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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 6: The Hanna IVA and IVB Field Test

Research Report

August 1985

U. S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
MORGANTOWN ENERGY TECHNOLOGY CENTER
MORGANTOWN, WEST VIRGINIA

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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 6: The Hanna ~~IVA~~ and ~~IVB~~ Field Test

Research Report

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PREFACE

This report is part of a seven-volume series on the Hanna, Wyoming, underground coal gasification field tests. Volume 1 is a summary of the project and each of Volumes 2 through 6 describes a particular test. Volume 7 is a compilation of all the data for the tests in Volumes 2 through 6. The reports in this series include:

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 1: General Information and Executive Summary (DE85013695).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 2: The Hanna I Field Test (DE85013696).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 3: The Hanna II, Phase I Field Test (DE85013697).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 4: The Hanna II, Phases II and III Field Test (DE85013698).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 5: The Hanna III Field Test (DE85013699).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 6: The Hanna IVA and IVB Field Test (DE85013700).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 7: Appendices (DE85013701).

These reports are available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22161.

Volume 6: Hanna IVA and IVB

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HANNA IVA and IVB

I. INTRODUCTION

The Hanna IV test was designed as the first UCG test using commercial well spacings of 100 and 150 feet between well pairs in a linear 3-well pattern. The test was initiated in late 1977 and completed in late 1979. This long duration was due to unfavorable geologic conditions (faulting) which could not be successfully overcome resulting in the test being split into Hanna IVA and Hanna IVB with about one year between the conduct of each.

II. SPECIFIC SITE SELECTION AND CHARACTERISTICS

Hanna IV was located at greater depth to overcome the water deficiency problems encountered during Hanna III and north of the line connecting Hanna I and Hanna II to minimize the potential for air leakage to either of these two sites. The location north rather than south of the line was due to the flatter topography thus requiring for less leveling and grading and making surface facility installation easier. The much increased piping size and, therefore, valve sizes necessitated the use of heavy equipment to install the surface piping system. Flat terrain was essential for shortening the amount of time needed and enhancing the safety of the personnel involved.

The well pattern as it eventually evolved during the course of Hanna IVA and IVB is shown in Figure 1. Additions over the original well pattern were the following wells: Wells 5 and 6 during Hanna IVA as additional process wells at a spacing of 20 feet with well 5 10 feet from Well 1; Wells 7 and 8 as process wells during Hanna IVB located at the midpoints of the 2-4 and 4-3 lines; and Wells NN, PP, RR, SS, TT, and ZZ as

Figure 1. Hanna IVA and IVB Well Pattern

additional instrumentation wells with ZZ devoted to subsidence monitoring.

The instrument wells included in the pattern were installed by Sandia National Laboratory. The downhole instrumentation installed in each well is shown in Table 1. No downhole instrumentation is shown for Wells Z and ZZ because they were devoted solely to subsidence monitoring.

The procedure for drilling process wells was as follows: Wells 1 and 3-A 6-7/8" pilot hole was drilled with air or air/water/foam from the surface to 30 feet below the coal seam. Openhole logs were then run. The hole was reamed to 18" using a 6-7/8" pilot bit run five feet below the reamer. This was done to minimize hole drift during drilling. Reaming stopped six feet from the bottom of the seam. The casing was run with a float shoe and five centralizers and positioned on the ledge at the bottom of the 18" hole. Prior to cementing, circulation was established with water, and one gauge volume (the volume of the open hole to total depth) of mud-flush was pumped through to clean the hole. The hole was then cemented using wooden plugs both top and bottom.

Well 2-A 6-7/8" pilot hole was drilled with air or air/water/foam to a point 10 feet above the coal seam. Cores were taken from 10 feet above to three feet below the coal. The coal cores were sent to CT&E for proximate and ultimate analysis. The cored interval was then drilled out to 6-7/8". The hole was then reamed to 18" to within six feet of the bottom of the coal. Casing was set and mud flush was run as described previously. A special high temperature cement consisting of 50 percent calcium aluminate and 50 percent fly ash was used in this well to provide maximum survivability due to its extended usage both as a production and injection well.

Well 4-A 6-7/8" hole was drilled from the surface to 35 feet below the coal. 4" A-120 line pipe was set and cemented in place. the casing was

Table 1. Downhole Instrumentation Fielded
for the Hanna IV UCG Experiment

<u>Well #</u>	<u>Thermocouples</u>	<u>Potential Probes</u>	<u>Geophones</u>	<u>Gas Sampling Canisters</u>	<u>Pressure Transducers</u>
A	12	1	4	3	3
B	12	1	-	3	3
C	12	1	-	3	3
D	12	1	-	-	-
E	12	1	-	3	3
F	12	1	3	3	3
G	12	1	-	-	-
H	12	1	-	3	3
J	12	1	4	3	3
K	12	1	-	3	3
L	12	1	4	3	3
M	12	1	-	3	3
N	12	1	-	3	3
P	12	1	-	3	3
R	12	1	-	3	3
S	12	1	4	-	-
T	12	1	4	3	3
U	12	1	-	-	-
AA	12	1	-	-	-
BB	12	1	4	3	3
CC	12	1	-	3	3
DD	12	1	-	3	3
EE	12	1	-	3	3
FF	12	1	4	-	-
GG	12	1	-	-	-
HH	12	1	-	3	3
JJ	12	1	-	3	3
KK	12	1	-	-	-
LL	12	1	-	-	-
MM	12	1	-	-	-
NN	16	1	4	3	3
PP	16	16	4	3	3
RR	16	15	4	-	-
SS	16	1	4	3	3
TT	16	1	-	3	3

then perforated over a 6 foot interval, the bottom six feet of the coal, with 4 shots per foot.

Table 2 shows a summary of the Hanna IV drilling. The available logs are included in the appendix. Ultimate and proximate analyses of the core taken from Well 2 are given in Table 3.

As can be seen from Table 2, the coal seam thickness varied from 26 to 30.5 feet at the Hanna IV site and the depth to the top of the coal varied from 307 to 335 feet. The dip angle at this site was 6.4° to the northeast.

III. TEST OBJECTIVES

The objectives set for Hanna IV were the following:

Determine relationship among injection rate, well separation and sweep width.

Maintain constant heating value by monitoring water content in production stream.

Control water content in the product gas stream by varying the blast rate (injection rate) and reservoir pressure thereby maintaining a relatively constant water/air ratio.

Define void shape and advancing front inclination during the life of a system (for process modeling studies).

Determine pressure gradients within the system during gasification and linkage (for process modeling studies).

Determine gas compositional gradients within the seam during gasification and linkage (for modeling studies).

Table 2. Hanna IV Process Well Completion Data

Well No.	1	2	3	4	5	6	7	8
Drilling Fluid	Mud	Mud	Mud	Air/foam	Air/foam	Air/foam	Air/foam	Air/foam
Top of Coal (ft)	307	312	335	328	307	306.5	318	325
Bottom of Coal (ft)	333	342.5	362	356	333	332.5	346	355
Coal Thickness (ft)	26	30.5	27	28	26	26	28	30
Casing Seat (ft)	327	336.5	356	365	327	326.5	340	349
Casing Size (In. ID)	12	12	12	4	6	6	12	6
Hole Size Drilled Below Casing (In.)	12	12	12	4	5&7/8	5&7/8	12	5&7/8
Total Depth (ft)	353	363	380	380	360	360	380	380
Cement Type	API Class G, 40% Silica Flour	Calcium- Aluminate- Fly Ash, 50 - 50	----- Rest the same as Well 1 -----					

Table 3. Summary of As Received Coal Analyses
from the Hanna IV Site

<u>Component</u>	<u>Wt. %</u>
Moisture	8.55
Ash	27.48
Volatiles	33.21
Fixed Carbon	30.76
Sulfur	0.75
Carbon	47.48
Hydrogen	3.74
Nitrogen	1.15
Chlorine	0
Oxygen (By difference)	10.84
Heating Value	8286 Btu/lb

Demonstrate relaying the process from one 2-well system to another.

Monitor product gas stream for particulates and trace components over total test duration.

IV. FACILITY DESCRIPTION

The surface piping and facilities layout for Hanna IV A and IV B are shown in Figures 2 and 3. Buildings used during Hanna II, phases II and III, and Hanna III to house the data acquisition system, office space, and maintenance facilities were also used during Hanna IVA and IVB. The gas analysis and flow measurement facilities were located in a building adjacent to the main gas production header immediately upstream from the flares.

Because of the high volumes of low pressure air required for this experiment, the decision was made to change from the IR-D2000 diesel powered screw-type air compressors used in past experiments to electric powered centrifugal compressors. The decision was also made to go to a complete turn key air supply contract to eliminate demands on manpower for compressor maintenance. Ingersoll-Rand was the successful bidder and offered three C-70 Centac compressors. These compressors (after derating for altitude) each supplied 6,000 scfm of 100 psia air for the gasification phase. The boosters, two IR-LR-100's were each capable of 500 scfm at 500 psig with air supplied to the boosters at 100 psig from the Centac's or from a diesel compressor. The boosters were propane-powered eliminating any concern for power failures during the linkage phases. Several diesel-powered compressors used in previous tests were also available at the site for use in an emergency situation.

The decision to use electric air compressors necessitated the acquisition of additional power for the Hanna site. The only power available was from a 34,500 volt feeder line. It was impossible to

Figure 2. Schematic of Hanna IVA Surface Facilities

Figure 3. Schematic of Hanna IVB Surface Facilities

secure additional power from this line as attempts had been made at regular intervals for the past three years, to no avail. The only power available in the area was located at a substation about a mile north of the site. Pacific Power and Light Company agreed to make available 115,000 volt power from this substation for line construction and removal costs.

To transform this 115,000 volt power to 4160 volt power for the compressors required construction of a minor substation at the Hanna site. Three surplus transformers were secured from the Bureau of Reclamation in Casper at no cost. These transformers were capable of supplying 3.6Mw of power and were upgraded to 4.1Mw with the addition of oil cooling fans. The maximum projected power requirements were in the coldest part of the year. The substation was used only to supply the needs of the air compression facility, substation lighting and the Hanna IV building used for production metering and gas analysis.

Based on past experience, the surface piping for Hanna IV was increased in size from 4" and 6" to 10" and 18". During the Hanna II and III tests, pipe and casing were undersized causing erosion and high frictional pressure loss through the piping system. The air injection supply piping was increased to Schedule 40, 10" line pipe with an A-106 material specification and a wall thickness of 0.365". This pipe has an allowable working pressure of 930 psig at 450° F.

The casing and line pipe from the well head to the 18" production header were nominal 12" I.D. The casing was 12" I.D. K-55 while the line pipe was A-106. The line pipe had a 0.375 inch wall thickness with an allowable working pressure of 400 psig at 950°F. The production header was nominal 18" line pipe with an A-106 material specification and a 0.375 wall thickness. The production header and meter run had an allowable working pressure of 480 psig and 600°F.

The product gas flowed from the production header into one of four flare stacks. These four stacks ranged in capacity from 4000 scfm to 36,000 scfm. the smallest of these stacks was air blown for combusting small volumes of wet gas (usually during linkage) and the other three were used as the production rate increased. One of the large stacks was refractory lined for use during periods when the product gas moisture content was excessive (more than 30 to 40 percent).

A 10" production line was installed on the injection side of the well heads. This line was to be used as an emergency vent should the 18" production line become plugged with particulate or hydrocarbon liquids.

This plumbing system as designed afforded a maximum flexibility in that any well could be used for high pressure injection, low pressure injection or production at any time for any one event. Low pressure injection air was metered through a 10" Daniel internal bypass orifice meter. The differential pressure output from the transducers was fed not only to the computer but to an analog Fisher flow controller. This was the primary control loop with the option of either manual, automatic or supervisory computer control. In this way very accurate control (as experienced during Hanna III with $\pm 1.5\%$ variance while injecting 3500 scfm) was obtained with maximum flexibility available through the computer software. This type of system was also used for high pressure flow control and production back pressure control with the static pressure being the input signal on the production line rather than differential pressure, which was the control variable for injection. The production gas was metered through either a 6" orifice meter or an 18" orifice meter depending on the amount of production. The high pressure air was metered through a 2" orifice meter. The 2" high pressure air injection line was heat traced to prevent plugging due to ice formation.

One of the major problems encountered during the Hanna UCG test series was locating a valve capable of positive shut off after exposure to the

product gas stream. Because of the severe conditions (600 to 800°F with the presence of tars, particulates, and corrosive trace components), until the Hanna III test a suitable valve was not found. During Hanna III a 6" WKM Posi-seal valve was tested that closed tightly after exposure to 1150°F and after completion of the test. All valves with the exception of the control valves on Hanna IV were WKM Posi-seal valves. The injection control valves were Fisher control valves with electro-pneumatic positioners. The production valves for backpressure controls were Dravo butterfly valves.

The configuration of the Hanna IV data acquisition and control system is shown in Figure 4. The system fulfilled three needs for the Hanna IV test: 1. Data collection; 2. Real time analysis; 3. Automated control. Every five minutes the system read all analog signals (from thermocouples and transducers), converted these signals to temperature or pressure, calculated flows and stored this information in the "COMMON" area of the CPU. At the end of the hour the computer calculated an hourly average which was dumped to a line printer for back-up and to the disc for later access.

For real time analysis of the data collected several user programs were available to the on-site operators. The programs were varied and flexible enough to allow identification of trends and transitions or analysis of efficiencies (material balance and energy balance).

The variable parameters, flow rate and pressure, were automatically controlled by the computer. The operator was able to enter a set point into the computer and, as each 5 minute data reading was taken, corrections were sent to control valves to maintain the desired set point. In addition, the computer controlled the gas chromatograph analyzing the production stream, automatically cycled the gas cleanup system, and calculated the results for dry gas/tar/water ratios.

Figure 4. Hanna IV Data Acquisition System Configuration.

The monitoring of the water content in the production stream was considered a very important part of the test. The basic system used to do this is shown in Figure 5. It consisted of a condenser to cool the small sample stream (about 3 scfm) to 33-38°F thereby condensing most of the tar and water in the sample stream. The relatively "dry" gas then passed through a mass flow meter and finally to the gas chromatograph. The liquids (tar and water) flowed into a sump which was drained into a container on a balance. The balance, flow meter and probes for determining liquid levels were interfaced into the data acquisition system which determined mass of tar, mass of water and volume of gas during a collection period. Then a ratio of tar/water/gas in weight percent was calculated. The tar/water/gas analysis system also provided a relatively clean gas sample for analysis in the gas chromatograph. These analyzed samples not only provided data on production parameters but also environmental data for determining the potential total impact of UCG.

All Hanna IV gas analyses were done on HP 5840A gas chromatographs interfaced to the data acquisition system (Figure 6). The product gas stream was sampled approximately once every 30 minutes. Data were stored on the disc and were accessible by user programs (hardcopy, CRT display, energy balance calculations, material balance calculations, plotting).

The following components were included in the analysis: Hydrogen, Nitrogen, Oxygen, Argon, Carbon Monoxide, Methane, Carbon Dioxide, Ethylene, Ethane, Hydrogen Sulfide, Propylene, Propane, iso-Butane and n-Butane.

The HP 5840A gas chromatograph was equipped with a TC detector, automatic gas sampling loop and a liquid CO₂ cryogenic oven. Analysis was done using a 20" x 1/8" SS column packed with Johns Manville Chromosorb 102 packing. A mixed carrier gas (7% Hydrogen in Helium) was used to provide a linear response for Hydrogen up to about 80 mole

Figure 5. Gas Clean Up System for Hanna IV.

COMPONENTS IN ANALYSIS INCLUDE THE FOLLOWING:

HYDROGEN, NITROGEN, OXYGEN, ARGON, CARBON MONOXIDE, METHANE, CARBON DIOXIDE, ETHYLENE, ETHANE, HYDROGEN SULFIDE, PROPYLENE, PROPANE, ISO-BUTANE AND N-BUTANE

Figure 6. Hanna IV Gas Analysis System

percent. A carrier gas flow rate of 30 ml/min at -50° C, temperature increase of 30°C/min to 225°C and isothermal for the remainder of the analysis. Detection limits were 0.02 mole percent for all components except Hydrogen and Hydrogen Sulfide which have much higher response factors and detection limits of 0.05 mole percent. Interface to the data acquisition system was through an ASC II interface card (18833A) allowing two-way communication between GC and computer.

V. PRE-OPERATION TESTS

The primary testing prior to initiation of Hanna IVA consisted of groundwater pumping tests at Wells 1 through 4 and air acceptance testing. The pump tests were designed to determine that sufficient groundwater was available at the test site such that the deficiency encountered during the Hanna III test would not recur. These short-term tests also were used as an indication of any restrictions existing in any of the wells due to cement or drilling fluid intrusion into the coal seam. The tests indicated that sufficient groundwater was available at the site. No restrictions were evident from the pump tests.

Air acceptance testing was conducted in November 1977. Injection of about 600 scfm at 260 psig was initiated at Well 1. Wells 2 and 4 were shut in and Well 3 was open to production. Within 8 hours production of about 300 scfm occurred at Well 3. These results greatly exceeded expectations.

The reservoir was bled down by continuing to produce Well 3 after terminating air injection. Well 3 was then shut in and Well 2 opened to production. Injection of about 450 scfm at 260 psig was started at Well 1. After 24 hours production at Well 2 was about 30 to 40 scfm. Injection was then switched to Well 2 with production from Well 1. About 500 scfm at 260 psig was injected and about 250 scfm was produced from Well 1. This check-valve like behavior around Well 2 was interpreted as a possible restriction around the base of the wellbore.

To eliminate this possibility Well 2 was subjected to an acidizing treatment. Upon repeating the air acceptance tests, no change was noted. As later became evident during linking operations between Wells 1 and 2, two different pathways of air movement were involved depending upon the injection point.

VI. TEST OPERATIONS SUMMARY

A. Significant Events Summary

December 4-6, 1977 (JD 338-340): ignition attempted at Well 1; high water influx rate quenched fire 3 times.

December 7- January 15, 1978 (JD 340-15): Ignition attempts at Well 2; air flow from Well 1 to Well 2 too low to sustain fire leading to quenching by water influx. Well 2 converted to a borehole producer with air injection down casing and production from 2" dewatering line in well; induced thermal stress resulted in casing separation at top of coal seam as detected with a downhole video camera.

January 15-19 (JD 15-19): Casing perforated 5 feet above and below separation point and cement squeeze job completed; high pressure air injection with packer below perforated area showed competent squeeze job with no air leakage from casing.

January 19-22 (JD 19-22): Ignition achieved in Well 2.

January 22-March 16 (JD 22-75): Reverse combustion linking operations from Well 2 to Well 1; link not completed. Thermal responses seen at Wells AA, HH, G, H, N, and C during this period.

March 16 (JD 75): High pressure air injection switched to Well 2 with production from Well 1.

March 17-23 (JD 76-82): High pressure (up to 450 psig) forward combustion link completed from Well 2 to Well 1. Thermal responses observed in Wells AA, HH, MM, NN, P, S, L, and K.

March 23-26 (JD 82-85): Gasification from Well 1 to Well 2.

April 1-10 (JD 91-100): Wells 5 and 6 drilled and completed.

April 11 (JD 101): Wells 5 and 1 linked by hydraulic fracturing.

April 12-17 (JD 102-107): Reverse combustion linking from Well 6 to Well 5.

April 18 - June 4 (JD 103-150): Gasification from Well 6 to Well 2.

June 4 (JD 150): Hanna IVA terminated.

June 4, 1978 - April 19, 1979: Drilling Wells 7 and 8 and 6 instrument wells plus modifying site for Hanna IVB

April 20, 1979 (JD 110): Ignition at Well 7.

April 20 - July 12 (JD 110-193): Reverse combustion linking from Well 7 to Well 3.

July 28 - August 4 (JD 209-216): Gasification from Well 3 to Well 7.

September 3-19 (JD 246-262): Gasification from Well 3 to Well 7.

September 19 (JD 262): Hanna IVB terminated.

B. Average Operating Parameters

The results for Hanna IVA and IVB are shown in Table 4. Plots of the various parameters versus time are shown in Figures 7 through 19.

C. Tar and Water Production

Due to the many difficulties encountered during Hanna IVA and IVB, no reliable measurements of tar and water content were obtained using the sampling system designed for this task.

As part of a contract to monitor the product gas for trace constituents and particulate matter, Radian Corp. obtained moisture and tar content of the product gas during both Hanna IVA and IVB. Those data are shown in Tables 5 and 6, respectively.

D. Instrumentation Responses

The downhole thermocouple responses during Hanna IVA and IVB are shown in Tables 7 and 8, respectively.

E. Product Gas Characterization

Radian Corp. was contracted to monitor the product gas for a number of trace constituents and to determine particulate loading and size distribution. The results for Hanna IVA and IVB are given in Tables 9 through 13.

VII. POST TEST ACTIVITY

The data from groundwater sampling and analyses are presented in the appendix to the report entitled "General Information and Executive Summary".

Table 4. Hanna IVA & IVB Average Operating Parameters

	<u>Hanna IVA</u>	<u>Hanna IVB</u>
Average Injection Rate (MMscfd)	4.0	2.3
Average Production Rate (MMscfd)	6.2	3.8
Average Injection Pressure (Psig)	80	94
Average Production Pressure (Psig)	68	57
Average Heating Value (Btu/scf)	105	135
Average Dry Gas Composition (Mole %):		
<u>Component</u>		
H ₂	11.75	16.27
CO	9.29	10.27
CO ₂	15.71	15.63
CH ₄	2.96	4.18
N ₂	59.22	52.52
Ar	0.73	0.59
C ₂ - C ₄ 's	0.25	0.39
Thermal Efficiency (%)	75	89
Total Coal Gasified (Tons)	3470	1120

Figure 7. Hanna IVA Injection and Production Flow Rates

Figure 8. Hanna IVA Injection Pressure

Figure 9. Hanna IVA Production Flow Temperature

Figure 10. Hanna IVA Product Gas Heating Value

Figure 11. Hanna IVA Product Gas Composition (Major Components)

Figure 12. Hanna IVA Product Gas Nitrogen Content

Figure 13. Hanna IVA Product Gas Composition (Minor Components)

Figure 14. Hanna IVB Injection and Production Flow Rates

Figure 15. Hanna IVB Injection and Production Flow Pressures

Figure 16. Hanna IVB Product Gas Heating Value

Figure 17. Hanna IVB Product Gas Nitrogen Content

Figure 18. Hanna IVB Product Gas Composition (Major Components)

Figure 19. Hanna IVB Product Gas Composition (Minor Components)

Table 5. Moisture and Tar Concentrations in the
Product Gas During Hanna IVA

<u>Date</u>	<u>Moisture</u> <u>(% v/v)</u>	<u>Tar</u> [*] <u>(gm/scf)</u>
4/23/78	32.3	0.50
4/24	26.6	-
4/25	25.6	0.27
4/26	18.1	0.11
4/27	14.8	0.14
5/2	17.4	0.06
5/3	17.6	-
5/4	14.6	-
5/9	19.7	-
5/10	21.4	-
5/16	20.5	-
5/17	22.3	-
5/18	23.2	-
5/23	22.2	-
5/24	21.8	-
5/25	20.8	-
5/29	19.3	-
5/30	20.7	-
5/31	19.7	-

* Concentration on a dry gas basis

Table 6. Moisture and Tar Concentrations in the
Product Gas During Hanna IVB

<u>Date</u>	<u>Moisture</u> <u>(% v/v)</u>	<u>Tar</u> [*] <u>(gm/scf)</u>
9/4/79	11.5	0.073
9/7	8.3	0.189
9/10	11.7	0.184
9/13	10.2	0.164
9/14	18.4	0.134

*Concentration on a dry gas basis

Table 7. Thermocouple Responses During Hanna IVA

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp. (°F)
A	0.0	115	131	1174
	3.3	110	131	1180
	6.7	113	131	1180
	10.0	110	131	1193
	13.3	109	131	1221
	16.7	109	131	1190
	20.0	109	131	1210
	23.3	109	131	1180
	26.7	110	131	1135
	30.0	111	131	1215
	33.3	112	131	1090
	36.7	113	131	1115
B	All Levels	No Response		
C	0.0	No Response		
	3	77	80	90
	7	77	84	140
	10	64	81	170
	13	51	76	340
	17	51	77	365
	20	54	77	370
	23	57	78	245
	27	70	149	115
	30	97	141	100
	33	139	151	66
	37	143	144	60
D	All Levels	No Response		
E	0	123	125	1815
	3	123	125	1950
	7	123	125	1880
	10	123	125	2010
	13	123	125	1830
	17	122	124	2260
	20	121	125	1905
	23	120	125	1880
	27	111	125	1990
	30	96	125	1940
	33	88	125	1860
F	37	90	128	1700
	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	150	157	75
	23	146	155	210
	27	137	154	315
	30	139	154	235
	33	133	155	210
	37	134	155	195

Table 7 (Cont'd)

Well	Level (ft. above coal floor)	Initial Response	Max. Response	
		(Julian Day)	Julian Day	Temp (°F)
G	0	22	23	145
	3	22	23	140
	7	22	23	150
	10	22	23	145
	13	22	23	140
	17	22	23	155
	20	22	23	145
	23	22	23	150
	27	22	23	140
	30	22	23	145
	33	22	23	150
	37	22	23	140
H	0	77	79	90
	3	84	145	2060
	7	83	104	80
	10	69	109	95
	13	52	141	960
	17	49	151	220
	20	48	155	1140
	23	48	148	880
	27	66	140	520
	30	117	152	530
	33	130	153	490
	37	134	153	260
J	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	149	157	65
	23	135	157	85
	27	126	157	135
	30	124	155	190
	33	124	155	180
	37	125	154	140
K	0	81	82	980
	3	80	81	1260
	7	81	82	975
	10	81	82	1125
	13	80	82	1000
	17	81	82	1000
	20	81	82	1000
	23	81	81	1815
	27	69	82	1000
	30	64	81	1250
	33	69	82	965
	37	75	130	1015

Table 7 (Cont'd)

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp. (°F)
L	0	80	81	1505
	3	80	81	1550
	7	80	81	1440
	10	80	81	1480
	13	80	81	1460
	17	80	81	1430
	20	79	97	1953
	23	80	97	1730
	27	71	98	1580
	30	60	99	2505
	33	71	125	1515
	37	82	128	2920
M	0	76	128	1460
	3	60	128	1515
	7	77	128	1545
	10	90	128	1360
	13	96	128	1515
	17	105	128	1500
	20	123	128	1555
	23	117	128	2080
	27	90	131	1465
	30	78	131	1045
	33	78	137	1450
	37	88	138	1820
N	0	79	80	1495
	3	79	81	1840
	7	79	81	2130
	10	79	80	1565
	13	80	81	2080
	17	72	81	1835
	20	53	81	1920
	23	52	81	1610
	27	52	81	1975
	30	54	81	1950
	33	54	81	1595
	37	52	81	1310
P	0	80	84	1795
	3	80	84	1785
	7	80	84	1800
	10	80	84	1790
	13	80	84	1785
	17	80	84	1950
	20	80	84	1775
	23	75	84	1805
	27	55	84	1770
	30	75	84	1750
	33	83	131	1345
	37	83	140	395

Table 7 (Cont'd)

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp (°F)
R	0	No Response		
	3	"		
	7	"		
	10	150	157	84
	13	134	157	173
	17	126	155	215
	20	113	155	200
	23	120	155	220
	27	125	155	210
	30	133	155	210
	33	135	155	210
	37	135	154	190
S	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	129	157	62
	23	80	157	77
	27	76	78	155
	30	85	157	105
	33	134	157	100
	37	142	157	100
T	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	"		
	23	148	149	60
	27	144	150	85
	30	144	150	135
	33	143	157	95
	37	140	157	100
U AA	All Levels	No Response		
	0	76	80	1830
	3	77	80	1585
	7	78	80	1745
	10	62	80	1720
	13	47	80	1160
	17	75	80	1790
	20	59	80	1820
	23	38	79	1020
	27	31	80	1755
	30	38	80	1815
	33	44	81	1420
	37	47	131	930

Table 7. (Cont'd)

<u>Well</u>	<u>Level</u> <u>(ft. above coal floor)</u>	<u>Initial Response</u> <u>(Julian Day)</u>	<u>Max. Response</u>	
			<u>Julian Day</u>	<u>Temp. (°F)</u>
HH	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	109	141	65
	23	80	113	75
	27	63	84	110
	30	61	84	120
	33	73	96	85
	37	93	115	65
MM	0	No Response		
	3	"		
	7	"		
	10	"		
	13	"		
	17	"		
	20	"		
	23	114	155	65
	27	86	153	85
	30	76	76	195
	33	80	152	90
	37	97	149	80

Table 8. Thermocouple Responses During Hanna IVB

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp. (°C)
J	36	No Response		
	33	"		
	30	117	121	380
	27	No Response		
	23	"		
	20	"		
	17	"		
	13	"		
	10	"		
	7	"		
	3	"		
	0	"		
U	36	"		
	33	"		
	30	"		
	27	"		
	23	"		
	20	"		
	17	122	127	50
	13	121	123	50
	10	No Response		
	7	"		
	3	"		
	0	"		
BB	36	217	263	160
	33	216	262	390
	30	124	258	620
	27	117	258	500
	23	119	258	400
	20	119	226	80
	17	120	130	50
	13	121	130	40
	10	118	124	40
	7	118	121	30
	3	No Response		
	0	"		
CC	37	219	277	200
	34	218	261	480
	31	217	264	350
	27	217	264	430
	24	130	256	740
	21	128	256	740
	18	130	220	300
	14	141	256	100
	11	204	256	50
	8	No Response		
	4	"		
	1	"		
DD	36	137	254	1200
	33	134	248	840
	30	134	247	1000
	27	132	255	1000

Table 8 (Cont'd)

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp. (°C)
DD	23	131	190	720
	20	132	189	980
	17	135	180	1130
	13	120	160	930
	10	120	162	70
	7	No Response		
	3	"		
	0	"		
EE	36	214	214	30
	33	213	214	200
	30	197	214	860
	27	186	213	1200
	23	184	213	110
	20	184	213	60
	17	200	213	40
	13	173	213	60
	10	170	213	60
	7	170	213	60
	3	170	213	60
	0	165	213	40
FF	36	No Response		
	33	170	194	30
	30	138	194	60
	26	137	166	165
	23	138	165	230
	20	141	188	70
	17	180	187	30
	13	No Response		
	10	"		
	6	"		
	3	"		
	0	"		
GG	All Levels	No Response		
HH	36	"		
	33	230	277	40
	30	226	277	50
	27	230	277	30
	All Other Levels	No Response		
JJ	All Levels	"		
KK	All Levels	"		
LL	All Levels	"		
NN	33	165	255	1200
	31	165	254	730
	29	153	153	1000
	All Other Levels	No Response		
PP	33	264	277	30
	31	262	277	30
	29	262	277	30
	27	267	277	25
	All Other Levels	No Response		

Table 8 (Cont'd)

Well	Level (ft. above coal floor)	Initial Response (Julian Day)	Max. Response	
			Julian Day	Temp. (°C)
RR	53	250	277	25
	51	250	277	30
	49	245	277	40
	47	235	277	50
	45	228	277	60
	43	223	277	60
	41	221	277	80
	39	218	277	90
	37	217	277	100
	35	217	258	160
	33	216	216	530
	31	216	216	780
	29	216	216	700
	27	215	215	800
	25	169	215	800
	23	160	215	550
SS	33	218	257	560
	31	218	257	500
	29	220	258	1200
	27	220	253	80
	25	218	255	780
	23	217	256	600
	21	217	257	900
	19	222	257	120
	17	224	257	60
	15	257	257	40
TT	13	257	257	30
	All Other Levels	No Response		
	33	218	277	100
	31	220	270	120
	29	219	266	130
	27	218	260	200
	25	217	257	460
	23	166	270	340
	21	125	265	570
	19	122	265	500
	17	126	265	250
	15	126	277	100
	13	126	265	70
	11	155	277	70
	9	162	277	40
	7	155	277	40
	5	No Response		
	3	"		

Table 9. Trace Nitrogen and Sulfur Species, Hanna IVA*

<u>Date</u>	<u>NH₃</u>	<u>HCN</u>	<u>H₂S</u>	<u>COS</u>	<u>SO₂</u>	<u>CS₂</u>	<u>CH₃SH</u>
4/23/78	3500	14	-	-	-	-	-
4/24	3200	47	2000	320	<1	<1	30
4/25	-	-	1500	340	<1	<1	14
4/26	1800	22	1100	250	<1	<1	10
4/27	2000	34	3700	1000	<1	<1	<1
5/2	2500	38	1700	30	<1	<1	<1
5/3	2800	34	2000	52	<1	<1	<1
5/4	-	-	2000	56	<1	<1	<1
5/9	1700	32	1600	61	<1	3	4
5/10	-	-	1100	300	<1	14	6
5/11	-	-	940	380	<1	12	4
5/16	1300	16	6.5	55	<1	4	4
5/17	960	24	5	32	<1	3	2
5/18	-	-	190	49	<1	3	4
5/23	1140	28	<1	64	<1	3	1
5/24	2070	20	<1	85	<1	4	2
5/25	-	-	2.3	165	<1	4	4
5/29	1800	9	540	620	<1	3	4
5/30	1800	10	420	220	<1	4	3
5/31	-	-	420	390	<1	4	5

*Concentrations as ppm (v/v) on a dry gas basis

Table 10. Volatile Trace Elements, Hanna IVA *

Date	4/24/78	4/27	5/4	5/10	5/18	5/25	5/30
<u>Component</u>							
As	9.9	5.6	4.4	7.3	9.3	24.	23.
Cd	0.21	0.065	0.15	0.12	0.12	0.39	0.020
Ca	150	36	85	95	92	98	28
Cl	2300	1250	590	11	4.5	6.7	4.4
F	0.05	2.7	5.3	62	180	290	130
Pb	2.2	0.45	0.75	3.3	4.6	6.6	3.6
Li	280	<10	<10	<10	140	220	140
Hg	5.6	4.3	9.6	0.67	0.9	0.18	0.22
K	78	43	65	71	76	25	17
Se	16	17	22	0.12	14	4.3	5.1
Na	2200	1200	3900	4600	4100	1600	1000
V	8.4	8.0	2.2	2.6	2.1	1.1	0.35

* Concentrations as ppb (v/v) on a dry gas basis

Table 11. Particle Size Distribution of Gas
Particulate Matter, Hanna IVA

Date	<2 μ m	Particulate Loading (grains/scf) *		Total
		2 - 10 μ m	> 10 μ m	
4/24/78	0.024	0.002	0.0004	0.026
4/26	0.0008	0.0007	0.0039	0.0054
5/3	0.009	0.012	0.022	0.0430
5/9	0.0018	0.0018	0.0028	0.0064
5/17	0.014	0.005	0.003	0.0227
5/24	0.011	0.005	0.006	0.0227
5/30	0.0028	0.0008	0.0005	0.0041

* Gas conditions: dry, 760 mm Hg, 60^oF

Table 12. Trace Nitrogen and Sulfur Species* (Hanna IVB)

Date	NH ₃	HCN	H ₂ S	COS	SO ₂	CS ₂	CH ₃ SH	C ₂ H ₅ SH	(CH ₃) ₂ S
9/4/79	1185	3.2	2360	48	<1	<1	27	2.7	2.5
9/5/79	2290	14.4	2490	79	<1	<1	25	1.9	1.5
9/6/79			3180	85	<1	<1	25	2.3	1.6
9/10/79	2430	17.3	2960	96	<1	<1	20	2.0	1.1
9/11/79			3270	81	<1	<1	20	1.8	1.2
9/12/79	2890	19.6	2460	90	<1	<1	21	1.6	1.1
9/18/79	915	1.7	3140	157	<1	<1	11	1.1	<1
9/19/79	1110	2.5	3040	30	<1	<1	12	1.3	<1

* Concentration as ppm (v/v) on a dry gas basis.

Table 13. Volatile Trace Elements* (Hanna IVB)

Date	9/6/79	9/11/79
Component		
As	160	9.2
Cd	0.086	0.039
Ca	97	130
Cl	2700	11000
F	11000	430
Pb	1.5	0.77
Li	6.1	<0.3
Hg	0.42	0.28
K	100	40
Se	0.32	<0.09
Na	1800	400
V	<9	<4

* Concentration as ppb (v/v) on a dry gas basis.

VIII. BIBLIOGRAPHY.

Bartke, T.C., et al., "Status of the Fourth Underground Coal Gasification Experiment at Hanna, Wyoming," SPE Preprint 7510, Presented at the 53rd Annual Fall Meeting of SPE of AIME, Houston, TX, Oct. 1-3, 1978.

Bartke, T.C., et al., "Status Report on the Hanna III and Hanna IV Underground Coal Gasification Experiments," Proceedings of the Fourth Underground Coal Conversion Symposium, Report No. SAND 78-0941 (June 1978), pp. 41-50. Sec. No. CONF-780723.

Covell, J.R., et al. "Results of the Fourth Hanna Field Test," Proceedings of the Sixth Underground Coal Conversion Symposium, DOE Report No. CONF No. 800716 (July 1980), pp. 55-62. NTIS Order No. DE81027669.

Magee, R.A., et al., "Hanna IV Product Gas Monitoring," Presented at the Sixth Underground Coal Conversion Symposium, Afton, OK, July 13, 1980. CONF-800716, pp. 13-19.

Wojdac, L.F. and T.C. Bartke, "Hanna IV Operational Difficulties -- an Evaluation," Presented at the Fifth Underground Coal Conversion Symposium, Alexandria, VA, June 18-21, 1979.