Comparison of oil recoveries using carbon dioxide and liquefied petroleum gas slugs

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RESUMEN

En este artículo se informa sobre los resultados de los ensayos de desplazamiento miscible en un crudo de gravedad media. En una serie de ensayos se inyectó dióxido de carbono desde el comienzo hasta el fin de la prueba. En una segunda serie de ensayos, se inyectó una masa de volumen de cinco por ciento de los poros de gas de petróleo licuado (LPG) (Propano). Esta masa fue impulsada por nitrógeno gaseoso.
Los ensayos se llevaron a cabo a temperaturas variables entre 112°F y 250°F. Se encontró que cuando se usó dióxido de carbono, la presión de miscibilidad aumentó aproximadamente de 1880 a 3040 psi, mientras que la temperatura del reservorio aumentaba de 112°F a 250°F. Lo contrario sucedió en el caso de desplazamiento miscible usando masas de LPG (propano) impulsadas por nitrógeno.

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INTRODUCTION

Many petroleum reservoirs of the world offer a tremendous opportunity for enhanced oil recovery programs by miscible displacement. Miscible oil displacement may be carried out in both sandstone and carbonate reservoirs. Some forms of miscible displacement may be effective and profitable when applied after waterflood.

Four pipelines have now been laid to transport carbon dioxide to various oil reservoirs in the Permian Basin of West Texas in a program designed to produce three to four billion barrels of additional oil. Most of the carbon dioxide will be injected into oil reservoirs wchich have been waterflooded. Many of the reservoirs contain crude oil ranging from 30 to 40°API gravity. The carbonate reservoirs may have porosities of less than ten percent and permeabilities of 3 to 20 md. primary oir recovery may be no more than twenty percent of the original oil in place. Waterflooding may porduce an almost equal amount of oil so that total oil recovery by primary and waterflooding is of the order 35 to 40 percent of the original oil in place. If the EOR proyect should recover an additional fifteen percent of the original oil-in-place this would increase the oil recovery to 50 to 55 percent of the original oil-in-place. This usually represents a lot of oil. Hence, the purpose of this study was to determine the response of a 31°API gravity crude oil to different miscible displacing fluids. Carbon dioxide gas was used as the displacing fluid in one series of tests and LPG (liquified petroleum gas) slugs, pushed by nitrogen, were uses in a second series of tests. LPG is primarily propane.

Considerable work has been presented on the displacement of several crudes by carbon dioxide [1] [2] [3]. The work by OLEARY, *et al* showed that CO_2 miscibility on Levelland San Andres crude might be expected at pressures near 1400 psi and a reservoir temperature of 105°F [1]. The displacement of Wasson San Andres crude with CO_2 resulted in miscibility at a slightly lower pressure.

The work FISCHER, *et al.* Reported on the Displacement of the Nort Cowden and Goldsmith crudes (2). In that work it was demonstrated that a fractionation process took place when crude oil was displaced by carbon dioxide. A clear or straw-colored liquid formed between the crude oil and the CO_2 . This clear slug had more of the light hydrocarbon components than the original crude. Reference (3) cites results of studying an Ellenburger crude oil.

EQUIPMENT AND PROCEDURE

The laboratory study was conducted using a slim tube forty feet in length packed with unconsolidated media to represent the reservoir matrix. The coiled pack was placed in a constant temperature oil bath. The cleaned and evacuated pack was filled with the stock tank crude oil at the desired reservoir pressure and temperature. No gas was in solution. When displacing the crude oil with carbon dioxide, the gas was injected at the desired temperature and displacement pressuere from teh beginning to the end of the test.

When LPG (liquified petroleum gas) was used as the displacing fluid, a five percent HCPV (hydrocarbon pore volume) slug of LPG was injected followed by nitrogen gas through the end of the test. An analysis of the LPG is shown in Table 1.

Oil recovery was measured in a separator and recorder as percent of the original oil in place (%OOIP) at gas breakthrough and as ultimate oil recovery at 30.000 to 1 gas-oil ratio (GOR). The experiment was terminated when the 30.000 to 1 gas-oil ratio was measured by a wet test meter. The equipment was cleaned with a solvent, evacuated, resaturated with the crude at the desired run pressure, and a successive run was initiated.

Cleaning the pack was especially important to eliminate the heavy, second fluid phase wchich apparently accumulated on the porous media for this particular crude oil-carbon dioxide system. The heavy liquid phase was not so pornunced for the crude oil-LPG nitrogen system.

A West Texas stock tank crude was used for these tests. No gas was in solution. The crude was 31°API gravity.

RESPONSE TO CARBON DIOXIDE

Using the 31°API gravity crude, tests were made to observe the effect of reservoir pressure on oil recovery by the injection of carbon dioxide. Oil recovery tests were made at 112°F and 250°F. The actual reservoir temperature is near 112°F. The higher temperature of 250°F was used to provide a basis for estimating the effect of temperature on miscible pressure.

Figure 1 shows the effect of pressure on oil recovery when displacing the 31°API gravity crude with 100 percent carbon dioxide at 112°F. The stock tank crude had no gas in solution. It can be seen from the figure that when

TABLE 1.— LPG Slug Composition. Gas Chromatograph Analysis of LPG or «Propane» Slug Showed the following composition.

	Mol Percent
Propane	91.958
Iso-butane	2.023
N-butane	1.372
Ethane	4.347
CO_2	0.104
$C6_+$	0.0019
Iso-pentane	5.822E-02
Methane	5.572E-02
Nitrogen	3.928E-02
Oxygen	1.455E-02
N-pentane	2.657E-02

displacing the crude at a pressure of 750 psi the oil recovery at gas breakthrough was approximately 56 percent of the original oil in place. The ultimate recovery was found to be just over 76 percent at a producing gas-oil ratio of 30.000 to 1.

By increassing pressure to 2000 psig the oil recovery was 92 percent at gas breakthrough, and the ultimate oil recovery at a 30.000 to 1 GOR was over 98 percent of the original oil-in-place.

Figure 2 shows the effect of pressure on oil recovery when displacing the crude with 100 percent carbon dioxide at a reservoir temperature of 25°F. This figure shows that when using a displacement pressure of 1600 psi, the oil recovery at gas breakthrough was 48 percent and the ultimate oil recovery was near 71 percent at a producing GOR of 30.000 to 1.

By increasing the displacement pressure to 3500 psi, the oil recovery at gas breakthrough was 94 percent of the original oil-in-place and nearly 96 percent of the original oil-in-place was ultimately recovered at a 30.000 GOR.

RESPONSE TO LPG SLUGS

Tests were made to observe the effect of reservoir pressure on oil recovery when displacing the crude with a five percent hydrocarbon pore volume slug of LPG pushed by nitrogen. The composition of the LPG is shwn in Table 1. The initial test were conducted at 112°F. From Figure 3 it can

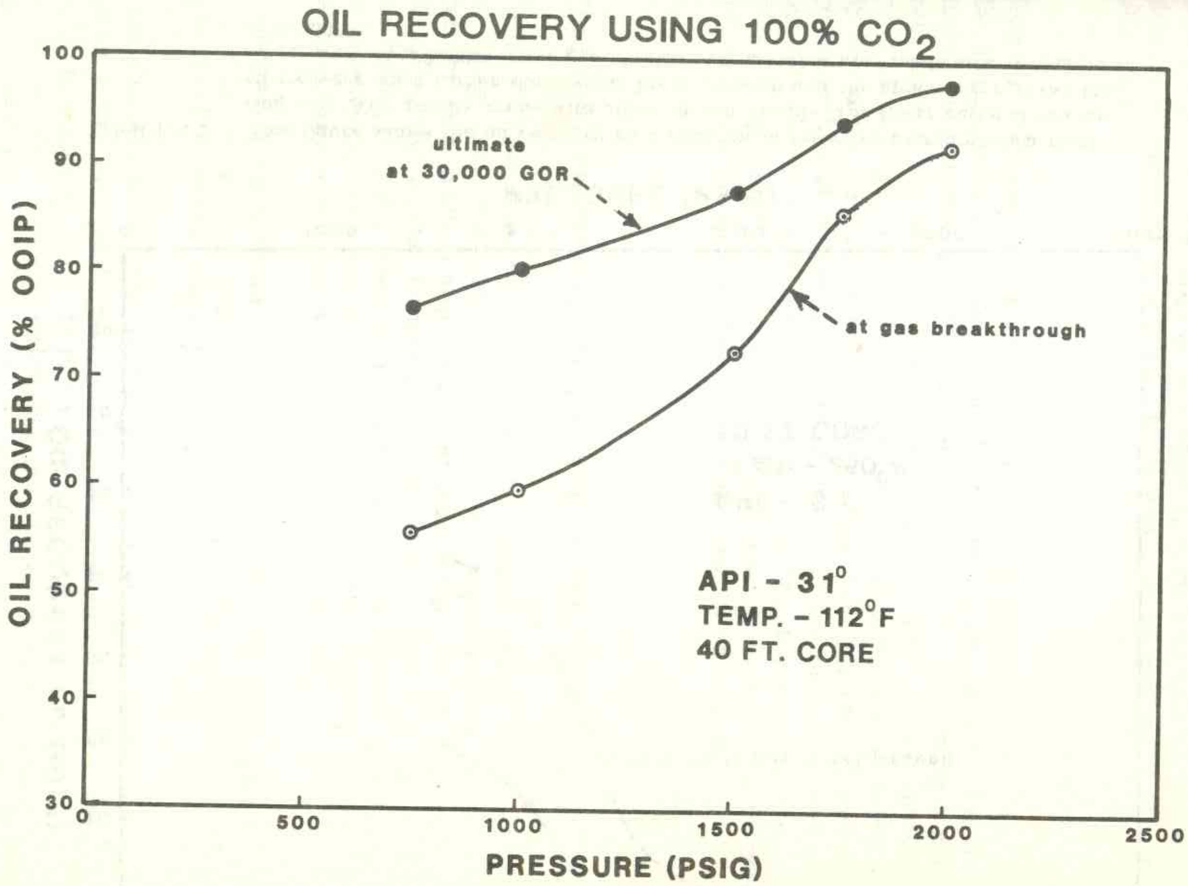

FIGURA 1.— This figure shows the oil recovery as a function of reservoir pressure when displacing a 31°API gravity crude oil with 100% carbon dioxide. The lower curve shows the oil recovery carbon dioxide gas broke through and the upper curve shows the oil recovery at a 30,000 to one gas-oil-ratio. Observations were made at a temperature of 112°F.

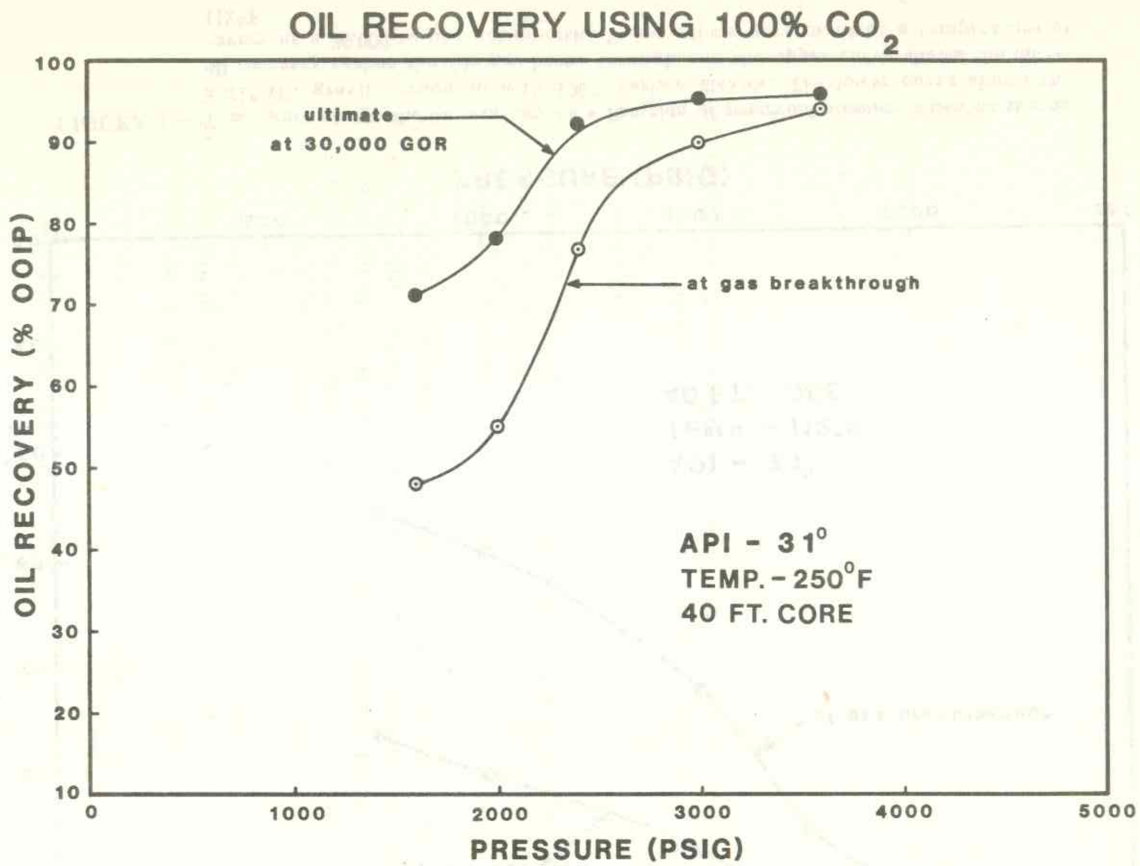

FIGURA 2.— This figure shows the oil recovery as a function of reservoir pressure when displacing a 31°API gravity crude with 100% carbon dioxide. The lower curve shows the oil recovery when carbon dioxide gas broke through and the upper curve shows the oil recovery at a 30,000 to one gas-oil-ratio . Observatins were made at a temperature of 250°F.

be seen that when displacing the crude at 2000 psi the oil recovery was near 53 percent at gas breakthrough and increased to over 88 percent at a producing gas-oil of 30.000 to 1. By increasing the displacement pressure to 3000 psi the oil recovered at gas breakthrough was near 85 percent. The ultimate oil recovery at a 30.000 GOR was over 98 percent of the original oil-in-place.

Figure 4 illustrates the effect of displacement pressure on oil recovery when displacing the same crude sample by a five percent HCPV slug of LPG pushed by nitrogen at 250°F. It can be seen that when using a displacement presseure of 1500 psi, less than 37 percent of the oil was recovered at gas breakthrough. The oil recovery was near 68 percent at a 30.000 GOR. By increasing the displacement pressure to 2000 psi the oil recovery at gas breakthrough increassed to 94 percent, and the ultimate recovery was near 98 percent at a 30.000 GOR. Increasing the displacement pressure to 3000 psi increassed the oil recovery at gas breakthrough to near 96 percent and increased the ultimate recovery to in excess of 98 percent.

PRESSURE-TEMPERATURE RECOVERY RELATIONSHIP

Figure 5 shows a summary of oil recovery data for the 31°API gravity crude. These data illustrate the conditions for approximately 90 percent oil recovery as a function of pressure and temperature for both carbon dioxide and LPS slugs pushed by nitrogen as the displacing fluid. it can be seen in this figure that the reservoir pressure required to achieve miscibility with carbon dioxide increases with temperature, but the reservoir pressere required to achieve miscibility with LPG decreases with temperature.

When carbon dioxide was used, the required pressure for 90 percent oil recovery increased from 1880 psi to 3040 psi as the temperature increased from 112°F to 250°F, respectively. See Figure 5.

When five percent HCPV LPG slugs were used, the pressure required decreases from 3300 psi to 2000 psi for temperatures ranging from 112° to 250°F respectively. Note that for low temperature reservoirs the use of carbon dioxide to achieve miscibility may be effective at pressures on the order of 1400 psi below the pressure required when using five percent HCPV LPG slugs. For high temperature reservoirs the use of LPG slugs to achieve miscibility may be effective at pressures as much as 1000 psi below the pressure required when using carbon dioxide.

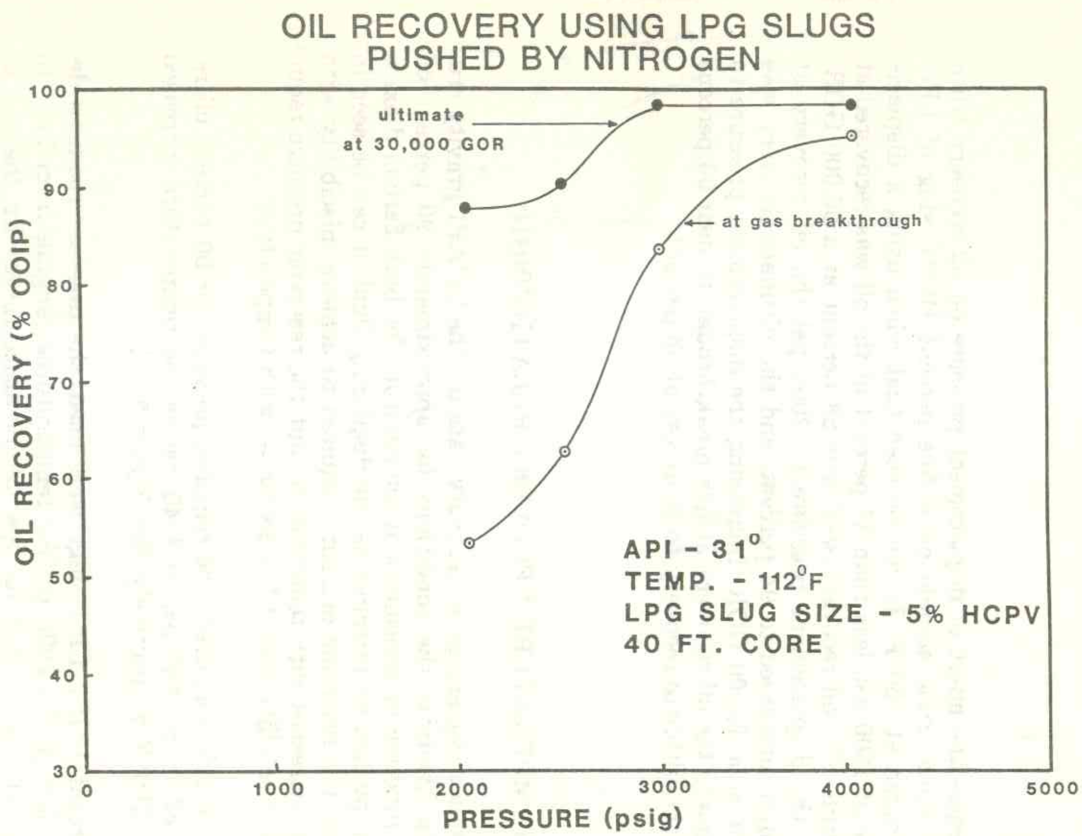

FIGURE 3.— This figure shows the oil recovery as a function of reservoir pressure when displacing a 31°API gravity crude with LPG (propane) slugs pushed by nitrogen. The lower curve shows the oil recovery at gas breakthrough. The upper curve shows the oil recovery at a 30,000 to one gas-oil-ratio. The data were obtained at 112°F.

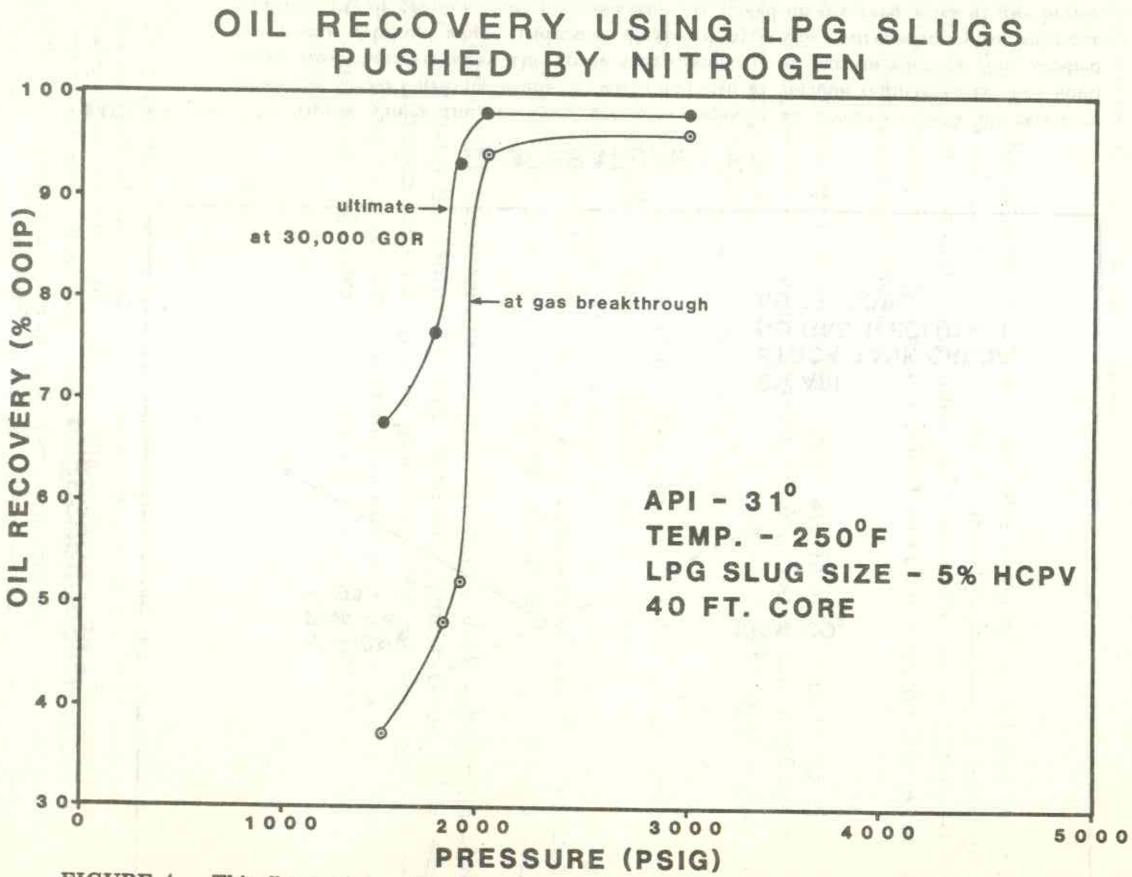

FIGURE 4.— This figure shows the oil recovery as a function of reservoir pressure when displacing a 31°API gravity crude with LPG (propane) slugs pushed by nitrogen. The lower curve shows the oil recovery at gas breakthrough. The upper curve shows the oil recovery at a 30,000 to one gas-oil-ratio. The data were obtained at 250°F.

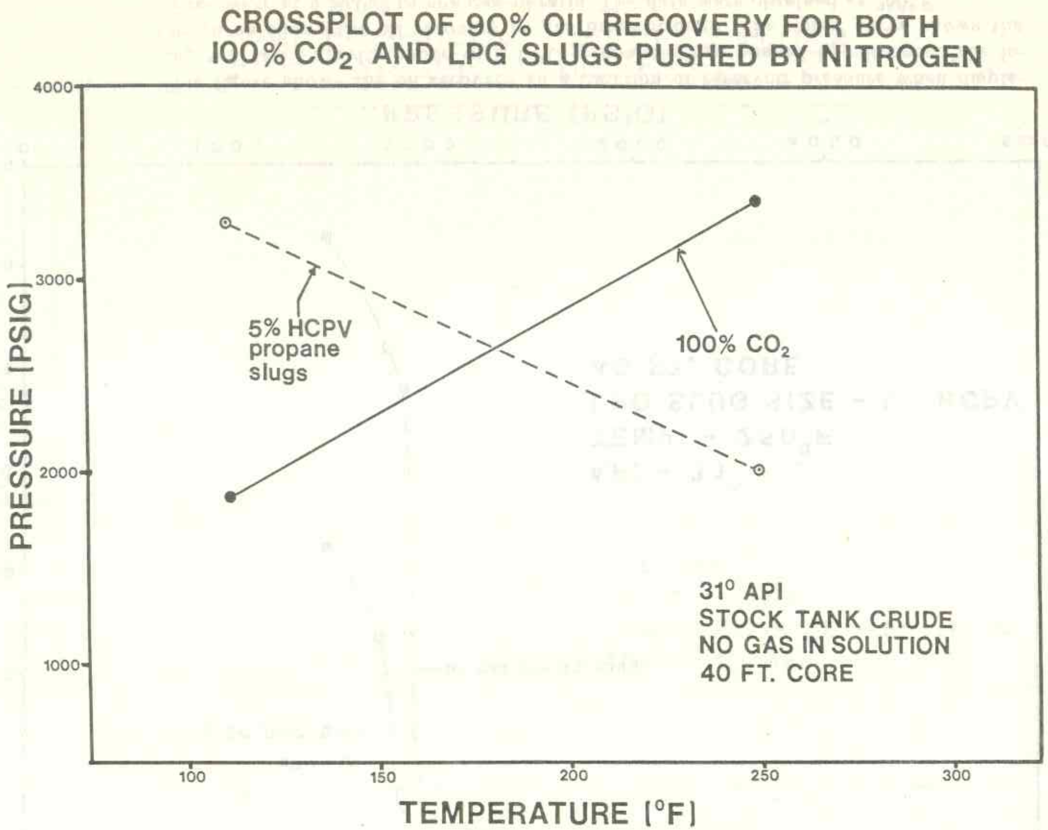

FIGURE 5.— This figure shows the reservoir pressure required to achieve a 90% oil recovery when the 31°API gravity crude oil was displaced at various temperatures. The solid curve was obtained when the crude was displaced by carbon dioxide. The dashed curve was obtained when crude was displaced by a 5% hydrocarbon pore volumne slug of LPG or propane. The oil recoveries are based on the recoveries at gas breakthrough.

SUMMARY

Laboratory studies have been made to study the oil recovery by miscible displacement of a 31° API gravity crude oil. Both carbon dioxide and and LPG slugs pushed by nitrogen were used for the displacing fluids. Two temperatures of 112°F were studied.

It was found that a pressure of 1880 psi was required to achieve miscibility (defined as 90 percent oil recovery at gas breakthrough) when using carbon dioxide as the displacing fluid and a temperature of 112°F. By contrast approximately 3040 psi was required to achieve miscibility when displacing the crude oil at 250°F.

When using carbon dioxide as the displacing fluid it was found that the miscible displacement pressure increased more than a thousand psi as the reservoir temperature increased from 112° to 250°. The reserve was true when using LPG slugs as the displacinf fluid.

The crude oil was displaced with a five percent HCPV (Hydrocarbon pore volume) slug of LPG pushed by nitrogen. At a temperature of 112° it required a pressure of 3300 psi to achieve a 90 percent oil recovery at gas breakthrough. When the temperature was increased to 250°F it required a pressure of 2000 psi to achieve a 90 percent oil recovery at gas breakthrough.

It was found that the reservoir temperature had a very substantial effect on the miscibility pressure. At high reservoir temperatures, LPG slugs pushed by nitrogen were effective at pressures 1000 psi less than the pressure when using CO_2. At lower reservoir temperatures the reverse was true, i.e., CO_2 achieved a 90 percent oil recovery at a pressure 1000 psi less than LPG slugs.

ABSTRACT

This paper reports on the results of miscible displacement tests on a medium gravity crude oil. In one series of tests carbon dioxide was inject from the beginning to the end of the run. In a second series of tests a five percent hydrocarbon pore volume slug of LPG (propane) was injected, and the slug of LPG was pushed by gaseous nitrogen. Tests were conducted over a temperature range of 112°F to 250°F. It was found that when using carbon dioxide the miscible pressure increased from approximately 1880 to 3040 psi as the reservoir temperature increased from 112°F to 250°F. The reserve was true for the case of miscible displacement using LPG (propane) slugs pushed by nitrogen.

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