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3rd Quarter, Fiscal Year 1993

"POST WATERFLOOD CO2 MISCIBLE FLOOD IN LIGHT OIL, FLUVIAL-DOMINATED DELTAIC RESERVOIR"

DE-FC22-93BC14960

Texaco Exploration and Production Inc.

July 15, 1993

Award Date	Completion Date
June 1, 1993	December 31, 1997

Government Award for Current Fiscal Year

$ 3,424,258.00

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Reporting Period: September 15, 1992 – June 30, 1993
(Initial Quarterly Report)

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"POST WATERFLOOD CO_2 MISCIBLE FLOOD IN LIGHT OIL FLUVIAL DOMINATED DELTAIC RESERVOIR"

DE-FC22-93BC14960

Executive Summary

The selection of the Port Neches CO_2 miscible flood project by DOE on April 22, 1992 has allowed Texaco the opportunity to further the development of a technology which may hold the most promising future for the increase of domestic oil reserves within the next decade. Texaco's objective on this project has been to utilize all available technologies, and to develop new ones, to design a CO_2 flood process which is cost effective and can be applied to many other reservoirs throughout the United States. This project will determine the recovery efficiency of CO_2 floods in waterflooded and partial waterdrive reservoirs. A PC-based CO_2 screening model will be developed and a database will be generated to show the utility of this technology throughout the U. S.

After Pre-award costs were approved on September 15, 1992, Texaco proceeded with the implementation phase of the project so that new data could be gathered and necessary steps required to initiate CO_2 injection could be accomplished. An expenditure of $7,080,191 has put Texaco in a position where CO_2 injection can begin by September 1, 1993. The following tasks have been accomplished:

(1) 10 workovers (4 injection, 6 producers) are complete. Production has increased from 78 BOPD to 183 BOPD.

(2) Reservoir pressure has been increased from 1850 psi to 2700 psi by injecting saltwater.

(3) Compressors, a CO_2 injection pump, and separators have been installed on a floating barge, and is being transported to the field by a tug boat.

(4) 3 miles of the 4.5 mile CO_2 pipeline has been installed.

(5) A residual oil saturation of 30% to 35% has been measured from a new conventional core. A set of relative permeability curves have been developed.

(6) Categorical exclusion to NEPA regulations is nearing completion.

These are but a few of the milestones reached thus far. Texaco invites DOE to the initiation of CO_2 injection!

Technical Progress Report
3rd Quarter, 1993

Objectives

This Class I Mid-Term Oil project for fluvial dominated deltaic (FDD) sandstone reservoirs, centers around the field implementation of a carbon dioxide (CO_2) miscible flood project in the Port Neches Field in Orange County, Texas. The primary objectives of the Pre-award activities, and those which have occurred since the effective date of the Cooperative Agreement, June 1, 1993, have been centered around the necessary work required to allow for CO_2 injection to begin by September, 1993. This work has involved five major tasks associated with Phase II of the project. These Implementation and Demonstration project tasks are:

(1) Recording Daily Production Rates
(2) Reservoir Characterization
(3) Site Operation and Field Work
(4) CO_2
(5) Environment, Health, and Safety Monitoring and Compliance

This early initiation of Phase II work on the Project was made possible by Texaco having completed a major portion of Phase I, the planning and analysis portion of the project, prior to the release of DOE's Class I Oil Program Opportunity Notice. The Department of Energy's (DOE's) selection of this project on April 22, 1992 has reduced the economic risk associated with this tertiary oil recovery project, thus allowing Texaco the opportunity to conduct this project.

Phase I work involved the geologic and engineering reservoir characterization of the Marginulina sandstone reservoir at a depth of 6000'. Texaco's objective during this phase was to use all available technologies present in the industry to develop the most effective project design. This work focused in on four (4) major areas of design:

(1) Field monitoring and evaluation,
(2) Laboratory testing.
(3) Reservoir simulation and
(4) Project design.

These tasks were performed to indicate the success probability of utilizing the process. An oil and CO_2 (gas) production forecast was developed and estimates were made on total project costs. From this information, an economic forecast was developed, thus leading to Texaco management approval.

The primary work since DOE's selection of this project has been

in all work required to expedite the injection of CO_2. These Phase II, Implementation and Demonstration tasks are as follows:

Task 2.1 - Recording Daily Production Rates, had two (2) major objectives:

(1) Record Daily Production Rates to monitor waterflood performance and
(2) Meet all DOE requirements to insure milestones of the project are met.

Task 2.2, Reservoir Characterization, had two (2) major objectives:

(1) Pressure up reservoir with water to 2700 psi and
(2) Obtain conventional core data to be used in reservoir simulation model.

Task 2.3, Site Operation and Field Work, had four (4) major objectives:

(1) Workover 11 wells during 1993,
(2) Drill horizontal CO_2 injection well during 1993,
(3) Install compressor barge and production facility and
(4) Install flowlines and injection lines.

Task 2.4, CO_2, had two (2) major objectives:

(1) Secure CO_2 contract and
(2) Install CO_2 pipeline.

Task 2.5, Environment, Health, and Safety Monitoring and Compliance, had five (5) major objectives:

(1) Determine future air emissions and obtain air permit from Texas Air Quality Control Board (TACB) if necessary,

(2) Obtain Army Corps of Engineers permits for CO_2 pipeline, facility installation, and drilling location,

(3) Prepare Department of Transportation (DOT) manual for CO_2 pipeline,

(4) Secure categorical exclusion to NEPA requirements and

(5) Prepare Hazardous Substance Plan.

In addition to Phase I and Phase II work, Technology Transfer (Phase III) has begun. Objectives for 1993 are:

(1) Develop stategy and theory for CO_2 Screening Model and
(2) Begin compiling data to screen FDD reservoirs for their CO_2 applicability.

A discussion of the status of this work is included in the section to follow.

Summary of Technical Progress

Phase I - Planning and Analysis

As stated previously, Texaco has classified geologic and engineering reservoir characterization and design work prior to September 15, 1992 as Phase I tasks. This work generated the following deliverables:

* New structure maps were developed for the Marginulina sandstone reservoir,

* Reservoir fluid properties in the presence of CO_2 were measured in the laboratory and

* A reservoir simulation model was developed.

The structure map, as shown in Figure 1, indicates that complex faulting exists in the reservoir, with an isolation of two fault blocks occurring in the project area. Historical reservoir pressure data obtained from these two fault blocks indicate that the fault which separates them is a sealing fault. Material balance and volumetric calculations applied to these two areas suggest that the large waterflooded fault block of the reservoir initially had 10.4 MMSTBO in place and the small fault block had 1.4 MMSTBO. The recoveries of 5.7 MMSTBO and 0.6 MMSTBO from these large and small fault blocks respectively, indicate that remaining oil saturations are 30.5% and 45.4% respectively. Laboratory slimtube tests indicate that the reservoir oil will become miscible with CO_2 at 3310 psia, the minimum miscibility pressure (MMP). For vaporization of the light components of the oil, an optimum vaporization pressure (OVP) of only 2740 psia must be achieved. In the design of this project, a reservoir pressure of 3400 psia, 90 psia above the MMP, is assumed.

It is important that we emphasize to DOE in this report the project design of the waterflooded fault block. Phase I work, and data gathered thus far during the implementation process, has resulted in the following design recommendations for the 235.1 acre waterflooded fault block:

* Raise the reservoir pressure from 1850 psi to 2700 psi, the original reservoir pressure, by injecting <u>water</u> in the Stark "B" No's 7 and 10, and in the Kuhn Tract 1 No's 17 and 36.

* Once the CO_2 pipeline, injection facility, and production battery are completed, shut-in all producers and raise reservoir pressure from 2700 psi to 3400 psi by injecting <u>CO_2</u> in the Stark "B" No's 7 and 10, the Kuhn Tract 1 No's 17 and 36, and in the Port Neches

(Marg. Area 1) Well No. 1-H (horizontal well).

* Once at 3400 psi, continue pure CO_2 injection, operating the following injection, production, and monitor wells:

CO_2 Injection Wells	Producing Wells	Monitor Wells
Horizontal No. 1-H	Stark "B" No. 8	Stark "B" No. 7
Stark "B" No. 10	Kuhn Tr. 1 No. 14	
Kuhn Tr. 1 No. 17	Kuhn Tr. 1 No. 15-R	
Kuhn Tr. 1 No. 36	Kuhn Tr. 1 No. 33	
	Kuhn Tr. 1 No. 38	
	Kuhn Tr. 2 No. 6	
	Polk "B" No. 2	

* 4.3 MMCFPD (250 tons/day) of liquid CO_2 will be purchased, with a total purchase volume of 8.5 BCF (494,186 tons).

* A peak recycle of 15 MMCFPD of gaseous CO_2 will be handled by compression and dehydration equipment.

This raising of the reservoir pressure from 2700 psia to 3400 psia with CO_2 will allow the CO_2 to contact a larger area of the reservoir over that which would have been contacted at a higher pressure. CO_2 was not used from the start of pressure buildup due to the large fillup volume required and associated production downtime. The fillup from 2700 psia to 3400 psia will take approximately 45 days.

Drilling of the horizontal CO_2 injection well will be coordinated with a 3-D seismic survey being shot in the field under a geological initiative to further develop the field. The noise of the drilling rig may affect the acquisition of the 3-D data. Workover of the Polk "B" No. 2 as a producing well will also be performed during the time of drilling.

The project design developed for the small partial waterdrive fault block is as follows:

* Drill vertical CO_2 injection well J. V. Polk "B" No. 39 during 1994.

* Workover J. V. Polk "B" No. 5 as a producing well during 1994.

* Increase reservoir pressure from 2200 psi to 3400 psi by injecting CO_2 into J. V. Polk "B" No. 39.

* Produce J. V. Polk "B" No. 5, with fluid withdrawals (oil, water, gas, and CO_2) being replaced by CO_2 injection into J. V. Polk "B" No. 39.

Phase II - Implementation and Demonstration

The attached Financial Status Report for this project shows that $7,080,191 has been spent from September 15, 1992 to June 30, 1993 on this project, with a DOE share of $2,521,256, or 35.61% of total cost. These expenditures can be broke out as follows:

Well Workovers	$3,248,957	(46%)
Well Drilling	215,619	(3%)
Facilities	2,840,156	(40%)
CO_2 Pipeline	467,554	(7%)
Operating Exp.	307,905	(4%)
Total	$7,080,191	

An additional $300,000 will be spent to sidetrack the J. V. Polk "B" Well No. 2 and $1,200,000 more will be required to drill the horizontal CO_2 injection well. The remaining expenditures during this fiscal year will be costs to complete the facilities and CO_2 pipeline, to purchase CO_2, and the operating costs associated with fuel and field maintenance.

Task 2.1 - Recording of Daily Production Rates

As a result of workover activity on these Marginulina wells and a change in the injection pattern, production from the project area has been increased from 78 BOPD, 1819 BWPD to 183 BOPD, 4119 BWPD. The additional water injection wells added are displacing moveable oil towards the producing wells. Before and after well tests for the producing wells and injection rates and surface tubing pressures for the water injection wells are as follows:

Producing Wells

Well Name	Before	After
Kuhn No. 6	8 BOPD, 51 BWPD	0 BOPD, 960 BWPD
Kuhn No. 14	Shut-in	0 BOPD, 800 BWPD
Kuhn No. 15-R	17 BOPD, 494 BWPD	106 BOPD, 777 BWPD
Kuhn No. 33	20 BOPD, 557 BWPD	55 BOPD, 729 BWPD
Kuhn No. 38	14 BOPD, 279 BWPD	15 BOPD, 156 BWPD
Stark No. 8	19 BOPD, 438 BWPD	7 BOPD, 697 BWPD
Polk "B" No. 2	Shut-in	Workover Pending

Water Injection Wells

Well Name	Before	After
Kuhn No. 17	1800 BWPD, 700 psi	394 BWPD, 890 psi
Kuhn No. 36	Shut-in	2085 BWPD, 890 psi
Stark No. 7	Shut-in	200 BWPD, 890 psi
Stark No. 10	Shut-in	1007 BWPD, 890 psi

Further discussion of this waterflood response will be addressed

under Task 2.2, Reservoir Characterization.

Under Task 2.1, Texaco carries cost for all administrative work associated with the project. Objectives under this task were met both by Texaco and DOE. Deliverables under this category are:

(1) Prepare Detailed Cost Propcsal,
(2) Secure subcontractor contracts,
(3) Secure Patent Waiver,
(4) Finalize Cooperative Agreement,
(5) Prepare Project Management Plan and
(6) Unitize project area as required.

The only tasks not completed are (2) and (3). The last subcontractor is signing the revision requested by DOE and will provide a completed copy within two weeks. The patent waiver is also being completed by Mr. Hugh Glenn with DOE.

The Detailed Cost Proposal was completed in August, 1992 and an audit by DCAA was conducted during October. After review by DOE, a total estimated project cost of $23,934,388 was agreed upon by Texaco and DOE, and the Cooperative Agreement was executed on June 1, 1993. It was determined in these negotiations that DOE's cost-share percentage would be 35.61% on all project related costs for budget periods 1 and 2, for a total DOE contribution of $8,523,824. These periods are as follows:

Pre-award Period - September 15, 1992 to May 31, 1993
Budget Period 1 - June 1, 1993 to December 31, 1994
Budget Period 2 - January 1, 1995 to December 31, 1997

On June 30, 1993, Texaco submitted the Project Management Plan, the Cost Plan, the Project Milestone Plan, and a Notice for RD&D work. These documents are included in the Appendix of this document.

The Port Neches (Marg. Area 1) unit was approved on February 22, 1993 by the Railroad Commission of Texas. With CO_2 injection scheduled to begin on approximately September 1, 1993, Texaco will notify the Railroad Commission of Texas that the effective date of the unit is September 1, 1993. This unit encompasses only the 235.1 acre waterflooded portion of the reservoir where CO_2 injection will begin. Under the new Port Neches (Marg. Area 1) Unit designation, well names will be changed to reflect that they are unit wells, therefore Kuhn No. 15-R will become Port Neches (Marg. Area 1) Unit Well No. 15-R.

Unitization, if required for the small fault block, will take place during 1994.

Task 2.2 - Reservoir Characterization

In the area of reservoir characterization, project milestones were reached and valuable data obtained. The reservoir was successfully pressured up with saltwater to 2700 psi. A conventional core was cut during the sidetrack of the W. H. Stark "B" No. 10. Rock properties such as porosity and permeability were measured on selected core plugs, relative permeability curves were developed for the reservoir rock, and connate water and residual oil to waterflood endpoints were established. It appears that the sand may be an oil wet reservoir, as evidenced by a high residual oil saturation to waterflood of 34.6% and a connate water saturation of 10.9%. Wettability tests are currently being run and capillary pressure curves are being developed on six core plugs of this sandstone reservoir.

Future reservoir characterization work involves the placement of a tritium radioactive tracer in the injected water of H. J. Kuhn Tract 1 Well No. 36 to determine if a fault exists in the reservoir between Kuhn No. 36 and Kuhn No. 33. All of the original maps of the reservoir showed a fault running through the large waterflooded fault block, which may support why Kuhn No. 9 is faulted out or shaled out. The response of the Kuhn No. 33 to injection seems to indicate, however, that the fault is not sealing, if in fact there is one. The radioactive tracer will provide valuable information about the flow paths which are developing in this area of the reservoir.

Task 2.3 - Site Operation and Field Work

A major part of task 2.3 has been completed since Pre-award funds were authorized on September 15, 1992. Ten workovers of existing wells were completed in April, 1993 which allowed for the reservoir pressure to be increased and for improvements in the sweep efficiency of the reservoir to be made. In addition to well work, major subtasks were accomplished in the construction of surface facilities, with the compressor barge completed and currently in route via water to the Port Neches Field. The CO_2 injection pump, low pressure compressor, high pressure recycle compressor, production manifold, and production separators all rest upon this two story compressor barge. A new production platform was constructed in the field, with oil and water tanks being erected and hooked up. Fiberglass flowlines and steel CO_2 injection lines have been purchased and are soon to be installed. The high pressure water injection pump was successfully hooked up on February 10, 1993 and water injection was established at a rate of 3000 BWPD.

The horizontal CO_2 injection well has been staked and is ready to be drilled. Texaco has designed the well to have 1500 feet of horizontal displacement through the Marginulina sand, with a series of 20' prepacked screens to be run inside a slotted liner

for sand control, as shown on Figure 2. These prepacked screens will be spaced approximately 120' apart, thus acting as though vertical wells are drilled every 120' along the horizontal section. It currently looks as though the well will be drilled in September or October to avoid disturbing a 3-D seismic survey Texaco is conducting in the field, as the drilling rig noise may affect the survey.

Task 2.4 - CO_2

The major objectives of Task 2.4 have also been accomplished. A contract with Liquid Air, parent company to Cardox, has been executed and the installation of the CO_2 pipeline is progressing well. Approximately 3 miles of the 4.5 mile 4 inch line has been laid and buried. The remaining line will be laid across the Port Neches marsh within two weeks. Mitigation for damages caused by the installation of this line were negotiated with the Texas Parks and Wildlife and will be accomplished by the closing of an existing canal in the field which is no longer being used. The cost of mitigation for this pipeline will be considered a project cost.

Task 2.5 - Environment, Health, and Safety Monitoring

All state and local regulatory requirements for the project have been met, and DOE is finalizing the paperwork necessary for a categorical exclusion to NEPA, the National Environmental Protection Act. Milestones accomplished during this initial reporting period are:

(1) All anticipated compressor, pump, separator, and storage tank emissions for the project were registered with the Texas Air Quality Control Board (TACB). The emission levels fell below the threshold level where an air permit is required. The TACB approved our application during June, 1993.

(2) Army Corps of Engineers permits were received for the disturbance of wetlands by the CO_2 pipeline and for dredging required for the new compressor and production facility and for both news wells anticipated to be drilled during this project.

(3) An Operations and Maintenance Department of Transportation manual was prepared for the CO_2 pipeline and sent to the Railroad Commission of Texas in June, 1993.

(4) The Hazardous Substance Plan for the project was completed and sent to DOE on June 30, 1993.

Texaco was notified on July 12, 1993 by DOE that the public notice which was issued for the CO_2 pipeline and facility on

April 8, 1993 by the Army Corps of Engineers, may satisfy NEPA requirements for public notice, thus expediting the categorical exclusion process. Texaco will not be paid for work performed on the CO_2 pipeline or drilling until NEPA requirements are met.

Phase III - Technology Transfer

The objectives of Phase III work during this initial reporting period have been focused primarily upon the development of a PC-based screening model by Texaco's research center, EPTD. The occasion did arise however, where Texaco had the opportunity of presenting our project design before an SPE Improved Oil Recovery luncheon on November 6, 1992. From this presentation, Mr. Guntis Moritis of the Oil and Gas Journal and Texaco prepared a paper for the journal's March 1, 1993 edition. This paper is included in this document.

Task 3.1 - CO_2 Screening Model Development

Work performed under this task has been primarily involved in the development of a PC-based screening model which uses parameters which are readily available to oil producers. The finished product will generate an oil, water, and gas (CO_2 and methane) production profile which can be utilized in an economics evaluation program. Texaco EPTD will make use of information gained from DOE's CO_2PM 5-spot prediction program to develop a model where the user can select from a number of injection patterns, such as an isolated 2-spot, special West Texas 7-spot, line drive, and others, or can generate his own injection and production scheme. The program will make use of the technologies present which utilize streamlines and streamtubes. By performing the calculations along the streamtubes, the flow patterns developed by injection and production, empirical correlations will not have to be used to calculate areal sweep efficiency.

The PC model should be developed by the end of 1994 and will be released to the public in Spring of 1995.

Task 3.2 - Environmental Analysis and Reporting

Work involved in the areas of air emissions, mitigation, and hazardous substances will be incorporated in a topical report during 1994. During the drilling and facility startup phases of this project, information will be gathered to characterize drilling solids and air emissions. A report will be completed by December 31, 1994.

Task 3.3 - FDD Database and Model

Limited work has been performed on this task due to the summer break at Louisiana State University. A meeting will be held with LSU in August to discuss the strategy of this work. LSU will

utilize the Louisiana Office of Conservation database to screen reservoirs for their CO_2 applicability, and will identify nearby CO_2 sources. By utilizing Texaco's access to production records, fluvial-dominated deltaic reservoirs listed in DOE's TORIS database will also be screened. A topical report will be compiled during 1995 to assemble this data into a format where oil producers can evaluate their use of this technology.

Task 3.4 - Technical Publications

As previously stated, an article appeared in the Oil and Gas Journal on March 1, 1993 which described the work which Texaco has performed. This article introduced the concept of a horizontal CO_2 injection well to the oil industry, thus generating interest by some operators of CO_2 floods in West Texas to look into the advantages of horizontal wells.

Objectives For 4th Quarter, 1993

The major objectives for the next three months of this project have been discussed previously, but will be reiterated here. These objectives are:

(1) Texaco will receive DOE's approval to initiate CO_2 injection.

(2) Radioactive tracer will be placed in the Kuhn No. 36 to monitor the fluid flow which is occurring in the reservoir.

(3) The Port Neches (Marg Area 1) Unit Well No. 1-H will be drilled and completed as a horizontal CO_2 injection well.

(4) The Polk "B" No. 2 will be sidetracked and completed as a producing well.

(5) The CO_2 pipeline will be completed and CO_2 purchases will begin.

(6) A categorical exclusion to NEPA requirements will be received.

(7) Further development of a PC-based CO_2 screening model will occur, and a database of fluvial-dominated deltaic reservoirs in Louisiana will be developed.

In addition to these, improvements in the reservoir model will be made by incorporating new relative permeability curves and productivity indices into a compositional model which incorporates a larger number of grids and layers. By December 31, 1993 this model should be complete.

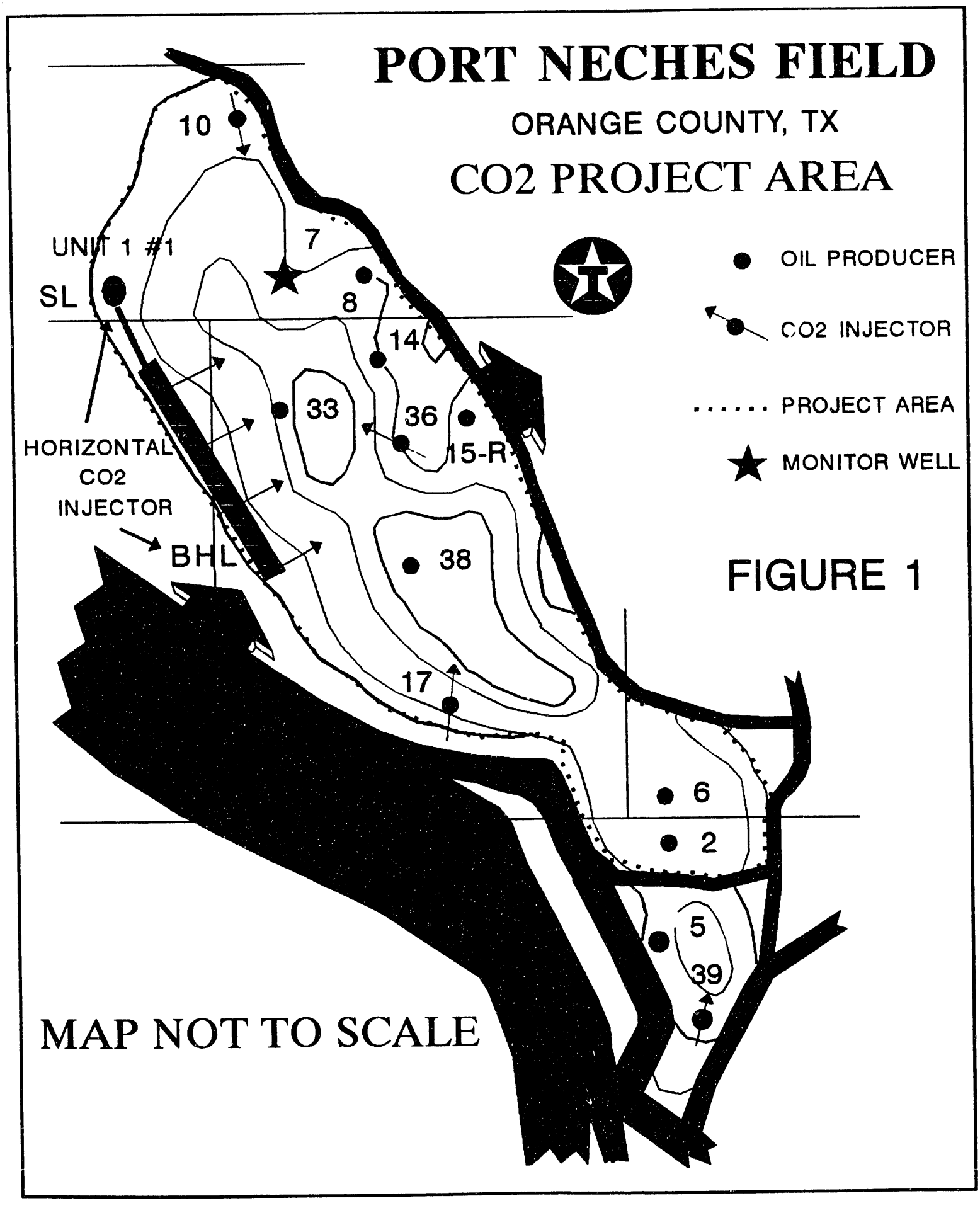
PORT NECHES FIELD
ORANGE COUNTY, TX
CO2 PROJECT AREA
OIL PRODUCER
CO2 INJECTOR
PROJECT AREA
MONITOR WELL
UNIT 1 #1
SL
HORIZONTAL CO2 INJECTOR
BHL
10
7
8
14
33
36
15-R
38
17
6
2
5
39
MAP NOT TO SCALE

FIGURE 1

PORT NECHES FIELD
HORIZONTAL CO2 INJECTION WELL

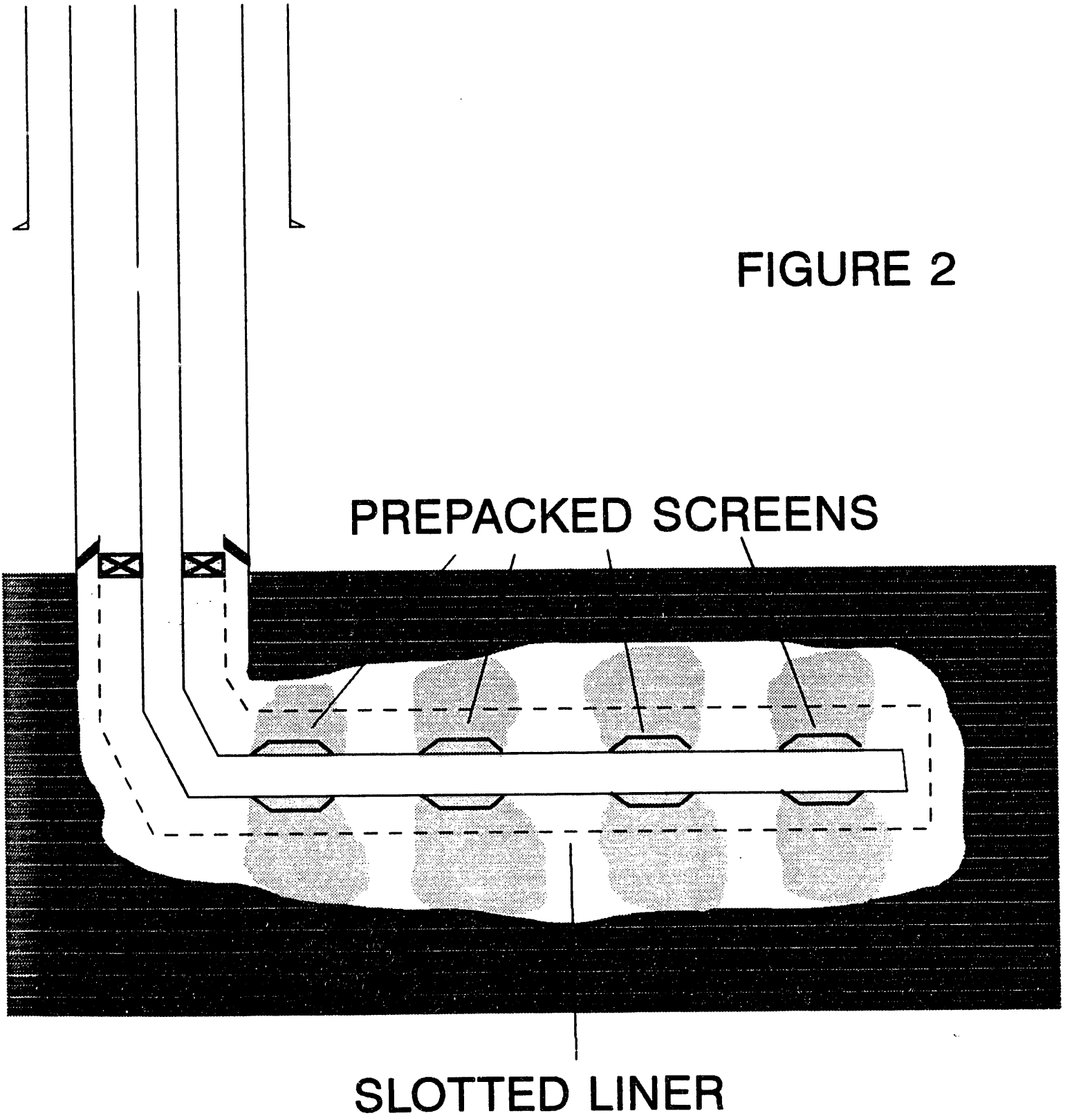

FIGURE 2

Wtr–Oil Relative Permeabilities

Water Saturation	Krw	Krow
13.3	0.0000	1.0000
31.5	0.0270	0.3680
35.5	0.0350	0.2890
39.6	0.0420	0.2200
45.8	0.0550	0.1360
53.2	0.0730	0.0610
59.7	0.0900	0.0190
63.5	0.1030	0.0057
65.6	0.1100	0.0020
67.4	0.1140	0.0003
68.0	0.1160	

Sor = 34.6%
Permeability to air = 3730 md
Effective Permeability to Oil = 2580 md
Porosity = 31.4%
Initial Water Saturation = 13.3%

Gas–Oil Relative Permeabilities

Gas Saturation	Krg	Krog
0.0	0.0000	1.0000
3.5	0.0045	0.7300
5.4	0.0082	0.6200
7.6	0.0130	0.5200
10.5	0.0210	0.4200
13.8	0.0300	0.3200
18.4	0.0470	0.2230
22.5	0.0670	0.1610
26.8	0.0900	0.1120
29.9	0.1090	0.0840
33.7	0.1390	0.0580
35.7	0.1550	0.0480
38.4	0.1850	0.0360
41.2	0.2200	0.0260
43.0	0.2400	0.0200
44.5	0.2700	0.0160
45.5	0.2900	0.0140
47.8	0.3350	0.0080
53.2	0.4770	

DATE FILMED

8/30/93

END