

Chapter 2

Ankleshwar Oil Field: A Proposed CO₂ Injection Site

2.1 Introduction

Ankleshwar oil field is one of the main onshore Cenozoic hydrocarbons bearing anticline of deltaic origin known in the Cambay Basin, runs into the Gulf of Cambay in an approximately ENE-WSW direction (Fig. 2.1). The utter jejune in the overall oil scenario in India received a promising impetus when Ankleshwar field was discovered in 1960, has been on production since August 15, 1961, and is at mature stage of exploitation. The Field is being operated by Oil and Natural Gas Corporation of India Pvt. Ltd. (ONGC). Initially, the field was with meagre oil production of 100 cubic meter per day (Sm^3/day), which rose with the further development and reached $\sim 5800 \text{ Sm}^3/\text{day}$ by April, 1966. Till date, it has produced $\sim 49\%$ of the oil in place reserves under natural aquifer drive and massive peripheral water flooding for about 50 years. Still, a significant amount of unswept pockets of oil is left in this reservoir, providing an ample scope for tertiary recovery operation. As of 2011, the field was producing at an oil rate of $391 \text{ Sm}^3/\text{day}$ with an average water cut of 88 %, which was found to be uneconomical to operate (ONGC Pvt. Ltd., personal communication). In this perspective, a CO₂ EOR and sequestration pilot study has been projected by the operator, targeting the most productive sand layers of Ankleshwar formation.

In this chapter, we will describe the geology, reservoir structure, production history, and previous study carried out for feasible CO₂-EOR and sequestration at the proposed field.

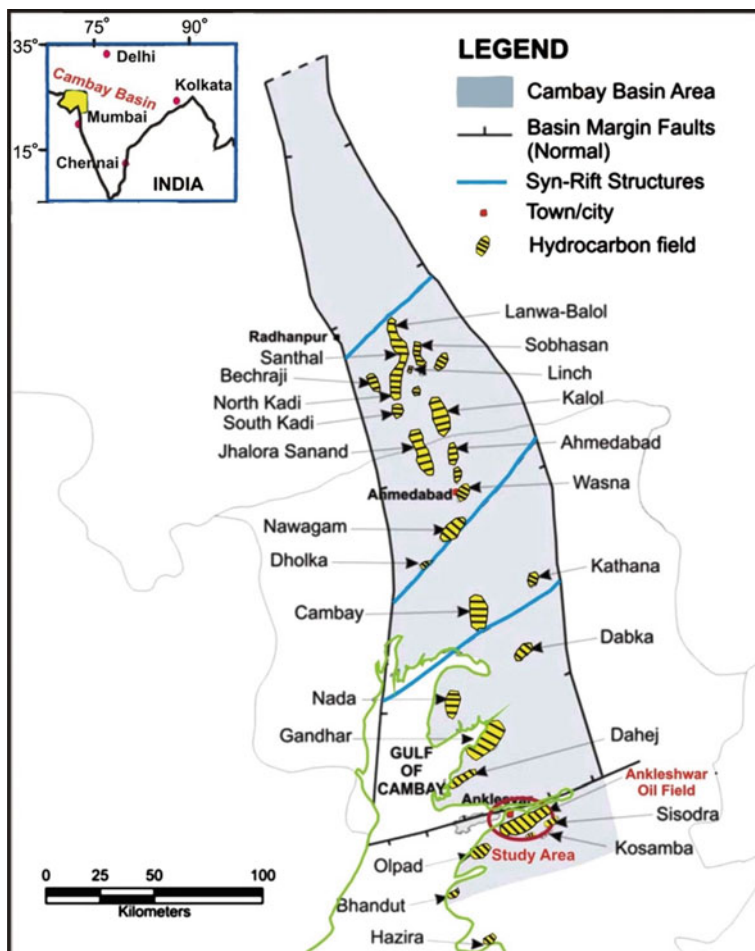


Fig. 2.1 The location map of the Ankleshwar oil field, with other major hydrocarbon bearing fields/structures in Cambay Basin, Western India. The red ellipse represents the field under study

2.2 Tectonics and Geologic Setting

The geotectonics and sediment deposition have played pivotal role in the evolution of Ankleshwar oil field along with other hydrocarbon bearing fields in Cambay Basin. Cambay Basin is a pericratonic rift graben situated in western India, came into existence during the late Mesozoic era with the development of major tensional faults along pre-existing basement (Biswas et al. 1993; Raju and Srinivasan 1993). It is believed that the regional tectonic is an overprint of the lithospheric thinning due to thermal expansion and the subsequent rift propagation took place along the pre-existing tectonic elements. The rift initiation took place around 65 Ma,

concomitant with the colossal Deccan volcanism, and is characterized by basin bounding extensional fault (listric/normal fault) aiding the initial basin subsidence with the upliftment of basin margin or rift shoulders (Biswas et al. 1993). Southern part of the basin is broad as compared to the northern part where the basin width is narrowed down, indicates possible diminishment of rift propagation (Fig. 2.1). The structural evolution of Cambay Basin can be categorised in three major parts: Syn-rift, Post-rift and Late post-rift thermal subsidence phase (Raju and Srinivasan 1993). Based on the transverse fault system, the entire basin can be divided into five tectonic blocks such as Sanchor-Patan, Ahmedabad-Mehsana, Tarapur, Broach and Narmada block. Ankleshwar oil field is located in the Narmada block and believed to be largely affected by the rifting event took place during late Cretaceous.

The study area, Ankleshwar oil field, is situated in the southern part of Cambay Basin, covering an area of 32 sq. km (Fig. 2.1). The geological section of this oil field encompasses thick sedimentary column of tertiary age (Eocene to Pliocene), deposited over the Deccan traps (Mukherjee 1981). The Deccan traps are composed of mostly labradorite and augite. The drilled thickness of the traps in this oil field was reported to be 320 m (ONGC report 2010). The entire area supposed to have subsided during late Paleocene, resulting in deposition of monotonous Cambay shale, which is composed of grey shales in thin alternations with silty and carbonaceous shales, considered as the main source rock. Subsequent to subsidence, several sand reservoirs developed in the progradational and retrogradational sequence of deposition during Upper to mid Eocene period. These Eocene sandstones are permeable and porous intervals with different level of cementation that affects their porosity and permeability. Further, these Eocene sedimentary rocks in this field can be broadly divided into Lower, Middle and Upper groups, depending upon the lithologic properties. The Lower Eocene deposits are the oldest sedimentary rocks drilled in this oil field, contains shales with separate clay sandstones. While, Middle group includes 262–316 m thick most productive deposits, with alternating shales and poorly cemented quartz sandstones, composed of fine to medium sized sand grains. This group is inferred to have been deposited mostly along the distributary channels and allied environments of lower deltaic complex. The Upper Eocene sediments are 82–203 m thick represented by sandstones, siltstones, and shales with numerous fauna (ONGC report 2010).

The individual oil bearing sand layers were designated in most of the case and were numbered progressively from top to bottom in each case. In total, 11 sand groups (S1–S11 bottom upwards) has been identified, constituting the pay zones, where S1–S5 represents the Middle sand group and S6–S11 represent the Upper sand group. Amongst all, S3 and S4 sand groups of fine to medium grained is the most productive, and essential target for CO₂-EOR. The main oil pools, confined to Middle and Upper sand groups, were discovered during the early exploratory drills in the formation. Thick shale interbedded with trapwacke, trap conglomerate and thin coal layers were also deposited above the trap (Srivastava et al. 2015).

2.3 Stratigraphy

The stratigraphy of Ankleshwar oil field consists of Paleocene to Pleistocene strata of marine and non-marine origin, overlying Deccan traps of Mesozoic-Cenozoic era. The post-trappean sedimentary sequence with boundaries of the time units of this basin has been classified into several rock stratigraphic units, illustrated in Fig. 2.2. The detail stratigraphic features resulted from the study of 478 core cuts are briefly described below.

Non-conformably overlying the Deccan traps is Olpad formation, a Paleocene sequence of exclusively traps derived non-marine sediments consisting of dark claystones and splintery shales (ONGC report 2010). It is barren and has varying thickness between 18–123 m. Also, it is separated from the overlying Cambay Shale group by an erosional unconformity.

The Cambay Shale group is conformable and 220–470 m thick, composed of monotonous grey shales in thin alterations with silty and carbonaceous shales, occasionally sideritic.

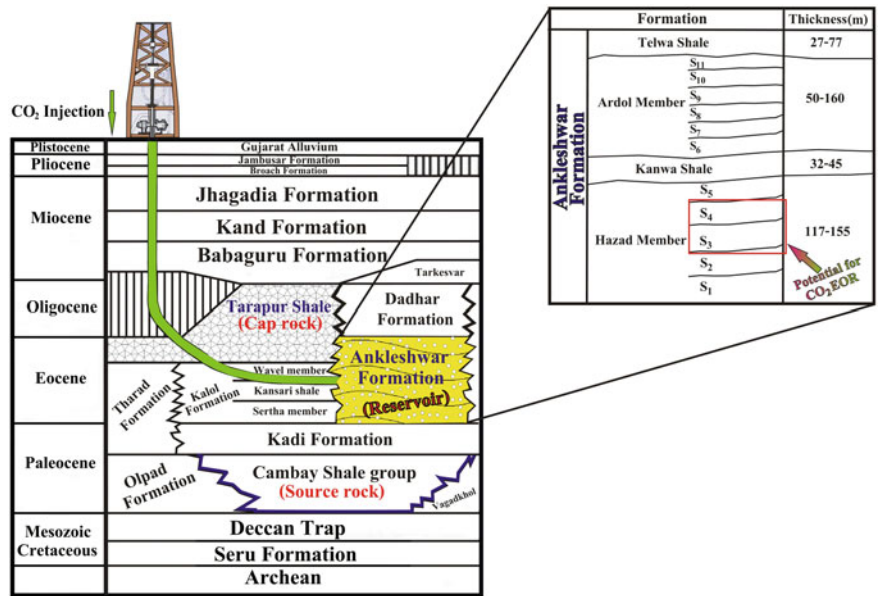


Fig. 2.2 Schematic distribution of the Litho-Stratigraphy of the study area. CO₂ injection is proposed into the Ankleshwar formation; particularly within S3+4 pay sands, the most productive layer. The trajectory of the possible injection well is shown within Ankleshwar formation

The Ankleshwar formation of Middle to Upper Eocene is the main stratigraphic unit in terms of hydrocarbon potential. It overlies the Cambay Shale group, comprises of a thick sequence (300–400 m) of prograding deltaic origin sediments. The sand isolith maps for individual horizons of this formation bring out bird-foot lobate type delta depositional model (ONGC report 2010). Marine influence for Middle and Upper sands is also validated by the presence of chloride-calcium type formation waters. This productive group can be further divided into four sub-lithological units: Ardol, Hazad, Telwa, and Kanwa, covering shales and sands. The Hazad unit, forms the major reservoir rock, is essentially sandstone deposited in a prograding deltaic facies. Kanwa shale acts as effective cap rock for this deltaic sequence, indicating a marine transgressive system due to the presence of planktonic foraminifera (Raina et al. 2010). The Upper Eocene Ardol member exhibit fairly good reservoir rock characteristics and accounts for about 15 percentages of volume of accumulated hydrocarbons. The Telwa shale member of late Eocene, devoid of coarser clastics, acts as cap rock for this sand unit.

Conformably overlying the Telwa shale member of Ankleshwar formation is Dadhar formation. It is about 90–145 m thick and encompasses interbedded sandstones, shales and a bioclastic limestone.

Non-conformably overlying Dadhar unit, the Tarkesvar formation comprises of molten red and grey claystones, grey shales and poorly sorted sandstones. This is barren and corresponds to late Oligocene to early Miocene age.

Babaguru formation of Miocene age is composed predominantly of sands with interbedded clays and occasionally shales. The succeeding Kand formation mainly includes grey claystone with local sandstone (sometimes known as kankar), and occasionally clay conglomerates (ONGC report 2010).

The Kand formation is disconformably overlain by Gujarat Alluvium comprising grey, brownish grey and bluish grey silty clays. This stratigraphic unit is of Recent to Sub-Recent age, which is about 15–40 m thick over Ankleshwar oil field.

2.4 Reservoir Structure

The reservoir structure is basically a doubly plunging asymmetric anticlinal fold of ENE-WSW trend, dissected by seven major faults. The long axis of the reservoir is ~ 17 km and the width is ~ 3 km. The North—Western flank has gentle dip of less than 8° whereas South-Eastern flank is steeper with maximum of 18° dip. The North-Eastern limb of the anticline is altered by a normal fault, which is also parallel to the anticlinal strike. It seems that main controlling factors for oil

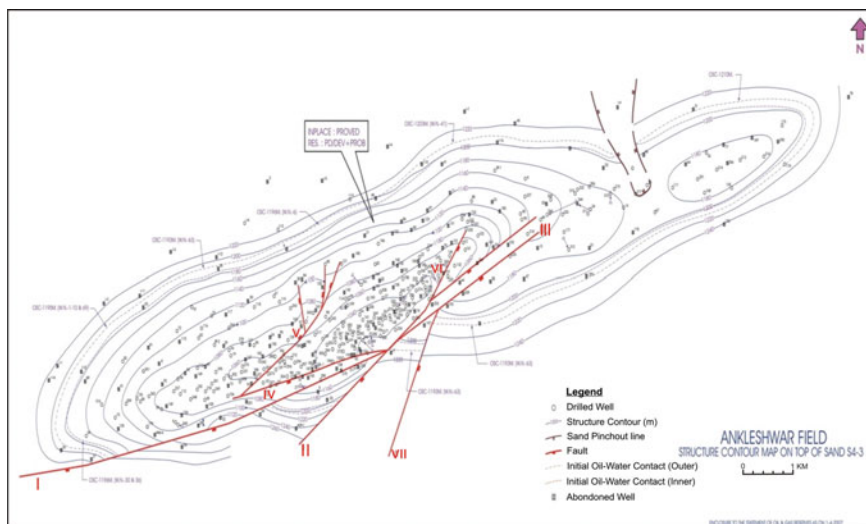


Fig. 2.3 Representation of the structure contour map on the top of sand S4 from the most productive sand layer of Ankleshwar formation. Legend represents the various structural features with well locations and oil-water contacts (ONGC, personal communication)

distribution within the reservoir are due to series of faulting and lateral variations in continuity of the layers and reservoir properties.

The operator has prepared structure contour maps on the reservoir tops of all classified horizons and layers to understand the structural features and its impact on the production scenario of the oil field. Figure 2.3 demonstrates the variable structural features of the main productive sand layer by contour map drawn on the top of sand S4, a part of Middle sand group. We can clearly see the fault system within this reservoir which indicates reverse faults, which have been verified from number of wells. Amongst all, Faults I and II are the key ones which affect almost the entire stratigraphic column. Repetition of horizons at different well locations helped to delineate various faults in this structure. Besides the seven major faults depicted in Fig. 2.3, there are several other faults of small magnitude and extent. Also, the layers are not continuous throughout the reservoir and some layers encountered pinch-outs in between, which pose production challenges.

The limb of the anticlinal reservoir and the most productive sand layers were also noticed in seismic section obtained from this field. The fault closure at levels of pay sand S3+4 and structural high at Hazad formation can be clearly noticeable in the seismic section (Fig. 2.4).

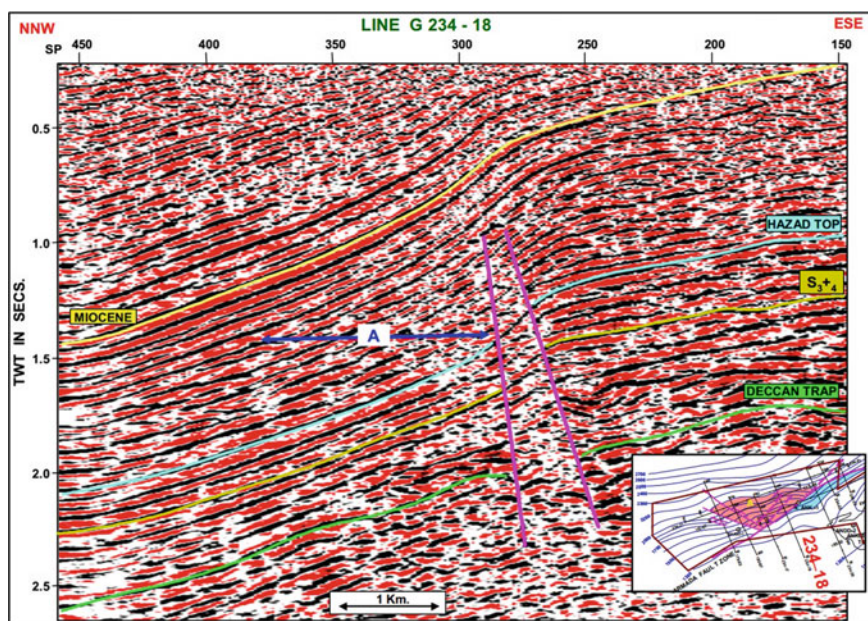


Fig. 2.4 Seismic section across the Ankleshwar oil field with various stratigraphical units (ONGC, personal communication)

2.5 Production Scenario

Ankleshwar oil field has produced cumulatively 65.35 million metric tons (MMt) as on April, 2011 against the estimated oil in place of 134.71 MMt. Average rate of production was 7500 Sm³/day during the year 1967–68, which reached to 7700 Sm³/day in the next year and the peak rate of about 8300 Sm³/day was attained towards the end of 1969 (ONGC, personal communication). Later, during 1973–74, the oil production declined to ~7800 Sm³/day from 8300 Sm³/day due to ceasure of large number of wells and inadequacy in work over facilities accessible at that time. Nevertheless, during early 1975, the oil production increased to 8300 Sm³/day due to drilling of few infill wells. In spite of remedial measures taken from time to time, there has been a decline in oil production from this field since 1977–78, and his uniform deteriorating trend till the year 2000 is summarized in Table 2.1.

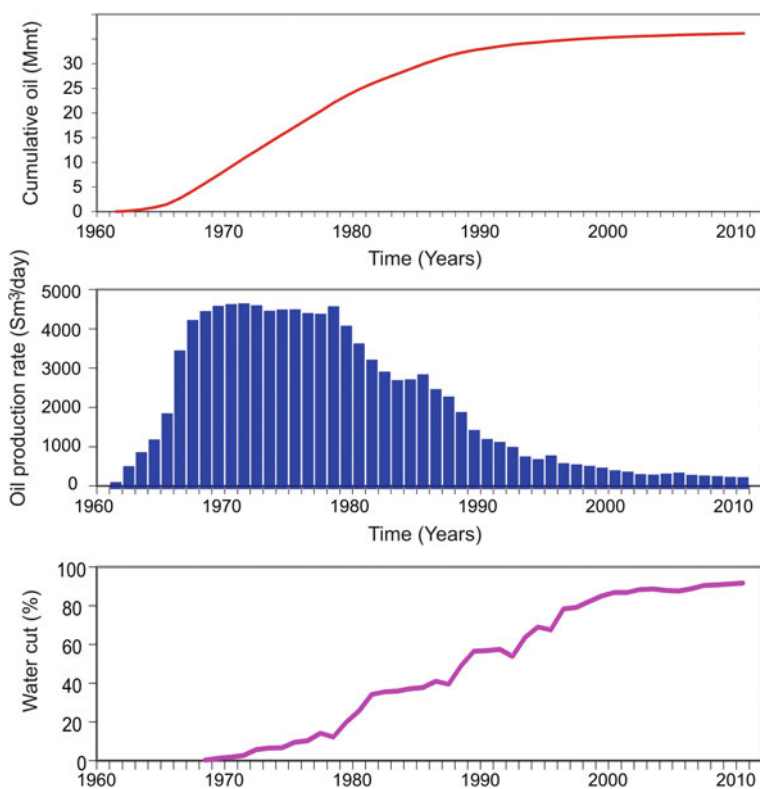
According to the operator, the reason for this kind of production behaviour is due to substantial increase in water cut (due to premature water breakthrough), increase in frequency of ceasing due to water loading, etc.

As we stated earlier, there are in total 11 producing sands of Ankleshwar formation, but pay sand S₃₊₄ is the largest reservoir unit within the Middle productive group. In the view of this, we discuss the production performance of S₃₊₄ sand layer. Sand S₃₊₄, including its six sub-layers (S₃₋₁, S₃₋₂, S₄₋₁, S₄₋₂, S₄₋₃, S₄

Table 2.1 Summary of the oil production (Sm³/day) from the oil field under study during the year 1976–2000 (ONGC report 2010)

Duration (Year)	Oil production (Sm ³ /day)	Duration (year)	Oil production (Sm ³ /day)	Duration (year)	Oil production (Sm ³ /day)
1976–77	8326	1984–85	4364	1992–93	1529
1977–78	7898	1985–86	4256	1993–94	1259
1978–79	7829	1986–87	3636	1994–95	1232
1979–80	6591	1987–88	3226	1995–96	1202
1980–81	6227	1988–89	2659	1996–97	958
1981–82	5448	1989–90	2067	1997–98	918
1982–83	3602	1990–91	1874	1998–99	800
1983–84	4257	1991–92	1759	1999–00	794

–4) produced about 38.8% of the total production from this oil field. This unit has produced in total ~36.3 MMT of oil with an oil rate of 159 Sm³/day, and average water cut was 91.3% as on April, 2011 (Fig. 2.5).

**Fig. 2.5** Representation of the production performance of S3+4, the most productive sand layer of Ankleshwar formation (ONGC report 2010)

2.6 Previous Work

A CO₂-EOR and sequestration pilot project is planned by the operator in Ankleshwar oil field and S3+4 sand unit of Ankleshwar formation was chosen as the target for the appropriate depth range, regional extent, the oil production significance and excellent cap rock. It is proposed that CO₂ will be supplied from the gas processing plant at Hazira, which exhaust CO₂ of about 600,000 m³/d, situated ~70 km away from the injection site.

Preliminary simulation and laboratory studies on representative Berea cylindrical core with oil from Ankleshwar field have been performed to evaluate the potential of CO₂ injection in mobilizing the residual oil within water flooded sand unit of S3 +4 at Institute of Reservoir Studies (IRS), Ahmedabad of ONGC. Experiments using CO₂, N₂, and HC gases at an injection rate of 1 cc/h were verified (IRS, ONGC, personal communication). The core study suggests that injection of CO₂ will lead to 11.8% of incremental oil recovery over water flood, unlike in the case of N₂ and HC gas injection at the same rate, where comparatively low incremental oil recovery is envisaged, which is about 4.8 and 4.0% of HCPV, respectively. In order to choose an optimum CO₂ injection rate, a series of experiments were conducted at different CO₂ flow rates such as 1 and 5 cc/h, respectively (IRS, ONGC, personal communication, Srivastava et al. 2015). Experiments suggest that repeated injection of CO₂ at the rate of 1 cc/h followed by one week closure ensued highest incremental oil recovery over water flood, i.e. 15.71% of HCPV.

However, the simulation study envisaged the most likely, high and low cases of oil recovery possibilities in the next 30–35 years of CO₂ injection, and suggests that at the high, most likely and low case, about 7, 4.5 and 2.3% of incremental oil recovery over the base case is feasible, respectively (Fig. 2.6).

As per the studies carried out by IRS-Ahmedabad, this project would require further 12 new injectors at the crest and 67 producers at the flank of the anticline. It is also envisaged that this project will help in sequestering 7.5 MMt of CO₂ during the entire life span.

2.7 Conclusions

In this chapter, we presented an overview of the Ankleshwar oil field's geology, oil bearing structure, stratigraphy, as well as the production performance and preliminary results from the experiments carried out at IRS-Ahmedabad, the R&D center of ONGC. The results are fairly encouraging to conduct further study in detail to evaluate the prospect of CO₂ injection for EOR and sequestration. Accordingly, we conducted several studies including reservoir simulation and other geophysical techniques such as seismic, rock physics, geomechanics, etc. to understand the CO₂-EOR and sequestration at the proposed site, Ankleshwar oil field, which will be presented in the following chapters.

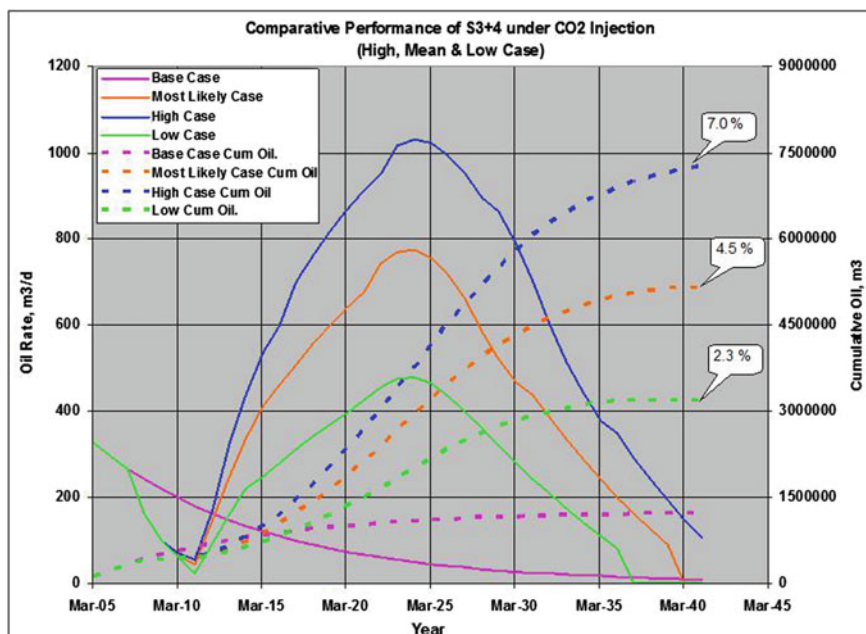


Fig. 2.6 Results from the comparative production performance of S3+4 sand unit under CO₂ injection (ONGC, personal communication). The legend signifies the various possible case scenarios such as base case, most likely, high and low case, respectively

References

- Biswas SK, Bhasin AL, Jokhan Ram (1993) Classification of Indian sedimentary basins in the framework of plate tectonics. In: Biswas, SK, Dave A Garg P, Pandey J, Maithani A, Thomas NJ (eds) Proceedings of the second seminar on petroliferous basins of India, vol 1. pp 1–46
- Mukherjee MK (1981) Evolution of Ankleshwar anticline, Cambay basin, India. *Geologic Notes, AAPG*, pp 336–345
- Oil and Natural Gas Corporation of India (ONGC) (2010) Annual report of Ankleshwar asset for the year 2009–2010 by Sub-surface team. Ankleshwar asset, ONGC
- Raina A, Pande HC, Saxena RK, Singh H, Singh RR (2010) Genetic characterization of shallow hydrocarbon gases by High Resolution Carbon Isotopic Studies: A case study of South Cambay Basin in India. *Petrotech conference, New Delhi, India, PID: 20100353*
- Raju ATR, Srinivasan S (1993) Cambay basin—Petroleum habitat. In: Biswas SK, Dave A, Garg P, Pandey J, Maithani A, Thomas NJ (eds) Proceedings of the second seminar on petroliferous basins of India, vol 2. Indian Petroleum Publishers, pp 33–78
- Srivastava RP, Vedanti N, Akervoll I, Bergmo P, Yerramilli RC, Yerramilli SS, Dimri VP (2015) Study of CO₂ EOR in a sector model from mature oil field, Cambay basin, India. In: Mukherjee S (ed) *Petroleum geosciences: Indian contexts*. Springer International Publishing, pp 87–98

Integrated Reservoir Studies for CO₂-Enhanced Oil
Recovery and Sequestration

Application to an Indian Mature Oil Field

Ganguli, S.S.

2017, XV, 134 p. 77 illus., 74 illus. in color., Hardcover

ISBN: 978-3-319-55842-4