Saturation Modeling: A quantitative approach for Geocellular model, Sobhasan Complex, Cambay Basin, India.

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Abstract

Saturation Modeling is one of the challenging tasks in Geocellular modelling process of matured reservoir. Unlike porosity, water saturation is a dynamic property which changes with hydrocarbon production of wells. Many literatures show different empirical and scientific efforts to produce robust saturations functions to address petrophysical properties of the rocks and fluid interaction. However, most of the saturation height functions have their own limitations and are reservoir specific. Heterogeneity and anisotropic properties of reservoir play an important role in deriving predictive saturation model.

Sobhasan Complex is a major field with a long hydrocarbon production history from four different reservoir sand units-Kalol, Sobhasan, Below Coal Sand (BCS) and Mandhali and a major challenge for saturation modelling is to arrive at an acceptable figure for initial water saturation. In a large number of wells that were drilled and logged subsequent to the commencement of hydrocarbon production, the observed fluid contacts in new wells have moved with production. Saturation model predicts the initial saturation of reservoir prior to commencement of production

This study presents a simple and convincing saturation modelling approach to address a structurally controlled KS-VI pay of Kalol reservoir. Sw logs of new wells were generated by applying saturation height function predicting initial hydrocarbon saturation in depleted part of reservoir. Synthetic saturation logs were created for old producing wells using model porosity. Finally, Geostastistical Krigging method propagated the Sw values in making a realistic saturation model depicting structural controls and facies variation of KS-VI reservoir. The predictive qualities of the model have been verified by comparing the log derived water saturations with the "back-calculated" water saturations from the model at the well locations. New development areas have been predicted for additional oil and reserve estimation was carried out using saturation model of KS-VI pay of Kalol Member.

Introduction

Saturation Modeling is one of the challenging tasks in Geocellular modelling process. Many literatures show different empirical and scientific efforts to produce robust saturations functions which attempt to address almost all petrophysical properties of the rocks and fluid interaction. Saturation Height (SwH) functions measures the variation of saturation as function of the Height above the Free Water Level (HAFWL). Mapping of water saturation away from the wellbore for Geocellular models is the main purpose of saturation height modeling. Predicted Saturations modelling plays key role in estimation of Inplace reserve.

Sobhasan Complex is a major field in North Cambay Basin and hydrocarbons have been established in four different reservoir sand units-Kalol, Sobhasan, Below Coal Sand (BCS) and Mandhali from top to bottom.

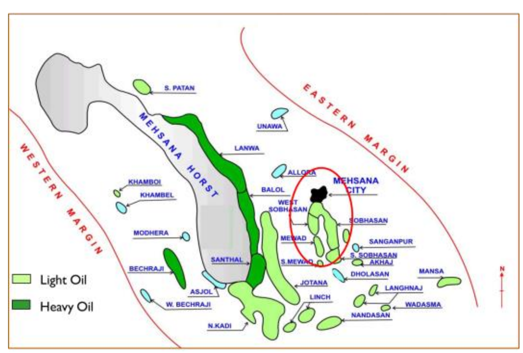


Fig.1 Location map of Sobhasan Complex

Geocellular Model was carried out with an objective of generating static model for Sobhasan complex with detailed study on reservoir characterisation on Kalol, Sobhasan, BCS and Mandhali pay sands. Re-estimation of initial hydrocarbon reserve was also an outcome of this project. Though detailed study was carried out for all the pay sands, Kalol pays were given focus of present study.

Sobhasan Complex is a major field with a long production history and a major challenge was to arrive at an acceptable figure for initial water saturation. In a large number of wells that were drilled and logged subsequent to the commencement of hydrocarbon production, the observed fluid contacts have moved with production of wells. Saturation model predicts the initial saturation of reservoir prior to commencement of production.

Background Theory

Water Saturation (Sw) corresponds to the ratio of water volume to pore volume of a rock sample. The water fraction that cannot be displaced by capillary forces and is normally attached to the matrix of the rock is often named as irreducible water saturation. There are many different approaches for calculating water saturations along the well-bore. The most common, in petrophysics field, is by the well know Archie´s Formula.

Several studies concerning to Saturation-Height Functions (SwH) were developed through the years, which give different methods to compute Sw through SwH modeling. The available literature divides them mostly into two types: those based on capillary curve averaging and those log-based methods.

There are various practical techniques for correlating capillary pressure curves according to rock type for a heterogeneous formation and generating field wide saturation-height function that relates capillary pressure curves to porosity, permeability or rock type in general. The classic method is based on Leverett’s J-function approach. Other commonly used methods include Cuddy et al. and Skelt-Harrison, The next few lines shall describe some of them.

1. Capillary Pressure-based Method (Leverett).

Leverett’s “J-function” attempts to convert all capillary pressure data, as a function of water saturation, to a universal curve:

$$J(Sw) = \frac{Pc}{\sigma cos\theta}\sqrt{\frac{K}{\varphi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The “cos θ” term was added later to adjust for wettablility.Special core analysis (SCAL) measurements of capillary pressure on core samples provide the most reliable means to establish J-functions for rock types with similar pore geometries. Capillary pressure measurements are performed on each core plug and, after conversion to reservoir conditions, are then converted to J values for each sample and plotted against saturation. For a set of samples with similar pore size distributions, a least squares regression analysis is then made using the J values as the independent variable. The best correlation is often obtained using a power law equation of the form:

$$J=a\,(Sw)\,b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The J-function has been widely used as a correlating group for all capillary pressure measurements using different fluid systems, but it only applies if the porous rock types have similar pore size distributions or pore geometry.

Log-based Method (Cuddy et al.

Cuddy et al. postulates that the product of porosity and saturation can be a function of height alone. one observes a self-compensating system between porosity and water saturation, above the transition zone, as porosity increases, so water saturation decreases, and vice versa. Hence, the Bulk Volume Water (BVW), which is the product of porosity and water saturation, is effectively a constant above the transition zone. Cuddy et al. uses log derived water saturation values only to derive the function, choosing to ignore SCAL based capillary pressure measurements. Thus, Cuddy et al. plots BVW vs. height above

FWL on log-log scale and the equation has the form:

$$\text{Log}\,(\varphi * Sw) = A.\log(h) + B \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where h is height above FWL and A and B are constants found by regression.

This technique is virtually independent of permeability and porosity. The method takes no account of lithology and is biased towards fitting the water saturation data in the better quality sands. This may produce incorrect water saturation values within the lower porosity intervals. However, the technique is much simpler and much easier to develop than the other methods. It also requires no porosity banding.

Objective of study

Saturation Modeling is a dynamic process of Geocellular model. A quantitative evaluation of saturation is key to the successful completion of Modeling process. The objective of present study is to apply the established saturation functions available in literatures and develop a simple workflow which can deliver a predictive saturation model for delineating future development areas and estimation of oil initial Inplace (OIIP) of Geocellular

Model in validating production performance of drilled wells.

Methodology

Most of the classical saturation height functions have their own limitations and are reservoir specific. Some of them really work to particular reservoirs where as others fail to deliver the required result based on certain reservoir petrophysical properties. Reservoir heterogeneity and anisotropic properties of reservoir play an important role in deriving predictive saturation model. Hydrocarbon oil dynamics has a lot of effects on saturation height function and structurally controlled reservoir make the saturation modelling process bit easier. Mostly stratigraphic entrapped reservoir needs porosity and permeability data to model quantitatively. However, it is difficult to model where both stratigrphy and structure play role in making the reservoir strati-structurally entrapped.

All those established methods have been attempted to model structurally controlled Kalol Reservoir of Sobhasan Complex. A quantitative approach has been developed by generating Sw logs of old as well as new wells by applying saturation height function. Subsequently, Sw logs are propagated through petrophysical modelling process based on principle of Kriging.The predictive qualities of the model have been verified by comparing the log derived water saturations with the “back-calculated” water saturations from the model at the well locations.

Geostatistical Krigging Method

Kriging is an interpolation method/process which uses variograms as its main input. Kriging is said to be the best linear unbiased estimator. The ultimate aim of most Kriging methods is to limit the difference between the estimated value and the true (unknown) value. The final output of the Kriging algorithm is a series of weights for each of the neighbouring points so that the estimate is essentially a weighted average of the control points.

Saturation Modeling of Kalol Pays of Sobhasan Complex, Cambay Basin

The Kalol Formation of Middle Eocene age lies between Tarapur Shale and upper Tongue of Cambay Shale.Thickness of Kalol Formation varies from 200m to 300m. Major lithological units are Sandstone, Shale, Carbonaceous Shale and Coal. The thickness of sandstone varies from 10m to 50m.The regional structure at the top of Kalol Formation can be described as a north-south trending broad anticline plunging south. The axial part of the structure shows flattening with local culminations and depressions.

Electrolog correlation of Kalol pays indicates six correlatable pay units (KS-I to KS-VI), separated by persistent impervious non-reservoir layers (Shale and Coal). It has also been observed that, the non-reservoir layers within the formation are sufficiently sealing to act as barriers and making the field into various permeable pay units.

KS-VI pay sand is the focus of present study as it accounts for around 75% of the total oil production from Kalol sands and has the longest production history in Kalol sands. Initial Oil in Place wise also, KS-VI tops amongst the six Kalol pay units.

KS-VI sands are medium to coarse grained, moderately sorted, carbonaceous at places and appear to have been deposited by distributary channels. Coal / carbonaceous shales were deposited in the inter distributary swamps and marshy areas (Fig.2)

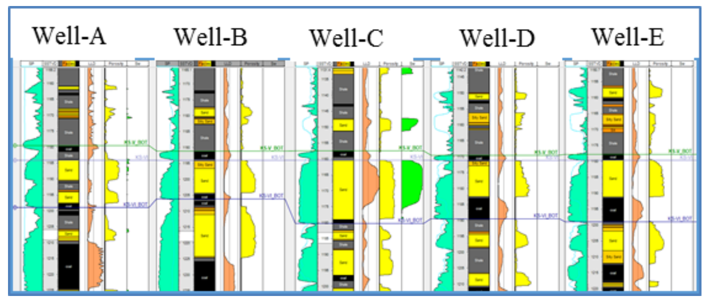


Fig.2 Electrolog Correlation of KS-VI sand

Initially the water cut behavior of KS-VI sand unit showed a gradual increasing trend. Subsequently, high withdrawal rates led to sharp increase of water cut and decline in oil rate.

While making saturation model of KS-VI sand keeping in view of long production history, major challenge was to arrive at an acceptable figure for initial water saturation.

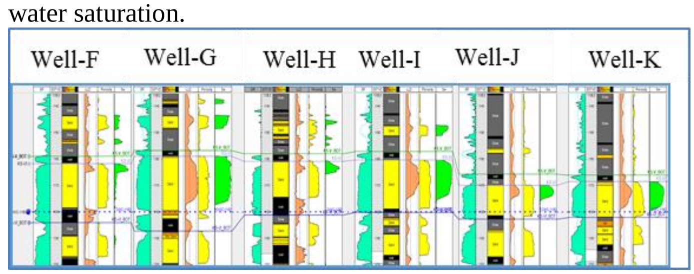


Fig.3 Correlation along KS-VI sand showing rise of OWC

Uneven rise of the aquifer water in different areas is noticed by the OWC values encountered at structurally higher levels at different stages of production. N-S electrolog correlation along KS-VI pay sand clearly show uneven rise of OWC (Fig.3) In absence of adequate core data, capillary pressure data, saturation modelling becomes a challenging task in petrophysical modelling process.

Though there are high density of wells in producing pools, but ELAN processed Sw logs belong to wells drilled in different stage of production and thus non-uniformity in values of saturations. This cannot be modelled directly in Petrel's petrophysical modelling process using geostatistical kriging principle. That is why log derived saturation needs to be back transformed to initial value of Sw using saturation functions. Non-availability of porosity related logs like RHOB, NPHI in old wells which have contributed substantially to oil production need to be modelled as they have initial reservoir hydrocarbon saturation.

The classic method based on Leverett's J-function approach was initially studied for KS-VI sand of Kalol. However, insufficient cores for generating capillary pressure data pertaining to KS-VI reservoir was main limiting factor to draw quantitative result about saturation height function.

Water saturation as function of depth was prepared from ELAN processed log data of wells to get a saturation height function. It clearly shows there is sharp contact at OWC in saturation plot and Sw decreases as height increases from OWC (Fig.4).However, there is much variation in shapes of curve above OWC as porosity factor has not been considered in making saturation function.

Other commonly used log based method of Cuddy et al. was studied in details and found to be best fit for specific structural controlled reservoir of KS-VI sand of Kalol. Due to less lithological heterogeneity and better reservoir properties of porosity and permeability, transition zone is not observed in log motifs of KS-VI sand which is one of the pre-requisite in Cuddy et al method.

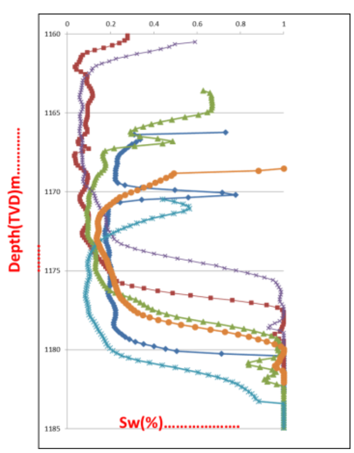


Fig.4 Saturation height function of initial wells of KS-VI sand

Product of porosity and saturation can be a function of height alone. one observes a self-compensating system between porosity and water saturation, above the transition zone, as porosity increases, so water saturation decreases, and vice versa. Hence, the Bulk Volume Water (BVW), which is the product of porosity and water saturation, is effectively a constant above the transition zone. Sw and porosity values pertaining to KS-VI pays were taken from log data and BVW was derived for each log point. Plot was generated between BVW and vertical depth. It has been observed that plot has shown uniformity of BVW curve above OWC. Subsequently, BVW was plotted against height above OWC for KS-VI sand (Fig.5).

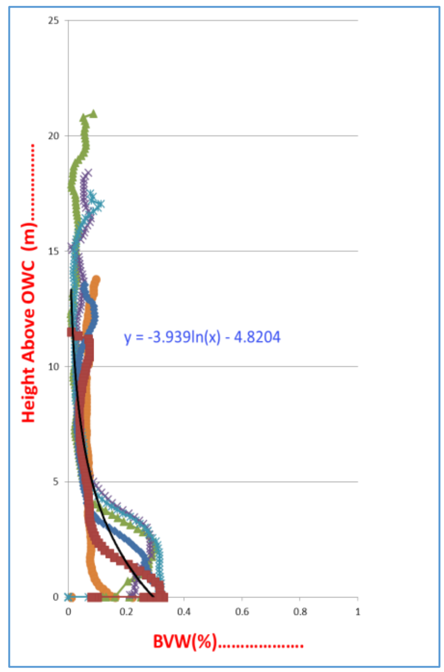


Fig.5 Saturation height function initial wells of KS-VI sand taking depth against BVW(product of porosity & saturation)

It has been observed that there is a good correlation between the bulk volumes of water with the height above the FWL that is independent of porosity. This implies that a Swh function based on the bulk volume of water avoids the problems associated with porosity banding and the variance of the OWC from the FWL.

A function derived from this data can easily be used in hydrocarbon reserve calculation by dividing the bulk volume of water by the mapped porosity:

$$\text{Water Saturation} = \frac{\text{Bulk Water Volume}}{\text{Porosity}} \quad \ldots\ldots\ldots\ (4)$$

Saturation Height Function Y=-3.939ln(X)-4.8204
Where
Y: Height above OWC
X: Product of Sw & Porosity

Using above function, Sw log of wells of KS-VI zone were run to get the new Sw logs. It has been surprised to see the conformity between Sw calculated from Archie's equation and Sw derived from saturation height function (Fig.6).

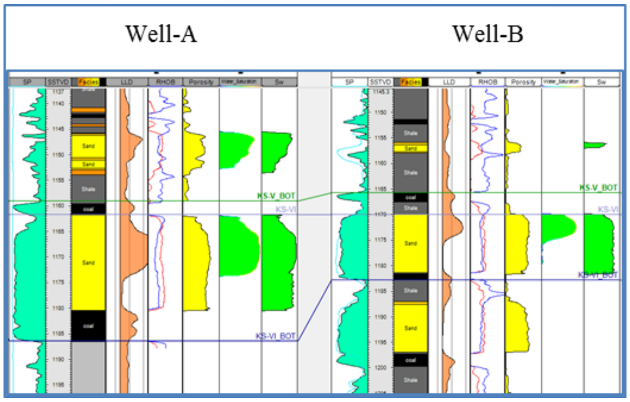


Fig.6 Generation of Sw log using saturation height function of KS-VI zone.

The hydrocarbon depleted part of KS-VI which was not in original processed logs, were generated using the above function. These synthetic Sw logs envisage probable initial condition of reservoir prior to commencement of production.

Krigging Techniques used in saturation modelling in PETREL software gives better modelling result, however number of sampling points need to be higher. Non-availability of porosity related logs like RHOB, NPHI in old wells which have contributed substantially to oil production have also been modelled as they retain initial reservoir hydrocarbon saturation.

As a part of Geocellular modelling of Sobhasan Complex, Facies and Petrophysical modelling were carried out using Petrel software through Geostatistical approach. Proper Variogram designing is very critical in facies modelling process as a Variogram is a quantitative description of the variation in a property as a function of separation distance between points and direction. It brings out spatial relationship of data and pattern by which the facies proportion changes laterally and vertically. All G & G data has been used to build facies model for Kalol Pays.Porosity model was prepared in modelling process by populating porosity logs. As porosity is correlated with Facies, so porosity model is biased with Facies model. Subsequently, model has been validated by making synthetic log from Facies and petrophysical model at well locations which were not included in modeling purposes (Fig.7).

Synthetic porosity logs were generated at well locations of old wells where there was non-availability of porosity logs. Subsequently, derived porosity logs were found to be correlated with existing logs of SP and Resistivity of old wells.

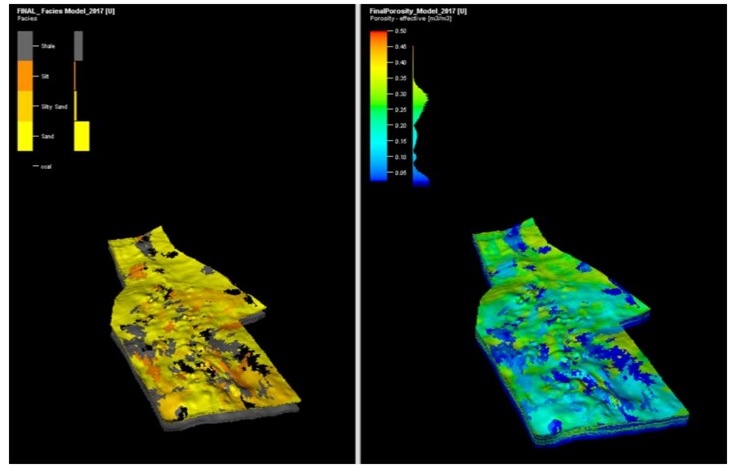


Fig.7 Facies and porosity models of KS-VI sand. Sobhasan Complex.

Subsequently, Sw logs were generated by using saturation height function(Fig.8)

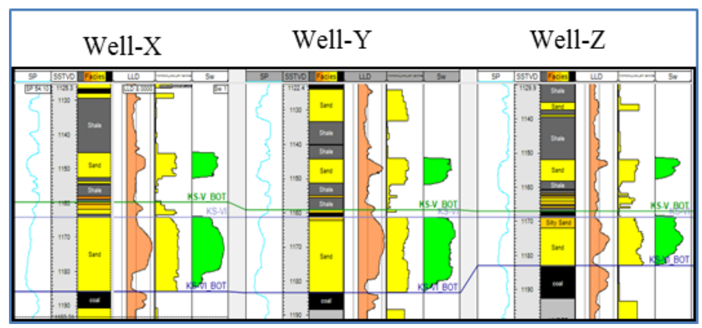
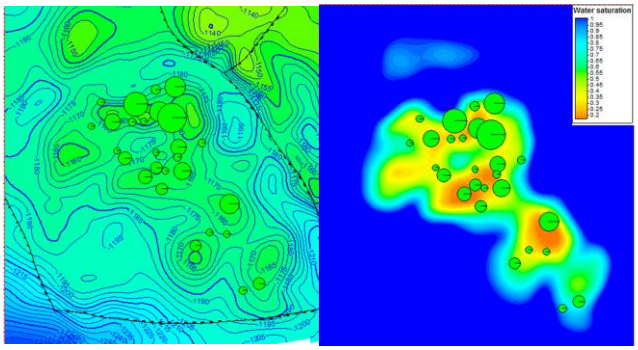


Fig.8 Generation of Sw log in old wells using saturation height function of KS-VI zone.

After quality checks of all Sw logs pertaining to KS-VI zone, saturation modelling process of petrel was run using Krigging Techniques. Sw values are structurally propagated using variogram principle and high density of data point made the modelling process more realistic. Average saturation map of KS-VI zone was generated and well production from KS-VI was superimposed as bubble.

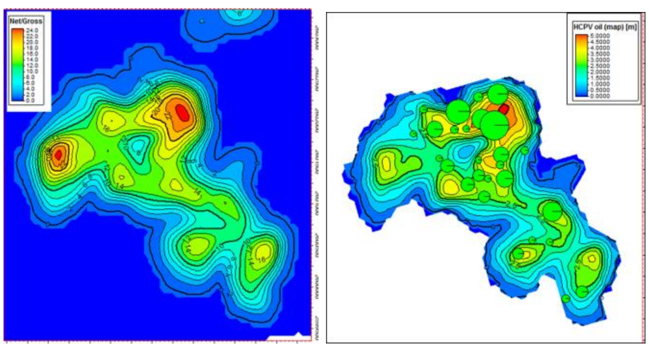
It was observed that saturation value well corroborated with production performance of wells. It is also to be mentioned that saturation map equally corroborating the structural trend depicting structural controls of hydrocarbon accumulation (Fig.9a&9b)



(a) **(b)**

Fig. 9a Structure map on top of KS-VI reservoir 9b. Average saturation map of KS-VI zone superimposed on production bubble map.

Net Pay map was prepared using porosity and water saturation cut off for KS-VI zone and it is matching with production performance of wells. Hydrocarbon pore volume (HCPV) map of KS-VI was generated depicting areas of future development (Fig.10a&10b)



(a) **(b)**

Fig. 10a Net pay map of KS-VI reservoir 10b.HCPV map of KS-VI reservoir depicting oil column of KS-VI reservoir.

By integrating all G & G data with saturation model, new areas have been predicted for development of additional oil from KS-VI reservoir (Fig.11).Reserve estimation was carried out using saturation model of KS-VI pay.

Conclusion & Discussion

Saturation modelling is a challenging task in geocellular modelling process.Geocellular modelling of Sobhasan complex was carried out through structural modelling, facies modelling and petrophysical modelling process using advanced software of PETREL.

This study presents a simple and convincing saturation modelling approach to address a structurally controlled KS-VI pay of Kalol reservoir. Sw logs of new wells were generated by applying saturation height function predicting initial hydrocarbon saturation in depleted part of reservoir. Synthetic saturation logs were created for old producing wells using model porosity. Finally, Geostastistical Krigging method propagated the Sw values in making a realistic saturation model depicting structural controls and facies variation of KS-VI reservoir. The predictive qualities of the model have been verified by comparing the log derived water saturations with the “back-calculated” water saturations from the model at the well locations.

New areas have been predicted for development of additional oil from KS-VI reservoir. Reserve estimation was carried out using saturation model of KS-VI pay.

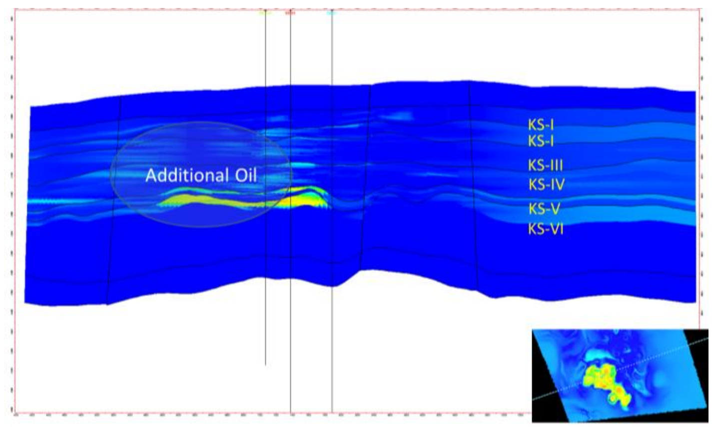


Fig.11 E-W cross sectional view depicting additional oil volume for KS-VI sand.

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References

1. Leverett, M.C.: “Capillary behaviour in porous solids” Petroleum Transactions of AIME 142 (1941) pp 152-169.
2. Cuddy, S., Allinson, G. and Steele, R.: “A simple, convincing model for calculating water saturations in Southern North Sea gas fields”, Paper H, SPWLA 34th Annual Logging Symposium,June 13th – 16th (1993).