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SOLVENTS AND EXPLOSIVES TO RECOVER HEAVY OIL

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Bureau of Mines Petroleum Research Program

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by

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ABSTRACT

Preliminary results of an explosive fracturing-solvent injection heavy oil recovery experiment conducted by the Bureau of Mines at a shallow oil reservoir near Bartlett, Kans., are given. Three wells 35 to 50 feet apart were drilled to a depth of 360 feet, and an open hole interval from 300 to 350 feet in the Bartlesville Sandstone Formation was explosively fractured with 3,000 pounds of pelletized TNT in each well. Laboratory tests were made on cores obtained from these wells to confirm the suitability of using an aromatic-type solvent. Injection of a 74-percent aromatic solvent was begun into one well and continued intermittently for approximately 2 months. Crude oil production amounted to 29.6 bbl, or 11.7 percent of the total oil contained within the three-well interwell zone.

INTRODUCTION

This research was designed to provide technical support to the Nation's energy program, supplement industry's petroleum and natural gas research, and more specifically, develop usable means for adding the billions of barrels of known, but nonproducible, petroleum resources to this country's storehouse of available energy. Prime energy resources not economically recoverable with present technology are crude oil in tar sands and heavy oil. A review of the technical literature revealed a poverty of information about the areal limits, the economic possibilities, and the depth of worldwide deposits of tar sands and heavy oil.[3]

Forty-two counties in Kansas, Missouri, and Oklahoma contain 40 percent of the recognized tar sand deposits reported by Ball Associates[4] as occurring in the United States. Many of these are fairly shallow, less than 500 feet,

[1]Project leader.

[2]Petroleum engineer.

[3]Phizackerley, P. H., and L. O. Scott. The Major Tar Sand Deposits of the World. Proc. 7th World Petrol. Cong. (Mexico, D.F.), Apr. 2-8, 1967, v. 3, pp. 551-571.

[4]Ball Associates, Ltd. Surface and Shallow Oil-Impregnated Rocks and Shallow Oil Fields in the United States. BuMines Monograph 12 (published by IOCC), 1965, 375 pp.

and could be mined; however, recovery of this crude by in situ methods might be more desirable. Crude oil having a viscosity normally associated with 15° API gravity oil and under will not flow readily at ambient temperatures; therefore, heat or dilution with a suitable solvent is required to produce such a crude oil. Since these heavy oil-containing sands generally occur at shallow depths, they are not responsive to standard fracturing or stimulating techniques.

A suitable reservoir was located on the H. H. Leap farm, in the SE ¼ sec 16, T 34 S, R 20 E, Labette County, Kans. (fig. 1). Three wells, 7, 8, and 9, were drilled and explosively fractured for use in the initial test. Although several wells had been drilled on this lease by oil-producing companies, oil production had not proved economically feasible.

This research combines modern chemical explosive fracturing techniques[5] with heat and solvent treatments to extract the oil. With chemical explosives, a rubblized condition was created within the interwell zone for establishing communication between wells. An aromatic-type solvent was used to dilute the

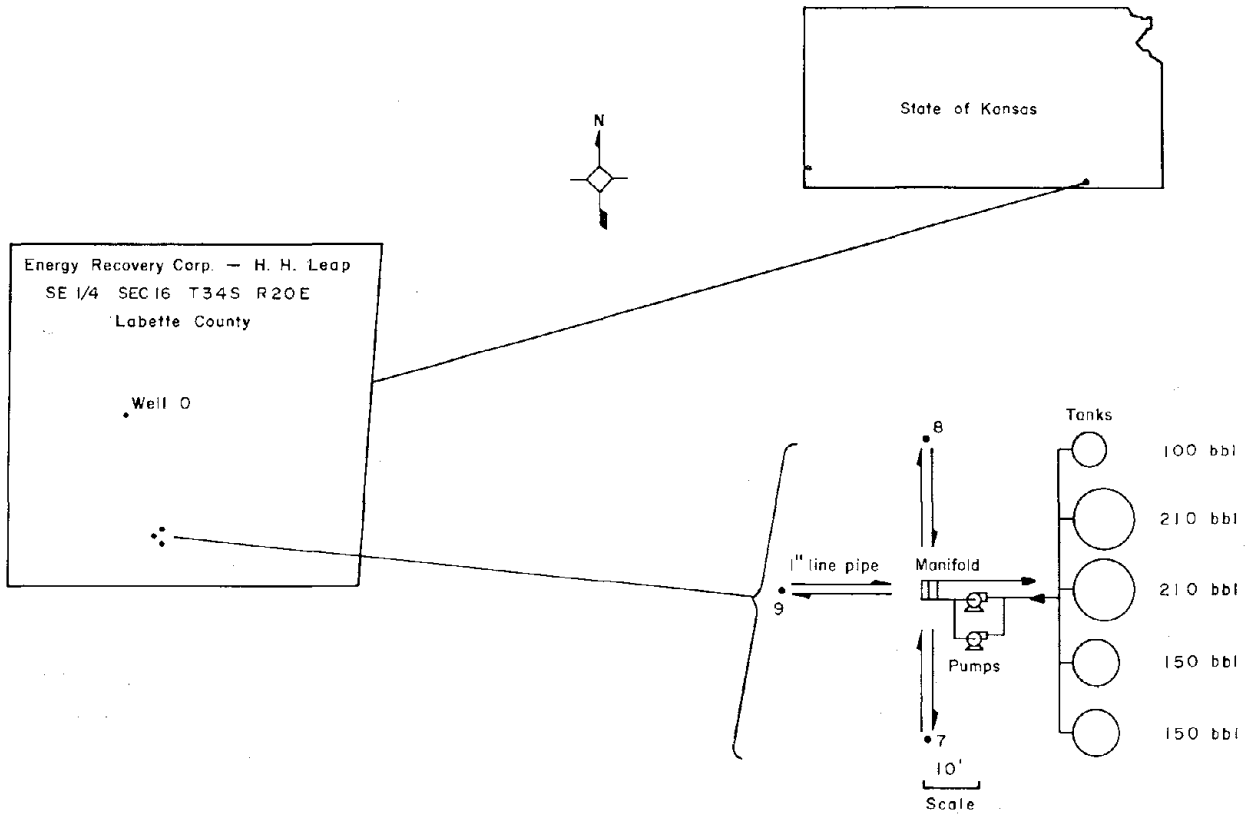

FIGURE 1. - Location of Lease and Simplified Schematic of Wells and Tank Battery, Heavy Oil Recovery Test Site.

[5]Eakin, J. L., and J. S. Miller. Explosives Research To Improve Flow Through Low-Permeability Rock. J. Petrol. Technol., v. 19, No. 11, November 1967, pp. 1431-1436.

oil and reduce viscosity. The purpose of this research is to study the several factors involved by which heavy oil can be efficiently and economically recovered from a consolidated sandstone petroleum reservoir by the use of suitable solvents and supporting techniques.

FORMATION PROPERTIES

Well 7 was cored over the interval 260 to 375 feet with 100-percent recovery. Core plugs were taken at 71 locations along the core and analyzed for porosity, permeability, and saturation. Porosity ranged from 10.7 to 26.0 percent with an average of 19.9 percent, permeability ranged from 0.03 to 654.6 md and averaged 135.6 md, the oil saturation ranged from zero to 75.8 percent and averaged 32.2 percent, and the water saturation averaged 2.2 percent. Indicated oil content based on these figures is 497.1 bbl/acre ft, or 57,167 bbl/acre. Although these inplace oil calculations are in agreement with the calculations made by several companies based on other analyses, they have been modified to reflect shale lenses throughout the sand body and the lack of oil saturation in the upper part of the formation.

The core was compared with the core plugs, and values representing the four physical characteristics previously mentioned were assigned each segment of the core. The oil in place determined in this manner over the entire cored range was calculated to be 36,994 bbl/acre. The cored interval was divided into four sections: from the top of the sand to the casing setting point (260 to 295 feet), from the top of the open hole interval to the cleanout point (295 to 330 feet), from the cleanout point to the final total depth (330 to 360 feet), and the bottom 15-foot interval which was cored in well 7 (360 to 375 feet). Well 7 was plugged back to 360 feet, and the other two wells were drilled only to 360 feet. The results of the modified and weighted average calculations are as follows:

Interval, feet	Total oil content, bbl/acre	Oil content, bbl/acre ft
260-295	1,226	35
295-330	17,731	507
330-360	16,967	566
360-375	1,069	71
Total	36,994	322

Recovery operations were limited to the open hole interval 295 to 360 feet.

INTERWELL RUBBLIZATION

An explosive fracturing treatment, using 9,000 pounds of pelletized TNT, was performed with these three wells as a part of this research. The treatment was performed to create fragmentation and paths of communication between wells, so that the heavy, high-viscosity oil could be produced by the experimental solvent application.

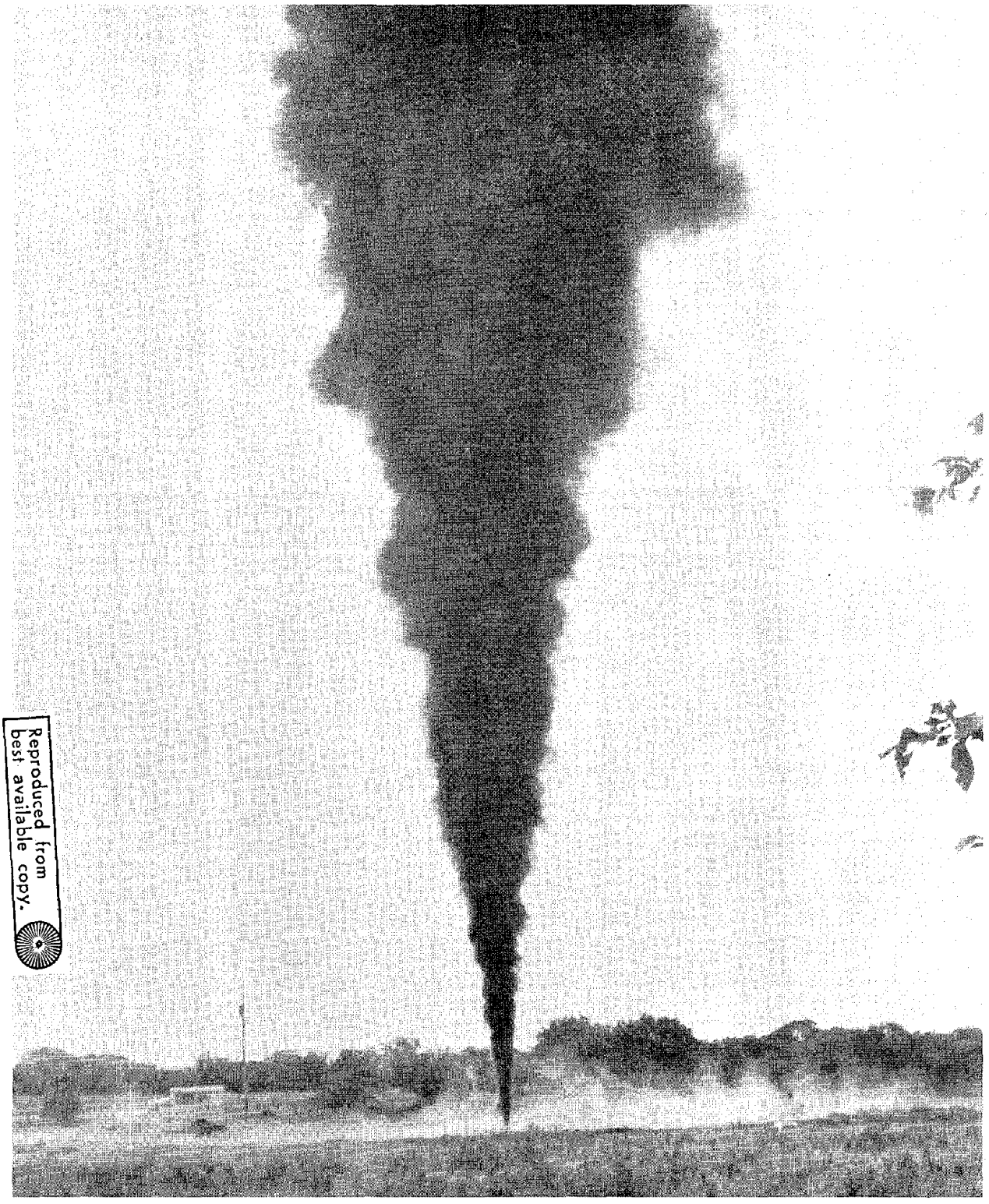

FIGURE 2. - Black Smoke Blowing From One of Three Test Wells Shot Simultaneously. Each well was shot with 3,000 pounds of pelletized TNT.

The wells form part of a 50- by 50-foot five-spot pattern: two side wells and the center well. The wells were drilled with a 13½-inch bit from the surface to a total depth of 360 feet. Each well was plugged back from total depth to 295 feet with sand, and 7-inch casing was set at this point and cemented to the surface. After proper cement-setting time, each well was cleaned to total depth.

All wells were bailed to total depth, and air was injected in one well while the other wells were observed to determine if fractures or paths of communication were evident between wells. No flow of air was observed from the injection well to the producing wells. Later each well was bailed to gage the rate of water influx and to determine if excess water was invading the wellbores. Each well could be bailed down, indicating limited water invasion.

The explosive detonating device consisted of a concrete weight, 50 feet of detonating cord, two 1-pound primers, and two No. 8 electric caps on 400-foot leads. The detonating device together with 3,000 pounds of pelletized TNT was placed at the approximate interval 300 to 350 feet in all three wells, the wells were sand tamped to 150 feet, and the explosives were fired simultaneously.

A strong shock wave was felt; ground disturbance and elevation rise were visually noted (fig. 2). Black smoke vented from well 7, the plume rising several hundred feet into the air as the pressure cleared the sand from the well. The black smoke gradually changed to clear gas, and the well was shut in after about 30 minutes; pressure built up to about 80 psig.

Testing indicated that a large volume of sandstone adjacent to the wellbore was pulverized. An estimated 75 cubic yards of sand was removed from each well. This sand was extremely fine, probably 90 percent of the grains being 200 mesh or finer. Complete cleanout of the wellbore became impractical with the equipment available. Wells 7, 8, and 9 were cleaned out to 331, 334, and 332 feet respectively.

The degree of communication between the three wells was tested by pressuring up each well in turn and testing the flow of air from the other wells. At a differential pressure of 100 psi, an average flow of about 100,000 cubic feet per day was measured at the production wells.

SELECTION OF SOLVENT

This phase of the investigation was conducted to find an inexpensive solvent that would lower the viscosity of the Bartlett oil and still retain the asphaltenes in solution. The solvents considered were limited to those having a boiling range higher than 300° F because of the anticipated need for injecting a hot solvent and lower than 425° F because of the need for distilling the solvent from the oil after production.

Selection of a solvent was based on tests using a sample of Bartlett oil obtained from the Leap "O" well located about 750 feet away, which was drilled, fractured, steamed (Huff & Puff), and produced by the Johnson & Fagg Company in 1967. A routine Bureau of Mines distillation was run on this oil (table 1). The oil sample contained approximately 10 percent water, which caused considerable trouble when running the analysis. It was necessary to centrifuge the sample before the distillation could be completed.

6-435 b
(April 1958)

TABLE 1. - Crude petroleum analysis

Bureau of Mines Bartlesville Laboratory
Sample 70101

IDENTIFICATION

Bartlett field
Bartlesville, Pennsylvanian
300 feet

Kansas
Labette County

GENERAL CHARACTERISTICS

Gravity, specific, 0.966 Gravity, ° API, 15.0 Pour point, ° F., 55
Sulfur, percent, 0.71 Color, brownish black
Viscosity, Saybolt Universal at 100°F. 13,466sec;at 130°F. 3,872sec Nitrogen, percent, 0.317

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

STAGE 1—Distillation at atmospheric pressure, 745 mm. Hg
First drop, 446 ° F.

Fraction No.	Cut temp. ° F.	Percent	Sum, percent	Sp. gr., 60/60° F.	° API, 60° F.	C. I.	Refractive index, n_D at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, ° F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482	1.8	1.8	0.846	35.8	-	1.46244	143.8		
10	527	5.3	7.1	.859	33.2	42	1.47350	153.5		

STAGE 2—Distillation continued at 40 mm. Hg

11	392	6.3	13.4	0.878	29.7	47	1.48047	159.5	39	Below 5
12	437	6.9	20.3	.895	26.6	51	1.49632	169.3	51	20
13	482	8.5	28.8	.916	23.0	58	1.51034	170.1	75	50
14	527	8.6	37.4	.927	21.1	60	1.52024	171.7	131	60
15	572	10.5	47.9	.934	20.0	60	1.52300	182.9	275	65
Residuum		51.5	99.4	1.020	7.2					

Carbon residue, Conradson: Residuum, 4.9 percent; crude, 2.7 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	° API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil	16.3	0.870	31.1	
Nonviscous lubricating distillate	12.1	.894-.921	26.9-22.2	50-100
Medium lubricating distillate	9.3	.921-.930	22.2-20.6	100-200
Viscous lubricating distillate	10.2	.930-.938	20.6-19.4	Above 200
Residuum	51.5	1.020	7.2	
Distillation loss	.6			

The test used to determine the amount of precipitation was modified from ASTM D 2042-66, Standard Method of Test for Solubility of Bituminous Materials in Organic Solvents. The only modification was increasing the oven temperature to evaporate the different solvents used.

Viscosities were obtained both on the solvents and on mixtures of 25 percent solvent in 75 percent Bartlett oil. Cannon opaque viscometers were used.

Data were obtained on 24 different solvents. Some were pure components; some were commercial solvents having a wide boiling range and different paraffinic, naphthenic, olefinic, and aromatic contents; and some were mixtures of commercial solvents. These data are shown in table 2.

TABLE 2. - Summary of solvents tested

Solvent	Aromatic content, percent	Viscosity of mix (75 pct crude oil, 25 pct solvent), cp	ASTM test, precipitate, percent
Diesel fuel	32.5	183	-
Benzene	99	36	1.11
2-Nitropropane	0	58	15.68
Decalin	0	148	-
Styrene	99.9	45	.73
N-pentane	0	72	12.70
Kerosine	0	235	7.19
Carbon disulfide	0	17	2.16
Stoddard solvent	4.6	127	6.57
Commercial mix 1	38.1	103	4.15
Commercial mix 2	55.5	93	2.55
Commercial mix 3	72.9	85	1.65
Commercial mix 4	98.6	68	.94
Commercial mix 5	74.2	77	1.97
Commercial mix 6	73.6	97	1.87
Commercial mix 7	97.9	89	1.05
Commercial mix 8	18.6	130	6.91
Commercial mix 8 w/5 pct pine oil	22.7	117	4.55
Commercial mix 8 w/10 pct pine oil	26.7	104	3.05
Commercial mix 8 w/15 pct pine oil	30.8	118	2.15
Commercial mix 1 w/5 pct pine oil	41.2	101	1.57
Commercial mix 9	98	78	-
Commercial mix 10	74	73	2.17
Commercial mix 11	0	49	12.26

Both the paraffinic and aromatic type solvents could cause a significant lowering of viscosity of the Bartlett oil. However, the aromatic solvents, such as benzene and styrene, dissolved most of the oil, whereas the paraffinic solvents, such as 2-nitropropane and normal pentane, gave very high percentages of precipitation. It was decided that the primary choice of solvent would have to be based on its ability to dissolve the oil completely or nearly so. A precipitate falling out in the formation could plug or drastically reduce the formation permeability.

The data obtained do not completely define the characteristics in the lower range of aromatic content. However, enough runs were in the higher range to establish that the aromatic content, for those solvents not containing pine oil, should be near 70 percent for the precipitate to be below 2 percent. Carbon disulfide has long been used as a standard for determining the amount of bitumen in a tar sand. What could not be dissolved with it was considered nonorganic mineral. The precipitate for carbon disulfide was 2.16 percent. Results shown are for the Bartlett oil only. Similar tests with other oils might give completely different results.

Several solvents were found which would precipitate less than 2.16 percent in the test used. Commercial mix 10 was selected for use in the laboratory core-solvent investigation.

CORE-SOLVENT INVESTIGATION

Several experiments were conducted on cores, some of which were cut to simulate a rubblized condition. A solvent that contained about 75 percent aromatics was used. Cold solvent was used in most tests, but hot solvent was used in parts of two tests. Several factors, such as soak time, forward flow, reverse flow, heat, and pressure, were changed to estimate the best operating conditions for the reservoir. A solvent (commercial mix 10) was selected from the 24 that had been tested for their ability to dissolve the Bartlett crude.

A total of 12 experiments were run, grouped in the following categories:

1. Simulated rubblized reservoir tests, using only solvents, in which such parameters as soak time, forward flow, reverse flow, heat, and pressure were varied.

2. Solvent flood tests, in which only solvent was used.

3. Waterflood-solvent flood tests, both rubblized and solid cores, in which flow was alternately solvent and water.

4. Soak drainage tests in which a given amount of solvent was allowed to drain through and around the solid core.

Horizontal core samples were cut from the cores taken from wells 0 and 7. These oil-saturated core samples were 2 inches in diameter and approximately 3 inches in length. Some were randomly cut at different angles, both lengthwise and radially, to simulate a rubblized condition of the interwell zone after explosively fracturing the formation.

After the core was placed in a holder, solvent was injected into the core from the bottom to purge the air that might be in the core. Direction of flow was often reversed and the core allowed to soak in the solvent. This cycle was repeated, with some modifications in soak time, reinjection of produced solvent, etc., until it was determined that very little crude oil recovery was taking place. The produced mixture was analyzed to determine the amount

of oil produced during each stage of the cycle. The fluids were then extracted and the physical properties of the cores determined.

The results of the 12 tests indicate the following:

1. Oil recovery rate increases after soaking.

2. Pressure seems to have little effect.

3. Heat, based on one experiment, does not increase recovery; however, heat did increase recovery during the latter part of one test.

4. After the solvent is recirculated about five times, its crude oil removal capacity seems to decrease.

5. Rubblization increases the rate of recovery but not necessarily the amount of recovery.

FIELD PRODUCTION TEST

All three wells were completed similarly. Two strings of 1-inch line pipe were installed through a dual-string tubing head (fig. 3). One string was set at 330 feet, and the other was set at 220 feet. Tank battery installation is shown in figure 4.

Field injection of solvent (commercial mix 10) was begun in well 9 on May 8, and the first production from wells 7 and 8 was on May 9. Injection of solvent was started into the annulus of well 9 while producing water through the 330-foot string until solvent flowed from the line. Thus, upon further injection, solvent was assured of being continuous along the sand face interval. During the first 3 days, injection was continuous, and the producing wells were emptied when full by compressing air down the annulus to clean out all liquids above the 220-foot level. Subsequently, a normal injection-producing day consisted of producing wells 7 and 8 in the morning, injecting solvent for approximately 12 hours, and producing wells 7 and 8 at the end of the injection period. Results of the first 2 months' production are shown in table 3. Periods of production without injection were necessary because of the buildup of solvent-oil mixture in the producing wells below the 220-foot level.

TABLE 3. - Field production data

Time period, days		Well 9, solvent injection, bbl	Well 7		Well 8		Total		
Produced	Soaked		Mixture production, bbl	Crude oil, percent	Mixture production, bbl	Crude oil, percent	Mixture production, bbl	Crude oil, percent	Water production, bbl
2	-	80.42	27.71	13.24	18.68	11.30	46.39	12.46	1.17
-	5								
5	-	121.66	65.11	7.20	42.89	4.91	108.00	6.26	10.00
-	2								
5	-	110.71	66.68	6.43	37.05	4.18	103.73	5.63	1.75
-	2								
5	-	0	33.37	11.26	.48	4.20	33.85	11.11	.58
-	24								
5	-	91.46	55.54	8.08	27.02	8.73	82.56	8.30	16.48
-	3								
2	-	0	8.46	6.86	0	-	8.46	6.86	1.73
[1]24	[1]36	[1]404.25	[1]256.87	[1]8.35	[1]126.12	[1]6.45	[1]382.99	[1]7.73	[1]31.71

[1]Cumulative.

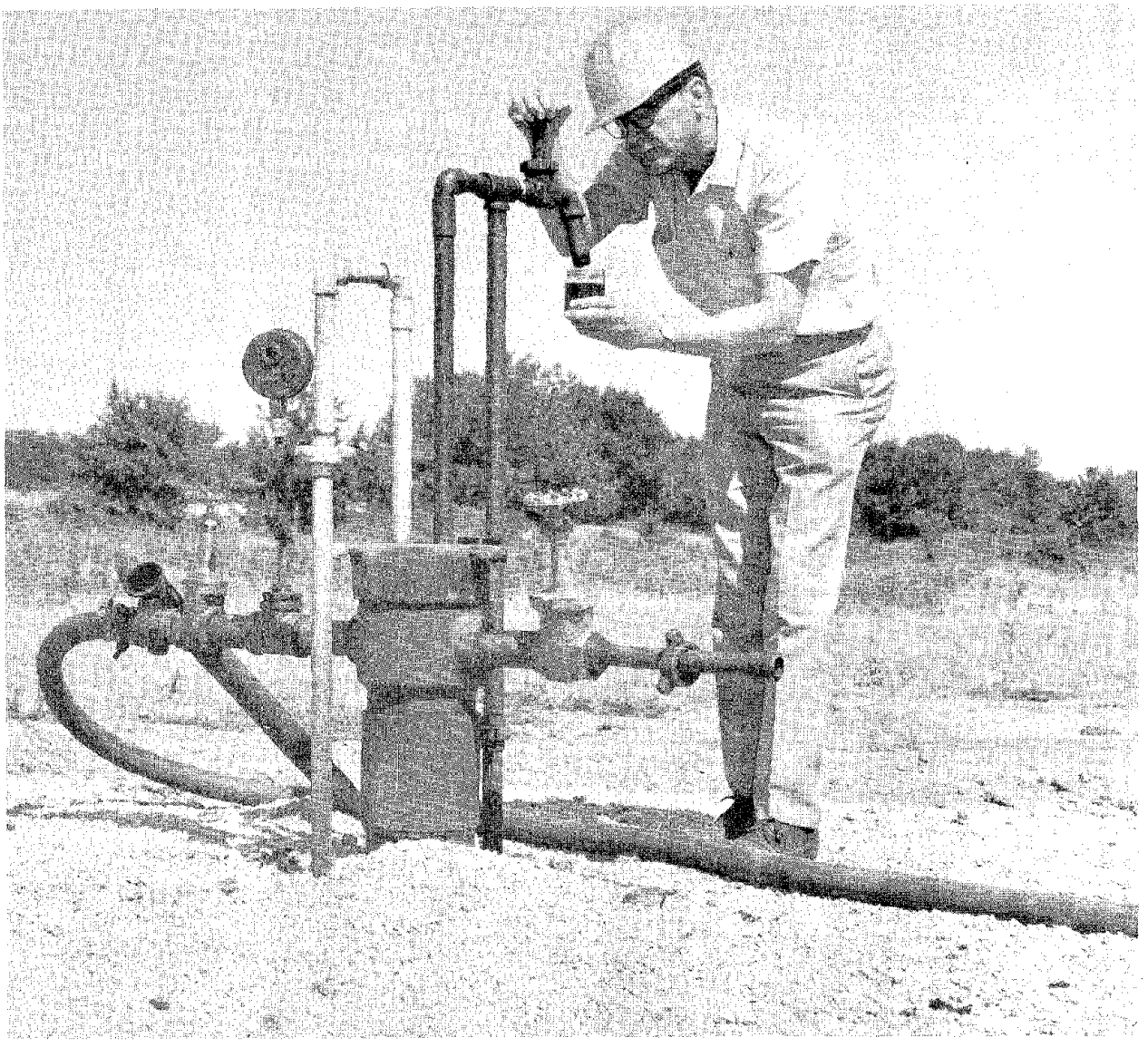

FIGURE 3. - Typical Wellhead Installation. A sample of solvent-oil mixture can be obtained during production.

Weighted average values of 36.1 percent oil saturation and 18.1 percent porosity were calculated for the interval 295 to 330 feet. The interwell area of 0.01435 acre has a pore volume of 704 bbl and an oil content of 254 bbl. Over the 2-month period, the total fluid produced by wells 7 and 8 was 383 bbl, or 0.544 pore volume. Crude oil production was 29.6 bbl, or 11.7 percent of the oil in place.

It is much too early to draw any conclusions as to the technical success of the venture. However, in comparing the crude oil recovery per pore volume of fluid produced, the recovery in the field has exceeded that which was achieved in the laboratory under simulated conditions.

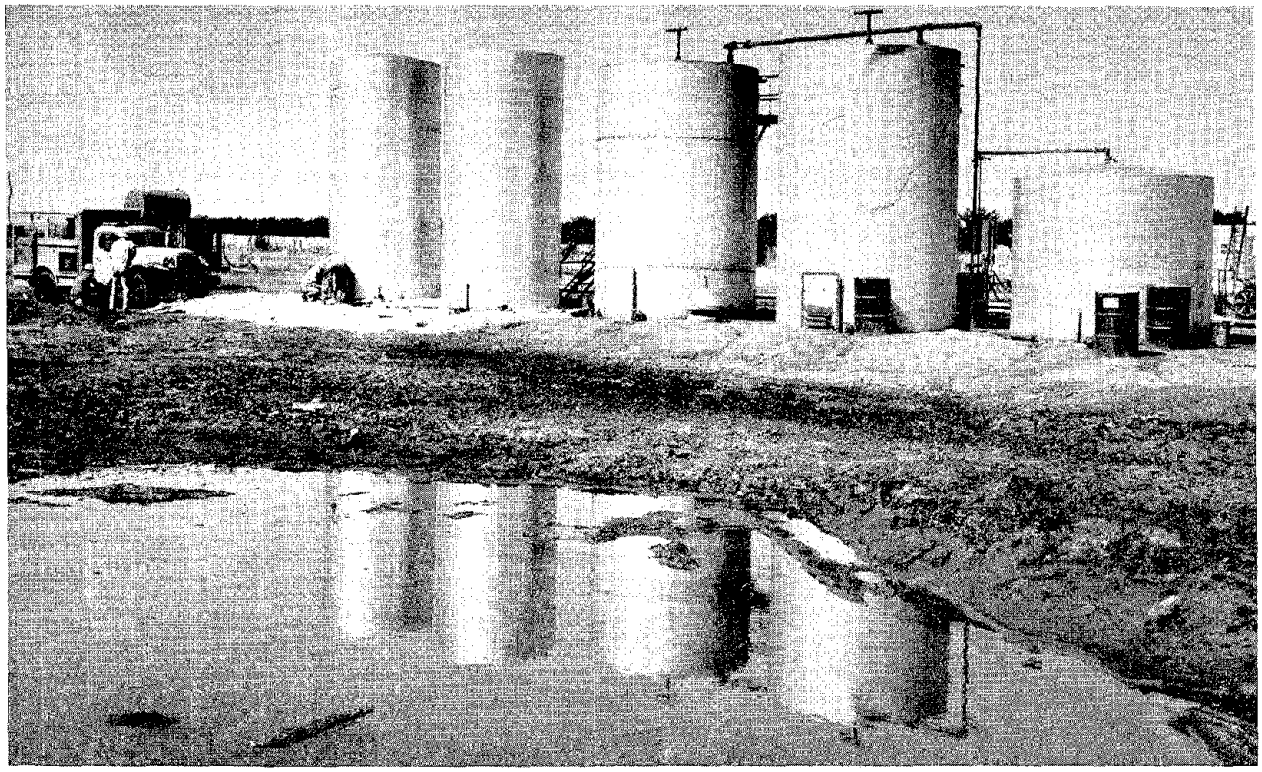

FIGURE 4. - Tank Battery Installation at the Heavy Oil Recovery Test Site.

Oil production from the heavy oil recovery test site at Bartlett is continuing. The test pattern will be expanded by the drilling of additional wells, and the rubblization of the interwell zone will be evaluated to determine, among other factors, the relationship between explosive charge and well spacing.

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