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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 4: The Hanna II, Phases II and III Field Test

Research Report

August 1985

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OFFICE OF FOSSIL ENERGY
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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 4: The Hanna II, Phases II and III 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.

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HANNA II, PHASES II & III

I. INTRODUCTION

Hanna II, Phases II and III, were conducted during the winter of 1975 and the summer of 1976. The two phases refer to linking and gasification operations conducted between two adjacent well pairs as shown in Figure 1 with Phase II denoting operations between Wells 5 and 6 and Phase III operations between Wells 7 and 8. All of the other wells shown were instrumentation wells. Wells 7 and 8 were linked in November and December 1975. Operations were discontinued until March 1976 in order to complete contracting with Radian Corporation for product gas monitoring to establish trace constituent and particulate loading.

The original plan for operations using the well pattern shown in Figure 1 consisted of the following steps:

- Link Wells 7 and 8

- Link Wells 5 and 6

- Gasify from Well 6 to Well 5.

- Link from the 5-6 gasified area to the linkage path between Wells 7 and 8 in a broad front by simultaneous injection at Wells 7 and 8.

- Upon successful linking to the 7-8 linkage path, gasify from the 7-8 line to the 5-6 gasified area.

This plan of operation was denoted as a line drive method. Because the fourth step listed above resulted in a channel linkage path rather than a broad-front linkage path, the plan was modified to conducting the gasification step from Well 8 to Well 7 to provide comparison with the results achieved during gasification from Well 6 to Well 5.

Figure 1. Hanna II, Phases II & III Well Pattern

II. SPECIFIC SITE SELECTION & CHARACTERISTICS

The site for the conduct of Hanna II, Phases II and III, was selected based on being sufficiently distant from the Hanna II, Phase I site to avoid any interference between sites but sufficiently close such that basically the same lithology could be expected. In addition, surface topography of the site was relatively flat such that no grading was required.

The summary of drilling for the 4 process wells is given in Table 1. Logs of each well are given in the appendix. No additional coal analyses were obtained from the cores taken from these wells. The composite coal analysis obtained from the core taken at the Hanna II, Phase I site was utilized for material and energy balance calculations. The 4 full-seam cores obtained from the Hanna II, Phases II and III site were distributed to outside organizations which were performing R & D functions on UCG under separate budget authority. The dip of the coal seam at this site ranged from 9 to 11° in the direction N54°E.

Lithology of the site may be found in the appendix where the driller's log of the cores from the post-test coring are given. The only aquifer encountered above the coal was about 85 feet above the top of the coal. Its productivity was not measured but was extremely low.

III. TEST OBJECTIVES

Test the "line drive" concept where a broad combustion front is driven through a coal seam after the subsequent linkage across the broad front.

During gasification between wells 5 and 6, maintain three different injection rates for a sufficient time period to determine if oxygen flux rate has any substantial effect on gas

Table 1. Summary of Drilling Site II Phase II

	Well 5	Well 6	Well 7	Well 8
Date Stated	July 18, 1975	July 28, 1975	Aug 14, 1975	Aug 27, 1975
Date Completed	July 28, 1984	Aug 14, 1975	Aug 26, 1975	Sept 3, 1975
Surface Elevation	7022.18'	7025.66'	7024.53'	7026.75'
Total Depth	320'	315'	322'	312'
Interval Cored	250-315'	250-315'	250-319.3'	260-310'
Top of Coal	270.0'	265.0'	276.5'	266.0'
Bottom of Coal	300.67'	293.08'	301.5'	293.5'
Thickness of Coal	30.67'	28.08'	25.0'	27.5'
Casing Set @	319'	314'	321'	311'
Perforated Interval	293-299'	287-293'	295-301'	287-293'
Maximum Deviation	.90	.45	1.8	1.8
Average Deviation	.8	.3	1.0	.45
Maximum Displacement	1.82' west	0 feet	5.9' west	2.2' ESE

composition and on sweep width.

Monitor gas composition with respect to dry gas - water - tar ratio.

Monitor gas composition with respect to trace components (HCN, NH₃, COS, CS₂, Hg, Pb, Cd, As, Se, Na, K, Li, V, Ca) and particulate loading and size distribution.

Sample gas composition at various points within the seam during linkage and gasification to determine changes relative to gasification front location.

Determine effects of backpressure on the gasification process and the effectiveness of controlling water influx into the gasification reactor.

Demonstrate effectiveness of flow control valve on the air injection line to achieve a constant air injection rate.

IV. FACILITIES DESCRIPTION

Layout of process Wells 5, 6, 7 and 8 and SLA instrumentation Wells A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, and S1 are shown in Figure 1. The general building and piping layout for the test is shown in Figure 2.

The only major change in the manner in which the surface plumbing was constructed for the test was the increase in production line size, from 4" to 6". To accommodate the increase in size, the meter runs were changed from Camco orifice plate assemblies to orifice flange taps with graphite-asbestos gasket materials. The compressors were still located to the east of the Hanna I site in the shop area and a 6" insulated and

Figure 2. Schematic of Hanna II, Phases II & III Surface Facilities

heat-taped injection line was installed over the 1000 feet distance to the test site. A manual Masoneilan flow control valve was installed at the Phases II and III site to control air injection rates.

The compressors consisted of the following: two Atlas-Copcos, two Ingersoll-Rand D-750's, four Ingersoll-Rand D-2000's, one Gardner-Denver 1000 (all diesel powered) and one electric Ingersoll-Rand XLE. The D-750's and D-2000's were leased from Ingersoll-Rand Compression Services and were the only compressors used during gasification operations.

With the benefit of the experience from Hanna II, Phase I all wells were plumbed such that a well could be used for either injection or production by closing and opening a series of valves. Separate buildings were provided for the computer with its special cooling/heating unit, an operations office, electrical repair and maintenance, injection building for housing meter runs and transmitters, and a production building for housing meter runs, transmitters and gas chromatograph. These buildings were eventually interconnected by enclosed exterior walkways to minimize snow removal in winter and mud accumulation within the buildings in the spring.

Prior to ignition, the wells were dewatered by air injection with the use of siphon jets. Ignition was accomplished using an electric heater that was lubricated into the ignition well while air injection was continued to keep the well dewatered.

Three product gas flares were used during the experiment. The first was an incinerator used for periods of low production, low heating value and large water content as found during linkage. It had an auxiliary fan, was refractory lined and had propane injection available to maintain combustion during periods of low heating value gas production. The second was a modified incinerator that was refractory lined, had no auxiliary blower, but depended on natural draft, and had no propane

addition capability but could handle large volumes of gas if the heating value was greater than 90 Btu/scf. The final flare was basically an oil field flare that would handle large volumes of low-Btu gas without auxiliary fuel addition.

Downhole instrumentation assemblies were installed by SLA in lettered wells in Figure 1. The well labeled S1 was used as a shot well for induced acoustic monitoring experiments. The specific instrument arrays and locations for thermocouples in each well are shown in Tables 2 and 3. In general the instrumentation consisted of:

1. Temperature - mostly Type K (Chromel-Alumel) thermocouples and either conventional, tip-branched or leg-branched in construction. The branched series allowed for greater diagnostic measurements than the conventional series. High temperature thermocouples were also fielded in four of the wells to measure temperature above 1600°F where the type K series started failing. As time was to prove, typically these high temperature thermocouples failed prior to the type K series, most likely due to mechanical reasons rather than temperature alone because the thermocouple string for these was much more fragile.
2. In-seam gas sampling and pressure - consisting of continuous tubing running from a canister in the seam to the surface where valving allowed opening of the line for extraction of a gas sample for analysis.
3. Tilt and Displacement - tilt meter and displacement gauges were installed in selected wells to detect extent of roof collapse in the first 50 feet above the coal seam.
4. Electrical - to detect the change in conductivity (resistivity) of the coal seam during the gasification

Table 2. Summary of Instrumentation for Phases 2 and 3 of the Hanna II Underground Coal Gasification Experiment

Instrumentation Wells	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Low Temperature Levels	10	9	10	10	8	9	9	10	10	10	10	10	10	7	9
High Temperature Levels		3	3		3	3									
Resistivity Probes	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Geophones	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Gas Sampling Canisters		1	1	1	1	1	1		1	1					1
Downhole Pressure Transducers			1			1	1								
Surface Pressure Transducers		1	1	1	1	1	1		1	1					1
Tilt Meters		2	2			2		2	2	2	2				
Displacement Levels			4		4		4								

Plus Surface: Geophone Array (20 ft depth)
Resistivity Probe Array

Table 3. Downhole Thermocouple Locations; Phases 2 and 3

Thermocouple Levels(Low Temp)	A	B	C	D	E	F	G	H
a	74.3	69.3	35.2	64.1	35.0	35.5	35.3	74.6
b	49.0	35.1	32.7	30.2	30.3	30.9	30.6	40.3
c	30.2	32.5	30.2	30.0	25.0	30.2	30.4	30.5
d	30.0	30.0	25.1	20.2	20.2	25.2	25.3	25.5
e	25.2	27.7	21.1	15.1	20.1	20.2	20.2	23.0
f	22.5	22.6	14.9	12.7	15.0	15.5	15.6	20.5
g	20.1	17.9	10.5	10.1	10.0	10.1	10.4	18.0
h	17.6	15.2	5.0	7.7	5.1	5.1	5.3	15.5
i	15.1	12.5	-0.1	5.2	0.0	0.0	0.0	13.0
j	12.5	5.2	-	2.8	-	-	-	10.7
k	10.0	0.2	-	0.2	-	-	-	0.0
l	0.0	-2.4	-	-10.0	-	-	-	-

Thermocouple Levels(Low Temp)	I	J	K	L	M	N	O
a	73.9	73.1	74.1	72.0	74.2	74.3	52.9
b	40.1	39.9	39.8	40.3	40.1	40.0	30.6
c	30.2	28.1	30.0	30.4	30.2	30.2	30.4
d	25.1	25.1	25.0	25.4	25.0	25.2	25.3
e	22.7	22.5	22.5	23.0	22.6	22.0	20.2
f	20.1	20.0	20.0	20.2	20.1	20.1	15.6
g	17.7	17.5	17.6	17.8	17.7	17.0	10.4
h	15.2	15.1	15.1	15.4	15.0	15.1	5.3
i	12.7	12.6	12.6	12.9	12.6	12.0	0.0
j	10.1	9.9	10.0	10.5	10.0	10.0	-
k	10.0	0.0	9.9	10.2	0.0	0.0	-
l	0.0	-	0.0	0.0	-	-	-

Notes: Locations are referenced to the bottom of the coal seam in each well.
Positive and negative numbers are distance in feet above and below the
reference, respectively.

process. Probes were placed in both the coal seam and in a shallow subsurface grid on 10 meter spacing.

5. Passive acoustics -- installation of geophones within the coal seam and the overburden to measure the times-of-arrival of discrete signals to determine the spatial origin of the acoustic activity.
6. Induced seismic -- also involved the use of geophones and the measurement of time-of-arrival and amplitude of seismic signals induced by small explosive charges set off within the coal seam. Reflection and diffraction modeling may then be applied to determine spatial area affected by the gasification.

The operation of the Hanna II, Phase I test demonstrated the usefulness of an on-site data acquisition system controlled by a minicomputer. It also pointed out that such a system required additional equipment to insure that a reliable and functioning system was always maintained. One of the early problems identified and corrected when the Hanna II, Phase II test was initiated was the incorporation of a lightning protection device on the AC power line. The Hanna basin was plagued with numerous storms during the late spring and early summer months. Although not able to provide protection from a direct hit, it was designed to protect from transients caused by nearby strikes.

As an additional backup to the minicomputer a Doric data logger was installed to provide recording of downhole temperature readings in the event the computer went down. To limit the likelihood of such an occurrence, the computer was moved to a separate building with a separate air conditioner and electrostatic precipitator to maintain a more dust free environment and to minimize personnel traffic in the computer area.

The data acquisition software was rewritten to handle the increase in input channels but the basic logic of averaging twelve 5-minute readings for the hour was maintained from the Hanna II, Phase I test. Added to the software capabilities was the interfacing of the computer to the Beckman process gas chromatograph (PGC) that was installed to provide complete on-site gas analysis. With the advent of current and complete gas analysis, i.e., to include hydrogen, the computer was able to supply a material balance calculation on an hourly basis.

All temperature and pressure measurements were done in the same manner as previously performed in Hanna II, Phase I. The gas analysis was the primary change in instrumentation that was implemented in Hanna II, Phase II. Initially this was done with the purchase of a Beckman 6700 Process Gas Chromatograph System. This system consisted of a sample conditioner, analyzer and programmer and was configured to provide analysis for the following components and ranges:

<u>Component</u>	<u>Concentration (mol%)</u>
Water	2-25
Hydrogen	3-50
Oxygen & Argon	0-10
Nitrogen	5-70
Methane	0-15
Carbon Monoxide	0-15
Ethane	0-2
Propylene	0-1
Propane	0-1
iso-Butane	0-.5
n-Butane	0-.5
Hydrogen Sulfide	0-4
Sulfur Dioxide	0-.4

The system consisted of multiple columns, 4 ten-port valves for column switching, iso-thermal conditions, a mixed carrier gas (8% H₂ in

He) and a thermal conductivity detector. The system worked reasonably well until liquids (from condensates in the gas stream) were carried into the column whereupon the reproducibility of retention times degraded to the point that analysis was impossible. The problem of condensates will be discussed later in Section VI.C, Tar and Water Production.

A backup system was available which had also been installed to analyze gas drawn from the in-seam gas sampling canisters installed as part of the downhole monitoring system. This gas chromatograph could accept samples manually from sample bottles whereas the Beckman PGC could only accept sample through the sample conditioner section. The backup gas chromatograph was a Hewlett-Packard 5830A with a 20'x1/8" SS column of Chromosorb 102 80/100 mesh and a thermal conductivity detector. The single column in conjunction with a temperature program running from -50°C to 200°C and a mixed carrier gas of 8% H₂ in He gave analyses for the following components: H₂, O₂, Ar, N₂, CO, CH₄, CO₂, C₂H₄, C₂H₆, C₃H₈, C₃H₆, n-C₄, i-C₄ and H₂S.

It should be noted that the reported gas analyses for Hanna II, Phases II and III list only ethane and not ethylene. Although the HP GC provided ethylene analysis, the ethane and ethylene concentrations were combined when entered manually into the computer's data base. The interfacing of the HP GC to the computer was not accomplished until after the Hanna II test series and all gas samples were injected manually and the hourly analyses results were entered into the data base by the operators through interaction with a specific program.

Mass spectrometer samples were continued on a once-a-day basis to provide confirmation of the on site gas analyses taken on an hourly basis. In addition, standard calibration gases were run on a regular basis to check the accuracy of the GC.

V. PRE-OPERATION TESTS

The only testing conducted prior to operations was determining air acceptance at Wells 6 and 8 and air recovery at Wells 5 and 7 to insure that reverse combustion linking operations could be successfully completed. Air was injected at each of Wells 8 and 6 at a pressure of about 275 psig. Production from Wells 7 and 5 was measured. In both cases sufficient air acceptance (100 scfm) and air recovery (10 to 30 scfm) was experienced to insure successful linking operations.

VI. TEST OPERATIONS SUMMARY

A. Significant Events Summary

December 3, 1975 -- Julian day 337 -- ignited coal in Well 7 with electric heater to initiate linking from Well 7 to Well 8.

December 4, Julian day 338 -- switched air injection from Well 7 to Well 8.

December 10, JD -344 -- production rate exceed injection rate.

December 13, Julian day 347 -- cut injection pressure from 245 psig to 130 psig.

December 18, Julian day 352 -- pressure pulsed well 8; restriction at bottom of Well 8 removed and link completed. Injection stopped, water injected to extinguish combustion.

March 25, 1976, Julian day 85 -- Initiate air injection to dry coal and remove water in Well 6.

March 30, Julian day 90 -- Initiate air injection to dry coal and remove water in Well 5.

April 4, Julian day 95 -- ignite coal in Well 5.

April 5, Julian day 96 -- switch injection to Well 6.

April 9, Julian day 100 -- temperature increase in thermocouples at 5' and 7.5' level in Well D.

April 11, Julian day 102 -- temperature rise at 5' level in Well O.

April 25, Julian day 116 -- apparent link completed.

May 3, Julian day 124 -- linkage complete after switching injection to Well 5 for 6 hours and then back to Well 6, injection at 1700 scfm and 43 psig began.

May 7, Julian day 128 -- Injection increased to 2500 scfm.

May 11, Julian day 132 -- Wells C, F and G showing increase in temperature.

May 12, Julian day 133 -- Injection rate increased to 3500 scfm.

May 13, Julian day 134 -- Rise in temperature in Well A.

May 14-20, Julian day 135-140 -- Thermal responses at all levels within the coal seam in Wells C, F, G, and O. Lower levels in Well D burned off and refused.

May 22-25, Julian day 142-145 -- Initial response at lower thermocouple levels in Wells I and J.

May 25, Julian day 145 -- Large surges of particulate matter being produced.

May 29, Julian day 150 -- Initial response at lower level thermocouples in Well H.

May 30, Julian day 151 -- Injection of air terminated into well 6. Gasification from Well 6 to 5 completed. All thermocouples within the coal seam in Wells A, B, C, E, F, O, and G burned off, only top level in D still valid.

May 31, Julian day 152 -- Air injection into wells 7 and 8 started for "line drive" link.

June 3, Julian day 155 -- Link completed but not a broad front linkage path; line drive concept abandoned.

June 4 - 21, Julian day 156-173 -- Moved and adjusted surface piping to allow air injection at Well 8 and production from Well 7.

June 22, Julian day 174 -- Start gasification from Well 8 to Well 7; injection rate of 2500 scfm.

June 27, Julian day 179 -- Backpressure intentionally increased from 13 psig to 50 psig. Immediate 1.5% increase in methane concentration observed.

June 29, Julian day 181 -- Increased injection rate to 3500 scfm and backpressure reduced to 15 psig.

July 7, Julian day 189 -- Increased air injection rate to 4500 scfm.

July 14, Julian day 196 -- Reduced backpressure on system to 30 psig with air injection going to 4200 scfm; water content in production stream increased within 12 hours from 15% to 25%. Heating value dropped from 125 to 110 Btu/scf.

July 19, Julian day 201 -- Increased backpressure on system to 50 psig.

July 31, Julian day 213 -- Stopped all air injection. Test terminated.

B. Average Operating Parameters

The average operating parameters for Phases II and III are summarized in Tables 4 and 5, respectively. Graphs of each parameter versus time are given in Figures 3 through 16.

C. Tar and Water Production

The dry gas/water/tar ratio was determined during Phase III by taking a small bleed stream (1 to 2 scfm) from the product line, passing it through a clean-up system to remove condensates, and measuring the resulting volumes of liquids collected and gas volume. The system was also intended to provide a clean gas stream for the Beckman PGC. Unfortunately the product gas proved to be more difficult to clean up than originally anticipated. The large majority (99.5%) of the condensates could be removed by simply cooling the gas to about 35°F but what remained was a persistent aerosol. The incorporation of filters downstream from the condenser removed a portion of the aerosol but enough was carried through the filters to cause the problems in the Beckman PGC mentioned earlier in Section IV. An electrostatic precipitator was constructed and installed downstream from the filters. This

Table 4. Average Operating Parameters for Hanna II Phase II

Parameter	Value
Injection Rate (MMscfd)	4.4 (5.0 Max)
Injection Pressure (psig)	72
Production Rate (MMscfd)	7.4 (8.5 Max)
Production Pressure (psig)	33
Product Gas Temperature (^o F)	540
Product Gas Heating Value (Btu/scf)	175
Product Gas Composition:	
Constituent (Mole %)	
Hydrogen	17.19
Carbon Monoxide	15.79
Carbon Dioxide	12.12
Methane	5.40
Nitrogen	48.33
Argon	0.53
Hydrogen Sulfide	0.10
Ethane, Propanes and Butanes	0.56
Total Coal Gasified (tons)	2520
Thermal Efficiency (%)	89

Table 5. Average Operating Parameters for Hanna II Phase III

Parameter	Value
Injection Rate (MMscfd)	5.4 (6.5 Max)
Injection Pressure (psig)	75
Production Rate (MMscfd)	9.2 (12 Max)
Production Pressure (psig)	34
Product Gas Temperature ($^{\circ}$ F)	550
Product Gas Heating Value (Btu/scf)	138
Product Gas Composition:	
Constituent (Mole %)	
Hydrogen	14.13
Carbon Monoxide	13.32
Carbon Dioxide	14.17
Methane	3.73
Nitrogen	53.47
Argon	0.60
Hydrogen Sulfide	0.10
Ethane, Propanes and Butanes	0.48
Total Coal Gasified (tons)	4200
Thermal Efficiency (%)	76

Figure 3. Hanna II, Phase II Injection and Production Flow Rates

Figure 4. Hanna II, Phase II Injection and Production Pressures

Figure 5. Hanna II, Phase II Injection and Production Flow Temperatures

Figure 6. Hanna II, Phase II Product Gas Heating Value

Figure 7. Hanna II, Phase II Product Gas Composition (Major Components)

Figure 8. Hanna II, Phase II Product Gas Composition (Minor Components)

Figure 9. Hanna II, Phase II Product Gas Nitrogen Content

Figure 10. Hanna II, Phase III Injection and Production Flow Rates

Figure 11. Hanna II, Phase III Injection and Production Pressures

Figure 12. Hanna II, Phase III Injection and Production Flow Temperatures

Figure 13. Hanna II, Phase III Product Gas Heating Value

Figure 14. Hanna II, Phase III Product Gas Composition (Major Components)

Figure 15. Hanna II, Phase III Product Gas Composition (Minor Components)

Figure 16. Hanna II, Phase III Product Gas Nitrogen Content

removed the aerosol which consisted of light volatile organics to acceptable levels but the device required frequent operator intervention and overall was not a satisfactory solution.

Calculation of water/tar/dry gas ratios was done by manual measurements of volume of water and tar collected over a measured time period (water and tar separated relatively easily upon standing). Gas volume was measured by a dry gas positive displacement meter.

The results of these measurements are given in Table 6.

D. Instrumentation Responses

The summary shown in Table 7 was taken from plots of the thermal data recorded during the conduct of the experiment. Dates are Julian days for 1976 and levels are in feet (rounded to nearest foot) above (or below if negative) the coal floor. Initial date of response is the first time the temperature rose above the ambient coal seam temperature (typically 45-47°F) and the maximum temperature is the highest temperature recorded before failure.

E. Product Gas Monitoring

During Phase II gasification operations 6 sampling periods were scheduled to measure trace components and particulate concentrations in the product gas stream at Well 5. The results of these 6 sampling periods are shown in Tables 8 through 13. The monitoring was conducted by Radian Corporation under contract to LERC.

Table 6. Tar and Water Production During Hanna II Phase III

Julian Day	Date	Dry Gas Produced (MMscfd)	Water Produced (bbl/day)	Tar Produced (bbl/day)
185	7/3/76	8.03	174.6	65.0
186		8.29	136.8	35.9
187		8.14	175.7	28.4
188		8.05	170.3	27.5
189		8.58	183.4	21.7
190	7/10	10.19	204.0	22.6
191		10.24	234.9	20.2
192		9.90	240.4	14.1
193		9.37	271.6	16.4
194		9.08	265.0	12.8
195	7/18	8.61	236.4	12.7
196		8.60	258.1	11.4
197		8.27	353.1	14.4
198		8.21	318.5	10.7
199		8.02	323.4	8.4
200	7/24	8.21	322.2	6.8
201		8.43	322.5	14.9
202		8.35	319.4	19.9
203		8.34	310.8	20.0
204		8.38	300.8	17.4
205	7/29	8.34	317.7	6.9
206		8.25	318.5	11.2
207		8.11	342.5	8.2
208		7.89	329.4	8.1
209		7.84	279.0	7.9
210	7/29	7.69	296.2	7.8
211		7.87	287.9	7.2

Table 7. Instrumentation Responses During Hanna II, Phase II and III

WELL	LEVEL(1)	MAXIMUM RESPONSE		
		INITIAL RESPONSE(2)	TEMP (deg F)	DATE(2)
A	40	143	450	154
A	30	142	400	144
A	25	140	380	145
A	23	138	1100	145
A	20	136	1380	143
A	18	137	1620	142
A	15	135	450	140
A	13	145	1200	140
A	10	145	1750	143
A	0	145	1750	144
B	35	130	1800	147
B	33	129	1150	145
B	30	128	1800	144
B	28	127	750	136
B	23	128	860	136
B	18	120	800	124
B	15	118	2000	130
B	13	117	2000	130
B	5	106	1750	110
B	0	106	60	106
B	-3	106	60	106
C	35	141	350	145
C	33	140	600	145
C	30	140	170	141
C	25	139	200	140
C	20	136	550	138
C	15	132	960	137
C	10	127	1160	134
C	5	127	1870	131
C	0	129	60	129
D	30	125	1900	165
D	20	137	1480	154
D	15	131	1800	151
D	13	115	1750	147
D	10	105	1350	132
D	8	95	1900	151
D	5	96	1230	133
D	3	102	1340	136
D	0	113	60	113
D	-10	NO RESPONSE - AMBIENT		
E	35	148	820	155
E	30	137	800	158
E	25	145	630	141
E	20	134	740	136
E	15	122	1720	142
E	10	116	150	127
E	5	106	2000	115
E	0	108	60	108

(1) Levels are with reference to bottom of coal seam rounded to the nearest foot. Positive and negative are with reference to above and below the bottom of the coal seam respectively.

(2) Dates for INITIAL RESPONSE and MAXIMUM RESPONSE are Julian Date for the year 1976.

Table 7. (continued)

WELL	LEVEL	INITIAL RESPONSE	MAXIMUM RESPONSE	
			TEMP (deg F)	DATE
F	35	141	750	154
F	30	140	680	150
F	25	139	200	140
F	20	136	580	139
F	15	128	620	135
F	10	119	850	128
F	5	119	1130	130
F	0	125	910	127
G	35	144	450	165
G	30	143	610	154
G	25	142	600	150
G	20	137	1360	154
G	15	130	820	142
G	10	117	1200	132
G	5	107	1900	118
G	0	NO RESPONSE - AMBIENT		
H	40	161	260	191
H	30	155	520	182
H	25	156	400	175
H	23	154	1100	170
H	20	154	1240	170
H	18	154	780	170
H	15	153	630	165
H	13	151	980	170
H	10	150	1190	170
H	0	147	1190	170
I	40	163	570	196
I	30	156	230	196
I	25	154	240	184
I	23	154	500	184
I	20	154	830	191
I	18	150	830	191
I	15	149	1000	190
I	13	149	1000	192
I	10	143	1030	192
I	0	142	1010	193
J	40	154	550	213
J	30	154	180	200
J	25	154	200	198
J	23	160	600	197
J	20	158	700	200
J	18	154	700	200
J	15	149	570	198
J	13	142	440	197
J	10	140	750	172
J	0	141	170	180

Table 7. (continued)

WELL	LEVEL	INITIAL RESPONSE	MAXIMUM RESPONSE	
			TEMP (deg F)	DATE
K	40	160	80	215
K	30	157	80	217
K	25	191	80	217
K	23	158	80	217
K	20	185	75	217
K	18	187	75	217
K	15	158	80	217
K	13	NO RESPONSE - AMBIENT		
K	10	155	90	217
K	0	155	90	217
L	74	204	150	217
L	40	185	800	192
L	30	178	700	182
L	25	177	1830	191
L	23	177	320	181
L	20	177	710	182
L	15	174	1400	190
L	13	172	1400	190
L	10	NO RESPONSE - AMBIENT		
L	0	177	570	177
M	74	NO RESPONSE - AMBIENT		
M	40	196	230	212
M	30	187	230	207
M	25	181	220	205
M	23	179	1370	207
M	20	178	530	207
M	18	178	630	208
M	15	175	1010	209
M	13	175	650	207
M	10	158	590	209
M	0	180	110	207
N	74	NO RESPONSE - AMBIENT		
N	40	NO RESPONSE - AMBIENT		
N	30	170	70	217
N	25	214	55	217
N	23	170	60	217
N	20	212	60	217
N	18	212	60	217
N	15	170	70	217
N	13	170	80	217
N	10	170	110	217
N	0	203	100	217
O	53	155	180	216
O	35	142	670	154
O	30	140	620	149
O	25	NO RESPONSE - AMBIENT		
O	20	137	300	140
O	15	127	220	134
O	10	112	970	128
O	5	105	1300	127
O	0	NO RESPONSE - AMBIENT		

Table 8. Particulate Size Distribution on May 2 and May 4, 1976

May 2		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
>15.0	80	3.3
15.0-9.3	250	10.4
9.3-6.2	-	-
6.2-4.4	100	4.2
4.4-2.7	100	4.2
2.7-1.39	140	5.8
1.39-0.87	130	5.4
0.87-0.62	-	-
<0.62	1,600	66.7
Total	2,400	100.0

May 4		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
>13.3	-	-
13.3-8.3	74	3.7
8.3-5.5	28	1.4
5.5-3.8	162	8.1
3.8-2.4	262	13.1
2.4-1.25	254	12.7
1.25-0.78	220	11.0
0.78-0.52	301	15.0
<0.52	701	35.0
Total	2,003	100.0

Table 9. Particulate Size Distribution on May 8 and May 10, 1976

May 8		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
> 10.6	828	2.4
10.6-6.7	777	2.3
6.7-4.5	704	2.0
4.5-3.2	761	2.2
3.2-2.0	1,436	4.2
2.0-1.0	5,474	15.9
1.0-0.62	5,006	14.6
0.62-0.41	5,531	16.3
<0.41	13,832	40.3
Total	34,349	100.0

May 10		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
>8.8	8,300	2.3
8.8-5.5	11,300	3.1
5.5-3.7	16,100	4.5
3.7-2.6	17,500	4.9
2.6-1.6	22,000	6.1
1.6-0.82	41,500	11.5
0.82-0.50	62,300	17.3
0.50-0.33	71,700	19.8
<0.33	109,800	30.5
Total	360,300	100.0

Table 10. Particulate Size Distribution on May 13 and May 15, 1976

May 13		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
>10.3	960	4.9
10.3-6.4	974	4.9
6.4-4.3	684	3.5
4.3-3.1	1,062	5.4
3.1-1.9	697	3.5
1.9-0.97	1,285	6.5
0.97-0.59	2,471	12.5
0.59-0.40	3,861	19.6
< 0.40	7,730	39.2
Total	19,725	100.0

May 15		
Size Range (microns)	Particulate Concentration (grains/MM scf)	Fraction (percent)
>10.7	47,300	37.2
10.7-6.7	26,900	21.1
6.7-4.5	23,900	18.8
4.5-3.2	12,100	9.5
3.2-1.9	3,860	3.0
1.9-1.0	4,250	3.3
1.0-0.61	1,880	1.5
0.61-0.40	1,770	1.4
< 0.40	5,250	4.1
Total	127,210	100.0

Table 11. Elemental Composition and Bulk Density of
Selected(1) Particulate Fractions

Component(2)	Date of Collection		
	May 4	May 10	May 15
Na ₂ O	0.14	-	0.24
K ₂ O	0.14	-	0.32
Li ₂ O	-	-	-
CaO	4.19	-	1.23
MgO	0.27	-	1.29
Al ₂ O ₃	0.89	-	7.10
Fe ₂ O ₃	4.83	-	2.50
TiO ₂	0.28	-	0.34
SiO ₂	3.83	-	13.05
Total Oxides(3)	13.66	-	25.81
C	78.72	60.33	58.06
H	6.47	1.01	3.26
O	7.87	2.62	11.08
Total	106.72	-	98.21
Bulk Density(4) (g/cc)	0.77	0.51	1.33

(1) Cyclone collection only. Particulate fraction >2 micron.

(2) All values as weight percent unless otherwise noted.

(3) Percent values corrected to pre-extraction weights. Total oxides should equal ash content.

(4) Samples packed in 16 lambda capillary tubes for density measurements.

Table 12. Concentration of NH_3 , HCN, COS, and CS_2
for Each Monitoring Period

Date	NH_3 (percent)	HCN (ppm)	COS (ppm)	CS_2 (ppm)
May 2	0.13	1.0	3.0	4.7
May 4	0.14	10.0	2.8	2.2
May 8	0.21	9.4	1.7	9.0
May 10	0.28	0.17	0.57	9.8
May 13	0.18	6.9	1.5	7.4
May 15	0.14	0.43	1.1	8.9

Table 13. Trace Metal Concentrations for Each Monitoring Period

Component*	May 2	May 4	May 8	May 10	May 13	May 15
Na	0.92	3.97	12.9	0.49	4.35	0.05
K	0.16	0.10	0.04	0.12	0.05	0.02
Li	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Ca	0.43	0.84	0.48	0.80	0.42	0.37
V	0.034	0.097	0.071	0.064	0.063	0.064
Hg	0.0068	0.0042	0.0130	0.0140	0.0076	0.0077
Pb	0.012	0.030	0.033	0.021	0.016	0.011
Cd	0.00054	0.00047	0.000222	0.000089	0.000083	0.00040
As	0.0066	0.0117	0.036	0.088	0.075	0.029
Se	0.0355	0.0137	0.0101	0.0186	0.0156	0.0169

* All concentrations ppm (v/v) on a moisture-free basis.

F. Tar Characterization Studies

Condensable hydrocarbons collected from the product gas stream were subjected to laboratory analysis to determine physical properties, elemental composition, and boiling range distribution. Tables 14 through 17 present the results of these analyses.

VII. POST TEST ACTIVITY

As after Hanna II, Phase I, the post test activities consisted of ground water monitoring and coring. The ground water data are contained in the appendix of the report entitled "General Information and Executive Summary".

The coring of the gasified area consisted of drilling 22 wells as shown in Figure 17. Figures 18 through 21 show the constructed cross-sections indicating the outstanding resource recovery during Phases II and III and the stabilization of the roof within about one seam thickness above the gasified areas. The lithology and analyses obtained from each well are shown in the appendix.

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Table 14. Physical Properties of Tars

Specific Gravity at 60 deg F	0.960-0.977
Viscosity at 100 deg F	3.5-13.2 centistokes
Heat of Combustion	14,000-17,300 Btu/lb

Table 15. Elemental Analysis of Tars

Carbon	86.33%
Hydrogen	10.43
Nitrogen	0.79
Sulfur	0.18
Oxygen *	2.27

* Percentage determined by difference.

Table 16. Boiling Range Distribution of Tars

Ambient- 400 deg F	400- 500	500- 600	600- 700	700- 800	800- 900	900- 1000	Residue
6.2*	16.9	25.6	28.2	16.0	5.3	1.8	0.0

* Expressed as a weight percent

Table 17. Composition of Tar

Tar Bases	2.5-8.0% (weight)
Tar Acids	0.1-1.0% Strong Acids 12-31% Weak Acids
Neutrals	55-77% with 70% Aromatic 30% Aliphatic

Figure 18. SW-NE Cross Section A-A'

Figure 19. SW-NE Cross Section B-B'

Figure 20. SW-NE Cross Section C-C'

Figure 21. NW-SE Cross Section D-D'

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

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