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PILOT DEMONSTRATION-ENHANCED OIL RECOVERY
BY MICELLAR-POLYMER WATERFLOODING
BELL CREEK FIELD

MONTHLY TECHNICAL PROGRESS REPORT
FOR AUGUST 1977

MASTER

GARY OPERATING COMPANY
ENGLEWOOD, COLORADO 80110
SEPTEMBER 10, 1977

PREPARED FOR THE UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT NO. EF-77-C-02-4207
ORIGINALLY CONTRACT NO. E(49-18)-2237

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BELL CREEK FIELD
MONTHLY TECHNICAL PROGRESS REPORT - 14
AUGUST 1977

ABSTRACT

This is the fourteenth Monthly Technical Progress Report submitted under ERDA Contract No. EY-77-C-02-4207, formerly Contract No. E(49-18)-2237. As such it continues the coverage of the activities undertaken by Gary Operating Company, as well as by the major subcontractors, Atlantic Richfield, Union Oil and Intercomp. The work described herein covers the tasks for: Micellar-Polymer Systems Selection and Evaluation, Site Development, Pilot Performance Predictions and Fluid Distribution Facilities.

The major activity at this time is Phase II, Task 1, the Micellar-Polymer Systems Selection as between the two competing designs being developed by Atlantic Richfield and Union Oil. This activity came to closure with Decision Point 2 on August 24, 1977.

PHASE II - PRELIMINARY TEST PROGRAM

Task 1: Micellar-Polymer Systems Selection and Evaluation

Work Accomplished:

Atlantic Richfield and Union Oil completed running their respective process optimal designs for the Bell Creek pilot through a standard set of laboratory tests (FE-2237-9, Third Quarterly Technical Progress Report, January 1977 - March 1977, Attachment 2). These standard tests were described in the May report (FE-4207-11, May 1977). The rock and fluids to be used were described in the April report (FE-2237-8, April 1977).

The results of these tests were submitted to the Contractor on August 1, 1977 in the form of two reports, one from each Contractor. The Contractor then distributed these reports to the members of the Technical Committee. The Technical Committee met August 23-24 to hear oral presentations and to make a source selection. The Minutes of the Meeting are attached. The Union Process was selected for final pilot design and additional work was specified. This action passes Decision Point 2 subject to ERDA concurrence.

Work Forecast:

A new subcontract between Gary Operating Company and Union Oil Company is now required, as the previous one concluded at Decision Point 2 and on August 31, 1977. The Mini-Injectivity Test is now being planned.

PHASE II - PRELIMINARY TEST PROGRAM

Task 2: Site Development

Work Accomplished:

As discussed previously, conventional log analysis did not lead to any consistent set of input-output data due to the common difficulty that R_w , the salinity of reservoir brine, in post waterflood logging is unknown. Thus, two courses of action were decided upon at the Technical Committee meeting of May 19, 1977: to pursue log-inject-log tests on wells MPP #1 and #3, and to obtain Professor G. R. Pickett of Colorado School of Mines and his colleague, Dr. J. L. Bedwell, as consultants to aid in the total log analysis.

There was a delay in the log-inject-log tests because Schlumberger's TDT-L tool needed for these tests was down for repairs. The test on MPP #1 was completed the last week of July. However, the analysis of this test was anomalous, giving extraordinarily high readings of S_{or} . It was subsequently deduced that during the approximately ten-hour time period between injection and logging, the injected brine had redistributed itself out of the pay zone, leading to the anomalously high deduced S_{or} values.

As a result, the log-inject-log test was re-run in MPP #1 with logging during brine injection. Analysis of this test result indicated an $S_{or} \approx 30\%$.

Work Forecast:

The Pickett/Bedwell study will now be completed and a written report submitted, including the log-inject-log tests. The pre-pilot waterflood to stabilize the pattern into a repeated 5-spot streamline pattern will begin. The tracer test definition will be completed.

PHASE III - ENGINEERING AND ANALYSIS

Task 1: Performance Prediction

Work Accomplished:

The chemical design groups, see Task II.1, provided the results of their work to Intercomp, the Chemical Flood Simulator group. Intercomp, using their Chemical Flood Simulator (CFS), matched the core flood data to indicate validity of the CFS; and then, the CFS was used to predict pilot performance. Finally, an economic study was made and curves of oil recovered versus slug size (i.e., chemical cost) was constructed for each process, see Technical Committee Minutes.

Work Forecast:

The Resolution of the Technical Committee (Exhibit 6, Attachment) called for additional work between Intercomp and Union. The regular Black Oil simulator will be used to aid in the tracer study work.

PHASE IV - DEMONSTRATION PROGRAM

Task 1: Fluid Distribution System Facilities

Work Forecast:

Final design of the fluid distribution system will now begin, since the decision has been made (Decision Point 2) with respect to the micellar-polymer process. Design and procurement of the equipment for the mini-injectivity test will also begin.

MINUTES
Technical Committee Meeting
Micellar-Polymer Pilot Demonstration Project
Bell-Creek 'A' Muddy Sand Unit
August 23-24, 1977

Attendance List: Attachment 1

The Technical Committee met August 23-24, 1977 at the Communication Center of the Denver Technological Center for the purpose of hearing oral presentations from the two design groups, Atlantic Richfield and Union Oil, and from the numerical simulation group, Intercomp; and to make a source selection of a micellar-polymer process for the Bell Creek/ERDA pilot demonstration project. The agenda (Attachment 2) was followed in its entirety. These minutes follow the agenda order.

INTRODUCTION

The Chairman's introduction indicated that the source selection for the micellar-polymer design is Decision Point 2 of the prime contract between GOC and ERDA, "Pilot Demonstration - Enhanced Oil Recovery By Micellar-Polymer Waterflooding". Decision Point 2 is the first of three decision points -- DP 2, DP 3 and DP 4 -- leading to the recommendation by the Technical Committee for injection into the Bell Creek Pilot of the final optimized micellar-polymer system. These three decision points with their corresponding contract milestone numbers are given below and are shown in Exhibit 1:

<u>Decision Point</u>	<u>Phase Task</u>	<u>Milestone Number</u>	<u>Title</u>	<u>Date*</u>
2	II.1	1400	Fluid System Selection	8/77
3	II.2	1600	Site, Configuration & Pattern Confirmation	12/77
4	III.1	1900	Pilot Test Project Confirmation	12/77

*Dates as per letter A. Goldberg to F. W. Burtch, July 1, 1977 and approval by J. E. Fletcher to F. A. Haddenhorst, July 19, 1977.

The Chairman indicated that Decision Point 2 is solely addressed to the selection of the most promising micellar-polymer system design based upon the work in Phase II.1, "Fluid System Selection". Decision Point 3, "Site Configuration & Pattern Confirmation", is based upon the work in Phase II.2, "Site Development", and its purpose is to indicate that the Technical Committee is satisfied that the reservoir site description (ϕ , h , k and S_{or} as functions of reservoir location) is sufficiently accurate to lend confidence in the design and interpretation of the pilot performance.

Decision Point 4, "Pilot Test Project Confirmation", is based upon engineering and numerical simulation work, Phase III.1, which in turn has as input the work in Phases II.1 and II.2. Decision Point 4 is where all previous work comes to a focus for the "Go/No-Go" decision with respect to the recommendation for injection of the chemical flood system. Decision Point 4 requires that there be reasonable confidence in four factors: 1) in the description of the site characteristics, 2) in the understanding of the operative micellar-polymer mechanisms, 3) in the related simulation of the pilot behavior and performance, and 4) in the expected level of the pilot recovery.

The Chairman reviewed the history of Phase II.1, "Fluid System Selection". Gary Operating Company elected to develop two micellar-polymer processes for consideration in the Bell Creek Pilot Demonstration -- one representing the oil-external design philosophy and the other representing the water-external design philosophy. For an oil-external system, the Uniflood process of Union Oil Company was chosen; for a water-external system, Atlantic Richfield was chosen to construct a system based upon the optimal salinity approach. Each system was optimized for the Bell Creek fluids and rock properties. Hereinafter, these terms will be used as labels for the two designs, respectively.

In order to select which design indicated the most promise for application at Bell Creek, a Selection Methodology was developed. This Selection Methodology was based upon a series of standard laboratory experiments and reservoir numerical simulations, all of which were specifically tailored to the given reservoir rock and fluid properties; then from such comparable laboratory data to select the best candidate process from among the system designs offered; this selected design then to be subjected to the pilot test.

This Selection Methodology was built of the following components:

Component I:

Standard Laboratory Core Tests, Bell Creek Pilot Area Fluids.

- A. Standard Berea cores, 4 feet long
- B. Bell Creek Pilot Area cores, 12 inches long

Component II:

Independent numerical simulation of laboratory core tests. Critical inputs to be obtained independently from and/or checked against laboratory test results. The phase diagram, viscosities and interfacial tensions.

Component III:

Numerical simulation of pilot and composite field 5-spot performances. Critical inputs to be obtained independently from or checked against laboratory and field experimental results.

The Standard Laboratory Core Tests, Component I of the Selection Methodology, consists of the following three test categories.

Test 1. Optimal Design in Berea Rock

- A. Optimal Design Micellar and Polymer Slug Sizes, Exhibit 2
- B. Optimal Design Micellar and Polymer Slugs, Sized 1 PV each

Test 2. Ruggedness of Design in Berea Rock

- A. Fractional Slug Size
- B. Maximum divalent ion concentration

Test 3. Optimal Design in Bell Creek Pilot Area Rock

In each core test, the core was set up with reservoir fluids to best represent the reservoir condition in the pilot area. The flooding rate was maintained near the expected average reservoir pilot rate of one foot per day. A full description of the test procedures can be found in Appendix Exhibits I and II of Reference 1.1.

PART IA & IB PROCESS DESCRIPTION AND COMPARISON OF TEST RESULTS

Each design group on August 1st submitted written reports covering their respective process descriptions and the results of the Standard Laboratory Core Tests -- References 1.1, 1.2, 1.3, and 2. References 1.1 and 2 were distributed to the Technical Committee on August 2nd. The oral presentations covered this material with detailed commentary. Exhibit 2 displays the general description of the two processes, and Exhibit 3 gives the results of the Standard Laboratory Core Test series, 1A, 2A and 2B. Exhibit 4 gives the economic comparison of the optimal designs derived from these one-dimensional Standard Laboratory Core Tests in Berea rock.

The Bell Creek pilot area core test results, Component 1B, showed serious degradations in performance from that obtained in Berea, Component 1A. Explanations for this deficiency were advanced: shortness of Bell Creek cores; loosely butted core plugs due to friability of rock; moving fines; and mis-design with respect to mobility control. These matters were further addressed in Parts III, IV and V described below.

PART II NUMERICAL SIMULATION OF CORE FLOODS & 5-SPOT PREDICTIONS

A six-component, two-dimensional finite difference chemical flood numerical simulator was used to aid in the selection between the two micellar-polymer designs. Using the laboratory physico-chemical data obtained for each process (i.e., phase diagrams, interfacial tensions, viscosities, etc.), and history matching to the one-dimensional core experiments for dispersion, adsorption and low tension k_r , an internally, self-consistent set of simulator input was obtained for each micellar-polymer process -- oil-external and water-external, respectively. Thereafter, varying only the input slug size, the core flood production histories of oil, surfactant and polymer were successfully simulated for the complete suite of fractional sized (1, 3/4 and 1/2) core floods for each respective design.

Thus, having established confidence in the simulator mechanics and the physico-chemical inputs, the simulator was then used in a predictive mode. Pilot scale, two-dimensional area simulations were used to fashion economic comparisons based on "Present Value Net Profit After Tax". These predictions confirmed the conclusion indicated by the core floods reported in Part I that the oil-external design appears to be the better of the two.

PARTS III, IV & V QUESTIONS AND SUPPORTING DOCUMENTATION

These parts of the agenda led to a deeper understanding of the phenomena and behavior of the two micellar-polymer systems and their respective performances. Special note was taken that the simulator used two different descriptions for the sulfonate behavior for the two different designs.

1. The Atlantic Richfield design was simulated by means of an 80%/20% split in the sulfonate between monosulfonates and disulfonates, respectively. The former was assumed to be oil soluble, more surface active and more susceptible to adsorption; while the latter was assumed to partition more to the brine, to be less surface active and to adsorb less.
2. The Union design was simulated by means of a 50%/50% split in the sulfonate, with one part being susceptible to adsorption and the other part not; but in all other respects the sulfonates were assumed to be the same.

Special note was also taken of the serious degradation in performance (by a factor approaching one-half) between the Berea core flood recoveries and those obtained in the Bell Creek segmented plugs. A further discussion ensued with respect to the most likely phenomena responsible for this behavior -- see Part IB.

The Atlantic Richfield presentation in Agenda Part IV raised the question of process performance in long cores (16') when compared to that obtained in the 4' lengths of the Standard Laboratory Core Tests.

Finally, the issue of the patent and information disclosure policies relative to a Uniflood selection was discussed. The Chairman entered into the minutes of the meeting a letter from Union Oil Company to Gary Operating Company, dated August 18, 1977, Exhibit 5, stating the Union Oil Company position that there would be full disclosure of the compositions and concentrations of the

Uniflood design injected into the Bell Creek pilot. This was confirmed by Dean Sanford at the meeting during this discussion.

PART VI EXECUTIVE SESSION

The Chairman briefly reviewed the material presented in Parts I - V and summarized the critical results as shown in Exhibits 3 and 4. The Chairman concluded that the oil-external design of Union Oil Company was the more promising for application in the Bell Creek/ERDA pilot demonstration, and he recommended to the Technical Committee that it be selected.

A resolution selecting the Union Process for final design, Exhibit 6, was proposed and adopted unanimously.

The Technical Committee also unanimously expressed a requirement that Union Oil Company and Intercomp work closely together in order to assure a physically reasonable and self-consistent description of the physico-chemical mechanics and behavior of the Union Process. Doubt was specially expressed with respect to the present description employing the 50%/50% sulfonate split described above. The Technical Committee requires additional work by Union and Intercomp in order to assure the Committee of the adequacy of the process simulation.

ACKNOWLEDGMENT

The Chairman, on his own behalf and on behalf of the Working Interest Owners, expressed his appreciation to Atlantic Richfield for taking on the task of developing a water-external micellar-polymer design to be compared for Bell Creek application with the oil-external design already available from Union Oil.

The Chairman further expressed his appreciation to both design groups for working with him in a spirit of cooperation to develop the Selection Methodology, to develop the Standard Laboratory Core Tests, and to carry these out in a professional and timely way, despite the great pressures under which both groups were working. He also expressed his appreciation to Intercomp, whose work essentially all came to be done in the immediately preceeding six weeks, because they had to await the outcome of the Standard Laboratory Core Tests before beginning their phase of the Selection Methodology.

The Technical Committee thanked the Chairman for his careful stewardship of the pilot program to date.

There being no further business, the meeting was adjourned.

Arnold Goldberg

Arnold Goldberg
Chairman
Technical Committee

REFERENCES

- 1.1 Micellar-Polymer Pilot Scale Demonstrations Process Selection Phase Final Report, Volume I, Preliminary Pilot Test Design and Laboratory Test Results, ERDA Contract EY-77-G-02-4207, Union Oil Company of California, July 29, 1977.
- 1.2 Micellar-Polymer Pilot Scale Demonstrations Process Selection Phase Final Report, Volume II, Laboratory Test Records and Petrographic Studies, ERDA Contract EY-77-G-02-4207, Union Oil Company of California, July 29, 1977.
- 1.3 Micellar-Polymer Pilot Scale Demonstrations Process Selection Phase Final Report, Volume III, Uniflood Fluid Compositions, Economics, Chemical Availabilities and Costs (PROPRIETARY INFORMATION), ERDA Contract EY-77-G-02-4207, Union Oil Company of California, July 29, 1977.
- 1.4 Micellar-Polymer Pilot Scale Demonstrations Process Selection Phase Final Report, Volume IV, Bell Creek A Unit Muddy Sandstone Core Flood Results, ERDA Contract EY-77-G-02-4207, Union Oil Company of California, July 29, 1977.
- 2 Laboratory Design and Evaluation of a Micellar-Polymer Flooding Process for Bell Creek Field Unit A, Powder River and Carter Counties, Montana, Atlantic Richfield Company, July 22, 1977.

ATTACHMENT 1

ATTENDEES
ERDA/BELL CREEK PILOT DEMONSTRATION
TECHNICAL COMMITTEE MEETING
AUGUST 23-24, 1977

* (1)	Fred W. Burtch	U.S. Energy Research and Development Administration Bartlesville Energy Research Center
	William H. Howell	U.S. Energy Research and Development Administration Bartlesville Energy Research Center
	Todd M. Doscher	Consultant, Gary Operating Company
	James J. Rathmell	Atlantic Richfield Company Dallas, Texas
	Fred I. Stalkup, Jr.	Atlantic Richfield Company Dallas, Texas
*	Wm. A. Walther, Jr.	Atlantic Richfield Company Denver, Colorado
	Gordon Bradshaw	Atlantic Richfield Company Denver, Colorado
	Ray Aldridge	Atlantic Richfield Company Denver, Colorado
*	Robert Boswell	Colorado Oil Company, Inc. Denver, Colorado
	F. W. Heiser	Colorado Oil Company, Inc. Denver, Colorado
	Reed Ferrill	Consultant, Jerry Chambers - Oil Producer
*	Douglas Hammond	Jerry Chambers - Oil Producer Denver, Colorado
	Jack L. Corkill	Husky Oil Company Calgary, Alberta, Canada

* Robert F. Meldau	Husky Oil Company Santa Maria, California
L. W. Holm	Union Oil Company Brea, California
Leo J. O'Brien	Union Oil Company Brea, California
Dean Sanford	Union Oil Company Brea, California
Michael Todd	Intercomp Houston, Texas
James Dietrich	Intercomp Houston, Texas
* (2) Arnold Goldberg	Gary Operating Company Englewood, Colorado
Fred Haddenhorst	Gary Operating Company Englewood, Colorado
Ronald Larson	Gary Operating Company Englewood, Colorado
Betsy Peterson	Gary Operating Company Englewood, Colorado

* Member, Technical Committee

(1) Ex Officio

(2) Chairman

ATTACHMENT 2

AGENDA
TECHNICAL COMMITTEE MEETING

Tuesday Morning, August 23, 1977, 9 a.m.-1 p.m.

	Time Allotted
Introduction: Selection Procedure	
Chairman	¼ hour
Part 1A: Process Description	
Results of Standard Laboratory Test Series, Final Design, Test I-VI One-Dimensional Economics	
Union Oil Company	1½ hours
Atlantic Richfield Company	1½ hours
Part 1B: Comparison of One-Dimensional Results	
Union Oil Company	¼ hour
Atlantic Richfield Company	¼ hour

Lunch: 1 p.m. - 2 p.m.

Tuesday Afternoon, August 23, 1977, 2 p.m.-5 p.m.

Part II: Matching of Core Floods and 5-Spot Predictions	
Intercomp	2 hours
Short Time Essential Questions on Parts I & II	

* Note: Question Policy. During the presentation of Parts I and II, only questions of points of information and clarification will be allowed.

Wednesday, August 24, 1977, 9 a.m.-4 p.m. (Lunch as Convenient)

Part III: Written Questions - Union to Atlantic Richfield
 Written Questions - Atlantic Richfield to Union
 Written Questions - Atlantic Richfield and Union
 to Intercomp

Part IV: Supporting Results and Documentation
 Atlantic Richfield Company 1 hour
 Union Oil Company 1 hour

Part V: Technical Committee: General
 Questions and Discussion

TECHNICAL COMMITTEE Working Interest Owners, Caucuses

EXECUTIVE SESSION: (Member and 1 Alternate Only)

Part VI: Operator: Discussion and Recommendations

Contact Telephone: Denver Technological Center
 c/o Patty Harms
 (303) 773-1700

BELL CREEK / ERDA PILOT

PHASE II. 1 CHEMICALS

LABORATORY DESIGN{
CHEMICAL
SELECTION
}

DP 2

MINI
INJECTIVITY

PHASE II. 2 SITE

TRACER, PRESSURE PULSE
LOGGING{
SITE
CONFIRMATION
}

DP 3

PHASE III. 1 ANALYSIS

PILOT DESIGN PREDICTION
SIMULATION{
PILOT TEST
CONFIRMATION
}

DP 4

EXHIBIT 2
MICELLAR PROCESS DESIGN
BELL CREEK FIELD

<u>SLUG</u>	<u>UNION OIL</u>		<u>ATLANTIC RICHFIELD</u>	
PREFLUSH	HIGH PH SILICATE	10% PV	NACL (OR OTHER INORGANIC SALT)	40% PV
MICELLAR	7.6% (VOL.) ACTIVE SULFONATE - SOLVENT	3% PV*	2.77% (WT.) ACTIVE SULFONATE - ALCOHOL	12% PV
POLYMER	GRADED CONCENTRATION POLYACRYLAMIDE	60% PV	GRADED CONCENTRATION POLYACRYLAMIDE	60% PV

* APPROXIMATELY HALF WATER.

EXHIBIT 3
OVERALL COMPARISON
% RECOVERY

	UNION OIL OIL-EXTERNAL		ATLANTIC RICHFIELD WATER-EXTERNAL	
	<u>TEST No.</u>	<u>%</u>	<u>TEST No.</u>	<u>%</u>
1A OPTIMAL DESIGN	196C	87	3T-26	68
	203C	86	1T-31	74
2A FRACTIONAL SLUG	202C (3/4)	84	2T-29 (3/4)	57
	204C (1/2)	67	1T-30 (1/2)	43
2B CA ⁺⁺ MAXIMUM	199C	50	2T-30	44
	(No PREFLUSH)		(WITH PREFLUSH)	
	203C	86		
	(25% PV PREFLUSH)			

EXHIBIT 4
ONE-DIMENSIONAL ECONOMICS
OPTIMAL DESIGN

RATIO: GROSS REVENUE/CHEMICAL COST @ S_{OR} = 30%

ATLANTIC (REF. 2): FIGURE 16: 2.9

UNION (REF. 1.1): P. 21: \$2.31 PER BARREL OIL RECOVERED

$$\frac{\$13.50}{\$2.31} \times \frac{30\%}{36\%} = \underline{\underline{4.9}}$$

EXHIBIT 5

Union Oil Company of California
Union Research Center
P. O. Box 76, Brea, California 92621
Telephone (714) 528-7201

Richard C. Hartman
Patent Counsel

Dean Sandford
Assistant Patent Counsel

August 18, 1977

Dr. Arnold Goldberg
Gary Operating Company
Four Inverness Court East
Englewood, Colorado 80110

Dear Arnold:

In our telephone conversation last Tuesday you requested that Union provide its written assurance that in the event that the Uniflood Process is selected for testing in the Bell Creek Field, Union will deliver the compositions of the fluids injected on a non-proprietary basis.

Union has already made such representation to Gary and ERDA, and the compositions would be a contract deliverable under the subcontract for Union's work for the field test. We have worked this way in the past on a government funded field test of the Uniflood Process.

However, we would expect that the contents of Volume III of our Final Report, together with other information we have supplied to Gary under our past Letter Agreements, would be maintained proprietary.

As you know, the contents of Volumes I, II and IV of our Final Report are deemed non-proprietary.

Very truly yours,

Dean Sandford

DS/ssd

EXHIBIT 6

RESOLUTION

The Union Process is selected for final pilot design. As part of this final pilot design, the following tests will be made. The purpose of this testing is to assure that the Union Process is designed to optimize performance in the Bell Creek reservoir.

1. A Long Core (16') Experiment will be carried out to assure that the overall efficiency remains high with length.
2. GOC will have a minimum of 10 Bell Creek pilot plug relative permeability curves determined from which a maximum effective viscosity will be determined for the mobilized oil/water bank. The Union Process will be designed for this maximum effective viscosity.
3. A set of three one-foot core tests will be conducted with Bell Creek pilot fluids.
 - A. Continuous one-foot Berea core.
 - B. Butted two-inch Berea segments sequenced into one one-foot core.
 - C. Butted two-inch Bell Creek segments sequenced into one one-foot core.

It is expected that results of Tests 3A and 3B will be close together. To the extent that the Test 3C results are dissimilar, the Union Process design is to be modified; or a satisfactory explanation is to be made for the discrepancy. Special attention is to be paid to the features: mobility control, oil bank formations and pressure drop characteristics.

The selection of the Union Process for final design passes Decision Point 2 subject to ERDA concurrence.

The Union letter of August 18, 1977, D. Sanford to A. Goldberg, relating to proprietary aspects is incorporated as part of this decision, Exhibit 5.

August 24, 1977