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**MICELLAR-POLYMER JOINT DEMONSTRATION PROJECT
WILMINGTON FIELD, CALIFORNIA
ANNUAL REPORT, 1976-77**

By

City of Long Beach, California

Prepared for DOE Under Contract No. EF-77-C-03-1395

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Bartlesville Energy Research Center
Department of Energy
Bartlesville, Oklahoma

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WILMINGTON FIELD, CALIFORNIA
ANNUAL REPORT
For the Period 1976-77

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INTRODUCTION

The Wilmington Field Micellar-Polymer Pilot is a jointly funded venture between the City of Long Beach and the United States Energy Research and Development Administration (ERDA) that will test a tertiary waterflooding technique in the Wilmington Field, largest in California. The project was initiated as a result of the City of Long Beach's response to the Request for Proposal No. E(49-18)-2237, Micellar-Polymer Tertiary Oil Recovery Pilot Demonstration and the subsequent execution of an ERDA cost sharing contract. Under the terms of the completed contract, No. E(49-18)-2486, dated July 6, 1976, (rev. EF-77-C-03-1395) ERDA and City will share equally in the \$7 million demonstration project.

Summary of Progress

Work accomplished under the contract during the first year of operation consisted of Micellar-Polymer laboratory systems design; Test Pattern Model Studies; Drilling and coring injection well FT-1; Pressure Transient Tests of Wells Z-81, Z1-16 and FT-1; as well as design and construction of a portion of the surface facilities.

Radial core floods conducted by Marathon Research Center using reservoir rock and fluid samples from the Wilmington Field demonstrated that Micellar-Polymer systems showing good recovery efficiency could be made from several different commercially available sulfonates. Residual oil saturations obtained were as low as 7 to 10% pore volume. Sulfonates

made from Wilmington crude oil also proved to be effective. Polyacrylamides, both liquid and dry, as well as polysaccharides proved equally effective as a mobility buffer.

Test pattern model studies were conducted on seven different arrays of wells. These studies showed that the pattern originally proposed exhibited poor areal sweep efficiency and was seriously affected by waterflood operations in the North Flank of the fault block. An E-W staggered line drive backed-up against the Pier A Fault appeared to be the best pattern studied, assuming the Pier A Fault to be a pressure barrier.

Injection well FT-1 was drilled, cored and completed in the Hx_a sand. Cores were taken using low-solids, polymer drilling fluid and were frozen on site. The frozen cores from the project area will be used in the Phase B laboratory work. Pressure Transient Tests run in Z-81 and Z1-16 indicated the Pier A Fault to be pressure competent.

The plant site was located adjacent to a railroad siding near the injection wells. The site was graded and seven 2000 barrel tanks were erected. The tanks were internally plastic coated on site. Mixing, filtering and injection facilities are being installed.

BACKGROUND DATA

Wilmington Field is located near the southwestern margin of the Los Angeles basin of Southern California, shown in Figure 1. This basin is one of the most prolific oil-producing basins of the world. The Wilmington structure, discovered in 1937, is a broad, asymmetric anticline broken by

a series of transverse normal faults which divide the producing reservoirs into many separate pools. An axial cross section depicting this structure is shown in Figure 2.

The oilfield is separated into two areas: Old Wilmington and East Wilmington or the Long Beach Unit. Primary development in Old Wilmington occurred during the years 1936-1950. Pilot waterflooding was commenced in mid-1953 and was expanded to full-scale in 1958.

The Department of Oil Properties of the City of Long Beach, as Trustee and Operator for the Tidelands portion representing about 80 per cent of the Wilmington Field is vitally interested in attaining maximum oil recovery and has been actively studying the potential for tertiary oil recovery for over five years. The applicability of certain licensed micellar-polymer waterflooding processes in Wilmington Field has been investigated in considerable detail and the Maraflood (TM) Process is planned to be tested in the joint demonstration project.

PROJECT AREA

The area selected for the pilot project is in the Hx_a sand of the Upper Terminal Zone, Fault Block VB located in the old part of the Wilmington Field, as shown in Figure 3. A larger scale plan of the pilot area is shown in Figure 4. The original proposal recommended a 10-well N-S line drive but included provision for computer model studies to determine optimum location and spacing of wells in the project area. Subsequent model studies

(details of which are given in the body of this report) indicated that the E-W line drive shown in Figure 4 was optimum for the project area and has been adopted. The pilot area was chosen for the following reasons:

Ownership

All of the Upper Terminal VB reservoir currently productive is located on Non-Unit lands under complete control of the City of Long Beach and its contractors, Long Beach Oil Development Company and Powerine Oil Company. All of the oil in place is owned jointly by the City and State. There are no other working interest owners or royalties.

Sand Watered-Out

The Hx_a sands in the pilot area are located on the flanks of an old peripheral water flood and this area is currently uneconomic to produce because of high water cut and low oil production. The remaining producers in this pool are located up-structure of the pilot area. Z1-16A, one of the proposed pilot producers, is the furthest downstructure well still producing from the Hx. In April 1977 this well had a total production of 8 B/D oil (18.1° API), 265 B/D water and a water-oil ratio of 31. The Hx_a sand comprises the top 50 feet of the total Hx section in the pilot area as shown on Figure 5. The initial Wilmington pilot water flood was conducted in the Hx sands, Fault Block VB - West Block. The waterflood performance was very good. The upper sand of the Hx shown on Figure 5A was selected for the Micellar-Polymer Pilot Demonstration Project because it contains only

50 net feet of sand which will limit the chemicals required for the pilot demonstration. Another advantage in selecting this location is that all the surface well sites are in one local area which will allow centralization of injection and production facilities. Five of the ten wells in the pilot area are existing wells which will only require redrilling. Several idle wells are available for conversion to observation wells.

GEOLOGY

The major producing zones in the Wilmington Oil Field are lithologic units with generally similar reservoir characteristics. The zones are designated Tar, Ranger, Upper Terminal, Lower Terminal, Union Pacific, Ford, 237 and Basement (Schist). Refer to Figure 5.

The Upper Terminal Zone belongs to the Upper Miocene (Puente formation) which consists of poorly sorted fine to coarse grained sandstones, interbedded with claystones, soapstone, shale and a few hard sandstone members locally referred to as "shells". Many sandstones contain feldspar. The upper sandstone beds are less consolidated and generally coarser grained than those of the lower section. Shale beds become more silty toward the top of the section and softer than the lower members of the formation. The shale and soapstone are rich in foraminifera and other organic and plant remains. The Upper Miocene sandstone, shale and siltstone members range in thickness from a few inches to 50 feet or more. Very few homogenous shale beds exceed 50 feet. The upper part of the Puente formation contains

approximately 50 to 70 percent sand, the middle part 25 to 35 percent and the lower section approximately 40 percent. The Upper Terminal Zone in Fault Block VB tops at about 2850' vertical sub-sea. An electric log fence diagram of the pilot area is shown in Figure 6.

RESERVOIR CHARACTERISTICS

The Hx subpool in Upper Terminal VB consists of 324 acres with a sand thickness of approximately 100 feet, comprising 30,400 acre feet. The Hx_a sand in the area of the pilot is the uppermost sand of the Hx subpool and has 50 feet of net sand. A recent isobaric map of the Hx VB subpool is shown in Figure 7 and reservoir temperatures are shown in Figure 8. Table 1 gives estimated volumetric data for the project area.

The Upper Terminal sands are very unconsolidated. Compaction tests and subsequent core analysis at confining pressures equivalent to overburden pressures have shown the original values of porosity and permeability to be too high. The interstitial water values were done by distillation from cores taken in oil base mud. These values of interstitial water are probably too low because the porosity values used were too high. Saraband logs indicate current in-situ porosities could be in the order of 27 to 28 percent. PVT data taken in December 1951 from Well Z1-32 producing from the JY subpool 150 feet east of the proposed pilot area are given in Figures 9 through 11. These PVT were considered average for the Upper Terminal pool and for the Hx_a sand in the pilot area during depletion gas drive recovery.

PRODUCTION HISTORY

The first successful producer from the Upper Terminal VB was Well J-14, completed in July 1945. Its initial production was 376 B/D of 20° API oil at a GOR of 436 Cf/B. The GOR rose to 1300 Cf/B by September 1946 at which time the well was shut-in for two and one-half months pending a study to reduce gas production.

Secondary Gas Cap

Late in 1947 development was resumed and 13 wells were drilled in down-structure locations in an attempt to avoid the secondary gas cap which had developed as a result of pressure depletion. The secondary gas cap was found in the JY-KZWA subpools of the Upper Terminal but not in the Hx sand. The formation of the secondary gas cap was largely the result of pressure depletion in previously developed fault blocks to the west (development started in 1936). Pressure depletion was generally the result of communication through the Allied and Allied A-1 fault systems as well as pressure communication in the aquifer. Pressure surveys and differing edge water limits demonstrate that the major faults are barriers in the oil zone but pressure communication exists around these faults in the aquifer.

Gas-oil ratio control proved unsuccessful and by late 1948 the average pool GOR had climbed to 2500 cubic feet per barrel. Nine more wells were completed in the north flank in 1949. The production of these wells, together with a program of GOR control inaugurated in late 1948, dropped the pool

GOR to 1100 cubic feet per barrel by early 1950. By January 1952 approximately 120 wells had been drilled and production peaked at 15,000 B/D.

Pressure Maintenance

The program of pressure maintenance by gas injection into the crestal portion of the Upper and Lower Terminal Zone was commenced in 1953. At about the same time a pilot water injection project was inaugurated in the upper Hx sand in the West Block.

The gas injection plan was scheduled to inject approximately 3 million cubic feet of gas per day into the gas cap area in the Upper Terminal Zone. A large proportion of the gas went away in the J, Y and K sands. Gas injection was moderately successful in maintaining reservoir pressure. Analyses of performance prior to waterflood expansion showed that gas injection aided in the recovery of oil. The long term decline in reservoir pressure leveled off and in some cases pressures increased.

Water Injection Program

The pilot water injection project in the Hx sand between the Allied A-1 and the Pier A faults was highly successful and soon expanded to include the Hx sand in the main block. Large pressure differentials occurred across Pier A fault during the period of pilot flood operation, this indicated that the Pier A fault was pressure competent in the oil zone. However, waterflood stimulation was noted in the main block east of the Pier A fault before expansion of the waterflood, indicating that water was migrating around the fault in the aquifer and was influencing oil production in the main block.

The Hx pilot flood operated by Long Beach Oil Development Company was the first waterflood in the Wilmington Field. Injection was commenced in two aquifer injectors at a total water injection rate of 5,000 B/D. The water injection rate was expanded to 20,000 B/D in May 1955. Waterflood performance is shown in Figure 12. It can be seen from this curve that gas injection in the Upper Terminal had little or no effect on the performance of the Hx subpool.

LABORATORY WORK

Almost all of the progress made during the first year of the Micellar-Polymer Joint Demonstration Project has been the Phase A laboratory work. The laboratory work is being conducted by Marathon Research Center and Phase A of this work had the following objectives:

1. To perform screening tests on various commercially available sulfonates and polymers which can be used to make a viable Micellar-Polymer system.
2. To conduct core flood tests on promising Micellar-Polymer systems.
3. To determine the adsorption characteristics of various polymers on Wilmington reservoir samples.
4. To make computer model studies to optimize the pilot demonstration pattern.

5. To investigate the possibility of developing an effective petroleum sulfonate made from Wilmington feedstocks.

Screening Tests

Various commercially available sulfonates and polymers were screened to determine which ones would efficiently displace oil in the Wilmington reservoir sand packs. This involved mixing a number of micellar slugs and screening them by bench top methods proprietary to Marathon in order to determine which slugs showed sufficient promise to justify testing with the radial flooding apparatus. The bench top work with polymer was to determine if reaction between polymer and the reservoir sand would be detrimental to micellar-polymer recovery.

Screening tests were run on slugs made from sulfonates manufactured by five different companies. Slugs tested contained about 70 percent water. Hydrocarbons investigated included kerosene, diesel fuel, light catalytic cycle oil and gas oil. Samples of some of these hydrocarbons were obtained from the Denver area. When the final design phase is reached, samples of appropriate hydrocarbons from a west coast source will be used. Alcohols used as cosurfactants ranged from Propanol to Hexanol.

For purposes of this preliminary screening the goal was to make a stable, clear slug with viscosity in the range of 35 to 50 centipoise at 125° F. The slug must have a fairly wide temperature stability range because of varying temperatures within the pattern area (refer to Figure 8).

The reciprocal relative mobility of the oil-water bank flowing ahead of slug in the Wilmington sand was calculated to be in the range of 20-50 cp with a possible maximum of 70 cp. This calculation is based upon relative permeability measurements of the sand, calculated from data taken during the waterflood portion of several slug displacement experiments; a measurement of the fractional flow of the oil bank during slug displacements and the oil and water viscosities. Calculations are based upon the equation presented on page 14.

Slugs were made from sulfonates as well as blends of available sulfonates. As a result of this screening work slugs made from sulfonates manufactured by four companies showed sufficient promise to justify further testing using the radial flooding apparatus.

Screening tests were made to evaluate polymers. These tests were made by flooding 100% wet Wilmington sand packs with the polymer to be tested on the basis that this more nearly represented the condition of the sand which would be exposed to the mobility buffer in the Micellar-Polymer system. Reactions were noted between the polymer and the reservoir sand which caused a degradation of the polymer viscosity. Initial indications were that this is not a polymer loss per se, but more likely an ionic reaction of the polymer molecule with an unfavorable cation. Some polymer bench type work was performed relative to this problem, however, it was determined that most of this type of work will have to be done in conjunction with the core flooding in Phase B.

Bench top work investigating the effect of brine salinity upon viscosity of polyacrylamide polymer solutions was performed. It was determined that the polymer concentration in Wilmington produced water will have to be twice that required in Wilmington fresh water in order to obtain equivalent viscosities. How this will translate to mobility in the sand will have to be determined in subsequent flooding experiments.

The basic objectives of the screening studies of sulfonates and polymers was completed in March of 1977. The results of this study showed that effective micellar slugs could be made from commercially available sulfonates. The preliminary polymer work indicated a possible adverse reaction between polyacrylamide polymers and the reservoir sand. The extent of this problem was investigated further when laboratory core floods were run. This showed that the buffering effect of the slug preceding the polymer eliminated most of the problems caused by polymer reaction in the formation.

Wilmington Flood Tests

The basic purpose of this work was

to demonstrate that a Micellar-

Polymer system can be designed to displace oil in a satisfactory manner with sand packs made using Wilmington reservoir sand. The reservoir sands used in this work were not from the pilot area but were weathered cores of unconsolidated sands taken from adjacent Upper Terminal and Ranger reservoirs. The work done under the Phase A core floods can be considered a feasibility study to demonstrate the effectiveness of this process in displacing tertiary oil after flood-out by waterflood. The Phase B laboratory work will be done

on fresh cores from the project area which were taken in Well No. FT-1 recently drilled and cored.

The core floods were done with a radial core flood apparatus designed by Marathon Research Laboratory in which actual reservoir core material was employed. Figure 13 shows a schematic drawing of the radial core flooding apparatus used in the Wilmington core floods. The core holder is designed to take a 5-1/2" diameter core to be flooded from the center to the outer perimeter. Overburden pressures can be maintained by axial loading. The Phase A core floods used unconsolidated Upper Terminal Hx sand. The sand was cold cleaned with a series of solvents, vacuum dried, and packed into the core holder using a special technique developed by Marathon. The sand is packed in the presence of produced water from the reservoir. It is then saturated with reservoir water, flooded with reservoir oil to residual water and then flooded with water to residual oil. At this time micellar flooding begins. The core floods are conducted in a constant temperature bath maintained at a reservoir temperature of 125° F. Overburden pressure of 1500 psi is maintained. Core pore volume and water permeability was determined during the water saturation phase of the operation.

A constant rate non-pulsating positive displacement pump is used to displace fluid. The core is flooded with 1.5 pore volume of fluid from the center to the outer perimeter. Pressures are measured at the injection well and at the two locations across the top of the core, as shown in Figure 13. Produced fluids are collected and measured to determine oil recovery.

Pressure data gives indication of mobility control achieved in the core floods. The ring between the well bore and the first tap includes 7.7% of the core pore volume. The first and second taps encompass the pore volume from 7.7 to 32.5%. The second tap to perimeter encompasses a pore volume from 32.5 to 100%. Reciprocal relative mobility in centipoise is defined as:

$$\lambda^{-1} = \frac{h k (p_o - p_i)}{141.2 q \ln (r_o/r_i)}$$

$$\text{or} = \frac{1}{\frac{K_{ro}}{U_o} + \frac{K_{rw}}{U_w}}$$

Where:

h	=	Thickness of Sand Pack - inches
K	=	Permeability - md
p _o	=	Pressure at the outer tap - psi
p _i	=	Pressure at the inner tap - psi
q	=	Injection rate - B/D
r _o	=	Radial distance to outer tap - inches
r _i	=	Radial distance to inner tap - inches
K _{ro}	=	Relative Permeability to oil - md
U _o	=	Viscosity of the oil - cp
K _{rw}	=	Relative Permeability to water - md
U _w	=	Viscosity of water - cp

The reciprocal relative mobility is an in-place measurement of the apparent viscosity of the flowing fluids. It includes all relative permeability effects. The detailed information which can be derived from the flood pot data is extremely valuable in modifying fluid systems to achieve the most favorable system for a given micellar flooding prospect.

The withdrawal of fluids from the Wilmington reservoir during the early days caused a severe subsidence problem. Subsequent water injection arrested the subsidence, but generally speaking, caused very little "rebound".

The subsidence naturally altered the reservoir parameters and, as a result, the in-situ values for such things as permeability, porosity, remaining oil saturations, etc. are in doubt. These are all critical parameters, but one of the most critical from a micellar polymer fluid system design standpoint is permeability. Estimates of the present in-situ permeability have ranged from 50 md to 1000 md. Permeabilities and porosities in the radial sand packs were subject to variation due to sand packing methods and applied overburden pressure. The porosities averaged 31.4% while the permeabilities averaged 85 md. Attempts will be made to determine in-situ permeability by transient testing in Phase B of this project. A radical departure from the 85 md figure could alter the design specifications for the Phase B injectivity test.

This ERDA project calls for the micellar-polymer process to be tested in the Hx_a zone of the Upper Terminal sand series. Included in the work schedule for Phase B is a core from the project area. The core will be used for the final fluid design phase of this project. No Hx_a core material from the test area was available for Phase A, so core material which the City of Long Beach had on hand was used for this work. The source of the core material was varied, being predominantly from the Upper Terminal with the remainder from the Ranger sand series. However, the majority of the core material was Hx_a although it came from other areas of the field.

During the initial stages of core flooding, troubles were encountered with the injectivity of polyacrylamide polymer. For this reason polysaccharide

(biopolymer) was used during much of the slug evaluation work. In the meantime, additional work was conducted with other polymers. During Phase B other polyacrylamides will be evaluated with the emphasis on finding a suitable liquid emulsion polyacrylamide polymer. As a result of this study, it was determined that in Wilmington reservoir sand packs, low molecular weight polymer (Dow 500 or equivalent) has a low retention and high mobility. Middle molecular weight polymers (Dow 700 or equivalent) has slightly more retention and a much more adequate mobility, and high molecular weight polymer (Dow 1000 or equivalent) a very high retention and extremely low mobilities, causing considerable propagation problems. A middle molecular weight polymer was thus selected as a polymer with the best qualities based on the Wilmington sand pack work. This polymer was then substituted for biopolymer in the latter series of radial core floods. These floods confirmed the selection of middle molecular weight polyacrylamides. Referring to Table 2, Runs WR 518, 520 and 521 using a middle molecular weight polyacrylamide had noticeably better recoveries than Run WR 519 made with low molecular weight polyacrylamide. Since the remaining oil saturations in each of these runs were below 10%, it was demonstrated that middle molecular weight polyacrylamide was functioning as an efficient mobility control agent.

Wilmington sand pack has been optically examined for the effects of crushing during simulated overburden pressuring. This preliminary study shows that at 1500 psi the sand size fraction quartz and feldspar grains remained unchanged. Fresh broken grains were not observed.

The biotite in the sample examined also did not appear to be altered by the simulated overburden pressure. The biotite exhibits its common perfect (001) cleavage and occurs as thin flexible plates. A more detailed study using the fresh core material from the test site is planned. The detailed study will incorporate grain size analysis and the Scanning Electron Microscope in addition to optical examination.

Problems were noted with all polymers when attempting to displace them by brine. Better displacements were noted when using fresh water as the flush water. Since polymer is propagated better by fresh water than by brine, it may not be beneficial to start brine injection before 1 PV of total injected fluids.

The attached Table 2 summarizes the core flooding work conducted in Phase A. All of the pertinent data are included in the table except for the slug compositions which are considered proprietary by Marathon Oil Company. The brand names of the sulfonates and polymers used are omitted from Table 2 to prevent unwarranted conclusions being drawn relative to the pros and cons of any particular chemical brand based on the disc flooding data.

The goal for this phase of the project, as stated by the City of Long Beach was to demonstrate that a Micellar-Polymer fluid system could be designed that would displace oil in a Wilmington reservoir sand pack to an oil saturation (second column from the right in Table 2) equivalent to the saturation that Marathon obtained in core floods using Robinson field (Illinois)

core discs. The Robinson residual oil saturations averaged approximately 11%. As seen from Table 2 a number of the remaining oil saturations during the latter core floods were 11% or less.

Polymer Adsorption Tests

Studies were made in an attempt to learn both the mineralogy and the potential water soluble materials which may be the cause of polymer degradation. Scanning electron microscope photographs and analysis of the sand by X-ray diffraction were used in this study. In addition, core floods were run by flowing various polymers through extracted cores and analyzing the effluent to determine the loss of polymer by adsorption.

Analysis of the sand by X-ray diffraction showed that the major component of the sand is quartz and feldspar with a minor component being clays, illite and chlorite. Scanning electron microscope photographs of the sand showed that the individual sand grains were covered with clay. Analysis of water extracts from both cleaned and uncleaned sand were performed. The unclean sand showed the presence of calcium, magnesium, sodium, potassium and manganese. Analysis of the water extract from the sand that had been previously cold cleaned by organic solvent showed the presence of iron, copper and aluminum in addition to the ions above and greater concentrations of the same ions. It was also noted that the pH of the water extract of the clean sand was 4.5, while that of the uncleaned sand was 6.6. This pH difference may, in part, account for the additional trivalent ions.

Several core floods were run using high molecular weight polymer and Wilmington fresh water. There was no indication of polymer present in the produced fluids. Calcium showed to be quite high, about 200 parts per million higher than the Wilmington produced water standard. This may be attributed to an ionic substitution between Wilmington clean sand and injected fluids. Chlorides in the produced water compared fairly well with the chlorides in the produced water standard. Tests continued to show that high molecular weight polymer did not propagate properly through the sand pack due to plugging. One run was made with a liquid emulsion polyacrylamide polymer which exhibited a very high retention and a considerable amount of well bore plugging. This is considered to be a misrun. In the interest of time, it was decided to postpone any further evaluation of liquid emulsion polymers until Phase B.

The core flooding under Phase A demonstrated that the indicated adverse reaction between polymer and the Wilmington reservoir sand was buffered to a very large extent by the slug which precedes the polymer in a micellar-polymer project. The relative retentions of low, middle and high molecular weight polymers in the Wilmington sand packs were again confirmed. Additional polymer retention work with the presently available reservoir samples was deemed to be non-productive. Marathon plans to again initiate this work under Phase B with the use of Hx₂ reservoir material from the pilot area in conjunction with liquid emulsion polyacrylamides.

Pattern Optimization Studies

Computer model studies were

made to optimize the location

and spacing of the wells in the pilot area. A considerable amount of work was conducted in reviewing the history of the producing wells in the proposed test area in addition to evaluating all of the available reservoir and pressure data.

The initial conclusion regarding the available core data was that it would furnish little useful input for the pattern study. It is scattered both areally and vertically with the Hx_a zone frequently being represented by one or two samples. Permeability and porosity measurements had been routinely determined under a confining pressure substantially lower than the reservoir overburden pressure. The resultant permeability and porosity values from this unconsolidated sand were much too high to represent the in-situ conditions.

Shut-in bottom hole pressure data were recorded annually for aquifer injection wells FZ-228 and FZ-229 during the period of 1953-1958. These two wells contributed about 80% of the water injected into the Hx_a in this area. The pressure data were not recorded in a manner to facilitate classic transient test pressure analysis. However, several of the shut-in histories were analyzed resulting in preliminary permeability values of about 50-150 md. Injection profile data for wells FZ-228 and FZ-229 permeability and PI distribution data for Upper Terminal sands and an up-to-date collection of data concerning the E log studies and laboratory compaction tests on core

samples were studied. This last report was very useful in estimating the reservoir parameters for use in the pattern study.

A number of preliminary streamline flood front runs were made using a Marathon computer model SNAP. This program allows variation in reservoir thickness, permeability, and porosity accepting these values in a grid or node format, SNAP generates streamlines based on unit mobilities but does have the capability of accepting heterogeneous permeability distribution. Eight patterns were studied with these runs. Two of the patterns studied were variations of the north-south line drive. One with infill injectors and the other with infill producers. These two patterns did not materially change the sweep efficiency and are therefore not included in the report. The waterflood patterns studied in detail are shown in Figures 14 through 19. They consisted of the following:

- A. The north-south line drive defined in the original proposal.
- B. Three inverted five-spots backed up against the Pier A fault.
- C. Two inverted five-spots backed up against the Pier A fault (same as above minus north five-spot).
- D. Two inverted five-spots located within the area of the proposed line drive pattern.
- E. Two normal five-spots located within the area of the proposed line-drive pattern.

- H. Nominal 10-acre staggered line drive backed up against the Pier A fault.

In addition to the various patterns studied runs were made to investigate the effect of the following:

1. Homogeneous permeability and current conditions of injection and production.
2. Increased south flank injection with homogeneous permeability.
3. Heterogeneous permeability - the frequency of occurrence of the permeability values from core analysis data approximates a log normal distribution. Random values of permeability were selected by computer and used as input for these calculations.
4. Operational changes - Changed waterflood operations to try and better confine test patterns.
5. Non-sealing faults - Assume Pier A fault non-sealing with 10% average permeability.

In most cases very little difference was seen between homogeneous and heterogeneous permeability or non-sealing faults. Some of the patterns were favorably influenced by increased south flank injection or converting additional wells to injectors, however, all of these effects were relatively small and the optimum pattern was not materially affected by the test

circumstances described above. For this reason the streamline diagrams included in the report reflect homogeneous permeability and normal conditions of production and injection. These diagrams for the six flood patterns are shown in Figures 20 through 25. General conclusions drawn from this study are as follows:

1. Waterflood operations in the north flank of the fault block dominate all the test patterns.
2. The North-South Line Drives (Test Patterns A, F and G) should not be used in the Maraflood process in the manner set forth in the proposal. These patterns exhibit poor sweep and, more importantly, the continual injection of mobility buffer against the pressured reservoir brine from the north flank will result in destruction of the mobility buffer. A stable displacement requires contact of the mobility buffer with reservoir fluids only at the displacement front where it is shielded from the reservoir fluids by the micellar slug.
3. All the alternate patterns (B, C, D and E) would have longer injection lives (5-7 years vs. 2.75 years) and, except for D, would require more chemical.

4. All the alternate patterns (B, C, D and E) can probably be made to exhibit acceptable sweep by adjusting waterflood injection and/or production. Patterns B and C or variations of such would probably be easiest to adjust.
5. Pattern H exhibits much better sweep efficiency than any of the alternate patterns tested, reaches floodout early and requires less chemical than originally proposed.

As a summary to this work it was concluded that the line drive pattern contained in the original proposal was unacceptable. The alternate patterns considered in this study were unattractive because of increased life, increased chemical cost and the probable need to alter present waterflood operations to protect the test pattern.

Pattern H appears to be relatively insensitive to circumstances that troubled other patterns studied. Uncertainties in waterflood operation, the ability of the Pier A fault to transmit fluid, the precise location of the fault, the location of existing wells and the actual rates of production and injection in the pattern wells would all serve to compromise this pattern. The area between the pattern injection wells and the Pier A fault is of particular concern since it will receive more injection than is shown by the streamlines due to system compressibility. This area could act as a thief zone for micellar-polymer fluids or it might eventually contribute to pattern production.

Additional modeling work will be done in an attempt to answer this question. The assumption that the Pier A fault will serve as a barrier to flow is major. This assumption is based on bottom hole pressure data and production data. It is planned to test the transmissibility of this fault zone in the transient testing program to be conducted during Phase B of this project. Marathon recommends that:

1. Pattern H be selected as the test pattern for the Wilmington project subject to verification that the Pier A fault will furnish an adequate barrier to fluid flow. This verification should consist of a review of available data and the interference testing scheduled early in the project.
2. Definition of the pattern pore volume should include further modeling to determine the significance of the area between the pattern injection wells and the Pier A fault.

Sulfonation of Wilmington
Feed Stocks

Research has been undertaken for the purpose of developing an effective sulfonate manufactured from Wilmington crude oil or local refinery feedstocks. The potential profitability of this project will depend upon the price of oil and the costs incurred, as well as the quantity of oil produced. A major cost item is the sulfonate which will be required for slug

formulation. The high price in transportation costs associated with currently available sulfonates could jeopardize favorable economics for a commercial project. To achieve sulfonate prices low enough for profitable oil recovery it will be necessary to produce the sulfonate near the Wilmington Field using relatively inexpensive feedstocks.

Samples of the Wilmington crude oil and various cuts from the Champlin Refinery were sent to Marathon and to four other manufacturers of commercial sulfonates. Two of these firms have provided samples of sulfonates made from Wilmington crude oil or Wilmington refinery stocks. These samples have been core flooded in the laboratory. A sample of topped crude oil bench sulfonated by Marathon has also been core flooded. The results of these core flood tests indicate that effective sulfonates can be manufactured from Wilmington crude oil or feed stocks. Core flood tests shown in Table 3 indicate that Wilmington sulfonates are comparable to commercial sulfonates in oil recovery efficiency. Additional work on this project is planned during the Phase B laboratory work.

Ft-1 Coring Program

Due to the compressibility of
the unconsolidated core material

it was necessary to obtain fresh samples of the reservoir rock to be used to determine in-situ porosity, permeability and saturation. Drilling was commenced on the first well in the pilot area June 25, 1977. This well is the redrill of idle well Z1-14 and was called FT-1 (formerly identified as Well "A"). The well is the central injection well in the pilot area. A

Christianson plastic sleeve core barrel was used to core the Hx_a sand. Coring was conducted in fresh water, clay-base mud with polymer additives. Samples of three drilling muds considered for use were analyzed and approved by Marathon Research. The cores are 4-3/4" diameter taken in 9-7/8" hole. Cores encased in plastic sleeves were cut into 3-foot lengths and frozen at the site. Sample plugs were cut from each 3-foot length and sent to Petroleum Testing Laboratory for porosity, permeability, oil and water saturation, and calculated grain density analyses. Porosity and permeability measurements will be made using overburden loading pressures of 350, 800, 1600 and 2000 psi. The balance of the frozen core material was shipped in a frozen state to Marathon Research Center in Denver, Colorado to be used for the Phase B core floods.

Transient Testing

The objectives of the transient test were: (1) to verify the sealing nature of the Pier A fault; and (2) to determine the permeability and compressibility of the Hx_a subzone in Fault Block VB. Final endorsement of the present test pattern (Pattern H) is contingent upon establishing that the Pier A fault will serve as a barrier to fluid flow. Permeabilities established by transient testing will be related back to the laboratory sand packs and used as an indication of how well in-situ conditions are being matched in the laboratory.

H-P 2811 quartz pressure gauges were run in Z-81 and Z1-16. Well Z-81 is located about 300 feet west of FT-1 and across the Pier A fault.

Well Z1-16 is located about 445 feet southeast of FT-1. Both of these wells have the majority of the Hx zone open to flow. Test pattern and well locations are shown in Figure 4. Pressure patterns in these wells were recorded while water injection was taking place in FT-1. Analysis of the transient test is not yet complete but preliminary results indicate:

1. The Pier A fault is competent in the oil zone.
2. Permeability to water at residual oil saturation is in the order of 7 md.

Prior to starting the transient test, pressure responses were calculated on the simulator for a well analogous to Z1-16 assuming a sealing Pier A fault and:

ϕ	-	28%
h	-	50 feet
μ	-	0.65 cp
Q	-	1000 BPD

The results are shown in Figures 26-31.

Two values of system compressibility were used: C_t of 10×10^{-5} and 5×10^{-5} . It was originally assumed C_t would be in the range of $20-40 \times 10^{-5}$. This assumption was based on a misinterpretation of available data. An experiment was run with a Wilmington sandpack by measuring the increase in porosity with the net increase in pore pressure. This resulted in an average compressibility of 10×10^{-5} . R. C. Earlougher, Sr. estimated C_t to be about 5×10^{-5} though he later revised his estimate to

3.7 to 4.2×10^{-5} . The range of $5-10 \times 10^{-5}$ should be adequate to illustrate the effect of this parameter on pressure responses. A major result of this interference testing should be a more precise measurement of the system compressibility.

Three values of effective permeability to water were used: 5 md, 10 md, and 50 md. Relative permeability to water at residual oil is estimated to be about 10% using the laboratory sandpacks as a guide. This figure is considered reasonable for a very water wet sand. This means an effective permeability of 10 md would translate to an absolute formation permeability of 100 md. The range of 5 md and 10 md is representative of the laboratory sandpacks. Figures 30-31 illustrate pulse test response at 50 md permeability. If this occurs the laboratory sandpacks are not representative of reservoir conditions.

FACILITIES

Site preparation, installation of tankage and preliminary design work for the field facilities required to store, blend, heat, mix, meter, filter and inject Micellar-Polymer fluids is underway. Preliminary design was based upon the estimated amounts and types of materials to be handled. The plant layout is shown in Figure 32. The preliminary design incorporates ideas observed by Long Beach Oil Development Company engineers during field inspection of facilities operated by ERDA at Nowata, Oklahoma and the following ERDA contractors:

Cities Service
Phillips
Kewanee

El Dorado, Kansas
North Burbank Unit
Shidler, Oklahoma

Plant Site

The plant site was selected as close to the injection wells as possible. Fortunately, an area close to the wells was located on a rail-road siding, facilitating delivery and handling of materials. All required utilities are in close proximity including a vapor recovery collection system. The site has been graded and prepared for installation of equipment.

Tankage

Seven 2000 barrel tanks have been installed on the plant site. These tanks were surplus lease equipment. They have been cleaned and internally coated with fiberglass. A small alcohol tank has also been installed.

Plant Design

E and L Associates, Inc. have been retained to do the detailed engineering and design of the plant. The design is based upon receiving slug components by rail or truck. Adequate storage of products is provided to permit continuous slug injection of 1200 B/D to four injection wells adjacent to the site. Tankage will be sufficient to allow batch blending and filtering. Since the slug injection period was estimated to be only several months, very little automation appears justified.

Petroleum sulfonate will be shipped by tank car to the project area. A rental boiler package will be used to heat the contents of the tank car to approximately 130° F. before unloading. The boiler package will include a portable, gas-fired, skid-mounted 40 H.P. boiler. The gear pump will take suction on the tank car and another centrifugal pump will dilute the sulfonate with a given ratio of previously stored hydrocarbon mixture (gas oil and/or cat cycle oil). The sulfonate hydrocarbon mixture will be heated and kept at a constant temperature before it is blended with softened fresh water and alcohol to make up the slug composition. The inline mixer and recirculation will thoroughly mix the sulfonate and hydrocarbon during unloading.

Blending, metering and mixing the slug will be done by the centrifugal pump. The desired blend will be obtained by adjusting positive displacement meters to a predetermined volume. When the desired volume of a component is measured through the meter it will automatically shut off. When all the meters have been shut off, batch blending is complete. However, the slug will continue to circulate in the blend tank until filtering takes place or until the operator shuts down the recirculation process. All tanks will be equipped with tape-type gauges to check or confirm the metered blend. Limit switches on the gauge tape will alarm on high or low levels.

Filtration

Marathon recommends diatomaceous earth filtering of the micellar slug prior to injection into the wells. However, the polymer solution will not

require filtration. Fresh water from the City's system will be treated with an oxygen scavenger(catalysed sodium sulfite) pass through a zeolite water softener and a cartridge filter before entering into a gas blanketed water storage tank. Plant design calls for a 300 square foot D.E. pressure type filter. This equipment will be rented. The filter will be skid-mounted, semi-automatic and complete with slurry and precoat tanks, mixer, body feed pump and sluicing pump for backwashing. The filter is sized to allow ample time for cleaning before the next batch of slug is ready for filter.

Injection Equipment

An existing 100 H. P. Ajax

Triplex pump will be moved

from another facility to provide injection for the project. This pump will provide from 1200 to 1600 B/D injection at 1600 psi to a manifold. The manifold located near the injection pump will discharge into four conventional orifice plate type meter runs. A constant upstream pressure will be maintained by means of a by-pass control valve to be bypassed into the pump suction. Injection rate will be kept constant by means of a manually adjusted flow control valve on each meter run. Injection lines will be laid to each well. A 2-pen recorder will record the injection rate and the pressure downstream of the flow control valves. After the micellar slug phase has been completed, polymer will be adjusted by a separate metering pump to each injector.

Space has been provided at the plant site for dry polymer mix equipment in the event that liquid polymer cannot be used. Based on past

experience, handling dry polymer requires more elaborate facilities and more operating labor.

Production Facilities

The six producing wells affected by the pilot flood will be manifolded into a separate automatic well tester.

A separate water knock-out and wash tank (or heater-treater) will be provided to treat emulsion problems which may result from the Micellar-Polymer test. An individual oil storage tank will be set aside to keep the produced oil separate. The oil volumes will be metered through LACT equipment. Water production from the wells will be separated, clarified, metered and disposed of in the existing waste water system. Accurate metering of all fluids from the six wells will permit direct and indirect costs to be obtained. Evaluation of these costs will aid in determining the economics of the pilot project.

PROGRESS AND PLANNING

Milestone Chart

An unofficial revised Milestone Chart is shown in Figure 33.

Referring to the original Milestone Chart contained in the Technical Proposal, the project is now six months behind. There was a three months delay in starting the Phase A laboratory work. An additional three months was lost in the preparation and evaluation of sulfonates made from Wilmington crude oil or cuts therefrom. This work is not finished yet but preliminary results

have been sufficiently encouraging to go ahead with design and construction of the facilities as well as the redrilling and coring of the first injector FT-1.

Decision Point One was declared reached June 29. The redrill of FT-1 was commenced June 25, by prior agreement of all parties. Coring of the Hx_a sand in this well was completed July 6. The cores have been frozen and were shipped to Marathon Research Center after sampling by Petroleum Testing Laboratories.

Transient testing of FT-1 commenced August 1. The mini-injection test in FT-1 will commence approximately October 1. Delay in starting the injection test is a result of long lead delivery time of the DE Filter Plant. The mini-injection test will be finished about February 1, however, this will not delay commencing work on the drilling of additional wells, the design of production facilities or production and injection tests.

Decision Point Two should be reached about November 1, one month after the start of the mini-injection test. By this time any problems in connection with injectivity of the sulfonate slug or polymer will have become evident or been resolved.

Drilling and recompletion of the nine additional wells in the project area will be commenced as soon as Decision Point Two is reached (about November 1). The design, engineering and construction of the production facilities will commence about a month after reaching Decision Point Two (about December 1).

Project Plan and
Progress Report

The late start of the laboratory

work is reflected in the under-

expenditure of the project budget through May 1977. All critical preliminary

Phase A laboratory work is now completed and work delayed until after

Decision Point One is now being started. In the near future expenditures

can be expected to increase. An unofficial revised chart of Project Plan

and Progress is shown in Figure 34.

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TABLE 1

ESTIMATED VOLUMETRIC DATA
PROJECT AREA

Area (To Pier A Fault)	10.7 Acres
HXa Sand Thickness (FT-1 Logs & Cores)	50 Feet
Sand Volume	535 Acre Feet
In-Situ Porosity (1)	27%
Initial Water Saturation (1)	35.4% P. V.
Initial Oil Saturation	1241 B/Aft
Stock Tank Oil in Place	664,000 Bbl.
Recovery to date (2)	304,000 Bbl.
Residual Oil in Place	360,000 Bbl.
7% P. V. Micellar Slug	78,400 Bbl.
93% P. V. Polymer	1,042,200 Bbl.

- NOTE: (1) In-Situ Porosity and Water Saturation (Unconsolidated Sand) Estimated from Logs, Cores and Laboratory Core Analyses Taken at 1600 PSI Overburden Pressures Applied Uniaxially.
- (2) Production of HXa Sand Not Metered Separately, But Estimated from Water Flood Recovery Performance of Total HX VB.

WILMINGTON RADIAL CORE FLOODING SUMMARY SHEET

TABLE 2

Design Temperature - 125°F

Flood Number	Pre-Slug	Sulfonate	Hydrocarbon	Polymer	Total Perm. To Water	Porosity	Slug Viscosity	Slug Injected % P.V.	Median Frontal Advance Rate (ft/day)	S _o After Waterflood	S _o After Chemical Flood	Oil Recovery
WR-430	No	Commercial	1	Polyacrylamide	28.7 md	28.5%	10.0 cp	7%	0.276	35.4%	16.8%	52.4%
WR-439	No	Commercial	1	Polysaccharide	49.7 md	29.5%	36.0 cp	7%	0.243	31.1%	16.4%	47.3%
WR-460	No	Commercial	2	Polysaccharide	50.3 md	29.6%	44.0 cp	7%	0.259	38.2%	25.0%	34.7%
WR-461	No	Commercial	None	Polysaccharide	90.4 md	33.7%	34.0 cp	7%	0.245	35.2%	19.2%	45.6%
WR-462	No	Commercial	2, 3	Polysaccharide	129.0 md	31.1%	38.6 cp	7%	0.283	39.7%	21.5%	45.8%
WR-463	No	Commercial	2	Polysaccharide	55.3 md	31.4%	46.1 cp	7%	0.284	38.8%	24.7%	36.2%
WR-472	No	Commercial	2, 4	Polysaccharide	79.5 md	31.5%	43.4 cp	7%	0.281	31.3%	15.1%	51.9%
WR-474	No	Commercial	2	Polysaccharide	62.2 md	31.8%	31.0 cp	7%	0.286	30.5%	12.4%	59.5%
WR-480	No	Commercial	2	Polysaccharide	107.0 md	32.7%	38.6 cp	7%	0.266	32.3%	10.5%	67.4%
WR-475	No	Commercial	2	Polysaccharide	129.0 md	31.9%	36.4 cp	7%	0.270	26.9%	7.2%	73.1%
WR-479	No	Commercial	2, 3	Polysaccharide	152.0 md	34.6%	39.6 cp	7%	0.253	40.4%	17.5%	56.7%

<u>Flood Number</u>	<u>Pre-Slug</u>	<u>Sulfonate</u>	<u>Hydrocarbon</u>	<u>Polymer</u>	<u>Total Perm. To Water</u>	<u>Porosity</u>	<u>Slug Viscosity</u>	<u>Slug Injected % P.V.</u>	<u>Median Frontal Advance Rate (ft/day)</u>	<u>S_o After Waterflood</u>	<u>S_o After Chemical Flood</u>	<u>Oil Recovery</u>
WR-491	No	Commercial	2, 3	Polysaccharide	30.0 md	29.1%	42.4 cp	7%	0.309	26.6%	12.6%	52.8%
WR-492	No	Commercial	2, 4	Polysaccharide	164.0 md	32.5%	39.0 cp	7%	0.259	25.1%	6.5%	74.2%
WR-493	No	Commercial	2, 4	Polysaccharide	31.0 md	30.6%	40.9 cp	7%	0.287	25.9%	11.7%	54.9%
WR-495	No	Commercial	2	Polysaccharide	108.0 md	33.2%	35.8 cp	7%	0.259	25.3%	9.8%	61.4%
WR-496	No	Commercial	2	Polysaccharide	111.0 md	33.1%	38.1 cp	7%	0.254	25.2%	7.8%	68.9%
WR-498	No	Commercial	2	Polysaccharide	124.9 md	31.6%	49.2 cp	7%	0.271	31.7%	15.4%	51.3%
WR-497	No	Commercial	2	Polysaccharide	127.6 md	30.1%	35.4 cp	7%	0.287	36.3%	22.5%	38.0%
WR-501	No	Commercial	2	Polysaccharide	90.18 md	31.7%	38.0 cp	7%	0.271	17.4%	7.0%	59.9%
WR-502	No	Commercial	2, 3	Polysaccharide	97.96 md	32.3%	47.1 cp	7%	0.272	22.8%	10.1%	55.8%
WR-518	No	Commercial	2	Polyacrylamide	51.85 md	31.1%	36.4 cp	7%	0.276	30.9%	9.7%	68.5%
WR-519	No	Commercial	2	Polyacrylamide	40.56 md	30.7%	36.4 cp	7%	0.278	26.7%	12.8%	52.1%
WR-520	No	Commercial	2, 3	Polyacrylamide	39.41 md	31.4%	39.6 cp	7%	0.275	29.3%	9.8%	66.4%
WR-521	No	Commercial	2, 4	Polyacrylamide	58.52 md	30.4%	39.0 cp	7%	0.291	21.9%	5.7%	74.1%

Flood Number	Pre-Slug	Sulfonate	Hydrocarbon	Polymer	Total Perm. To Water	Porosity	Slug Viscosity	Slug Injected % P.V.	Median Frontal Advance Rate (ft/day)	S _o After Waterflood	S _o After Chemical Flood	Oil Recovery
WR-528	No	Commercial	2, 3	Polyacrylamide	35.0 md	30.2%	47.1 cp	7%	0.293	37.6%	14.0%	62.9%
WR-529	No	Commercial	3, 4	Polyacrylamide	38.8 md	30.2%	39.0 cp	9%	0.291	27.2%	9.5%	65.1%
WR-530	No	Commercial	3, 4	Polyacrylamide	87.5 md	31.0%	39.0 cp	5%	0.270	25.1%	9.8%	61.1%
WR-536	No	Commercial	2, 3	Polyacrylamide	81.3 md	30.6%	40.1 cp	7%	0.283	36.4%	19.6%	46.1%
WR-537	No	Commercial	2, 3	Polyacrylamide	95.4 md	30.9%	44.3 cp	7%	0.287	31.3%	14.1%	54.9%
WR-538	No	Commercial	2, 3	Polyacrylamide	73.1 md	31.0%	38.6 cp	7%	0.284	31.9%	10.9%	65.7%
WR-548	No	Commercial	2, 3	Polyacrylamide	163.9 md	34.0%	39.6 cp	7%	0.258	40.3%	21.2%	47.4%
WR-549	No	Commercial	2, 4	Polyacrylamide	128.4 md	33.3%	39.0 cp	7%	0.255	28.0%	9.8%	65.1%

Hydrocarbons

- 1 - Diesel #2
- 2 - Wilmington Gas Oil
- 3 - Light Cat Cycle Oil
- 4 - Kerosene

TABLE 3

WILMINGTON RADIAL CORE FLOODS
USING SULFONATED WILMINGTON
CRUDE OIL OR CUT THEREFROM

<u>Flood No.</u>	<u>WR-619</u>	<u>WR-636</u>	<u>WR-642</u>
Sulfonate	Crude Oil	Crude Oil	Vac. Gas-Oil
Hydrocarbon	None	None	Cat Cycle Oil
Polymer	Polyacrylamide	Polyacrylamide	Polyacrylamide
Tot. Perm. to Water	115 md	95 md	87 md
Porosity	32.1%	31.8%	31.3%
Slug Vis.	51.5 cp	54.0 cp	31.7 cp
P. V. Slug	10.0%	7.0%	7.0%
Frontal Advance Ft/D	0.266	0.274	0.276
So After Water- Flood (% PV)	28.9%	30.5%	26.9%
So After Micellar Flood (% PV)	15.2%	14.0%	11.8%

LOS ANGELES BASIN OIL FIELDS

Figure 1

Figure 4

CITY OF LONG BEACH
 MICELLAR-POLYMER PILOT
 TYPE ELECTRIC LOG
 WILMINGTON OIL FIELD

ELECTRIC LOG
SHOWING
HX SAND - UPPER TERMINAL VB

Figure 5A

CITY OF LONG BEACH
 MICELLAR - POLYMER PILOT
 ELECTRIC LOG CORRELATION MAP
 HX SUB POOL, UPPER TERMINAL ZONE
 WILMINGTON FIELD

SCALE
 0 100' 200'

Figure 6

Figure 8

CITY OF LONG BEACH
MICELLAR - POLYMER PILOT
PRESSURE VOLUME RELATIONSHIP LIQUID PHASE
HX_a SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 9

CITY OF LONG BEACH
 MICELLAR - POLYMER PILOT
 SOLUTION GAS-OIL RATIO
 HXa SAND, UPPER TERMINAL ZONE
 WILMINGTON FIELD

Figure 10

CITY OF LONG BEACH
MICELLAR - POLYMER PILOT
VISCOSITY OF LIQUID PHASE
HXa SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 11

Figure 12

CITY OF LONG BEACH
 MICELLAR-POLYMER PILOT
 SCHEMATIC DIAGRAM-RADIAL CORE FOR FLOOD POT
 HX_A SAND UPPER TERMINAL ZONE
 WILMINGTON OIL FIELD

PATTERN B
 CITY OF LONG BEACH
 MICELLAR-POLYMER PILOT
 HX_a SAND, UPPER TERMINAL ZONE
 WILMINGTON FIELD

Figure 15

PATTERN D
CITY OF LONG BEACH
MICELLAR-POLYMER PILOT
HX_a SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 17

PATTERN H
CITY OF LONG BEACH
MICELLAR-POLYMER PILOT
HXd SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 19

WILMINGTON PATTERN STUDY RUN R-I-1

40
Z-61

105
Z-231

375
Z-I-17

60
Z-I-67

225
J-31

930
J-66

170
J-130

590
J-124

340
J-17

1030
J-46

1050
J-106

130
J-47

FJ-53
500

225
J-52

CITY OF LONG BEACH
MICELLAR-POLYMER PILOT
STREAMLINE DIAGRAM FRONT-TRACKER MODEL
PATTERN A-I
HX₀ SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 20

CITY OF LONG BEACH
MICELLAR-POLYMER PILOT
STREAMLINE DIAGRAM FRONT-TRACKER MODEL
PATTERN B-1
HXO SAND, UPPER TERMINAL ZONE
WILMINGTON FIELD

Figure 21

[illegible]

Figure 22

Figure 23

Figure 24

Figure 25

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS KAB=50 CT=10X10-5

Figure 26

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS KAB=50 CT=5X10-5

Figure 27

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS K_{AB}=100 CT=10X10⁻⁵

Figure 28

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS $KAB=100$ $CT=5 \times 10^{-5}$

Figure 29

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS $KAB=500$ $CT=10 \times 10^{-5}$

Figure 30

WILMINGTON ERDA PROJECT PULSE/INTERFERENCE TEST
PREDICTIONS KAB=500 CT=5X10-5

Figure 31

MILESTONE CHART

WILMINGTON FIELD MARAFLOOD™ PROCESS TEST

WILMINGTON FIELD, CALIFORNIA

Figure 33

PROJECT PLAN & PROGRESS REPORT

* PHASE "A" TASKS
C COMPLETED TASKS

LEGEND

- SCHEDULED
- INTERMITTENT
- PROGRESS
- SCHEDULE EXTENDED
- EARLY START
- BUDGET
- ACTUAL

BUDGET REPORT

TOTAL	\$ 7,000,000
SPENT	380,726
PLANNED	600,000
VARIANCE	219,274

Figure 34