51
1/30/89

5

M.F.P.

DR/10 597-6

DOE/MC/12004-6
(DE89000719)

WEEKS ISLAND GRAVITY STABLE CO₂ PILOT

Final Report

By
J.R. Johnston
G.E. Perry

January 1989

DO NOT MICROFILM
COVER

Performed Under Contract No. AC05-77ET12004

Shell Offshore Inc.
New Orleans, Louisiana

Bartlesville Project Office
U. S. DEPARTMENT OF ENERGY
Bartlesville, Oklahoma

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/MC/12004-6
Distribution Category UC-122

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

WEEKS ISLAND GRAVITY STABLE CO₂ PILOT

Final Report

By
J.R. Johnston
G.E. Perry

DOE/MC/12004--6

DE89 000719

January 1989

Work Performed Under Contract No. AC05-77ET12004

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Royal J. Watts, Project Manager
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, WV 26505

Prepared by
Shell Offshore Inc.
P.O. Box 61933
New Orleans, LA 70160-1933

EB
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	<u>PAGE</u>
ABSTRACT	1
INTRODUCTION	2
RESERVOIR DESCRIPTION	2
PILOT HISTORY	4
Slug Injection and Monitoring History	4
Early Production Response	5
Evaluation of Well A-18	7
Other Core and Fluid Data	10
Late Production Response	11
PILOT INTERPRETATION - SIMULATION	13
Fluid Properties	14
Coning Model	15
3-D Model	19
PILOT FACILITIES AND CORROSION	23
CONCLUSIONS AND SUMMARY	27
NOMENCLATURE	28
REFERENCES	29

LIST OF ILLUSTRATIONS

- Figure 1. Radial North-South Cross Section
- Figure 2. "S" Sand Structure
- Figure 3. Pressure History
- Figure 4. Pre-Pilot History
- Figure 5. Gas-Cap Cycling
- Figure 6. History of Pilot Development and Operation
- Figure 7. Neutron Porosity Monitoring of CO₂ Flood Movement
- Figure 8. "S" RB Water Analysis
- Figure 9. Total History
- Figure 10. Strike Section
- Figure 11. WISUA-18 Dual-Induction SFL
- Figure 12. WISUA-18 Litho Density Log
- Figure 13. Core Data Well A-18 12/82
- Figure 14. Core Data Well A-17 12/77
- Figure 15. Permeability and Porosity Distribution
- Figure 16. "S" RB Core Data Stressed vs. Unstressed
- Figure 17. "S" RB PVTs
- Figure 18. CO₂-Crude Phase Behavior
- Figure 19. Well Production Histories
- Figure 20. Produced API Gravities and OGRs
- Figure 21. Phase Behavior Simulation Input
- Figure 22. Density and Viscosity
- Figure 23. CO₂-Crude Phase Behavior
PVT Calculations for Separator Conditions

- Figure 24. "S" RB Coning Model
- Figure 25. "S" RB Coning Simulation 3-Phase k_{ro} Model
- Figure 26. "S" RB Coning Model Saturation Profiles and Capillary Pressure
- Figure 27. "S" RB Coning Model and Log Saturation Profiles at January 1983
- Figure 28. "S" RB Coning Model History Match
- Figure 29. Grid Block Composition and Saturation History from Coning Model
- Figure 30. MULTISIM History Match Grid
- Figure 31. 3-D History Match
- Figure 32. Cumulative CO_2 Production, 3-D Simulation Versus Actual
- Figure 33. Well A-17 Simulated Production History at Bottom-Hole Conditions
- Figure 34. Process Flow CO_2 Pilot Production Facility

WEEKS ISLAND GRAVITY STABLE
CO₂ PILOT

FINAL REPORT
AUGUST 1988

ABSTRACT

The Weeks Island "S" sand Reservoir B ("S" RB) gravity-stable CO₂ field test was completed during February 1988. Injection started in October 1978 and production began in January 1981 in this high-permeability, steeply-dipping sandstone reservoir. About 264,000 barrels of oil or 65 percent of the starting volume has been recovered. A 24-percent pore-volume slug of CO₂ mixed with about six mole percent of natural gas (mostly methane) was injected at the start of the pilot. Since 1983, produced CO₂ plus hydrocarbon gases have been recycled. CO₂ usage statistics are 9.34 MCF/BO with recycle and 3.24 MCF/BO based on purchased CO₂.

There are four previous annual reports, plus a SPE/DOE technical conference paper by Perry and others^{1,2,3,4,5} which document the pilot design, implementation, and early results for the 1977 to June 1981 time period. This report is a review of early pilot history and a more detailed account of the post June 1981 results and overall interpretation. A reservoir-simulation history match of pilot performance plus core and log data from a 1983 swept-zone evaluation well are described in this report. A brief description of the production facility and an account of the corrosion control program are also included.

INTRODUCTION

The Weeks Island field is located in New Iberia Parish, Louisiana. The structural features of the Weeks Island reservoirs are typical of many piercement salt-dome fields in the Gulf Coast. Sand quality and continuity in most reservoirs in the field are exceptionally good. Oil recoveries are typically 60 to 70 percent of original oil in place, and water-displacement sweep efficiencies are very high in these strong water-drive reservoirs. Figure 1 shows a large-scale dip cross section from the north face of the salt dome where the pilot and the identified enhanced oil recovery (EOR) candidate reservoirs are located.

The Miocene aged sandstone reservoirs at Weeks Island are deep and hot, e.g., 13,000 feet and 225°F in the pilot. The dip in the "S" RB is about 32 degrees. Average in situ permeability is between 1,000 and 2,000 md. Under these reservoir conditions, gravity-stable CO₂ flooding is the selected EOR process. The implementation and about half of the operational life of the pilot was a joint effort with the U. S. Department of Energy.

RESERVOIR DESCRIPTION

The "S" sand Reservoir B was chosen for the pilot because it has properties similar to the largest EOR candidate reservoir at Weeks Island and because it is relatively small, confined by faulting, and geologically simple. The "S" RB originally contained about three million STB of oil underlying a 38-BCF gas cap. The oil column was first

produced by gas-cap expansion and later by water injection. The one oil production well was completed near the gas-oil contact.

Figure 2 is a structure map of the pilot portion of the "S" RB illustrating the relative position of the pilot wells. The gas cap extends along the face of the dome to the right in this figure. Figures 3, 4, and 5 illustrate the "S" RB pressure, oil column pre-pilot production, and the gas-cap cycling histories. Table 1 shows key reservoir parameters plus production and injection volumes prior to the start of CO₂ injection. The original oil-water contact was not logged in this reservoir; therefore, the original oil in place is uncertain.

The pre-pilot oil-column production history ended in July 1978 in preparation for CO₂ injection. At that time, Weeks Island State Unit A No. 16A was producing at relatively low oil rates with a high water cut and increasing gas/oil ratios (GOR). A relatively thin oil column, about 23 feet of mobile oil, remained at the start of pilot injection when A-16A was converted for CO₂ injection. See Refs. 1 and 2 for more details.

The geometry of the pilot is defined by faulting, the face of the salt plug, and the intersection of horizontal planes passing through the injection well and the production well perforations. The bulk rock volume defined with these limits is about 960 net-acre-feet (NAF) (see Ref. 5). About 160 NAF or 16 percent is the volume of the starting mobile oil rim.

PILOT HISTORY

Figure 6 is a time-line of significant pilot events. The logging monitor and first pilot production well, Weeks Island State Unit A No. 17, was drilled, cored, and evaluated for remaining oil saturation early in 1978. Several techniques were used to measure S_{or} including fluid extraction of conventional core, laboratory core measurements, open-hole logs and log-inject-log (pulsed neutron log) measurements. The average waterflood S_{or} in the pilot portion of the "S" RB is 22 percent based on these evaluations (see Kidwell and Guillory⁶ and Ref. 1). There is exceptionally good agreement among the several field and laboratory measurements.

Slug Injection and Monitoring History

The CO_2 plus hydrocarbon-gas slug was injected into Well A-16A from October 1978 through February 1980. The slug volume was 853 MMCF of CO_2 (about 24 percent pore volume) and 55 MMCF of natural gas. The natural gas was added, as discussed in Ref. 1, to help achieve gravity stability by reducing slug density. At "S" RB reservoir conditions, CO_2 density is slightly greater than the density of CO_2 -free oil; however, the added, lighter natural gas had little if any impact on gravity stability because of the properties of the CO_2 -crude phase behavior. Fluid mixing in the reservoir provides vapor and liquid phase compositions which are different from the injected or originally present compositions. Although this was known at the outset, the CO_2 slug was

diluted to lessen the risk of gravity instability. The dilution had little effect on oil recovery from sand pack floods as shown in Ref. 1.

During slug injection and the following eleven months until oil production started, water was produced from a down dip well, Smith State Unit G-2, to allow the CO₂-rich vapor bank to displace the growing oil bank structurally downward to the production well. During this time, the position of the CO₂-rich vapor-phase front was monitored in Well A-17 by pulsed neutron (PNC) logs. The monitoring program and results are described in Refs. 4 and 5. The position of the CO₂ front was defined by the calculated neutron-porosity profile. Figure 7 which was previously published in Ref. 4 shows the position of the CO₂ front with time. The oil bank could not be monitored by neutron logs because water salinity varied with structure as a result of fresh water injection into a saline reservoir. Some of the salinity data representing in situ, injected and produced water conditions are plotted on Figure 8.

Early Production Response

The oil bank was monitored by production testing two sets of perforations in Well A-17. The log-inject-log (LIL) perforations were tested first. Then the final pilot production perforations, which are located 130 feet structurally lower than the injection well perforations, were tested. The results of these tests, which were reported in Refs. 4 and 5, defined oil-bank arrival time. The oil bank grew to about 57 feet by early 1981 from the starting 23-foot thickness. Based on measurements of CO₂-crude phase-behavior properties, CO₂ causes only a 10-15 percent

swelling of the starting oil bank. Increases in the width of the reservoir toward the bottom of the pilot, however, eliminates the oil bank growth due to swelling. Therefore, the 34-foot increase in oil bank thickness is a result of mobilization of waterflood S_{or} plus changes in S_w in the oil bank. The effect of the water saturation in the oil bank will be discussed later under "Pilot Interpretation-Simulation".

Late January 1981 marked the start of sustained production from the pilot. Well A-17 produced with a high water cut and higher-than-expected CO_2 content from the start. Figure 9 is a composite production and injection history of the total pilot. The oil-production history through 1982 is from Well A-17 only. A second producer and swept-zone evaluation well was drilled, cored, and completed on about the beginning of 1983.

The first one and one-half years of production was characterized by greater than 50 percent water, about 50 percent CO_2 in the separator vapor phase, and solution GOR. The high concentration of CO_2 in the production stream means that the injectant had penetrated the entire oil column primarily by gravity assisted convective forces.

The rapid increase in water cut during August through October 1981 was caused by injecting water into Well G-2 to prevent the oil column from moving below the production perforations. The increasing water-cut response in Well A-17 was rapid and caused the well to stop flowing. Injection was stopped after less than three months. The volume of water injected during this period is uncertain because of an inaccurate meter run. This fact is important to the reservoir simulation of the pilot.

During the Fall 1981 shut-in period, a gas-lift system was installed and the well was squeezed and perforated to eliminate any extraneous water production. Well A-17 then produced by gas lift at high water cuts until free-gas production began in Fall 1982 which is indicated on Figure 9 by the increase in gas-production rate. Well A-17 was shut in during December 1982 to stabilize the CO₂-oil front prior to logging the new evaluation well, Weeks Island State Unit A No. 18. The higher than anticipated water production resulted from a combination of upstructure draining and coning. This interpretation is based on reservoir simulation and will be described in more detail later.

Evaluation of Well A-18

Well A-18 was designed to evaluate the CO₂-swept part of the reservoir for remaining oil saturation and to provide a second drainage point. The well penetrated the "S" sand slightly lower than and about 260 feet southwest from Well A-17. Figure 10 is a comparison of the neutron and resistivity logs from Well A-18 and a neutron log from Well A-17. The logs which were run during January 1983, show that the CO₂ front was essentially flat at that time. The A-17 perforations and the approximate position of the oil bank are also shown on Figure 10. Well A-18 found the "S" sand between 12,794 feet and 13,009 feet measured depth or -12,746 to -12,961 feet subsea. The interval with high gas saturations was obvious from the neutron response and extended to -12,870 feet subsea. Figures 11 and 12 are open hole logs (SP-dual

induction and gamma ray-density) from Well A-18. Logs from Well A-17 are included in Ref. 1.

Measurements from Well A-18 cores are plotted in Figure 13. The well was cored from a subsea depth of -12,780 feet to the base of the "S" sand. The CO₂ flooded part of the well was cored with one 30-foot conventional core and four 15-foot pressure cores. Conventional and pressure-retaining cores were cut in the lower, high-liquid-saturation part of the "S" sand. The A-18 core results show greater than a 90 percent recovery of residual oil by gravity-stable CO₂ flooding in 59 feet of core in the gassed-out part of the well. Much of the CO₂-flooded core had no remaining residual oil from Dean Stark extractions. In the CO₂ swept zone, the oil saturation was reduced from about 22 percent to an average of 1.9 percent. These results and the oil saturations presented in Figure 13 are corrected to in situ conditions by oil formation volume factors and for the effect of stress on porosity. The correction for stressed porosity is based on several A-17 and A-18 core measurements. Oil saturations measured from the cores below the gassed-out section are of questionable value because loss of liquid volume prior to core extraction was observed. Well A-17 core data from 1978 are plotted in Figure 14 for comparison with the A-18 data. Tables 2 and 3 are detailed core data from Well A-18. The A-17 data are reported in Ref. 1.

The position of the oil bank in Well A-18 is not precisely known. Based on log analysis, the probable oil bank limits are -12,870 and -12,908 feet subsea. The gas-oil contact was easily identified by a neutron porosity log. The position of the oil-water contact is not

obvious because of the apparent elongated water-saturation profile observed in the oil bank. The existence of a salinity gradient makes resistivity-log evaluations uncertain. Short duration production tests were conducted to obtain water samples and to determine oil productivity. Test results are presented in Table 4.

The upper set of perforations are certainly in the oil bank. The middle set of test perforations falls within the identified oil-bank limits; but, the short-duration, low-production rate test resulted in only a trace of oil. Subsequent production from the middle set of perforations at higher, sustained rates resulted in substantial oil production. Coning might resolve part of the difference in tested productivity. Obviously, the elongated water-saturation profile or transition zone, plus the salinity gradient, do not allow identification of an "oil-water" contact. The water-saturation profile calculated from open-hole-log data and an assumed salinity profile are plotted in Figure 13. The location of production test perforations is also identified.

The elongated water-saturation profile, as will be discussed later, is different than predicted by simulation using measured rock capillary pressure curves. The saturation profile was probably at capillary equilibrium because A-17 had been shut in for about a month. If the profile is different than plotted on Figure 13, it is probably due to errors in assumed water salinities or saturation exponents used for the calculations. The profile is also different than observed during two other high-permeability, gravity-stable CO₂ pilots in S. Louisiana. Nute⁷ reported that for the Bay St. Elaine test, the oil bank (top and

bottom) was successfully monitored by pulsed-neutron logs even when the oil bank was moved structurally upward. We infer that no unusual saturation profile was observed, otherwise, some mention would have been made of such an observation. Moore⁸ reported success in monitoring the CO₂-rich vapor-phase front and the oil bank using pulsed-neutron logs. Figure 10 of Ref. 8 clearly shows sharp saturation transition zones in contrast to the log-based calculations for Well A-18 at Weeks Island.

Other Core and Fluid Data

Figure 15 shows the distribution of "S" sand permeability and porosity data from Wells A-17 and A-18 cores. The data are not corrected for in situ stress. Figure 16 illustrates the relationship of stressed to unstressed core porosity and permeability from these two wells. The correction for stressed porosity is approximately one percent. The mean permeability from Figure 15 is about 3200 md at 200 psi or between 1000 md and 2000 md at reservoir conditions based on Figure 16.

Oil PVT data taken prior to the pilot from Well A-16A was included in Refs. 1 and 2. During 1983 surface samples were collected from Well A-18 and a conventional PVT analysis was made on the recombined reservoir fluid. Figure 17 is a comparison of the PVT from the CO₂-containing crude with the A-16A measurements. Crude PVT properties were measured from A-16A production from samples taken during 1968 and 1978. The most recent evaluation was reported in Ref. 1. Based on field GOR, the earlier PVT is most representative of before-pilot fluid properties. Figure 18 is a ternary diagram of the "S" RB CO₂-crude phase

behavior based on laboratory data reported in Refs. 1 and 2 and compositions from pilot production. On Figure 18, the label RRF is an abbreviation for recombined reservoir fluid, the saturated CO₂-free reservoir oil, and the label CO₂PG represents the experimental and field injection composition.

Late Production Response

Well A-17 resumed and A-18 started production during the second quarter 1983. Both wells have produced with high water cuts, increasing GOR's, and declining oil rates. The injection of produced gas which is a combination of CO₂ and hydrocarbon gases started during late July 1983. Water injection at rates approximately equal to water production was started during late 1983. The reason for water injection was to prevent the oil rim from moving below the production well perforations. A secondary effect of water injection was to reduce GOR. Observe on Figure 9 the increase in GOR during early 1987 when water injection was temporarily stopped.

The production history of the individual wells is plotted on Figure 19 (see Figure 9 for total pilot production and injection performance). Production was continuous except for a two-month shutdown for repair of the recycle compressor during late 1983. Figure 20 is a history of API gravity and oil or condensate-gas-ratio (OGR) from the "S" RB. Scatter in gravity data reflects imperfect field measurements. Relative to the 32° API gravity from waterflood history and the start of the pilot, the gravity has steadily increased to 40° ± 3° as the GOR has

increased. The increase in gravity indicates that vaporization has been an increasingly significant oil-recovery mechanism. The ending gravity of the pilot production is less than the 49° gravity from gas cap producers. The difference in gravity from the two pilot wells is not fully explained. Perhaps part of the difference is because A-18 is completed a few feet structurally lower than A-17 and therefore produces less vaporized crude; however, there is not much difference in GOR from these wells. The lower panel of Figure 20 compares the OGR from pilot wells to the OGR from the gas cap producer (recycle operation).

Table 5 is a summary of recent and cumulative pilot performance. Monthly production and injection histories for each well and total project are documented in Tables 6, 7, and 8.

Pilot operation was terminated during February 1988 after the tubing parted in the injection well. Cumulative oil recovery significantly exceeds the 210 MSTB target set at the start. Cumulative oil production from the pilot is about 265 MSTB or 65 percent of the starting oil volume (408 MSTB). The expected primary recovery from the oil rim remaining at the beginning of the pilot (23 feet thick) is 65 MSTB. Therefore, tertiary recovery at termination is about 200 MSTB or 58 percent of the estimated oil volume not recoverable by water displacement. If the tubing in Well A-16A had not parted and the pilot had continued for another six months or so, approximately 270 MSTB or 66 percent of the starting in-place volume would have been recovered.

PILOT INTERPRETATION - SIMULATION

Shell's MULTISIM reservoir simulator was used to model the pilot performance. The version of MULTISIM used in this study is a multicomponent, multiphase, and compressible reservoir-simulation package which is used to model compositionally-dependent phase behavior with ternary diagrams. Ternary diagrams are stacked to provide pressure-dependent phase definition. Phase density and viscosity values used in the simulation are based on pressure and composition. A mixing-parameter model was not used because phase behavior data show that the process is more immiscible than miscible. Complex geology and reservoir rock properties can be represented in MULTISIM. A fully implicit model was used.

Data from the pilot used for the simulation history match include production records, the position of the CO₂ front, and fluid saturation data from cores and open-hole logs. The history of the position of the CO₂ front was provided by pulsed-neutron log evaluations. The first simulation model used was a 2-D vertical cross section. This model proved useful in establishing the swept-zone pore volume by matching the advance of the CO₂ front. Predictions with the cross-section model indicate that coning of both gas and water strongly influenced the performance of Well A-17. This model was abandoned and a 2-D cylindrical-coordinate (coning) model was used to simulate the performance of the pilot from start of injection through the time Well A-18 was drilled and logged. When two wells were on production, a 3-D model was required. Pseudo-relative-permeability functions were

employed to approximate the coning phenomena in the large grid-block model.

Fluid Properties

CO₂-crude phase-behavior measurements are reported in Ref. 1. A ternary diagram of the "S" RB CO₂-crude phase behavior based on laboratory data was previously introduced as Figure 18. The phase behavior input to MULTISIM is represented on Figures 21, 22, and 23. The fluid property description was created with the aid of an equation-of-state (EOS) computer program to extrapolate experimental data to different pressures and to provide estimates where experimental data were not available. Comparison of the 5,100-psi phase envelopes from Figures 18 and 21 show good agreement of MULTISIM input to experimental data. The split of the hydrocarbon components for the ternary pseudocomponents was subjective. Methane is the dominant component in the light-hydrocarbon pseudocomponent. Table 9 shows the composition of the bubblepoint oil at "S" RB reservoir conditions from Ref. 1. The EOS program used for phase behavior description employed twelve pseudocomponents to characterize the ternary heptanes-plus (C₇₊) pseudocomponent and to match the experimental data.

The EOS program together with a regression package was used to correlate phase density and viscosity values with composition and pressure. The model predictions for density and viscosity along the liquid and vapor phase boundaries at 5,100 psi and 225°F are compared to the experimental-EOS data set on Figure 22. Model input for the phase

behavior of the high pressure and intermediate pressure separators and the stock tank are shown as Figure 23. For purposes of separator flash calculations the vapor phases are assumed to contain no C_{7+} .

Coning Model

The 2-D cylindrical-coordinate (radial) grid used for this phase of simulation plus the non-fluid input parameters are shown on Figure 24. This grid provides small grid blocks around the perforated interval of Well A-17 and progressively larger grid blocks away from the well. Other "S" RB wells were located in larger grid blocks consistent with their structural position. The porosity of the grid blocks in the top and bottom layers were increased to represent the pore volume of the gas cap and water legs of the reservoir. The variable width of the reservoir was modeled by changing porosity and permeability by layer consistent with elevation. The pore volume in the oil column is the same as the 2-D cross-section model which was used to match the CO_2 frontal advance. Reservoir dip was neglected as a practical necessity because that would require a 3-D cylindrical-coordinate grid. Including reservoir dip is not necessary to accurately model coning in this application because of reservoir characteristics and geometry and because the process is gravity stable.

Injection and production rates were input for all wells except for A-17. Total stock-tank liquid rates were input for Well A-17. Therefore, water cuts and GOR's or gas rates were the parameters used to gauge the accuracy of the predictions.

Absolute permeability, relative permeability, and capillary pressure relationships were altered to achieve a match. Core measurements, represented by Corey functions, were used as a starting point for the simulations. Figure 25 is a plot of the final relative-permeability functions used. The Corey exponents for the two-phase relative-permeability functions are shown on this figure. Experimental relative-permeability measurements and interpretative results from "S" sand cores have been previously published by Hagoort⁹ and van Spronsen¹⁰. Two and three-phase oil relative-permeability measurements are documented in these references.

The simulated oil saturation behind the CO₂ front is low and is in agreement with A-18 core data. The curvature of the oil relative-permeability curve for gas-oil displacement (k_{rog} in Figure 25), has a significant impact on the oil-saturation profile. A Corey exponent of 3.5 for the final simulation model contrasts with approximately 4.5 from recent, unpublished centrifuge measurements.

As previously discussed, an unusual feature of the pilot which strongly influenced the capillary pressure used in the model was the water-saturation profile. Relative-permeability functions had little impact on the predicted water-saturation profile. This is so because the process is gravity stable and because Well A-17 was shut in for about a month prior to logging A-18. However, an oil-water capillary-pressure curve drastically different from laboratory measurements did allow an acceptable match of the profile. Figure 26 shows the capillary-pressure curves (experimental and simulation) and the resultant saturation-profile match.

The impact of using the long transition zone in the capillary pressure function is illustrated by Figure 27 which shows water saturation profiles predicted from simulations using each of the curves. With relatively small changes to the k_{rw} function, either capillary-pressure function can provide the same accuracy in matching production history, but not the water-saturation profile. This occurs because the production performance is strongly influenced by coning.

During 1981 the rapid increase in water production by Well A-17, shown on Figure 9, followed a short period of water injection in Well G-2. This response proved difficult to model. Changes to model pore volume, relative-permeability curves or capillary-pressure curves failed to allow a match of water cut both before and after the Well A-17 shut-in period during 1981. One or the other of the water production periods could be matched by changing relative-permeability curves, but not both. Increasing the field-recorded water injection volume during the three-month period significantly improved the match. An increase of a factor of almost three to an average of about 1,100 BPD provided the match shown in Figure 28. Justification for using the increased volume is weak even though the added volume is a small fraction of the pore volume and the water volume measurements are relatively inaccurate (i.e., the orifice in the meter run was too large). The increased volume made no noticeable impact on the simulated reservoir pressure. A very drastic change to relative-permeability and/or capillary-pressure functions in the imbibition cycle might account for the water cut behavior during that time period; however, this was not tested.

As shown in Figure 28, gas breakthrough and GOR were accurately modeled. GOR predictions proved to be a strong function of absolute permeability and a weak function of the ratio of vertical to horizontal permeability. The values selected for the match (i.e., 1,200 md and $k_v/k_h = 1.0$) are reasonably consistent with core data. The predicted volume of CO_2 production was understated in all simulations. This will be discussed later.

Composition and saturation paths and histories for the coning model for a grid block located between the injector and the producer are shown on Figure 29. Water has been excluded from the compositional plots. These diagrams illustrate the simulated displacement processes for the Weeks Island pilot. The panels on the left show changes with time. The ternary diagrams show changes compared to phase compositional boundaries and compared to oil relative permeabilities. The plots start just before invasion by the oil bank at saturation conditions of $S_o = 22\%$ and $S_g = S_{gc} = 8\%$. The composition path begins at near zero CO_2 . As the oil bank invaded the grid block and CO_2 content increases, the path is parallel to and near the liquid phase boundary until the CO_2 -rich vapor phase front invades the grid block. The overall composition then shifts to a point near the vapor phase boundary. Subsequent changes of path occur toward lower CO_2 content along the vapor phase boundary because CO_2 content is diluted with gas-cap gas.

The saturation path is from residual oil saturation to higher oil saturation at constant critical gas saturation as the oil bank invades the grid block. Then the oil saturation decreases at ever increasing gas saturation and slowly changing water saturation as water

drains and the oil bank is displaced by gas. Several oil relative permeability isoperms are shown on the saturation path ternary.

3-D Model

The coning model was abandoned for a cartesian grid in order to continue the simulation beyond 1982 when two wells were on production. A 17x10x5, 850-grid-block, three-dimensional cartesian, variable-mesh grid was used and is illustrated in Figure 30. Grid-block porosity and y-direction permeability were defined to be a function of elevation to model the variable-width geometry. The variable-sized grid was used to keep a practical number of grid blocks and to keep the producer grid blocks small enough to model coning effects with pseudo-relative-permeability functions. The 50x50x35-foot producer grid block size is large enough to accommodate the gross dimensions of the gas and the water cones based on the 2-D coning model results. Larger grid blocks would dwarf the cone and reduce the effectiveness of pseudo functions.

The pseudo functions for coning were constructed from 2-D radial simulations in a manner similar to the technique used by Woods et al¹¹. The procedure was:

- (a) model the displacement at several constant rates,
- (b) average the saturations at several times during the displacement from each of the constant-rate simulations over the radial-model grid-block range that represents in size the 3-D model production grid block,
- (c) record reservoir-condition fractional flow production for each phase, and

- (d) solve for the oil relative permeability assuming phase viscosities and water phase and vapor phase relative-permeability functions. The end product is a table of relative-permeability values representing each of the constant-rate simulations.

The water relative-permeability function was selected from the simulation period prior to the invasion of mobile gas into the grid blocks of interest. Similarly, the gas relative-permeability function was selected from later simulation times when water mobility was low. The resultant coning pseudo-relative-permeability input data were assigned to Wells A-17 and A-18 based on the approximate position of the perforations in the 3-D model grid blocks and based on well voidage rates. Only three such tables were used. A greater number of tables could more accurately account for changes in voidage rate and perforation position.

The oil-water relative permeability and capillary-pressure functions used in the 3-D model for grid-block flow were changed slightly compared to those used in the coning study. This should be true for the liquid phases even with gravity stability because of the long capillary-pressure transition zone. However, the opposite is true for the gas-oil functions. With the assumption of zero gas-oil capillary pressure, and with low displacement velocities, pseudo-relative-permeability functions should be approximately linear. However, a linear relative-permeability function caused MULTISIM to oscillate and to run very slowly. Therefore, Corey function exponents as small as practical (about 1.5) were used. The variable-mesh grid caused significant cusping-like flow artifacts with this model. This is due in part to the

solution routine and is aggravated by contrasting grid block widths. To minimize this effect, the Corey function exponent for the gas phase was made as small as possible.

Relatively few simulations were made with this model because of the long computer time experienced. The 850-grid-block simulation required 7,500 to 10,000 cpu seconds to simulate about eight years of pilot history on a CRAY X-MP/14 computer.

The method of achieving the match of production data was to make minor alterations to relative-permeability functions and pore volume. The pore volume from the final match run was the same as defined by the coning model and the 2-D vertical cross-section simulation that matched the CO₂ frontal advance rate. The match illustrated on Figure 31 shows oil, water, and gas production volumes for Wells A-17 and A-18 compared to history.

The agreement is not perfect but it is acceptable. Improvements could be made with further adjustments to relative-permeability input for grid-block flow and for well production. The significant features of pilot performance are represented in the history match. Of the two wells, the production history of Well A-17 is more accurately matched. The watercut prediction is too high for Well A-18, which is completed about four feet lower than A-17. This inaccuracy would probably be eliminated with a revised pseudo relative-permeability function to reflect the deeper perforations.

As with the coning model, prediction of CO₂ production volumes was understated by about 30 percent. The failure to match CO₂ volumes suggests that phase behavior phenomena are not adequately modeled by

ternary diagrams under "S" RB conditions. The predicted CO₂ production rates were low prior to free-gas production (before 1983) and afterwards. Predicted cumulative recovery is compared to actual recovery of CO₂ for both producers in Figure 32. In both simulation models, CO₂ production was relatively insensitive to simulator input such as relative-permeability functions and grid-block size. Increased dispersion did not improve the match. Only an exaggerated change in the boundaries of the two-phase region on ternary diagrams increased the CO₂ production volume. This alteration is not supported by experimental data and is not used in the reported results. Similarly, scouting studies with a mixing parameter model show no improvement in CO₂ volume prediction. Increasing the dispersivity of CO₂ only in the liquid hydrocarbon phase would probably improve the match.

Composition and saturation paths and histories discussed earlier and plotted on Figure 29 show the significant features of the process. Similarly, the modeled outflow performance on Figure 33 provides added understanding of the pilot. These plots are phase flow rate and fractional flow production histories at bottomhole conditions for Well A-17 from the 3-D simulation model. The illustrations provide a visualization of process mechanisms showing that after gas breakthrough, liquid oil production is primarily from the vapor phase at the wellbore. The prediction is not precise because the 3-D model gridblocks are thicker than the oil bank during the last few years of the pilot. Based on production response, we believe that some liquid phase production continued throughout the life of the pilot.

PILOT FACILITIES AND CORROSION

Injection facilities were described and illustrated in Ref. 1. Production facilities were installed to separate, meter, and analyze fluids produced from the pilot and to furnish a test model for field-scale equipment. As previously described, injection (recycle) of produced gas in updip Well A-16A and injection of water in down dip Well G-2 were required. Relatively low surface pressures early in the pilot life demanded the use of a glycol dehydration system for recycle operations. Production facilities also include a high and low pressure separator plus heater and metering equipment as illustrated on the flow-sheet, Figure 34. Equipment design capacities are on the flow-sheet. The production facility provided daily measured production data for each well.

Special instrumentation systems for the pilot include corrosion probes, a net oil computer for oil production, mass flow measurements for the vapor phase, and a means to measure gas composition. The corrosion-monitoring system utilized corrosion probes or coupons located in the flowline, at each separator, at the heater and on liquid and gas product lines.

A turbine meter, a capacitance probe calibrated for zero to 100 percent water, and a solid-state net oil computer are used for wet-oil measurements. The vapor-phase flow rate is determined by orifice meter differential pressure and gas density. A flow computer accepts on-line differential pressure measurements and density values and calculates flow rates. Orifice meters were chosen because the error is proportional to

the square root of density while the error from displacement meters is proportional to density. Density values are determined by table look-up. On line gas composition was initially measured by a gas chromatograph. An infrared metering device was added later. The system of measurement is automated and designed to provide frequent reports. Routine calibration is required.

Corrosion protection of the production tubing, flowline and facilities was provided by continuously injecting an inhibitor-crude oil mixture through a second tubing string. Because of high cost and long delivery times for stainless steel, carbon steel vessels which are internally plastic coated were used in the corrosive, wet-CO₂ production environment. The tubing strings are coated with SC-707, an epoxy phenolic coating. The separators are internally plastic coated. Some difficulty was experienced in obtaining an effective coatings of the deflectors, the defoaming sections, and the vortex breakers. Piping within the facility is either 316L stainless steel, internally plastic coated carbon steel or bare carbon steel.

A number of chemical inhibitors were field tested. After early problems of excessive corrosion and emulsions, an inhibitor was selected which was effective at injection rates of about 10 barrels of inhibitor-crude mix per day at a concentration of about 2 barrels of inhibitor per 100 barrels of crude. None of the chemicals tested provided adequate protection at turbulent-flow conditions, e.g., choke bodies. Therefore, corrosion resistant alloys are required at locations where turbulent flow is expected.

The entire wellhead of Well A-18 is made of 410 stainless steel but the flowlines to the facility are uncoated carbon steel. Rates of corrosion have been acceptable and low in coated and uncoated flowlines. All equipment was examined internally during a shutdown in 1983 and was found to be in excellent condition with no corrosion detected after 27 months of CO₂ service.

The corrosion rate experienced in the flowlines and facilities was monitored by electrical resistance probes and coupons. The coupons located in a flowline bypass showed a corrosion rate of less than 3 MPY. There is also a coupon located downhole in Well A-18 in a 410 stainless locking mandrel. The downhole coupon detected very high corrosion rates, i.e., 25-30 MPY, because of turbulent flow in the area of the coupon. The holder was redesigned to locate the coupon in a laminar flow area resulting in downhole corrosion rates of approximately 2 MPY. The downhole coupon was used to gather data on the effect of the wet CO₂ environment on bare metal as corrosion inhibitor rates were varied. There are ten electrical resistance probes located throughout the system at various locations from the wellheads to the compressor. These monitoring systems in addition to visual inspections provided a valuable data base for full scale flooding facility design as well as the means to spot problem areas in a timely manner. A post-pilot inspection to quantify the amount of corrosion is planned. At this time, the experience from the pilot has indicated the following:

- (1) Wellheads should be 410 stainless steel because of turbulent flow and high temperature conditions and for yield strength.

- (2) Other components of the system where turbulent flow occurs should be 316 stainless steel because inhibitor cannot maintain a film on these areas. This includes valve bodies, ELL's, and TEE's.
- (3) Tubulars and production vessels can be protected by internal phenolic coating. This coating has maintained integrity and is, for the pilot, cost effective.
- (4) Flowlines can be effectively inhibited without internal coatings. The amount of chemical required is not well defined.

CONCLUSIONS AND SUMMARY

The Weeks Island pilot has demonstrated that gravity stable CO_2 flooding in these high-permeability, steeply dipping oil reservoirs is very effective. Conclusions are:

- ° A gravity stable displacement was achieved.
- ° The displacement efficiency of the process is excellent. Conventional and pressure retaining cores taken during the pilot have vividly demonstrated a displacement of greater than 90 percent of the waterflood residual oil saturation. The relative importance of the two main process mechanisms for oil displacement, CO_2 -crude phase behavior effects and gravity drainage, has not been defined by the pilot.
- ° The production phase of the pilot has also been very effective, resulting in the recovery of about 265 MSTB of oil. This corresponds to a purchased CO_2 usage rate of 3.24 MCF/Bbl. Final recovery volumes are about 65 percent of the starting oil volume. The primary recovery part of these volumes is about 65 MSTB. The tertiary recovery, therefore, is about 200 MSTB or 58 percent of the oil unrecoverable by water displacement.
- ° The duration of the production phase of the pilot was longer than originally imagined. The capture of the relatively thin oil bank required almost continuous recycle of produced gases. Water and gas coning dominate the production character. If an active aquifer exists in full scale applications, water coning will be even more bothersome. For the pilot, downdip water injection was required to prevent the oil rim from moving below the perforations.
- ° A combination of (1) special alloy steels in places where turbulence exists, (2) internal phenolic coating of tubulars and certain internals of facilities, and (3) inhibition from the bottom of the tubing through the separators has been an effective system of corrosion control for the pilot.

NOMENCLATURE

- k_{rg} = relative permeability to gas
- k_{ro} = relative permeability to oil
- k_{rog} = relative permeability to oil in the two-phase oil-gas system
- k_{row} = relative permeability to oil in the two-phase water-oil system
- k_{rw} = relative permeability to water
- k_v/k_h = ratio of vertical to horizontal permeabilities
- S_l = saturation of phase l
- S_{gc} = critical, immobile, gas saturation
- S_{or} = residual oil saturation
- S_{orw} = residual oil saturation in the two-phase water-oil system
- S_{org} = residual oil saturation in the two-phase oil-gas system
- S_{wc} = irreducible water saturation

References

1. Shell Oil Company and Shell Development Company, "First Annual Report, Weeks Island 'S' Sand Reservoir B Gravity Stable Miscible CO₂ Displacement, Iberia Parish, Louisiana", DOE Contract EF-77-C-05-5232, June 1978.
2. Perry, G. E., "Weeks Island 'S' Sand Reservoir B Gravity Stable Miscible CO₂ Displacement, Iberia Parish, Louisiana", Second Annual Report, June 1978-June 1979, DOE Contract EF-77-C-05-5232, November 1979.
3. Perry, G. E., "Weeks Island 'S' Sand Reservoir B Gravity Stable Miscible CO₂ Displacement, Iberia Parish, Louisiana", Third Annual Report, June 1979-June 1980, DOE Contract EF-77-C-05-5232, November 1980.
4. Perry, G. E., "Weeks Island 'S' Sand Reservoir B Gravity Stable Miscible CO₂ Displacement, Iberia Parish, Louisiana", Fourth Annual Report, June 1980-June 1981, DOE Contract AC05-77ET12004, April 1982.
5. Perry, G. E., "Weeks Island 'S' Sand Reservoir B Gravity Stable Miscible CO₂ Displacement, Iberia Parish, Louisiana", SPE/DOE 10695, presented at the 1982 SPE/DOE Third Joint Symposium on Enhanced Oil Recovery of the SPE, Tulsa, Oklahoma, April 4-7, 1982.
6. Kidwell, C. M. and Guillory, A. J., "A Recipe for Residual Oil Saturation Determination", SPE Journal of Petroleum Technology, November 1980, p. 1999.
7. Nute, A. J., "Design and Evaluation of a Gravity-Stable, Miscible CO₂ Injection Project", SPE 11506, presented at the Middle East Oil Technology Conference, Manama, Bahrain, March 14-17, 1983.
8. Moore, S. J., "Design, Installation, and Early Operation of the Timbalier Bay S-2B (RA) SU Gravity-Stable, Miscible CO₂ Injection Project", SPE 14287 presented at the Fall meeting, Las Vegas, Nevada, September 22-25, 1986.
9. Hagoort, J., "Oil Recovery by Gravity Drainage", Society of Petroleum Engineers Journal, p. 139-150, June 1980.
10. van Spronsen, E., "Three-Phase Relative Permeability Measurements Using the Centerfuge", SPE/DOE 10688, presented at the 1982 SPE/DOE Third Joint Symposium on Enhanced Oil Recovery, Tulsa, Oklahoma, April 4-7, 1982.
11. Woods, E. G. and Khurana, A. K., "Pseudo-functions for Water Coning in a 3-D Reservoir Simulation", SPE 5525, presented at Fall Annual Meeting, Dallas, Texas, September 28-October 1, 1975.

TABLE 1

"S" RB PARAMETERS AND VOLUMES

Original oil in place	3.0 MMB
Original gas cap size	37.7 BCF
Gas cap area	61 acres
Oil area	29 acres
Oil zone net pay	186 feet
Reservoir pressure @-12,800':	
Original	6,013 psi
During pilot	4,700 psi
Average porosity	26%
Average permeability	1.2 darcy
Oil formation volume factor	1.62 at 6013 psi
Gas Cap formation vol factor	.00358 RCF/SCF at Pi
Volumes @ 10/78 (pilot start):	
Oil produced	2.61 MMB
Oil-well-gas produced	2.84 MMCF
Oil in place (pilot portion)	408 MSTB

Weeks Island S RB WISUA-18 Core Data

- - - - Cored January 1983 - - - -

Zone	depth	core	Average Sor	Std dev	Average Perm
002	above 12,918'	all	1.90	2.19	4,012
		P core	2.52	2.18	NA
Oil bank	to 12,956'	all	24.13	7.60	2,690
		P core	26.83	4.66	NA
Sor	below 12,956'	Conv.	15.68	7.39	3,545

$$\text{Por}(s) = \text{Por}(u) - 1.0$$

$$\text{So}(s) = \text{Bo} * \text{So}(u) * F$$

$$\text{Sw}(s) = \text{Bw} * \text{Sw}(u) * F$$

$$\text{where } F = \{\text{por}(u)/\text{por}(s)\} * \{1 - \text{por}(s)\} / \{1 - \text{por}(u)\}$$

$$\text{Bo} = 1.695 \text{ above } 12,956'$$

$$1.492 \text{ below } 12,956'$$

$$\text{Bw} = 1.04$$

Measured Depth (ft)	Not Stressed				Core Press (psi)	Stressed			
	Perm (md)	Porosity (%)	Sw (%)	So (%)		Por (%)	Sw (%)	So (%)	Sw+So (%)
12,843.00	4,740	23.1	47.1	3.8	0	22.1	51.9	6.8	58.7
12,844.00	4,990	23.7	34.9	1.1	0	22.7	38.4	2.0	40.4
12,845.00	5,170	24.4	33.9	2.2	0	23.4	37.2	3.9	41.2
12,846.00	4,860	24.1	32.0	1.5	0	23.1	35.2	2.7	37.9
12,847.00	3,630	23.8	36.6	0.0	0	22.8	40.3	0.0	40.3
12,848.00	3,540	24.2	35.2	0.3	0	23.2	38.7	0.5	39.2
12,849.00	3,420	23.0	36.3	0.0	0	22.0	40.0	0.0	40.0
12,850.00	3,500	23.2	37.1	0.0	0	22.2	40.8	0.0	40.8
12,851.00	3,900	22.7	38.5	0.2	0	21.7	42.4	0.4	42.8
12,852.00	3,140	22.8	41.7	0.0	0	21.8	45.9	0.0	45.9
12,853.00	2,760	25.7	42.2	0.0	0	24.7	46.3	0.0	46.3
12,854.00	2,760	25.6	45.4	0.0	0	24.6	49.8	0.0	49.8
12,855.00	2,720	25.5	48.1	0.0	0	24.5	52.8	0.0	52.8
12,856.00	3,320	25.1	41.0	0.0	0	24.1	45.0	0.0	45.0
12,857.00	3,000	24.8	43.8	1.1	0	23.8	48.1	2.0	50.1
12,858.00	4,420	24.6	39.7	0.0	0	23.6	43.6	0.0	43.6
12,859.00	4,360	23.8	45.6	0.0	0	22.8	50.2	0.0	50.2
12,860.00	3,370	22.4	48.2	0.0	0	21.4	53.1	0.0	53.1
12,861.00	4,790	23.4	42.1	0.6	0	22.4	46.3	1.1	47.4
12,862.00	5,000	23.5	46.1	1.7	0	22.5	50.7	3.0	53.8
12,863.00	4,010	22.6	47.6	0.0	0	21.6	52.5	0.0	52.5
12,864.00	4,600	22.8	42.0	0.0	0	21.8	46.3	0.0	46.3
12,865.00	4,270	22.7	37.9	0.0	0	21.7	41.8	0.0	41.8
12,866.00	3,850	22.9	56.4	0.0	0	21.9	62.1	0.0	62.1
12,867.00	4,560	22.8	41.9	0.0	0	21.8	46.2	0.0	46.2
12,868.00	3,540	24.2	46.3	0.0	0	23.2	50.9	0.0	50.9
12,869.00	4,590	24.5	51.9	0.0	0	23.5	57.0	0.0	57.0
12,870.00	4,160	24.3	47.9	0.0	0	23.3	52.6	0.0	52.6
12,870.83	4,520	25.5	47.1	0.0	0	24.5	51.7	0.0	51.7
12,876.29		29.0	72.5	0.0	4,700	28.0	79.2	0.0	79.2
12,879.33		27.0	78.3	1.8	4,700	26.0	85.7	3.2	88.9
12,880.50		26.8	82.3	0.1	4,700	25.8	90.1	0.2	90.3

Measured Depth (ft)	Not Stressed				Core Press (psi)	Stressed			
	Ferm (md)	Porosity (%)	Sw (%)	So (%)		Por (%)	Sw (%)	So (%)	Sw+So (%)
12,881.63		27.7	77.8	0.0	4,700	26.7	85.1	0.0	85.1
12,882.58		28.5	75.8	0.5	4,700	27.5	82.8	0.9	83.7
12,883.75		27.8	76.4	0.5	4,700	26.8	83.6	0.9	84.5
12,885.63		28.2	77.7	2.9	4,700	27.2	84.9	5.2	90.1
12,887.08		26.1	79.1	1.7	4,700	25.1	86.7	3.0	89.7
12,887.92		25.7	79.5	3.5	4,700	24.7	87.2	6.3	93.4
12,888.88		24.6	83.6	2.9	4,700	23.6	91.8	5.2	97.0
12,889.67		25.4	81.7	1.6	4,700	24.4	89.6	2.9	92.5
12,890.67	4,910	24.6	47.3	0.5	0	23.6	52.0	0.9	52.9
12,891.00	5,270	24.2	42.2	1.3	0	23.2	46.4	2.3	48.7
12,892.00	5,450	24.9	48.0	1.0	0	23.9	52.7	1.8	54.5
12,893.08	5,030	24.6	43.5	1.4	0	23.6	47.8	2.5	50.3
12,894.00	2,010	23.3	52.4	0.0	0	22.3	57.7	0.0	57.7
12,895.00	1,890	25.0	48.6	1.2	0	24.0	53.4	2.1	55.5
12,896.00	3,410	23.3	49.6	0.4	0	22.3	54.6	0.7	55.3
12,897.00	3,740	25.2	44.1	2.1	0	24.2	48.4	3.8	52.2
12,898.00	2,840	24.7	39.7	2.3	0	23.7	43.6	4.1	47.7
12,899.08	3,960	25.4	44.8	3.0	0	24.4	49.2	5.4	54.5
12,900.00	3,530	25.2	45.9	3.0	0	24.2	50.4	5.4	55.7
12,901.00	4,540	26.2	43.7	2.6	0	25.2	47.9	4.6	52.5
12,902.00	4,700	25.9	46.5	3.2	0	24.9	51.0	5.7	56.7
12,903.08	4,690	25.9	43.7	2.9	0	24.9	47.9	5.2	53.1
12,904.00	4,650	25.8	41.5	2.7	0	24.8	45.5	4.8	50.3
12,904.83	4,430	26.0	37.1	3.8	0	25.0	40.7	6.8	47.5
12,920.00	1,940	26.3	50.8	24.2	0	25.3	55.7	43.2	98.9
12,921.00	2,970	25.5	49.8	21.3	0	24.5	54.6	38.1	92.7
12,922.00	2,710	25.3	44.7	12.9	0	24.3	49.0	23.1	72.1
12,928.58		26.4	69.3	13.4	2,400	25.4	75.9	23.9	99.9
12,929.33		21.9	72.4	11.4	2,400	20.9	79.9	20.5	100.4
12,930.00		30.6	61.3	13.2	2,400	29.6	66.9	23.5	90.3
12,930.83		29.8	64.7	11.4	2,400	28.8	70.6	20.3	90.9
12,931.58		29.2	65.0	11.0	2,400	28.2	71.0	19.6	90.6
12,932.29		28.4	66.0	12.7	2,400	27.4	72.1	22.6	94.8
12,933.00		26.3	72.6	13.1	2,400	25.3	79.6	23.4	102.9
12,933.67		24.3	78.2	17.2	2,400	23.3	85.9	30.8	116.7
12,934.46		26.1	74.5	15.2	2,400	25.1	81.7	27.2	108.8
12,935.33		28.9	66.2	14.3	2,400	27.9	72.3	25.5	97.8
12,936.04		27.9	64.5	11.1	2,400	26.9	70.5	19.8	90.3
12,936.75		34.1	55.8	6.2	2,400	33.1	60.7	11.0	71.7
12,937.00	6,110	24.1	54.3	24.8	0	23.1	59.7	44.4	104.1
12,938.00	7,010	25.1	34.4	9.9	0	24.1	37.8	17.7	55.5
12,939.00	3,160	24.9	47.1	11.0	0	23.9	51.7	19.7	71.4
12,940.00	3,640	25.1	46.2	8.7	0	24.1	50.7	15.6	66.3
12,941.00	7,130	25.1	36.7	5.5	0	24.1	40.3	9.8	50.1
12,942.00	6,180	24.6	37.7	7.5	0	23.6	41.4	13.4	54.8
12,943.00	1,180	21.8	39.4	18.7	0	20.8	43.5	33.6	77.1
12,944.00	2,130	24.2	40.9	14.2	0	23.2	45.0	25.4	70.4
12,945.00	1,500	22.6	32.8	15.5	0	21.6	36.2	27.8	64.0
12,946.00	1,520	24.6	46.1	11.7	0	23.6	50.6	20.9	71.6
12,947.00	1,590	24.5	47.7	11.0	0	23.5	52.4	19.7	72.1
12,948.00	1,560	23.7	49.0	11.0	0	22.7	53.9	19.7	73.6
12,949.00	1,370	24.0	47.7	13.1	0	23.0	52.4	23.5	75.9

Measured Depth (ft)	Not Stressed				Core Press (psi)	Stressed			
	Perm (md)	Porosity (%)	Sw (%)	So (%)		Por (%)	Sw (%)	So (%)	Sw+So (%)
12,950.00	1,270	23.4	43.9	12.0	0	22.4	48.3	21.5	69.8
12,951.00	1,000	22.7	53.9	12.6	0	21.7	59.4	22.6	82.0
12,953.00	920	24.5	56.8	16.6	0	23.5	62.4	29.7	92.1
12,954.00	1,430	25.4	44.9	15.0	0	24.4	49.3	26.8	76.1
12,955.00	1,530	25.3	61.2	14.6	0	24.3	67.2	26.1	93.3
12,956.00	1,320	26.4	48.1	16.7	0	25.4	52.7	29.8	82.5
12,957.00	1,940	27.3	55.7	12.1	0	26.3	61.0	19.0	80.0
12,958.00	1,200	25.8	57.9	16.1	0	24.8	63.5	25.3	88.8
12,959.00	1,370	25.9	51.0	15.9	0	24.9	55.9	25.0	80.9
12,960.00	227	24.5	52.1	0.0	0	23.5	57.2	0.0	57.2
12,961.00	3,330	25.6	49.6	25.4	0	24.6	54.4	40.0	94.4
12,962.00	5,550	26.2	58.3	0.0	0	25.2	63.9	0.0	63.9
12,963.00	3,890	25.1	45.5	13.1	0	24.1	49.9	20.6	70.6
12,963.92	2,610	25.2	38.8	12.9	0	24.2	42.6	20.3	62.9
12,967.33	757	24.4	62.4	8.2	0	23.4	68.6	12.9	81.5
12,968.17	1,780	25.5	47.2	6.8	0	24.5	51.8	10.7	62.5
12,969.58	1,350	25.6	50.5	11.6	0	24.6	55.4	18.3	73.6
12,970.00	1,910	25.7	50.3	7.8	0	24.7	55.2	12.3	67.4
12,971.00	1,890	26.5	49.6	9.6	0	25.5	54.3	15.1	69.4
12,972.00	1,060	26.0	48.3	15.7	0	25.0	52.9	24.7	77.6
12,973.17	1,810	26.6	51.5	8.7	0	25.6	56.4	13.7	70.1
12,974.00	1,770	27.1	52.2	7.6	0	26.1	57.1	11.9	69.1
12,975.00	1,800	27.0	51.7	8.7	0	26.0	56.6	13.7	70.3
12,976.00	1,210	26.9	52.5	8.1	0	25.9	57.5	12.7	70.2
12,977.00	1,580	26.5	50.3	9.2	0	25.5	55.1	14.5	69.6
12,979.33	347	23.8	53.2	11.2	0	22.8	58.5	17.7	76.2
12,980.00	1,740	27.6	40.6	18.0	0	26.6	44.4	28.3	72.7
12,981.00	2,490	28.3	48.8	12.2	0	27.3	53.3	19.1	72.5
12,982.00	682	25.6	52.9	14.2	0	24.6	58.0	22.3	80.4
12,983.00	3,020	27.3	51.3	9.9	0	26.3	56.1	15.5	71.7
12,984.00	4,310	27.8	47.4	7.8	0	26.8	51.8	12.2	64.1
12,985.00	3,590	27.6	45.3	11.9	0	26.6	49.6	18.7	68.2
12,986.00	3,340	27.6	49.3	8.4	0	26.6	53.9	13.2	67.1
12,987.00	2,570	26.3	52.8	11.4	0	25.3	57.9	17.9	75.8
12,997.00	1,800	25.1	64.7	14.9	0	24.1	71.0	23.5	94.5
12,998.00	6,110	24.8	49.6	6.0	0	23.8	54.5	9.5	63.9
12,999.00	6,500	24.9	50.5	4.4	0	23.9	55.4	6.9	62.4
13,000.00	10,380	24.8	42.5	4.9	0	23.8	46.7	7.7	54.4
13,001.00	10,570	25.2	40.5	5.9	0	24.2	44.4	9.3	53.7
13,002.00	8,530	25.3	40.0	7.5	0	24.3	43.9	11.8	55.7
13,003.00	10,440	25.7	42.6	6.7	0	24.7	46.7	10.5	57.3
13,004.00	10,060	24.8	39.7	7.0	0	23.8	43.6	11.0	54.6
13,005.00	5,140	23.9	45.8	9.3	0	22.9	50.4	14.7	65.0
13,006.00	6,060	21.0	33.1	9.7	0	20.0	36.6	15.4	52.0

TABLE 3
MISCELLANEOUS CORE DATA
WEEKS ISLAND STATE UNIT A-18
(PAGE 1 OF 2)

END POINT RELATIVE PERMEABILITY DATA

All measurements made under an applied stress of 7,800 psi.

Brine contained 35,000 ppm NaCl.

LAB NO.	DEPTH FT., IN.	POROSITY %	$K_{BRINE}, MD.$ @ $S_w = 100\%$	$k_{OIL}, MD.$ @ S_w	S_w %	$k_{BRINE}, MD.$ @ S_{or}	S_{OR} %
A-3717	12,846' 0"	23.1	950	820	33.3	192	30.5
A-3720	12,878' 5"	25.2	1,440	1,311	23.7	596	25.6
A-3727	12,929' 9"	25.6	688	494	34.2	108	34.1
A-3730	12,948' 0"	22.1	401	341	25.5	244	31.0
A-3732	12,967' 0"	25.4	724	514	36.7	112	27.0

RESISTIVITY RATIO, SATURATION, AND FORMATION RESISTIVITY FACTOR

All measurements were made at a stress of 7,800 psi.

Brine contained 35,000 ppm NaCl, $R_w = .184$ @ 23°C.

SAMPLE NO.	LAB NO.	DEPTH FT.	POROSITY %	$K_{BRINE}, md.$ @ $S_w = 100\%$	$k_{OIL}, md.$ @ S_w	S_w %	FRF	m	I	n
28	A-3851	12,870' 0"	21.9	1,040	1,388	13.6	11.71	1.62	28.60	1.68
42	A-3852	12,902' 1"	25.0	1,139	1,411	13.9	10.06	1.67	27.39	1.68
63	A-3853	12,947' 0"	23.9	708	869	11.0	11.48	1.70	34.76	1.61

CATION EXCHANGE CAPACITY

<u>SAMPLE DEPTH</u> <u>FT.</u>	<u>POROSITY</u> <u>%</u>	<u>GRAIN DENSITY</u> <u>GMS/CC</u>	<u>CEC</u> <u>(MEQ/100G)</u>	<u>Q_v</u> <u>(MEQ/ML)</u>
12,846' 0"	23.3	2.642	0.000	0.000
12,878' 0"	25.3	2.635	0.000	0.000
12,929' 9"	26.0	2.641	0.328	0.025
12,948' 0"	22.8	2.642	0.243	0.022
12,967' 0"	25.5	2.647	0.266	0.021

STRESSED POROSITY, PERMEABILITY, RESISTIVITY RATIO, m & n

<u>SAMPLE</u> <u>NO.</u>	<u>LAB</u> <u>NO.</u>	<u>DEPTH</u> <u>FT.</u>	<u>POROSITY</u> <u>%</u>	<u>FRF</u>	<u>m</u>	<u>S_w</u> <u>%</u>	<u>I</u>	<u>n</u>	<u>k_{brine}, md.</u> <u>@ S_w = 100%</u>	<u>k_{oil}, md.</u> <u>@ S_w</u>
1	A-3717	12,846' 0"	23.4	10.85	1.64	17.4	16.42	1.60	923	882
2	A-3718	12,855' 0"	25.2	10.61	1.71				1,027	
3	A-3719	12,865' 0"	20.6	13.09	1.63				1,098	
4	A-3720	12,878' 5"	24.8	10.20	1.67	16.7	17.14	1.59	1,300	1,463
5	A-3721	12,881' 11"	24.2	10.39	1.65				749	
6	A-3722	12,884' 6"	24.7	10.12	1.66				1,334	
7	A-3723	12,895' 1"	25.4	12.25	1.83				667	
8	A-3724	12,904' 1"	25.7	10.13	1.70				1,298	
9	A-3725	12,920' 3"	26.5	14.15	1.99				490	
10	A-3726	12,928' 5"	27.1	10.54	1.80				140	
11	A-3727	12,929' 9"	25.8	10.49	1.73	25.4	15.26	1.99	620	593
12	A-3728	12,935' 7"	24.9	9.85	1.65				1,683	
13	A-3729	12,940' 0"	24.5	10.70	1.69				1,485	
14	A-3730	12,948' 0"	22.8	13.16	1.74	24.9	15.90	1.99	621	465
15	A-3731	12,956' 0"	25.7	10.86	1.76				359	
16	A-3732	12,967' 0"	25.5	11.32	1.78	30.5	12.34	2.12	784	517

Brine = 35,000 ppm NaCl, R_w = .187 ohmmeters @ 23°C.

All measurements were made under an apparent stress of 7,800 psi.

TABLE 4
RESULTS OF SHORT PRODUCTION TESTS
WELL A-18

<u>MEASURED DEPTH</u>	<u>OIL PRODUCTION</u>	<u>SALINITY PPM CL-</u>	<u>ARCHIE N</u>	<u>CALC'D S_w</u>
12,928-29	44% Oil	3,950	1.99	31%
12,945-49	Trace oil	13,300	1.99	40%
12,963-65	Trace oil	29,700	2.12	61%

TABLE 5
SUMMARY OF PILOT INJECTION AND PRODUCTION VOLUMES
VOLUMES THROUGH FEBRUARY 1988

	<u>FEBRUARY AVERAGE*</u> <u>(MCF/D OR BPD)</u>	<u>CUMULATIVE</u> <u>(MMCF OR MB)</u>
<u>Injection</u>		
CO ₂	553	2,462
Natural Gas	2,025	3,789
Total Gas	2,578	6,252
Water	628	797
<u>Production</u>		
Oil	39	263.6
Water Cut (%)	94	-
CO ₂	729	2,100
Total Gas	3,336	6,372
GOR (MCF/Bbl)	86.7	24.2

To Date Process Statistics

Oil Recovery: 64.6% of oil in place at start of pilot
 CO₂ Usage: 9.34 MCF/BO (total injection)

3.24 MCF/BO (purchased CO₂)

* Rates are adjusted to a days-on average.

Monthly Production History
 Weeks Island S RB CO2 Pilot Well A-17
 (Units are Bbls & MCF)

	Year	Oil	Water	CO2	HC Gas	Total Deg API Gas Gravity
October	1980	0	30	0	0	0
November		0	0	0	0	0
December		56	156	0	210	210
January	1981	761	862	747	611	1,358 32.5
February		3,682	3,688	2,701	2,301	5,002 33.1
March		4,279	5,410	2,694	2,918	5,612 33.1
April		4,732	6,692	2,735	3,208	5,943 33.1
May		5,279	7,493	3,396	3,602	6,998 33.1
June		4,374	5,943	3,078	3,037	6,115 33.1
July		4,821	7,430	3,736	3,479	7,215 33.1
August		4,113	7,973	2,741	2,828	5,569 33.1
September		4,239	10,001	2,907	2,884	5,791 33.1
October		2,106	5,789	1,664	1,475	3,139 33.1
November		0	0	0	0	0
December		0	0	0	0	0
January	1982	459	2,414	361	316	677 30.1
February		2,878	9,984	3,600	4,715	8,315 30.1
March		2,857	11,588	3,423	3,281	6,704 30.1
April		1,304	7,499	1,046	1,075	2,121 30.1
May		5,655	19,391	1,657	9,795	11,452 30.1
June		3,029	9,064	2,890	3,212	6,102 30.1
July		5,589	17,270	8,211	6,288	14,499 30.1
August		5,032	18,504	7,583	4,395	11,978 30.1
September		5,625	21,501	20,821	9,958	30,779 30.1
October		7,335	27,929	37,027	20,109	57,136 30.1
November		7,397	24,448	35,676	20,333	56,009 30.1
December		4,097	13,626	21,981	13,625	35,606 30.1
January	1983	0	0	0	0	0
February		10	143	0	0	0
March		0	0	0	0	0
April		0	0	0	0	0
May		0	0	0	0	0
June		5,467	14,058	22,533	15,138	37,671 30.1
July		7,828	19,324	45,835	37,632	83,467 30.1
August		6,888	16,914	51,780	48,393	100,173 30.1
September		2,484	6,659	23,125	26,577	49,702 30.1
October		0	0	0	0	0
November		2,354	1,662	9,850	8,337	18,187 30.1
December		3,317	3,173	19,643	18,192	37,835 37.9
January	1984	3,103	4,088	22,870	21,835	44,705 37.9
February		2,624	4,654	18,621	23,069	41,690 37.9
March		2,700	5,016	21,705	26,791	48,496 37.9
April		2,483	4,682	21,464	29,316	50,780 37.9
May		2,505	4,217	21,178	31,050	52,228 37.9

	Year	Oil	Water	CO2	HC Gas	Total Gas	Deg API Gravity
June		2,564	3,574	21,716	36,073	57,789	39.6
July		2,353	3,927	23,511	37,449	60,960	32.2
August		716	1,309	6,061	13,664	19,725	32.2
September		1,268	1,802	9,585	15,811	25,396	37.9
October		2,023	3,955	19,271	35,794	55,065	37.9
November		1,868	3,668	17,998	35,970	53,968	34.4
December		1,781	4,049	18,391	37,538	55,929	32.1
January	1985	1,604	4,454	16,745	35,143	51,888	33.7
February		1,311	4,951	14,399	31,776	46,175	34.1
March		1,547	6,436	16,354	40,281	56,635	39.3
April		1,371	6,231	15,690	38,828	54,518	39.4
May		826	3,909	9,817	25,813	35,630	38.0
June		1,414	6,456	16,036	38,241	54,277	39.5
July		743	2,040	9,329	18,221	27,550	37.9
August		1,094	4,705	12,335	31,153	43,488	39.0
September		759	3,323	8,181	20,580	28,761	38.8
October		1,214	4,648	14,477	34,145	48,622	39.2
November		906	3,848	10,398	26,186	36,584	39.8
December		1,062	5,093	13,707	32,220	45,927	40.1
January	1986	1,133	6,174	14,528	40,592	55,120	39.8
February		915	5,905	14,551	40,204	54,755	40.0
March		749	6,182	15,244	40,277	55,521	40.3
April		821	5,978	14,617	42,112	56,729	40.2
May		766	5,654	14,892	43,851	58,743	39.8
June		733	5,962	16,482	46,250	62,732	39.8
July		764	6,137	17,080	42,501	59,581	39.6
August		980	7,134	15,175	46,393	61,568	39.6
September		954	7,321	14,706	44,563	59,269	39.8
October		974	7,646	14,587	45,480	60,067	39.6
November		747	6,488	12,131	32,422	44,553	39.6
December		930	7,154	12,850	35,998	48,848	40.3
January	1987	977	6,238	11,091	33,703	44,794	41.3
February		879	5,156	13,692	49,531	63,223	41.5
March		847	3,846	13,667	50,056	63,723	41.8
April		649	2,199	10,821	40,752	51,573	41.8
May		622	1,986	12,023	47,299	59,322	41.6
June		575	1,649	13,498	53,324	66,822	42.3
July		437	2,240	11,215	42,361	53,576	42.2
August		421	3,007	12,097	44,070	56,167	41.8
September		375	2,995	11,190	39,299	50,489	40.7
October		437	3,001	9,681	34,053	43,734	43.0
November		510	3,825	8,584	29,355	37,939	41.4
December		767	5,051	12,792	45,004	57,796	42.6
January	1988	657	5,554	11,721	41,291	53,012	41.7
February		270	2,927	5,173	17,983	23,156	41.7
Totals		176,772	535,062	1,057,368	2,063,595	3,120,963	

Monthly Production History
Weeks Island S RB CO2 Pilot Well A-18
 (Units are Bbls & MCF)

	<u>Year</u>	<u>Oil</u>	<u>Water</u>	<u>CO2</u>	<u>HC Gas</u>	<u>Total Gas</u>	<u>API Gravity</u>
January	1983						
February							
March							
April		81	93	134	146	280	
May		301	4,509	514	625	1,139	32.5
June		3,330	20,562	8,073	5,432	13,505	32.5
July		4,115	24,548	20,594	13,172	33,766	32.5
August		3,990	19,792	24,434	14,113	38,547	32.5
September		1,912	9,252	21,707	9,744	31,451	32.5
October		0	0	0	0	0	
November		2,295	6,089	7,238	5,000	12,238	32.8
December		3,016	13,402	22,169	16,941	39,110	36.9
January	1984	2,906	15,876	26,478	24,416	50,894	36.9
February		2,539	16,353	28,693	27,826	56,519	36.9
March		2,727	18,108	35,194	38,232	73,426	36.9
April		2,542	16,581	32,654	41,804	74,458	36.9
May		2,550	16,093	33,008	47,112	80,120	36.9
June		2,704	16,009	34,633	55,141	89,774	37.1
July		2,335	14,467	31,981	54,210	86,191	32.2
August		2,167	13,379	26,380	46,545	72,925	32.2
September		2,056	14,139	24,261	43,883	68,144	36.9
October		2,151	14,951	28,916	53,725	82,641	36.9
November		2,116	13,917	28,851	58,543	87,394	31.4
December		1,896	12,407	25,977	53,915	79,892	31.9
January	1985	1,638	11,793	21,578	48,493	70,071	31.9
February		1,494	11,201	18,150	41,620	59,770	32.6
March		1,706	12,925	21,799	53,426	75,225	37.7
April		1,533	12,153	20,197	51,192	71,389	36.9
May		929	7,231	13,422	31,300	44,722	34.5
June		1,621	14,063	19,952	45,720	65,672	36.0
July		948	8,131	14,972	24,421	39,393	36.3
August		1,515	14,225	18,905	44,302	63,207	37.5
September		902	9,468	12,529	29,096	41,625	36.3
October		1,475	14,811	20,743	48,029	68,772	36.6
November		1,048	11,916	15,359	36,139	51,498	37.2
December		1,238	16,116	20,069	43,521	63,590	37.6
January	1986	1,297	16,652	18,123	50,725	68,848	37.7
February		1,188	14,762	18,465	45,238	63,703	37.0
March		1,161	13,744	17,936	46,491	64,427	36.7
April		1,286	15,001	17,956	47,489	65,445	36.7
May		1,155	14,364	17,863	48,689	66,552	37.4
June		1,200	14,052	18,173	50,153	68,326	36.5
July		1,318	14,219	20,288	55,007	75,295	36.3
August		1,372	12,162	14,347	38,960	53,307	35.6
September		908	13,418	12,934	36,099	49,033	35.5

	Year	Oil	Water	CO2	HC Gas	Total Gas	API Gravity
October		906	13,966	12,589	35,084	47,673	35.7
November		704	11,037	10,370	24,415	34,785	35.8
December		647	10,542	8,219	21,683	29,902	35.6
January	1987	841	15,639	11,100	30,387	41,487	36.3
February		1,014	13,299	14,647	50,239	64,886	38.0
March		964	12,295	18,279	64,846	83,125	37.4
April		927	10,177	17,109	63,666	80,775	38.2
May		834	8,643	16,452	63,593	80,045	37.7
June		745	6,592	13,220	51,513	64,733	38.8
July		701	7,340	13,411	50,133	63,544	37.7
August		693	8,608	12,942	46,730	59,672	37.9
September		548	8,736	10,880	37,859	48,739	36.7
October		498	8,708	8,994	32,024	41,018	38.3
November		506	8,206	8,060	28,069	36,129	37.4
December		737	12,387	12,463	44,016	56,479	38.2
January	1988	618	14,520	13,057	45,767	58,824	36.6
February		279	5,588	5,038	18,505	23,543	36.6
		86,822	729,217	1,042,479	2,235,164	3,277,643	

Table 8
Total Pilot Injection & Production History
(volumes in Bbls & MCF)

		Gas Injection		Downdip Water Well		Pilot Production Wells A-17 & A-18				
		Well A-16A		Well G-2						
		Injection		Production						
Year		CO2	HC Gas	Water	Water	Oil	Water	CO2	HC Gas	Tot Gas
October	1978	55,758	3,711	0	18,611	0	0	0	0	0
November		52,948	3,085	0	10,322	0	0	0	0	0
December		50,330	3,098	0	19,611	0	0	0	0	0
January	1979	54,782	2,533	0	42,049	0	0	0	0	0
February		55,177	2,560	0	29,215	0	0	0	0	0
March		59,317	2,623	0	36,418	0	0	0	0	0
April		54,556	2,602	0	30,790	0	0	0	0	0
May		57,455	2,676	0	32,121	0	0	0	0	0
June		56,330	2,631	0	32,622	0	0	0	0	0
July		21,483	1,015	0	7,866	0	0	0	0	0
August		57,427	2,673	0	31,498	0	0	0	0	0
September		38,355	1,801	0	28,290	0	0	0	0	0
October		28,582	1,271	0	15,836	0	0	0	0	0
November		52,250	2,455	0	19,386	0	0	0	0	0
December		58,894	2,605	0	30,707	0	0	0	0	0
January	1980	57,792	2,805	0	29,737	0	0	0	0	0
February		41,536	2,246	0	29,844	0	0	0	0	0
March				0	33,249	0	0	0	0	0
April				0	29,127	0	0	0	0	0
May				0	31,793	0	0	0	0	0
June				0	29,173	0	0	0	0	0
July				0	2,086	0	0	0	0	0
August				0	9,014	0	0	0	0	0
September				0	35,001	0	0	0	0	0
October				0	34,447	0	30	0	0	0
November				0	31,540	0	0	0	0	0
December				0	32,055	56	156	0	210	210
January	1981			0	33,493	761	862	747	611	1,358
February				0	23,972	3,682	3,688	2,701	2,301	5,002
March				0	0	4,279	5,410	2,694	2,918	5,612

Table 8
Total Pilot Injection & Production History
(volumes in Bbls & MCF)

		Gas Injection		Down Dip Water Well		Pilot Production Wells A-17 & A-18				
		Well A-16A		Well G-2						
Year		Injection		Production						
		CO2	HC Gas	Water	Water	Oil	Water	CO2	HC Gas	Tot Gas
April				0	0	4,732	6,692	2,735	3,208	5,943
May				0	0	5,279	7,493	3,396	3,602	6,998
June				0	0	4,374	5,943	3,078	3,037	6,115
July				0	0	4,821	7,430	3,736	3,479	7,215
August				27,715	0	4,113	7,973	2,741	2,828	5,569
September				12,112	0	4,239	10,001	2,907	2,884	5,791
October				4,446	0	2,106	5,789	1,664	1,475	3,139
November				0	0	0	0	0	0	0
December				0	0	0	0	0	0	0
January	1982			0	0	459	2,414	361	316	677
February				0	0	2,878	9,984	3,600	4,715	8,315
March				0	0	2,857	11,588	3,423	3,281	6,704
April				0	0	1,304	7,499	1,046	1,075	2,121
May				0	0	5,655	19,391	1,657	9,795	11,452
June				0	0	3,029	9,064	2,890	3,212	6,102
July				0	0	5,589	17,270	8,211	6,288	14,499
August				0	0	5,032	18,504	7,583	4,395	11,978
September				0	0	5,625	21,501	20,821	9,958	30,779
October				0	0	7,335	27,929	37,027	20,109	57,136
November				0	0	7,397	24,448	35,676	20,333	56,009
December				0	0	4,097	13,626	21,981	13,625	35,606
January	1983			0	0	0	0	0	0	0
February				0	0	10	143	0	0	0
March				0	0	0	0	0	0	0
April				0	0	81	93	134	146	280
May				0	0	301	4,509	514	625	1,139
June				0	0	8,797	34,620	30,606	20,570	51,176
July		13,634	12,131	0	0	11,943	43,872	66,429	50,804	117,233
August		42,684	40,684	0	0	10,878	36,706	76,214	62,506	138,720
September		34,560	28,268	0	0	4,395	15,911	44,832	36,321	81,153
October		0	0	0	0	0	0	0	0	0

Table 8
Total Pilot Injection & Production History
(volumes in Bbls & MCF)

		Gas Injection		Downdip Water Well		Pilot Production Wells A-17 & A-18				
		Well A-16A		Well G-2						
Year		Injection			Production					
		CO2	HC Gas	Water	Water	Oil	Water	CO2	HC Gas	Tot Gas
November		14,367	12,213	0	0	4,649	7,751	17,088	13,337	30,425
December		34,612	31,390	4,160	0	6,332	16,575	41,812	35,133	76,945
January	1984	41,660	40,570	13,148	0	6,010	19,964	49,348	46,251	95,599
February		41,126	46,618	17,274	0	5,162	21,007	47,314	50,895	98,209
March		48,888	57,676	18,618	0	5,427	23,124	56,899	65,023	121,922
April		44,879	61,201	17,940	0	5,024	21,263	54,118	71,120	125,238
May		48,797	72,901	17,534	0	5,055	20,310	54,186	78,162	132,348
June		42,758	70,766	17,960	0	5,267	19,583	56,349	91,214	147,563
July		51,681	87,351	18,769	0	4,688	18,394	55,492	91,659	147,151
August		31,972	56,490	18,563	0	2,884	14,688	32,441	60,209	92,650
September		30,681	55,758	17,598	0	3,324	15,941	33,846	59,694	93,540
October		45,333	86,409	18,572	0	4,174	18,906	48,187	89,519	137,706
November		43,471	89,717	18,587	0	3,984	17,585	46,849	94,513	141,362
December		41,142	87,170	18,535	0	3,677	16,456	44,368	91,453	135,821
January	1985	31,958	67,433	18,560	0	3,242	16,247	38,323	83,636	121,959
February		31,128	72,306	16,747	0	2,805	16,152	32,549	73,396	105,945
March		34,574	88,107	18,559	0	3,253	19,361	38,153	93,707	131,860
April		34,336	88,593	17,913	0	2,904	18,384	35,887	90,020	125,907
May		21,470	53,765	18,327	0	1,755	11,140	23,239	57,113	80,352
June		32,957	79,189	17,834	0	3,035	20,519	35,988	83,961	119,949
July		16,442	36,838	14,652	0	1,690	10,171	24,301	42,642	66,943
August		26,581	68,131	17,117	0	2,608	18,930	31,240	75,455	106,695
September		18,711	46,941	10,692	0	1,660	12,791	20,710	49,676	70,386
October		33,234	78,864	17,144	0	2,689	19,459	35,220	82,174	117,394
November		23,601	58,681	17,881	0	1,954	15,764	25,757	62,325	88,082
December		30,377	68,313	17,016	0	2,300	21,209	33,776	75,741	109,517
January	1986	30,157	85,839	21,970	0	2,430	22,826	32,651	91,317	123,968
February		30,484	80,179	16,903	0	2,103	20,667	33,016	85,442	118,458
March		27,660	71,637	18,620	0	1,910	19,926	33,180	86,768	119,948
April		30,613	84,958	17,715	0	2,107	20,979	32,573	89,601	122,174

Table 8
Total Pilot Injection & Production History
(volumes in Bbls & MCF)

		Gas Injection			Downdip Water Well		Pilot Production Wells A-17 & A-18			
		--- Well A-16A ---			--- Well G-2 ---		-----			
Year		Injection			Production					
		CO2	HC Gas	Water	Water	Oil	Water	CO2	HC Gas	Tot Gas
May		29,578	80,752	18,139	0	1,921	20,018	32,755	92,540	125,295
June		32,389	92,245	17,736	0	1,933	20,014	34,655	96,403	131,058
July		34,226	90,963	18,553	0	2,082	20,356	37,368	97,508	134,876
August		28,023	82,720	18,497	0	2,352	19,296	29,522	85,353	114,875
September		25,707	77,015	17,871	0	1,861	20,739	27,640	80,662	108,302
October		25,158	77,422	18,579	0	1,880	21,612	27,176	80,564	107,740
November		18,555	51,625	16,040	0	1,451	17,525	22,501	56,837	79,338
December		20,424	57,786	14,997	0	1,577	17,696	21,069	57,681	78,750
January	1987	17,640	53,617	8,967	0	1,818	21,877	22,191	64,090	86,281
February		25,014	89,343	0	0	1,893	18,455	28,339	99,770	128,109
March		28,985	105,379	0	0	1,811	16,141	31,946	114,902	146,848
April		24,675	93,794	0	0	1,576	12,376	27,930	104,418	132,348
May		25,621	100,850	0	0	1,456	10,629	28,475	110,892	139,367
June		18,637	74,015	1,325	0	1,320	8,241	26,718	104,837	131,555
July		22,716	86,651	10,215	0	1,138	9,580	24,626	92,494	117,120
August		24,396	90,201	11,269	0	1,114	11,615	25,039	90,800	115,839
September		18,918	67,026	12,790	0	924	11,731	22,070	77,158	99,228
October		14,078	50,721	15,454	0	936	11,709	18,675	66,077	84,752
November		14,065	49,982	7,963	0	1,016	12,031	16,644	57,424	74,068
December		23,597	85,279	15,833	0	1,504	17,438	25,255	89,020	114,275
January	1988	22,624	81,484	19,588	0	1,276	20,074	24,778	87,058	111,836
February		7,744	28,355	13,820	0	549	8,515	10,211	36,488	46,699
		2,462,270	3,776,702	796,817	769,873	263,594	1,264,279	2,099,847	4,298,759	6,398,606

TABLE 9
BUBBLE POINT CRUDE COMPOSITION

<u>COMPONENT</u>	<u>MOLE FRACTION</u>
carbon dioxide	.0061
nitrogen	.0043
methane	.5772
ethane	.0293
propane	.0155
iso-butane	.0057
n-butane	.0082
iso-pentane	.0057
n-pentane	.0049
hexanes	.0121
Subtotal	.6690
heptanes plus	.3310
Total	1.0000

FIGURE 1

SHELL WESTERN E&P INC.
WEEKS ISLAND FIELD
IBERIA PH., L.A.
RADIAL NORTH-SOUTH
CROSS SECTION

SCALE IN FEET
0 1600'
HORIZONTAL AND VERTICAL

FIGURE 2

WEEKS ISLAND S RB Pressure History

Figure 3

Figure 4

Figure 5

Weeks Island Gravity Stable CO₂ Pilot History of Pilot Development & Operations

Figure 6

NEUTRON POROSITY MONITORING OF CO₂ FLOOD FRONT MOVEMENT

FIGURE 7

S RB Water Analysis

Figure 8

WEEKS ISLAND S RB CO₂ PILOT

Total History

WEEKS ISLAND CO₂ PILOT STRIKE SECTION

FIGURE IC

WEEKS ISLAND STATE UNIT A-18
 DUAL INDUCTION SFL
 JANUARY 16, 1983

TOOL Pulling ↓ 13000

BS (IN)
6.0000 16.0000

CGR (GAPI)
0.0 150.00

SGR (GAPI)
0.0 150.00

CALI (IN...)
6.0000 16.0000

HY SIZE

CORRECTION CURVE

PE

BULK DENSITY CURVE

BULK DENSITY Backup

TENS (LB)
12000. 2000.0

DRHO (G/C3)
-0.250 0.25000

RHO (G/C3)
2.0000 3.0000

Weeks Island SRB CO₂ Pilot Core Data Well A-18 12/82

Porosity values corrected for stress
Sor values corrected for shrinkage, Bo=1.492 below oil bank & 1.695 in & above

Figure 13

Weeks Island SRB CO₂ Pilot Core Data Well A-17 12/77

Porosity values corrected for stress
Sor values corrected for shrinkage, $B_o=1.533$

Figure 14

S RB CO₂ PILOT CORE DATA *Permeability & Porosity Distribution*

SRBCORE
8/26/87

Figure 15

S RB Core Data Stressed vs Unstressed

Figure 16

Weeks Island S RB PVT's

Weeks Island S RB CO₂-Crude Phase Behavior (225 deg F & 5100 psig)

Figure 18

S RB Well Production Histories

Figure 19

Weeks Island CO₂ Pilot Produced API Gravities and OGR's

Figure 20

Phase Behavior Simulation Input

Figure 21

Figure 22

S RB CO₂-Crude Phase Behaviour PVT Calculations for Separator Conditions

Figure 23

Weeks Island S RB CONING MODEL

Radial Grid (10 x 1 x 23)

Model Input Data

permeability = 1200 md

porosity = 26%

$k_v/k_h = 1.0$

ave pressure = 4800 psi

variable width (porosity)

Figure 24

S RB Coning Simulation 3-Phase Kro Model

- $K_{ro} \text{ exp} = 2.1$
- $K_{rw} \text{ exp} = 3.9$

- $K_{rog} \text{ exp} = 3.5$
- $K_{rg} \text{ exp} = 3.2$

Figure 25

S RB Coning Model Saturation Profiles and Capillary Pressure

Figure 26

S RB Coning Model & Log Saturation Profiles @ Jan. 1983

Figure 27

*S RB Coning Model
History Match*

Grid Block Composition & Saturation History from Coning Model

Figure 29

WEEKS ISLAND S RB MULTISIM HISTORY MATCH GRID

(areal view of 17 X 10 X 5 grid)

(1100' x 950' x 186')

Model Data

Sor = 22%

Sgc = 8%

Swc = 3%

$K_h = 1.2 D$

$\phi = 26\%$

dip = 32°

17 x 10 x 5 grid

1100' in x direction

950' in y direction

186' in z direction

Figure 30

3-D History Match

*S RB A-17**S RB A-18*

Figure 31

Cumulative CO₂ Production 3-D Simulation versus Actual

Figure 32

Well A-17 Simulated Production History at Bottom Hole Conditions

FIGURE 34

SHELL OIL COMPANY			
PROCESS FLOW			
CO ₂ PILOT PROJECT			
WEEKS ISLAND FIELD			
ORIGIN: 30	DATE: 7/8/89	CHECKED:	QTY. CAL: 6
APP'D: _____		329-83-6	
APPROV'D DATE: _____			