SABLE UNIT AUTOMATIC CO_2 INJECTION SYSTEM

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FIELD DESCRIPTION:

Arco's Sable Unit is located in Yoakum County, Texas, seven miles northwest of the town of Plains. (See Figure 1) The unit produces from the San Andres Formation from a nominal depth of 5100 feet. Water injection operations began in 1967. CO2 injection began in April, 1984. CO2 is transported to the Sable Unit via Arco's Sheep Mountain pipeline from the Sheep Mountain CO2 field in Colorado.

SYSTEM OBJECTIVES:

The automation system was designed to provide accurate measurement and control of the CO2 injection process and to provide communications between the wells and a central terminal unit. The central terminal unit was to make automatic scans of the field and generate alarm/alert reports in the event of a malfunction at a well. In addition, the central terminal unit would provide historical reports of injection volumes, rates and pressures from all wells.

The planned injection pressure was between 1600 and 1700 psig and the expected temperature was between 40 and 70 degrees F. Under these conditions, the CO2 is in the critical phase. In this phase, the density and therefore the flow rate are sensitive to changes in temperature and pressure. It was determined that, in order to obtain accurate measurement, it would be necessary to compensate the flow equation for specific gravity based on process temperature and pressure and on composition of the CO2 injection stream.

THE SYSTEM:

WELL EQUIPMENT

The well equipment consists of:

1. Process transmitters including:
    a. flow line pressure
    b. well head pressure
    c. flow line temperature
    d. differential pressure

2. Flow measurement element, a Taylor flow wedge.

3. A ten turn Hydril vci variable choke, equipped with a reversing 24 VDC reversing electric actuator.

4. Microprocessor based remote terminal unit with the capacity to:

    a. calculate critical flow rate, as by a differential pressure device or turbine meter.

    b. integration of the flow to provide a measurement of accumulated flow.

    c. compare the calculated flow rate with a set point and to provide control pulses to open or close a valve to cause the flow to equal the set point.

    d. compare pressure down stream of choke to a maximum pressure set point and control on pressure if flow rate set point is not reached.

    e. manually override the control system through an auto/manual switch.

    f. local volume readout by means of a six digit LCD display.

    g. serial communications.

MASTER TERMINAL UNIT (MTU):

The Master Terminal Unit (MTU) automatically scans all of the RTUs on an operator assigned schedule and reports any alerts and/or alarms. The master terminal unit also stores historical data and produces reports regarding the operation of the field.

The Master Terminal Unit consists of:

1. An IBM PC desk top computer with:
    a. 256K bytes of RAM memory
    b. two disk drives (360K bytes)
    c. a synchronous serial communications port

2. 13 inch Monochrome Monitor

3. 80/132 column dot Matrix Printer

4. RS232C/TTL Signal Level Converter

5. Bell 103 (300 Baud) compatible, wireline modem

6. System software including:

    a. system operating program (main program)
    b. utility program (add and delete wells, assign RTU address, etc.)
    c. technician service program (read and write to all RTU registers)
    d. alert/alarm scan program
    e. CO2 density calculation / K factor calculation

6. f. gas composition calculation program
   g. data collection/storage program
   h. operational report generator (day, week, month)

   NOTE: All software is written in interpretive Basic.

REMOTE TERMINAL UNIT (RTU):

The Remote Terminal Unit (RTU) is a microprocessor based (Intell 8749) unit with eight (8) analog inputs, four (4) status inputs and four (4) control outputs.

The analog inputs are used to read the values of the well head pressure, differential pressure, meter temperature and the meter pressure.

The status inputs are used to determine the operation of the control section of the RTU i.e. manual or automatic, determine the type of injection fluid (CO2 or water) and to detect the presence of high casing pressure.

The control outputs are used to operate a reversing electric actuator on the control valve and to drive a local LCD volume readout.

The logic portion of the RTU makes flow calculations, stores data and provides communications through a UART and a modem.

The RTU is equipped with a nonvolatile memory (battery backed up random access memory or BRAM). All data and information pertinent to the operation of the RTU is stored in the BRAM. (RTU address, setpoints, calibration factors, configuration parameters, etc.) After any power interruption, the RTU reads the BRAM and takes up operation as it was before the loss of power. The volume accumulation is written to the BRAM once each minute to prevent loss of information due to power interruption.

COMMUNICATIONS/POWER SYSTEM:

The MTU is connected to seven (7) RTUs, located at injection wells, via a six pair 19 gauge buried telephone cable. The cable provides a communications party line via one pair and a path for 48 VDC via the rodent (common) shield and two conductor pairs (positive). A 48 VDC power supply is located at the MTU and supplies power to all RTUs.

OPERATION:

The RTU accepts inputs from a well head pressure transmitter, a differential pressure transmitter, a meter pressure transmitter and a meter temperature transmitter. The values of pressure and temperature at the meter are transmitted to the MTU which uses these values and the molecular weight of the CO2 stream to calculate the gravity of the CO2 and thereby a K factor for the meter. The K factor is transmitted to the RTU where, in combination with the differential pressure, it is used to solve the equation:

	Q	=	K * D/P **.5
Where	Q	=	Flow rate in barrels per day
	K	=	Flow constant for the meter corrected for specific gravity of the fluid (1/g **.5)
	D/P	=	Differential pressure in inches of water

The flow rate calculation is made once each second and is used for a control parameter and for accumulation of total volume injected into the well.

The control section of the RTU compares the well head pressure and flow rate with their respective setpoints (set by the operator). The controller's objective is to allow as much fluid as possible to be injected without letting either process exceed its setpoint. This is accomplished by selecting the process which is highest with respect to its setpoint and using that variable for determining the control output to the valve. Control is accomplished by sending either open or close control pulses to the actuator to cause the valve to move to a position which will cause the process to satisfy the setpoint requirements. Proportional control is accomplished by varying the length of the control pulses. The duration of the control pulse is proportional to the magnitude of the error times the gain factor (set by the operator).

INSTALLATION AND COMMISSIONING:

In the initial phase of the project, one well was equipped with control relays and control valve. Six wells were equipped to measure flow only. This arrangement was used to allow evaluation and "debugging" of the control system on a small scale rather than being faced with the necessity to retrofit all well equipment to correct any problems.

As with most new projects, some problems were encountered during startup and commissioning.

Device I/O errors in the master terminal unit were caused by the presence of noise on the communications line after the completion of the message. Initially, this error would "lock up" the system. The initial effort to deal with the problem was to trap out the error and allow the system to run after the occurrence of the error. This procedure, while technically acceptable, in that no data was affected, was not operationally acceptable. The device I/O error was eliminated by modifying the RTU firmware to allow the communications carrier to remain on for 50 mSec after the message transmission is complete.

The valve operator had a high current drain (over 2.5 amps at 24 VDC). This high current required the installation of a battery at the RTU to supply adequate operating voltage to the valve actuator. One result of the high power drain was the discharge of the battery during power interruptions. Damage of electronics in the RTU was associated with the loss of regulated power associated with deep discharge of the batteries.

A "watch dog" relay was installed at the RTU to disconnect the valve actuator from the electrical system in the event of interruption of the 48 VDC power. This allows the measurement and communication functions of the RTU to continue while the control function is discontinued for the duration of the power outage. When the power is disconnected from the valve, the valve remains at its last position as called for by the controller.

It was found, the keying of a communications radio in the area of the well would cause the valve to operate. The cause of this problem was traced to induced RF energy in the process transmitters. The induced signal provides incorrect information to the controller, thus causing the controller to operate the valve. Bypassing and shielding had some effect on the problem but did not totally eliminate the interference. The only means to prevent RF interference is to refrain from using high power RF transmitters in the immediate vicinity of the well head.

Cross talk between channels of the multiplexed A to D converter in the event of an over range of one of the process transmitter outputs was eliminated by clamping the input with zener diodes.

FUTURE ENHANCEMENTS:

Tests with lower cost control valves are planned to access the feasibility of their use on future wells.

A test is planned to use one system pressure and temperature measurement to calculate the K factor for a specific group of wells. If successful, this procedure will greatly reduce the hardware cost required for each well.

CONCLUSIONS:

1. The measurement techniques used in this project are feasible and accurate. Physical measurements of the gas have shown the calculated specific gravity, and therefore the volume to be within 2%.

2. The control of the flow of the injected fluid is accurate and reliable.

3. The information provided by the system is timely and accurate.

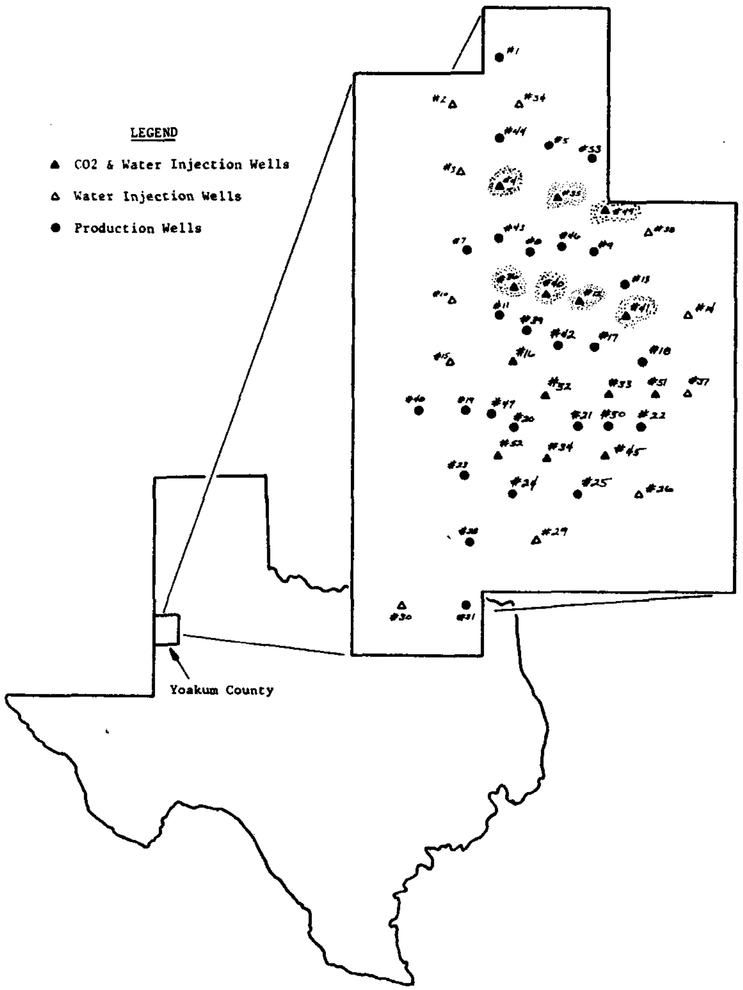

Figure 1 - Sable Unit - location and arrangement of wells

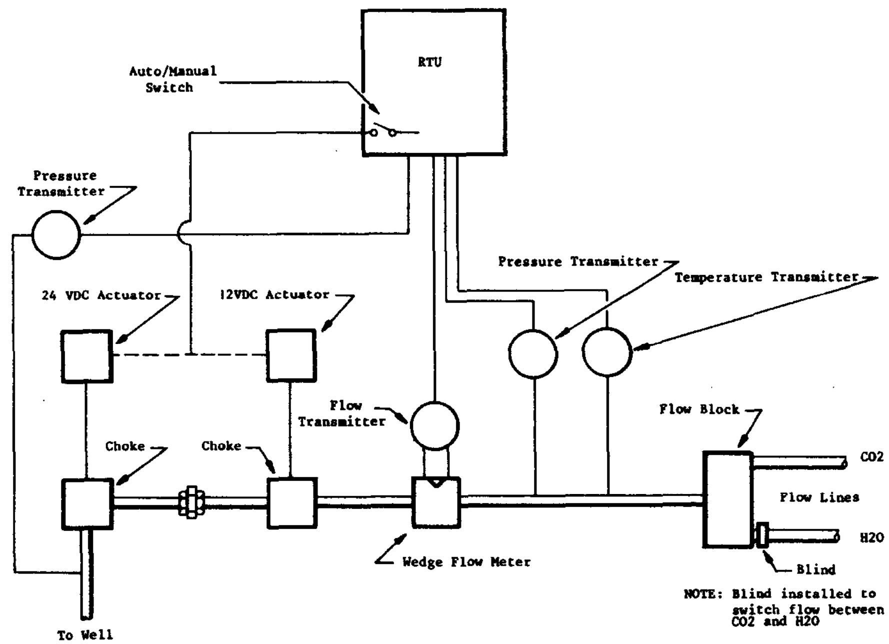

Figure 2 - Well head assembly

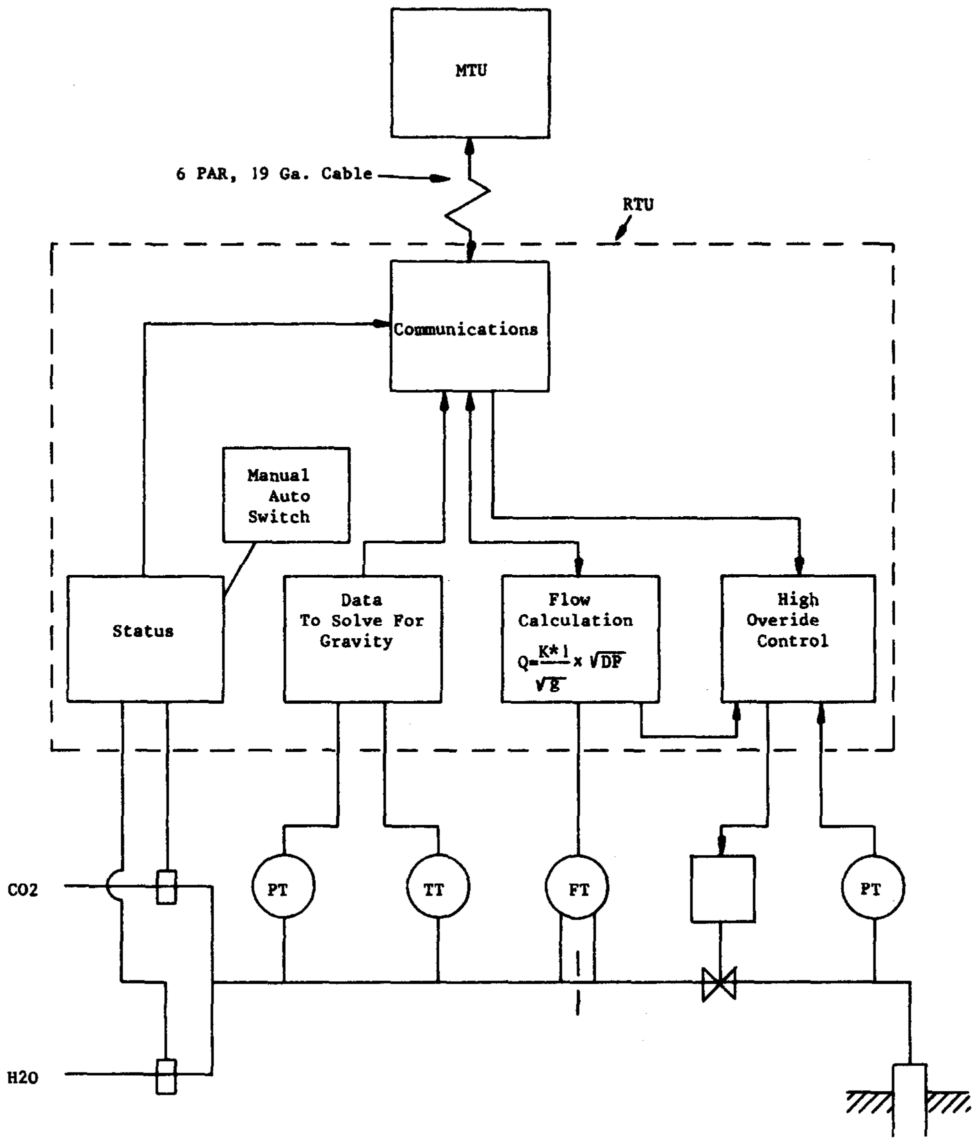

Figure 3 - Block diagram - Sable Unit simplified system

DATE
02-05-1985
TIME
07:01:43

SABLE UNIT MORNING REPORT

MOLECULAR WEIGHT OF SHEEP MOUNTAIN CO2 = 43.538
OVERALL TOTAL VOLUME FOR ALL WELLS

DAILY CO2 VOL 220 MSCF (77 BBLS)
DAILY WTR VOL 448 BBLS

CO2 WELLS

WELL NO	FLUID VOLUME (MSCF/BBLS)	AVG WHP (PSIG)	AVG FVF (BBL/MCF)	AVG METER PRESS	AVG TEMP (F.)	ALARM
35	220/ 77	-750	0.3506	1740	44.2	MANUAL CHOKE

WTR WELLS

WELL NO	FLUID VOLUME (BBLS)	AVG WHP (PSIG)	AVG FVF (BBL/MCF)	AVG METER PRESS	AVG TEMP (F.)	ALARM
4	73	1131	1.0000	1139	47.4	OK
12	100	-750	1.0000	1162	51.6	MANUAL CHOKE
36	0	0	1.0000	0	0.0	OK
40	0	-750	1.0000	1146	49.9	MANUAL CHOKE
41	115	-750	1.0000	1126	52.3	MANUAL CHOKE
49	160	-750	1.0000	1133	48.6	MANUAL CHOKE

SABLE UNIT WEEKLY REPORT 12/14/84

4	0	BBLS CO2
4	577	BBLS WTR
12	0	BBLS CO2
12	727	BBLS WTR
35	638	BBLS CO2
35	0	BBLS WTR
36	0	BBLS CO2
36	868	BBLS WTR
40	0	BBLS CO2
40	774	BBLS WTR
41	0	BBLS CO2
41	1025	BBLS WTR
49	0	BBLS CO2
49	1240	BBLS WTR

SABLE UNIT MONTHLY REPORT 10/31/84

4	2135	BBLS CO2
4	-1225	BBLS WTR
12	3967	BBLS CO2
12	9502	BBLS WTR
35	7542	BBLS CO2
35	9502	BBLS WTR
36	7713	BBLS CO2
36	16991	BBLS WTR
40	8972	BBLS CO2
40	29253	BBLS WTR
41	9129	BBLS CO2
41	37526	BBLS WTR
49	10059	BBLS CO2
49	50710	BBLS WTR

COMMUNICATIONS FAILURE WELL # 36
02-04-1985 07:03 LO RATE(0 BBLS/D) WELL 40

SABLE UNIT PRESSURE AND RATE SURVEILLANCE REPORT
07:23:36 02-04-1985

FORWARD THIS REPORT TO MIKE REDDEN IN MIDLAND

well #-	4		12		35		36		40		41		49	
	RATE	PRES	RATE	PRES	RATE	PRES	RATE	PRES	RATE	PRES	RATE	PRES	RATE	PRES
TIME	bpd	psi	bpd	psi	bpd	psi	bpd	psi	bpd	psi	bpd	psi	bpd	psi
07:30	88	1125	106	1140	79	1740	0	0	0	1125	117	1110	170	1110
08:00	80	1125	99	1140	82	1740	0	0	0	1125	117	1110	169	1125
08:30	77	1125	99	1140	82	1740	0	0	0	1140	117	1110	173	1125
09:00	80	1125	106	1155	87	1740	0	0	0	1140	119	1110	174	1125
09:30	80	1125	106	1155	82	1740	0	0	0	1140	119	1110	168	1125
10:00	80	1125	106	1155	79	1740	0	0	0	1140	119	1110	161	1125
10:30	77	1125	99	1155	77	1740	0	0	0	1140	119	1110	155	1125
11:00	71	1125	99	1155	77	1740	0	0	0	1140	117	1110	148	1125
11:30	71	1125	99	1155	77	1740	0	0	0	1140	120	1110	150	1125
12:00	71	1125	99	1140	77	1740	0	0	0	1125	120	1110	147	1125
12:30	71	1125	99	1140	77	1740	0	0	0	1125	120	1110	152	1125
13:00	71	1125	106	1140	77	1740	0	0	0	1125	120	1110	155	1125
13:30	71	1125	106	1140	77	1740	0	0	0	1125	120	1110	161	1125
14:00	71	1125	106	1140	90	1740	0	0	0	1125	120	1110	165	1110
14:30	71	1125	106	1140	87	1740	0	0	0	1125	120	1110	168	1125
15:00	77	1125	106	1140	85	1740	0	0	0	1125	120	1110	164	1110
15:30	80	1125	106	1140	85	1740	0	0	0	1125	120	1110	166	1110
16:00	83	1125	106	1140	85	1740	0	0	0	1125	120	1110	166	1110
16:30	83	1125	106	1140	85	1740	0	0	0	1125	120	1110	169	1110
17:00	83	1125	106	1140	85	1740	0	0	0	1125	120	1110	165	1110
17:30	83	1125	106	1140	85	1740	0	0	0	1125	120	1110	166	1110
18:00	80	1125	106	1140	87	1740	0	0	0	1125	119	1110	164	1110
18:30	80	1125	106	1140	93	1740	0	0	0	1125	119	1110	165	1110
19:00	80	1110	106	1140	90	1740	0	0	0	1125	119	1110	165	1110
19:30	77	1110	99	1140	87	1740	0	0	0	1125	119	1095	165	1110
20:00	77	1110	99	1140	87	1740	0	0	0	1125	119	1095	165	1110
20:30	77	1110	99	1140	87	1740	0	0	0	1125	119	1095	165	1110
21:00	77	1110	99	1140	85	1740	0	0	0	1125	119	1095	162	1110
21:30	77	1110	99	1140	85	1740	0	0	0	1125	119	1095	164	1110
22:00	77	1110	99	1140	82	1740	0	0	0	1125	119	1095	165	1110
22:30	77	1110	106	1140	82	1740	0	0	0	1125	119	1095	161	1110
23:00	77	1110	106	1140	82	1740	0	0	0	1125	119	1095	162	1110
23:30	77	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
24:00	77	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
00:30	77	1110	99	1140	79	1740	0	0	0	1125	119	1095	164	1110
01:00	77	1110	106	1140	85	1740	0	0	0	1125	119	1095	162	1110
01:30	77	1110	106	1140	82	1740	0	0	0	1125	119	1095	164	1110
02:00	77	1110	106	1140	85	1740	0	0	0	1125	119	1095	162	1110
02:30	77	1110	99	1140	85	1740	0	0	0	1125	119	1095	165	1110
03:00	77	1110	106	1140	82	1740	0	0	0	1125	119	1095	164	1110
03:30	77	1110	106	1140	85	1740	0	0	0	1125	119	1095	162	1110
04:00	77	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
04:30	77	1110	106	1140	82	1740	0	0	0	1125	119	1095	165	1110
05:00	75	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
05:30	75	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
06:00	75	1110	99	1140	82	1740	0	0	0	1125	119	1095	162	1110
06:30	77	1110	99	1140	79	1740	0	0	0	1125	119	1095	164	1110
07:00	75	1110	99	1140	79	1740	0	0	0	1125	119	1095	162	1110

```
02-04-1985  08:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  08:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  08:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  08:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  09:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  09:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  09:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  09:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  10:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  10:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  10:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  10:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  11:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  11:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  11:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  11:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  12:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  12:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  12:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  12:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  13:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  13:01  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  13:30  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  13:31  LO RATE( 0 BBLS/D) WELL  40
02-04-1985  14:00  *****SYSTEM UP AND RUNNING OK*****
COMMUNICATIONS FAILURE WELL # 36
02-04-1985  14:01  LO RATE( 0 BBLS/D) WELL  40
```

```
DATE  02-05-1985
TIME  13:17:45
WELL #   40              RTU ADDRESS =  40      TYPE = WTR
 PRESSURE SETPOINT=                 1225        PSIG
 GAIN =                             16
 FLOW SETPOINT =                    215         BBLS/D
 CASING PRESSURE HI LIMIT =         1000        PSIG
 METER LO LIMIT                     1000        PSIG
 KD2 =                              .211

1WELL # 2RTU #  3PRS SP 4GAIN   5FLO SP 6CSP HI 7MTR LO 8WEDGE  9TYPE    0EXIT
```

```
SYSTEM DATE AND TIME --> 02-05-1985  13:16:19
DO YOU WANT TO CHANGE DATE AND TIME???

1SUMMAR 2ANALOG 3SINGLE 4F RATE 5SCAN    6PROGS  7TIME    8MOL%    9CONT    0FILES
```

```
DATE  02-05-1985
TIME  13:16:42

NITROGEN        =  .563
CARBON DIOXIDE  =  97.99699
METHANE         =  1.302
ETHANE          =  .138
PROPANE         =  0
BUTANES         =  0
PENTANES        =  0
HEXANES         =  0
OXYGEN          =  0
                   ----------
TOTAL           =  99.99999

MOL WT    =  43.53755

1N      2CO2    3C1     4C2     5C3     6C4     7C5     8C6     9O2     0EXIT
```

```
SCANNING...
DATE  02-05-1985
TIME  13:13:10
WELL #    40

ANALOG PT  1  =  59
ANALOG PT  2  =  126
ANALOG PT  3  =  119
ANALOG PT  4  =  0
ANALOG PT  5  =  0
ANALOG PT  6  =  0
ANALOG PT  7  =  0
ANALOG PT  8  =  0
```

```
***READY***                                                        13:13:16

1SUMMAR 2ANALOG 3SINGLE 4F RATE 5SCAN   6PROGS  7TIME   8MOL%   9CONT   0FILES

SCANNING...
DATE  02-05-1985
TIME  13:13:49
WELL #    40           FLUID-WTR
MODE - MANUAL CHOKE

PRESS-WELL HEAD             -750    PSIG
PRESS-METER                 1140    PSIG
D/P-METER                      6.8  INH2O
TEMP-METER                    52    DEG-F
PRESS-CASING                -250    PSIG
WTR VOLUME-SINCE 7AM           0    BBLS
RATE-INST                      0.00 BBL/D

PRESSURE SETPOINT           1230    PSIG
GAIN                          16
FLOW SETPOINT                215.01 BBLS/D
```

```
***READY***                                                        13:14:01

1SUMMAR 2ANALOG 3SINGLE 4F RATE 5SCAN   6PROGS  7TIME   8MOL%   9CONT   0FILES
```

```
SCANNING...
DATE  02-05-1985
TIME  13:14:49
WELL #    12            FLOW RATE =  99.44196      BBLS/D
```

```
***READY***                                                        13:14:52

1SUMMAR 2ANALOG 3SINGLE 4F RATE 5SCAN   6PROGS  7TIME   8MOL%   9CONT   0FILES

CURRENT SCAN TIME IS 30  MINUTES.
PASSWORD FOLLOWED BY 'ENTER'
TYPE SCAN TIME (2-30 MINS) FOLLOWED BY 'ENTER' 30
```

```
1SUMMAR 2ANALOG 3SINGLE 4F RATE 5SCAN   6PROGS  7TIME   8MOL%   9CONT   0FILES
```