

## Miscible CO<sub>2</sub>-EOR Process in an Onshore field ‘T’ – A step towards Reducing Carbon Footprint and Increasing Oil Recovery

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### Keywords

CCUS, Sequestration, Decarbonisation, Lab study, Equation of State, Reservoir Simulation, Enhanced Oil Recovery

### Abstract

As oilfields enter mature stage, it encounters prominent issues such as difficulty in exploiting remaining hydrocarbon, increased water-breakthrough and rapid decline in oil/gas production. How to maximize hydrocarbon recovery from reservoirs producing with high water-cut and improve oil rates is a challenge. Implementation of suitable Enhanced Oil Recovery (EOR) process is one of the major means for achieving higher recoveries. Miscible CO<sub>2</sub>-EOR process emerges as one of the potential EOR methods to improve ultimate recovery of H-5 reservoir of onshore field ‘T’ in Western India.

This paper explores technical feasibility of Miscible CO<sub>2</sub>-EOR process from Laboratory to Simulation for H-5 Reservoir. It discusses results of compositional reservoir simulation study along with CO<sub>2</sub>-sequestration potential. Study indicates that CO<sub>2</sub>-EOR has potential to rejuvenate the matured waterflood reservoir along with reducing the carbon footprint. Study indicates that miscible CO<sub>2</sub> injection has the potential to yield an incremental oil recovery of ~9% over BAU. The study envisages peak oil rate of ~300m<sup>3</sup>/d and peak CO<sub>2</sub> requirement of 6.6LCMD.

Since, this shall be a **CCUS (Carbon Capture, Utilization & Storage) project and 4.27MMt of CO<sub>2</sub> will be sequestered into the target reservoir.** Therefore, this study is a step towards decarbonisation and achieving Net Zero Goals.

### Introduction

The field ‘T’ is one of the oldest producing fields in Western India. It covers a vast area of about 240 Sq. Km. Field comprises of multi-layered clastic reservoirs with several hydrocarbon bearing sands, bottom-most named as H-0. All hydrocarbon

bearing layers are of Mid-Eocene age overlain and underlain by Shale sequence acting as barrier between the layers forming different hydrodynamic systems with different fluid contacts. The field is characterised by good reservoir permeability of 100-500 mD, Dykstra-Parsons Coefficient of 0.9, high reservoir temperature of 125-137 °C and low oil viscosity of 0.2 cP.

Oil production from H-5 reservoir of the field ‘T’ commenced in Aug-1986. Initial reservoir pressure was 293 kg/cm<sup>2</sup> at datum depth of 2866m and current average reservoir pressure is ~ 240 kg/cm<sup>2</sup>. The study area is a saturated reservoir with rich gas cap. Owing to rich gas cap, wells in GCG zone have produced condensate along with gas production. To maintain the reservoir health, Lean Hydrocarbon Gas injection in the GCG zone commenced from January-1997. During initial development phase, pattern water injection started in oil zone in January-1991. Water and Gas injection is already stopped in the reservoir. At present, reservoir is at mature stage of waterflood and producers, mainly in structurally shallower GCG zone, are flowing with high water-cut. Production Performance of H-5 reservoir is given in **Figure-1**.

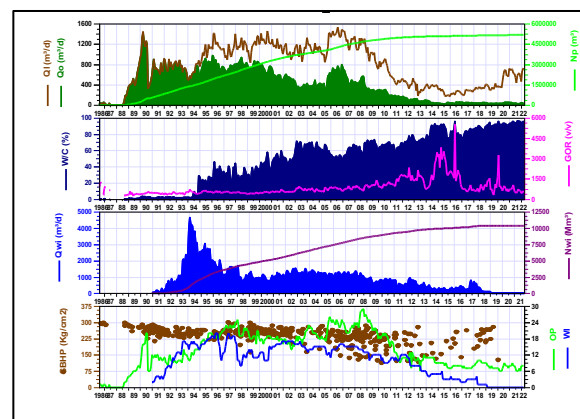
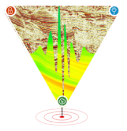


Figure-1: Performance Plot



### Scope of Work

Feasibility study of Miscible CO<sub>2</sub>-EOR process (Lab to Simulation) along with assessment of sequestration potential of H-5 reservoir (Figure-2).

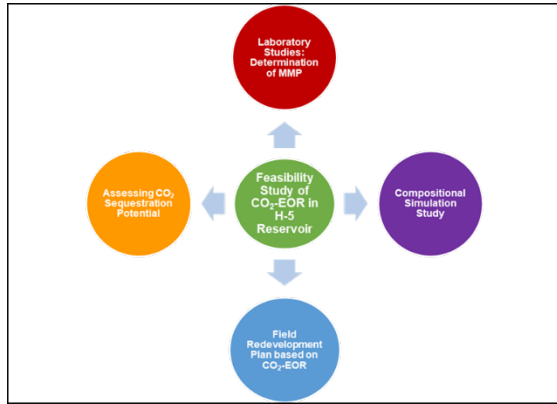


Figure-2: Scope of Work

### CO<sub>2</sub> EOR Technology

Injecting carbon dioxide (CO<sub>2</sub>) into oil reservoirs to enhance oil recovery (EOR) has been commercially used for several decades in the petroleum sector. As the increasing pressure to combat climate change has brought Carbon Capture, Storage and Utilization (CCUS) to the forefront as an emissions mitigation tool, greater attention is being paid to the CO<sub>2</sub>-EOR to support geological CO<sub>2</sub> storage for climate change mitigation. Carbon dioxide displaces oil through a combination of different mechanisms viz. swelling of oil, reduction of its viscosity and miscible effects resulting from extraction of hydrocarbon components up to C<sub>30</sub> from oil. CO<sub>2</sub> is preferred over other gases for gas injection projects due to its tendency to remain in super critical state (P<sub>c</sub>~73 atm & T<sub>c</sub>~31°C) at typical reservoir condition at which CO<sub>2</sub> gas and liquid are indistinguishable (Figure-3). It exhibits higher viscosity & density resulting in a stable displacement front. Secondly, at miscibility condition (dependent on reservoir pressure, temperature & composition of oil), the interfacial tension becomes negligible and there is no oil trapped by capillary forces. When the reservoir pressure is above MMP, miscibility between CO<sub>2</sub> and reservoir oil is achieved with time is classified as multiple-contact or dynamic miscibility (Figure-4).

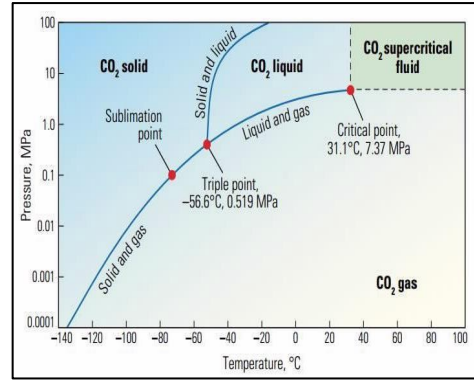


Figure-3: Phase Diagram of CO<sub>2</sub>

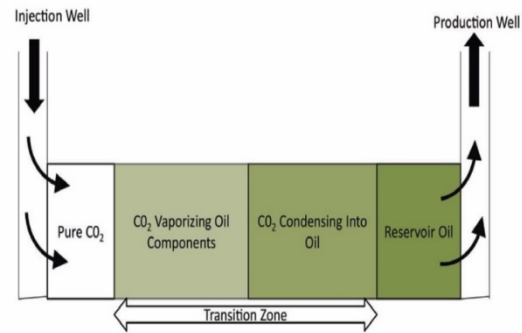


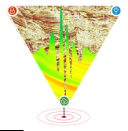
Figure-4: Dynamic Miscibility of CO<sub>2</sub>

### Screening Criteria

Screening of reservoir is first stage before feasibility study of any suitable EOR application. Similarly, for CO<sub>2</sub> EOR process, reservoirs should meet following rock & fluid parameters as given in Table-1. Based on reservoir characteristics, H-5 Reservoir is found suitable for CO<sub>2</sub>-EOR process (Table-2).

Criteria for Screening Reservoirs for CO <sub>2</sub> EOR Suitability	
Depth, ft	< 9,800 & >2,000
Temperature, °F	<250, but not critical
Pressure, psia	>1,200 to 1,500
Permeability, md	>1 to 5
Oil gravity, ° API	> 27 to 30
Viscosity, cp	≤ 10 to 12
Oil Composition	Intermediate fraction rich

Table-1: Screening Criteria



Reservoir Parameters for H-5 Sand	
Depth, ft	9400
Temperature, °F	260
Pressure, psi	3400
Avg. Permeability, mD	220
Oil Gravity, °API	41.6
Oil Viscosity at P <sub>i</sub> , cP	0.13
Intermediate Components	34%

Table-2: H-5 Reservoir Parameters

### Laboratory Studies

#### Slim Tube experiment results of CO<sub>2</sub> for Crude oil of H-5 Reservoir

Technical feasibility of CO<sub>2</sub>-EOR was first ascertained in laboratory by determination of Minimum Miscibility Pressure (MMP) for CO<sub>2</sub> as a solvent using Slim Tube experiment. Current reservoir pressure of H-5 Sand is around 240 kg/cm<sup>2</sup> and initial reservoir pressure was 293 kg/cm<sup>2</sup>. Hence, it was decided to carry-out miscibility experiment at 250 kg/cm<sup>2</sup> and 230 kg/cm<sup>2</sup>.

In Slim tube **Experiment-I**, study was carried out at a pressure of 250 kg/cm<sup>2</sup> and temperature of 128°C. The ultimate displacement efficiency after injection of 1.27 HCPV of gas was 95.7% of OIIP. Non-appearance of any interface between the displacing and displaced fluids till 1.27 HCPV of CO<sub>2</sub> gas injection and high ultimate recovery indicates process is miscible at 250 kg/cm<sup>2</sup>. Increased ratio of gas to oil (GOR) helps in ascertaining the phase separation or gas breakthrough during the slim tube experiments. Plot between PV injected and GOR measured during experiment conducted at 250 kg/cm<sup>2</sup> is given in **Figure-6**.

In Slim tube **Experiment-II**, study was carried-out at a pressure of 230 kg/cm<sup>2</sup> and temperature of 128°C. The ultimate displacement efficiency after injection of 1.18 HCPV of gas was 85.9% of OIIP. Non-appearance of any interface between the displacing and displaced fluids till 1.18 HCPV of CO<sub>2</sub> gas injected and ultimate recovery indicate process is partially miscible at 230 kg/cm<sup>2</sup>. Based on high displacement efficiency, MMP of 250 kg/cm<sup>2</sup> was estimated for H-5 oil (**Figure-5**).

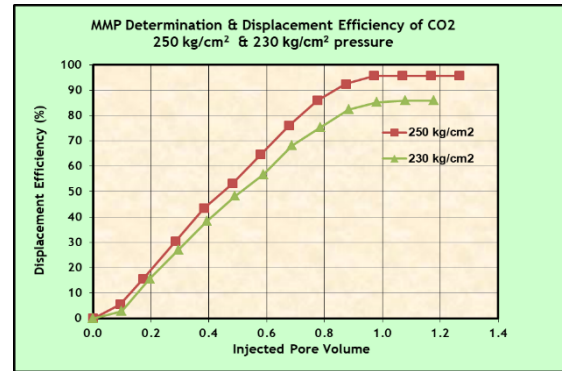


Figure-5: Displacement Efficiency

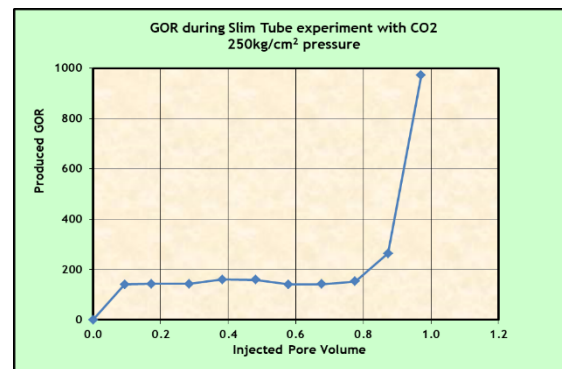


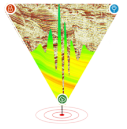
Figure-6: PV injected vs Produced GOR

### Reservoir Simulation

Fine scale static model of 50m x 50m grid with 22 vertical mathematical layers has been used for simulation purpose to capture reservoir heterogeneity.

#### PVT Modeling

Representative equation of state model (EOS) for describing reservoir fluid and its interaction with carbon-dioxide was prepared. Vintage compositional PVT study report of well W-406 falling in the oil zone is available. However, PVT sample was collected in Oct'1998 from well W-406 after significant production from H-5 Sand and at declined reservoir pressure of 260 kg/cm<sup>2</sup>. In absence of any other compositional PVT data, available compositional PVT experimental data of W-406 was matched using WinProp PVT Simulator to tune the Equation of State (EOS). Reservoir fluid was represented by 7 pseudo-components EOS model. After tuning EOS, representative initial fluid sample for H-5 Sand was prepared by re-combining separator oil and gas composition based on the PVT data of initial well of W-31. Compositional gradient with depth was generated using WinProp and used



in the simulation model. PVT experiment match and generated compositional gradient is given in the **Figure-7**. Model was initialized using OWC at 2926 mMSL and GOC at 2866 mMSL.

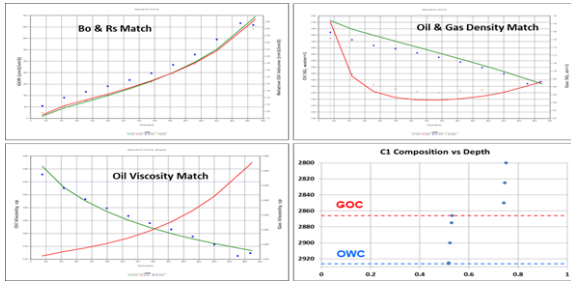


Figure-7: PVT Experiments match and Generation of compositional gradient

History Match & Performance Prediction

Oil rate, pressure, water-cut and gas rate have been considered as history matching parameters. A satisfactory history match has been achieved at reservoir level and for majority of the wells (**Figure-8 & 9**). After history match, STOIP of 8.721 MMt is obtained in the study area.

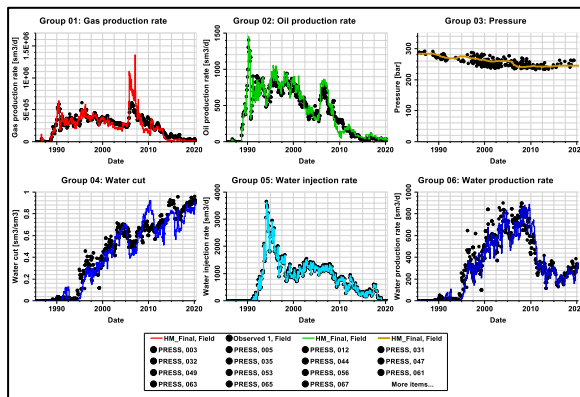


Figure-8: History Match Plot (H-5 Sand)

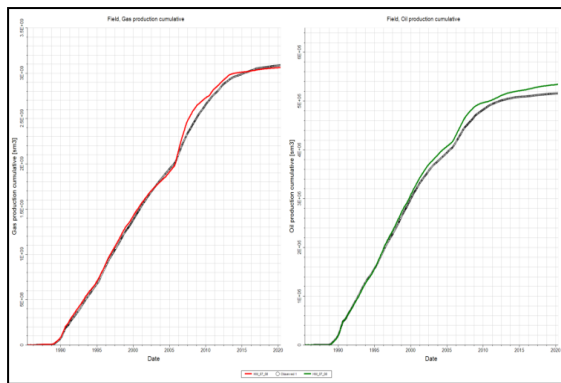


Figure-9: Np & Gp History Match (H-5 Sand)

Number of prediction variants were run to optimize the numbers and sub-surface locations of oil producers and CO<sub>2</sub> injectors. Sensitivities on injection fluid and injection rates were also carried-out. Summary of recommended prediction variant is given below:

- Reservoir Pressure Jacked-up till 275 kg/cm<sup>2</sup> (above MMP) by injecting CO<sub>2</sub> to achieve miscibility
- 25 new locations (14 OP + 11 CO<sub>2</sub> Injectors) as given in Oil Saturation map at the end of history & prediction (**Figures-10 & 11**).
- **Incremental oil gain: 0.772 MMt in 15 Years (Incremental oil recovery 8.9%)**
- Peak oil rate ~300 m<sup>3</sup>/d (**Figure-12**) and Peak CO<sub>2</sub> requirement: 6.6 LCMD
- Net CO<sub>2</sub> utilization: 1.594 bbl of oil / ton of CO<sub>2</sub>
- Sequestration Potential: 4.265 MMt of CO<sub>2</sub> (**Reducing Carbon Footprint**)

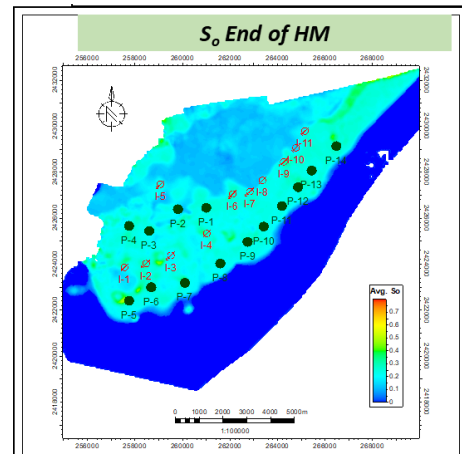


Figure-10: Proposed 25 new locations in Oil Saturation map (End of history)

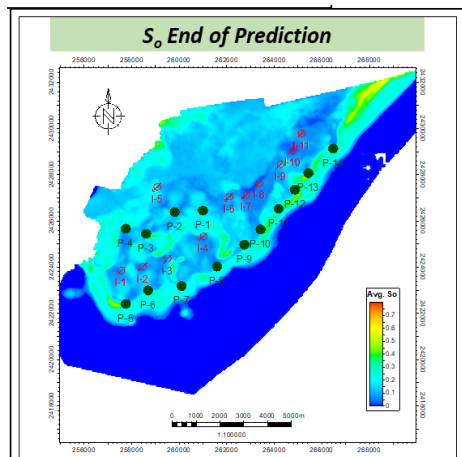


Figure-11: Proposed 25 new locations in Oil Saturation map (End of Prediction)

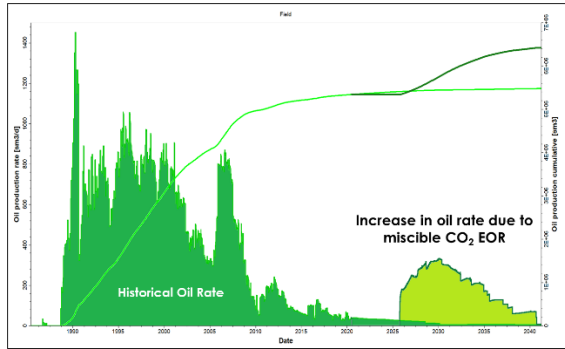
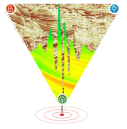


Figure-12: Enhancement in Oil Rate due to miscible CO<sub>2</sub>-EOR

### Conclusion & Way Forward

H-5 Reservoir is at mature stage and producing with very low oil rate and average water-cut of >95 %. Laboratory and Simulation Study indicates Miscible CO<sub>2</sub>-EOR process as effective mode of tertiary recovery along with sequestration of CO<sub>2</sub> for H-5 reservoir.

CO<sub>2</sub> EOR is proven & matured technology for increasing tertiary recovery in matured water flood reservoirs across the world. Significant potential of CO<sub>2</sub> in India exists as a miscible EOR agent, especially in mature water flooded/ strong aquifer driven reservoirs. As the increasing pressure to combat climate change has brought Carbon Capture, Utilization and Storage (CCUS) to the forefront as an emissions mitigation tool, greater attention is being paid to the CO<sub>2</sub>-EOR to support geological CO<sub>2</sub> storage for climate change mitigation. CO<sub>2</sub> Capture and transportation technology is cost intensive, needs huge upfront capital infusion. Therefore, synergy and collaboration amongst Industry, Academia and Government is required.

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