RESPONSE OF WASSON AND LEVELLAND CRUDES TO NITROGEN AND CARBON DIOXIDE

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ABSTRACT

Laboratory studies have been made to determine the oil recovery by displacing the Levelland and Wasson crudes by carbon dioxide at various pressures. For the case of the Wasson crude it has been found that a slug of carbon dioxide equal to ten percent of the hydrocarbon pore volume pushed by nitrogen resulted in an oil recovery of 96 percent of the original oil in place. The use of a slug of carbon dioxide of five percent hydrocarbon pore volume pushed by nitrogen resulted in an oil recovery of 90 percent.

The cost of carbon dioxide brought in from Colorado or New Mexico is expected to be $1.00 to $1.25/mcf. The cost of nitrogen is expected to be less than 50¢/mcf delivered at high pressure. At Wasson or Levelland reservoir conditions one mcf of nitrogen will occupy three times as much pore space as one mcf of carbon dioxide. The cost of nitrogen at reservoir conditions is estimated to be only 15 percent of the cost of carbon dioxide at reservoir conditions. It appears the nitrogen-driven carbon dioxide slug oil-recovery method may have application to various West Texas crudes.

INTRODUCTION

A wide variety of tertiary oil recovery methods are now being studied. Laboratory tests are being performed; pilots are being run; and field data are coming in. From analysis of these data, it appears that the use of carbon dioxide may find considerable application for increasing the tertiary oil recovery from the oil fields of the Permian Basin. There are three to four billion barrels of oil in the Permian Basin providing the target for possible application of oil recovery by use of carbon dioxide. It has been estimated that it will require over twenty trillion cubic feet of carbon dioxide to do the job. The available sources from New Mexico and Colorado may be only about one-third of that required. A large number of carbon-dioxide wells must be drilled and an 800 mile pipeline must be laid. The cost of carbon dioxide will likely be $1.00 to $1.25 per MCF, and the availability will tend to limit the prospective applications. Research has been underway to study the response of various crudes to carbon dioxide. Hopefully a way may be found which uses a smaller amount of carbon dioxide in each oil field, thereby stretching the limited supply of carbon dioxide in each oil field, thereby stretching the Research at Texas A&M University has involved both carbon dioxide and nitrogen injection to increase oil recovery.

Figure 1 shows an artist's sketch of carbon dioxide slugs pushed by nitrogen. The carbon dioxide would be injected into the well using a slug size determined by competent reservoir engineering. Following injection of the carbon dioxide slug, pure nitrogen would be injected to push the slug along. The purpose in using the slug of carbon dioxide is to reduce the amount required and also the cost. If nitrogen can replace a portion of the carbon dioxide, it will stretch the supply. For reservoir temperatures of near 100 to 110°F and pressures of near 1500 psi, nitrogen will only cost about fifteen percent as much as carbon dioxide on a reservoir barrel basis. Nitrogen costs about half the estimated CO_2 costs of $1.00 to $1.25/MCF and the compressibility factor of nitrogen is about three times greater than carbon dioxide at 107°F and 1500 psia.

EQUIPMENT AND PROCEDURE

This laboratory study was conducted using two slim tubes. The tubes were either 40 or 100 feet in length. The tubes were packed with unconsolidated media to simulate the porous media of the reservoir. The coiled pack was placed in an oil bath so that the reservoir temperature could be simulated. The pack

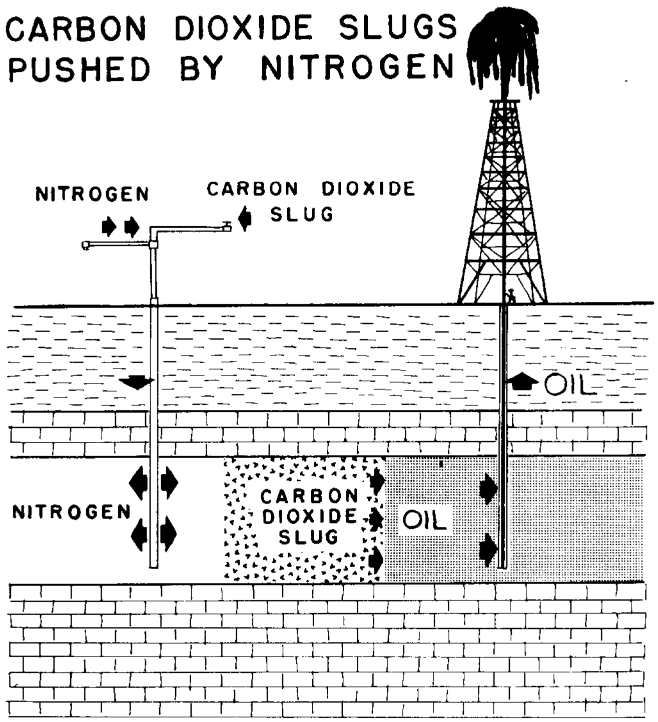

FIGURE 1—THIS FIGURE SHOWS AN ARTIST'S SKETCH OF OIL RECOVERY BY INJECTING A SLUG OF CARBON DIOXIDE PUSHED BY NITROGEN. THE NITROGEN WOULD BE OBTAINED FROM THE AIR.

was cleaned by injecting a hydrocarbon solvent. The solvent was flowed through the pack until the solvent came out clear after which the temperature in the bath was raised to approximately 250° to evaporate the solvent. A vacuum was applied overnight or up to about 30 hrs. The cleaned core was used in the reservoir simulation studies.

The stock-tank crude oil selected for the study was injected into the coiled sand pack, and the pressure was increased to the desired simulation pressure. For the West Texas crudes discussed here, most pressure tests were conducted in the 700 to 1500 psi range but some tests were made at pressures of a few thousand psi.

Two gas cells were available to hold the gases used in the laboratory study. One cell contained pure commercial-grade carbon dioxide. A second cell contained commercially pure nitrogen. In making a study with a crude oil, the temperature was brought to the reservoir temperature, usually in the order of 105 to 107°F, and the oil recovery determined by displacing the crude with the desired gas. The produced crude was measured in a graduated cylinder. The gas-oil ratio was determined by use of a wet test meter. In subsequent runs, the reservoir pressure might be varied, and the oil recovery determined as before.

In separate studies, nitrogen might be injected throughout the entire run to determine the oil recovery by injection of pure nitrogen. In simulating the CO_2 slug runs, both gas cells were used. The CO_2 slug was injected of the proper size. Slug sizes ranged up to about 24 percent of the hydrocarbon pore volume. After the injection of the CO_2 slug, nitrogen was then injected to push the CO_2 slug through the pack. The oil recovery was measured until the gas-oil ratio reached approximately 25,000 cu ft per barrel.

MATERIALS FOR STUDY

Stock tank crudes from the Levelland and Wasson fields of West Texas were selected for study. There was no gas in solution. These two reservoirs provide a potential target for oil recovery by carbon dioxide of over 800 million barrels of oil. The initial work on the Levelland crude was conducted using carbon dioxide as the injected gas from the beginning to the end of the run. The initial oil stock tank gravity was 35.6°, and the temperature for reservoir simulation was 105° F.

Following the work with the Levelland crude, the Wasson crude was used with CO_2 slugs. It has been reported that the Wasson reservoir provides a target for CO_2 oil recovery of approximately 670 million barrels of oil. The stock tank oil had a gravity of 34° API. Displacement tests were made at a reservoir temperature of 107° F. The 100 ft pack was used primarily when studying the Wasson crude.

Effect of Pressure on Oil Recovery

Figure 2 shows the effect of carbon dioxide displacing pressure on the oil recovery using the Levelland stock tank oil. The initial oil gravity was 35.6° API. The sample weathered during the course of the study, and some tests were made on oil of near 31.4° API. There was no gas in solution. The 40-foot core was used, and the temperature was 105° F. The figure shows that the oil recovery was near 60 percent for displacement pressures ranging from 600 to 900 psia. At 1200 psia, displacement pressure the oil recovery was near 84 percent. Above 1400 psia, the oil recovery was over 90 percent of the stock-tank oil in place. In the above tests carbon dioxide was injected from the beginning to the end of the run. The tests were stopped at a gas-oil ratio of 25,000 to one.

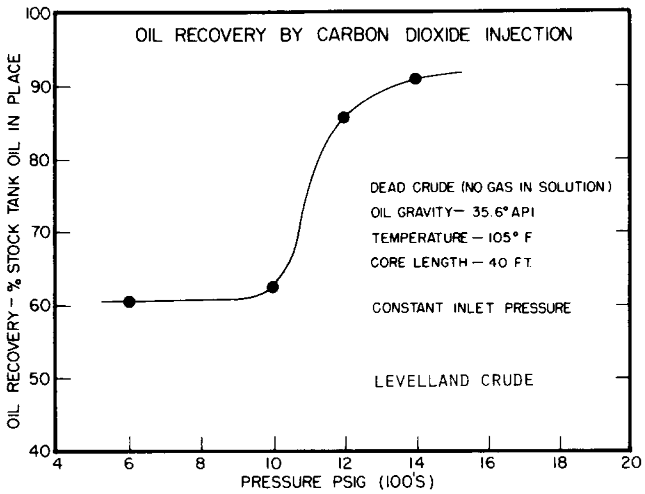

FIGURE 2 THIS FIGURE SHOWS THE EFFECT OF PRESSURE ON OIL RECOVERY BY DISPLACEMENT WITH CARBON DIOXIDE FROM BEGINNING TO END OF THE RUN.

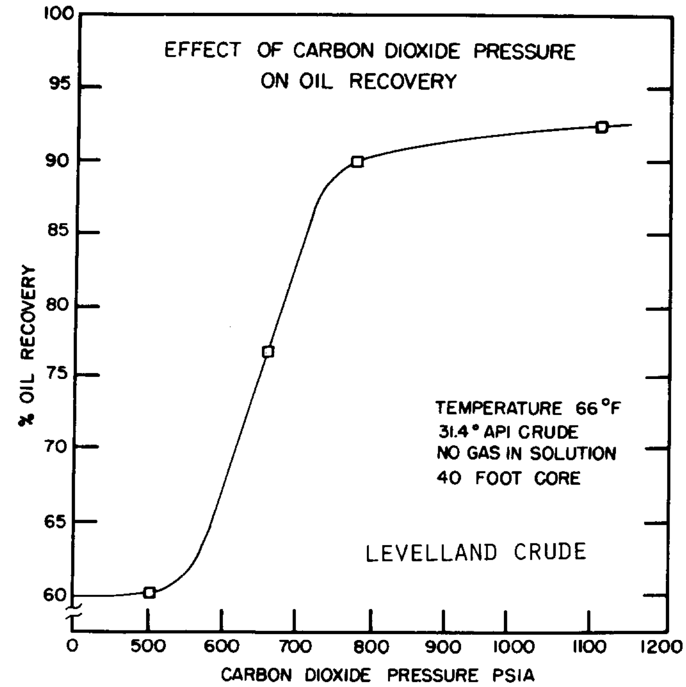

FIGURE 3 THIS FIGURE SHOWS THE EFFECT OF CARBON DIOXIDE PRESSURE ON OIL RECOVERY BY DISPLACEMENT OF THE CRUDE AT A TEMPERATURE OF 66°F.

EFFECT OF TEMPERATURE ON OIL RECOVERY

A number of shallow reservoirs will have a temperature of less than 100° F. Although miscible displacement may be desirable, the oil reservoirs, being shallow, will tolerate only a modest pressure. For these reasons, the oil recovery by carbon dioxide injection was studied at low temperature and low pressures. Figure 3 shows the oil recovery as a function of pressure for a simulated reservoir temperature of 66° F. The tests were made on slightly weathered Levelland stock-tank crude oil at a temperature of 66° F. For this crude it is seen that the miscible pressure was less than 800 psi. The oil recovery at 650 psi was near 76 percent for the 31.4° API gravity crude oil.

These data indicate that some shallow oil reservoirs may be displaced miscibly at pressures of 1000 psi or less. Attention should be called to the high oil recovery at 66° F and 1,100 psi. A carbon dioxide vapor pressure chart shows that the carbon dioxide is liquid at these conditions. Carbon dioxide can be a quite effective displacing agent as either a gas or as a liquid.

Oil Recovery by Nitrogen Injection

Figure 4 shows a comparison of the oil recovery by nitrogen injection and carbon dioxide injection for the Levelland crude. The tests were made at 105°F using the 40 feet unconsolidated pack. The figure shows that at nitrogen pressures of 1,200 and 1,850 psi the oil recovery was near 62 percent of the stock tank oil originally in place. There was no gas in solution. When CO_2 was used at 1200 psi, the oil recovery was 86 percent, and at 1350 psi the oil recovery was greater than 90 percent. This comparison of the oil recovery between nitrogen and carbon dioxide at low reservoir pressures shows clearly the marked difference in the gases on depleted or stock tank crudes.

Oil recovery by nitrogen injection is different from recovery by carbon dioxide injection. The light ends and intermediates are very important for nitrogen miscibility. This does not appear to be the case for carbon dioxide. For determination of the miscible pressure for reservoir conditions using nitrogen, it would be necessary to recombine the stock tank oil with the wet separator gas. Whereas nitrogen drives may recover less than 70 percent of a dead stock tank crude, the nitrogen recovery may be over 95 percent when wet gas is added back to the stock tank oil. Nitrogen drives will pick up intermediates which induce miscibility. For this reason the wet gas should be added back to the stock tank crude for applicable nitrogen miscibility studies.

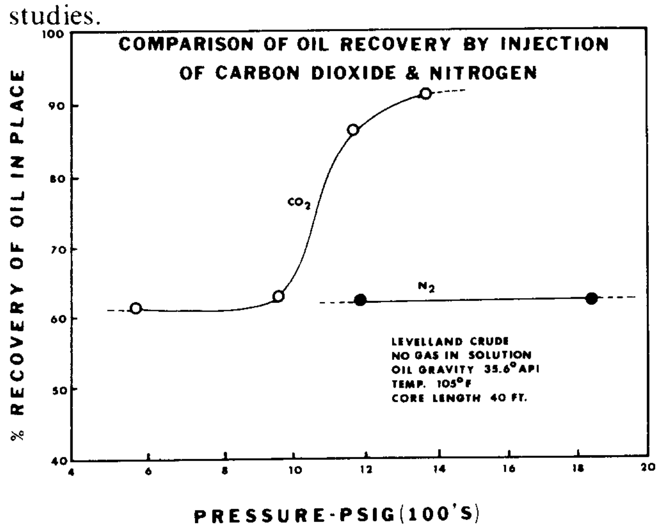

FIGURE 4 THIS FIGURE SHOWS A COMPARISON OF OIL RECOVERY BY INJECTION OF CARBON DIOXIDE AND NITROGEN.

WASSON CRUDE RESPONSE

Most of the Wasson crude oil tests were made at a constant injection pressure of 1250 psi. When pure nitrogen was injected from beginning to the end of the run, the oil recovery was 62 percent of the oil in place. A slug of pure carbon dioxide was injected and pushed by nitrogen. With the injection of a slug of CO_2 equal to approximately 24 percent of the hydrocarbon pore volume, the oil recovery was approximately 98 percent. See Figure 5. The pure carbon dioxide slug was pushed by the pure nitrogen. With 5- and 10-percent slugs of carbon dioxide followed by nitrogen, the oil recovery was 90 percent and 96 percent of the oil originally in place, respectively. These preliminary laboratory tests indicate the possibility of using slugs of carbon dioxide pushed by nitrogen as a means of stretching limited CO_2 supplies and perhaps reducing costs.

The actual slug size to be used in the field will depend on many factors. The relative costs of the carbon dioxide and nitrogen, rock heterogeneities, mobility ratio, amount of water used, rates, and other factors will all need to be considered in sizing the slug.

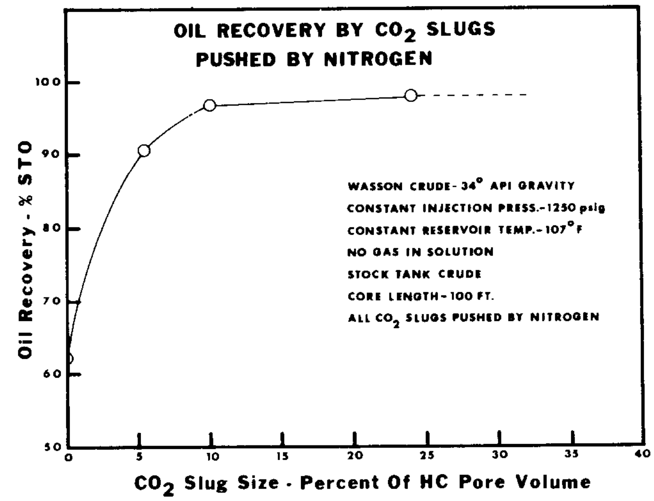

FIGURE 5 THIS FIGURE SHOWS THE OIL RECOVERED BY CO_2 SLUGS PUSHED BY NITROGEN FOR THE WASSON CRUDE.

MOBILITY CONTROL

The use of carbon dioxide in a miscible displacement process may also require the use of water. The alternate use of water with gas is recommended for mobility control. Controlling the mobility may produce increased sweep efficiencies. The injection of water following gas results in the water plugging the pores where gas normally goes. This forces the gas into pores which would be bypassed if gas alone were injected.

COSTS OF NITROGEN

Pure nitrogen may now be made at the site of the oil field by a nitrogen plant designed for the purpose. Such a nitrogen plant may be powered by either electricity or natural gas. Air is compressed to a fairly modest pressure, and then by progressive cooling using the Joule-Thompson effect the air is cooled to a temperature of about minus 300°F. At this low temperature the air will liquefy and permit fractionation and purification.

Pure nitrogen is taken from the top of the fractionating column. The cold nitrogen from the top of the column is warmed by counter-current heat exchange with the incoming air so that the nitrogen from the plant is a gaseous material at near atmospheric temperature. With this method, nitrogen can be produced in the field for less than half the cost per mcf of carbon dioxide piped in from New Mexiço and Colorado. The cost of CO_2 would be in the range of $1.00 to $1.25 per mcf. Cryogenic nitrogen will cost about half as much.

In addition to costing less, nitrogen occupies more reservoir pore space. One mcf of nitrogen occupies three times as much reservoir pore space as carbon dioxide at reservoir conditions for the reservoir temperatures and pressures which are considered here. This is due to the difference in compressibility factors. Nitrogen gas will only cost about fifteen percent of the cost of carbon dioxide to fill a barrel of reservoir pore space. Thus the potential for savings is evident.

SUMMARY

Laboratory data has been obtained which indicates the feasibility of using nitrogen-driven carbon-dioxide slugs in a tertiary oil recovery method. Carbon dioxide slugs of only 5- to 10-percent have been successful in recovering 90- to 95-percent of the oil in place in the laboratory. However, the field applications will require very much larger slug sizes than the laboratory tests due to a number of factors.

The use of carbon dioxide slugs rather than pure CO_2 from beginning to the end of the run would permit a stretching of available CO_2 supplies. Using cryogenic nitrogen to push the carbon dioxide could reduce the cost of the process. Since the nitrogen costs about half as much as CO_2 on an MCF basis and the compressibility factor of nitrogen is three times as great as CO_2 for the reservoir conditions considered here, the cost of nitrogen per barrel of reservoir pore space may be only fifteen percent of the cost using carbon dioxide.