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FY 80 TAR SANDS PROGRAM
SECOND QUARTERLY REPORT
APRIL 1980

MASTER

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R. L. FOX

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ABSTRACT

The research and development efforts in support of the Tar Sands 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 Tar Sands has been investigated. The steam quality sampler is undergoing laboratory testing. Plans for a Tar Sands enhanced permeability workshop have been initiated. A special report on possible application of sand control methods to the Tar Sands steam injection test (TS-1S) experiment 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 Laramie Energy Technology Centers' Tar Sands 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 bitumen from tar sands. 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 LETC 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. Drilling Technology

Within the Tar Sands program activity plans, there is a subactivity for the education of small rig operators. The objective of this task is to educate and train shallow hole drilling operators in the use of drilling fluids, additives, packed hole assemblies and other techniques and equipment. This would include the proper methods for rapid drilling of shallow straight wells up to 12-inch diameter. The possibility of establishing a short course to train small rig operators has been investigated.

The first approach taken was to contact Colorado Northwestern Community College, Kennedy Drive, Rangely, Colorado. Mr. Billy E. Bennett felt that there would be no problem to incorporate the necessary training into their two year petroleum technology program. The most likely approach

would be to include the material in two courses: (1) PET 102 - Methods of Well Completion; and (2) PET 221 - Well Recompletion and Stimulation. Their petroleum technology program has been well received by industry. This approach has a long turn around (two years) and it would only be a small part of a larger program.

Other approaches examined included contact with William J. Murchison, President of Murchison Drilling Schools, to explore the possibility of establishing a drilling short course to meet the needs of this task. The Murchison Drilling School runs a successful two week USGS certified course on operations drilling technology and well control. The segment of the course that is of most interest is the top hole chapter which includes: speed and surface hole considerations - USGS rules, USGS regulations related to conductor/surface casing, deviation, solids control, hole cleaning, hydraulics, tripping in unconsolidated formations, well control--shallow shoes - diverting - big hole well control problem, shallow gas and kick problems, lost circulation, pump and mechanical problems, washouts and twist-off, corrosion, stuck pipe, transition zone indicators, mud solids, logs--for shale detection - formation stability - hole stability, bit selection and grading, casing and cementing. Although it may be possible to use this rather extensive material for the tar sand drilling course, Murchison felt that discussion with field personnel was necessary before such a course could be fully defined. All instructors in their school have had a minimum of 20 years oil field experience.

B. Well Completion, Physical Stimulation and Downhole Steam Production

1. Insulated Injection String - The tar sands steam injection experiment TS-1S utilizes surface steam generation. Thus, the problem of well-bore heat loss had to be addressed. A series of calculations quickly established that, because of low mass flow rate, substantial heat losses occur. To reduce the heat loss, insulation has been added to the steam injection string.

The 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 are 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 steam quality is gained for mass flow rates above 150 B/D, but the method of installation of the

insulation can allow it to become wet if moisture is present in the annulus. This results in the steam quality reduction shown in curves AA and BB of Figure 1 for injection pressures of 700 and 1000 psia. Now the mass flow rate must be increased to above 100 B/D to maintain a steam quality of order 50% at the depth of 500 ft.

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 "Effects of Insulation for the Steam String of the TS-1S Experiment"³ for mass flow rates of 50, 100, 150, 200 and 500 B/D. 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 $\dot{m}$

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

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

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

where l is the depth in ft. and X_0 , T_0 and P_0 are the steam quality, temperature ($^{\circ}\text{R}$), and the pressure (psia) at the wellhead.

If the use of an insulation with proven field performance were desired, Conco Calcium Silicate could be used, the cost is about \$10,000 for 500 ft. and if Thermocase III is used, about \$27,000. A manual has been prepared for the wellbore heat loss code.²

2. Measurement of Downhole Steam Quality - The measurement of downhole steam quality in the tar sand experiment TS-1S is now in the laboratory

FIGURE 1.

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 of the TS-1S experiment.

The requirement for a high temperature wire line has been solved. The Sandia high temperature logging mast truck and instrument trailer will provide the necessary equipment for field measurement. In addition, a flow meter will be utilized to provide information of the injection steam profile into the tar sands.

3. Simulation of Downhole Steam Injection into Tar Sands - A program to simulate the downhole steam injection into tar sands has been initiated. The first approach being considered is to use a new code being developed by P. J. Roache. The Roache code is a finite difference simulator to the fluid mechanics of an oil reservoir. The present version is one-dimensional, but will be extended to two-dimensional if used for the tar sands simulation. The second code that might be used is the Intercomp reservoir simulator.

4. Tar Sands Enhanced Permeability Workshop - Sandia National Laboratory will host a workshop on permeability enhancement of tar sands on May 8 and 9, 1980, in Albuquerque, New Mexico. The purpose of the workshop is to identify useful areas of investigation to overcome the lack of permeability in the saturated beds associated with tar sands. In addition to representatives from the United States, there will be representatives from the Canadian Alberta Oil Sands Technology and Research Authority. The workshop will begin with a series of review papers on the present state of the art of permeability enhancement as applied to tar sands and be followed by a workshop to identify the most productive areas for research.

5. Sand Control - The original review of the plan of the TS-1S experiment indicated some concerns for sand control problems. Sandia in conjunction with Completion Technology Company, has prepared a backup program that can help guide the action of the field crew if problems develop during the course of the 120-day experimental run. The main concentration is upon corrective actions that can be taken to relieve sand buildup at the production wells.

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 tar sands. Richard Welch of Dispatch Industry, Inc., Minneapolis, has found $K = \epsilon' / \epsilon_0$ (ϵ_0 = dielectric constant of vacuum) to be 1.8 and $\tan \delta = \epsilon'' / \epsilon'$ = 0.06 at 915 MHz for a tar sand. Jack Bridges of IIT Research Institute, obtained for Utah tar 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

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

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 would conclude that the lower the 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.)

Another 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 tar 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 $3.8 \times 10^{-5} \text{°F/sec}$ ($2.2 \times 10^{-5} \text{°C/sec}$). 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 tar 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 $\sqrt{K} \tan \delta$ 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 tar 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 (but where does the vapor go?) 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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