Vol.(Ark.)	17.7	74.4	7.9	.88	442	446	482	509	22
Low Vol.(Ark.)	17.3	74.0	8.7	.95	442	446	487	507	7
Petroleum Coke	12.2	87.6	.2	1.15		No Fusion			
Gilsonite	77.7	21.9	.4	.19		Too Fluid To Test			

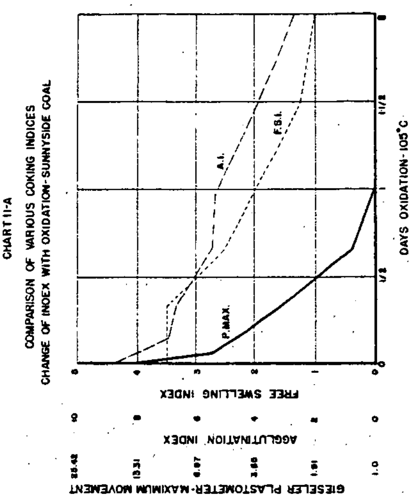
CHART II-A
COMPARISON OF VARIOUS COKING INDICES
CHANGE OF INDEX WITH OXIDATION-SUNNYSIDE COAL
A.I.
F.S.I.
P.MAX.
DAYS OXIDATION-105°C
FREE SWELLING INDEX
AGGLUTINATION INDEX
GIESELER PLASTOMETER-MAXIMUM MOVEMENT

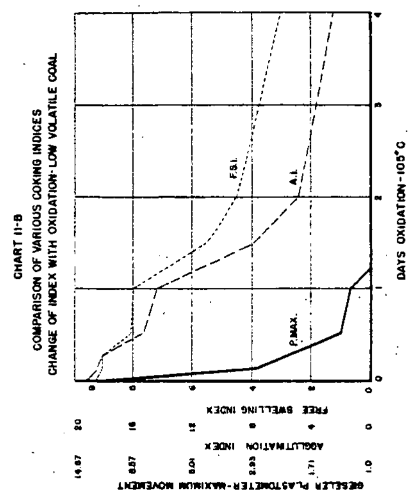
CHART II-B
COMPARISON OF VARIOUS COKING INDICES
CHANGE OF INDEX WITH OXIDATION-LOW VOLATILE COAL
F.S.I.
A.I.
P.MAX.
DAYS OXIDATION-105°C
FREE SWELLING INDEX
AGGLUTINATION INDEX
GIESELER PLASTOMETER-MAXIMUM MOVEMENT

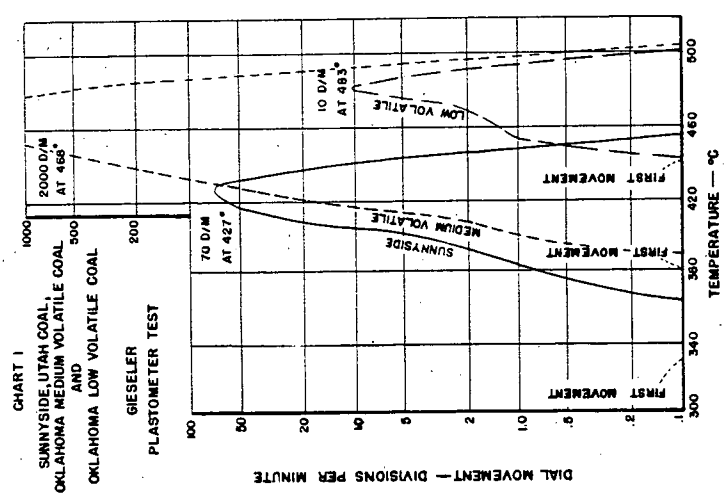
CHART I
SUNNYSIDE, UTAH COAL,
OKLAHOMA MEDIUM VOLATILE COAL
AND
OKLAHOMA LOW VOLATILE COAL
GIESELER
PLASTOMETER TEST
2000 D/M AT 466°
10 D/M AT 483°
70 D/M AT 427°
LOW VOLATILE
MEDIUM VOLATILE
SUNNYSIDE
FIRST MOVEMENT
FIRST MOVEMENT
FIRST MOVEMENT
TEMPERATURE — °C
DIAL MOVEMENT — DIVISIONS PER MINUTE

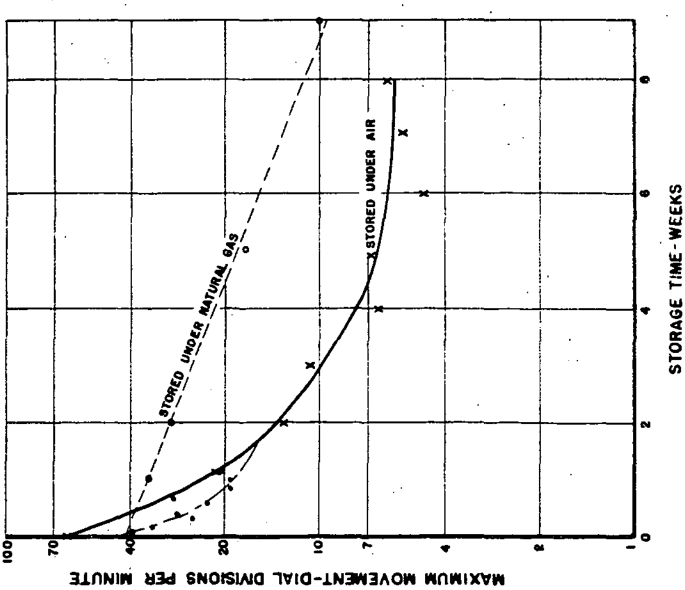

CHART III
CHANGE IN MAXIMUM FLUIDITY IN STORAGE
-35 MESH SUNNYSIDE COAL

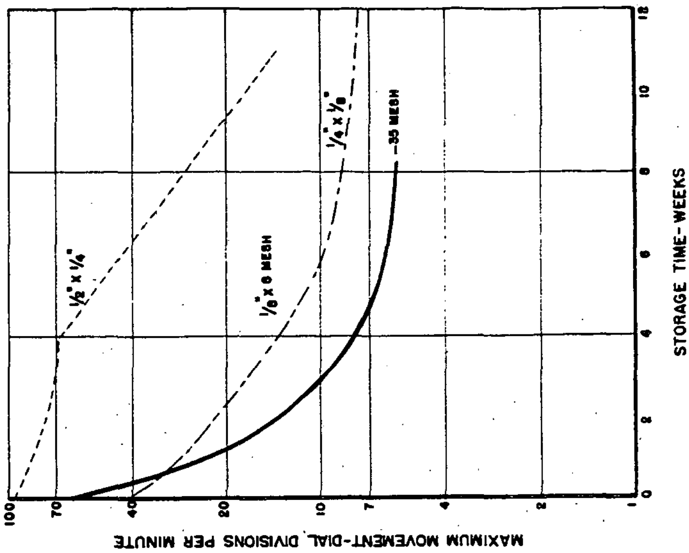

CHART IV
CHANGE IN MAXIMUM FLUIDITY IN STORAGE
EFFECTS OF COAL PARTICLE SIZE-SUNNYSIDE COAL

CHART VI

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE-MEDIUM VOLATILE COAL BLENDS

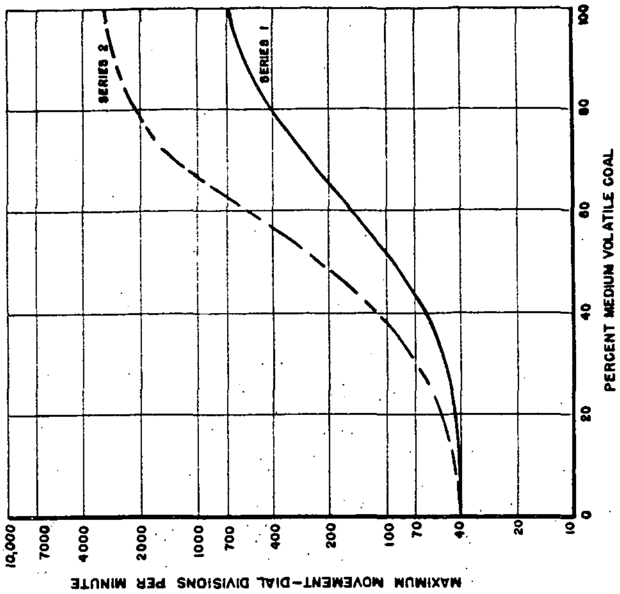

CHART V

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE-LOW VOLATILE COAL BLENDS

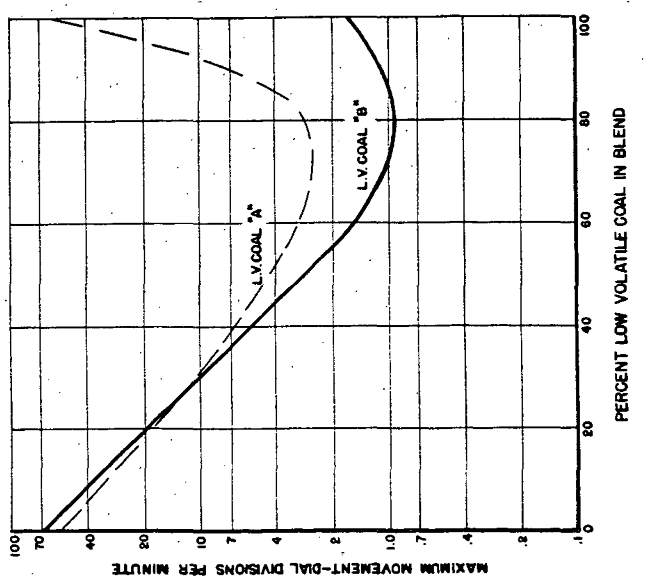

CHART VII

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION

SUNNYSIDE-KOEHLER COAL BLENDS

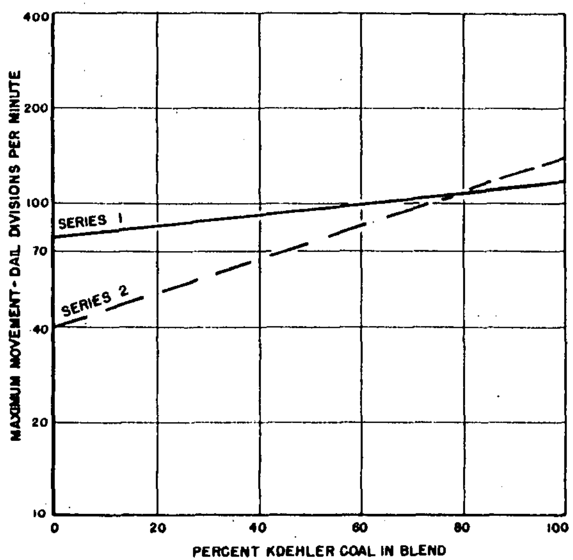

CHART VIII

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION

LOW VOLATILE-MEDIUM VOLATILE COAL BLENDS

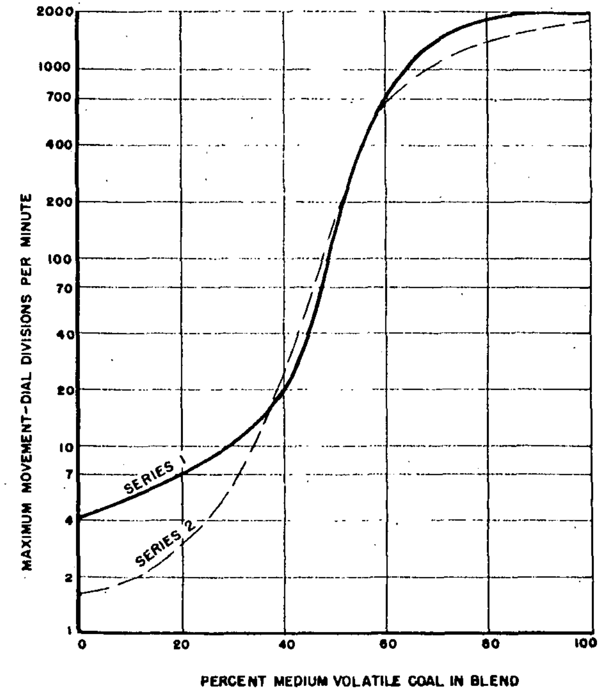

CHART IX

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE WITH LOW & MEDIUM VOLATILE COALS

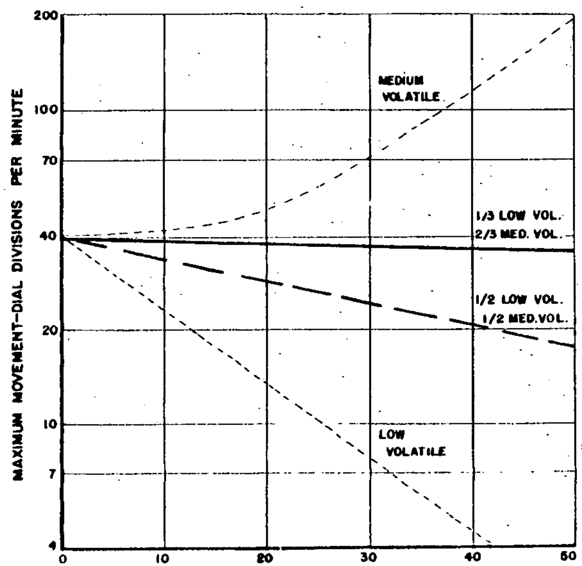

CHART X

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE-GILSONITE & LOW VOLATILE-GILSONITE BLENDS

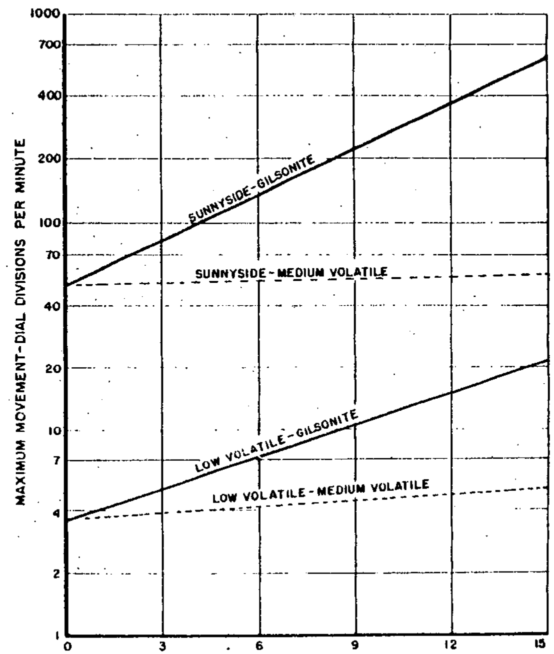

CHART XI

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE-LOW VOLATILE COALS WITH GILSONITE

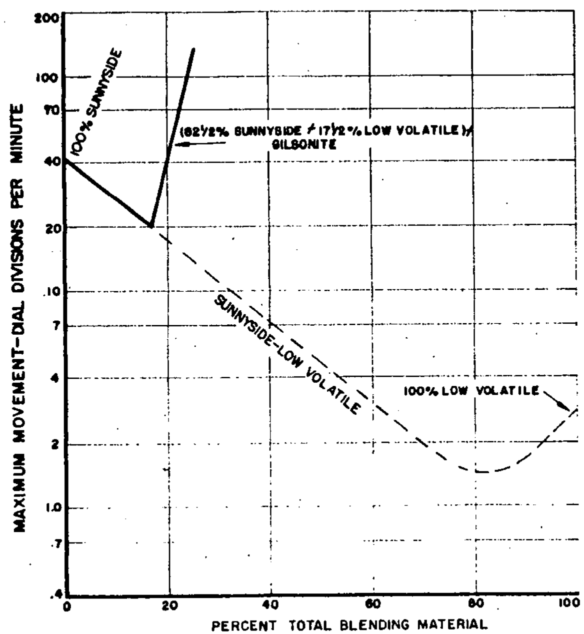

CHART XII

CHANGE IN MAXIMUM FLUIDITY WITH CHANGE IN COMPOSITION
SUNNYSIDE-PETROLEUM COKE & KOEHLER-PETROLEUM COKE BLENDS