POTENTIAL FOR CARBON DIOXIDE FLOODING IN TRINIDAD

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ABSTRACT

Revenues from crude oil production and the petroleum sector in general make a significant contribution to the economy of the Republic of Trinidad and Tobago. Annual crude oil production has declined by 24 % over the last 10 years. It is generally accepted that the dependence on the petroleum sector will continue well beyond the year 2000. It is imperative, therefore, that steps be taken to arrest this decline in production and preferably reverse it. In the absence of the discovery of new reserves in the recent past, Enhanced Oil Recovery (EOR) has the potential to achieve this objective.

This paper shows that there is a potential for CO_2 flooding in Trinidad. Produced as a by-product of the Petrochemical Plants at the Point Lisas Industrial Estate, CO_2 is mainly vented to the atmosphere. Environmental concerns indicate that this practice should not continue much longer. Capture of this CO_2 for injection into oil reservoirs will provide a means of safe disposal of the CO_2 and, concurrently, will contribute to increased crude oil production.

1.0 PRODUCTION

The land-based petroleum industry is more than 100 years old. The producing fields are way down on their production decline curves. Waterflooding and steamflooding are the only EOR methods that have been tried as full-scale projects in local reservoirs. Several waterflood projects have been undertaken but most of them have been unsuccessful. The average recovery due to waterflooding is estimated to be 10% of the Original Oil In Place (OOIP). Recoveries from steamflood projects have ranged from 5% to 50% OOIP with an estimated average recovery of approximately 25% OOIP. This dismal picture is further darkened by the fact that no new oil reserves have been discovered in recent years.

Table 1 shows Trinidad's total annual Hydrocarbon Production for the period 1983 to 1996. The contribution of primary and secondary oil production is shown in columns 3 and 4 respectively, while secondary production as a percentage of total oil production is shown in column 5. The last column shows natural gas production. This data is represented in **Figure 1**. Approximately 87% of the 1996 total production is due to primary production. For the 10-year period (1986 - 1996), total annual production has declined by 24%, primary production has declined by about 23% while secondary production has declined by about 30%. The percentage contribution of secondary recovery has also decreased from 14.6% to 13.3%. Because the economy of the Republic of Trinidad and Tobago is substantially dependent on the Petroleum Sector [1], it is essential that measures be taken to maintain if not increase production levels. Over the period 1989 - 1996, natural gas production has increased by some 37%. It is anticipated that future revenues from this resource will surpass that of crude oil.

The most efficiently managed reservoir will give a maximum primary recovery factor of 20%. Trinidad's experience has shown a primary recovery factor of less than 15%. Private operators producing marginal and idle wells contribute to primary production. At best, they achieve a primary recovery factor of 1% to 2% OOIP. This is a short-term benefit of insignificant recovery and has adverse consequences to proper management of the reservoirs in the long-term.

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YEAR	TOTAL OIL PRODUCTION bbl/d	PRIMARY OIL PRODUCTION bbl/d	SECONDARY OIL PRODUCTION bbl/d	PERCENT SECONDARY PRODUCTION	NATURAL GAS PRODUCTION MMcf/d
1983	159846	138557	21289	13.30	-
1984	169513	146780	22733	13.40	-
1985	176052	152668	23384	13.30	-
1986	168878	144221	24657	14.60	-
1987	155180	131251	23929	15.40	-
1988	150842	125865	24977	16.60	-
1989	134052	111131	22921	17.10	496.21
1990	151194	125095	26099	17.30	358.66
1991	145395	122899	22496	15.50	520.62
1992	137057	117971	19086	13.90	526.63
1993	124604	106505	18099	14.50	448.65
1994	131532	112056	19476	14.80	505.57
1995	131801	113303	18496	14.00	559.92
1996	128931	111734	17197	13.30	679.52

Table 1: Annual Hydrocarbon Production of Trinidad and Tobago

Oil reservoirs are capable of producing for 20 - 30 years and often for longer periods. Planning, decisions and management of these reservoirs must address not only the short-term but the long-term also. The petroleum industry has placed too much emphasis on the short-term (primary production) and not enough on the long-term (EOR). Hence, the situation that presently exists is one of declining production from mature reservoirs, a large number of stripper wells and very few EOR projects.

Two options are available for the continued production from Trinidad's reservoirs. Firstly, the wells can be produced until the reservoir pressure falls below some economically determined value after which the producing zone is abandoned. If at the end of its economic life, the producing zone is abandoned and the well is re-completed in an uphole horizon, it means that more than 80% of the OOIP would have been left in the reservoir. This is unacceptable. The second option is to implement an EOR project. The target for EOR is the remaining oil in place after primary recovery, i.e., the more than 80% of the OOIP. Some of the risks in primary recovery are not present in EOR. With an EOR project, the following are known:

- Volume of oil in place;
- Shape and delineation of the reservoir;
- Communication between wells

The cost of implementing an EOR project escalates with time. The longer the implementing of an EOR Project is delayed while producing primary oil, the more the reservoir pressure decreases. This means a greater volume of fluid will be required for injection to attain reservoir operating pressure for the EOR process and hence increased costs. Also, the risk of technical failure increases as wellbore conditions deteriorate (e.g., liner failures and parted casing) and fluid saturations change, sometimes irreversible resulting in adverse consequences to continued productions. In other words, the time to implement an EOR project is now.

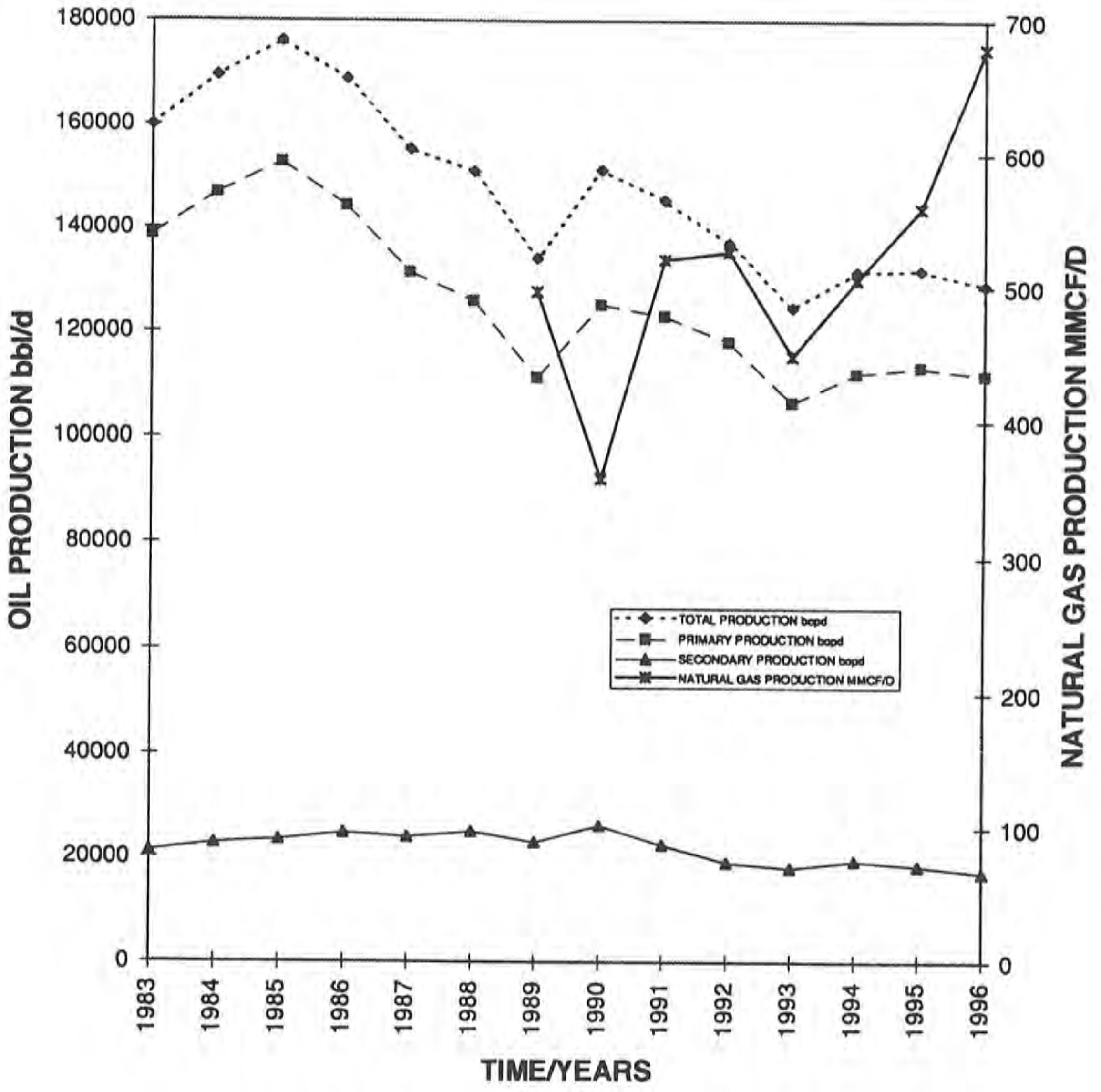

Figure 1: Annual Hydrocarbon Production of Trinidad and Tobago

Of all the EOR methods employed in the USA, CO_2 flooding has the highest implementation rate with about 60 CO_2 floods presently in operation [2]. About half of these were started in the middle 1980s. Most of these have shown good incremental oil recovery. The largest and oldest (SACROC) was started in 1972 and is still producing at approximately 13,000 bopd which is about 54% of the total production from that field. CO_2 reserves in the USA are estimated to be in excess of 50 trillion cu. ft. Five of the major pipelines, with lengths ranging from 200 miles to 600 miles, for transmission of CO_2, have a combined deliverability of 2 billion cu. ft. per day.

2.0 MECHANISMS OF CO_2

A CO_2 flood can be carried out as either an immiscible or as a miscible displacement process. Generally, the miscible type is preferred because it ensures the higher recovery. This is not always possible, however, since the maximum displacement pressure is limited by the reservoir fracture pressure. The mechanisms of recovery for both the miscible and immiscible displacements depend on reservoir temperature, injection pressure, oil composition and purity of the CO_2.

2.1 Immiscible Flooding

The four major factors that contribute to oil recovery of an immiscible displacement are oil swelling, viscosity reduction, interfacial tension reduction and blowdown recovery [3]. CO_2 is very soluble in crude oil. As it dissolves, the oil volume increases by 10% to 40% and this increases the recovery factor. Also, the viscosity of the crude decreases. Viscosity reduction can range from one-tenth to one-hundredth of the original viscosity. The interfacial tension of a crude can decrease by 30% because of CO_2 dissolved in it. This increases the mobility of the oil resulting in greater recovery. After the injection phase, the reservoir pressure starts to decrease. This causes CO_2 to come out of solution from the crude oil and drives the oil to the offtake wells. This effect is similar to the mechanism of solution gas drive and may contribute as much as 30% of the recovery due to CO_2.

There are several methods for conducting a CO_2 Immiscible Flood [4].

Continuous CO_2 Injection

CO_2 is injected continuously into the reservoir and drives the oil to the production wells. This approach is satisfactory for light oils but recoveries for viscous crudes can be small.

CO_2 Slug Driven by Water

In this process, continuous injection of water drives a slug of CO_2 through the reservoir. This results in higher recovery while using a smaller volume of CO_2 than in the continuous injection process. This process is rate-dependent i.e., as the injection rate increases, the oil recovery during the CO_2 injection phase decreases while that during the water injection phase increases.

Water Alternating Gas (WAG) Using CO_2

The CO_2 volume requirement for the reservoir is divided into 4 or 5 equal slugs. Oil recovery depends on the total volume of CO_2 injected and not on the number or size of the slugs. Each slug is injected alternately with water based on a pre-determined water-gas ratio. CO_2 channelling is reduced because water decreases the CO_2 mobility and hence the volumetric sweep efficiency is increased. This method gives higher recoveries than either of the two previous methods. The laboratory data shown in **Table 2** was acquired using sand-packed cores [5]. WAG displacement gave recoveries of 50% and 76% for 16°API and 29°API crudes, respectively, whereas continuous injection of CO_2 on the same crudes gave recoveries of 37% and 42% respectively.

Cyclic CO_2 Stimulation

In initiating an immiscible CO_2 flood, particularly for heavy crudes, it is sometimes useful to start with cyclic CO_2 stimulation also called Huff 'n' Puff. In this method, a slug of CO_2 is injected at a high rate. The well is then shut in for a soak period after which it is put on production. When the production declines below a certain critical value, another slug of CO_2 is injected and the sequence is repeated. After 2 or 3 cycles on a few wells, CO_2 can be continuously injected into some of the wells and crude produced from the others. This simple approach can be expanded by increasing the number of injectors and producers to form a pilot and further expansion can result in a full-scale flood.

Simultaneous Injection of CO_2 & Water

Simultaneous injection of CO_2 and water into the reservoir gives better recoveries than the other mentioned processes. While dry CO_2 is non-corrosive, carbonic acid formed with water lowers the pH to 3.2. Generally, most of the corrosion occurs in the producers and flowlines and to a lesser extent in the injection wells. However, corrosion in the injection wells is an inevitable consequence of this procedure. Plastic-coated tubing, stainless steel and carbon steel have been used to minimise corrosion. Fibreglass lines have also been used with a good degree of success. Injection of corrosion inhibitors into the producers has also been employed.

Because the injection pressure for an immiscible flood is low (900 psi to 1,000 psi), the number of candidate reservoirs suitable for this type of flood is large since it can be conducted in shallow and deep reservoirs. For an approximate pressure gradient of 0.45 psi/ft, reservoirs as shallow as 2,000 ft become possible candidates.

2.2 Miscible Flooding

A miscible displacement is one in which there exists no interfacial tension between the displaced and displacing fluids. The interfacial tension between reservoir fluids and injected fluids gives rise to capillary forces in the reservoir matrix and these account for the residual oil that is left behind an advancing flood front. Since there is no interfacial tension in a miscible displacement process, the capillary forces are reduced to zero so that total oil recovery could be achieved in the swept zone. This accounts for the high percentage recoveries that are so characteristic of a miscible displacement.

Carbon dioxide is not immediately miscible with crude oil. This means that if it was used to displace a crude in a controlled environment, an interface between both phases would be detected. If the displacing pressure was gradually increased, the interface would eventually disappear and only one phase would exist. The pressure at which this occurs is called the Minimum Miscibility Pressure (MMP). MMP is the single most important parameter that must be determined when designing a miscible flood. The MMP must not be greater than the reservoir fracture pressure. Maintenance of the reservoir pressure at or slightly above the MMP ensures the displacement will be miscible and not immiscible.

The MMP of a crude oil/CO_2 system can be determined theoretically as well as experimentally. Theoretically determined, MMP is not always reliable and so experimentally determined ones are preferred. However, experimental determination can be a long and tedious exercise.

Theoretical methods of determining MMP include:

- Empirical Correlations
- Calculations using EOS and/or K-value correlations
- Ternary Diagrams

Experimental methods of determining MMP include:-

- Slim tube displacements (STD)
- High-pressure volumetric (PVT) and vapour-liquid equilibrium (VLE) studies
- Core displacements
- Continuous multiple-contact experiments
- Rising Bubble Apparatus (RBA) studies

The MMP of several local crudes was determined using empirical correlations and slim tube displacements [6]. The values from the correlations ranged between 1,100 psi and 3,900 psi while those from the slim tube displacements ranged from 1,900 psi to 3,000 psi. This suggests that conservative estimates of reservoir depths range between 4,200 ft and 6,600 ft for potential candidates for miscible flooding although deeper reservoirs would be more suitable. In Trinidad, there is a large number of reservoirs that fall within this range of depth and a substantial number that are deeper.

3.0 SOURCE OF CO_2

Carbon dioxide is produced as a by-product by some of the companies in the Point Lisas Industrial Estate. Some of it is consumed while the rest is vented to the atmosphere. **Table 3** shows volumes produced, utilised and vented in scf/d and the percentage vented. This data shows a 41% increase in production over the period 1989 to 1996 but a 60% increase in percent vented for the same period. If adequate volumes of this vented CO_2 are injected into an oil reservoir:

YEAR	PRODUCED (scf/d)	USED (scf/d)	VENTED (scf/d)	% VENTED
1989	135 E+06	46.1 E+06	88.9 E+06	66%
1996	190 E+06	47.5 E+06	142.5 E+06	75%

Table 3: CO_2 Production/Utilisation

- Significant increases in crude oil production can be realised. The volume of CO_2 required for a field project ranges between 30% - 40% of the hydrocarbon pore volume.
- The volume vented to the atmosphere will be reduced.
- An environmentally acceptable method of safe disposal of this CO_2 will be realised.

CO_2 produced with the crude should be compressed and re-injected into the reservoir. This reduces the volume to be purchased and cuts project costs. The objective is to keep the CO_2 in the reservoir because it promotes crude oil production.

4.0 ECONOMIC CONSIDERATIONS

In the USA, the price of CO_2 is tied to the oil price via a linear relationship such that as the oil price increases, the price of CO_2 increases [2]. The price of CO_2 in Trinidad is fixed. This means that as the oil price increases, the profit margin increases, everything else being constant (e.g., operating cost).

Economic calculations and parameters currently used in the local Petroleum Industry were applied to two types of CO_2 projects. One was cyclic stimulation of a single well and the other was an immiscible pilot with one injector updip and the offtake wells downdip. The single well Huff 'n' Puff had an initial production (IP) of 25 bopd and a decline rate of 12%. The payout time was 2.5 months for oil prices of US$12.00 and $15.00 per bbl and 1.25 months for oil prices of US$20.00 and $25.00 per bbl. The discounted cash flow rate of return (DCFROR) was very favourable, being greater than 100% for each of the oil prices above.

The immiscible pilot had an IP of 100 bopd and a decline rate of 12%. The payout time was 5 months, 3.5 months, 2.5 months, 2.5 months, for oil prices of US$12.00, $15.00, $20.00 and $25.00 per bbl respectively. As above, the DCFROR was very favourable, being in excess of 100% for each of the oil prices investigated.

These figures are applicable to areas where the CO_2 transmission line exists and the initial investment cost is that of running spur lines to the wellheads, purchase and compression cost of CO_2 and winchwork cost. Implementation of small pilots as these and larger ones close to the CO_2 transmission line will provide much needed revenue which can be invested in other EOR projects that require larger capital investment.

A transmission line for the transport of CO_2 from Point Lisas to Fyzabad already exists. Spare capacity, if available, reduces considerably the initial cost of implementing a CO_2 flood in Petrotrin's acreage in this area. If the line capacity is fully utilised, then the cost of a transmission line must be included. Trinmar's initial cost of implementing a CO_2 flood can also be considerably reduced since CO_2 can be transported by barge from Point Lisas to Soldado for a pilot project. In the likely event that this pilot proves viable, a transmission line of approximately 35 miles would be required.

5.0 TRINIDAD'S EXPERIENCE

At present, CO_2 is being injected into the Oropouche and Forest Reserve fields. These projects were initiated because idle or low-producing wells were in close proximity to the CO_2 transmission line and not based primarily on technical screening criteria. The wells were used as injectors for continuous injection and Huff 'n' Puff. In spite of this, some of the wells have shown a significant increase in production. An inactive well was worked over and after CO_2 injection, it was pumping 100 bopd. Another well was closed in, uneconomic and after reactivation and CO_2 injection, it was producing 40 bopd on gaslift. This favourable response indicates that this technique can be successfully applied in Trinidad. Further field tests in shallow wells producing heavy oil are required.

It must be emphasised that careful selection of wells for injection and production is crucial to the success of a flood. Reservoirs should be screened for proper selection of EOR methods to be implemented and shortlisted. A proper engineering study should be carried out on the best two or three of this list and the one with the highest confidence of technical and economic success should be implemented. Ideally, implementation should be carried out before the reservoir pressure falls below the MMP in the case of a miscible flood. However, both miscible and immiscible floods can be technically and economically successful even if implemented after a waterflood. A common practice of the past was to implement a waterflood project after primary production. In some reservoirs, it can be more beneficial to implement a CO_2 immiscible flood immediately after primary production rather than after waterflooding the reservoir.

6.0 CONCLUSION

1. EOR is an option for arresting the declining production in Trinidad.
2. An adequate supply of CO_2 is available from the Point Lisas Industrial Estate.
3. There are several candidate reservoirs for implementing CO_2 miscible and immiscible floods.
4. Preliminary field tests have shown that CO_2 can be successfully used as an EOR fluid in Trinidad.
5. Injecting CO_2 into oil reservoirs provides a safe and environmentally-friendly method of disposing CO_2.

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SI METRIC CONVERSION FACTORS

bbl	x 1.589 873	E-01	= m^3
cu ft	x 2.831 685	E-02	= m^3
ft	x 3.048	E-01	= m
psi	x 6.894 757	E+00	= kPa
milex	1.609 344	E+00	= km