

REACTIONS OF COAL AND RELATED MATERIALS IN MICROWAVE DISCHARGES IN H<sub>2</sub>, H<sub>2</sub>O AND Ar

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## INTRODUCTION

Recent investigations on the reaction of carbon in a high frequency discharge have shown that it produces methane, acetylene and minor amounts of other hydrocarbons in the hydrogen discharge,<sup>1-3/</sup> but produces primarily an H<sub>2</sub>-CO mixture downstream from a water discharge.<sup>3/</sup> Similar work with respect to coal, however, is almost non-existent except that carried out by Letort et al.<sup>4/</sup> and by Pinchin.<sup>5/</sup> Though some work on coal in a plasma jet<sup>6-9/</sup> has been reported, the characteristic of those reactions is generally the thermal decomposition of coal by rapid heating to high temperatures in an inert atmosphere.

In a microwave-generated discharge, hydrogen or water vapor can be excited or dissociated into atoms, ions and electrons at temperatures much lower than those attained in a plasma jet. The present study is concerned with the reactions of various coals, a polynuclear hydrocarbon, and graphite, in microwave discharges in H<sub>2</sub>, water vapor and Ar. The results are compared in terms of the product yield and distribution in each type of discharge. Differences observed between the reactions of the various coals and the other materials suggest that the amount and type of volatile material, carbon content, and the type of the carbonaceous material, as well as the type of the gas discharge, are all factors affecting the product yield and distribution. The difference between coal and graphite in their behavior toward water vapor in the microwave discharge is of particular interest. In the water discharge, the graphite yields almost no hydrocarbons but only an H<sub>2</sub> + CO mixture while the coal yields appreciable amounts of C<sub>2</sub>H<sub>2</sub> and CH<sub>4</sub> in addition to H<sub>2</sub> + CO. Experiments using D<sub>2</sub>O and Ar discharges indicate that the D<sub>2</sub>O and the water actually do participate in the reactions with coal to form hydrocarbons. It is also demonstrated that the C<sub>2</sub>H<sub>2</sub> yield from coal in the hydrogen discharge can be drastically increased by condensing at a low temperature part of the primary products formed during the discharge reaction.

## ACKNOWLEDGEMENTS

The authors wish to thank Dr. Irving Wender for his valuable discussions, Gus Pantages for his technical assistance, A. G. Sharkey, Jr. and Janet Shultz for their mass spectrometric analyses, and John Queiser for his infrared analysis.

## EXPERIMENTAL

The experiments were carried out in a static system with the discharge produced by a Raytheon microwave generator in the air-cooled Ophthos coaxial cavity at 2450 Mc/sec. Chemical analyses and origins of the vitrains of the different coals used are given in table 1. All the vitrains were -200 mesh. Ultra purity spectroscopic graphite powder (325 mesh, United Carbon) and chrysene (C<sub>18</sub>H<sub>12</sub>) were used for comparison. As reactant gases, a 9.7:1 H<sub>2</sub>-Ar mixture, H<sub>2</sub>O-Ar mixtures and Ar were used. The H<sub>2</sub> and Ar were obtained from cylinders and passed through a liquid N<sub>2</sub> trap prior to storage. The water vapor was obtained from distilled water degassed in high vacuum.

In the experimental procedure, a known weight of graphite or coal powder was placed in a cylindrical Vycor tube (ID = 11 mm, vol = 32 ml) and degassed in a high vacuum at an elevated temperature (150°C for graphite and 100°C for coal) for a half to one hour to remove the moisture and the air adsorbed on the carbon. A known pressure of the reactant gas or gas mixture measured by a Pace Engineering pressure

transducer was then introduced into the reactor tube. For the H<sub>2</sub>-Ar mixture, a known pressure of the water vapor was first introduced to the reactor containing the degassed carbon, and then a known pressure of the argon was introduced while the water was condensed in the end of the tube by dry ice and acetone. The portion of the tube cooled by the dry ice was so small compared to the total volume that no correction on the pressure reading seemed to be necessary. The discharge was then produced with the carbon in the discharge zone. The gaseous products were analyzed by mass spectrometer.

The solid product obtained from the high volatile bituminous coal in the H<sub>2</sub> discharge was analyzed by infrared spectrometer. The sample was obtained either by scraping the reactor wall or by solvent (benzene or acetone) extraction. In some instances, a reactor consisting of a tube divided by a fritted Vycor disc was used. The coal was placed on the disc and KBr powder was introduced on the other side of the disc. During the discharge, the lower end of the tube was immersed in liquid N<sub>2</sub>, thus permitting the condensable low volatile products to pass through the disc and be adsorbed on the surface of the KBr powder. This was later removed, pressed into a pellet, and examined by infrared analysis.

TABLE 1. - Analysis of vitrains (moisture free basis, percent)

	C	H	N	S	O (by diff.)	Volatile matter	
Anthracite <sup>1/</sup>	91.06	2.49	0.96	0.83	2.89	1.77	6.1
Low volatile aminous <sup>2/</sup>	89.57	4.67	1.25	.81	2.17	1.53	20.2
bituminous <sup>3/</sup>	81.77	5.56	1.71	.97	5.87	2.06	39.2
Lignite <sup>4/</sup>	66.45	5.40	.31	1.40	22.84	3.06	44.0

<sup>1/</sup> Dorrance Mine, Lehigh Valley Coal Co., Luzerne County, Pennsylvania.

<sup>2/</sup> Pocahontas No. 3 Bed, Buckeye No. 3 Mine, Page Coal and Coke Co., Stephenson, Wyoming County, West Virginia.

<sup>3/</sup> Bruceton, Pittsburgh Bed, Allegheny County, Pennsylvania.

<sup>4/</sup> Beulah-Zap Bed, North Unit, Beulah Mine, Knife River Coal Mining Co., Beulah, Mercer County, North Dakota.

#### RESULTS AND DISCUSSION

All results were obtained from experiments using 5 mg of the carbonaceous material in each discharge at 35 watts of power input. For consistency, an initial total pressure of about 25 mm was used for most runs, but in the runs with H<sub>2</sub>O vapor it was varied in the range of 12 to 25 mm. The time of the discharge reaction was intended to be 60 seconds in most runs, but the discharge would not sustain itself in some runs. It is suspected that the solid product (probably polynuclear hydrocarbons) formed may tend to draw away the electrons in the discharge to form negative ions and create a shortage of energetic species in the gas phase. However, under the experimental conditions employed, a large part of the reaction occurred within 30-60 seconds, and prolonged treatment resulted only in some change in the product distribution and a little increase in the extent of the gasification. A few runs were made for as long as 3 minutes.

#### Hydrogen-Argon and Argon Discharges

In preliminary runs with graphite in an H<sub>2</sub> discharge, we attempted to interpret the data on the basis of the hydrogen balance before and after reaction. It appears, however, that appreciable amounts of hydrogen were consumed in the formation of solid product or were taken up by the carbon. Therefore, to allow

interpretation of the data, Ar was introduced into the reactant gas as an internal standard. The presence of Ar in the system gives no noticeable effect on product type or distribution.

Table 2 summarizes the results obtained from the reactions of each material in microwave discharges in an H<sub>2</sub>-Ar (9.7:1) mixture and in Ar. In the Ar discharge, coal is partially gasified to give H<sub>2</sub>, CO, and C<sub>2</sub>H<sub>2</sub> as the major gaseous products, CO<sub>2</sub>, CH<sub>4</sub>, and minor amounts of other hydrocarbons (C<sub>2</sub> and C<sub>3</sub> hydrocarbons, biacetylene and benzene were detected), in addition to a solid product and residual char. In the H<sub>2</sub>-Ar discharge, the percent of carbon forming gaseous hydrocarbons is increased as compared with the Ar discharge; the total amount of carbon gasified is also increased. In this discharge, C<sub>2</sub>H<sub>2</sub>, CO, and CH<sub>4</sub> are the main constituents of the gaseous product, and minor amounts of other hydrocarbons are also formed as in the Ar discharge. Comparison of the several 60-second runs indicated that the net amount of hydrogen remaining after the reaction was decreased, except for high volatile bituminous coal and lignite. Besides that converted to hydrocarbons, part of the hydrogen was probably consumed in the formation of solid product or was taken up by the coal residue. With high volatile bituminous coal and lignite, gasification was extensive and resulted in a net increase of hydrogen.

The percent of carbon converted to gaseous hydrocarbons increases with the volatile matter of coal as shown in figure 1, suggesting that a rapid release of the volatile matter and its subsequent gas phase reaction in a discharge may be the determining factors. Figure 1 includes the data for graphite. Lignite, with the highest volatile matter, however, gave only small amounts of hydrocarbons in both discharges. The high oxygen content of the lignite results in higher yields of carbon oxides and water but apparently inhibits hydrocarbon formation. Water vapor, in a discharge, can reverse the reactions of hydrocarbon formation by reacting with the hydrocarbon species to form carbon oxides and hydrogen.<sup>10/</sup>

Chrysene did not behave particularly different from coal in both discharges; the extent of gasification was appreciably small, approximately the same as that for anthracite. Interestingly, the carbon contents of the chrysene and the anthracite are also close to each other and are much higher than the other coals.

For coal in general, the higher the carbon content the lower the volatile matter. The extent of the reaction of graphite with H<sub>2</sub> was very much smaller under comparable conditions, probably due to the absence of volatile matter. The main products from graphite were CH<sub>4</sub> and C<sub>2</sub>H<sub>2</sub>; however, the hydrogen balance indicated, for example, that with an initial pressure of the H<sub>2</sub>-Ar mixture of 25 mm Hg, the percentage of the initial hydrogen present in each component of the product is H<sub>2</sub>, 77.6; CH<sub>4</sub>, 9.2; C<sub>2</sub>H<sub>2</sub>, 3.3; C<sub>2</sub> + C<sub>3</sub> hydrocarbons, 1.6; and the remainder (8.3%) was apparently consumed in the formation of polymer or was taken up by the graphite.<sup>11/</sup>

It is interesting to note that C<sub>2</sub>H<sub>2</sub> accounted for 75-92% of the gaseous hydrocarbons produced from coal in both discharges. Hydrogasification or carbonization of coal usually gives CH<sub>4</sub> as the major hydrocarbons. It has been suggested that, in a microwave hydrogen discharge system, transport of carbon from the solid to the vapor phase takes place by bombardment of the carbon by energetic ions and electrons, and that the gaseous carbon species could react with H atoms or CH species to form hydrocarbons.<sup>2,3/</sup> A similar mechanism appears to apply to the system containing coal except that H and CH species would also be evolved from the coal in addition to gaseous carbon species, even in the absence of an initial hydrogen. The predominance of C<sub>2</sub>H<sub>2</sub>, however, is also observed in rapid heating of coal by various high temperature methods such as plasma jet,<sup>6-9/</sup> laser beam<sup>12/</sup> and flash heating,<sup>13/</sup> etc. A comparison of our experimental results with those obtained with an Ar plasma jet by Bond et al.<sup>7/</sup> indicates that the percentage of carbon converted to C<sub>2</sub>H<sub>2</sub> in our system is somewhat lower, but the effect of volatile matter on the hydrocarbon

yield is quite similar. The conversion of carbon to  $C_2H_2$  for the high volatile bituminous coal (VM = 39.2%) in table 2 is 9.2% in the  $H_2$ -Ar discharge as compared to 12.5% in the Ar plasma for a coal of similar volatile matter content.

TABLE 2. - Reactions of coal and related materials  
in microwave discharges of  $H_2$  and Ar

Material	Pressure, mm		Time, sec	Yield x 10 <sup>4</sup> , mole/g of solid					Percent of C present as	
	H <sub>2</sub>	Ar		H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>	CO	CO <sub>2</sub>	Gaseous products	Gaseous hydrocarbons
hvab	22.7	2.3	60	63.9	4.7	31.1	21.1	0.2	13.6	10.4
	22.7	2.3	60	53.6	10.2	28.6	20.2	.2	13.1	10.3
	23.4	2.4	60	12.5	4.5	27.0	23.6	.4	12.8	9.4
	22.8	2.4	90	<u>1/</u>	3.9	29.8	22.2	.2	13.1	9.9
	21.8	2.3	105	<u>1/</u>	4.8	21.0	16.9	.2	9.9	7.4
	21.9	2.3	110	<u>1/</u>	3.6	20.0	16.0	.2	9.4	7.0
	-	25.7	17	3.3	.1	1.2	7.1	.1	1.5	.4
	-	24.0	60	56.4	.9	13.4	23.0	.2	7.7	4.3
	-	23.6	180	44.0	1.1	16.5	22.6	.2	8.7	5.3
lvb	23.8	2.5	34	<u>1/</u>	4.1	15.6	7.3	.1	6.1	5.1
	21.6	2.2	60	<u>1/</u>	3.8	17.5	8.1	.1	6.7	5.6
	-	23.5	60	19.3	.3	3.6	7.7	trace	2.1	1.1
Lignite	21.6	2.2	60	25.4	2.1	9.3	66.2	3.5	16.7	4.1
	22.6	2.3	180	22.9	2.1	7.7	80.3	1.8	18.3	3.4
	20.7	2.1	180	26.0	2.1	7.3	69.2	1.7	16.1	3.3
	-	24.7	32	50.4	.7	6.9	61.7	3.2	14.1	2.7
	-	23.0	60	18.4	.6	5.0	68.4	3.2	15.1	2.1
Anthracite	21.6	2.2	60	<u>1/</u>	4.2	8.3	4.0	trace	3.6	3.1
	22.6	2.4	60	<u>1/</u>	4.6	9.6	3.0	trace	3.9	3.4
	-	24.0	60	.3	trace	trace	2.0	.1	.3	-
Chrysene	22.7	2.4	10	<u>1/</u>	6.5	12.8	2.0	trace	4.6	4.4
	20.0	2.0	30	<u>1/</u>	10.4	5.8	trace	trace	3.4	3.4
	-	22.0	30	18.6	.8	2.6	trace	trace	.9	.9
Graphite	22.4	2.3	60	<u>1/</u>	3.5	2.5	trace	trace	1.2	1.2
	22.6	2.4	60	<u>1/</u>	3.4	1.8	trace	trace	1.0	1.0

1/ Net decrease of hydrogen was indicated.

#### Solid Product

The solid product obtained from coal is brownish and is similar to that usually observed from the thermal treatment of coal. No appreciable amount of solid product was formed from anthracite or from lignite. Though the extent of the gasification for the chrysene was not appreciable, the original white powder was instantaneously converted to a brown solid upon the initiation of both discharges. The infrared spectra of the solid product and the residual char obtained from the high volatile bituminous coal in the  $H_2$ -Ar discharge showed the usual aliphatic C-H bands and some weak aromatic bands which are typical of pitch and coal.

#### Effect of Cooling by Liquid Nitrogen

Since the indications are that the water formed can retard the hydrocarbon formation and that the hydrocarbons produced may undergo further destructive reactions, it can be expected that a rapid quenching of the primary products should give a pronounced effect on the result. Experiments were carried out in a reactor consisting of the

tube divided by a fritted Vycor disc. The coal was placed on the disc, and was subjected to reaction in the  $H_2$  discharge while the lower end of the tube was cooled in liquid  $N_2$ . Though the process of condensing water and some hydrocarbons at this temperature is diffusion controlled, the effect is pronounced, as shown in table 3. For both the bituminous coal and the lignite, the yield of the hydrocarbons,  $C_2H_2$  in particular, was greatly increased. The amount of  $H_2$  remaining and the amount of CO produced after the reaction were also decreased. Therefore, the increase of hydrocarbon yield can be attributed mainly to subsequent hydrocarbon formation by reaction of  $H_2$  and CO; this hydrocarbon yield is greatly enhanced by rapid removal of  $H_2O$  formed.

#### Water-Argon Discharge

There is a marked difference between the products obtained from graphite and coal in a water discharge. In the discharge in  $H_2O$ -Ar mixtures, as shown in table 4, graphite yields hydrogen and CO but practically no hydrocarbons; while the coals yield an appreciable amount of  $C_2H_2$  and some  $CH_4$  in addition to  $H_2$  and CO. The amounts of  $H_2$  and carbon oxides produced in the reaction with graphite were stoichiometric. The extent of gasification was also much greater for the coals than for the graphite. The active hydrogen species produced in the water discharge did not react further with the graphite or the CO formed from it to produce significant amounts of hydrocarbons. This is further evidence demonstrating that the presence of water vapor retards hydrocarbon formation.

For the reaction of a given coal in a  $H_2O$ -Ar discharge, an initial  $H_2O$  pressure of less than 12 mm Hg appears to give the optimum gasification and hydrocarbon production. Higher initial  $H_2O$  pressures cause a decrease in both gasification and hydrocarbon production. So long as the  $H_2O$  pressure is not at its highest values, more hydrocarbons are formed than in the Ar discharge. (Also, with the higher initial  $H_2O$  pressures, the discharge could not be initiated readily and would not sustain itself for as long as 60 seconds, perhaps due to too large an increase in the total gas pressure in the reactor.) The data seem to indicate that 60 seconds may have been too long a period for the maximum production of hydrocarbons. The formation of the hydrocarbons should be a maximum at the time when a plateau of the extent of coal gasification is attained, and prolonged treatment probably allows the remaining  $H_2O$  vapor to diffuse into the discharge zone, giving an adverse effect. It was also noticed that, at an initial  $H_2O$  pressure of less than 12 mm, the hydrogen content of the products exceeded that which could possibly be derived from the stoichiometric amount of the  $H_2O$  initially present.

These results seem to indicate the following. The active hydrogen species formed in the  $H_2O$  discharge participate in the reactions which lead to the formation of hydrocarbons from (some of) the species derived from the coal. This occurs despite the retarding effect of  $H_2O$  on hydrocarbon formation. (If the  $H_2O$  pressure is too high, this latter effect decreases the hydrocarbon yield.) Presumably, the coals when gasified supply enough CH species to allow hydrocarbons to be formed, even though the active oxygen species present react with some of the gaseous carbon and CH species. On the other hand, graphite produces negligible amounts of CH species in a  $H_2O$ -Ar discharge, and therefore cannot produce hydrocarbons since the reaction of the CO formed with the active hydrogen species is retarded by the  $H_2O$  present.

Lignite, with its high volatile matter content, was extensively gasified but gave a relatively low hydrocarbon yield, presumably due to the inhibition by its high oxygen content. For lignite, the production of  $CO_2$  was also higher in the  $H_2O$ -Ar discharge than in the  $H_2$ -Ar or Ar discharge. Again, the extent of gasification for chrysene was rather small.

TABLE 3. - Effect of cooling at reactor end by liquid nitrogen

Material	Pressure, mm H <sub>2</sub> -Ar mixture (9.7:1)	Time, sec	Yield x 10 <sup>4</sup> mole/g of solid						Percent of C present as		
			H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	CO	CO <sub>2</sub>	Gaseous products	Gaseous hydrocarbons
HVA-bituminous	23.0	60	2/	8.2	22.6	3.2	2.4	8.6	0.4	11.1	9.8
	24.6	60	2/	4.9	23.8	2.3	1.7	7.6	.2	10.0	8.9
Lignite	24.5	180	2/	4.5	51.8	5.5	3.6	13.7	.5	20.4	18.3
	25.9	60	2/	2.8	17.0	.7	.7	38.0	3.6	14.8	7.3
	23.8	180	20.8	2.0	25.2	.7	.7	39.6	5.0	18.2	10.1

1/ Peaks attributed to HCN was neglected.  
 2/ Net decrease of hydrogen was indicated.

TABLE 4. - Reactions of coal and related materials in microwave discharges of H<sub>2</sub>O-Ar mixtures

Material	Pressure, mm		Time, sec	Yield x 10 <sup>4</sup> mole/g solid						Percent of C present as	
	H <sub>2</sub> O	Ar		H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	CO	CO <sub>2</sub>	Gaseous products	Gaseous hydrocarbons
hvac	18.1	7.6	40	17.3	0.5	8.6	28.4	2.1	7.3	2.8	
	18.0	5.7	35	25.8	.8	10.2	30.0	1.0	8.0	3.4	
	12.3	6.9	57	40.0	.8	16.5	42.6	.7	11.7	5.3	
	12.0	8.0	40	70.0	1.7	22.7	36.0	.7	12.8	7.3	
	11.2	7.7	47	34.0	1.2	18.2	39.0	1.0	11.8	5.9	
	10.5	8.2	60	56.4	2.0	24.4	44.8	2.0	14.8	7.9	
	7.9	8.6	45	102	2.0	23.0	38.6	.7	13.2	7.1	
	7.3	6.4	60	24.2	.9	15.8	27.0	.8	10.1	5.2	
	6.6	9.3	30	42.8	1.6	23.5	28.7	.8	11.9	7.6	
	11.2	6.7	180	115	1.9	15.4	60.0	.6	14.2	5.3	
	18.4	7.3	25	13.8	.4	4.6	21.2	2.4	4.6	1.4	
	10.0	7.7	60	20.9	1.1	13.6	25.8	.5	7.6	4.0	
Lignite	17.5	5.7	40	63.8	3.7	trace	52.6	16.6	13.4	.9	
	11.0	8.8	60	89.0	1.5	10.0	87.2	5.0	20.9	4.1	
Anthracite	7.3	5.0	60	45.4	.6	10.4	42.4	.8	8.7	3.0	
Chrystene	8.2	6.6	23	30.4	2.0	6.4	7.4	.2	3.0	2.0	
Graphite	16.3	5.4	60	24.2	trace	trace	19.4	3.0	2.8	-	
	18.9	5.9	180	37.8	trace	trace	28.8	5.4	4.1	-	

## Deuterium Oxide-Argon Discharge

It is of interest to obtain further evidence as to whether water is actually involved in the reaction with coal to form hydrocarbons in addition to the production of  $H_2 + CO$ . The gaseous product obtained from the reaction of the high volatile bituminous coal in a  $D_2O$ -Ar mixture was analyzed by the high resolution mass spectrometer. At a resolution of 1 part in 20,000, precise masses for doublets and in some instances triplets that occurred at the same nominal masses could be used to identify completely deuterated, monodeuterated and nondeuterated species present in the product. For example, peaks due to  $C_2H_2$  (mass = 26.0156),  $C_2D$  (26.0141) and  $CN$  (26.0031) were observed at the nominal mass of 26 and peaks due to  $C_2D_2$  (28.0282),  $N_2$  (28.0061) and  $CO$  (27.9931) were observed at the nominal mass of 28. The whole spectrum up to the nominal mass of 44 contained peaks attributed to all species present including minor amounts of oxygenated and N-containing compounds, but the major products were  $H_2$ ,  $HD$ ,  $D_2$ ,  $C_2H_2$ ,  $C_2HD$ ,  $C_2D_2$  and partially deuterated methanes in addition to  $D_2O$ ,  $DHO$ ,  $H_2O$  and carbon oxides. Thus it is apparent that  $D_2O$  is initially dissociated into  $D$ ,  $OD$  and possibly an active oxygen species which in turn recombine to give  $D_2O$  and  $D_2$ , or react with the active species derived from coal such as  $H$ ,  $CH$ ,  $C_1$ ,  $C_2$  and  $CO$ , etc., to give  $DHO$ ,  $HD$ ,  $CO$ ,  $CO_2$  and deuterated hydrocarbons.

## CONCLUSIONS

In the microwave discharges of  $H_2$ ,  $H_2O$  and Ar, coal is gasified to give gaseous hydrocarbons and carbon oxides plus a solid product and residual char. Hydrogen is also produced either by dissociation of the water vapor or by devolatilization of the coal in the  $H_2O$  and/or Ar discharges. But, in most cases in the hydrogen discharge, hydrogen is consumed rather than produced (except for hvab coal and lignite). The yield of the hydrocarbons is highest in the hydrogen discharge and that of carbon oxides is highest in the water discharge. Both the hydrogen and the water discharges give greater extents of gasification and yield more hydrocarbon products than the Ar discharge, indicating the occurrence of gas phase reactions of  $H$ ,  $OH$ , and active oxygen species with the active species derived from the coal. The gasification of coal in the water discharge is of particular interest because it produces  $H_2 + CO$  (~ 1:1) plus  $C_2H_2$  and  $CH_4$ . The high oxygen content of the lignite results in a higher yield of carbon oxides but apparently inhibits the hydrocarbon formation in the discharge. The hydrocarbon yield from the lignite or other coals in the hydrogen discharge, however, can be increased dramatically by rapidly condensing part of the product species produced, especially  $H_2O$ , during the discharge reaction.

$C_2H_2$  accounts for as much as 92% of the gaseous hydrocarbons produced, and, excepting for lignite, the amount of the hydrocarbons is related to the volatile matter of coal. The extent of gasification, however, is increased with the volatile matter content of coal including lignite. Thus, if the hydrocarbons are formed by the recombination of the species derived from the volatile material and other species present in the discharge, another interesting study would be to employ a flow system in which coal is devolatilized by ordinary means and the evolved gases are subsequently reacted in a discharge.

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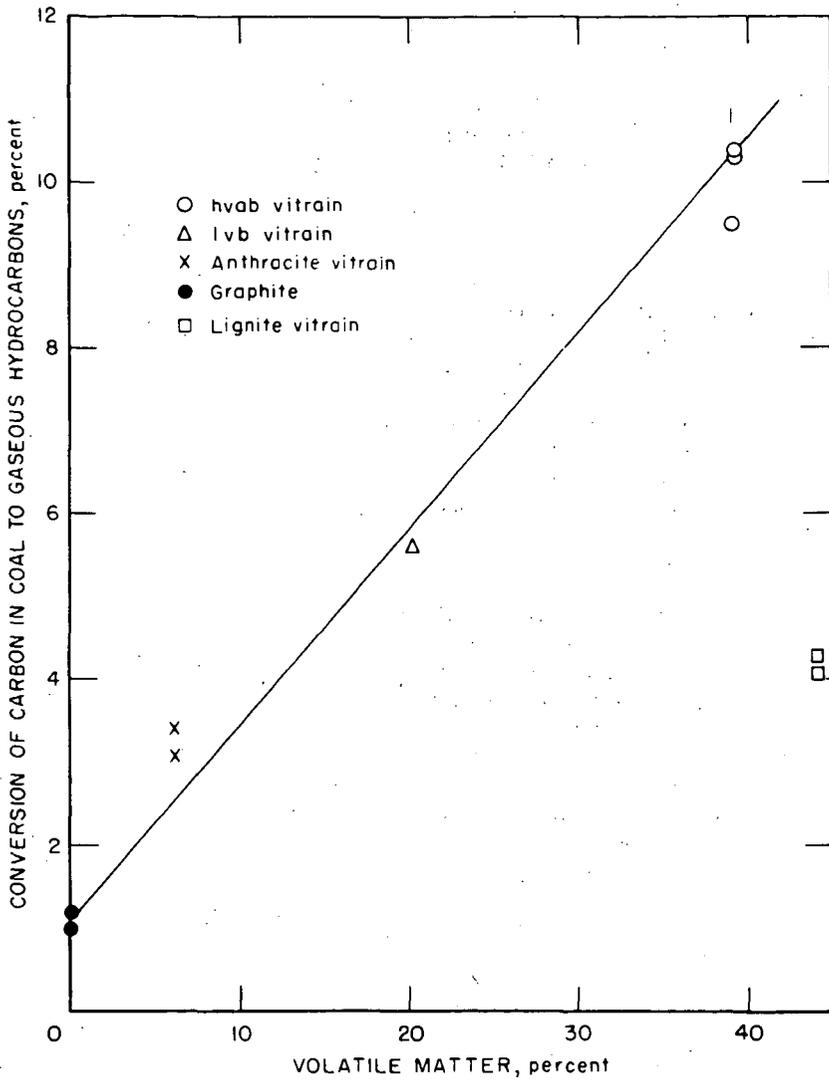


Figure 1 - Effect of volatile matter on yield of hydrocarbons in H<sub>2</sub>-Ar discharge (60 second run)