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TECHNICAL PROGRESS REPORT

DOE Contract No DE-AC22-93BC14860

Detailed Evaluation of the West Kiehl
Alkaline-Surfactant-Polymer Field Project
and It's Application to Mature Minnelusa Waterfloods

submitted by
Surtek, Inc.

Contract date: January 7, 1993

Anticipated Completion Date: September 30, 1994

Government Award for Fiscal Year October 1, 1993 to September 30, 1994: \$148,487

Principle Investigator: Malcolm J. Pitts
Surtek Program Manager: Harry Surkalo

Contract Specialist: William R. Mundorf
Contract Officer's Representative: Tom Reid

Report for the Period of
April to June 1994

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I. Objectives of Study

The objective of "Detailed Evaluation of the West Kiehl Alkaline-Surfactant-Polymer Field Project and It's Application to Mature Minnelusa Waterfloods" is to 1) quantify the incremental oil produced from the West Kiehl alkaline-surfactant-polymer project by classical engineering and numerical simulation techniques, 2) quantify the effect of chemical slug volume on incremental oil in the two swept areas of the field, 3) determine the economics of the application of the alkaline-surfactant-polymer technology, 4) forecast the results of injecting an alkaline-surfactant-polymer solution to mature waterfloods and polymer floods, and 5) provide the basis for independent operators to book additional oil reserves by using the alkaline-surfactant-polymer technology.

This report will document the numerical simulation waterflood, polymer flood, alkaline-surfactant flood and alkaline-surfactant-polymer flood predictions from the West Kiehl and Prairie Creek South fields.

II. Summary of Technical Progress

Fields Selected for Numerical Simulation - A geological study of 72 Minnelusa fields surrounding the West Kiehl is complete. Of the 72 fields, 35 were studied in detail and, from these 35 fields, Prairie Creek South and Simpson Ranch were selected for numerical simulation as representative of Minnelusa waterfloods and polymer floods, respectively. Prairie Creek South and Simpson Ranch were selected because their geology and reservoir size were similar to West Kiehl, both floods are more mature than the West Kiehl, and both reservoirs have a single injection well.

The West Kiehl and Prairie Creek South reservoir characteristics used in the numerical simulation are listed in Table 1. The average formation characteristics are from the history matches.

Both Minnelusa reservoirs were modeled using the GCOMP reservoir simulator. The GCOMP reservoir simulator provides black-oil, compositional, pseudo-miscible or chemical matching or forecasting capabilities.

West Kiehl Simulation Predictions - The West Kiehl field alkaline-surfactant-polymer flood was history matched through December 1993. A 12 x 33 grid with 3 layers was used in the West Kiehl numerical simulation. The chemical option of the simulator was calibrated by matching laboratory corefloods.

Figure 1 shows the cumulative oil, cumulative water and oil cut of the alkaline-surfactant-polymer history match with the field production data. The alkaline-surfactant-polymer forecast extends to October 2001.

Figure 1 also depicts the prediction for a waterflood, mobility control polymer flood, and an alkaline-surfactant flood. Volume of alkaline-surfactant solution injected was equal to the volume of alkaline-surfactant-polymer solution in the alkaline-surfactant-polymer forecast. The volume of mobility controlled fluid injected into the polymer flood was equal to the volume of mobility controlled fluid injected into the alkaline-surfactant-polymer forecast. Projected oil for each forecast are listed in the following table.

West Kiehl Numerical Simulation Predicted Oil and Water

<u>Flooding Process</u>	Cumulative Oil MSTB	Cumulative Water MSTB	Incremental Oil MSTB	Project Ending Date
Waterflood	830	1,953	-----	4-2002
Mobility Control Polymer	863	1,799	33	12-2003
Alkaline-Surfactant	859	1,413	29	7-1998
Alkaline-Surfactant-Polymer	1,023	1,893	193	10-2001

Figure 2 depicts the volume of incremental oil as a function of alkaline-surfactant-polymer solution injected. For each prediction, the volume of mobility controlled solution injected was the same and the mobility control polymer flood is the 0 volume alkaline-surfactant-polymer solution case. Incremental oil volumes are over waterflood. Essentially no incremental oil by alkali-surfactant addition to an injected polymer solution was produced until the reservoir was satiated of chemical adsorption.

Prairie Creek South Predictions - The Prairie Creek South field waterflood was history matched through 1993. The numerical simulation consisted of a 9 x 13 grid with three layers. Relative permeability data were identical to the West Kiehl with the exception of the initial oil saturation which was consistent with log calculations. Figure 3 depicts the cumulative oil, cumulative water, and oil cut for the waterflood history match with the field production data.

An alkaline-surfactant-polymer flood and polymer flood were forecast with the chemical option parameters being identical to the West Kiehl forecast. Figure 3 shows the waterflood, polymer flood and alkaline-surfactant-polymer flood forecasts. Incremental oil observed with the chemical floods are listed in the following table.

Prairie Creek South Numerical Simulation Predicted Oil and Water

<u>Flooding Process</u>	Cumulative Oil MSTB	Cumulative Water MSTB	Incremental Oil MSTB	Project Ending Date
Waterflood	899	1,707	-----	12-2007
Mobility Control Polymer	985	1,594	86	4-2008
Alkaline-Surfactant-Polymer	1,137	1,506	238	10-2008

Analyses Application to Waterflooded Minnelusa Fields - The grid systems have been designed and the initial reservoir properties interpolated for Simpson Ranch reservoir model. History match has not been achieved.

III. References

1. Clark, S.R., Pitts, M.J. and Smith, S.M.: "Design and Application of an Alkaline-Surfactant-Polymer Recovery System to the West Kiehl Field," SPE Advanced Technology Series, Vol 1, Number 1, April 1993, pages 172-179.
2. Meyers, J.J., Pitts, M.J., and Wyatt, K.: "Alkaline-Surfactant-Polymer Flood of the West Kiehl, Minnelusa Unit," SPE/DOE 24144, presented at the SPE/DOE Eight Symposium on Improved Oil Recovery, April 1992.

Table 1

West Kiehl and Prairie Creek South Reservoir Characteristics

	<u>West Kiehl</u>	<u>Prairie Creek South</u>
Field Characteristics		
Producing Sand	B	B
Depth (ft)	6,630	6,975
Temperature (°F)	134	138
Initial Reservoir Pressure (psi)	2,225	2,580
Field Pore Volume (MMbbl)	3.10	2.65
Unit Pore Volume (MMbbl)	1.37	---
Kotraba Pore Volume (MMbbl)	0.73	---
Formation Characteristics		
Average Permeability (md)	457	336
Average Porosity (%)	18.3	17.4
Thickness (ft)	15.1	22.0
Average Initial Water Saturation (%)	21.5	23.1
Fluid Characteristics		
Crude Oil API Gravity (deg)	24	20
Crude Oil Viscosity at Reservoir Conditions (cp)	17.0	18.3
Water Viscosity at Reservoir Conditions (cp)	0.56	0.56

West Kiehl Oil Rate, Water Rate, and Oil Cut versus
Cumulative Oil plus Water

Figure 1

Figure 2

West Kiehl Incremental Oil Recovery by Alkaline-Surfactant-Polymer
versus Volume of Alkaline-Surfactant-Polymer Injection

Figure 3

Prairie Creek South Oil Rate, Water Rate, and Oil Cut versus Cumulative Oil plus Water

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Status Report

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**Report for the Period of
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I. Geological and Reservoir Engineering

A geological study of 72 fields surrounding the West Kiehl has been completed. Of the 72 fields, 35 were studied in more detail with the following items developed and submitted to the Department of Energy: 1) an information sheet describing reservoir characteristics, number and type of wells, production information, initial oil saturation, etc., 2) an isopachous map, and 3) a plot showing oil production, oil cut and cumulative injection.

The 35 fields were studied from a reservoir engineering stand point to define: 1) the primary producing mechanism, 2) can the field be used as an analog to the West Kiehl, and 3) ultimate potential of the current oil recovery scheme. Ultimate oil recovery of the West Kiehl was also defined from a classical engineering stand-point.

From the geological and reservoir engineering studies, two fields were selected for comparison to the West Kiehl. The fields selected for comparison are:

Polymer Flood - Simpson Ranch
Waterflood - Prairie Creek South

The West Kiehl, Simpson Ranch, and Prairie Creek South were divided into producing zones and isopachous maps developed for each field. Oil saturation distribution, oil and water production, etc. were defined for each field. Classical engineering predictions of the ultimate oil production were made for each field.

This section is complete.

II. Laboratory Evaluation and Numerical Simulation of the West Kiehl

Interfacial tension and static chemical adsorption data were developed for in-input into the numerical simulator. Two linear corefloods were performed to define the rheological information. 7 radial corefloods were performed to provide oil recovery data to calibrate the chemical portion of the numerical simulator.

A history match of three corefloods to calibrate the numerical simulator has been achieved. The core simulation consists of 5 uniform thickness layers of 5 radial grid blocks each of equal porosity. A waterflood followed by alkaline-surfactant-polymer injection, a mobility control polymer flood, and an alkaline-surfactant-polymer flood were matched.

The West Kiehl field alkaline-surfactant-polymer flood was history matched through December 1993. A 12 x 33 grid with 3 layers was used in the West Kiehl numerical simulation. The prediction for a waterflood, a mobility control polymer

flood, an alkaline-surfactant flood and the forecast for the alkaline-surfactant-polymer flood are 830, 863, 859, and 1,023 MSTB, respectively. Corresponding, incremental oil over waterflood are 33, 29 and 193 MSTB.

Simulation results indicate incremental oil is a function of the volume of alkaline-surfactant-polymer injected. Essentially no incremental oil by alkali-surfactant addition to an injected polymer solution was produced until the reservoir was satiated of chemical adsorption.

This section is complete.

III. Numerical Simulation of Other Minnelusa Reservoirs

The Prairie Creek South field waterflood was history matched through 1993. The numerical simulation consisted of a 9 x 13 grid with three layers. A waterflood, a polymer flood and an alkaline-surfactant-polymer flood were forecast with the chemical option parameters being identical to the West Kiehl forecast. The prediction for a waterflood, a mobility control polymer flood, and an alkaline-surfactant-polymer flood are 899, 985, and 1,137 MSTB, respectively. Corresponding, incremental oil over waterflood are 86 and 238 MSTB. Differences in oil recovery between Prairie Creek South and West Kiehl are due to well placement and the resulting reservoir contact efficiency.

The Simpson Ranch grid system and the thickness of each layer has been developed. History match for the Simpson Ranch polymer flood has not been achieved.

This section is 85% complete.

IV. Extrapolation of Results of Mature Minnelusa Reservoirs

Extrapolation of the alkaline-surfactant-polymer technology to mature Minnelusa fields and the technology's potential will be performed after the numerical simulation of Simpson Ranch is finalized.

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