MINISTRY OF ENERGY AND ENERGY INDUSTRIES
REPUBLIC OF TRINIDAD AND TOBAGO

GUIDELINES TO OPERATORS FOR THE APPROVAL OF STEAM INJECTION PROJECTS BY THE RESOURCE MANAGEMENT DIVISION

CONTENTS

1. Introduction

This guidance document is a subset of the legal framework governing the approval of a steam injection project by the Resource Management Division of the Ministry of Energy and Energy Industries (MEEI).

Steam injection is a type of thermal Enhanced Oil Recovery (EOR) method. It can be implemented to boost oil production in Trinidad and Tobago's mature fields and is commonly used for heavy oil deposits worldwide. It is therefore important that the MEEI plays its part in assisting and encouraging operators to carry out steam injection projects. In saying this, it is imperative that the MEEI be kept abreast with the actions of the operators to ensure that the projects are successful and beneficial to all parties.

2. Objectives

Before granting approval for a steam injection project, the MEEI must be provided with relevant documentation to demonstrate that the operator has:

i. a suitable rationale for the steam injection project
ii. the required facilities and infrastructure,
iii. technical knowledge
iv. financial support
v. adequate environmental protection considerations in place.

3. Authority

These Guidelines are established pursuant to the authority prescribed in the Petroleum Act Chapter 62:01 of 1969 and in the Petroleum Regulations 1970 and specifically with reference to Clause 43 (h) of the Act, which states: "*the licensee shall exert his utmost efforts to develop any discovered fields to the maximum extent consistent with good petroleum industry practice and in particular observe sound technical and engineering principles regulating the conservation of the deposits of hydrocarbons, in preventing damage to adjoining petroleum bearing strata, in controlling the flow, in preventing the escape or waste of petroleum discovered, in preventing the entrance of fluids through wells into petroleum bearing strata except in* ***approved fluid injection operations*** *and in protecting water bearing strata encountered in the course of drilling;".*

4. Applicability

Thermal recovery processes depend on the use of thermal energy, in some form, to increase the reservoir temperature, reduce the oil viscosity, thermally expand and distil steam in order to displace the oil to a producing well. Steam injection is the most common type of thermal EOR. Thermal recovery methods are usually implemented in:

a. Shallow reservoirs i.e. depth < 3000 ft.
b. Loosely consolidated formation
c. Oil with a gravity from 10 – 20 degrees API
d. Reservoirs with a Net sand thickness 50 – 100 feet
e. Reservoirs with Oil In Place > 600 stb/acre-feet[1]

Steam injection has two (2) distinct categories:

i. Cyclic steam stimulation (CSS) or "Huff and Puff" is a "single well" method and is usually the first stage in the development of a steam injection project. It involves injecting a slug size of steam into the reservoir for several weeks at the highest practical safe injection rate, in order to minimize heat losses. The well then goes through a "soak" phase where it is shut in for several days to allow uniform heat distribution. Afterwards, the well is placed back onto production until it reaches the economic limit and then the entire cycle is repeated.

ii. Steamflooding (continuous steam injection) is a multi-well, pattern driven process where steam is injected in a manner to displace the oil towards the producing wells. The hot water that condenses from the steam and the steam itself generate an artificial drive that sweeps oil toward producing wells. In addition to the previously mentioned factors, another factor that enhances oil production during steam injection is related to near-wellbore clean-up. The injection rate is an important factor as a high injection rate can cause early steam breakthrough while a low rate would lead to excessive heat losses.

Thermal recovery methods can be complicated, due to heat losses, and the potential damage that can be done to infrastructure because of the high temperatures involved. Improper practices in the past while conducting steam injection in Trinidad has led to major setbacks. These practices include but are not limited to: improper grades of casing and cement, gravel packing steam injectors and lack of insulation [2].

This guidance document applies to any steam injection process that is described above.

5. Guidelines to Operators on the Approval Process for Steam Injection Projects by the Resource Management Division

There are two (2) phases of guidelines which are to be followed: Pre-Approval Phase and Post Approval Phase.

[1] Sinanan, *B. UTT PTRE 524G Course Notes 2010*
[2] Ramkhalawan, C.D., Khan. J. and Bainey K.R (1995), "*Thirty years of Steamflooding: Reservoir Management and Operation Exercises"*, SPE 30772, 739-746

Pre- Approval Phase

1) Company/operator who is interested in conducting steam injection should present a steam injection project presentation in a meeting to MEEI officials. Subsequently, company/operators should officially submit a steam injection study proposal to:

   Mrs. Penelope Bradshaw-Niles
   Permanent Secretary
   Ministry of Energy and Energy Industries,
   Level 26 Tower C,
   Port of Spain International Waterfront Centre,
   #1 Wrightson Road,
   Port of Spain.

   in the form of two (2) hard copies and one (1) soft copy. This study proposal should be submitted at least three (3) months prior to desired project approval date. During this period, a project site visit is required.

2) The steam injection study proposal should include but is not limited to:

   Project Background and Description

   - Project scope, project phases and objectives.
   - State the anticipated oil production increase and incremental recovery by well from reservoir simulation studies done or by the use of analogs.
   - State type of injection pattern for example line drive, 5-spot, inverted 5-spot, etc as applicable.
   - List active and inactive wells in the steam injection project.
   - Identify and map reservoirs targeted for steam injection, showing the area/field of the proposed steam injection project.
   - State sands/reservoirs/formation for steam injection study and state reason for choosing these.

   Reservoir Description

   - Provide geologic and stratigraphic description of reservoir. Describe the drive mechanisms present in the project area, for example, water drive, solution drive, gravity drainage etc.

- Provide a well correlation of the target sands over the project area. Include digital LAS files for correlated wells.
- Show georeferenced net pay, net sand and structure maps of the formation of interest with project boundaries, faults, lease or licence boundaries highlighted.
  A static model project in Petrel, CMG or other similar format if available may be supplied in addition to the maps above.
- Supply any dynamic simulation (numerical) software model of the area of interest (Petrel RE, CMG, MBAL etc) or analytical calculations in spreadsheet format.
- Show a georeferenced base/surface map for the project area highlighting the location of proposed:
  - conversion injectors
  - new drill injectors
  - existing producers
  - new drill producers
  - observation wells.
- Give reservoir parameters and fluid properties of the project study area. (i.e porosity, permeability, saturations, bulk rock volume, current bottomhole pressure, Original Oil In Place (OOIP), Gas to Oil ratio (GOR), mobility ratio, API gravity, specific gravity etc.). Identify for each parameter/property its source as well as the date it was measured or calculated.
- Explain how the reservoir parameters and fluid properties will affect the performance of the thermal recovery method. Describe any mathematical models utilised to obtain performance estimates and discuss the results. For example, Marx-Langenheim, Myhill-Stegemeier,Jones models etc.
- Provide historical production/injection data and cumulative production/injection. Provide written narrative on production/injection history.
- State expected recovery efficiency.

Steam Injection and Water Production Parameters/Criteria

- Identify the water source for steam injection.
- State volume of steam required to carry out steam injection and state whether company/operator has adequate supply of water to carry out steam injection. State also, volume of water required per day to carry out steam injection activities. State how the volume of steam and production rates would be determined.
- State the range of qualities, rates, pressures and temperatures of the steam being injected.
- Provide detailed justifications for the maximum steam temperature to avoid excessive thermal stresses in the well.

- State the maximum depth to which the steam would be injected.
- State well spacing and depth of all wells being used in the steam injection project.
- Provide a listing of producer well names, injector well names and observation well names.
- Provide complete wellbore diagrams for all injector and producer wells.
- State what parameters would be recorded from observation wells (if any).
- Provide coordinates of all injectors, producers and observation wells under the steam injection study. For onshore wells these should be in Naparima 1955 datum and for offshore wells these should be in WGS1984 datum.
- Provide Injectivity test results if available.
- State voidage of target area and fill up time and show calculation inputs and processes.
- State the amount of water production from the field both historically as well as a forecasted value for the project.
- State what would be done with the produced water and how the company operator intends to dispose of it.
- Show that the steam generator feedwater is compatible with the formation water. The operator/company shall inform MEEI of plans for treatment in any instance where the produced water to be injected is sourced from a different formation. State how the compatibility of steam injection with the reservoir was determined. Show what compatibility tests would be carried out, as well as the steam compatibility test results.
- The company/operator should monitor and record the injection pressure, injection depth and fracture pressure for each injection well which should be provided to MEEI.
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Surface Equipment

- Show schematic of surface equipment for example: steam generators, water treatment equipment, well pads, well heads, drilling/workover rigs, rod pumps, injection pumps, compressors, pressure gauges, valves, water supply trucks, water supply tanks, battery tanks, gathering stations, insulated pipelines, roads, fencing, and workman sheds.
- Show a process diagram of the steam generator(s) in use in the project describing the flow from feedwater pump through to convection and radiant section then to steam output. Describe how the steam quality and total dissolved solids are adjusted.
- Discuss how corrosion problems due to low steam quality will be mitigated, for example, chemical injection.

- State condition of all surface equipment/materials being used in the injector and producer wells.
- Ensure that all storage tanks are up to international standard.
- Provide the range of operational parameters for steam generator(s):
    - Minimum and maximum flow rate in barrels per day cold water equivalent (bpd CWE),
    - Minimum and maximum operating pressure (in psig),
    - heat rating in MMBTU/hr.
- Provide typical maximum pressure at wellhead (in psig) and justification for the same.

Drilling and Production Considerations

- State procedures involved in wellbore integrity testing and state integrity of wells being used in the steam injection. Ensure that all injectors, producers and observation wells being used are in proper workable conditions.
- Show that the tubing, packer and casing completion configuration reduces heat losses in the wellbore to avoid damaging the well. This can be achieved through tubing insulation where practical for instance. From early experiences with steam injection, casing failure was common due to unavailability of thermally suitable grades of casing and cement. Casing programmes have now been standardized and thermally cemented for both injectors and producers.
- Drilling infill wells, ensure that the casing and cementing should be designed to withstand the high temperature and pressure of the steam injection, as well as prevent fluid leakage and gas migration. The casing and cementing should also be protected from corrosion and scaling by using appropriate materials, coatings, inhibitors, and additives.
- Infill wells should be located in areas with high oil saturation, low steam saturation, and favourable reservoir quality. The well spacing should be designed to avoid interference with existing wells and optimize the steam-oil ratio.
- The wellbore should be designed to withstand the thermal and mechanical stresses induced by the steam injection. This may include using thermal casing, cement, and tubing materials, installing thermal packers and anchors, and applying proper drilling and completion fluids
- Additionally, the wellbore should be protected from steam breakthrough and corrosion by using various techniques such as steam injection control devices, inflow control devices, chemical inhibitors, and mechanical barriers.
- Show historical and planned workover work and status of wells involved in the steam injection project. The operator/company should implement an inspection and maintenance program to ensure the internal and external integrity of all injection wells. This programme should include, but not be limited to, ensuring the absence

of leakage in the casing, tubing or packer of the injection wells. These records of such inspections and maintenance should be made available to MEEI upon request. Refer to the '***Disposal and Injection Well Technical Guidance***' document.

- State intervals in wells that should be abandoned in accordance with Ministry of Energy and Energy Industries '***Procedures for the Plugging and Abandonment of Oil and Gas Wells***' if any, to isolate sands under study from others to prevent any cross-flow of fluids if applicable.
- Except where changes may be deliberate for operational reasons, if the company/operator observes any significant changes in the relationship between injection pressure and injection flow rate, immediate measures should be taken to correct the problem and the company/operator should inform MEEI within twenty-four (24) hours of detecting such change. Subsequently, a report should be submitted to MEEI within seven (7) days of detecting significant changes in the relationship between injection pressure and injection flow rate. The report should include:
    - The cause of change in the relationship between the injection pressure and injection flow rate.
    - Measures implemented to correct the problem.
    - A statement of the time taken for the situation to return to normal.
    - A discussion of the environmental impacts likely to result from the change.

Environmental Considerations

- State precautionary measures that will be used to ensure that the fresh water aquifers/water tables are not contaminated by either hydrocarbons or saline water. Ensure that there is no pollution to the environment or contamination of the aquifer, rivers, lakes, water wells and earth's surface.
- A georeferenced map showing the location of the surface water sources, aquifer systems and private or Water and Sewerage Authority (WASA) wells that are located in the specific area/block being considered for steam injection. State the number and depth of WASA water wells in the area/block. State any precautionary measures for dealing with H2S production.
- The company/operator should apply for a Certificate of Environmental Clearance (CEC) from the Environmental Management Authority (EMA). A copy of the Certificate of Environmental Clearance (CEC) should be provided to MEEI. Otherwise, it should be provided after Resource Management approval, which will be conditional upon CEC delivery.
- Give proof that the environment would not be affected in a negative way while undertaking steam injection operations. Ensure that Corporate Social Responsibility is maintained for the environment. Precautionary measures should

be met with relevant supporting documents to ensure that the operation of the proposed steam injection project would be taken in a safe manner with minimal harm to the environment upon approval.

Project Economics and Timelines

- Show project cash flow tables with inputs such as: operating expenditure, capital expenditure, discount rate, oil price assumption, royalties and taxes as well as determinants of profitability like: net present value (NPV), payout and internal rate of return (IRR).
- State peak oil rate, production decline rate and recovery by project and by producer.
- State risked forecasted incremental steam injection production for each block/area being injected into.
- State work activities for the steam injection project and the timeframes for completion & procedures involved in conducting the steam injection project.

Miscellaneous

- Provide any contracts/agreements between licencee and sub-licencee if any.
- Provide any service contracts/agreements between operator and service companies.
- State any concerns/risks and uncertainties that may affect the project.

Post Approval Phase

Steam Injection Data Monitoring

- Submission of production and injection data including PROD4s.

Quarterly Reports (Acceptable format: PDF, Word or PowerPoint Document)

- Highlight any well/equipment integrity/HSE issues.
- Submit pressure data (acoustic fluid level survey) and flow test data from wells in chart and excel format.
- Production, injection profiles for each sand and well in excel format.
- Water quality/steam quality results.
- Briefly explain other major issues faced, works conducted during the quarter.
- Briefly highlight upcoming works, issues for next quarter.

N.B. If there was no activity/injection for the period of review, a submission is still expected as a reporting mechanism to the MEEI.

Annual Report (Acceptable format: PDF, Word or PowerPoint Document)

- Brief background of project - date started, type of flood, number of patterns, other relevant data.
- List number and names of active injector wells.
- List number and names of active producer wells.
- List number and names of active observation wells.
- Structure map of reservoir showing active injectors, producers and observation wells, patterns, project boundary, location relative to other fields.
- Chart of injection and production of fluids from inception to report date for at least ten (10) years, whichever is lesser.
- Provide production and injection narrative for last three (3) years to explain chart.
- Tables with all fluids production and injection for all wells in the project in Excel format to accompany report.
- State figure for recovery under project influence in barrels of oil and as a percentage (%) of OOIP at the end of the reporting period.
- State average production (in bopd) for the reporting period and for the previous reporting period.
- State average injection (in bfpd) for the reporting period and the previous reporting period.
- Show results of any surveillance such as oil density, WOR, BHP, salinity, steam quality, hall plots, bubble plots, pulse tests.
- Highlight major issues, economics and key learnings of the project.
- State and discuss future plans for the project including forward drilling plan, workovers, surveillance, analysis.

N.B. If there was no activity/injection for the period of review, a submission is still expected as a reporting mechanism to the MEEI.

Project Implementation Report

• Implementation report must be based on:
  - o Completion of injectivity test for all wells under study area
  - o Major changes of any proposed producers, injectors and observation wells
  - o Provide a Forward Drilling Plan if new wells are being drilled in the CO2 injection area.
  - o CEC issues
  - o Status and condition of the injection stations and equipment used for the project
- The following must be highlighted:
  - Well/equipment integrity/HSE issues.
  - Well pressure and flow trends in chart and excel format.
  - Water quality/steam quality results.

- Any other major issues faced.

Monitoring Discussions and Site Visits

- Routine site visits and/or meetings with Ministry of Energy and Energy Industries officials as necessary.
- Recommendations should be made throughout the life of the project depending on economic factors, environmental concerns incremental oil etc.

6. References

i. Olsen, D. K. & Sarathi, P.S. (1992). "Practical Aspects of Steam Injection Processes – A Handbook for Independent Operators" retrieved from https://digital.library.unt.edu/ark:/67531/metadc1446569/m2/1/high_res_d/7170963.pdf

ii. Sinanan, B., UTT PTRE 524G, Course Notes (2010)

iii. Ramkhalawan, C.D., Khan. J. and Bainey K.R (1995), "Thirty years of Steamflooding: Reservoir Management and Operation Exercises", SPE 30772, 739-746

7. Queries

Queries on this guidance document can be forwarded to Christian Welsh, Senior Petroleum Engineer (Ag), Resource Management Division of the Ministry of Energy and Energy Industries.

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