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DOE/PC/89759--T3

**INVESTIGATION OF THE RANK
DEPENDENCE OF TAR EVOLUTION**

DOE/PC/89759--T3

DE91 005884

CONTRACT NUMBER: DE-AC22-89PC89759

QUARTERLY REPORT FOR PERIOD: 1 April 1990 - 30 June 1990

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CONTRACT PERIOD: Sept. 22, 1989 - June 22, 1991

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EXECUTIVE SUMMARY

The following report contains results obtained for the third quarter period, April 1 - June 30, 1990, of contract DE-AC22-89PC89759 entitled "Investigation of the Rank Dependence of Tar Evolution." Elemental composition summaries of the parent coal are included so that the report can be used as a stand alone document for those researchers engaged in rapid coal devolatilization modeling. PSOC XXXXD samples ranging in rank from a Texas lignite to a Pennsylvania anthracite are investigated. Three HVA bituminous coals from three different geologic provinces - Rocky Mt., Interior, and Appalachian - are examined to gain insight into the influence that moderate changes in parent coal structure can exert upon tar evolution phenomenology.

Zero hold time (ZHT) tar evolution determinations for the six parent coals as observed in the UTRC heated grid (UTRC-HG) apparatus are presented. The ZHT tar evolution is phenomenologically associated with the transient volatiles evolution behavior during particle heating in pulverized coal combustion conditions. Results are presented in tabular and graphical form. Results are presented relative to the long hold time (LHT), potential, tar yields detailed in the quarterly report for the previous period. Results are also presented relative to the reference HVA bituminous coal, PSOC 1451D.

It is observed that the transient tar evolution phenomenology in rapid heating varies significantly with changes in coal rank. Relative to the reference coal, the low rank coals display more rapid evolution of tar at particle temperatures less than 500°C, but lower evolution rates at transient particle temperatures greater than 500°C. It is observed that the transient tar evolution behaviors of the Interior Province, PSOC 1493D, and Rocky Mt., PSOC 1499D, coals are similar to the reference coal at temperatures less than 550°C, but slower than the PSOC 1451D at particle temperatures greater than 550°C. In general, the transient tar evolution process for these coals is less temperature sensitive than the PSOC 1451D coal in the 500 to 650°C particle temperature range. PSOC 1451D tar evolution shows a steep temperature sensitivity in this temperature range. The results are understandable in view of the position of the samples relative to PSOC 1451D in a coalification band plot, that is, in terms of parent coal structural differences.

Differences in transient tar evolution phenomenology are reflected in differences in the char evolution phenomenology. The Appalachian Province HVA coal displays a steep mass loss sensitivity in the 500 to 650°C range, reflecting the tar evolution process, while the non-Appalachian coals show a broader, less steep temperature sensitivity. This difference in ZHT char evolution behavior among HVA bituminous coals is in sharp contrast to LHT behavior, which showed considerable similarity. In short, kinetic tar evolution behavior varies significantly both with coal rank and geologic province for similar coal ranks.

Finally, the high volatiles yields observed for final particle temperatures greater than 700°C in the LHT investigations of the low rank coals, and, in particular, the Wyoming subbituminous sample are preserved in the ZHT results. That is, these coals display mass loss yields on a dry, ash free basis of 70% or greater. As observed in the LHT data for high temperature runs, a significant fraction of this "apparent" volatility appears to be due to a particle fragmentation process. Because of its fundamental and practical importance, this particle fragmentation phenomenon needs to be investigated in more detail.

PROJECT DESCRIPTION

Objectives:

The objectives of this study are to develop an improved understanding of the process of coal tar evolution, its relationship to the structural characteristics of the parent coal, and the dependence of the chemical and physical properties of the tar products on the conditions of devolatilization. Data from this study are expected to allow hypothesis testing and refinements of coal devolatilization models relevant to the pulverized coal combustion process.

Program Structure:

The program is divided into seven major technical areas in which the following rank dependence issues are addressed:

1. tar evolution rates in rapid heating conditions;
2. molecular weight and vapor pressure characteristics of tars;
3. chemical structure and calorific values of tars;
4. influence of interphase mass transport phenomena;
5. gas phase secondary reactions of "primary" tars;
6. parent coal nitrogen evolution during devolatilization;
7. model hypothesis testing.

The PSOC 1451D coal is the reference coal, that is, its structural characteristics and tar evolution phenomenology become the defined references for the other coals. Parent coal structural parameters, tar yields, chemical and physical properties of tars, nitrogen evolution behavior, and global kinetic parameters are defined relative to it.

Coal Characterization:

A range of coal ranks, from a Texas lignite to a Pennsylvania anthracite, are employed in the investigation. In addition, a high temperature polymer, a polyimide, is utilized as an additional reference case. The polyimide serves as a truly polymeric reference material for examining the nitrogen evolution behavior of coal. The samples are subjected to elemental composition determination (Table I), infrared absorbance characterization, calorific value measurement, high temperature ash analysis, and maceral composition. Consideration is being given to NMR analysis as well as tetrahydrofuran (THF) solubility.

Experimental Measurements:

Potential tar yields are determined by long hold time heated grid investigations of each coal at a final temperature and heating rate observed to maximize tar yields for the reference coal. Relative tar evolution kinetic behavior is determined by zero hold time heated grid (1) investigations of each coal.

"Primary" tar samples are obtained by collecting tar samples from rapid heating of parent coal samples in the UTRC entrained flow reactor and aerosol separation systems

(2). Volatility and molecular weight characteristics of these samples are determined by heated grid revaporization experiments (3) and compound-type calibrated GPC examination of the tars. The compound-type calibration curve employed for each tar type is determined by elemental composition and IR absorbance measurements of each tar type to determine which calibration compound, homologous series most resembles the structural characteristics of the collective tar sample.

Gas phase secondary reactions of "primary" tar samples is investigated by comparing light gas evolution behavior in the heated grid, entrained flow reactor and flash lamp reactor systems.

Nitrogen evolution behavior is a result of the tar evolution properties of a coal and the secondary reaction chemistry of the residual char and evolved tars. Nitrogen balance determinations are made on two of the reactors - heated grid and entrained flow - directly (4) and the flash lamp indirectly. In addition to the reference behavior of PSOC 1451D, the nitrogen evolution behavior of a high temperature polyimide in rapid heating thermal decomposition conditions is investigated to serve as a truly polymeric reference.

EXPERIMENTAL RESULTS

Transient Tar Yields - Kinetic Phenomenology:

Heated Grid Determination of Tar Evolution Phenomenology

The calibration and characterization details of the UTRC heated grid technique (UTRC-HG) are given elsewhere (1). In the determination of transient tar evolution processes, zero hold times at peak temperatures are programmed. Peak temperatures in excess of 650°C are observed necessary (1) to maximize the transient tar yield for the reference coal, PSOC 1451D, and consequently, such conditions were employed in this investigation in order to characterize the relative behavior of the selected samples. Since the zero hold time (ZHT) temperature sensitivity of these coals relative to both the reference coal ZHT behavior and their own LHT tar evolution behavior is of interest, intermediate ZHT peak temperatures were employed in this phase of the investigation.

Figures 1 and 2 display the heating condition data summary sheets for a typical ZHT run. A blank, unloaded screen is temperature programmed using the semi-empirical enthalpy and heat loss expressions determined for the particular wire mesh system employed at UTRC (1). An estimation of the enthalpy requirements of the coal sample are taken into account. Figure 1 shows a data sheet summary for a typical blank screen run. The sample is then loaded in the screen and the experiment performed. Figure 2 displays the corresponding "run" data sheet summary. The light gas evolution is monitored using a Fourier Transform Infrared Spectrometer (FTIR) that scans a gas cell attached to the heated grid reactor. The residual char mass is determined directly, as is the evolved tar. The data is entered into a matrix data sheet (See Row 19, Table II for this particular blank-run pair.). The time resolved current, voltage, pressure and temperature trajectories are stored in a set of corresponding arrays filed under the Run I.D. associated with the blank-run pair. These are available and communicable via standard computer transmission techniques. Figure 3 displays a typical light gas IR absorbance spectrum, in this

case, that obtained for Run 88. The quantitative measure of each significant gas evolved is determined by comparing absorbance at specific wavenumbers to calibration curves for specific gases. CH_4 , C_2H_6 , C_2H_5 , C_2H_2 , HCN , CO_2 , CO and C_6H_6 are determined in this manner. The quantitative yields of these gases will be entered into Table II.

Results:

Coal Structure Dependency of Maximum Tar Yields

Table II summarizes the raw, ZHT, char and tar and total "apparent" volatiles determined for the coals being investigated. Figures 4 - 9 display the ZHT yields observed for PSOC 1443D, PSOC 1520D, PSOC 1499D, PSOC 1493D, PSOC 1516D and PSOC 1468D, respectively. Also shown are the LHT yield data, described in more detail in the previous quarterly. ZHT and LHT yields are nearly indistinguishable for the Texas lignite coal PSOC 1443D, implying that the kinetics of intraparticle tar formation and transport are fast for those tars capable of desorbing at a given peak temperature. That is, given a peak particle temperature, the particle tar fraction capable of evolving at that temperature or below does so during the transient heating process. There is no lag introduced by intraparticle tar formation kinetics or mass transport in order for the potential tar yield for a given transient temperature to be realized. This is in sharp contrast to the HVA bituminous coal tar evolution behavior (Figures 6 and 7) wherein considerably different tar yields are observed in ZHT and LHT experiments to the same peak temperature.

PSOC 1520D displays somewhat erratic ZHT behavior relative to its LHT yields. At temperatures of 450°C and above, the ZHT tar yields are "apparently" greater than the LHT yields. Also, there is considerable range in the tar yields for a given peak temperature at these temperatures. It is observed in some cases that the tar films formed within the reactor had particle fragments associated with them. The low char yields observed for the LHT runs with this coal have been tentatively associated with particle fragmentation. (See Quarterly Report for the period 1 January 1990 - 31 March 1990 of Contract DE-AC22-89PC89759.) The difficulty in obtaining consistent elemental composition analysis for this coal has also been noted. It appears that this coal, similar to PSOC 1507D, a North Dakota lignite, tends to fragment in rapid heating conditions. This fragmentation in a heated grid experiment allows small char/coal fragments to leave the grid fold and contribute to the apparent total yield (1 - char fraction). If the fragments come to rest with the tar film, they become weighed as apparent tar yield. This fragmentation phenomenon is to be investigated in more detail in the crosslinking investigation.

In any case, the PSOC 1520D sample, similar to PSOC 1443D, shows no systematic difference between ZHT and LHT tar yields. Again, for a given peak temperature and rapid heating conditions, the tar yield is immediately realized during the transient heating. The rapid heating process does not push the kinetics of tar evolution to higher temperatures.

The displacement of the transient tar evolution process to higher evolution temperatures is apparent in Figure 6 for the Colorado bituminous coal, PSOC 1499D, and in Figure 7 for the Illinois #6 coal, PSOC 1493D. Both HVA coals show a significant differential in LHT and ZHT yields for intermediate temperatures. The 1499D coal ZHT yields appear to be converging to the LHT yields at high peak temperatures. This is not the case for

the Illinois #6 coal, PSOC 1493D. The ZHT tar yield behaviors of both coals in the 400 - 800°C range, relative to their respective LHT behavior, indicate that intraparticle tar formation and evolution kinetics are not fast compared to the particle heating rate. This behavior is in sharp contrast to that of the low rank coals. Rapid heating of HVA coals tends to push their transient tar evolution process to higher temperatures, whereas rapid heating of low rank coals has no appreciable effect on transient tar evolution.

The low volatiles bituminous coal investigated, PSOC 1516D, displays no significant difference in low temperature (< 500°C) ZHT and LHT tar evolution behavior. However, the high temperature data display significant differentials in LHT and ZHT yields. Again, this bituminous coal has a high temperature tar evolution wherein intraparticle tar formation kinetics and evolution are not able to track the transient particle heating rate. The anthracite yields, PSOC 1468D, are consistently low on an absolute basis and show no significant differential in ZHT or LHT behavior.

ZHT Tar Yields Relative to Reference Coal PSOC 1451D:

Non-HVA Bituminous Coals

Figure 10 displays the ZHT tar yield behavior of the low and high rank coals relative to the HVA reference coal, PSOC 1451D. Figure 11 shows the corresponding ZHT char yields on a dry, ash free basis. The low temperature "tar" evolution of the low rank tars relative to the reference coal is obvious. The overall transient tar evolution is much less temperature sensitive than that of the HVA bituminous coal, which shows a steep temperature sensitivity in the 500 - 650°C range. Although the LHT tar yield temperature sensitivity of the low rank coals is more similar to the reference coal, the ZHT behavior is obviously very different. The implication is that the intraparticle tar formation kinetics and volatility characteristics of the low rank tars are such that the tar evolution process is able to track the particle heating process. Volatility experiments using low rank tars collected in the UTRC entrained flow reactor do indeed show very different vapor pressure characteristics than the HVA tars. (See Quarterly Report for period 1 October 1989 - 31 December 1989, DE-AC22-89PC89759.) In general, the polymethylene tars evolved from low rank coals (2) can be revaporized from a heating surface at temperatures several hundred degrees lower than HVA bituminous tars. The HVA bituminous intraparticle tar formation kinetics and vaporization properties are such that the tar evolution process is not able to track particle heating rates at temperatures less than 500°C and particle heating rates of 1000°C/sec.

HVA Bituminous Coals

The Illinois #6 and Colorado bituminous coals, although both are HVA ASTM rank as is PSOC 1451D, display variant ZHT tar evolution temperature sensitivity in the 550 - 800°C range relative to the reference coal. On an absolute basis, the tar yields of all three coals track relatively closely in the 300 - 550°C peak temperature range. It is for 550°C and above peak temperatures that the tar evolution behavior diverges from that of the reference coal. The 1451D coal displays a sharp rise to its asymptotic transient yield in the 550 - 650°C range. PSOC 1499D (Figure 12) shows a gradual rise to its

asymptotic yield over the 550 - 800°C range of peak temperatures. PSOC 1493D, on the other hand, shows (Figure 13) even less increase in tar yield than 1499D with peak temperature over the 550 - 800°C range. For these coals there appears to be a slower rate of high temperature tar formation and evolution than that observed for the Appalachian province HVA bituminous coal. These coals also have greater oxygen or sulfur functionality than 1451D, which would tend to impart lower vapor pressure characteristics and greater susceptibility to pyrolytic cracking during rapid particle heating. The net effect is obviously to change the temperature sensitivity of the transient tar evolution process relative to the reference coal. In short, the differences in coal structure impart significant differences in their transient tar evolution phenomenology. Bulk samples of 1499D and 1493D tars will be collected in the UTRC entrained flow reactor for comparison of elemental composition, functionality and volatility to the reference coal tars. This data will help determine the relative importance of intraparticle tar formation kinetics relative to tar volatility and cracking susceptibility in overall tar evolution kinetics.

ZHT Char Yields Relative to Reference Coal PSOC 1451D:

Non-HVA Bituminous Coals

Because the tar evolution process represents a large fraction of the particle mass loss, the differences in transient tar evolution phenomena with coal rank are clearly reflected in the char yield behavior (Figure 11). The extremely low char yields associated with very high total yields for the low rank coals are believed to be due to particle fragmentation, which occurs at a given extent of reaction for these low rank coals. This is being extensively investigated.

HVA Bituminous Coals

Although the ZHT tar yields are similar for the HVA bituminous coals over the 300 - 550°C range, the char yield behavior is not. Both the Colorado bituminous (Figure 12) and the Illinois #6 (Figure 13) coals show greater low temperature total yields (lower char yields) than the reference coal, indicating greater gas yields at these temperatures than 1451D. However, the total volatile yields lag those of 1451D at particle temperatures greater than 550°C. That is, during the transient heating conditions in which the 1451D coal displays a sharp increase in tar yields and a corresponding decrease in char yield, these HVA coals experience a less intense tar release and a corresponding moderate decrease in char yield. The transient behavior is in contrast to the LHT char yield behaviors where little significant difference in char yield behavior is observed among the three coals. (See Quarterly Report for the period 1 Jan. 1990 - 31 Mar. 1990 of Contract DE-AC22-89PC89759.)

REFERENCES

1. Freihaut, J.D. and Proscia, W.M., *Energy and Fuels*, 1989, 3, 625.
2. Freihaut, J.D., Proscia, W.M., and Seery, D.J., *Energy and Fuels*, 1989, 692.
3. Proscia, W.M., Freihaut, J.D., Mackie, J., *Volatility and Pyrolysis Characteristics of Primary Coal Tars Produced in an Entrained Flow Reactor*, submitted to *Energy and Fuels*, 1990. (Included in DE-AC22-89PC89759 Quarterly Report for Period 1 October 1989 - 1 January 1990.)
4. Freihaut, J.D., Proscia, W.M., et. al., *Combustion Properties of Micronized Coal for High Intensity Combustion Applications*, Final Report, U.S. DOE Contract DE-AC22-85PC80263, April, 1989.

TABLE I
RANK EFFECTS ELEMENTAL COMPOSITION SUMMARY

	A	B	C	D	E	F	G
1	Coal I.D.	AVE. D, mic.	SEAM, LOCAT.	APP. RANK	AS-RCD H ₂ O%	ME%	%ASTM(Ash)-MMF
2							
3	PSOC 1443D	69	LOWER WILCOX, TEXAS	LIGNITE	7.13	4.95	20.34
4	PSOC 1520D	69	SMITH ROLAND, WY	SUBC	13.83	4.15	12.45
5	PSOC 1499D	69	COLORADO B, CO	HVA	2.97	1.7	4.88
6	PSOC 1493D	69	ILLINOIS #6, ILL	HVA		2.05	13.34
7	PSOC 1451D	69	PITTSBURGH #8, PA	HVA	NA	1.6	3.35
8	PSOC 1516D	69	LOWER KITTANNING, PA	LVB		0.21	16.97
9	PSOC1468D	69	BUCK MOUNTAIN, PA	ANTHRACITE		1.05	6.60
10	POLYIMD E				0.00	0	0.00

	A	H	I	J	K	L
1	Coal I.D.	(%C)DAF	(%H) DAF	(%N)DAF	(%S+O) DAF	HEAT VAL (BTU/LB)
2						
3	PSOC 1443D	66.45	5.16	1.28	27.11	8973
4	PSOC 1520D	69.03	5.04	0.98	24.96	10001
5	PSOC 1499D	79.90	5.49	1.57	13.04	13158
6	PSOC 1493D	75.52	5.02	1.46	18.01	11670
7	PSOC 1451D	83.95	5.62	1.62	8.81	14279
8	PSOC 1516D	87.40	4.69	1.55	6.36	12476
9	PSOC1468D	94.34	1.86	0.74	3.06	
10	POLYIMD E	72.18	2.67	7.12	18.03	

	A	M	N	O	P	Q
1	Coal I.D.	HEAT VAL(BTU/LB)(DAF)	MACERAL GROUPS VOL %			%TAR YIELD (daf), He, 10s
2			VITRINITE	INERTINITE	LIPTINITE	
3	PSOC 1443D	11264				17.6
4	PSOC 1520D	11423	88.5	5.7	5.8	19.3
5	PSOC 1499D	13834				22.2
6	PSOC 1493D	13466				22.6
7	PSOC 1451D	14766	89	7.4	3.6	31.04
8	PSOC 1516D	15026	84.8	7.7	7.5	10.8
9	PSOC1468D		88.6	11	0.4	2.5
10	POLYIMD E					7.05

TABLE II
UTRC-HEATED GRID TAR EVOLUTION RANK EFFECTS:
ZERO HOLD TIME DATA

A	B	C	D	E	F	G	H	I	J	K
Coal I.D.	Run I.D.	d1-d2, microns	Atmos.	Sample Size(mg)	Prog. T-asymp (C)	Prog. T-Dot(C/sec)	Prog. Max I, amps	Prog. Max Volts	Prog. Max. Pow. watts	Prog. Hold (sec)
1	PSOC 1443D	1	63-75	Helium	19.5	446.1	1023.4	31.7	10.7	339
3	PSOC 1443D	3	63-75	Helium	18.2	546.8	1026.6	33.3	11.6	386
4	PSOC 1443D	2	63-75	Helium	13.8	492.9	1019.6	32.3	11.2	362
5	PSOC 1443D	4	63-75	Helium	10.7	589.5	1019.2	34.3	13.1	449
6	PSOC 1443D	5	63-75	Helium	15.2	642.8	1003.6	36.2	14.8	529
7	PSOC 1443D	6	63-75	Helium	15.9	707.9	1036.2	38.9	14.7	542
8	PSOC 1443D	89	63-75	Helium	11.3	834.7	1285.1	40.9	14.4	589
9	PSOC 1443D	90	63-75	Helium	14.5	931.2	1323.5	43.3	14	606
11										
12	PSOC 1520D	7	63-75	Helium	14	442	1021.3	33.3	10.7	356
13	PSOC 1520D	8	63-75	Helium	14	492.2	1007.9	34.5	11.5	397
14	PSOC 1520D	9	63-75	Helium	14.8	545.9	1027.2	35.2	13.4	472
15	PSOC 1520D	13	63-75	Helium	14.7	711.4	1032.9	34	12.4	422
16	PSOC 1520D	10	63-75	Helium	12.8	590.9	1018.5	36.3	13.2	479
17	PSOC 1520D	12	63-75	Helium	13.7	643.8	1014.8	35.4	13.3	471
18	PSOC 1520D	11	63-75	Helium	13	654	990.7	34.3	13.4	460
19	PSOC 1520D	88	63-75	Helium	10.8	940.8	1309.6	42.1	15	632
20										
21	PSOC 1483D	20	63-75	Helium	16.3	447.1	1027.9	33.6	10.7	360
22	PSOC 1483D	14	63-75	Helium	14	441.7	999.9	31.8	10.4	331
23	PSOC 1483D	21	63-75	Helium	13.7	442.7	1012.8	32.1	10.6	340
24	PSOC 1483D	17	63-75	Helium	16.2	589.9	1008.2	32.7	11.5	376
25	PSOC 1483D	15	63-75	Helium	14.4	500.4	1019.6	32.2	11.4	357
26	PSOC 1483D	16	63-75	Helium	18.1	541.3	1008.1	35.2	11.2	394
27	PSOC 1483D	82	63-75	Helium	13.5	740	1312	40.3	12.3	496
28	PSOC 1483D	19	63-75	Helium	15.2	790.3	1012.6	34.8	11.8	414
29	PSOC 1483D	18	63-75	Helium	14.5	646.4	1012.9	34.7	11.8	409
30	PSOC 1483D	78	63-75	Helium	11.1	682.4	1288.6	38.3	12.1	463
31	PSOC 1483D	81	63-75	Helium	11.5	736.1	1307.7	39.3	12.7	499
32	PSOC 1483D	80	63-75	Helium	11.9	739.4	1312.9	40.1	12.5	501
33	PSOC 1483D	78	63-75	Helium	11.1	840.2	1310.4	38.4	13.1	503
34	PSOC 1483D	79	63-75	Helium	14.6	947.1	1312	43	14.6	628
35	PSOC 1483D	77	63-75	Helium	9.3	825.2	1278.8	40.9	13.3	544
36										
37	PSOC 1480D	21	63-75	Helium	13.7	442.7	1012.8	33.8	10.5	355
38	PSOC 1480D	22	63-75	Helium	16.4	496.2	1012	33.5	11	369
39	PSOC 1480D	23	63-75	Helium	11.5	548.7	1017	32.6	10.6	346
40	PSOC 1480D	26	63-75	Helium	13.1	684.9	1004.9	35	12.1	424
41	PSOC 1480D	27	63-75	Helium	11.9	457.7	1045.6	32.2	10.5	338
42	PSOC 1480D	24	63-75	Helium	13.3	591.6	1018.3	33.2	10.9	362
43	PSOC 1480D	25	63-75	Helium	13.7	659.5	1033.7	36.6	13.1	479
44	PSOC 1480D	83	63-75	Helium	13.2	733	1288.4	41	13.6	558
45	PSOC 1480D	84	63-75	Helium	13.1	812.8	1348.3	14	42.5	585
46	PSOC 1480D	85	63-75	Helium	13.2	917	1339.9	13.9	42.7	594
47	PSOC 1480D	86	63-75	Helium	13.4	814.2	1308.8	12.9	38.1	491
48	PSOC 1480D	87	63-75	Helium	12.7	839.1	1308	13.1	39.7	520
49										
50	PSOC 1451D	4XX	63-75	Helium		350	1000			0
51	PSOC 1451D	456	63-75	Helium	50.1	725	1000			0

TABLE II (continued)
UTRC-HEATED GRID TAR EVOLUTION RANK EFFECTS:
ZERO HOLD TIME DATA

	A	B	C	D	E	F	G	H	I	J	K
1	Coal ID	Run ID	d1-d2, microns	Atmos.	Sample Size(mg)	Prog. T-asymp (C)	Prog. T-Dot(C/sec)	Prog. Max I, ampe	Prog. Max Volts	Prog. Max. Pow. watts	Prog. Hold (sec)
52	PSOC 1451D	458	63-75	Helium	24.2	520	1000				0
53	PSOC 1451D	457	63-75	Helium	35	710	1000				0
54	PSOC 1451D	454	63-75	Helium	18.4	730	1000				0
55	PSOC 1451D	453	63-75	Helium		563	1000				0
56	PSOC 1451D	447	63-75	Helium	19.1	600	1000				0
57	PSOC 1451D	455	63-75	Helium	10.4	700	1000				0
58	PSOC 1451D	451	63-75	Helium	8.6	670	1000				0
59	PSOC 1451D	452	63-75	Helium	8.9	700	1000				0
60	PSOC 1451D	450	63-75	Helium		577	1000				0
61	PSOC 1451D	459	63-75	Helium	25.5	990	1000				0
62	PSOC 1451D	456	63-75	Helium		609	1000				0
63	PSOC 1451D	446	63-75	Helium	17.5	1000	1000				0
64	PSOC 1451D	445	63-75	Helium	19.8	950	1000				0
65	PSOC 1451D	455	63-75	Helium		718	1000				0
66	PSOC 1451D	448	63-75	Helium	19.4	960	1000				0
67	PSOC 1451D	449	63-75	Helium	19.8	900	1000				0
68	PSOC 1451D	450	63-75	Helium	9.2	850	1000				0
69											
70	PSOC 1516D	27	63-75	Helium	11.9	457.7	1045.6	32.2	10.5	338	0
71	PSOC 1516D	33	63-75	Helium	14.3	440.8	1007	29.3	8.3	243	0
72	PSOC 1516D	29	63-75	Helium	11.9	552.4	1024.9	34.6	11	381	0
73	PSOC 1516D	28	63-75	Helium	12.4	501.4	1024.7	33.8	10.7	362	0
74	PSOC 1516D	30	63-75	Helium	14.1	589.6	1000.4	32.4	11	356	0
75	PSOC 1516D	32	63-75	Helium	17	691.3	1009.8	33.3	11	366	0
76	PSOC 1516D	31	63-75	Helium	15.4	652.1	1018.3	34	12.6	428	0
77	PSOC 1516D	31	63-75	Helium	10.9	785.5	1309.8	40.5	13	527	0
78	PSOC 1516D	32	63-75	Helium	10.8	855.8	1316.2	39.2	12.5	490	0
79											
80	PSOC 1468D	33	63-75	Helium	14.3	440.8	1007	29.3	8.3	243	0
81	PSOC 1468D	34	63-75	Helium	13.2	517	1064.7	35.2	10.6	373	0
82	PSOC 1468D	35	63-75	Helium	12.4	542.2	1068.1	32.6	10.4	330	0
83	PSOC 1468D	36	63-75	Helium	14	610.7	1053.8	35.8	11.5	412	0
84	PSOC 1468D	37	63-75	Helium	15.2	641.8	1001.3	32.3	10.7	346	0
85	PSOC 1468D	38	63-75	Helium	14.7	707.1	1035.2	34.3	11.4	391	0
86	PSOC 1468D	39	63-75	Helium	14	861.9	1292.7	37.7	12.3	464	0
87	PSOC 1468D	34	63-75	Helium	12.3	944.1	1320.1	44.1	15.2	670	0

TABLE II (continued)
UTRC-HEATED GRID TAR EVOLUTION RANK EFFECTS:
ZERO HOLD TIME DATA

A	B	L	M	N	O	P	Q	R	S	T
Coil I.D.	Run I.D.	Run T-Asym (C)	Run T-dec(C/sec)	Run Max Lamp	Run Max Vols	Run Max Pow, watts	Run Hold (sec)	% Char, Run	% Tar, Run	% Vol, Run
1										
3	PSOC 1443D	1	299.2	31.8	10.6	337	0	92.8	4.6	7.2
4	PSOC 1443D	3	251.8	32.6	11.5	375	0	90.7	6	9.3
5	PSOC 1443D	2	295.9	33.3	11.3	376	0	88.4	7.2	11.9
6	PSOC 1443D	4	476.9	35.8	12.9	482	0	90.4	10.3	16.6
7	PSOC 1443D	5	551.5	40.7	14.5	590	0	59.6	12.5	41.4
8	PSOC 1443D	6	590.1	41.7	14.7	613	0	55.3	13.8	44.7
9	PSOC 1443D	8	712.3	42.9	13.1	562	0	52.2	13.3	47.8
10	PSOC 1443D	9	960.7	45.1	14.1	636	0	48.4	14.5	51.6
11										
12	PSOC 1520D	7	245.1	32	10.7	342	0	87.3	8.6	12.1
13	PSOC 1520D	8	403	35.4	11.4	404	0	83.6	11.4	16.4
14	PSOC 1520D	9	410.9	38	13.4	509	0	83.1	9.5	16.9
15	PSOC 1520D	13	453.3	33.5	12.1	405	0	78.0	15.6	21.1
16	PSOC 1520D	10	479.9	39.5	13.1	517	0	78.1	18	21.9
17	PSOC 1520D	12	497.8	37.7	13.3	501	0	78.1	16.1	21.9
18	PSOC 1520D	11	673.1	37.5	13.3	486	0	87.7	20	32.3
19	PSOC 1520D	8	860.2	45.2	14.9	673	0	35.8	13.2	64.2
20										
21	PSOC 1493D	20	242.8	33.1	10.8	357	0	96.3	1.8	3.7
22	PSOC 1493D	14	304.7	31.7	10.4	339	0	92.1	2.1	7.9
23	PSOC 1493D	21	331.2	33.8	10.5	355	0	94.9	1.5	5.1
24	PSOC 1493D	17	364.5	33.1	11.4	377	0	93.8	4.3	6.2
25	PSOC 1493D	15	370.1	33.1	11.4	377	0	93.1	2.8	6.9
26	PSOC 1493D	16	372.3	35.2	11.2	394	0	95	3.1	5
27	PSOC 1493D	82	381.2	41	12.2	500	0	88.1	4.4	11.9
28	PSOC 1493D	19	445.9	34.9	11.6	405	0	93.4	3.9	6.6
29	PSOC 1493D	18	449.1	35	11.8	413	0	89	4.8	11
30	PSOC 1493D	78	461.3	39.9	12.1	483	0	84.7	4.5	15.3
31	PSOC 1493D	81	555	36.8	12.7	505	0	73.1	8.7	20.9
32	PSOC 1493D	80	595.1	42.1	12.7	535	0	78.2	8.4	21.8
33	PSOC 1493D	78	627.6	39.9	13.1	523	0	79.3	8.3	20.7
34	PSOC 1493D	79	757.5	43.8	14.7	644	0	83	9.6	37
35	PSOC 1493D	77	774.1	43	13.3	572	0	78.5	7.5	21.5
36										
37	PSOC 1499D	21	358	10.6	32.1	340	0	94.9	1.5	5.1
38	PSOC 1499D	22	332.3	33.1	10.9	381	0	96.3	1.8	3.7
39	PSOC 1499D	23	378.1	31.9	10.5	335	0	94.8	2.8	5.2
40	PSOC 1499D	26	411.7	35.6	12.1	431	0	93.9	3.1	6.1
41	PSOC 1499D	27	412.6	32.8	10.5	344	0	92.4	2.5	7.6
42	PSOC 1499D	24	423.3	33.4	10.9	384	0	93.2	3	6.8
43	PSOC 1499D	25	507.6	38.8	13.1	508	0	87.8	8.6	12.4
44	PSOC 1499D	83	476	43.1	13.5	582	0	83.3	8.3	16.7
45	PSOC 1499D	84	660.8	14	45.8	841	0	69.5	12.2	30.5
46	PSOC 1499D	85	821.8	13.9	44.5	819	0	64.4	20.5	35.6
47	PSOC 1499D	86	659.9	12.6	41.4	530	0	73.9	11.2	26.1
48	PSOC 1499D	87	602.5	12.7	40.8	518	0	74.8	11.8	25.2
49										
50	PSOC 1451D	4XX	350				0	98	1	2
51	PSOC 1451D	456	470				0	94	2.2	6

TABLE II (continued)
UTRC-HEATED GRID TAR EVOLUTION RANK EFFECTS:
ZERO HOLD TIME DATA

	A	B	L	M	N	O	P	Q	R	S	T
1	Coal ID	Run ID	Run T-Avgm (C)	Run T-dec(C/sec)	Run Max Lamp	Run Max Vols	Run Max Pow, watts	Run Hold (sec)	% Char, Raw	% Tar, Raw	% Vol., Raw
82	PSOC 1451D	458	506	1000				0	91.7	6.6	8.3
83	PSOC 1451D	457	506	1000				0	91.4	5.4	8.6
84	PSOC 1451D	444	533	1000				0	90.8	6	9.2
85	PSOC 1451D	4XX	563	1000				0		13	
86	PSOC 1451D	447	565	1000				0	83.2	9.4	16.8
87	PSOC 1451D	455	566	1000				0	83.7	11.5	16.3
88	PSOC 1451D	451	575	1000	34.7	10.3		0	78.1	10.5	20.8
89	PSOC 1451D	452	575	1000	33.5	11.1		0	74.2	13.5	25.8
90	PSOC 1451D	4XX	577	1000				0		12.5	
91	PSOC 1451D	459	600	1000				0	65.9	20.8	34.1
92	PSOC 1451D	4XX	609	1000				0		18	
93	PSOC 1451D	448	620	1000	41.9	13.7		0	60.6	22.3	39.4
94	PSOC 1451D	445	677	1000				0	51.8	23.2	38.4
95	PSOC 1451D	4XX	718	1000				0		24.6	
96	PSOC 1451D	448	737	1000	37.9	12.7		0	58.2	24.2	41.8
97	PSOC 1451D	448	757	1000	37.1	11.7		0	65.2	22.7	34.8
98	PSOC 1451D	450	777	1000				6	62	21.7	58
99											
70	PSOC 1518D	27	412.8	943.5	32.8	10.5	344	0	92.4	2.5	7.6
71	PSOC 1518D	33	286	596.4	28.4	8.3	236	0	97.2	0.7	2.8
72	PSOC 1518D	29	377.5	708.8	34.4	11	378	0	95	3.2	5
73	PSOC 1518D	28	383.3	807.2	33.9	10.7	363	0	95.2	1.6	4.8
74	PSOC 1518D	30	441.6	751.7	32.3	10.9	352	0	92.1	2.8	7.9
75	PSOC 1518D	32	492.1	710.8	34.3	11	377	0	91.8	2.9	8.2
76	PSOC 1518D	31	520.6	819.6	35.1	12.7	446	0	90.9	3.2	9.1
77	PSOC 1518D	91	680.2	1146.3	42.5	12.9	548	0	86.2	3.7	13.8
78	PSOC 1518D	92	672.2	1024.7	39.9	12.5	499	0	90.7	3.7	9.3
79											
80	PSOC 1488D	33	266	596.4	28.4	8.3	236	0	97.2	0.7	2.8
81	PSOC 1488D	34	412.4	852.9	35.1	10.5	389	0	97	7.6	3
82	PSOC 1488D	35	417.9	781.7	33.2	10.4	345	0	97.5	0.81	2.5
83	PSOC 1488D	38	434.2	739.7	35.9	11.3	406	0	98.4	1.4	3.6
84	PSOC 1488D	37	513	907.4	33.8	10.8	365	0	95.4	1.97	4.6
85	PSOC 1488D	38	583.9	844.3	35.3	11.4	402	0	95.2	2	4.8
86	PSOC 1488D	93	781.6	1148.5	40	12.2	488	0	95	1.4	5
87	PSOC 1488D	94	759	1059.7	46.1	15.1	696	0	95.9	1.8	4.1

FIGURE 1 EXAMPLE OF UTRC-HG ZHT BLANK SCREEN SUMMARY DATA TABLE

HEATED GRID 5
Thursday, July 12, 1990 3:38 PM
Front Panel

HEATED GRID 5
Thursday, July 12, 1990 3:38 PM

FIGURE 2
EXAMPLE OF UTRC-HG ZHT RUN SUMMARY DATA TABLE

HEATED GRID 5
Thursday, July 12, 1990 3:38 PM

HEATED GRID 5
Thursday, July 12, 1990 3:38 PM

Front Panel

FIGURE 3
IR ABSORPTION SPECTRA
PSOC 1520D - RUN 80

PSOC 1443D TAR YIELDS
 Open = 10 sec hold; Closed = 0 sec hold

FIGURE 4

PSOC 1520D TAR YIELDS
 Open = 10 sec hold; Closed = 0 sec hold

FIGURE 5

PSOC 1499D TAR YIELDS
OPEN = 10 SEC HOLD; CLOSED = 0 SEC HOLD

FIGURE 6

PSOC 1493D TAR YIELDS
Open = 10 sec hold; Closed = 0 sec hold

FIGURE 7

PSOC 1516D TAR YIELDS
Open = 10 sec hold; Closed = 0 sec hold

FIGURE 8

PSOC 1488D TAR YIELDS
Open = 10 sec hold; Closed = 0 sec hold

FIGURE 9

FIGURE 10

Zero Hold Time Tar Evolution Comparison
Non-HVA Bituminous Coals
Heated Grid; 63-75 Microns; 1 Atmos. He

FIGURE 11

Zero Hold Time Char Evolution Comparison
Non-HVA Bituminous Coals
Heated Grid; 63-75 Microns; 1 Atmos. He

FIGURE 12

**ZHT Char and Tar Yield Comparison
PSOC 1499D AND PSOC 1451D
Triangles= 1499D; Squares = 1451D**

FIGURE 13

ZHT Char and Tar Yield Comparison
PSOC 1493D AND PSOC 1451D
Triangles= 1493D; Squares = 1451D

END

DATE FILMED

02 / 12 / 91