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# Twenty-Five Years of Oil Recovery by Steam Injection

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## ABSTRACT

Thermal oil recovery was first started in 1966, in Trintopec's operations, with a small cyclic pilot project in the Palo Seco field. Twenty-five (25) years of thermal recovery, comprising cyclic and flood operations, have witnessed vigorous growth and dynamic expansion to the extent that, by 1991, the thermal recovery statistics are as follows :

(a) Steamflood operations exist in all the Company's major land fields, viz., Palo Seco, Central Los Bajos, Guapo, North Fyzabad and Apex-Quarry/Coora/Quarry.

(b) Total production from thermal recovery averages 9100 bopd, representing 55% of Trintopec's current land production.

(c) A total of approximately 40000 bspd is being supplied by 23 steam generators to more than 150 steam injectors.

This paper presents highlights of Trintopec's experiences in the design, implementation and operation of thermal oil recovery schemes. New concepts, innovations, modelling and monitoring techniques over the past twenty-five (25) years are outlined, and, in addition, projections for the future are indicated.

## INTRODUCTION

Of the enhanced oil recovery techniques available to the industry, viz., thermal (steam and in-situ combustion), miscible, chemical and polymer floods, the single method that has attained most widespread acceptance has been the use of steam, both in cyclic and flood-type operations.

Not surprisingly, this method has manifested itself as the major thrust of EOR operations at Trintopec. The primary factors that motivate its use are as follows :

(i) Cost effectiveness, with water being cheap and readily available,

(ii) Abundance of heavy oil reserves in Trintopec's leases,

(iii) Projected recovery of lighter oil, by distillation,

(iv) Proven success of method, both internationally and at Trintopec.

Significantly, and expectedly, the growth of associated technology in the Company's thermal operations has paralleled the increased production rates from thermal operations. Although the current performance of the Company's thermal schemes is such that 55% of land production is thereby accrued, and prospects for further enhancement of thermal production are encouraging, it would be erroneous to suggest that the path was not fraught with difficulties and operational problems. Nevertheless, through a vigorous and dynamic growth and expansion programme, the method employed in the thermal recovery schemes, although not fully state of the art, have been refined to the point of acceptable confidence levels. Trintopec then, continues to maintain its pioneering status in thermal recovery in Trinidad and Tobago.

## DISCUSSION

For the purpose of clarity, the growth of thermal recovery over the past twenty-five years of interest (1966 - 1991) and the bases for its further applications, the development will be viewed in the several phases as indicated hereafter.

## HISTORICAL HIGHLIGHTS

Thermal recovery was initiated in Trintopec's operations in 1966 with a small cyclic pilot project in the Palo Seco field. Comprising a single 5.8 MM BTU/day steam generator, with an output of 1000 bspd, and four wells, the results were so encouraging as to stimulate an unprecedented growth in this recovery mechanism, with the result that six (6) major steamfloods are currently in force in the Company's operations, in all its major fields.

### (a) PALO SECO

The pilot scheme was started in 1966 with a 5.8 MM Btu/hr generator supplying three (3) wells. In 1970, a 25 MM Btu/hr generator was installed to further increase the steam output with consequent increases in net production. Continuous steamflooding began in May 1975 with two (2) inverted seven spot patterns increasing to four (4) patterns by June 1976. At present there are thirty-one (31) active patterns with fifty-three (53) injectors and one hundred and thirty-five (135) offtakes spread over an area of about 250 acres. The total volume of steam injected under continuous injection up to 1991 was approximately 45.8 MM bbls which yielded a cumulative oil production of 18.15 MM STB. Production from the scheme averages about 2500 bopd with water cut of about 72%.

### (b) GUAPO

Guapo was the second field in which steam injection was implemented following the successful pilot in Palo Seco. Cyclic steam injection began in 1969 with commencement of continuous injection in 1976 with four (4) patterns. At present, there are fifteen (15) active patterns extending over an area of about 1000 acres, with the cumulative steam injected being 30.02 MM bbls with cumulative production yield of 9.42 MM STB of oil. Average production rate is approximately 1500 bopd.

### (c) CENTRAL LOS BAJOS

Cyclic steam injection began in 1974 while continuous injection commenced in 1977. However, several operational problems forced the curtailment of injection of steam injection in the area until 1981. Today, there are seventeen (17) patterns covering an area of about 110 acres. Cumulative steam injected up to December 1986 was 16.83 MM bbls and cumulative production was 8.24 MM STB of oil. Average production rate is 1700 bopd.

### (d) FYZABAD

Cyclic steam injection started in North Fyzabad in 1978 and the continuous injection phase began early in 1979 with four (4) patterns in the Forest Horizon. Two (2) patterns in the Cruse horizon were also started towards the end of 1979. Today there are ten (10) Forest and seven (7) Cruse patterns covering an area of about 100 acres with cumulative steam injection volume of 12.91 MM bbls and cumulative oil produced being 4.71 MM STB of oil. The average production is 600 bopd.

### (e) APEX QUARRY/COORA/QUARRY

Continuous injection started in January 1981 with four (4) patterns. Today there are twenty-nine (29) patterns encompassing a total area of 171 acres. Cumulative steam injected is 34.28 MM bbls with a corresponding cumulative production of 5.48 MM STB of oil. The average production rate is 1500 bopd.

### (f) BENNETT VILLAGE

Continuous injection began in 1985 and there are presently seven (7) active patterns. Today there are six (6) patterns traversing a total area of 150 acres. Cumulative steam injected is 4.91 MM bbls with a cumulative oil production of 2.40 MM bbls.

## CURRENT CONDITIONS

In light of the current economic climate, it is even more incumbent that all operations be optimised in the thermal recovery schemes. The experiences garnered over the past twenty (20) years have provided a basis for innovations, refinement, monitoring and implementation, in existing and projected thermal recovery schemes. To this end, a standard format of design, implementation and operation of all projects is in force.

### (a) Design

Although the implication of design is as applied to new schemes, the methods developed over the years are also applicable to existing floods. The design phase, in principle, is constrained by the following stepwise procedure :

(i) Geological definition and demarcation - Improvement of Geological mapping achieved over the period under consideration is to such a degree as to instill a higher level of accuracy in the selection and optimal placement of flood patterns. Reserves and recoveries are thereby also more accurately predicted.

(ii) Identification of rock and fluid properties. In general, unfortunately, PVT analyses, mineralogical identification and definition, in-situ measurements of rock and fluid properties and full-hole core data are at a premium. Albeit, these properties are gleaned from the existing tools and information currently available, viz., log data, sidewall cores, correlations and, where available, from the preceding techniques.

(iii) Performance Prediction - With the advent of upgraded computer facilities, most reservoir modelling is achieved through the facility of software developed in-house at Trintopec, with the available models being :

(1) Boberg - Lantz (for cyclic stimulation)

(2) Mandl - Volek

(3) Neumann

(4) Jones et. al

(5) Gomaa and

(6) Material Balance

(iv) Project Economics - All projects are screened on the basis of economic viability, and software, incorporating all the parameters of allowances, taxes and expenditure is available. In addition, a system whereby project economics are to be evaluated periodically is shortly to be brought in force, under the categories of micro and macro economics. Sensitivity analyses to this end are conducted on the various parameters of oil prices, operating and capital expenditure resulting from operating conditions and pattern configurations.

(b) **Implementation**

The implementation phase of the thermal schemes is undertaken in recognition of the cost savings that may accrue as a result of optimisation of operating conditions. A concerted effort by all personnel, with due adherence to PERT and CPM planning, addresses this condition. Safe practice, optimisation and injection and production characteristics are enforced as a matter of course.

(c) **Operation**

In order to maximise the benefits to be derived from steamflooding, the operation of the scheme needs to be closely monitored. In light of the fact that the Company's thermal operations incorporates six (6) floods, comprising 550 offtakes, twenty-three (23) generators with a combined output of 40000 bspd, and supplying over 125 thermal injectors, it is a fortuitous circumstance that several computer assisted surveillance techniques have been developed.

The following are currently in place :

(i) Daily inspection of injectivity characteristics on all injectors,

(ii) Monthly profiles of injectivity characteristics,

(iii) Fluid maps for contouring and tracking flood performance, viz., isothermal, isopach, isobaric (static and dynamic), iso-salinity, iso-nett and iso-gross rate, iso-water cut and iso-cumulative.

(iv) Surveys (temperature and dummy) to monitor injection profiles.

(v) History matching and forecasting, with a view ultimately to heat scavenging by conversion to waterflood.

## INNOVATIONS

It is inevitable that over a period of twenty-five (25) years, thermal recovery operations would have been beset by a variety of operational problems. The healty state of the steamflood schemes is ample testimony that these difficulties have been faced and solved in the first instance, and circumvented in the further implementation of additional schemes. In addition, with the downturn in the industry, company personnel have had recourse to several innovative techniques, in many instances of a pioneering nature. Several of these are enunciated below :

(i) **Completion Methods**

(a) **Cluster Locations**

In light of declining oil prices, the use of cluster locations, whereby cost savings are derived by centralised location of offtakes and injectors, has been implemented (cf. Bennett Village thermal project).

(b) **Slim-hole injectors**

Tubular and drilling costs have been significantly reduced by use of slim-hole injectors (4½" and 3½" injectors, replacing the conventional 6-5/8" and 7" completions).

(c) **Insulated tubing and packers**

Recovery is a direct function of sand-face steam quality. In an effort to reduce wellbore heat losses, insulated tubing and packers with a variety of combinations has been implemented (cf. Guapo field). The use of insulating gases on the annulus, viz., nitrogen and natural gas, have also been utilised. In addition, tubing completions, sans packer, but with high pressure annular gas, has found favour in some instances.

(d) **Non-gravel packed injectors**

Dissolution of silica at high steam temperatures has been demonstrated in the literature. The dispensation of gravel-packing of steam injectors has been a natural consequence of this research, and, coupled with slim-hole completions, represents further cost savings. Also, the thicker insulating cement sheath associated with slim-hole completions is a further plus.

(e) **High Volume Pumps**

To maintain efficient flood performance, it is imperative that displaced fluids be captured, i.e. wells need to be pumped off. The use of high-volume electrical submersible pumps has been tried with favourable success.

(f) **Limited Entry Perforations**

In order to combat the adverse effects of gravity segregation by steam over-ride, limited entry perforating techniques were carried out with successful results.

(g) **Insulated Casing Completions**

As outlined previously, production performance is functionally dependent on heat losses in the wellbore. Insulated casing was tried in a pilot-scale five spot patterns in the Guapo field. Results indicate that the bottom steam quality is vastly improved and an earlier response is obtained in associated offtakes.

(h) **Furfuryl Alcohol**

The problem of high-water cut offtakes resulting from breakthrough due to gravity over-ride of steam is a pereninal problem. Furfuryl alcohol as a plugging agent has been evaluated, with limited success, in the Palo Seco field.

(i) **Diverting Agents**

In order to circumvent the problem of water breakthrough resulting from high-injectivity, over-riden zones, steam foam/diverting agents have been utilised.

(ii) **Monitoring Aids**

Improved computer oriented surveillance tools have been devised for the purposes of monitoring flood performance and predicting steam breakouts, viz., steam injectivity relationships, and production performance statistics. In addition, the computer models are regularly used for history matching and continual forecasting.

Fluid maps, viz., iso-thermal, iso-baric (static and dynamic), iso-salinity, iso-pack, iso-gross and nett rates, iso-cumulative and iso-water cuts assist in closer monitoring of flood performance.

Further, weekly meetings, reviewing and addressing problems, performance and field projections, among Reservoir Engineering, Petroleum Engineering, Production and Artificial Lift personnel provide up to date and hands on approaches to monitoring.

(iii) **Others**

(i) **Portable Steam Lines**

Handling of conventionally lagged steam lines has proved to be an expensive and time consuming exercise, with deterioration of lagging a perenimal problem. Concentic insulated surface lines have been tried with considerable success, utilizing a portable steam generator allocated to huff and puff evaluation schemes. The types used are as follows :

(i) 2" steam lines with 4" galvanized outer jacket and sodium silicate insulation,

(ii) 2" steam line with 6" galvanized outer jacket and sodium silicate insulation,

(iii) 2" steam line with 4" PVC outer jacket and sodium silicate insulation.

An ongoing cyclic injection programme with portable liner and generator is in force, primarily geared at well-bore stimulation and paraffin and asphaltenic deposition clean-up.

(ii) **Steamflooding Light Oil Reservoirs**

The misconception that steamflooding is limited to heavy oil reservoirs has been recognised. The benefits of steamflooding light oil reservoirs, primarily by the distillation process are to be demonstrated by the institution of a new scheme, viz., Fyzabad Forest 'D' thermal scheme, which came on stream 1991 September.

## CONCLUSIONS

Trintopec has been a pioneer in the field of thermal recovery in Trinidad and Tobago. Twenty-five (25) years of active participation have amply demonstrated the Company's commitment to this recovery mechanism. Development in this area started with a basic field pilot, and although the current techniques are not fully state of the art, the methods currently employed have sound engineering and economic bases. In light, then, of the preponderance of heavy oil reserves in Trintopec's leases, the prospects for the future are encouraging. Despite the fact that the Company's achievements have been occasionally hampered by operational problems, the experiences gained and the techniques developed suggest continued profitable effort in this direction.