13
23
5/29/80

SAND 80-0483
UNLIMITED RELEASE

~~MASTER~~
CATEGORY No. UC ~~92C~~ 926

FY 80 HEAVY OIL PROGRAM
FIRST QUARTERLY REPORT
JANUARY 1980

R. L. Fox
J. R. WAYLAND

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of
Energy under Contract DE-AC04-76DP00789.

MAY 1980

Sandia National Laboratories

DISCLAIMER

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

DISCLAIMER

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

Issued by Sandia Laboratories, operated for the United States
Department of Energy by Sandia Corporation.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available from

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy: \$3.50
Microfiche: \$3.00

Category No. UC926

SAND 80-0483
Unlimited Release
Printed May 1980

FY 80 Heavy Oil Program
First Quarterly Report
January 1980

DISCLAIMER

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

R. L. Fox
J. R. Wayland
Sandia National Laboratories
Albuquerque, New Mexico 87185

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. <u>Introduction</u>	1
II. <u>Well Completion</u>	1
A. High Temperature Packers	1
B. Insulated Injection String	2
C. Measurement of Downhole Steam Quality	6
D. Downhole Steam Generator	7
III. <u>Alternate Extraction Concepts</u>	7
A. Overburden Replacement	7
B. Microwave Heating	11
C. In Situ Hydrogenation	11
D. Literature Survey	11

INTENTIONALLY LEFT BLANK

I. Introduction

Research and development efforts in support of the Heavy Oil program well completions and stimulation subactivity and alternate extraction concepts task have been initiated. The objectives of the well completion and stimulation efforts are to carry out research and development in areas with significant potential for long-range heavy oil extraction development. Evaluation testing of packers and computational analysis of well bore insulation for heavy oil steam recovery injection wells have been investigated this quarter. An experimental program to measure downhole steam quality is under development. Initial examination of the application of the DOE downhole steam generator program to heavy oil reservoirs has commenced.

The examination of alternate extraction concepts of heavy oil has been initiated. An overburden replacement technique was evaluated both computationally and in a laboratory scale experiment. Microwave heating and in situ hydrogenation are being analyzed. A literature survey of heavy oil technology is to be initiated.

II. Well Completion

A. High Temperature Packers

A test program for evaluation of high temperature packers has been established for examination of performance under conditions encountered in thermal recovery from deep reservoirs. The thermodynamic parameters are more severe than those expected in current heavy oil projects; however the data can be related to conditions of interest in heavy oil recovery through application of analysis developed for the study of enhanced aging.

The rates of chemical reactions are functions of temperature. The mechanisms accountable for the failure of packers are related to chemical bonding. An example of a failure mechanism for an elastomeric seal element in a packer is an increase in the number of bonds between molecules which results in the embrittlement of the material. Relationships between the development of failure processes with time and temperature are given through the Arrhenius relationship for the quantity of a reaction product Q ;

$$Q = At \exp(-\Delta E/RT) \quad (1)$$

where ΔE is the activation energy, R is the gas constant, T is the temperature, and t is the time. Using the Arrhenius equation to determine the thermodynamic conditions, T_1 , T_2 which will produce the same quantity of reaction product in times t_1 , t_2

$$\ln \left(\frac{t_1}{t_2} \right) = \frac{\Delta E}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \quad (2)$$

An example of the time-temperature relation for an oxidizable elastomeric material used in packer seal elements is given in Figure 1.

The high temperature packers which have been evaluated to date were manufactured by Brown Oil Tools, Baker Packer, Haliburton, and Guiberson. The Brown and Guiberson packers were commercial units, the Baker and Haliburton packers were modified versions of commercial units. The packer performances obtained in a test of 640°F are given in Table 1. The survival for a five-day test at the elevated conditions is equivalent to several years under the conditions of existing shallow field operations.

B. Insulated Injection String

Insulated injection string is not currently utilized in steam recovery operation at depths less than 1000 ft. The low flow rates which are anticipated in the heavy oil extraction increase the attractiveness of applying insulation to the injection string. Analysis of the steam flow in the string has been carried out for two injection conditions.

	<u>Temperature</u>	<u>Flow Rate</u>
CASE A:	430°F	263 lb _m /hr
CASE B:	460°F	526 lb _m /hr

In both cases, the surface steam quality was 80%. Calculations were carried out using the Sandia wellbore heat loss code,⁽¹⁾ which

(1) C. E. Hickox, "Wellbore Heat Loss for Steam Injection Into Deep Reservoirs", SAND79-1298, October 1979.

FIGURE 1.

TABLE 1

High Temperature Packer Test

Test Conditions: Temperature = 650°F
 Pressure = 2100 psi

<u>PACKER</u>	<u>TEST NO.</u>	<u>TEST TIME</u>	<u>RESULTS</u>
Brown Emjay	GE-1	2 days	No seal at packer.
	GE-2	5 days	Held with small steam leak; difficult to pull.
Halliburton CT	GE-3	2 hours	No seal, set in tension
	GE-4	0 hours	Seal failed at 1000 psi, set in tension.
	GE-5	24 hours	Seal failed, set in compression.
Guiberson	GE-6	2 days	Seal failed.
	GE-7	23 hours	Seal failed.
Baker HB-1 (with advanced seal)	GE-8	1/2 hour	Seal leak.
	GE-9	4 days	Packer seal held.
	GE-10	0 hours	Injection string joint failure.

provides a one-dimensional description of the steam flow. The governing equations are

$$\frac{dT}{dz} = \frac{\frac{g}{GA} - \left(\frac{Cf}{8A}\right) G^2 v^2 + A^* \left(\frac{g}{G^2 v} - \frac{Cfv}{8A}\right)}{v \frac{\partial p}{\partial T} - \frac{\partial h}{\partial T} + A^* \left(\frac{\partial v}{\partial T} + \frac{1}{G^2} \frac{\partial p}{\partial T}\right)}, \quad (3)$$

$$\frac{d\chi}{dz} = \frac{\left(\frac{Cf}{8A}\right) G^2 v^2 - g - B^* \left(\frac{g}{GA} - g\right)}{B^* \frac{\partial h}{\partial \chi} + (B^* - 1) G^2 v \frac{\partial v}{\partial \chi}}, \quad (4)$$

where

$$A^* = \frac{\left(\frac{\partial h}{\partial \chi}\right)}{\left(\frac{\partial v}{\partial \chi}\right)}$$

(5)

and

$$B^* = \frac{v \frac{\partial p}{\partial T} + G^2 v \frac{\partial v}{\partial T}}{\frac{\partial h}{\partial T} + G^2 v \frac{\partial v}{\partial T}}$$

where

- A cross-sectional area of injection tube
- C circumference, inside surface of injection tube
- f friction factor for pipe flow
- G mass velocity
- g acceleration of gravity
- h steam enthalpy

p = pressure
 q = heat transfer rate per unit length of injection tube
 T = temperature
 v = specific volume
 z = axial coordinate
 χ = steam quality

The simultaneous solution of the above equations subject to the initial conditions $T(0) = T_0$ and $\chi(0) = \chi_0$ allows the determination of the steam temperature and quality as functions of position along the injection tubing.

It was found that for case A and no insulation (bare wall) that the steam quality had dropped to zero 400 ft from the surface. At the higher injection rate of case B the steam quality is only 12% at 580 ft. Clearly there is a need for improvement. One possibility is the use of an insulated injection string. If one inch of calcium silicate insulation is added to the outer surface of the injection string, the steam quality is increased to 47% for case A and to 62% for case B. Another possibility is to use the commercial product developed by General Electric, Thermocase III. The gain in steam quality above that for calcium silicate is not great; $\chi = 59\%$ for case A and $\chi = 68\%$ for case B. If steam quality of 50% or greater is to be maintained at depth, it will be necessary to insulate the injection string if normal oilfield practice is to be followed in the injection process. The wellbore heat loss code has provided useful information for several oil producers, including Husky Oil and Aminoil.

C. Measurement of Downhole Steam Quality

The measurement of downhole steam quality is being pursued through application of a downhole sampler. The sampler is designed to obtain a known volume of steam at the sand face. Measurement of the mass of the fluid trapped by the sampler is sufficient to provide a set of two equations for the mass of the vapor phase and liquid phase water at the downhole location. The sampler is designed to require a minimum of surface control and appears to be compatible with existing well head configurations when applied with a well head lubricator.

D. Downhole Steam Generator

The downhole steam generator program carried out by DOE under the DEEP STEAM project appears to have significant possible application to the heavy oil program. The potentiality of overcoming many of the wellbore heat losses and simultaneously increasing the steam quality is being investigated. The ability of some of the generator designs under consideration to mobilize the oil at large distances ahead of the condensation front could have significant economic implications for recovery of the highly viscous shallow reservoir. The possibility of overcoming environmental problems with downhole steam production is also attractive. Computational investigations and laboratory scale experiments to evaluate the application of this technology to heavy shallow oil production are being initiated.

III. Alternate Extraction Concepts

A. Overburden Replacement

A technique has been proposed for recovery of shallow heavy oil which involves strip mining of the overburden followed by construction of a pool of water over the hydrocarbon-bearing formation. A schematic diagram of such a recovery operation is shown in Figure 2. The water within the pool has a greater density than the oil within the formation and thus constitutes the conditions for a classical Rayleigh-Taylor instability. The unstable condition is relaxed by reversing the positions so that the lighter liquid is on top, having been displaced by the liquid with greater density. The hydrocarbons, which have moved to the surface, can be easily collected without the need for additional mining. Modifications to enhance the recovery process include using hot water, addition of surfactants, and drilling of penetrating wells. The recovery of heavy oils by this process of removal of overburden and replacement with a water pool has been analyzed from the view of the properties of the fluids involved and the reaction of these fluids to the applied recovery forces. In addition, bench scale experiments were conducted to test some of the recovery procedures.

The statement of Darcy's Law, applicable to most oil recovery processes is,

FIGURE 2. SCHEMATIC REPRESENTATION OF OVERBURDEN REPLACEMENT (FLIP-FLOP) METHOD FOR THE RECOVERY OF BITUMEN FROM SHALLOW HEAVY OIL.

(6)

$$\vec{v}_m = -\hat{e}_h \frac{K_h}{\mu} (\nabla P) \cdot \hat{e}_h - \frac{K_v}{\mu} \left[(\nabla P) \cdot \hat{e}_v + \rho_o g \right] \hat{e}_v$$

where $K_{h(v)}$ is the horizontal (vertical) permeability of the reservoir, P is the pressure, $\hat{e}_{h(v)}$ is a unit vector in the horizontal (vertical) direction, and v_m is the porous flow velocity. The driving force for the overburden replacement method is the bouyant force instead of a pressure gradient, for this process

$$v_m = - \frac{K_v}{\mu} \left(\rho_w - \rho_o \right) g \hat{e}_v . \quad (7)$$

Thus, the driving force for most enhanced oil recovery techniques acts on the reservoir fluids through the horizontal permeability; however, the overburden replacement mining processes act through the vertical permeability. The stratigraphic nature of the sedimentary formations which comprise oil reservoirs results in a horizontal permeability much larger (often by a factor of 5) than the vertical permeability.

The rate of production, based on v_m , is

$$\Omega = \frac{\alpha K_v}{\mu} \left(\rho_o - \rho_w \right) g . \quad (8)$$

Evaluating the predicted recovery for a large recovery project

$$\begin{aligned} K_v &= 2 \text{ Darcies} \\ \mu &= 130 \text{ Ns/m}^2 \\ \rho_o &= 975.10 \text{ kg/m}^3 \\ \rho_w &= 10^3 \text{ kg/m}^3 \\ g &= 9.8 \text{ m/s}^2 \\ \alpha &= 1 \text{ square mile} \end{aligned}$$

the predicted recovery is 4.95 BOPD.

The effect of temperature on the recovery rate in an overburden replacement operation can be determined from equation (7). An increase in temperature can affect the density difference between the crude oil and water, and can affect the oil viscosity. The change in density of bitumen with temperature is not significantly greater than that of water. The major effect of heat addition on the recovery rate is therefore the reduction in viscosity of the oil.

The rate of production from an overburden replacement operation can be increased by heating the water pool. If the pool is heated to 130°F, the predicted production rate increases from 3-5 BOPD to 780-1300 BOPD.

If the pool were heated to 130°F, the heat loss from air convection over the pool surface would be a major problem. The energy loss would be equivalent to 7000 BOPD from the one square mile pool. The pool heat loss without insulative measures is thus greater than the production from the project. The cost of insulation of the surface would be expected to be prohibitive in addition to interfering with the attractive simplicity of the recovery technique.

A series of laboratory-scale recovery experiments was carried out to test the results of the computational analysis of the overburden replacement recovery method. A core sample consisting of an unconsolidated sand matrix (2 Darcy permeability) and 12.5° API crude oil were utilized in the experiments. The cores used in the test had very small quantities of connate water. Samples were also prepared which consisted of the same crude oil without the presence of a reservoir matrix. Testing of the recovery of the 12.5° API oil by locating the water pool above the oil without the effect of the reservoir matrix resulted in rapid recovery of 99% of the oil within six hours.

Measurement of oil produced in the laboratory experiments with reservoir matrix averaged over several weeks were $1.5 \times 10^{-8} \text{ m}^3$ of oil per day from vessels with .114-m diameter surfaces at the oil/water interface. The recovery predicted from the same theoretical analysis as used to evaluate the large scale field operation was $1.3 \times 10^{-8} \text{ m}^3$ of oil per day. The small scale experimental test agrees with the mathematically predicted production rate for an overburden replacement operation.

B. Microwave Heating

Another concept for enhanced oil recovery is by the microwave heating of the bitumen to lower its viscosity and hence increase mobility. A systems analysis will be undertaken in the second quarter to establish the feasibility and economic requirements of this approach. Some preliminary experiments reported in the literature indicate that L band (915 MHz) does not penetrate deep enough into the formation to be useful. However, lower R.F. heating (about 80 MHz) may be more promising.

C. In Situ Hydrogenation

One possible enhanced oil recovery concept involves hydrogenation of the resources prior to and during recovery to improve physical and chemical properties. A literature search found a number of undeveloped patents and little information on laboratory assessment. A sample of Kern River crude was analyzed. The core sample contained 7.5 weight % pentane soluble oil, and another 19% by weight was removed upon ashing. The residue from the ashing will be used for assessment of catalysis from the formation.

D. Literature Survey

A complete literature survey is necessary to any careful program for a good understanding of past and present activity in the field. To insure a complete knowledge of the heavy oil technology, a literature search will be undertaken in the second quarter.

DISTRIBUTION:

George Fumich
Acting Assistant Secretary
for Fossil Energy
Mail Stop B-126
U.S. Department of Energy
Germantown, MD 20545

Office of Deputy Assistant (4)
Secretary for Oil & Gas Technology
U.S. Department of Energy
Mail Stop D-107
Washington, DC 20545
Attn: L. M. Burman
P. R. Wieber
G. Stosur
H. R. Anderson

Ronald S. H. Toms
Division of Geothermal Energy - RA-233
U.S. Department of Energy
MS3344 Federal Building
12th & Pennsylvania Ave. NW
Washington, DC 20461

Dr. R. J. Braitsch
Office of Planning and
Technology Assessment
Assistant Secretary for
Fossil Energy
U.S. Department of Energy
Mail Stop C-125 (GTN)
Washington, DC 20545

Office of Program Coordination &
Management in Fossil Energy Programs
U.S. Department of Energy (3)
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612
Attn: G. W. Dean, Director
A. J. Leighton, Program Coord.
H. J. Lechtenberg, Program Coord.

Leo A. Schrider
Assistant Director
Extraction & In Situ Conversion Div.
U.S. Department of Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, WV 26505

U.S. Department of Energy (4)
Bartlesville Energy Tech. Center
P.O. Box 1398
Bartlesville, OK 74003
Attn: R. T. Johansen
C. C. Linville
C. R. Williams
J. Miller

D. L. Krenz
Special Programs Division
U.S. Department of Energy
Albuquerque Operations Office
Albuquerque, NM 87185

Dr. W. Somerton
Mechanical Engineering Dept.
University of California/Berkeley
Berkeley, CA 94306

Dr. L. Handy
Chairman
Petroleum Engineering Dept.
Univ. of Southern California
Los Angeles, CA 90007

Dr. Paul Crawford
Department of Petroleum Engr.
Texas A & M University
College Station, TX

Joseph T. Hamrich
Aerospace Research Corp.
5454 Jae Valley Road
Roanoke, VA 24014

B. F. Birdwell
Getty Oil Company
Exploration & Production Research
3903 Stoney Brook
Houston, TX 77063

Dr. James Irving
Manager
Oil Recovery Division
Chevron Oil Field Research Co.
P.O. Box 446
La Habra, CA 90631

Steve Pursley
Exxon Production Research Co.
3120 Buffalo Speedway
Houston, TX

R. Huerkmans, Project Engineer
for Yorba Linda Field
Shell Oil Company
P.O. Box 481
Houston, TX 77001

A. E. Trimble
Manager
Petroleum Recovery Research
Getty Oil Company
3903 Stoney Brook
Houston, TX 77001

DISTRIBUTION (cont.):

Wes Densmore
Cities Services Co.
Box 300
Tulsa, OK 74102

Frank Ducey
KVB
17332 Ervine Blvd.
Tustin, CA 92680

R. F. Meldau
Husky Oil Company
1125 East Clark Avenue
Santa Maria, CA 93454

George B. Miller
Occidental Research Corp.
2100 SE Main Street
P.O. Box 19601
Irvine, CA 92713

G. N. Buttram
Operations Manager
Western Division
Occidental Petroleum Inc.
5000 Stockdale Highway
Bakersfield, CA 93309
Attn: J. L. Turner

John C. Fair
Director
Production Engineering Section
Gulf Research & Development Co.
P.O. Drawer 2038
Pittsburgh, PA 15230

Dr. Paul Kydd
HCR
R & D Center
P.O. Box 6047
Lawrenceville, NJ 08648

D. H. Desty
British Petroleum Research Centre
Chertsey Road
Sunbury-on-Thames
Middlesex, TW16 7LN ENGLAND

Dr. M. F. Mohtadi
University of Calgary
2920 24 Avenue, NW
Calgary, CANADA
T2N 1N4

4700 J. H. Scott
4730 H. M. Stoller
4731 M. G. Thomas
4738 R. L. Fox
4738 W. D. Lyle
4738 J. R. Wayland (10)
4740 R. K. Traeger
Attn: C. Hart
8266 E. A. Aas
3141 T. L. Werner (5)
3151 W. L. Garner (3)
DOE/TIC (25 - For Unlimited Release
3154-3 R. P. Campbell

* Recipient must initial on classified documents.