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EFFECT OF DILUENTS ON THE PLASTIC PROPERTIES OF COAL AS MEASURED BY THE GIESELER PLASTOMETER

BY

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ABSTRACT

The effect of some diluents on the plastic properties of two high-volatile bituminous A coals of different maximum-fluidity levels was studied. The diluents, in increments of 10 to 20 percent, were mixed with each coal, and plastic properties were determined with the Gieseler plastometer. Data indicate that the duplicability of this method is not satisfactory quantitatively but is adequate for qualitative grouping of coals; that use of diluents to improve results is not satisfactory; that addition of increasing amounts of diluents progressively decreases maximum fluidity but not in a linear pattern; and that the chars studied may lower fluidity somewhat more than other diluents.

INTRODUCTION

The study of plastic properties of coal for fundamental understanding of behavior and for practical application is of definite importance, but there are many experimental difficulties and uncertainties in interpretation. Numerous descriptions of laboratory methods designed for this purpose are available, but it is not the aim of this report to discuss their relative merits. There is considerable disagreement as to the best method available, and even as to the measure by which a method may be judged to be useful. There are those who insist that to be useful a method for measuring plastic properties of coal must be quantitative and duplicable from laboratory to laboratory. On the other hand, there are those who believe that a method which gives only qualitative or semiquantitative results may be useful in providing data on the basis of which coals may be grouped and comparisons made.

In our laboratory we tend to agree with the latter group. We have found that the Gieseler plastometer yields results which permit useful evaluation of coals for certain applications (Reed et al., 1952). Consequently we have continued to use it and have studied the variables involved for the purpose of possible improvement of the instrument and for better understanding of the results obtained.

Table 1. Duplicability of Gieseler Plastometer Results

	Soft. temp. °C.	Fusion temp. °C.	Max. fluid temp. °C.	Setting temp. °C.	Max. fluidity (dial div./min.)
All data					
No. of pairs	128	109	129	131	131
Av. diff., %	0.6	0.5	0.5	0.5	15.9
Min. diff., %	0.0	0.0	0.0	0.0	0.0
Max. diff., %	1.9	1.7	2.5	2.2	100.0
Hernshaw coal with diluents					
No. of pairs	55	48	56	56	56
Av. diff., %	0.7	0.6	0.6	0.4	15.1
Min. diff., %	0.0	0.0	0.0	0.0	0.0
Max. diff., %	1.9	1.7	2.5	2.2	77.8
Elkhorn No. 3 coal with diluents					
No. of pairs	52	43	52	54	54
Av. diff., %	0.5	0.4	0.4	0.4	19.3
Min. diff., %	0.0	0.0	0.0	0.0	0.0
Max. diff., %	1.0	1.2	1.6	1.8	100.0
Base coals only					
No. of pairs	16	16	16	16	16
Av. diff., %	0.6	0.4	0.5	0.6	6.9
Min. diff., %	0.3	0.0	0.0	0.0	0.0
Max. diff., %	1.0	1.5	1.1	1.0	13.3

This report covers a study of the effect of diluents on the plastic properties of two high-volatile bituminous A coals of different maximum-fluidity levels as measured with the Gieseler plastometer. The objectives of this work were: 1) to better evaluate the Gieseler plastometer as an instrument for measuring plastic properties of coals, 2) to learn more about the effect of diluents on the plastic properties of coal, 3) to learn whether diluents may be added in definite amounts to badly swelling coals to obtain better plastic property data for them, and 4) to learn whether chars as diluents behave in a distinctive manner.

APPARATUS

The Gieseler plastometer used in this work was built in the Survey machine shop according to the description published by Soth and Russell (1943) but with certain changes described in a recent publication (Rees and Pierron, 1954). The instrument includes a modification in the head to permit a fixed position of the thrust bearing and provision for removal of decomposition gases by suction. Temperature control is accomplished manually by means of an auto-transformer to give a rate of heat rise of 3°C. per minute. Temperature readings are obtained by means of a chromel-alumel thermocouple and a Bristol pyrometer calibrated from 250°C. to 500°C.

The values determined with the Gieseler plastometer are defined as follows:

Softening temperature. - The temperature at which dial pointer movement reaches 0.5 dial divisions per minute.

Fusion temperature. - The temperature at which dial pointer movement reaches 5.0 dial divisions per minute.

Maximum fluid temperature. - The temperature at which dial pointer movement reaches maximum rate.

Setting temperature. - The temperature at which dial pointer movement stops.

Maximum fluidity. - The maximum rate of dial pointer movement in dial divisions per minute.

Plastic range. - The temperature range from the softening temperature to the setting temperature, in which the coal is plastic.

SAMPLES

For this work, coals representing two levels of maximum fluidity were used, one of >15000 dial divisions per minute, and the other of 2000 or less dial divisions per minute. The former, or more fluid, coal was from the Hernshaw seam of West Virginia; the other was from the Elkhorn No. 3 seam of eastern Kentucky. Two samples of each coal were obtained at different times. In the discussion which follows they will be referred to as the base coals.

The materials used as diluents were as follows:

With the Hernshaw coal - Illinois high-volatile C bituminous coal (HVCB), Illinois high-volatile B bituminous coal

Table 2. Duplicability of Maximum Fluidity

(Percent difference between duplicates for each diluent)*

Diluent	Base coal: *Hernshaw coal*		Base coal: Elkhorn No. 3 coal	
	Av. diff. (%)	Range (%)	Av. diff. (%)	Range (%)
Illinois HVCB coal	8.9	0.0 - 19.8		
Illinois HVBB coal	16.1	3.2 - 28.6	28.5	5.1 - 100
Char - approx. 22% V.M.	21.8	0.0 - 77.8	25.9	7.3 - 47.2
Pocahontas No. 3 coal	19.0	0.0 - 50.7	17.5	1.8 - 26.7
Char - approx. 16% V.M.	19.1	0.0 - 63.4	14.2	0.0 - 43.8
Anthracite	26.6	0.0 - 66.7	14.6	3.1 - 43.2
Coke	9.3	0.0 - 21.1	18.4	0.0 - 52.6
Graphite	11.6	0.0 - 22.9	15.5	0.0 - 31.3
Carborundum	8.1	0.0 - 22.2		

$$^{*}\text{ Percent difference} = \frac{\text{Numerical difference between duplicates}}{\text{Average of duplicates}}$$

(HVBB), Pocahontas No. 3 coal, anthracite, char of approximately 22% volatile matter, char of approximately 16% volatile matter, coke, graphite, and carborundum.

With the Elkhorn coal - Illinois high-volatile B bituminous coal, Pocahontas No. 3 coal, anthracite, char of approximately 22% volatile matter, char of approximately 16% volatile matter, coke, and graphite.

To obtain fresher samples and to minimize oxidation effects, samples of the base coals and some of the diluent coals were obtained at intervals during the course of the work rather than taking the entire sample at the beginning. Because of this, plastic property data for base coals and, to some extent, for certain diluent coals, appear somewhat different in the tabular data. However, samples were never changed within a given series.

PROCEDURE

The base coals and diluents were each manually stage-ground to pass a 40-mesh sieve. Test portions were prepared by mixing the diluents, in increments of 10 or 20 percent, with each of the base coals. Each portion was thoroughly mixed, and plastic properties were determined with the Gieseler plastometer. Determinations on the base coals were made at the beginning and at the end of each series of tests. All determinations were made in duplicate.

RESULTS

Tables 1 and 2 present a study of the duplicability of results for this work. Data obtained for mixtures of diluents with the Hernshaw coal are shown in table 3. Data for mixtures of diluents with the Elkhorn coal are shown in table 4. Graphic representation of the effect of diluents on both base coals is shown on semilogarithmic scale in figures 1 to 9. Table 5 shows percentage reductions of maximum fluidities of base coals by diluents, arranged according to decreasing volatile-matter content.

DISCUSSION

Reference to table 1 will give a picture of the duplicability of data. Duplicate temperature values checked satisfactorily throughout the work. Considering all data, the average difference between duplicate maximum-fluidity values was 15.9% with a range of difference from 0 to 100%. For the Hernshaw coal with diluents the average difference was 15.1% and the range from 0 to 77.8%. For the Elkhorn coal with diluents the average difference was 19.3% and the range from 0 to 100%. For the base coals only, the duplicability was better, being 6.9% average, with a range from 0 to 13.3%.

A comparison of maximum fluidity duplicabilities obtained for mixtures of base coals with the various diluents is shown in table 2. The best duplication was obtained when high-volatile C bituminous coal was used as a diluent with Hernshaw coal. Of the diluents that have no Gieseler fluidity, coke and carborundum gave best duplication of results with the Hernshaw coal. For the Elkhorn coal with diluents, the lowest average difference between dupli-

Table 3. Gieseler Plasticity Data for Hernshaw Coal with Diluents

Diluent	Percent diluent added to base coal										
	0	10	20	30	40	50	60	70	80	90	100
Ill. HVCB											
Soft. temp.	390	395		399		391		389			379
Fusion temp.	409	415		423		418		422			427
Max. fluid.temp.	437	446		454		440		425			427
Setting temp.	485	485		482		469		458			455
Max. fluidity	18,750	15,000		666		64		5.7			4.9
Plastic range	95	90		83		78		69			76
Ill. HVBB											
Soft. temp.	393	392		395		393		397		404	397
Fusion temp.	413	413		418		416		422			427
Max. fluid. temp.	444	444		443		438		430		432	430
Setting temp.	488	483		477		468		458		457	457
Max. fluidity	17,708	14,319		875		125		9.4		2.5	5.4
Plastic range	95	91		82		75		61		53	60
Char - 22% V.M.											
Soft. temp.	386	388	390	398	402	410	416				
Fusion temp.	407	408	412	416	421	427	441				
Max. fluid. temp.	439	444	448	447	449	449	442	432			
Setting temp.	489	487	486	481	477	474	462	462			
Max. fluidity	37,500	30,000	8,475	1,375	600	72	3.8	0.3			
Plastic range	103	99	96	83	75	64	46				
Poca. No. 3 coal											
Soft. temp.	390	390		399		409		423		444	456
Fusion temp.	409	411		418		427		454			
Max. fluid. temp.	437	443		449		455		462		475	488
Setting temp.	485	482		488		493		497		506	510
Max. fluidity	18,750	15,000		760		71		7.9		3.9	3.1
Plastic range	95	92		89		84		74		62	54

Char - 16% V.M.										
Soft. temp.	386	389	394	395	401	407	411	421		
Fusion temp.	407	409	414	415	417	424	430			
Max. fluid. temp.	440	447	449	447	449	450	448	447		
Setting temp.	487	485	483	478	477	481	474	469		
Max. fluidity	37,500	25,000	3,541	1,136	901	423	41	1.7		
Plastic range	101	96	89	83	76	74	63	48		
Anthracite										
Soft. temp.	388	394		395		398		404		422
Fusion temp.	410	414		415		421		426		
Max. fluid. temp.	441	445		445		447		448		435
Setting temp.	486	485		483		479		471		456
Max. fluidity	17,708	15,836		10,000		529		39		0.9
Plastic range	98	91		88		81		67		34
Coke										
Soft. temp.	386	390	395	397	392	395	398	408	421	
Fusion temp.	407	414	417	417	413	416	421	436		
Max. fluid. temp.	440	445	451	450	445	448	449	436	435	
Setting temp.	485	487	492	491	479	477	475	470	460	
Max. fluidity	17,708	16,665	15,000	7,984	1,112	518	118	5.1	1.0	
Plastic range	99	97	97	94	87	82	77	62	39	
Graphite										
Soft. temp.	386	391		393		401		409		
Fusion temp.	407	412		411		418				
Max. fluid. temp.	436	446		444		446		430		
Setting temp.	481	487		478		472		453		
Max. fluidity	17,708	16,665		5,265		385		2.5		
Plastic range	95	96		85		71		44		
Carborundum										
Soft. temp.	390	385	388	394	394	391	395	395	401	405
Fusion temp.	412	407	410	414	413	412	415	415	423	429
Max. fluid. temp.	442	436	442	447	447	444	448	444	446	451
Setting temp.	488	484	486	484	485	480	480	477	473	476
Max. fluidity	17,708	16,665	15,833	15,000	13,637	11,250	2,864	923	324	63
Plastic range	98	99	98	90	91	89	85	82	72	71

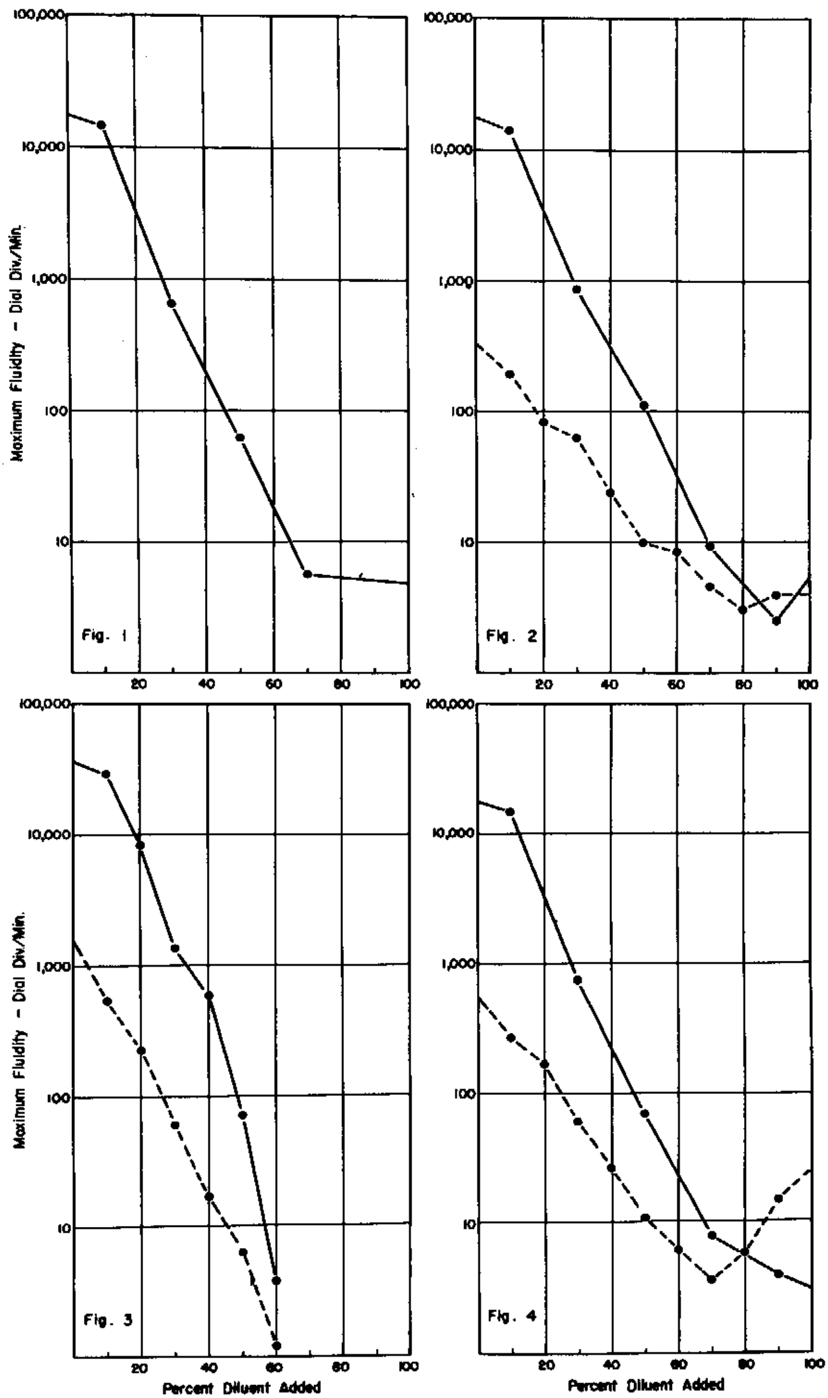

Fig. 1. - Effect of Illinois HVCB coal as diluent on maximum fluidity.
Fig. 2. - Effect of Illinois HVBB coal as diluent on maximum fluidity.
Fig. 3. - Effect of char (22% V. M.) as diluent on maximum fluidity.
Fig. 4. - Effect of Pocahontas No. 3 coal as diluent on maximum fluidity.

Solid lines identify the Hernshaw coal, dotted lines the Elkhorn No. 3 coal.

cates was found when char of approximately 16% volatile matter was used (14.2%). In this case, however, the range of differences between the lowest and highest was rather large (0 to 43.8%). The lowest range of differences was obtained when Pocahontas coal was used as diluent. It is of interest to note that in no case did the diluents tried improve duplicability of results for base coals.

TEMPERATURE VALUES

The apparent influence on Gieseler plasticity values of diluents added to base coals is shown in tables 3 and 4. The data indicate that fusion temperatures increase as increased amounts of Pocahontas coal, both chars, coke, and anthracite are added to the base coals. This is true also for anthracite with the Hernshaw coal, whereas this diluent with the Elkhorn coal shows no marked influence on fusion temperature. Addition of high-volatile B bituminous coal as a diluent to both base coals showed no marked influence. High-volatile C bituminous coal was tried as a diluent with the Hernshaw coal only. The data indicate a gradual increase in fusion temperature as increasing amounts of diluents were added. Carborundum with Hernshaw coal showed no marked influence on fusion temperature up to 70% addition. Temperatures with 80 and 90% addition were higher.

With one exception, no striking influence of diluents appears in the maximum-fluidity temperature data. Increasing additions of Pocahontas coal to both base coals raises maximum-fluidity temperatures.

Increasing amounts of all diluents, with the exception of Pocahontas coal, appear to lower setting temperatures for both base coals.

MAXIMUM FLUIDITY

All diluents used progressively lowered maximum fluidities of both base coals as the amount of diluent added was increased. However, this lowering is not directly proportional to the amount of diluent added (figs. 1 to 9). Furthermore, the lowering effect of the diluents varies considerably for each base coal.

Table 5 gives data for the percentage reduction of maximum fluidity of base coals by increasing amount of diluents, and shows that percentage reduction of maximum fluidity of base coals increases rapidly as increasing amounts of diluents are added. The data also indicate considerable differences among diluents in their ability to lower fluidity. Not only is this true for different diluents with the same base coal, but the effect of each diluent on each base coal is different. With regard to this point, there is evidence that additions of 10 to 30% diluent to the Hernshaw coal reduce its maximum fluidity less and less as the volatile-matter content of the diluent decreases. This effect is not evident with the Elkhorn coal; in fact, there is some indication of the reverse. The question arises as to the cause of the difference in behavior of diluents with the two base coals. We cannot answer this question definitely but suspect that there may be a difference in kind as well as quantity of constituents, which may affect the plastic properties of the two base coals and lead to the differences shown.

Table 4. Gieseler Plasticity Data for Elkhorn No. 3 Coal with Diluents

Diluent	Percent diluent added to base coal										
	0	10	20	30	40	50	60	70	80	90	100
Ill. HVBB											
Soft. temp.	396	393	393	391	393	395	391	397	396	397	391
Fusion temp.	415	413	418	415	417	422	422				
Max. fluid. temp.	439	437	436	437	438	431	432	433	431	429	422
Setting temp.	473	471	466	466	464	459	457	460	455	454	453
Max. fluidity	323	195	84	63	24	10	8.5	4.6	3.1	4.0	4.1
Plastic range	77	78	73	75	71	64	66	63	59	57	62
Char - 22% V.M.											
Soft. temp.	398	400	403	407	410	417	426				
Fusion temp.	418	418	420	422	428	434					
Max. fluid. temp.	444	443	444	440	439	440	435				
Setting temp.	478	477	471	469	467	460	459				
Max. fluidity	1,607	546	229	61	17	6.4	1.2				
Plastic range	80	77	68	62	57	43	33				
Poca. No. 3 coal											
Soft. temp.	400	401	407	412	414	417	423	434	450	444	452
Fusion temp.	419	416	422	428	431	438	450		482	477	476
Max. fluid. temp.	445	444	443	448	453	451	454	460	484	484	488
Setting temp.	477	478	481	482	485	484	486	492	507	511	514
Max. fluidity	573	276	170	62	27	11	6.2	3.6	5.9	15	27
Plastic range	77	77	74	70	71	67	63	58	57	67	62
Char - 16% V.M.											
Soft. temp.	398	402	403	407	410	412	418	428			
Fusion temp.	414	420	421	423	426	429					
Max. fluid. temp.	442	445	443	444	443	440	441	438			
Setting temp.	475	476	475	470	466	466	462	458			
Max. fluidity	2,000	700	317	117	48	14	4.8	0.8			
Plastic range	77	74	72	63	56	54	44	30			

Anthracite										
Soft. temp.	395	398	400	401	405	402	405	404	413	
Fusion temp.	415	417	417	420	421	420	422	423	430	
Max. fluid. temp.	444	443	441	444	441	439	440	439	439	
Setting temp.	478	475	470	471	471	468	468	465	462	
Max. fluidity	1,000	508	349	181	74	51	32	20	8.0	
Plastic range	83	77	70	70	66	66	63	61	49	
Coke										
Soft. temp.	399	401	401	403	406	407	407	413	426	
Fusion temp.	417	417	420	420	424	425	428	433		
Max. fluid. temp.	441	439	440	441	440	438	435	439	436	
Setting temp.	474	472	471	467	464	463	461	461	456	446
Max. fluidity	752	375	188	83	32	20	9.5	5.8	1.9	0.2
Plastic range	75	71	70	64	58	56	54	48	30	
Graphite										
Soft. temp.	402	402	404	409	425	430				
Fusion temp.	416	416	419	428	433	440				
Max. fluid. temp.	443	445	440	439	442	443				
Setting temp.	479	474	471	466	466	463	453			
Max. fluidity	969	326	123	43	16.	6.7	0.2			
Plastic range	77	72	67	57	41	33				

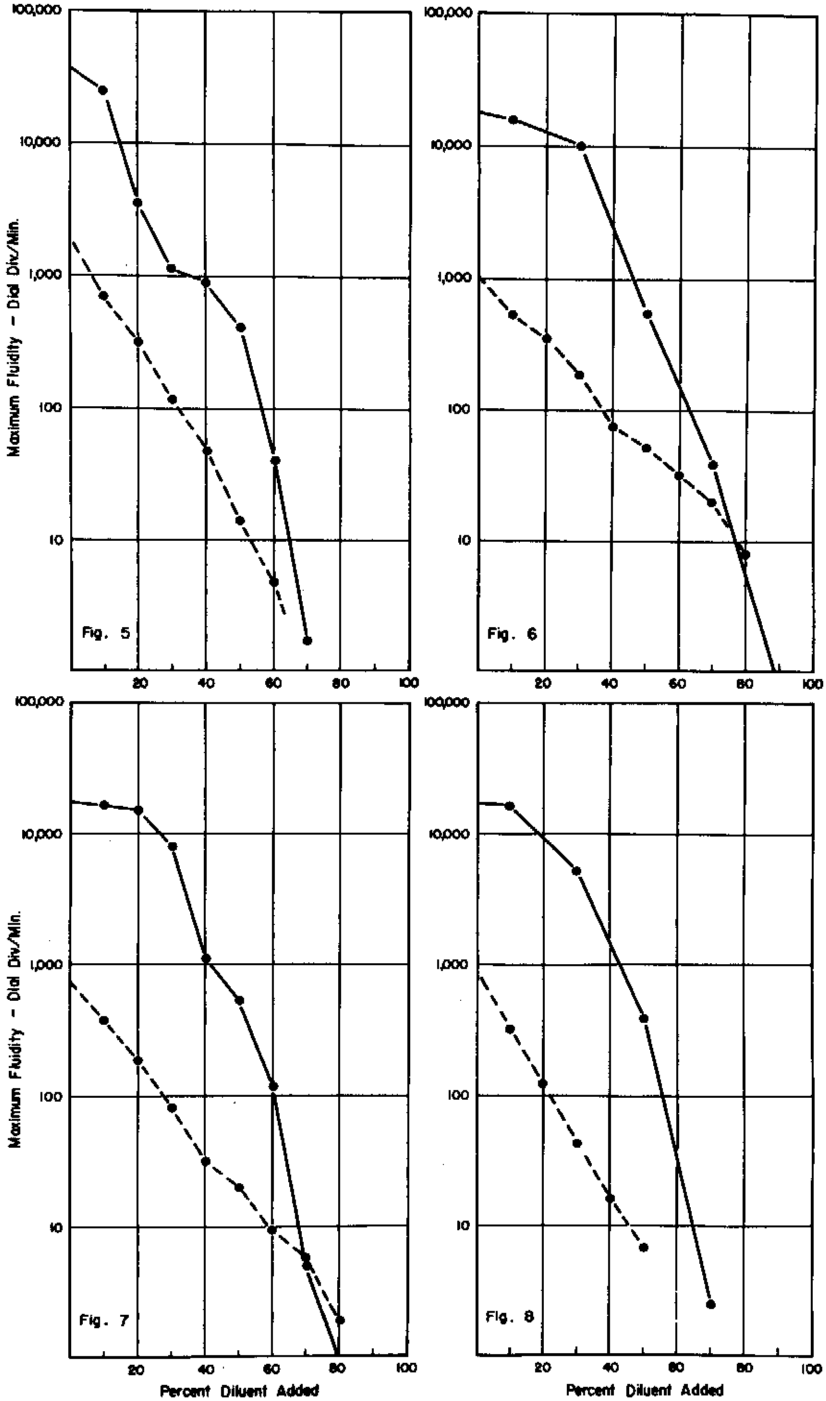

Fig. 5. - Effect of char (16% V.M.) as diluent on maximum fluidity.
Fig. 6. - Effect of anthracite as diluent on maximum fluidity.
Fig. 7. - Effect of coke as diluent on maximum fluidity.
Fig. 8. - Effect of graphite as diluent on maximum fluidity.

Solid lines identify the Hernshaw coal, dotted lines the Elkhorn No. 3 coal.

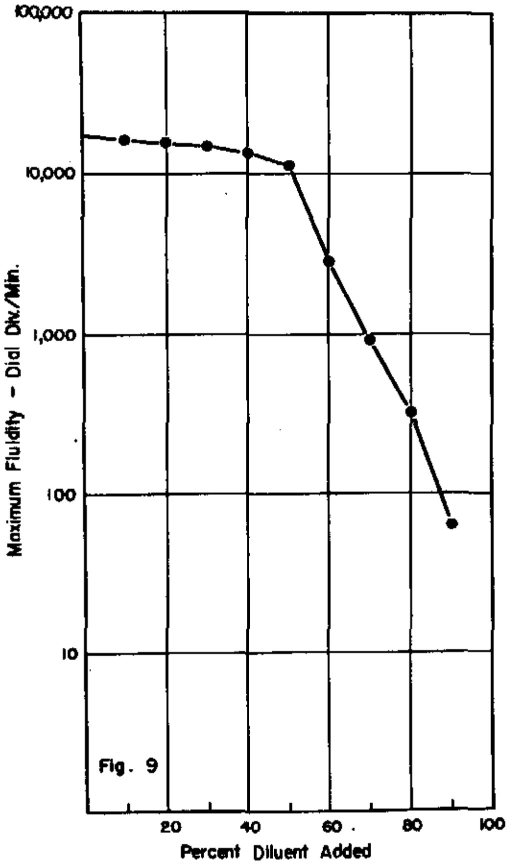

Fig. 9. - Effect of carborundum as diluent on maximum fluidity.

Another interesting point in table 5 is the indication that there is something more than simple dilution involved in the reduction of maximum fluidity by the diluents. If simple dilution alone were involved, then maximum fluidities of base coals should be reduced by the same percentage as the percentage of diluent added. In only one case is this approximated - addition of 10% anthracite to the Hernshaw coal reduced the maximum fluidity 10.6%. Diluents (10% added) of volatile-matter content greater than that of anthracite reduced the maximum fluidity of Hernshaw coal more than can be accounted for by simple dilution, and diluents of less volatile-matter content reduced it less than can be accounted for in this way. In all cases, diluents reduced the maximum fluidity of the Elkhorn coal more than can be accounted for by simple dilution. We are not certain how this additional reduction, over and above simple dilution, is accomplished. However, interchemical action between base coal and diluent, solvent effect of one on the other, and difference in wettability of solid diluent particles by melted base coal might be possible factors involved. Whatever the cause may be, it appears that each base coal *in admixture with each diluent is a distinct and individual problem.*

Table 5. Effect of Diluents on Gieseler Maximum Fluidity

(Percentage reduction of maximum fluidity)

Diluent	Approx. V.M. of diluent	Percent diluent added								
		10	20	30	40	50	60	70	80	90
					Hernshaw coal					
Ill. HVCB	40	20.0		96.4		99.7		99.9+		
Ill. HVBB	36	19.1		95.0		99.3		99.9+		99.9+
Char	22	20.0	77.4	96.3	98.4	99.8	99.9+	99.9+	100	100
Poca. No. 3	17	20.0		96.0		99.6		99.9+		99.9+
Char	16	33.3	90.6	97.0	97.6	98.9	99.9	99.9+	100	100
Anthracite	5	10.6		44.0		97.8		99.8		99.9+
Coke	1	5.9	15.3	54.9	93.7	97.1	99.3	99.9+	99.9+	100
Graphite	0	5.9		70.0		77.8		99.9+		100
Carborundum	0	5.9	10.6	15.3	23.0	36.5	83.8	94.8	98.2	99.6
					Elkhorn No. 3 coal					
Ill. HVBB	36	40.0	74.0	90.5	92.6	96.9	97.4	98.6	99.0	98.8
Char	22	66.0	85.7	96.2	98.9	99.6	99.9	99.9+	100	100
Poca. No. 3	17	51.8	70.3	89.2	95.3	98.1	98.9	99.4	99.0	97.4
Char	16	65.0	84.2	94.2	97.6	99.3	99.8	99.9+	99.9+	100
Anthracite	5	49.2	65.1	81.9	92.6	94.9	96.8	98.0	99.2	99.9+
Coke	1	50.1	75.0	89.0	95.7	97.3	98.7	99.2	99.7	99.9+
Graphite	0	66.4	87.3	95.6	98.3	99.3	99.9+	100	100	100

Attention also is called to the behavior of the two chars as diluents as shown in table 5. The data indicate that the char of 16% volatile matter was more effective in reducing the maximum fluidity of Hernshaw coal than the char of 22% volatile matter. The reverse appears to be true for the Elkhorn coal. With the Hernshaw coal, both chars appear to behave more nearly like the Illinois HVCB and HVBB coals and Pocahontas coal. With the Elkhorn coal, they behave more nearly like graphite.

In general, data presented in this report indicate that of the diluents tried with Hernshaw coal, char of 16% volatile matter (up to 30% addition) exerted the greatest influence in reducing maximum fluidity and carborundum the least. Data are somewhat less indicative for the Elkhorn coal, but possibly the two chars and graphite exerted the greatest influence and anthracite the least.

PLASTIC RANGE

In general, addition of increasing amounts of all diluents brings about progressive decreases of plastic ranges of both base coals. However, these decreases are not linear. Carborundum appears to narrow the plastic range of Hernshaw coal less than the other diluents. Beyond this, no generalizations are definitely apparent.

CONCLUSIONS

The following tentative conclusions are made, based on the data presented in this report:

1. The Gieseler plastometer is useful in obtaining qualitative or semiquantitative data on the plastic properties of coals. For quantitative results, the instrument is not satisfactory.
2. Addition of diluents to improve results is not satisfactory, as their effect is not linear and not the same for different coals.
3. Additions of increasing amounts of diluents progressively decrease the fluidity of the coals to which they are added, but not in a predictable amount.
4. There is some indication that the chars lower fluidity of base coals slightly more than certain other diluents, but the data are not too impressive.

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