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MOBILE LABORATORY: RESULTS FROM THE FIRST YEAR

Contract No. RP 741-1

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The EPRI Mobile Geothermal Laboratory, designed and operated by the Energy Systems Group of Rockwell International, works toward three major project objectives; these are the generation of reliable analytical data for inclusion in the EPRI brine data base, the support with physical and chemical information of EPRI projects and utility field tests, and the establishment of standard procedures for physical and chemical measurements on geothermal systems. To meet these objectives, the laboratory was designed to have extensive capability for the analysis of geothermal brine, steam condensate, and non-condensable gases. A portable sampling unit, the fluid sampling system, is operated in conjunction with the mobile laboratory, and adds the capability to collect geothermal samples on site at an established geothermal facility or a test site. The laboratory, with the fluid sampling system, travels to the geothermal site and conducts sampling and analysis on site; this procedure gives maximum assurance of sample integrity and maximum flexibility in response to unusual occurrences in the field.

The laboratory has the capability to measure a large quantity of physical properties and chemical constituents of the geothermal fluid. Table 1 lists the important analytical and support equipment in the laboratory, and Table 2 lists the chemical species and physical properties which may be measured in the laboratory.

Because one of the objectives of the mobile geothermal laboratory is to generate a standard collection of physical and chemical data to characterize geothermal wells, a broad, inclusive characterization, called a signature test, has been designed. This test includes measurement on geothermal fluid of all of the properties and species measured by the laboratory; the results of a signature test become part of the EPRI data base package for that well and are readily compared to similar data for other geothermal wells.

Figure 1 is a diagram of the signature test and shows the methods of sample collection and analysis used. The fluid sampling system is capable of collecting samples in two ways; the temperature may be dropped and then the pressure (ΔT mode), or the pressure may be dropped and then the temperature (ΔP mode). For the collection of liquid samples for chemical analysis, the ΔT mode is used, and for the collection of gas samples and the evaluation of physical properties, the ΔP mode is used.

Any combination of measurements may be made in the laboratory in response to the requirements of a particular project. A tracking test comprises repetitive sampling and analysis at specified times of particular properties and species and is designed for a particular project and purpose. A special test is generally performed once and may measure any combination of properties and species

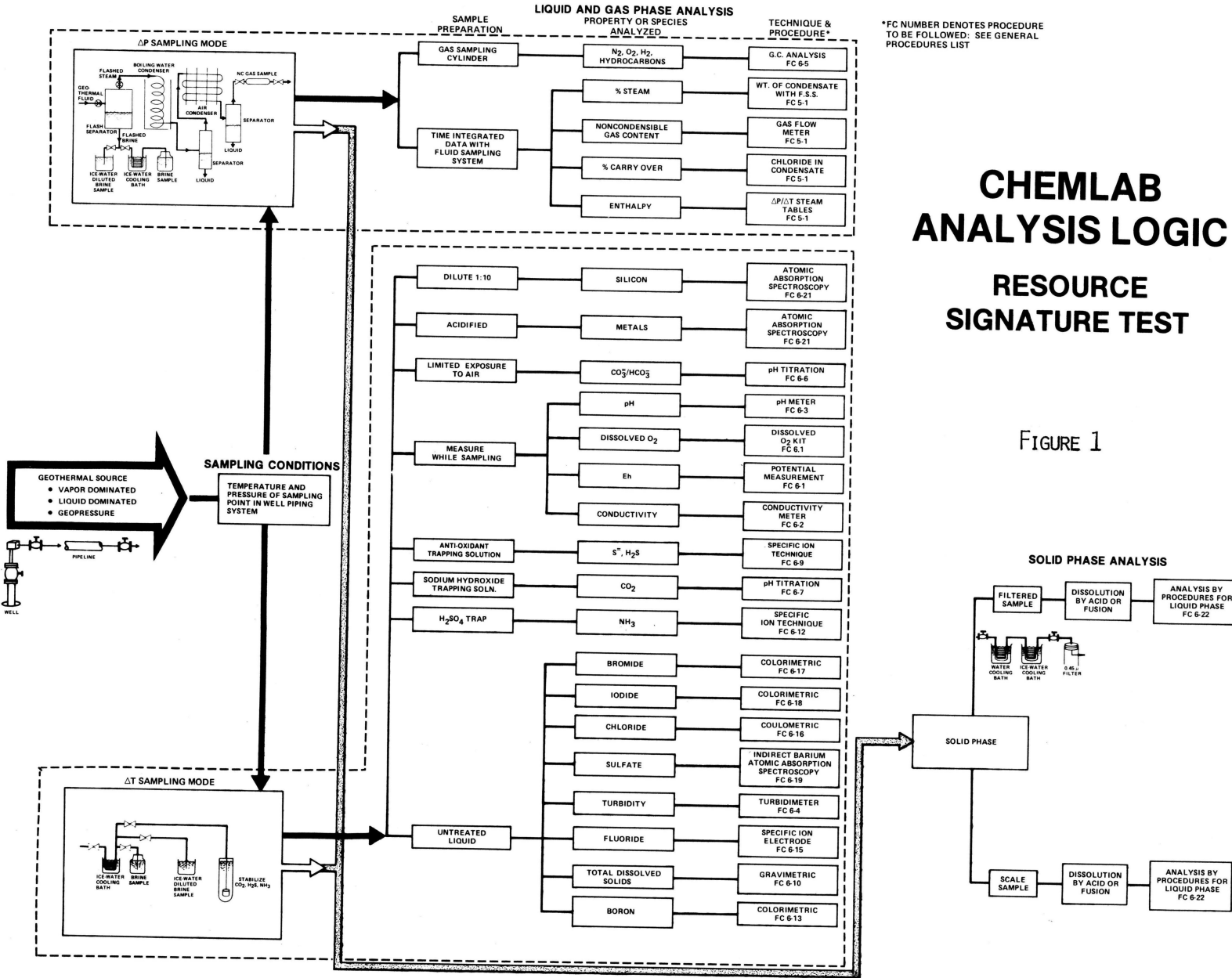
TABLE 2

CHEMICAL SPECIES AND PHYSICAL PROPERTIES MEASURED

A. Cations:	Ag, Al, As, B, Ba, Ca, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Si, Sn, Ti, V, Zn, NH ₄ ⁺
B. Anions:	Br, Cl, HCO ₃ , CO ₃ , F, I, S, SO ₄
C. Gases:	CO ₂ , O ₂ , H ₂ , H ₂ S, N ₂ , hydrocarbons
D. Properties:	TDS, conductivity, pH, E _H , turbidity, enthalpy, gas: brine ratio, steam fraction

TABLE 1
 MAJOR ANALYTICAL EQUIPMENT FOR CHEMICAL ANALYSIS
 AND PHYSICAL PROPERTY MEASUREMENT

Equipment	Test Capability
Atomic Absorption Spectrophotometer	Analysis of Metals
UV-Visible Spectrophotometer	Colorimetric Analysis
Coulometric Chloride Meter	Chloride Ion Measurement
Automatic Titrating System	Analysis of Total Alkalinity, Carbonate-Bicarbonate
Gas Chromatographic System	Analysis of Noncondensable Gases
pH, Specific Ion Meter	Measurement of pH and Redox Potentials, Specific Ion Concentrations
Fluid Sampling System	Sampling Noncondensable Gases, Steam and Geothermal Brine
Balances	
Analytical - 200 g \pm 0.2 mg	Weighing samples requiring accurate results on small samples
Top Loading Electronic - 3000 g \pm 0.1 g	Weighing of large samples and quick rough weighings
Turbidimeter	Determination of turbidity
Conductivity Meter	Measurements of conductivity samples
Drying Oven	Determination of moisture content, total dissolved solids
Stereomicroscope	Microscopic examination of samples



CHEMLAB ANALYSIS LOGIC

RESOURCE SIGNATURE TEST

FIGURE 1

TABLE 3
ANALYTES CHOSEN FOR ANALYTICAL REPRODUCIBILITY TESTING

Analytes Expected To Be Stable	
Analyte	Method
TDS	Gravimetry
Cl ⁻	Coulometric titration
CO ₂ (dissolved)	pH titration
K, Na, Li, Ca, Si, Mn	Atomic absorption
B	Colorimetry
HCO ₃ ⁻	pH titration
Gases	Gas chromatography

Analytes Suspected To Be Unstable	
Analyte	Method
S ⁼	Colorimetry
E _H	Redox electrode
pH	Glass electrode
O ₂ (dissolved)	Membrane electrode

TABLE 4
RESULTS OF ANALYSIS REPRODUCIBILITY STUDY: STABLE GEOTHERMAL SAMPLES

Analyte	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Ave	σ^*	$\lambda \frac{\sigma}{\bar{x}} \dagger$
TDS (mg/kg)	4120	4110	4160	4200	4110	4110	4110	-	4131	35.3	0.8%
Cl ⁻ (mg/kg)	1980	1980	1980	1960	1980	1980	1980	-	1977	7.56	0.4%
CO ₂ (mg/kg)	693	487	716	663	600	659	717	-	648	81.6	12%
K (mg/kg)	110	101	105	104	107	103	108	107	106	2.9	2.3%
Na (mg/kg)	1430	1490	1390	1410	1360	1490	1450	1440	1432	45.6	2.7%
Li (mg/kg)	3.91	4.13	4.15	4.12	4.16	4.18	4.19	4.22	4.13	0.096	1.9%
Ca (mg/kg)	23.6	24.0	23.8	24.6	25.1	23.8	23.7	24.4	24.1	0.53	1.8%
Si (mg/kg)	109	104	103	105	103	106	105	104	105	1.96	1.6%
Mn (mg/kg)	0.010	0.0085	0.0225	0.0215	0.012	0.011	0.011	0.0225	0.015	0.0061	34%
B (mg/kg)	4.53	4.55	4.85	4.62	4.65	4.75	4.51	-	4.64	0.12	2.5%
HCO ₃ ⁻ (mg/kg)	429	429	427	427	431	433	431	-	430	2.2	0.5%

* Standard deviation.

$$\dagger \lambda \frac{\sigma}{\bar{x}} = \frac{t\sigma/\sqrt{n}}{\bar{x}} \times 100, \text{ where } t = \text{Student } t \text{ factor}$$

TABLE 5
RESULTS OF ANALYSIS REPRODUCIBILITY STUDY: UNSTABLE GEOTHERMAL SAMPLES
Day 1

Analyte	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean	σ^*	$\lambda \frac{\sigma}{\bar{x}}$ †
$S^{=}$, mg/kg	0.186	0.164	0.135	0.160	0.119	0.176	0.141	0.163	0.156	0.022	11%
E_H , mV	-10	-125	-12	-115	-105	6	-100	-50	-64	54	69%
pH	5.87	5.86	5.87	5.87	5.87	5.95	5.88	5.88	5.88	0.029	0.4%
O_2 (dissolved), 5.8 mg/kg	2.8	1.6	2.4	2.7	3.4	2.3	2.5	2.9	2.9	1.3	34%

Analyte	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Mean	σ^*	$\lambda \frac{\sigma}{\bar{x}}$ †
$S^{=}$, mg/kg	0.186	0.151	0.176	0.176	0.183	0.199	0.147	0.112	0.163	0.029	16%
E_H , mV	-10	40	93	92	152	130	180	205	127	57	40%
pH	5.87	5.95	6.03	6.01	5.95	6.03	6.00	6.01	6.00	0.034	0.5%
O_2 (dissolved), 5.8 mg/kg	5.8	3.1	4.0	3.7	3.7	3.6	5.2	4.4	4.0	0.68	15%

* Standard deviation

† $\lambda \frac{\sigma}{\bar{x}} = \frac{t\sigma/\sqrt{n}}{\bar{x}}$ x 100, where t = Student t factor

TABLE 6
RESULTS OF ANALYSIS REPRODUCIBILITY STUDY: GAS SAMPLES

Analyte	Day (1)						Mean	σ^*	$\lambda \frac{\sigma}{\bar{x}}$ †
	(1)	(2)	(3)	(4)	(5)	(6)			
H ₂ S mole %	78.5	79.7	79.8	79.2	79.1	78.6	79.2	0.54	0.7%
CH ₄ mole %	11.9	12.3	12.2	12.4	12.4	12.4	12.3	0.2	2%
C ₂ H ₆ mole %	0.139	0.142	0.142	0.144	0.144	0.144	0.142	0.002	2%
C ₃ H ₈ mg/kg	236	230	259	256	200	195	229	27	12%
N ₂ mole %	7.66	7.86	7.84	8.03	8.05	8.06	7.92	0.16	2%
H ₂ O mole %	3.77**	1.46	1.47	1.77	1.68	1.47	1.57	0.15	12%
H ₂ mole %	0.212**	0.160	-	0.155	0.160	-	0.158	0.003	5%

* Standard deviation

† $\lambda \frac{\sigma}{\bar{x}} = \frac{t\sigma/\sqrt{n}}{\bar{x}}$ x 100, where t = Student t factor

** Not included in mean

within the capability of the laboratory. Auxiliary analytical capability available at Rockwell International laboratories may be used in support of special tests; x-ray diffraction of solid scale samples is the most frequent example.

To ensure the reliability of all data generated on the mobile geothermal laboratory, a series of quality control procedures has been developed. These include collection of multiple samples or measurement during sampling of unstable species and performance of multiple analyses for most chemical species. Chemical measurements are made against commercially prepared analytical standards and instrument calibration is routinely checked during analytical activities. Control solutions are measured along with standard and sample solutions; these controls are the same solutions at each field site and so provide a valid measure of the reproducibility of the analytical measurements at different sites. Before a control solution is completely used, another is prepared and the solutions are cross-checked, assuring continuity of measurement as the laboratory moves from one site to another. All sampling and analytical procedures conform to the standard quality control and quality assurance procedures used in the Rockwell International Environmental Monitoring and Services Center laboratories.

East Mesa, CA Site Visit, August - September 1980 In August 1980, the mobile laboratory traveled to the East Mesa, CA geothermal site to conduct reproducibility tests on the sampling and analytical procedures and to conduct a signature test on East Mesa Well 8-1. The results of the reproducibility tests were used to modify the quality control procedures, the sampling procedures, and the analytical procedures used on the mobile laboratory.

Analysis reproducibility tests were designed to demonstrate the reliability of analytical measurements made in the laboratory; a collection of species, representative of the types of species measured and analytical methods used, was chosen for the analysis reproducibility tests. These species are listed in Table 3, in two groups, those expected to be stable and those suspected to be unstable. Each chemical species measured as a liquid sample was measured once a day for eight days, and in addition those species suspected to be unstable were measured eight times the first day. Gas samples were measured six times the same day. Repetitive

measurements were made on aliquots of the same solution. Statistical analyses were conducted on all repetitive measurements. The results for the stable species are presented in Table 4, those for the unstable species in Table 5, and those for the gases in Table 6.

From Table 4, it is clear that most of the samples are stable over an eight-day period for the analysis of those species listed, and that the analyses are reproducible. Two of the analyses gave a 95% confidence interval larger than 10%: total CO₂ and Mn. Samples for total CO₂ should be considered potentially unstable; procedures have been modified to specify analysis as soon as possible after the sampling. The measured value for Mn, 0.015 mg/kg was very close to the detection limit of 0.01 mg/kg and so the high confidence interval is not unexpected. Analysis of the results for those species suspected to be unstable indicate that precautions should be taken during these measurements; sulfide, E_H and dissolved oxygen have unacceptable reproducibility. As a result of these studies, a flow-through sampling probe has been fabricated and E_H, pH, and dissolved oxygen are measured while sampling. The measurement of S⁼ is performed as soon after sampling as possible. The analyses for gases gave satisfactory results; twelve percent reproducibility was achieved for the propane fraction, which was very near the detection limit of 200 mg/kg, and for the gaseous water fraction.

Experiments were conducted to examine the reproducibility of results on samples collected in the ΔP and ΔT modes. Again a small subset of the signature test analytes was chosen for the test; these are listed in Table 7. Samples for each measurement were collected in the ΔP mode and in the ΔT mode, and then analyzed for the chosen species. The results of these analyses are presented in Table 8.

Differences brought about by the two different sampling modes were insignificant for the analyses of TDS, Cl⁻, Si, and enthalpy. In the other cases, the samples reflect the effect of the different sampling modes on the chemical equilibria involving CO₂ and H₂S dissolution in the liquid samples and the CO₃⁼ and S⁼/H₂S equilibria in solution. In the ΔT sampling mode, CO₂ and H₂S remain in solution upon sampling, while in the ΔP mode, they may flash from the solution under the reduced

TABLE 7

ANALYTES CHOSEN FOR SAMPLING
REPRODUCIBILITY TESTING

Analyte	Method
TDS	Gravimetry
Cl ⁻	Coulometric titration
Cu, Mn, Si	Atomic absorption
CO ₃ ⁼ , HCO ₃ ⁻	pH titration
S ⁼	Colorimetry
Enthalpy	ΔP/ΔT steam tables

TABLE 8

RESULTS OF SAMPLING
REPRODUCIBILITY STUDY

Analyte	Sampling Mode	
	ΔP	ΔT
TDS (mg/kg)	4150	4200
Cl ⁻ (mg/kg)	2055	2030
Ca (mg/kg)	11.3	25.1
Mn (mg/kg)	(0.004)*	0.03
Si (mg/kg)	98	95
CO ₃ ⁼ (mg/kg)	28.5	0
HCO ₃ ⁻ (mg/kg)	332	437
S ⁼ (mg/kg)	0.24	0.45
Enthalpy (BTU/lb)	287	280

*Estimate, value was below detection limit of 0.01.

pressure, giving less representative samples. As a result of these experiments, procedures were modified to specify collection of samples to be analyzed for total CO₂, total H₂S/S⁼, metals, and anions in the ΔT mode. Non-condensable gas samples are collected in the ΔP mode.

Following the reproducibility tests at East Mesa, a signature test was performed to characterize the geothermal fluid from well 8-1. The results of the signature test are presented in Table 9.

The geothermal fluid from East Mesa

Well 8-1 has significant ionic content, with the major components being calcium, potassium, sodium, silicon, chloride, bicarbonate, and sulfate. Minor components include boron, lithium, ammonium, strontium, and fluoride, and trace components include arsenic, barium, iron, magnesium, manganese, sulfide, and zinc. The most abundant gaseous component is carbon dioxide, while nitrogen and methane are also present in significant quantities, and hydrogen, water, ethane, and propane are present in small quantities.

Brazoria County, TX Site Visit, October 1980

In October 1980, the mobile laboratory travelled to the DOE geopressure facility in Brazoria County, TX to conduct signature tests on Pleasant Bayou well number 2. Because the brine pressures at the wellhead (3600 psig) exceeded the capacity of the fluid sampling system (1000 psig), samples were collected downstream of the separator (800 psig) from both the gas stream and the liquid stream. Figure 2 is a simplified diagram of the system. The sample values were then normalized to the original wellstream using flow values obtained from site personnel.

Two signature tests were performed on Pleasant Bayou well number 2; for the first, samples were collected from the separator gas outlet (A, Figure 2) and from a sample cock downstream of the separator dump valve (C, Figure 2) and for the second, both gas and liquid samples were collected from a sample cock upstream of the separator dump valve (B, Figure 2). The results of the analysis of gases collected at the gas outlet and upstream of the dump valve were very different. These results are presented in Table 10. The differences in gas concentrations at the two sampling sites reflect the differences in water solubility among the gases. Carbon dioxide is very soluble in water and so is found in a large concentration in the liquid stream. The hydrocarbons, in contrast, dissolve very little in water and so are found primarily in the gas stream. The data for the signature test on Pleasant Bayou well number 2 are presented in Table 11; all values are normalized to represent the wellstream (before the separator) values.

TABLE 9
SIGNATURE TEST RESULTS SUMMARY, EAST MESA WELL 8-1

Analyte	Result	Analyte	Result
TDS, mg/kg	4100	Br ⁻ , mg/kg	ND (8)
Conductivity, μ mho/cm	7290	Ca, mg/kg	245 (0.01)
pH	5.55	Cl ⁻ , mg/kg	1980
E _H , mV	-213	Co, mg/kg	ND (0.05)
Dissolved O ₂ , mg/kg	0.15	CO ₃ ⁼ , mg/kg	ND (30)
Turbidity, NTU	0.18	CO ₂ , mg/kg	*
Enthalpy, BTU/lb	280	Cr, mg/kg	ND (0.05)
Gas/brine ratio, l/kg	15	Cu, mg/kg	ND (0.02)
Steam fraction, %	8.95	F ⁻ , mg/kg	3.7
Ag, mg/kg	ND [†] (0.01)	Fe, mg/kg	0.98
Al, mg/kg	ND (0.1)	HCO ₃ ⁻ , mg/kg	426
As, mg/kg	0.3	Hg, mg/kg	ND (0.2)
B, mg/kg	4.7	I ⁻ , mg/kg	ND (0.05)
Ba, mg/kg	0.60	K, mg/kg	109

(continued)

TABLE 9 (con't)
SIGNATURE TEST RESULTS SUMMARY, EAST MESA WELL 8-1

Analyte	Result	Analyte	Result
Li, mg/kg	4.15	Sr, mg/kg	2.97
Mg, mg/kg	0.90	Ti, mg/kg	ND (0.4)
Mn, mg/kg	0.031	V, mg/kg	ND (0.2)
Mo, mg/kg	ND (0.1)	Zn, mg/kg	0.008
Na, mg/kg	1428	CO ₂ (gas), mg/kg	22083
NH ₃ , mg/kg	9.2	H ₂ (gas), mg/kg	0.20
Ni, mg/kg	ND (0.04)	H ₂ O (gas), mg/kg	180
Pb, mg/kg	ND (0.1)	H ₂ S (gas), mg/kg	ND (5)
S ⁼ , mg/kg	0.47	N ₂ (gas), mg/kg	1400
Sb, mg/kg	ND (0.2)	CH ₄ (gas), mg/kg	1250
Si, mg/kg	93	C ₂ H ₆ (gas), mg/kg	30.3
Sn, mg/kg	ND (0.8)	C ₃ H ₈ (gas), mg/kg	5.6
SO ₄ ⁼ , mg/kg	119	C ₄ H ₁₀ (gas), mg/kg	ND (5)

† Not detected (detection limit).

* Traps saturated.

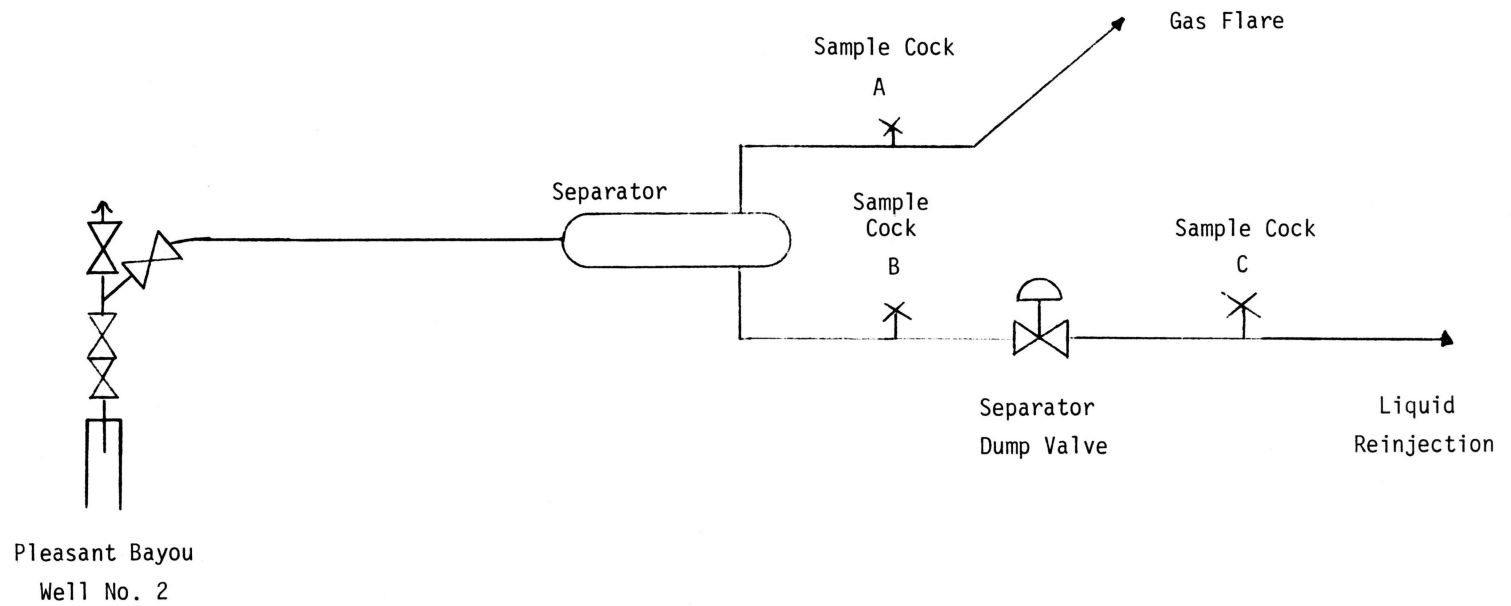


Figure 2. System Diagram

DOE GEOTHERMAL SITE, BRAZORIA COUNTY, TX.

TABLE 10
 NON-CONDENSIBLE GASES MEASURED
 AT PLEASANT BAYOU WELL NUMBER 2

<u>Analyte</u>	<u>Location</u>	
	<u>Gas Outlet (A)**</u>	<u>Upstream of Dump Valve (B)**</u>
CO ₂ (gas)	267630*	763000
H ₂ (gas)	31	81
H ₂ O (gas)	ND†	10600
H ₂ S (gas)	ND	ND
N ₂ (gas)	8350	2380
CH ₄ (gas)	666400	212700
C ₂ H ₆ (gas)	25980	6560
C ₃ H ₈ (gas)	25880	2880
C ₄ H ₁₀ (gas)	4794	531

* Values are mg/kg of gas at the site of collection.

† Not detected

**See Figure 2

TABLE 11
SIGNATURE TEST RESULTS SUMMARY, PLEASANT BAYOU WELL NUMBER 2

Analyte	Result	Analyte	Result
TDS, mg/kg	124500	Br ⁻ , mg/kg	52
Conductivity, μ mho/cm	1.4×10^5	Ca, mg/kg	7231
pH	5.18	Cl ⁻ , mg/kg	72100
E _H	-37	Co, mg/kg	ND (0.05)
Dissolved O ₂ , mg/kg	ND (0.05)	CO ₃ ⁼ , mg/kg as CO ₃ ⁼	ND (30)
Turbidity, NTU	4.2	CO ₃ ⁼ , mg/kg, total	12600
Enthalpy, BTU/lb.	224	Cr, mg/kg	0.07
Gas/brine ratio, l/kg	4.30	Cu, mg/kg	0.03
Steam fraction, %	3.4	F ⁻ , mg/kg	2.0
Ag, mg/kg	ND (0.01)	Fe, mg/kg	80.7
Al, mg/kg	ND (0.1)	HCO ₃ ⁻ , mg/kg	191
As, mg/kg	ND (0.2)	Hg, mg/kg	ND (0.2)
B, mg/kg	26	I ⁻ , mg/kg	8
Ba, mg/kg	817	K, mg/kg	504

(continued)

TABLE 11 (con't)
SIGNATURE TEST RESULTS SUMMARY, PLEASANT BAYOU WELL NUMBER 2

Analyte	Result	Analyte	Result
Li, mg/kg	28.3	Sr, mg/kg	947
Mg, mg/kg	612	Ti, mg/kg	ND (0.4)
Mn, mg/kg	20.3	V, mg/kg	ND (0.2)
Mo, mg/kg	ND (0.1)	Zn, mg/kg	0.751
Na, mg/kg	37097	CO ₂ (gas), mg/kg	2169
NH ₃ , mg/kg	77	H ₂ (gas), mg/kg	0.24
Ni, mg/kg	0.094	H ₂ O (gas), mg/kg	17.8
Pb, mg/kg	0.85	H ₂ S (gas), mg/kg	ND (0.5)
S ⁼ , mg/kg	0.125	N ₂ (gas), mg/kg	31.7
Sb, mg/kg	ND (0.2)	CH ₄ (gas), mg/kg	2209
Si, mg/kg	55.3	C ₂ H ₆ (gas), mg/kg	97
Sn, mg/kg	ND (0.8)	C ₃ H ₈ (gas), mg/kg	91
SO ₄ ⁼ , mg/kg	ND (10)	C ₄ H ₁₀ (gas), mg/kg	17

The geothermal fluid for Pleasant Bayou Well number 2 has a very high ionic content, of which the major components are barium, calcium, potassium, magnesium, strontium, and chloride. Minor components are boron, iron, lithium, manganese, ammonium, silicon, bromide, fluoride, bicarbonate, and iodide, and trace components are chromium, copper, nickel, lead, zinc, and sulfide. The most abundant gases are carbon dioxide and methane, while ethane, propane, butane, hydrogen, water and nitrogen are present in measurable quantities. Sodium hydroxide traps were saturated during the collection of samples for the measurement of total CO₂, indicating very large concentrations. Techniques for the collection of total carbon dioxide need additional improvement.

Recent Activity, 1981 The mobile laboratory travelled to a demonstration geothermal power plant at Brawley, CA to conduct signature tests of the geo-

thermal fluid, tracking tests of important chemical components at six sites around the system, and a special test on a scale sample.

The laboratory then travelled to a well site at Dixie Valley, NV in support of the test of a heat exchanger; a signature test on the brine entering the heat exchanger was performed along with tracking tests on the fluid at four ports within the heat exchanger and special tests of solid scale samples taken from within the heat exchanger.

Planned Activity, 1981 The mobile laboratory will travel in the future to conduct signature tests at hydrothermal and geopressure facilities, to collect data for the EPRI brine data base. In addition, it will lend support to EPRI field tests including tests of a rotary separator turbine, an upstream hydrogen sulfide removal process, and a steam separator.