A FURTHER STUDY OF THE RELATIONSHIP BETWEEN THE CHEMICAL, PLASTIC, AND PETROGRAPHIC PROPERTIES OF ALABAMA MEDIUM-VOLATILE COALS AND THEIR CARBONIZATION BEHAVIOR

B. R. Kuchta, B. Perlic, R. J. Gray, and J. D. Clendenin

U. S. Steel Corporation
Applied Research Laboratory
Monroeville, Pa.

Introduction

During the past several years, studies have demonstrated that the petrographic properties of coals can be correlated with their carbonization behavior and coking properties.[1,2,3,4,5)*] While coal is being examined petrographically, a measurement is made of the reflectance of the vitrinite in the crushed coal sample. This reflectance has been shown to be directly related to the rank of the coal. Furthermore, it is well known that rank is important in the determination of other carbonization characteristics such as volume change and coking pressure. Since a general relationship prevails between rank and these parameters, a correlation would be better if it were confined to a narrow range of coals or coal blends.[6,7)]

In a previous paper[6)] the authors showed that the volume-change characteristics (expansion-contraction in the sole-heated oven) were related to the plastic and chemical properties of several Alabama medium-volatile coals. In the present paper, the authors demonstrate how not only volume change but also coking pressure are related to the chemical and plastic properties and petrographic characteristics of washed coal samples.

Experimental

The samples consisted of a series of six composites of the daily production from each of several mines operating in the Pratt, American, and Mary Lee seams (Table I). All samples were taken on consecutive days except for those from Mine B in the Pratt seam; the last three samples from this mine were taken six months after the first three.

For the tests in both the 30-lb pressure-test oven and the sole-heated oven, the coals were pulverized to minus 1/4 inch and dried to about 1 percent moisture. These conditions were used to obtain more reliable results in these small ovens and to permit comparisons with the results of the earlier work. The oven designs and heating programs have been described in earlier publications.[6,7,8)] Petrographic, chemical, and plastic properties of the various samples are listed in Table I. Corresponding carbonization data are given in Table II.

* See references.

Relation Between Petrographic and Chemical Characteristics

Since reflectance furnishes a relatively precise measurement of rank,[1] the amounts of the entity types present in the coal as determined petrographically should be related to a chemical-rank parameter, such as volatile matter content. Figure 1 shows the relation between volatile matter content and reflectance of the entities in coals.[3] In general, the exinoids in a coal contain considerably more volatile matter than the vitrinoids of the same rank, and both the exinoids and the vitrinoids contain more volatile matter than the inert semifusinoids, micrinoids, and fusinoids.[4] This is illustrated in Figure 1, in which reflectance of the principal entities is plotted against their volatile matter contents. The different volatile matter contents of the entities are apparent from the lines connecting entities of the same rank. Also one can see how the differences in volatile matter contents become less as the rank increases.

The average vitrinoid reflectance calculated from the quantitative petrographic analysis can be used to calculate the volatile matter content of a coal, by means of the following formula developed by Van Krevelen and Schuyer.[3]

$$VM_c = \frac{E}{100} VM_e + \frac{V}{100} VM_v + \frac{M}{100} VM_m$$

where VM_c is the dry, ash-free volatile matter content of the coal; VM_e, VM_v, and VM_m the dry, ash-free volatile matter contents of the entities; E the percentage of exinoids and resinoids in the coal; V the percentage of vitrinoid plus 1/3 semifusinoids; and M the percentage of inert entities (micrinoids, fusinoids, and 2/3 semifusinoids). In Figure 2 a good correlation is apparent between the volatile matter from the proximate analysis and that obtained by use of the above equation. The calculated volatile matters in Figure 2 are based on the use of the entity volatile matter values published by Van Krevelen and Schuyer.[3] If volatile matter contents are obtained for these entities of the coals being worked with, even better agreement between the calculated values and those from the proximate analysis should be obtained.

Volume-Change Characteristics

Figure 3 shows the relationship of the maximum fluidity of these coals to the average reflectance of the vitrinoids in them. In general, as the average reflectance of the vitrinoids increases, the maximum fluidity decreases. Pratt-seam Mine-B samples exhibit the highest fluidity; Pratt-seam Mine-C and the Mary Lee-seam samples, intermediate fluidities; and Pratt-seam Mine-A and American-seam samples, the lowest fluidities.

Figure 4 shows the relationship between the volume-change characteristics of these coals and the average reflectance of the vitrinoids present. The volume-change data have been corrected[9] to a bulk density of 55 lb of dry coal per cubic foot. This figure indicates that the coals containing vitrinoids with reflectance below about 1.14 percent contract strongly, and that those having vitrinoid reflectance above 1.14 percent are less contracting and show increasing tendency toward expansion as the vitrinoid reflectance increases. It should be noted that the Mine-B Pratt-seam samples showed the widest range in volume change and also the widest range in total inerts (Table I) of all the coals. This range of inerts shows the importance of the inert content of a coal in determining its volume-change characteristics.[5] This is illustrated in Figure 5, in which the volume change of

American-seam coal is plotted against its total inert content. The samples included a very narrow range of rank and had reflectances between 1.206 and 1.223 percent. The transition between contraction and expansion falls between a total inert content of 20 to 21 percent. Beyond this the contraction increases as the amount of inerts increases. Evidently the "pure" coal reactive entities could be expected to be expanding in nature and any increase in the amount of inerts would dilute this effect so that the coal would be less expanding or even contracting. The particle size of the inerts would influence the degree of this effect. Conversely, the opposite effect has been noted wherein if the "pure" coal reactive entities are contracting, the addition of inerts results in less contraction. This would be expected since the inert material, which shows little change in volume during carbonization, would dilute the contracting nature of the "pure" coal reactives.

In the previous study,[6)] volume changes of the coals in the sole-heated oven were correlated with their maximum fluidities. This relationship is shown in Figure 6. The band represents the range of values noted in the earlier work,[6)] within which the washed coal samples fall. This demonstrates the usefulness of the Gieseler Plastometer in assaying the expansion-contraction properties. Here again, those coals having a maximum fluidity above 10,000 dial divisions per minute should be contracting, and could be expected to give no difficulty in the pushing of the coke if operating practices are under control.

Figure 7 shows the correlation between the volatile matter content and the volume changes for these coals. Because both volatile matter and reflectance are measures of rank, volatile matter would be expected to yield a relationship similar to that obtained in Figure 4. The authors' earlier work[6)] indicates that a useful method of estimating the comparative expansion-contraction characteristics of these washed coals should result from a multiple correlation with the ash along with the volatile matter contents. However, because the present washed samples did not show enough variation in ash content between samples from each mine, ash is not significant in the correlation. This does not mean that it should be disregarded in coals that show a greater degree of variability than these samples had. Within a narrow range of ash contents, however, inerts are important, as shown in Figure 5.

Coking Pressure

Since both volume change and coking pressure appear to be the result of the same basic phenomena occurring in coal during heating, these two carbonization characteristics would be expected to correlate under certain conditions. Furthermore, it is generally accepted that coals exhibiting a coking pressure greater than about 2 lb per square inch or having less than approximately 7 percent contraction should not be used.[10)] It is not within the scope of this paper to judge the validity of these limits. However, if these or any similar set of limits are used, then some coals will, at a particular operating bulk density, meet one of these limits, but not the other. Therefore, it would be desirable if petrographic, chemical, or plastic properties of these coals could be used to estimate the coking pressure that might develop.

The relationship between coking pressure of the coal and average reflectance of the vitrinoids in the coal is shown in Figure 8. The data on the Mary Lee-seam samples are not shown in this figure nor in those that follow, because these samples had higher oven bulk densities than the samples from the other seams. These higher bulk densities were the result of the coarser particle-size distribution obtained in pulverizing the higher ash Mary Lee coals, even though they were pulverized to the same top size as the lower ash coals used. In Figure 8, samples having an average reflectance of less than 1.18 percent should not exhibit a coking pressure in excess of the 2 lb per square inch usually considered as the limiting pressure for safe oven operations.

A similar relationship is noted in Figure 9 between coking pressure and volatile matter. In this figure, those coals having a volatile matter greater than 28 percent exhibit coking pressure less than this 2-psi limit, and therefore could be used safely at the bulk densities listed.

The relationship between the coking pressure and the maximum fluidity is shown in Figure 10. Those coals having a Gieseler maximum fluidity in excess of 10,000 dial divisions per minute should not offer any problems with pressure in the oven. Note that this is the same limit that was found for the volume-change characteristics. This lends support to the idea put forth by Potter[11] that these carbonization properties could be expected to correlate under certain conditions.

Summary

The chief finding of this investigation was that reflectance of the vitrinoids, volatile matter content, and maximum fluidity can be used to obtain an estimate of the expansion-contraction behavior and coking pressure exhibited by these medium-volatile coals. Thus, these carbonization characteristics can be estimated from the parameter most readily available.

References

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* In reference 6 two graphs were reversed and should be corrected as follows: that on page 767 should be titled "Figure 8. Comparison of Site and Zone Samples from the Mary Lee Seam Mine;" and that on page 768 should be titled "Figure 7. Comparison of Site and Zone Samples from American Seam Mine."

Table I

Petrographic, Chemical, and Physical Properties

Coal	Sample No.	Entity Composition of the Coal, volume percent* — Reactive Entities: V9	V10	V11	V12	V13	V14	E	R	SF	Total	Inert Entities: SF	M	F	MM	Total	Avg Ro	Proximate and Sulfur Analyses, wt percent: Volatile Matter	Fixed Carbon	Ash	Sulfur
Pratt Seam Mine A	1		1.5	18.3	48.8	7.6		3.6	0.2	0.6	80.6	1.2	10.4	3.8	4.0	19.4	1.239	26.3	67.0	6.7	1.29
	2		2.9	18.2	48.1	3.7		2.4	0.2	0.6	76.1	1.3	14.0	4.2	4.4	23.9	1.215	27.6	65.1	7.4	1.38
	3		0.8	16.8	51.2	7.7		2.5		0.5	79.5	1.0	11.4	3.8	4.3	20.5	1.242	26.2	66.6	7.2	1.41
	4		0.8	14.6	49.2	12.3		2.7	0.1	0.8	80.5	1.6	8.9	4.6	4.4	19.5	1.248	25.8	66.8	7.4	1.39
	5		0.8	13.9	47.1	15.5		3.0		0.7	81.0	1.3	9.5	3.7	4.5	19.0	1.250	25.7	66.8	7.5	1.37
	6		0.8	14.2	51.2	12.6		1.6	0.3	0.4	81.1	0.7	8.7	5.3	4.2	18.9	1.244	26.6	66.4	7.0	1.25
Pratt Seam Mine B	1	2.9	17.2	45.8	3.6	2.1		3.8	0.1	0.7	76.2	1.5	12.0	5.9	4.4	23.8	1.125	29.8	63.0	7.2	1.59
	2	0.7	26.6	37.0	4.9	0.7		3.4	0.1	0.8	74.2	1.6	13.5	5.7	5.0	25.8	1.107	30.8	60.9	8.3	1.68
	3	1.5	23.2	46.4	3.0	0.8		3.5	0.1	0.4	78.9	0.7	11.2	5.0	4.2	21.1	1.122	30.2	62.9	6.9	1.57
	4	1.3	23.5	36.9	4.7	0.7		5.1	0.2	0.8	73.2	1.8	15.7	5.1	4.2	26.8	1.116	29.9	63.1	7.0	1.43
	5	2.1	24.8	39.2	2.7			4.8	0.2	0.9	74.7	1.9	14.4	4.8	4.2	25.3	1.114	29.9	63.1	7.0	1.41
	6	1.4	27.5	37.8	1.4	0.7		3.3		0.7	72.8	1.5	14.0	7.3	4.4	27.2	1.109	29.9	62.9	7.2	1.63
Pratt Seam Mine C	1	0.7	13.9	48.5	10.3			2.4	0.2	0.5	76.5	1.1	11.5	6.6	4.3	23.5	1.151	27.9	64.9	7.2	1.46
	2		7.9	42.7	20.1			3.5	0.1	0.5	75.8	1.1	11.8	6.9	4.4	24.2	1.168	27.4	65.3	7.3	1.40
	3	0.7	18.7	43.3	11.2	0.7		3.5	0.1	0.4	78.6	0.8	10.8	5.4	4.4	21.4	1.147	27.7	65.3	7.3	1.40
	4	0.8	14.8	46.0	12.6			3.6	0.2	0.4	78.4	0.9	12.3	4.4	4.0	21.6	1.159	26.0	67.4	6.6	1.45
	5		12.6	48.0	13.3			2.3	0.2	0.6	77.0	1.2	12.2	5.2	4.4	23.0	1.155	27.9	64.9	7.2	1.53
	6		6.7	36.4	30.5	0.7		3.0	0.2	0.6	78.1	1.3	11.3	5.2	4.2	21.9	1.179	27.8	65.2	7.0	1.48
Mary Lee Seam	1	0.7	14.0	32.4	23.6	3.0		5.2	0.1	0.6	79.6	1.1	8.1	4.2	7.0	20.4	1.168	28.0	59.8	12.2	0.75
	2	0.7	14.4	39.6	15.1	2.2		5.4	0.2	0.7	78.3	1.3	8.5	4.8	7.1	21.7	1.152	28.1	59.7	12.2	0.79
	3	2.2	12.3	34.8	20.3	2.9		4.4		0.4	77.3	0.7	10.7	4.4	6.9	22.7	1.162	27.6	60.5	11.9	0.82
	4	1.4	12.9	32.9	22.2	2.2		5.0	0.3	0.5	77.4	0.9	10.1	4.3	7.3	22.6	1.167	27.7	59.7	12.6	0.92
	5		11.8	37.6	20.6	3.7		4.4	0.3	0.7	79.1	1.4	8.2	4.2	7.1	20.9	1.170	28.1	59.7	12.2	0.82
	6	0.7	15.7	38.9	17.9	1.5		3.2	0.1	0.6	78.6	1.3	9.3	3.7	7.1	21.4	1.158	28.2	59.6	12.2	0.80
American Seam	1	0.8	13.7	22.8	24.4	14.4		4.3	0.1	0.6	81.1	1.2	10.3	4.3	3.1	18.9	1.206	27.3	66.8	5.9	0.83
	2	1.5	10.7	26.1	15.4	20.0	3.1	4.4	0.2	0.5	81.9	1.1	9.8	4.2	3.0	18.1	1.210	27.3	67.5	5.2	0.88
	3		13.0	19.5	17.3	19.5	2.9	5.5		0.7	78.4	1.5	12.4	4.4	3.3	21.6	1.223	27.2	67.1	5.7	0.89
	4	3.0	11.9	17.0	24.5	17.1	0.7	4.2		0.6	79.0	1.1	11.3	5.6	3.0	21.0	1.214	27.0	67.8	5.2	0.89
	5	1.4	11.4	20.6	21.3	13.5	2.9	4.1	0.1	1.0	76.3	2.0	12.3	6.1	3.3	23.7	1.211	27.5	66.7	5.8	0.84
	6																	27.4	65.8	6.3	0.85

* Abbreviations for entities:
V = vitrinoids; numeral indicates type.
E = exinoids
R = resinoids
SF = semifusinoids
M = micrinoids
F = fusinoids
MM = mineral matter

Table II

Physical Properties of Indicated Coal and Coke Samples

Coal	Sample No.	Gieseler Plasticity Data: Softening Temp, C	Maximum-Fluidity Temp, C	Solidification Temp, C	Maximum-Fluidity ddpm	Oven Bulk Density*	Oven Pressure, psi	Sole-Heated Test-Oven Data: Oven Bulk Density*	Volume Change, %: Actual Maximum	Actual Final	Corrected** Maximum	Corrected** Final
Pratt Seam												
Mine A	1	371	452	500	8,300	50	2.0	56	+4.9	+3.6	+3.0	+1.8
	2	369	455	500	7,200	54	2.6	55	+6.9	+4.7	+6.9	+4.7
	3	370	460	501	8,000	51	2.6	55	+2.9	+0.3	+2.9	+0.3
	4	369	453	502	7,200	52	3.6	56	+4.7	+2.6	+2.8	+0.8
	5	372	460	500	6,800	50	2.7	55	+4.1	+1.5	+4.1	+1.5
	6	370	460	502	8,200	50	2.0	54	+3.6	+0.3	+5.4	+2.2
Mine B	1	354	437	493	25,300	50	1.3	53		-8.0		-4.5
	2	351	437	495	19,100	50	0.8	53		-11.9		-8.5
	3	353	437	498	21,200	49	1.3	54		-7.5		-5.7
	4	352	439	ND***	12,900	53	1.3	56		-16.6		-18.0
	5	352	436	ND	13,800	52	1.1	56		-8.4		-10.0
	6	ND	ND	ND	ND	53	1.5	58		-7.9		-12.6
Mine C	1	355	441	499	18,400	52	1.7	56	+2.5	+0.2	+0.7	-1.5
	2	356	442	ND	10,250	53	1.9	56	+3.3	+0.2	+1.5	-1.5
	3	357	440	ND	9,530	52	1.4	56	+2.0	-0.5	+0.2	-2.2
	4	370	449	492	11,000	53	1.6	56	+3.2	-2.5	+1.4	-4.2
	5	358	447	498	9,160	51	1.3	57	+4.6	+3.0	+1.0	-0.6
	6	360	444	495	8,510	54	1.5	57	+4.9	+0.3	+1.3	-3.2
Mary Lee Seam	1	359	452	491	8,400	55	6.3	58	+8.6	+6.8	+3.0	+1.3
	2	357	445	487	9,100	54	5.8	59	+9.7	+7.9	+2.3	+0.6
	3	363	451	487	800	54	4.1	58	+6.9	+4.6	+1.4	-0.8
	4	361	450	487	1,200	54	3.0	58	+5.4	+3.2	+0.0	-2.1
	5	353	445	490	9,400	55	5.1	56	+4.6	+1.6	+2.8	-0.2
	6	354	448	490	11,500	ND	ND	56	+1.8	-1.1	+0.0	-2.8
American Seam	1	365	446	501	4,800	52	4.0	56	+5.6	+3.1	+3.7	+1.3
	2	372	453	500	7,200	50	5.0	54	+5.1	+2.2	+7.0	+4.1
	3	373	451	505	5,700	52	3.1	56	+0.7	-0.8	-1.1	-2.6
	4	373	450	498	6,500	50	4.0	55	+1.6	-0.6	+1.6	-0.6
	5	372	451	499	6,100	ND	ND	56	+0.7	-1.8	-1.1	-3.6
	6	373	449	503	6,100	49	3.8					

* lb dry coal per cu ft.
** At 55 lb per cu ft.
*** Not determined.

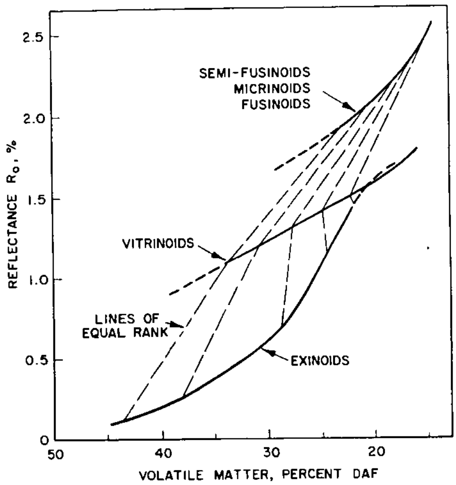


Figure 1. Relationship Between Reflectance and Volatile Matter

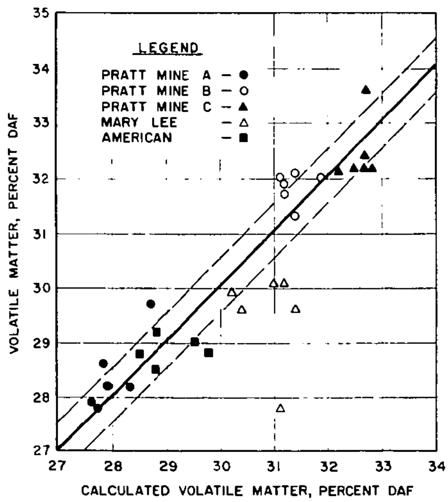


Figure 2. Relationship Between Chemically Determined Volatile Matter and Calculated Volatile Matter

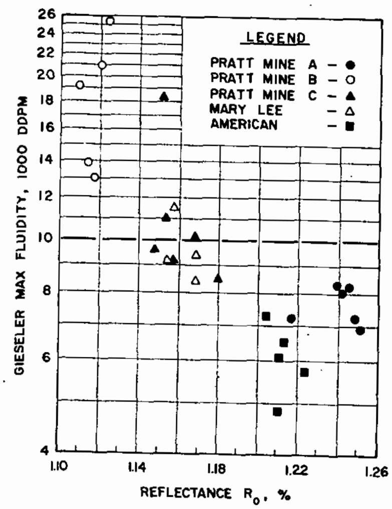


Figure 3. Relationship Between Plasticity and Reflectance

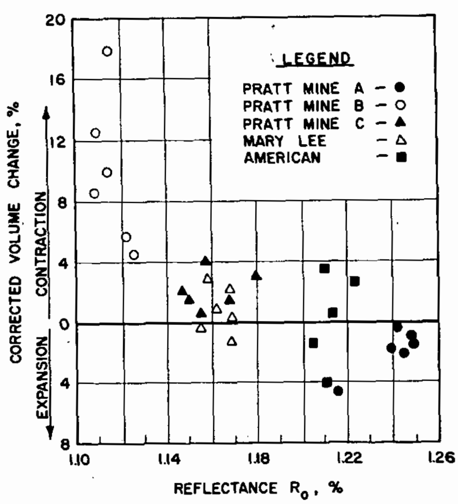


Figure 4. Relationship Between Volume Change and Reflectance

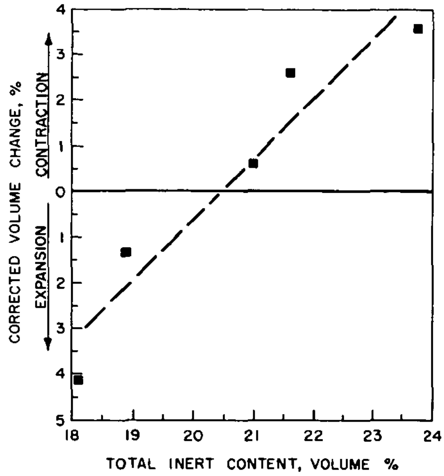
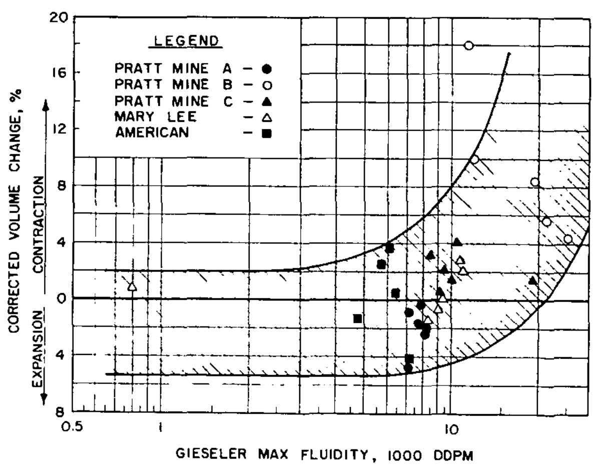


Figure 5. Relationship of Volume Change and Inert Content



.igure 6. Relationship Between Volume Change and Plasticity

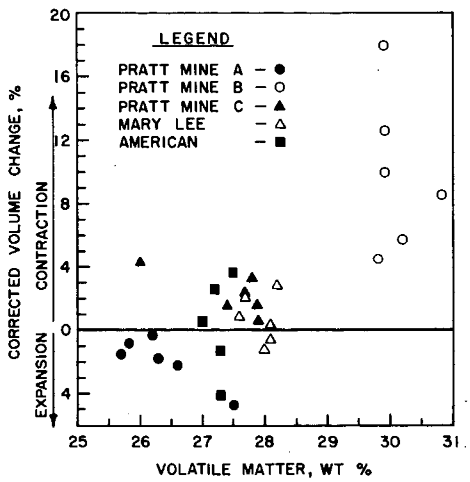


Figure 7. Relationship Between Volume Change and Volatile Matter

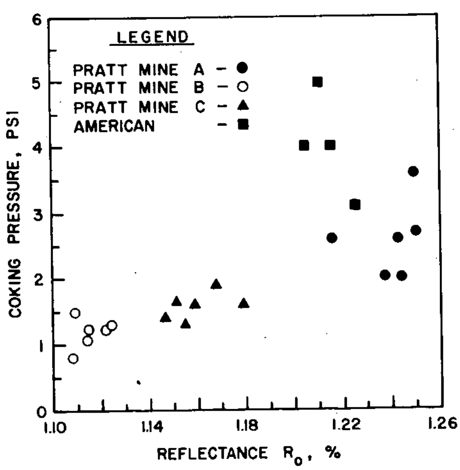


Figure 8. Relationship of Coking Pressure and Reflectance

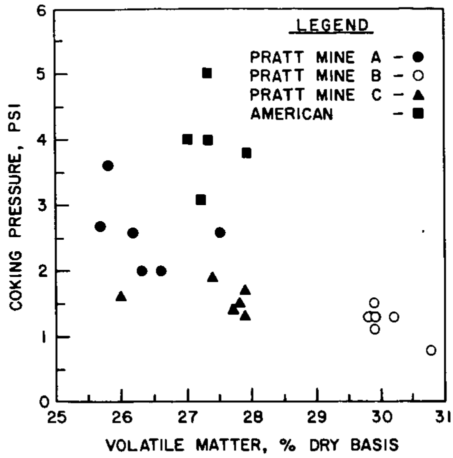


Figure 9. Relationship of Coking Pressure and Volatile Matter

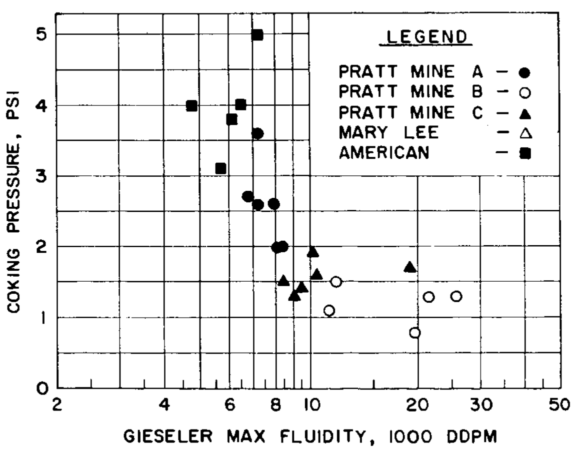


Figure 10. Relationship of Coking Pressure and Plasticity