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# Exploitation of a Low Permeability Reservoir in Kalol- Limbodra Area, Cambay Basin, India

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## Abstract

The study area falls in western rising flank of Limbodra Field in eastern part of Kalol Field in the Mehsana-Ahmedabad tectonic block of Cambay Basin. During course of exploration and exploitation of K-VA/K-VIII paysands of Kalol Formation of Eocene age, after drilling of recent well LM#A, a horst like feature has been identified in southern part of Nardipur Low which connects Kalol Field in the west to Limbodra Field in the east. In this well, apart from K-VA pay, K-VIII pay is also well developed which produced oil @ 29$m^3$/d during testing. Similarly in recently drilled development wells LM#B and LM#C, about 10m & 3m of K-VIII pay is developed which also produced oil about 20$m^3$/d each, thus increasing the exploitation potential of this area. Based on the lead, this area was re-mapped and appreciable reserve accretion for K-VIII pay is made.

K-VIII reservoir is under depletion drive with very low production until 2010. With drilling of new wells, oil production increased five folds. From K-VIII pay, only ~3 % of in-place oil has been recovered so far. The large balance reserves & an average productivity of about 7 m3/d/well offer a good scope for further improving the oil production from this field.

The K-VIII reservoir is having relatively low permeability resulting in localized pressure sinks in areas of exploitation and initial / high reservoir pressures in virgin areas. In order to exploit this type of reservoir with poor transmissibility, wells need to be drilled at close spacing with adequate pressure support, thereby improving the well productivity and enhancing the sweep efficiency.

The paper discusses the methodology of exploiting this low permeability reservoir. Based on the updated geological model, a simulation study was carried out to devise a development scheme for this area. The localized pressure sinks in the field were captured in the simulation model by modeling the permeability. Based on ‘permeability-thickness’ calculated for this reservoir and making use of the existing wells & available locations, the well spacing has been optimized to 250-350m. Development scheme has been made with pressure support by water injection in inverted 5-spot pattern considering new & existing wells, available locations and converting marginal oil producers as water injectors. An incremental oil of about 0.86 MMt from K-VIII pay is envisaged by 2030.

## Introduction

Limbodra field (**Fig-1**) is located about 45 km. towards North of Ahmedabad in the Mehsana-Ahmedabad tectonic block of Petroliferous Cambay Basin. Limbodra field is producing oil & gas from Limbodra pay (within Tarapur shale), K-III, K-VIII & K-IX+X of Kalol Formation, Chhatral & Mandhali pays of Younger Cambay Shale and Olpad pays. Limbodra pays, K-III, K-IX+X, Mandhali and Olpad pays are mainly developed in the northern part of Limbodra field. K-VIII is developed in the rising flank of SW part of main Limbodra field. The Chhatral pays of Chhatral member of Kadi formation is spread all over the main Limbodra field. Chhatral pays are the main producer of Limbodra Field.

The study area, K-VIII sand of Limbodra field, falls in the western rising flank of Limbodra Field and to the east of the main Kalol field (**Fig-1**). It encompasses an area of about 9 sq. km. LM-X was the first exploratory well drilled in 1993 on the structural high in eastern part of this area and it encountered oil bearing reservoir facies in K-VIII. Another exploratory well LM-Y drilled on the rising flank of the adjoining low trend, penetrated greater thickness of oil bearing reservoir. Drilling of these two producers established the presence of hydrocarbon in K-VIII sands. Later on, two more wells LM-P and LM-Q, drilled on either side in NE and SW directions were dry and abandoned as they were found to be devoid of reservoir facies and marked the outer limit of the reservoir.

During course of exploration and exploitation of K-VA/K-VIII pay sands of Kalol Formation of Eocene age, after drilling of recent well LM-A, a horst like feature has been identified in southern part of Nardipur Low which connects Kalol Field in the west to Limbodra Field in the east. In this well, apart from K-VA pay sand, K-VIII pay is also well developed which produced oil around $30m^3$/d during initial testing. Similarly in recently drilled development wells LM-B and LM-C, it was found that about 10m & 3m respectively of K-VIII pay is developed. These two wells have also produced oil @ ~$20m^3$/d each and this lead increased the exploitation potential of this area.

A reservoir is said to be tight when its permeability is low. Effective permeability of a reservoir depends on some of the import parameter like effective porosity, viscosity, fluid saturation and the capillary pressure. Besides the factors relating to the fluid nature, the rock parameters are also equally important which are controlled by depositional and post depositional environments of the reservoir. The deep basinal site or the over-bank levees in flood plain areas of deposition are more prone to the deposition of very fine sand to silt and clays, which form poor reservoirs. Post-depositional diagenetic changes also reduce the effective porosity as well as permeability.

The K-VIII reservoir of Limbodra field is currently under exploitation through 19 wells. However till date only ~3% of OIIP has been produced. It is having poor reservoir characteristics with permeability ranging from 4 to 10 md. The gross lithology of this pay is very fine grained sandstone/ siltstone and silty shale with thin carbonaceous laminations which is occasionally sideritic. The high balance of reserves with an average oil productivity of ~$7m^3$/d/well offers a good scope for further improvement of oil production from this reservoir. Hence attempts have made to formulate a suitable development scheme to exploit this poor transmissibility reservoir.

## Geological set-up

Cambay Basin is a narrow elongated intra-cratonic rift Basin in western part of India bounded on its eastern and western margins by master faults (basin margin faults) trending parallel /sub-parallel to the Basin axis and intersected by transfer fault zones. The basin is divided into five tectonic blocks based on major lineament trends. Kalol Formation is the main producer of hydrocarbon in Cambay Basin and it has been further divided into three Members, viz. the lower most Sertha, the middle Kansari Shale and the upper most Wavel Members. The Wavel member comprises K-II to K-V pay sands whereas Sertha member comprises K-VI to K-XI pay sands (**Fig-2**). The trapping mechanism is strati-structural in K-II to K-V and it is stratigraphic in K-VI to K-XI pay. The dominant lithological assemblages of Kalol Formation are siltstone to fine grained sandstone intercalated with shale/ carbonaceous shale and coals. Generally the reservoir characteristics are better in the sands belonging to Wavel Member than the Sertha Member which are relatively poor. The Tarapur shale acts as the regional cap rock for the htdrocarbon accumulation of Kalol formation. Like all other oil producing fields in this region, Cambay Shale has sourced the hydrocarbon for individual reservoirs.

K-VIII pay sand of Limbodra field belongs to Sertha Member of Kalol Formation of Middle to Upper Eocene age and it has been divided to two identifiable sand units i.e. K-VIII (Upper pay) and K-VIII (Lower pay). K-VIII (Upper pay) occurs below K-VIII coal after a thin shale barrier whereas K-VIII (Lower pay) occurs just above K-IX coal, isolated from K-VIII (Upper pay) by a thin shale barrier (**Fig-3**). However sometimes both the units almost merge together and it is difficult to distinguish. In the study area, the main producer is K-VIII (Upper pay). The gross lithology of this pay is fine grained sandstone/ siltstone and silty shale with thin carbonaceous laminations which is occasionally sideritic. K-VIII (Lower pay) is more shaly in comparison to K-VIII (Upper pay). There are coarsening upward and finning upward sequences observed in different stacking patterns. Generally the density is high and hydro-fracturing is a routine job in this area.

## K-VIII Reservoir Facies Distribution

Attempts have been made to understand the facies distribution of K-VIII reservoir by electro-log correlations, sand isolith maps & fence diagram (**Fig-4, 5, 6**). It is observed that the sand unit pinches out towards SW and becomes shaly & pinches out towards N. It also becomes shaly and pinches out towards LM-C in South direction and beyond LM-X in east direction. The best reservoir facies is found to be around wells LM-Y, LM-B, LM-L and follows the path of the channel. As we move away from this channel, the argillaceous content increases at the cost of arenaceous component and fine sand turns into silt / silty shale. In LM-X, it is interesting to observe that the K-VIII coal is absent as it has been cut by a channel. In LM-Y, both the sands (Upper and Lower units) are well developed and both the sands show finning upward sequence log motif which is typical of channel. These sands are stacked channels separated by a thin shale barrier perhaps due to short period marine incursion. From the fence diagram it can be observed that the gross thickness of stacked channels vary from well to well apart from vertico-lateral heterogeneity.

Sand Isolith map indicates that facies is better developed in central, eastern and south-western part of the study area (**Fig-6**). Better reservoir facies and thickness development are observed along the axis of the channel lobes. Three facies maxima viz., central, eastern, south-western have been mapped. It can be inferred that two main channels of transportation of sediments existed during this time and they might have converged in further south-west or south. Sand isolith map suggests that the main entry for the sediments was from the NE.

## Structure

From the Sand Relief map of K-VIII, it can be observed that the study area of Limbodra is dissected by a southeast hading NEE-SWW normal fault in North, a westerly hading N-S normal fault in East, another westerly hading N-S normal fault in West and a minor north hading E-W normal fault in South-west (**Fig-7**). It can be observed that the highest relief area is towards well LM-X in eastern part. The lows exist towards west & south-west direction of the study area. The low trend continues towards Nardipur Low in the west.

## Hydrocarbon Play

The study on distribution of reservoir facies in the depositional model of K-VIII reservoir indicates sediment inputs from NE to SW directions. The reservoir facies distribution has played an important role in the entrapment of hydrocarbons in this area, thus a stratigraphic model of entrapment has been envisaged for this sand.

## Performance

K-VIII reservoir is being exploited under depletion. Most of the wells have been drilled in the central part and a localized pressure sink is observed in this area (**Fig-8**). It is seen that the reservoir characteristics of the sand is generally poor and the wells require hydro fracturing for activation. Recording of initial pressures in wells drilled in new areas suggests low permeability of the sand. Initial reservoir pressure of the sand is 185 Ksc. and the current reservoir pressure is in the range of 50-185 ksc.

## Simulation Model set-up

Simulation studies have been carried out using industry standard 3 D/ 3 Phase Black oil Simulator incorporating all the geological and reservoir properties on a 230 X 120 X 3 grid having 82800 cells with a cell dimension of 50m X 50m.

The porosity in general varies from about 10-20% while the permeability varies from about 4-10 md. The oil saturation varies in general from about 35-70% in the sand. PVT data from LM-Y was used in the study. As not enough well test data / core data was available for permeability, the same were calculated from available drawdown data using Darcy's law. Permeability data was modelled in the simulator by using the Phi-K transform so developed. It helped in capturing the localized pressure sinks in the simulation model.

## Development strategy

As the wells are producing under depletion, the poor transmissibility is leading to a drop in flowing pressure to below bubble point pressures. This is leading to increase in GOR and subsequently low oil recoveries. It is suggested to supplement the reservoir pressure by water injection to increase the oil recovery. However in this low transmissibility reservoir, the efficacy of water injection can be increased by reducing the spacing between the producer and water injector.

As the field is currently producing from only 16 oil producers without any water injection, for maximizing the recovery from the field, a development scheme has been made considering pressure maintenance by water injection in an inverted 5-spot pattern. Based on the 'permeability-thickness' calculated for this reservoir, the optimized well spacing was calculated to be 200m (**Fig-9**). However as a considerable number of wells were already available and considering these existing wells, available locations and 27 additional oil producers & 20 water injectors forming 25 inverted 5-spot patterns, the well spacing was optimized to 250-350m (**Fig-10**). Hydo-fracturing is planned in each well (**Fig-11**). The recommended variant envisages peak water injection rate of around 650 $m^3$/d for the field and it cumulatively produces around 1.5 MMt oil. An incremental oil of about 0.86 MMt is envisaged by 2030. The oil recovery improves from around 11% in the base variant to around 30% in the recommended variant.

## Conclusion

Hydrocarbon is entrapped in the sandstone/ siltstone reservoir facies of K-VIII which is developed in western rising flank of Limbodra Field. Sand Isolith map indicates that facies is better developed in central, eastern and south-western part of the study area. Better reservoir facies and thickness development are observed along the axis of the channel lobes. Three facies maxima viz., central, eastern, south-western have been mapped. It can be inferred that two main channels of transportation of sediments existed during this time and they might have converged in further south-west or south. Sand isolith map suggests that the main entry for the sediments was from the North-east. Hydrocarbon entrapment is stratigraphic. For this low permeability heterogeneous clastic reservoir, development scheme with close well spacing of 250-350m, with pressure maintenance by water injection in inverted 5-spot pattern and hydro fracturing is suggested. With implementation of the scheme, the recovery factor would increase to about 30% of initial in-place of hydrocarbon by 2030.

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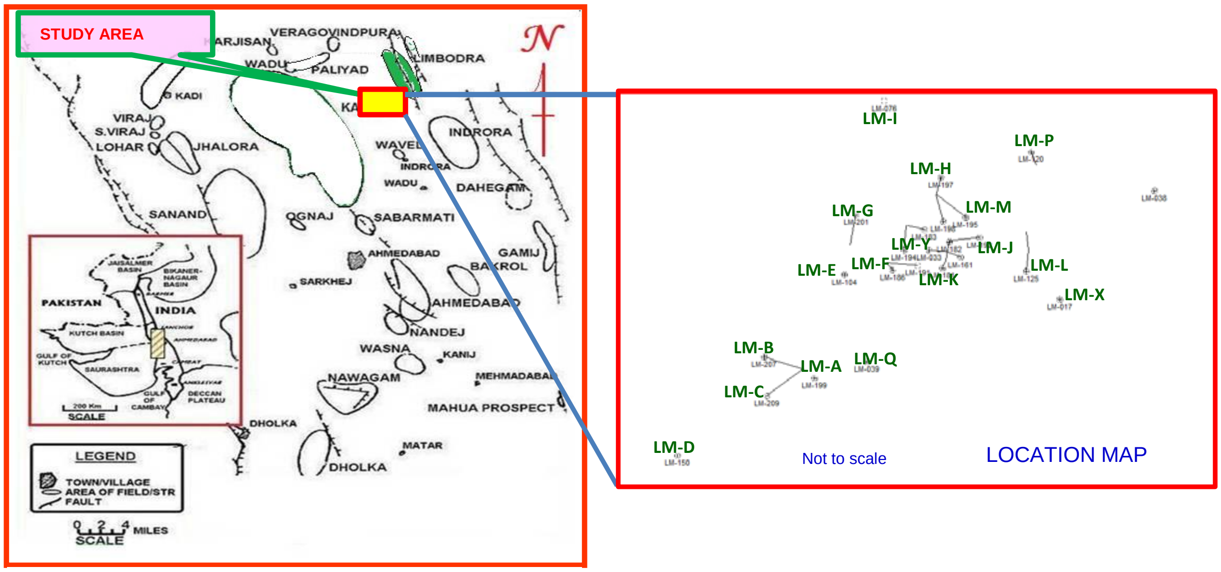


**Fig-1** : Location map of study area

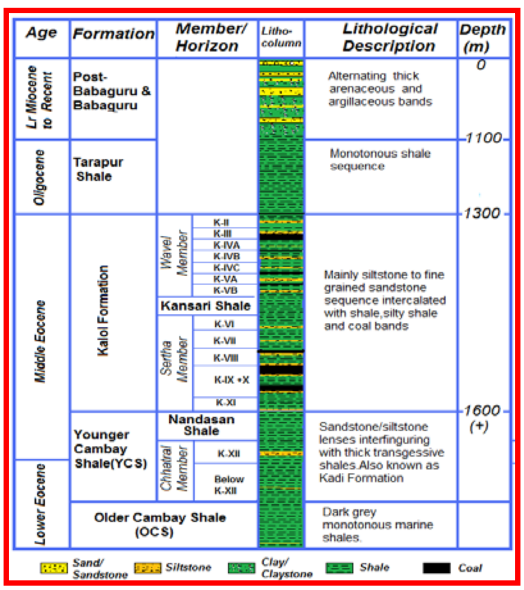


**Fig-.2** : Generalized stratigraphy of Kalol-Limbodra area

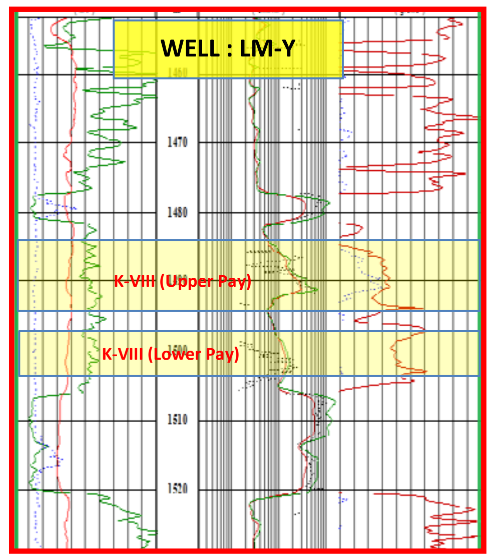


**Fig-3** : Log motif of well LM-Y

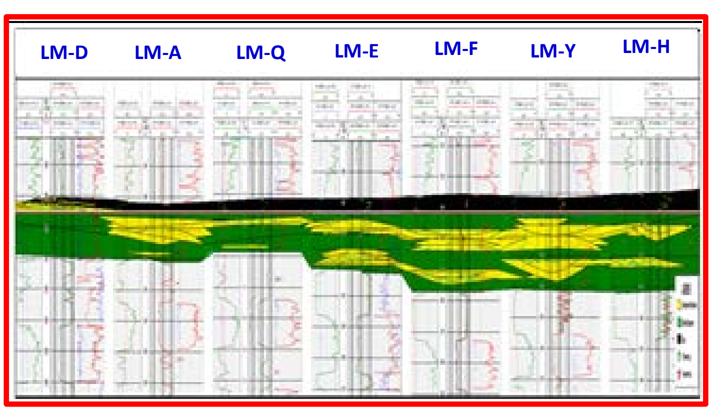


**Fig-4** : Electro-log correlation along SW-NE profile

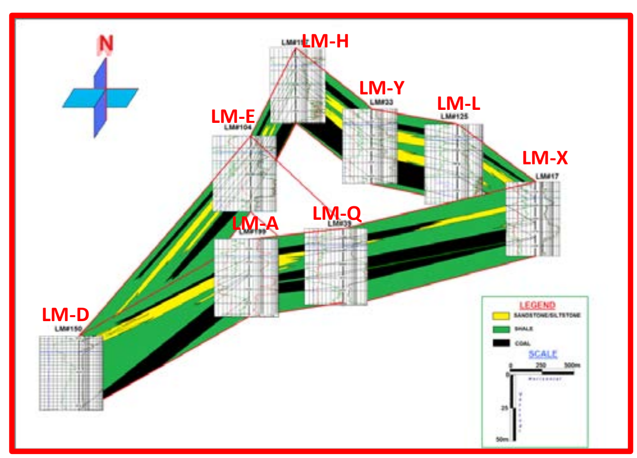


**Fig-5** : Fence diagram showing Vertico-lateral dispersal of K-VIII pay sand in some key wells of the study area.

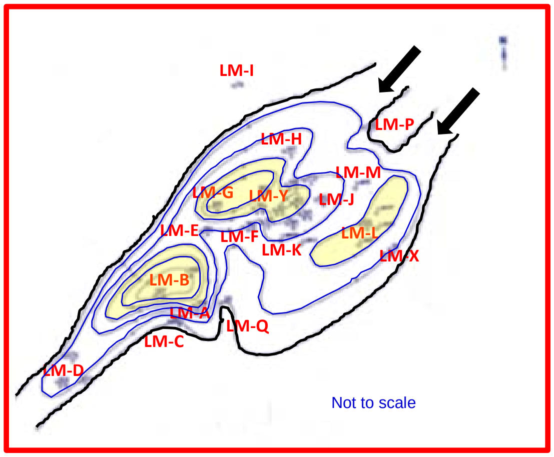


**Fig-6** : Sand isolith map of K-VIII

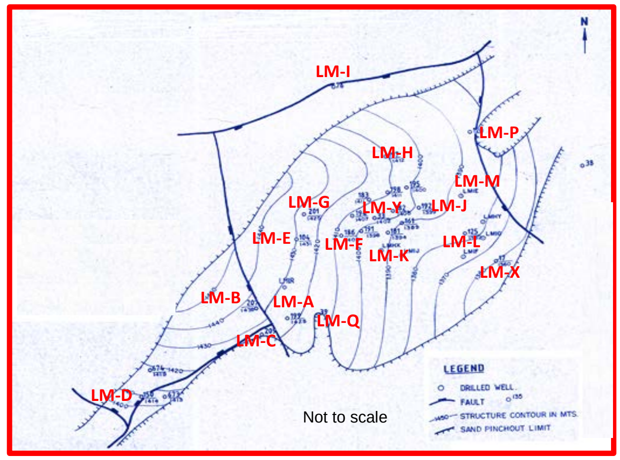


**Fig-7** : Sand relief map on top of K-VIII pay

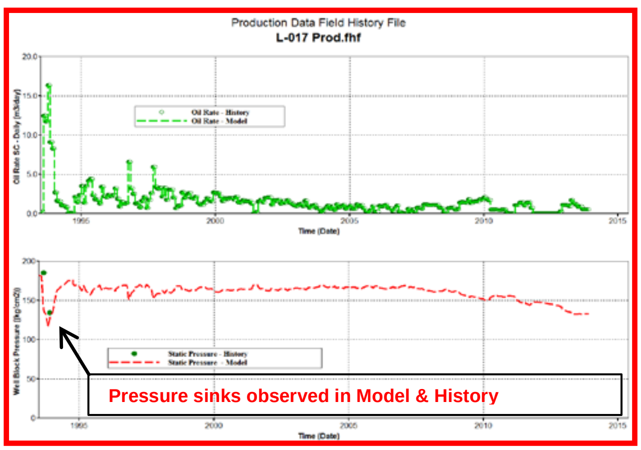


**Fig-8** : Pressure sink near the wellbore (from 185 to ~138 ksc) created in short period of production (3 months, Np-750 m3) indicating poor influx towards the well bore due to low transmissibility

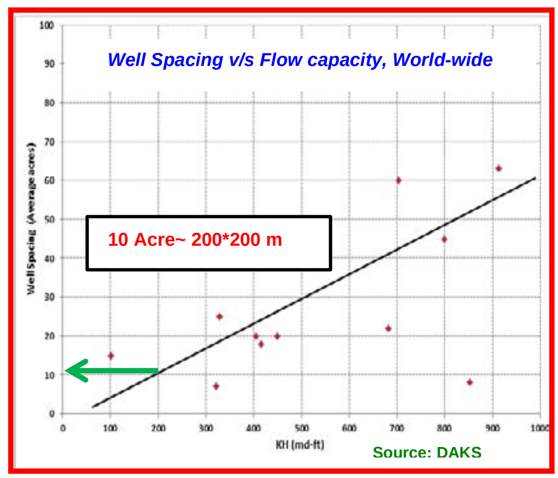


**Fig-9** : Calculation of optimal well spacing

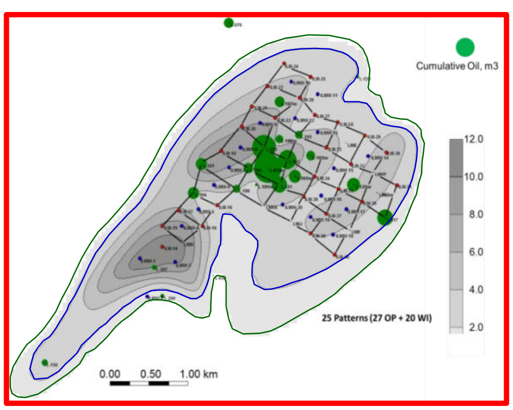


**Fig-10** : Map showing inverted 5-spot pattern scheme on isopay map of K-VIII sand

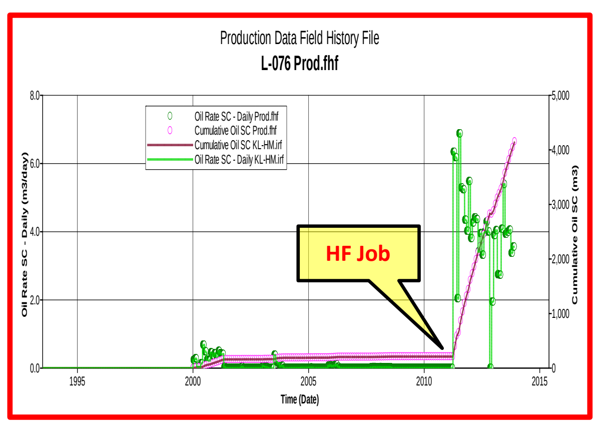


**Fig-11** : Improvement in oil production rate after HF