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SAND 80-1019
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FY 80 HEAVY OIL PROGRAM
SECOND QUARTERLY REPORT
APRIL 1980

J. R. WAYLAND
R. L. Fox

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

JUNE 1980

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ABSTRACT

The research and development efforts in support of the heavy oil program reservoir access and alternate extraction activities that were initiated last quarter have been continued and expanded. The development of a short course on the utilization of specialized drilling technology to heavy oil sands has been investigated. The steam quality sampler is undergoing laboratory testing. A special report on possible application of sand control methods to heavy oil steam injection tests has been prepared. The first stage of the analysis of R. F. and microwave heating has been completed. The results of a series of laboratory experiments on in situ hydrogenation are presented.

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I. INTRODUCTION

Sandia has the responsibility of assisting the heavy oil program in the areas of reservoir access and alternate extraction concepts. The reservoir access activity has the objective of developing improved well completion and stimulation techniques for tar sand oil production. Sandia is assisting in this area by helping in the transfer of technology from other oil production programs to the extraction of heavy oil. Another activity has been in the determination of wellbore heat losses and steam quality. The problems of sand control have been investigated and suggestions have been made to help overcome possible trouble areas should they occur. The need to enhance permeability will be receiving more and more attention as the tar sands program continues.

The alternate extraction techniques program at Sandia for SAN/DOE has dealt with new and novel in situ techniques. In the past this has included the overburden replacement concept. The current effort is mainly with radio frequency/microwave heating and in situ hydrogenation.

II. RESERVOIR ACCESS

A. Insulated Injection String

Steam injection experiments into shallow heavy oil deposits utilizing surface steam generation, require the problem of wellbore heat loss to be addressed. A series of calculations quickly established that, for low mass flow rate, substantial heat losses occur. To reduce the heat loss, insulation has been added to the steam injection string. One inexpensive approach that has been suggested is the use of fiberglass insulation.

An injection well with fiberglass insulated steam injection string has been modeled using the BORE wellbore heat loss code.^{1,2} Steam quality, temperature and enthalpy were computed as functions of depth for given wellhead temperature, pressure or steam quality.³ The results are shown in Figure 1 as a function of mass flow rate and indicate that steam quality is improved for mass flow rates above 150 B/D. If the method of insulation allows moisture present in the annulus to wet the insulation, the steam quality is reduced as shown in curves AA and BB of Figure 1 for injection pressure of 700 and 1000 psia. Thus, the mass flow rate must be increased to above 100 B/D to maintain a steam quality of order 50% at a depth of 500 ft.

FIGURE 1.

To estimate the conditions one might encounter in the field for a properly designed system, a series of simulations were performed. The range of injection pressures, all for an injection steam quality of 75%, included 300, 500, 700 and 1000 psia. The time dependent behavior is given in the report SAND 80-0687 for mass flow rates of 50, 100, 150, 200 and 500 B/D.³ For each case a linear fit of the form

$$X(\%) = A_1 t(\text{hr}) + A_0$$

is given for each mass flow rate. Also, the steam quality at equilibrium as a function of mass flow rate is given. Perhaps more useful in the field is the empirical expression for steam quality as a function of injection pressure p and mass flow rate m ;

$$X(\%) = 64.6 \dot{m}^{(0.02478)} - 0.192 p \dot{m}^{(-0.8783)}$$

which reproduced the calculated results to within $\pm 2\%$ when m is in B/D and p in psia. The steam quality is given by

$$X = X_0 - \frac{(0.2031 T_0 - 111.86)}{1318 \dot{m} P_0^{(-0.0874)}}$$

where l is the depth in feet and X_0 , T_0 and P_0 are the steam quality, temperature ($^{\circ}\text{R}$), and the pressure (psia) at the wellhead. A manual has been prepared for the wellbore heat loss code.²

B. Measurement of Downhole Steam Quality

The measurement of downhole steam quality is now in the laboratory stage. The sampler has been designed and the first prototype has been constructed. The laboratory test chamber has been obtained and is being used to test the prototype. The release mechanism is being tested for durability under expected field conditions.

The requirement for a high temperature wire line has been solved. The Sandia high temperature logging mask truck and instrument trailer will provide the necessary equipment for field measurement.

III. ALTERNATE EXTRACTION CONCEPTS

A. Radio Frequency/Microwave Heating

The 150 million dollar Texaco/Raytheon program to use R.F./microwave heating for enhanced oil recovery has placed added emphasis upon our efforts in this area. A study of the background information needed for the analysis of the feasibility of using electromagnetic radiation has been made.⁴

A general analysis of the frequency dependency of the absorption of electromagnetic fields (EMF) shows that the absorption term dominates at lower frequencies. This implies that EMF in the radio frequency range will be more useful for induction heating. There is precious little information in the literature for real and imaginary components (ϵ' and ϵ'' , respectively) of the complex dielectric constant for heavy oil sand. Jack Bridges of IIT Research Institute, obtained for Utah sands values of $K = 10$ and $\tan \delta = 0.1$ up to $K = 50$ and $\tan \delta = 10.0$ as the moisture content varied from 0% to 7%. The IIT measurements were made at three to five MHz.

When an electromagnetic wave enters an imperfect dielectric, it is attenuated so that the initial power P_0 in transversing a distance X is decreased by the amount

$$\Delta P = P_0 [1 - \exp(-2\alpha X)] \quad (1)$$

where

α = attenuation coefficient

$$= \omega \sqrt{\frac{\mu' \epsilon'}{2}} \left(\sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon'^2}} - 1 \right)$$

μ' = real part of the complex magnetic permittivity

ω = angular frequency of the EMF

σ = conductivity of the imperfect dielectric

Normally $\mu' = \mu_0$ = magnetic permittivity of free space for materials we are interested in. The penetration depth l_p is defined as the depth at which the power has been reduced by $1/e$, i.e., $l_p = 1/2\alpha$. If we assume that K and $\tan \delta$ vary linearly from $K = 10$ and $\tan \delta = 0.1$ at 5 MHz to $K = 1.8$ and $\tan \delta = 0.06$ at 915 MHz, the values for l_p are given in Table 1.

These results are ambiguous, mainly because of the lack of measurements of K and $\tan \delta$. For example, if $K = 1.8$ and $\tan \delta = 0.06$ at 5 MHz, then $l_p = 118.6$ meters (389 ft.). Clearly we must obtain some measurements of K and $\tan \delta$ as a function of frequency and physical parameters, e.g., water content. In fact, if we use the frequency dependence reported by IITRI, we could conclude that the lower frequency, the greater l_p , so why not use 60 Hz.

TABLE 1. WAVE LENGTH AND DEPTH OF PENETRATION AT VARIOUS FREQUENCIES

FREQUENCY (MHz)		5.0	13.56	27.12	40.0	915	2450*
Wave Length λ_0	Metres	60.0	22.1	11.1	7.5	0.33	0.12
	Feet	197	72.6	36.3	24.6	1.07	0.40
Depth of Penetration l_p	Metres	30.2	11.1	5.6	1.65	0.65†	0.24
	Feet	99	36.4	18.3	5.41	2.11†	0.79

* Assuming $K = 1.8$ and $\tan \delta = 0.06$ at 2450 MHz.

† If $K = 50$ and $\tan \delta = 10$ then $l_p = 7.43 \times 10^{-4}$ metres (2.44×10^{-3} ft.)

An estimate of the depth to which R.F./microwave heating might be effective can be found from estimates of needed power levels. To reduce the viscosity down into the 10 cp range, the heavy oil sands will probably have to be heated to a temperature of 400°F or more. If the ambient temperature is 100°F and the time of application is about three months, the heating rate is about 3.8×10^{-5} F/sec (2.2×10^{-5} C/sec). Then using equation (1) and the results from Table 1, we find the generator power levels needed to produce this heating rate in a one cm^3 block of heavy

oil sand at a production well in a 0.1 acre five-spot well pattern (Table 2). Of course, this is assuming that there is perfect absorption of the generated electromagnetic field at the wellbore surface. If one has a 150KW generator, it is simple to show that $K \tan \delta$ must be less than 14.8 at 5 MHz or 0.08 at 915 MHz. Thus, practical application at 915 MHz is unlikely and requires heavy oil sands with very low water content at 5 MHz.

Another way to look at this problem is that excessive heat is generated in close to the borehole in order that an adequate temperature rise will occur at the production well. The extra near field energy will, however, evaporate the local moisture and thus lower the K and $\tan \delta$. This in turn will allow greater penetration of the less lossy near region for larger energy deposition farther out. However, this is self limiting when the temperature rise is not large enough to evaporate local moisture.

TABLE 2. REQUIRED R.F./MICROWAVE GENERATOR POWER LEVELS

FREQUENCY (MHz)	K	$\tan \delta$	POWER LEVEL (KW)
5	50	10	6.5×10^{-8}
	10	0.01	4×10^{-8}
915	1.8	0.06	158
	50	10	$> 10^{99}$

B. In Situ Hydrogenation

The potential for in situ hydrogenation of Kern River Crude was evaluated in a series of microautoclave runs. The sample of crude studied was obtained from steam recovery; thus it should be representative. Elemental analysis of the crude was C 85.82, H 11.32, N 0.70, S 1.23, O 1.09.

Eight parametric runs were performed and conditions are described in Table 3. Temperatures of 200° and 325°C were chosen to represent a typical temperature (200°) and a rather severe condition (325°) typical of hydrotreating.

No cracking, production of H_2 , or light hydrocarbons was observed in any of the runs, even under inert gas. Some CO_2 generation was seen. The addition of core material (non-hydrocarbon) from the Kern River area did not perturb the gas make, nor did a commercial hydrodesulfurization catalyst, American Cyanamid HDS 1442A ground and sieved to -200 mesh. Heating apparently reduced the viscosity, but no other effects on viscosity were seen. No consumption of hydrogen was observed. Some trace amounts of CO_2 were produced.

It is certainly possible that the residence times and temperatures the crude was exposed to in processing were as great and greater than in our laboratory experiments. Thus, under the conditions studied, the samples were stable. This is in agreement with the thermal stability observed.

Two additional sets of experiments are suggested.

1. Obtain a sample representative of the crude in place in the formation. The H/C ratio should be lower, and the thermal stability less. Hydrogenation rates would thus be enhanced.
2. Longer times and/or higher pressures may be in order. Contact time is especially important if rates are low.

TABLE 3. PARAMETRIC MICROAUTOCLAVE RUNS WITH KERN RIVER CRUDE

Run #	Time Minutes	Temp °C	Pressure PSIG (charged)	Gas	Gas Make	Catalyst	Initial 1100 cps @ 47°C	Final
1	15	200	200	H_2	CO_2 /trace	-	1100	1100
2	15	200	200	N_2	CO_2 /trace	-	1100	1050
3	15	200	200	H_2	CO_2 /trace	CoMo	1100	1070
4	15	200	200	H_2	CO_2 /trace	formation	1100	-
5	15	325	200	H_2	CO_2 /trace*	-	1100	940
6	15	325	200	N_2	CO_2 /trace	-	1100	940
7	15	325	200	H_2	CO_2 /trace	formation	1100	-
8	15	325	200	H_2	CO_2 /trace	CoMo	1100	920

* Greater at 325° than 200°C.

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