AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

SURTEK

DOE/BC/14886--7
6/17/94

1511 Washington Avenue — Golden, Colorado 80401 — [303] 278-0877 — FAX: [303] 278-2245

RECEIVED

SEP 20 1994

OSTI

TECHNICAL PROGRESS REPORT

DOE Contract No DE-AC22-92 BC14886

Investigation of Oil Recovery Improvement by Coupling
an Interfacial Tension Agent and a Mobility Control Agent
in Light Oil Reservoirs

submitted by
Surtek, Inc.

Contract date: September 28, 1992

Anticipated Completion Date: September 30, 1995

Government Award for Fiscal Year October 1, 1993 to September 30, 1994: \$178,053

Principle Investigator: Malcolm J. Pitts

Project Manager: Jerry Casteel

Contracting Officer's Representative: Mary Sue Price

Report for the Period of
April to June 1994

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

I. Objectives of Study

The study will investigate two major areas concerning co-injecting an interfacial tension reduction agent(s) and a mobility control agent into petroleum reservoirs. The first will consist of defining the mechanisms of interaction of an alkaline agent, a surfactant, and a polymer on a fluid-fluid and a fluid-rock basis. The second is the improvement of the economics of the combined technology.

This report examines the changes in the relative permeability characteristics with addition of alkali, surfactant, and polymer to the injected solution, the effect of matrix type on relative permeability characteristics with alkali-surfactant-polymer and the effect of different polymer concentrations on oil recovery by an alkaline-surfactant-polymer solution.

II. Summary of Technical Progress

Solutions were dissolved in 1,000 mg/l NaCl. 1,000 mg/l NaCl was used to saturate the core and as the displacing fluid when water was injected. Crude oil used was from the Adena field, Morgan County, Colorado; a fluvial deltaic reservoir. Crude oil is a 42 API gravity crude oil with a dead oil viscosity of 3.8 cp at 72°F and 1.3 cp at the 180°F reservoir temperature. All studies performed for this report were performed at 150°F. Dead crude oil viscosity was 1.4 cp at evaluation temperature.

Relative permeability studies were performed in Berea Sandstone linear core, 1 inches diameter by 6 inches long. Solutions for displacing crude oil from the core were:

- 1,000 mg/l NaCl - interfacial tension between crude oil and water is 19.6 mN/m
- 1.0 wt% Na_2CO_3 plus 0.2 wt% Petrostep B-100 - interfacial tension between crude oil and solution is 0.001 mN/m
- 1.0 wt% Na_2CO_3 plus 0.2 wt% Bioterge AS-40 - interfacial tension between crude oil and solution is 0.130 mN/m

Figure 1 depicts the relative permeability curves. Interfacial tension (alkali-surfactant) agents added to the displacing aqueous phase affects the relative permeability curves in the following manner:

- a small shift in the oil saturation waterflood end point
- a significant increase in water relative permeability
- the solution with the greatest interfacial tension reduction has the greatest increase in water relative permeability
- a shift of the point at which k_{ro} equals k_{rw} to a lower water saturation

The oil recoveries and mobility ratios for each solution are summarized in the following table.

<u>Injected Solution</u>	<u>Initial Oil saturation (PV)</u>	<u>Final Oil saturation (PV)</u>	<u>Oil recovery %S_{oi}</u>	<u>mobility ratio</u>
water	0.687	0.354	48.5	0.56
Na ₂ CO ₃ -Petrostep B-100	0.669	0.301	55.5	3.86
Na ₂ CO ₃ -Bioterger AS-40	0.622	0.346	44.4	1.00

Addition of alkali and surfactant to the aqueous solution increased the mobility ratio with the lowest interfacial tension solution having the greatest effect. No additional oil recovery was observed with the Na₂CO₃-Bioterger AS-40 solution and additional oil recovery was low for the Na₂CO₃-Petrostep B-100. The increase in mobility ratio with little if any increase in oil recovery agree with viscous instability discussions by Bentsen¹ and suggest mobility control is a necessity if an interfacial tension reducing agent is added to the injection water.

Polymers are added to injected solutions to improve mobility ratio. A second series of relative permeability curves were performed to determine the effect of polymer addition to the alkaline-surfactant solutions. Figure 2 depicts the data for the Na₂CO₃-Petrostep B-100 and Na₂CO₃-Bioterger AS-40 solutions with Flopaam 3330S added at 250 mg/l. Injected viscosities for the two solutions are 1.6 and 1.4 cp, respectively. Changes in the relative permeability curves with polymer addition are:

- the shift in the oil saturation to a lower saturation end point
- the water relative permeability increases to larger values at the final oil saturations but are lower at identical water saturations than the corresponding solutions with no polymer.
- the solution with the greatest interfacial tension reduction has the greatest increase in water relative permeability
- the point at which k_{ro} equals k_{rw} has shifted to higher water saturation relative to an alkaline-surfactant solution

The oil recoveries and mobility ratios for each solution are summarized in the following table.

<u>Injected Solution</u>	<u>Initial Oil saturation (PV)</u>	<u>Final Oil saturation (PV)</u>	<u>Oil recovery %S_{oi}</u>	<u>mobility ratio</u>
Na ₂ CO ₃ -Petrostep B-100	0.669	0.301	55.5	3.86
Na ₂ CO ₃ -B-100-3330S	0.633	0.080	87.4	8.2
Na ₂ CO ₃ -Bioterge AS-40	0.622	0.346	44.4	1.0
Na ₂ CO ₃ -AS-40-3330S	0.606	0.276	54.5	1.4

Mobility ratio was calculated according to Smith.² Even though polymer was added to the solution, the mobility ratio increased significantly for the Na₂CO₃-Petrostep B-100-Flopaam 3330S solution due to the considerably greater reduction of oil saturation. Increasing the polymer concentration to 500 mg/l, decreased relative water permeability at all oil saturations as shown in Figure 3. The mobility ratio declined to 6.1. Essentially no further decrease in oil saturation occurred with increasing polymer concentration.

Changing the porous matrix from Berea sandstone to Adena sandstone had a pronounced effect on the relative permeability of water and the Na₂CO₃-Petrostep B-100-250 mg/l Flopaam 3330S solution. 2 inch diameter by 6 inch long Adena core were used in the evaluations. Figure 4 depicts the relative permeability curves. Adena produces less oil with water injection as well as alkaline-surfactant-polymer solution than Berea; 33.5% S_{oi} versus 48.5% S_{oi} for water and 64.8% S_{oi} versus 87.4% S_{oi} for Na₂CO₃-Petrostep B-100-Flopaam 3330S solution. Mobility ratio changes with alkaline-surfactant-polymer solution relative to water were similar as well as the shapes of the curves. Mobility ratio in Berea sandstone increased from 0.56 for water to 8.2 for alkaline-surfactant-polymer solution and in Adena core mobility ratio increased from 0.24 to 9.1.

III. Continued Evaluations

Future studies will investigate the effect of polymer concentration on alkali plus surfactant plus polymer oil recovery. Oil recovery efficiency of alternate chemical solutions will be investigated as well as changes to improve the economics of oil recovery with the alkaline-surfactant-polymer technology.

IV. References

1. Bentsen, R.G.: "A New Approach to Instability Theory in Porous Media", Soc. Pet. Eng. J., volume 25, pages 765-779 (1985).
2. Smith, R.S.: Mechanisms of Secondary Oil Recovery, Robert E. Drieger Publishing Co, Inc., Huntington, New York, 1966, pages 74-75.

Figure 1

Comparison of Water and Alkaline-Surfactant Relative Permeability versus Water

Figure 2

Effect of Polymer Addition to Alkaline-Surfactant Solution
on Relative Permeability versus Water

Figure 3

Effect of Polymer Concentration on Alkaline-Surfactant-Polymer Solution Relative Permeability versus Water

Figure 4

Effect of Rock Type on Relative Permeability

SURTEK

1511 Washington Avenue — Golden, Colorado 80401 — [303] 278-0877 — FAX: [303] 278-2245

Environmental Status Report

DOE Contract No DE-AC22-92 BC14886

**Investigation of Oil Recovery Improvement by Coupling
an Interfacial Tension Agent and a Mobility Control Agent
in Light Oil Reservoirs**

**submitted by
Surtek, Inc.**

Contract date: September 28, 1992

Anticipated Completion Date: September 30, 1995

Government Award for Fiscal Year October 1, 1993 to September 30, 1994: \$178,053

Principle Investigator: Malcolm J. Pitts

Project Manager: Jerry Casteel

Contracting Officer's Representative: Mary Sue Price

**Report for the Period of
April to June 1994**

SURTEK

1511 Washington Avenue — Golden, Colorado 80401 — [303] 278-0877 — FAX: [303] 278-2245

Milestone Status Report

DOE Contract No DE-AC22-92 BC14886

Investigation of Oil Recovery Improvement by Coupling
an Interfacial Tension Agent and a Mobility Control Agent
in Light Oil Reservoirs

submitted by
Surtek, Inc.

Contract date: September 28, 1992

Anticipated Completion Date: September 30, 1995

Government Award for Fiscal Year October 1, 1993 to September 30, 1994: \$178,053

Principle Investigator: Malcolm J. Pitts

Project Manager: Jerry Casteel

Contracting Officer's Representative: Mary Sue Price

Report for the Period of
April to June 1994

RECEIVED
USDOE/PETC
94 JUL 27 PM 1:44
ACQUISITION & ASSISTANCE DIV.

I. Planned Technical Accomplishments

The technical portion of this study will be broken into four Milestone groups. The four groups are:

- Milestone 1 - Milestone 1 is a fluid-fluid study of the interaction of an alkaline agent and surfactant to produce low interfacial tensions. Deciphering the mechanisms of the development of low interfacial tension is the goal of this milestone. Milestone 1 is element code 1.1.
- Milestone 2 - Milestone 2 is a continuation of the fluid-fluid study. The difference is Milestone 2 will key in on the effect of adding a mobility control fluid to the alkaline-surfactant solution. Milestone 2 will examine how a mobility control agent will affect the synergistic interaction of the alkali and surfactant. Milestone 2 is element code 1.2.
- Milestone 3 - Milestone 3 is a fluid-rock study. Milestone 3 will examine the effect of reservoir rock on the fluid-fluid interactions studied in Milestones 1 and 2. Milestone 3 also will study the rock-surfactant, rock-polymer, and rock-alkali interactions and the impact of these interactions on oil recovery. Milestone 3 is element code 1.3.
- Milestone 4 - Milestone 4 objective is to use the mechanistic knowledge obtained in Milestone 1 through 3 to aid in developing different methods of applying co-injection of alkali-surfactant-polymer to make the process economic in a field application. Milestone 4 is element code 2.1.
- Milestone 5 - Milestone 5 is to write a final report incorporating the findings of Milestones 1 through 4 in a summary document. Milestone 5 is element code 1.4.

II. Actual Milestone Accomplishments

The research program has been underway since September 24, 1992. Surtek has collected crude oil and core from the Adena Field in Washington County, Colorado. The Adena field is a fluvial deltaic deposition sandstone reservoir. Core was also collected from a Muddy sand in Crook County, Wyoming.

Element code 1.1 is composed of seven sections. Each section which Surtek has worked on will be discussed individually. Element code 1.1 is complete.

Element code 1.1.A.1. is a study of how pH, alkali type, and surfactant structure affect the ability of a mixture of the various components to reduce the interfacial tension between the chemical solution and the Adena crude oil. This phase is complete. The types of alkaline agent evaluated are Na_2CO_3 , $\text{Na}_2\text{CO}_3\text{-NaHCO}_3$ buffered systems, $\text{Na}_3\text{PO}_4\text{-Na}_2\text{HPO}_4$ buffered systems, and NaOH . Surfactants tested include different molecular weights of the following: linear alkyl-aryl sulfonate, branched alkyl-aryl sulfonate, internal olefin sulfonate, alpha olefin sulfonate, linear toluene sulfonate, and linear xylene sulfonate.

Element code 1.1.A.2 is to study the effect of temperature on the interfacial tension between the alkaline-surfactant solution and the Adena crude oil. A branched and un-branched alkyl-aryl sulfonate plus alkali blends were selected for interfacial tension evaluations at 72°F, 125°F, and 170°F. This phase is complete.

Element code 1.1.A.3 is to study the effect of surfactant structure and alkaline agent type on the critical micelle concentration. A branched alkyl aryl sulfonate, an alpha olefin sulfonate, and a linear alkyl xylene sulfonate were selected for blending Na_2CO_3 , NaHCO_3 , NaOH , Na_3PO_4 , and Na_2HPO_4 . This phase is complete.

Element code 1.1.A.4. is to study the effect of alkali on the charge mass/balance of different surfactants. This phase has been started and difficulties arose in moving the surfactant on paper. A different form of electrophoresis may be required. Surtek suspended the work on this section due to equipment problems.

Element code 1.1.A.5 is to study the effect of salinity on the various parameters in defined in element codes 1.1.A.1 through 1.1.A.3. This phase is complete.

Element code 1.1.A.6. is to study the effect of cations on the various parameters in defined in element codes 1.1.A.1 through 1.1.A.3 and 1.1.A.5 . This phase is complete.

Element code 1.1.B is to study the effect of Adena reservoir brine on the various parameters in element codes 1.1.A.1 through 1.1.A.3. This phase is complete.

Element code 1.2 is composed of four sections. Each section which Surtek has worked on will be discussed individually. Element code 1.2 is 100% complete.

Element code 1.2.1 is to study the effect of alkali plus surfactant on various polymer solutions. Polyacrylamide, xanthan gum, and hydroxy ethyl cellulose are the polymers to be blended with selected alkaline-surfactant solutions. This phase is complete.

Element code 1.2.2. is to study the effect polymer addition to the aqueous solutions on the interfacial tension between the alkali plus surfactant solution and the Adena crude oil. This phase is complete.

Element code 1.2.3 is to study the effect of polymer addition on the critical micelle concentration values of the solutions studied in element code 1.1.A.3 and is complete.

Element code 1.2.4. is the long term stability of the alkaline-surfactant and alkaline-surfactant-polymer solutions. This phase is complete.

Element code 1.3 is divided into three major sections. The first major section is composed of five sections. Element code 1.3 is complete.

Element code 1.3.A.1.a is to study the effect of surfactant structure on the adsorption characteristics onto reservoir sand. Element code 1.3.A.1.a is complete.

Element code 1.3.A.1.b is to study the effect of cation type on surfactant structure and is complete.

Element code 1.3.A.1.c is to study the effect of alkali type on surfactant and alkali adsorption by reservoir sand. Element code 1.3.A.1.c is complete.

Element code 1.3.A.1.d is to study the effect of polymer on alkali and surfactant adsorption. Element code 1.3.A.1.d is complete.

Element code 1.3.A.1.e is to study the effect of different brine composition on adsorption. Element code 1.3.A.1.e is complete.

Element code 1.3.A.2 is to study the effect of alkali-surfactant and alkali-surfactant-polymer on relative permeability. Element code 1.3.A.2 is complete.

Element code 1.3.A.3 is to study the effect of the level of mobility control on alkaline-surfactant polymer oil recovery. Element code 1.3.A.3 is 90% complete.

Element codes which have been started are listed above. Element codes 1.1.A.1, 1.1.A.2, 1.1.A.3, 1.1.A.5, 1.1.A.6, 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.3.A.1.a through e, and 1.3.A.2 are on schedule and were completed by 6-30-94. Element code 1.1.A.4 was scheduled to be completed by 9-30-93 and is delayed due to equipment problems. Element codes 1.3.A.3 and 1.3.B are on schedule and should be complete in the next quarter.

A milestone log is attached.

Milestone Log

DOE Contract No DE-AC22-92 BC14886
Investigation of Oil Recovery Improvement by Coupling
an Interfacial Tension Agent and a Mobility Control Agent
in Light Oil Reservoirs

Element Code	Proposed Study Section	Planned Completion Date	Actual Completion Date	Comments
1.1.A.1	Task 1 - Mechanistic Studies 1. Fluid-Fluid Interactions A. Alkali-Surfactant 1. pH and Alkali Type and Surfactant Structure Effect on Interfacial Tension	2-28-93	2-28-93	This phase of the project is complete.
1.1.A.2	2. Effect of Temperature on the Alkali-Surfactant Interfacial Synergism	4-15-93	3-15-93	This phase of the project is complete.
1.1.A.3	3. Critical Micelle Concentration of Surfactants Blended with Alkali	5-31-93	5-31-93	This phase of the project is complete.
1.1.A.4	4. Charge/Mass Ratio of Surfactants Blended with Alkali	6-30-93		This portion of the project is approximately 40% complete. It is currently on hold for equipment problems.
1.1.A.5	5. Effect of Salinity on Measured Parameters	7-15-93	9-30-93	This portion of the project complete.
1.1.A.6	6. Effect of Cation on Measured Parameters	8-15-93	11-30-93	This portion is complete.
1.1.B	B. Effect of Reservoir Brine on Alkali-Surfactant Interaction	9-30-93	1-31-94	This portion is complete.

Element Code	Proposed Study Section	Planned Completion Date	Actual Completion Date	Comments
1.2.1	C. Effect of Mobility Control Agent on Alkali-Surfactant Interaction 1. Maximum Viscosity of Polymer-Alkaline-Solutions	2-15-93	3-1-93	This phase of the project is complete.
1.2.2	2. Effect of Polymer Addition on Interfacial Tension	3-31-93	4-30-93	This phase of the project is complete.
1.2.3	3. Effect of Polymer Addition on Critical Micelle Concentration	5-15-93	5-31-93	This phase of the project is complete.
1.2.4	4. Long Term Stability of Chemical Solutions	9-30-93	9-30-93	This phase of the project is complete.
1.3.A.1.a	Task 2. - Fluid-Rock Interactions A. Rock-Water Interface 1. Adsorption of Chemical onto rock a. Surfactant Type Affect on Adsorption	11-15-93	12-31-93	This phase of the project is complete.
1.3.A.1.b	b. Effect of Cation Type on Adsorption	12-31-93	1-31-94	This phase of the project is complete.
1.3.A.1.c	c. Effect of Alkali Type on Chemical Adsorption	1-31-94	12-31-93	This phase of the project is complete.
1.3.A.1.d	d. Effect of Polymer Type on Chemical Adsorption	2-28-94	2-28-94	This phase of the project is complete.
1.3.A.1.e	e. Effect of Salinity on Chemical Adsorption	3-31-94	3-31-94	This phase of the project is complete.
1.3.A.2	2. Effect of Alkali-Surfactant on Relative Permeability	5-30-94	5-30-94	This phase of the project is complete.

Element Code	Proposed Study Section	Planned Completion Date	Actual Completion Date	Comments
1.3.A.3	3. Mobility Ratio	7-31-94		This phase of the project is 90% complete. Expected Completion is July 1994.
1.3.B	B. Rock-Oil Interface	8-31-94		This phase is 96% complete. Expected completion date is July or August 1994.
1.3.C	C. Effect of Rock Composition on Oil Recovery	11-30-94		This phase is 10% complete.
2.1	Task 3 - Improvement of Process Economics 1. Injected Volume Effect on Recovery	6-30-95		
1.4	Fifth Milestone Report - Final Report	9-30-95		

Milestone Schedule X Plan X Status Report

Attachment B

Title		Investigation of Oil Recovery Improvement by Coupling an Interfacial Tension Agent and a Mobility Control Agent in Light Oil Reservoirs												Reporting Period April 1, 1994 to June 30, 1994												Identification Number DE-AC22-92BC14886							
Participant Name and Address		Surtek, Inc. 1511 Washington Golden, Colorado 80401																								Start Date 9/24/92				Completion Date 9/24/95			
Element Code	Reporting Element	FY93												FY94												FY95				Per Cent Complete			
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	Q1	Q2	Q3	Q4	Plan	Actual		
1.1	Fluid-Fluid Interfacial Tension	[Redacted]																								100	100						
1.2	Fluid-Fluid Mobility Control and IFT	[Redacted]																								100	100						
1.3	Fluid Rock	[Redacted]																								67	96						
1.4	Report	[Redacted]																								0	0						
2.1	Economic Improvement	[Redacted]																								0	0						
Signature of Project Manager and Date		<i>Michael J. Potts</i> 7-21-94																															

**DATE
FILMED**

10/14/94

END