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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 5: The Hanna III 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 5: The Hanna 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.

Volume 5: Hanna III

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HANNA III

I. INTRODUCTION

Hanna III was conducted during the spring and summer of 1977. The test involved only two process wells but also had twelve water monitoring wells, eight in the Hanna No. 1 coal seam and four in an aquifer above the coal seam as shown in Figure 1.

The test was designed to obtain information regarding the effects of the process on groundwater within the target seam and the overlying aquifer. The site for Hanna III had a low productivity aquifer above the Hanna No. 1 seam. The wells within the seam and the overlying aquifer were placed in such a manner that maximum information on groundwater flow and quality could be obtained.

II. SITE SELECTION AND CHARACTERISTICS

The site was selected because it was 500' up dip from the two Hanna II sites and the likelihood of groundwater contamination from other test sites was minimal. In addition, the coal seam was shallower (about 165 feet) thereby reducing drilling costs and allowing for lower operating pressures during linkage and gasification, also at a cost savings.

The drilling summary for the 14 wells at Hanna III is given in Table 1. Logs of each well are included in the appendix. Lithology description and coring results obtained during post-test coring of the site are also given in the appendix.

A full seam core was taken from Well 2 for analysis. The coal analysis obtained is given in Table 2.

Figure 1. Hanna III Well Pattern

Table 1. Tabular Summary of Hanna III Drilling

Well number	1	2	3	4	5	6	7
Date Started	10-4-76	10-19-76	10-6-76	10-7-76	10-5-76	10-18-76	10-14-76
Date Completed	11-16-76	11-22-76	11-16-76	11-16-76	11-16-76	11-17-76	11-17-76
Total Depth	199'	210'	139'	139'	139'	205'	209'
Top of Coal	150'	161'				158'	162'
Bottom of Coal	183'	195'				189'	194'
Thickness of Coal	33'	34'				31'	32'
Casing Set @	177'	189'	120'	120'	120'	160.5'	161'
Open to Coal	X	X				X	X
Logging Depth	198'	208'	134'	134'	137'	204'	202'

Well number	8	9	10	11	12	13	14
Date Started	10-13-76	10-13-76	10-14-76	10-12-76	10-7-76	11-11-76	11-9-76
Date Completed	11-17-76	11-19-76	11-18-76	11-18-76	11-17-76	11-19-76	11-19-76
Total Depth	210'	211'	209'	208'	205'	199'	153'
Top of Coal	163'	163'	161'	164'	161'	165'	
Bottom of Coal	194'	196'	190'	193'	190'	199'	
Thickness of Coal	31'	33'	29'	29'	29'	34'	
Casing Set @	162'	163'	163'	162'	162'	166'	143'
Open to Coal	X	X	X	X	X	X	
Logging Depth	206'	204'	202'	201'	198'	None	None

Table 2. Analyses of Hanna No. 1 Coal Seam, Hanna III Site

Ultimate Analysis

	As Received	Dry Basis
% Moisture	8.25	-
% Carbon	43.85	47.79
% Hydrogen	3.49	3.81
% Nitrogen	1.02	1.11
% Chlorine	0.01	0.01
% Sulfur	0.67	0.73
% Ash	31.33	34.14
% Oxygen (by difference)	11.38	12.40

Proximate Analysis

	As Received	Dry Basis
% Moisture	8.25	-
% Ash	31.33	34.14
% Volatile	30.58	33.32
% Fixed Carbon	29.85	32.53
Heating Value	7536	8212

Sulfur Forms

	As Received	Dry Basis
% Pyritic Sulfur	0.27	0.30
% Sulfate Sulfur	0.00	0.00
% Organic Sulfur	0.40	0.43

Each of the wells completed into the coal seam and into the overlying aquifer were sampled in triplicate prior to the initiation of linking and gasification to determine baseline water quality. A summary of these analyses is shown in Tables 3 and 4.

III. TEST OBJECTIVES

The Hanna III test has been called an environmental test of UCG. It was designed to determine the impacts of UCG on groundwater quality and to further refine the process. The objectives are therefore divided into two major areas:

Environmental:

Characterize the groundwater in the coal seam aquifer and in an overlying aquifer.

Determine pre-test water quality in both aquifers.

Determine post-test water quality.

Determine impacts of UCG on groundwater quality based on observed compositional changes versus time.

Process:

Refine the mathematical process model.

Test process control techniques.

Demonstrate constancy of product gas heating value by controlling the air-water ratio in the gasification zone.

Table 3. Pre-test Water Quality, Hanna No. 1 Coal Seam
Hanna III UCG Test

Component	Concentration (ppm)	Component	Concentration (ppm)
SO ₄ =	15	Cu	0.008
CO ₃ =	23	Mn	0.035
HCO ₃ ⁻	1170	Mo	0.03
SiO ₂	11	Ti	< 0.03
TDS @ 180 deg C	1300	V	< 0.002
Na	575	NH ₃ -N	1.6
K	7.5	Cl	22
Ca	12	F	2.9
Mg	5.4	DOC	49
Cd	0.003	P, total	0.6
Pb	0.04	N, total	2.8
Zn	0.03	Hg	< 0.0001
Fe	0.08	S=	< 0.04
Al	0.05	pH	8.3-8.5

Table 4. Pre-test Water Quality, Overlying Aquifer
Hanna III UCG Test

Component	Concentration (ppm)	Component	Concentration (ppm)
SO ₄ =	713	Cu	0.009
CO ₃ =	0	Mn	0.19
HCO ₃ ⁻	1985	Mo	< 0.01
SiO ₂	9	Ti	< 0.03
TDS @ 180 deg C	2805	V	0.002
Na	1320	NH ₃ -H	1.5
K	21	Cl	30
Ca	43	F	1.1
Mg	28	DOC	11
Cd	0.005	P, total	0.05
Pb	0.06	N, total	4.3
Zn	0.05	Hg	< 0.0001
Fe	4.5	S=	< 0.04
Al	0.03	pH	7.5

IV. FACILITIES DESCRIPTION

The layout of the buildings, compressors, flares and plumbing are shown in Figure 2. The compressors (3 Ingersoll-Rand D-2000) had a combined output of 4500 scfm at 165 psig. The injection was controlled through two four-inch injection lines each with an automatic remote controlled Fischer globe valve. Production was routed through either a four inch or six-inch production run. The six inch production line had a Masoneilan Camflex control valve located about 12 feet downstream of the metering point.

The process wells were completed with a nominal 6" casing using the open hole method where the bottom six feet were not cased but exposed to the coal seam.

Downhole monitoring wells were also completed with the open-hole technique with slotted screens set in the bottom portion of the well and cemented all the way to the surface such that they were known to contact only one aquifer. Then the rat hole below the casing was drilled out and slotted pipe was installed in each well of the monitoring wells. Each monitoring well contained the following:

1. Electrical conductivity cell to monitor changes in the aquifer.
2. Thermocouple to monitor water temperature.
3. Pressure transducer to measure changes in water level.
4. Pressure transducer located on the top of the well to measure static pressure within the casing above the static water level.

As in the previous experiments, these instruments were interfaced into the data acquisition system on site and readings were taken every 5

Figure 2. Schematic of Hanna III Surface Facilities

minutes with hourly averages stored for later analysis. Flow temperature and pressure measurements were conducted as in Hanna II, Phase II and III using the same techniques. Tar-water measurements were conducted as before except that the electrostatic precipitator was eliminated due to the numerous problems encountered maintaining that portion of the system. The results from the system were not as successful as from Hanna II primarily due to the large amounts of particulate matter produced in the Hanna III test. The particulate caused plugging in the sampling lines which rendered the system almost completely inoperative.

Another system to measure water vapor only was tested during the Hanna III test and was provided by Gulf R&D Co. The system was designed to detect the dew point of the gas on a cooled mirror after removing the condensible hydrocarbons from the gas stream. The system was not reliable because tars condensed on the mirrored surface causing inaccurate reading. This was attributed to the aerosols created when the gas was cooled and their persistence in spite of numerous attempts to remove them prior to water vapor measurement. This system also suffered from the problem with plugging since the sampling port off the production line was at the same location as for measuring dry gas/water/tar production.

V. PRE-OPERATION TESTS

Hydrological characterization of the two aquifers was conducted prior to test startup. The desired hydrological information consisted of the permeabilities and porosities and the continuity and directional natures of both the coal seam and the overlying aquifer. Pumping (drawdown) and shut-in (recovery) tests were conducted in Wells 10 and 1 in the coal seam and Well 3 in the overlying aquifer. Water levels in all other wells were monitored to detect the occurrence of drawdown. Because of problems with the downhole pressure transducers no information was obtained for wells 13 and 14.

Pre-test water levels showed that the two aquifers were isolated. The static water level in the seam was 120 feet from the surface while the overlying aquifer had water 95 feet from the surface.

From data obtained in an observation well in the Hanna II, Phase I area, an estimate of about 3 md for seam permeability was made. A short drawdown and buildup on Well 10 showed this value to be low. Based on the new value a rate of about 10 gal/hr was calculated as being proper for the test.

A bottom hole turbine-type pump was rigged with a pressure transducer hung below it to measure responses in the pumping well. The pump was installed at the coal seam -- overburden interface in Well 10. Flow was measured through a 5' length of 1/4" tubing with pressure taps at each end connected to a flow transducer so the rate could be recorded.

Water levels were measured for five days before the short term drawdown-buildup was conducted in Well 10 to establish that stable conditions existed. Well 10 was pumped at an average rate of 9.6 gal/hr for 6 days. Pressures were recorded at 5 minute intervals in all wells (except 13 and 14). Responses to the drawdown were seen in all wells completed into the seam with no responses in the wells in the overlying aquifer. Pumping was then stopped and the water levels allowed to build up to pre-pumping levels; the changes in water levels during this time were also monitored.

A similar procedure was carried out on Well 3 in the upper aquifer. A rate was chosen by doing a short-term preliminary drawdown buildup at Well 3. During the long-term drawdown, Well 3 was produced at a rate of 4.0 gal/hr for 6.7 days, at which time the rate was increased to 4.6 gal/hr for two days, whereupon the rate was again increased to 5.6 gal/hr for the final 3.3 days of the test. The well was then shut in and the buildup and responses were recorded. Responses to both drawdown and buildup were observed at both Wells 4 and 5.

A drawdown at Well 1 was then conducted in the same manner except a preliminary drawdown buildup was not used because the properties near Well 1 were anticipated to be similar to those at Well 10. This proved to be unfortunate, as the seam proved to be much less permeable around Well 1 than around Well 10 and a rate of 10 gal/hr could not be sustained. The rate was reduced twice during the test, the final time to 4 gal/hr. By then, even this rate could not be sustained. The drawdown lasted only about one day.

The data from the drawdown-recovery testing at Well 10 yielded a calculated coal seam permeability of 4.7 md with the major permeability direction N82°W. For the overlying aquifer the major permeability direction was parallel to the line connecting Wells 3 and 5 with a transmissivity of 140 md-ft, essentially the same as the coal seam. The data for Well 1 yielded an average permeability of 2.1 md. However, this result is not considered representative since Well 1 was not well interconnected to the coal seam as was discovered during air acceptance testing.

Linking operations were planned for propagating the link from Well 2 to Well 1. Pre-test air acceptance testing indicated that sufficient air acceptance could not be achieved at Well 1. Thus, it was decided to ignite at Well 1, inject air at Well 1 for a short period of time to remove the restriction, and quench the fire by filling the casing with water and forcing the water into the coal seam with air injection. Upon completion of these steps, it was discovered that the fire had not been quenched. Therefore, linking was conducted from Well 1 to Well 2 rather than as originally planned with no complications.

Three sets of ground water samples were collected from each of the 14 wells in May 1977. The samples were collected in a polypropylene bailer. The methods for preparing and preserving the samples consisted of the following instructions:

Plastic jugs (2 of them) of one gallon capacity will be permanently labeled for Wells 1 through 14 and Corehole 4 so that the same jugs are used at the same wells all the time. For each sampling period, a small amount of water from the bailer will be used to rinse out the jugs prior to filling the jugs. The jugs are not to be rinsed with distilled water. The filled jugs will then be transported to the laboratory building for preparation. After each well is sampled, it is to be bailed. The bailer should be emptied before proceeding to the next well.

Sample Preparation

The first thing done after getting the samples to the laboratory building will be to measure and record the pH of each sample. The temperature and conductivity readings will be obtained from the computer so time and date of collection must also be recorded. A record book will be available for recording these data.

Each sample will then be filtered through 0.45 filter paper. Buchner funnels, filter paper, and filtration flasks are available for this step. The valves on the vacuum line should be adjusted to minimize frothing of the filtrate during the filtering operation.

A nylon screen (about 1/2 the diameter of the filter paper) for filter support should first be placed in the Buchner funnel. Then a piece of 0.45 u filter paper should be placed on top of this while being sure that all holes in the funnel are covered by the paper. With no vacuum being applied, spray the filter paper with distilled water to wet the entire paper. Press on the paper to remove any air bubbles. Then open the valve on the vacuum line to set the filter paper properly. Add a small portion (200-300 ml) of sample to the Buchner funnel. After it has been filtered, shut off the vacuum line and pour the filtrate in the filtration flask out after swirling it around the flask to rinse the flask. Replace the Buchner funnel, open the vacuum line, and filter the

sample. Collect at least 4 liters of filtrate. After completion of filtering, the filtrate will be split into 5 fractions with different handling of each fraction.

Remember to rinse the sample bottles with a small amount of filtered sample prior to filling.

Fraction I (Sample bottles identified with pink labeling tape)

Fill a 1000-ml (32 oz, 1 qt) sample bottle with filtered sample. Place the filled, labeled (with sample #) bottle in the refrigerator. No additional preparation is necessary. This fraction will be analyzed for $\text{SO}_4^{=}$, HCO_3^{-} , $\text{CO}_3^{=}$, Si, Total Dissolved Solids, Cl^{-} , F^{-} , Total P, B, Total Inorganic Carbon, and Total Dissolved Organic Carbon.

Fraction II (Sample bottles identified with green labeling tape)

Measure 500-ml of filtered sample in a graduated cylinder and add to a 16-oz sample bottle which has been rinsed with a small amount of filtered sample. Then add 10 ml of 1:8 HNO_3 to the bottle using a graduated pipette to measure the 10 ml addition. Then fill the bottle, cap, and shake to mix. This fraction will be analyzed for Na, K, Ca, Mg, Cd, Pb, Zn, Fe, Al, Cu, Mn, Mo, Ti, V, As, and Se.

Fraction III (Sample bottles identified with blue labeling tape)

Measure 1000 ml of filtered sample in a graduated cylinder and add to a 32-oz sample bottle which has been rinsed with a small amount of filtered sample. Then add 10 ml of 1:10 H_2SO_4 to the bottle using a graduated pipette to measure the 10 ml addition. Then fill the bottle, cap, and shake to mix. This fraction will be analyzed for NH_3 , Total N, NO_2 and NO_3^{-} .

Fraction IV (Sample bottles identified with orange labeling tape)

Add 12.5 ml of concentrated HNO_3 to a 250 ml (8oz) sample bottle using a graduated pipette to measure the 12.5 ml addition. Then add a measured 250 ml of filtered sample to the bottle. Cap the bottle and shake to mix. Then add 5 ml of the 5% $\text{K}_2\text{Cr}_2\text{O}_7$ to the bottle using a graduated pipette to measure the 5-ml addition. Fill the bottle, cap, and shake to mix. This fraction will be analyzed for Hg.

Fraction V (Sample bottles identified with red labeling tape)

Measure 250 ml of filtered sample using a graduated cylinder and add to an 8-oz sample bottle which has been rinsed with a small portion of filtered sample. Then add 2.5 ml of 0.1 M $\text{Zn}(\text{Ac})_2$ solution to the bottle using a graduated pipette to measure the 2.5-ml addition. Fill the bottle, cap, and shake to mix. This fraction will be analyzed for $\text{S}^{=}$.

Fraction VI (Sample bottles identified with white labeling tape)

Fraction VI will be the same as Fraction I except it will be a centrifuged rather than a filtered sample. The centrifuge contains 4-50 ml centrifuge tubes. Fill each tube to the 50-ml mark with unfiltered sample, place the tubes in the centrifuge, and centrifuge for 5 minutes with the speed control knob set at 6. Remove the tubes from the centrifuge, gently pour the contents of one tube into a 1000-ml (32 oz) bottle, cap, and swirl the bottle, and pour out the contents. Then add the contents of the remaining 3 centrifuge tubes. Centrifuge sufficient unfiltered sample to fill the 1000-ml sample bottle. Then place the full labeled bottle in the refrigerator.

Fraction VII (Sample bottles identified with yellow labeling tape)

This fraction is the same as Fraction III except centrifuged rather than filtered sample will be used. Follow the same directions for centrifuging as given for Fraction VI and centrifuge sufficient unfiltered sample to fill a 1000-ml sample bottle with rinsing of the sample bottle with centrifuged sample prior to filling. Don't forget to add a measured 10 ml of 1:10 H_2SO_4 to the sample bottle, to cap, and to shake to mix.

Fractions VI and VII will be collected to check whether sample preparation (filtering vs. centrifuging) has any effect on the analyses for HCO_3^- , CO_3^{2-} , NH_3 , and Dissolved Organic Carbon. These two fractions will not be collected all the time unless the results indicate that it is preferred to filtering.

Sample Identification

The following system will be used to identify samples:

First: III for Hanna III

Second: Well Number

Third: Sequential number for Sample Number

Fourth: Letter to Identify the Fraction

Thus, the first set of samples to be collected on May 12 will be identified as follows for wells 1, 3, and 5 for Fractions I through VII, respectively.

III-I-IA; III-3-1A; III-5-1A

III-I-1B; IV-3-1B; III-5-1B

-1C

-1C

-1C

-1D	-1D	-1D
-1E	-1E	-1E
-1F	-1F	-1F
-1G	-1G	-1G

The second set of samples collected on May 16 for the same wells will be identified as follows:

III-1-2A; III-3-2A; III-5-2A

-2B	-2B	-2B
-2C	-2C	-2C
-2D	-2D	-2D
-2E	-2E	-2E
-2F	-2F	-2F
-2G	-2G	-2G

Samples from Corehole 4 will be identified as III-CH4-1A, etc.

Spiked blank samples will be III-15-1A, etc., and III-16-1A, etc. as if they were from Wells 15 and 16.

Preparation of Spiked Blanks

Spiked blanks for each of Fractions I through V will be prepared by taking distilled water through the filtering technique used for

preparing the fractions. A measured amount of the known concentrates prepared by Bill Ferguson will then be diluted to the proper volume with this filtered or centrifuged distilled water and handled just like the fractions of water collected from the wells. At least one full set of fractions of spiked blanks will be prepared during each sampling period.

Remember to record sample numbers and dates of collection in the record book in the lab building.

VI. TEST OPERATIONS SUMMARY.

A. Significant Events Summary

June 6, 1977 - (JD 157) Ignition of coal in Well 1 to enhance permeability at bottom of Well 1.

June 7, 1977 - (JD 158) Injection switched to Well 2 to draw fire away from bottom of Well 1; water added to Well 1 to quench combustion.

June 7, 1977 - (JD 158) Ignition of coal in Well 2 and switched injection to Well 1 to start reverse combustion link from Well 2 to Well 1.

June 11, 1977 - (JD 162) Switched air injection to Well 2, increase in well head temperature of Well 1, fire still present at bottom of Well 1, will link from Well 1 to Well 2.

June 22, 1977 - (JD 173) Link complete, reignition of coal at bottom of Well 2 and commencement of gasification from Well 1 to Well 2.

June 27, 1977 - (JD 178) Rapid increase in wellhead temperature at Well 2, shut down of air injection, water injection into Well 1 commenced with air injection.

July 8, 1977 - (JD 189) Commenced water injection into Wells 6 and 12 to moderate wellhead temperatures at Well 2.

July 18, 1977 - (JD 199) Started water injection into Well 10 to moderate well head temperature at Well 2, discontinued water injection in Wells 6 and 12.

July 20, 1977 - (JD 201) Temperature in Well 3 increases from 250°F to 810°F.

July 30, 1977 - (JD 210) Cease air injection into Well 1.

B. Average Operating Parameters

The average operating parameters are shown in Table 5. Graphs of these parameters are given in Figures 3 through 8.

C. Tar and Water Production

No reliable measurements of tar and water production were available due to particulate plugging the sampling line. Values shown in the raw data contained in the appendix should be disregarded.

D. Instrumentation Responses

July 16, 1977 - (JD 197) Initial response at Well 3; Max. temp 1050°F on July 22 (JD 203)

Table 5. Average Operating Parameters for Hanna III

Parameter	Value
Injection Rate (MM scfd)	4.0
Injection Pressure (psig)	48
Production Rate (MM scfd)	6.5
Production Pressure (psig)	26
Product Gas Temperature (deg F)	645
Product Heating Value (Btu/scf)	138
Product Gas Composition:	
Component (mole %)	
Hydrogen	13.47
Carbon Monoxide	15.16
Carbon Dioxide	13.79
Methane	3.51
Nitrogen	52.90
Argon	0.59
Hydrogen Sulfide	0.10
Ethane, Propane, and Butanes	0.48
Total Coal Gasified (tons)	2850
Thermal Efficiency (%)	76

Figure 3. Hanna III Injection and Production Flow Rates

Figure 4. Hanna III Injection and Production Pressures

Figure 5. Hanna III Injection and Production Flow Temperatures

Figure 6. Hanna III Product Gas Heating Value

Figure 7. Hanna III Product Gas Composition (Major Components)

Figure 8. Hanna III Product Gas Nitrogen Content

None of the other thermocouples in the other monitoring wells showed any response. All of the conductivity data shown in the raw data in the appendix should be taken with a large grain of salt. Inspection of the conductivity probes after being immersed in the ground water for variable periods of time (a few days minimum) showed a buildup of salts (presumably carbonates and sulfates) on the probes which raised the readings to very high levels. After cleaning and reinstalling the probes downhole, the conductivity readings returned to pre-test levels.

VII. POST-TEST ACTIVITY.

As after previous tests, the two post test activities consisted of groundwater sampling and analysis and coring of the gasified area. The groundwater quality data are included in the report entitled "General Information and Executive Summary" in the appendix.

The post-test coring consisted of 10 wells located as shown in Figure 9. The description of the cores and analyses obtained are included in the appendix. Cross-sections constructed from these data are shown in Figures 10 and 11 again showing excellent sweep efficiency and stabilization of the roof within one seam thickness above the coal seam.

VIII. BIBLIOGRAPHY

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Figure 10. Cross Section of Post-Test Coring Results Along A - A'

Figure 11. Cross Section of Post-Test Coring Results Along B - B'