Comparative analysis of well Log derived methods for 3D Saturation Modelling based on lithological characteristics of the reservoir: An example from Clastic reservoirs of Upper Assam Shelf region.

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Key-Words: Saturation modelling, BVW, Geo-statistical propagation, depositional environment, hydrocarbon entrapment and distribution.

Abstract

The paper aims to provide a comparative study of different methods of saturation modelling (BVW or Bulk Volume of Water method proposed by Cuddy et al. (1993, 2017), which postulates that the product of porosity and saturation can be a function of height alone and Geo-statistical method using collocated co-krigging) in the absence of SCAL data and their applicability based on the depositional history, entrapment, and hydrocarbon distribution in the reservoir taking examples of fields of Upper Assam North basin. Although well data gives the highest possible resolution of pore fluid distribution vertically, however the areal extent is limited and as a result populating properties such as saturation becomes uncertain. As a result uncertainty creeps into populated saturation volumes owing to non-reliance of saturation with seismic attributes. This has profound effect on the estimated hydrocarbon volumes and in turn the field development schemes. In this paper both the methods were applied in tandem in the reservoirs of deltaic and fluvial origin from Upper Assam Shelf region. Pros and cons of the both the methods were analysed in details. The effects of structural disposition, stratigraphic framework etc. have been catalogued for both the methods. It is observed that BVW method works best in case of structural entrapment while in case of strati-structural entrapment Geo-statistical method provides better results.

Introduction:

Saturation modelling is carried on through multiple methods in a reservoir with integrating height above free water level and reservoir permeability and porosity. Some of the most widely used methods include Leverett method, Johnson method and Skelt-Harrison and Skelt method involve using of Capillary pressure data (Harrison. et al., 2001). Capillary pressure data sets are obtained through different lab methods using core data from the reservoir. Such approaches involve deterministic methods for prediction of water saturation in the reservoir with high degree of precision. However, in the absence of any core based capillary pressure data, the above methodologies may not be applicable. It is usually seen that log based saturation propagation are the only reliable methodologies available. But prediction using log based saturation methodologies involve a lot of uncertainty and each method needs to be analysed based on the depositional history, entrapment, and hydrocarbon distribution. The paper aims to demonstrate the applicability of two such methods namely, BVW method (deterministic propagation) and Geo-statistical propagation using collocated krigging methodology, their efficacy and pros & cons depending on the nature of reservoir. The work is a comparative study for the methodologies involved with examples from fields of Upper Assam Shelf region.

BVW method:

In BVW method, Saturation and porosity logs of wells which depict the initial water saturation (not moved oil saturation) are selected. The product of saturation and porosity at log sample point gives us the Bulk Volume of water in each sample point. The Bulk Volume of water thus obtained is plotted against height of reservoir in log-log scale. A linear equation of the form **log (BVW) = a*log (Hfwl) + b** is obtained (Kumar, 2012). This equation is then used to populate BVW in each cell. The saturation volume is then obtained by dividing the BVW computed in each cell with the corresponding porosity. The method is applicable where there is clean sand throughout the reservoir as in this case saturation is a function of both height and porosity.

Geo-statistical method:

This method involves population of the upscaled saturation logs in the reservoir using SGS algorithm. The first step involves upscaling of the saturation logs for each facies class with porosity biasness. The uspcaled saturation logs of wells are then populated in the reservoir using collocated krigging methodology with porosity as secondary trend. In current work, since a good correlation was obtained between upscaled porosity and saturation data values, variograms used for saturation population was same as that of porosity.

Geological settings:

Field X: The target reservoir facies (Fig. 1) of X field has fluvio-marine to fluvial characteristic of upper delta plain settings (Fig. 2). In the current study the reservoir is showing development of massive sandstone corresponding to cleaner reservoir facies with blocky gamma nature. The reservoir X5 belongs to Lower Barail sands of Barail group deposited during Oligocene period. The X5 reservoir is sandwiched between Barail Coal Shale at the top and Kopili Shale at the Bottom. Previous studies carried out in this field shows development of good porosity sands throughout the study area. Carbonaceous shale overlying the thick X5 sand acts as regional seal arresting vertical as well as lateral migration of hydro-carbon.

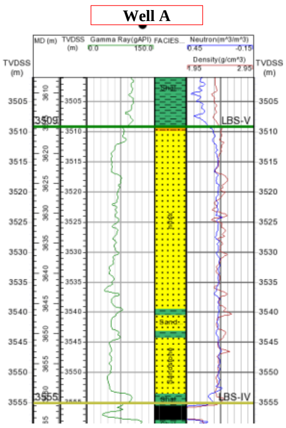

Figure 1: Log motif of reservoir facies of X5 showing blocky sand.

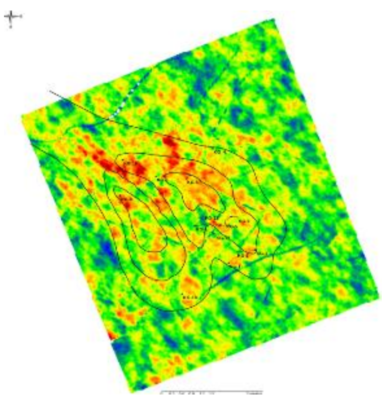

Figure 2: Depositional model of reservoir facies of reservoir X5 showing upper deltaic plain settings.

Field Z: The present study has also been validated taking analogy of nearby fields. In the (Fig. 3), the reservoir facies of field Z is showing development of thick blocky sandstone deposited in nearshore environment. The reservoir belong to Middle Bokabil sands of Surma group of sediments deposited during Miocene. The massive sandstone corresponds to clean reservoir facies with good effective porosity as evident from log signature. The reservoir facies is bounded by Upper Bhuban formation at the top and Barail unconformity in the bottom. Shale developed at the top of blocky sand acts as a seal in this area.

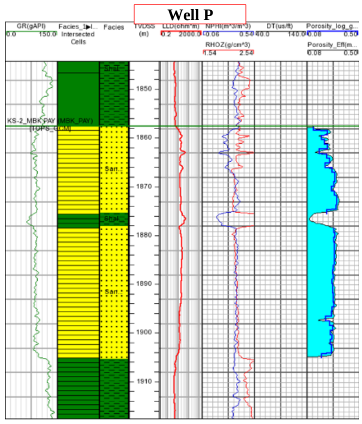

Figure 3: Log motif of reservoir facies of Z5 showing blocky sand

Field Y: The target reservoir facies in field Y are deposited in fluvial braided stream environment. From electro log-motif (Fig. 4), it can be seen that the reservoir predominantly consists of massive sandstone showing fining upward trend. In such cases due to increase in clay content, the sand becomes tighter in nature in the upper part of the reservoir as can be seen in the processed log. The formation belongs to Upper Miocene period. It is bounded by Girujan clay at the top and Barail coal shales at the bottom. Girjuan clay acts as a regional seal in this region.

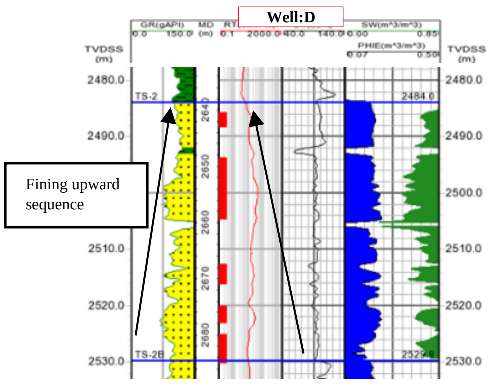

Figure 4: Log motif of reservoir facies of Y5 showing fining upward sequence.

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Results and Discussion:

Saturation was propagated using both BVW and geo-statistical methods. In both cases, blind wells were taken and a comparison has been made based on the results.

For Field X: In case of reservoir X5, 3 wells which depicted the virgin condition of the reservoir were selected. 2 of these wells (A&B) were used for modelling while Well C was kept as blind well to check the results. The relation between BVW and height in log-log scale is shown below:

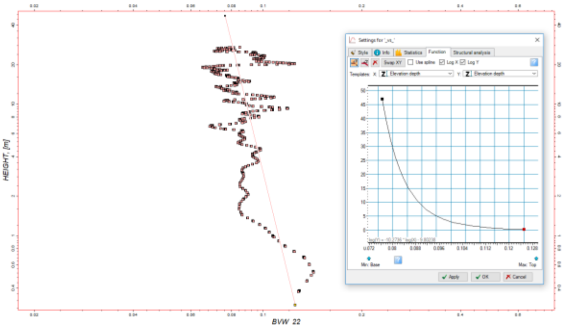

Figure 5: Height vs BVW relationship of reservoir X5 log-log scale. A correlation of 0.60 is there in the relationship.

A good correlation was achieved in BVW vs Height function in log-log scale which was used to generate the empirical constants a and b in the equation **(log(BVW) = a*log (Hfwl) + b).** Using the relation, saturation model was carried out in the reservoir X5.

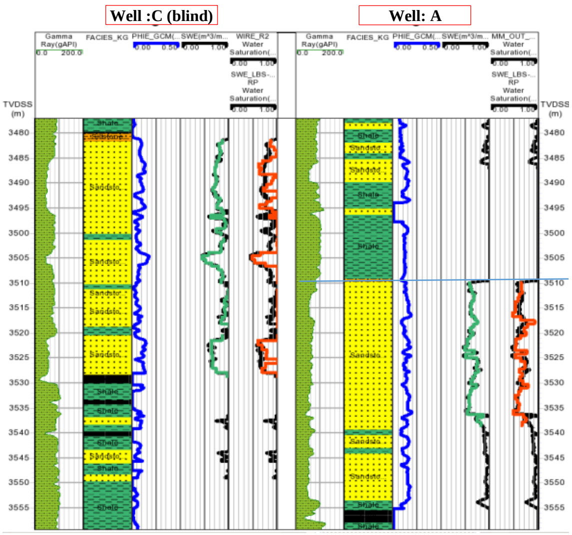

Figure 6: Saturation modelling results in blind well C and modelled well A. **Black colour** line represents the well log. **Dark Green colour** represents the **modelled saturation log using geo-stats method**. **Red colour** line represents the modelled saturation log using **BVW method**.

In case of field X, BVW method had very good results within the reservoir as shown in Fig. 6. In blind well C we can see that as we move away from the contact at structurally higher positions there is a good match in modelled saturation (**Red colour, BVW method)** and actual processed **log saturation (Black colour)**.

For Field Z: In case of reservoir Z5, 3 wells which depicted the virgin condition of the reservoir were selected. Well P was used for modelling while Well Q and R was kept as blind well to check the results. The relation between BVW and height in log-log scale is shown below:

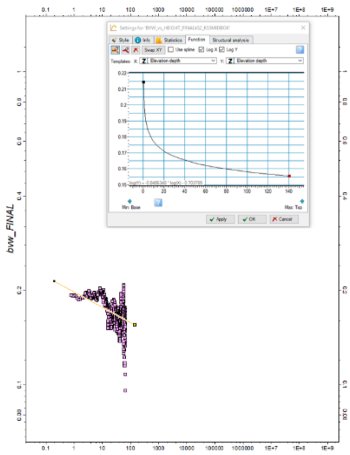

Figure 7: Height vs BVW relationship of reservoir Z5 log-log scale. A correlation of 0.65 is there in the relationship.

A good correlation of 0.65 was achieved in BVW vs Height function in log-log scale which was used to generate the empirical constants a and b in the equation **(log(BVW) = a*log (Hfwl) + b).** Using the relation, saturation model was carried out in the reservoir Z5. In case of this reservoir, which had clean and blocky sands, BVW method had very good results within the reservoir as shown in Fig: 8. In blind wells Q and R we can see that as we move away from the contact at structurally higher positions there is a good match in modelled saturation (**Dark green filled colour, BVW method)** and actual processed **log saturation (Black colour)**.

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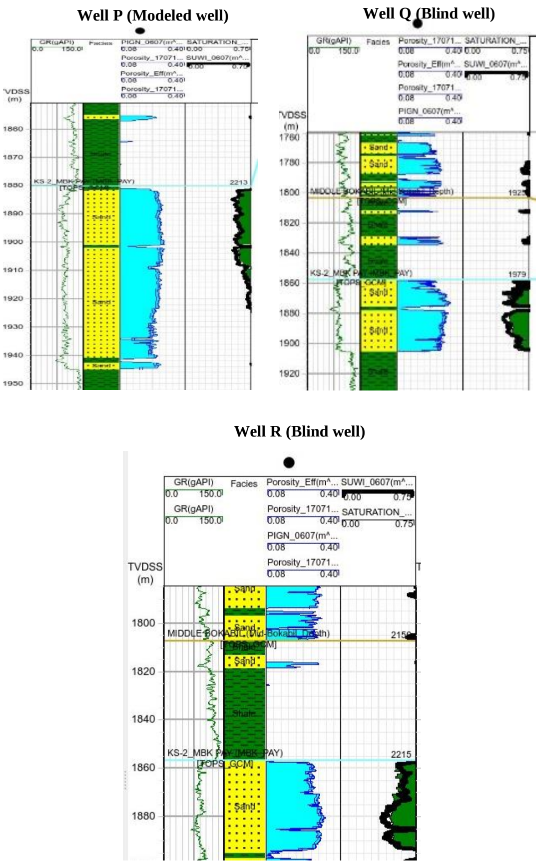

Figure 8: Saturation modelling results in blind well Q and R and modelled well P. Black **colour line actual processed log**. Dark **Green filled** represents the modelled saturation using **BVW method**.

In case of blocky sands with clean reservoir facies throughout as seen in reservoir X5 and Z5, saturation modelling can be done using BVW methodology which has an edge over geo-statistical modelling which is highly dependent on input parameters and generally smoothening in nature. Krigging estimator guarantees minimum estimation variance if variogram is optimally fit and stationary conditions are through appropriate transformation of input data. In case of saturation modelling, these pre-conditions are difficult to achieve.

For **Field Y**: In case of reservoir Y5, 6 wells which depicted the virgin condition of the reservoir were selected. 3 of these wells (D, E &F) were used for modelling while Well G,H and I was kept as blind well to check the results. The relation between BVW and height in log-log scale is shown below:

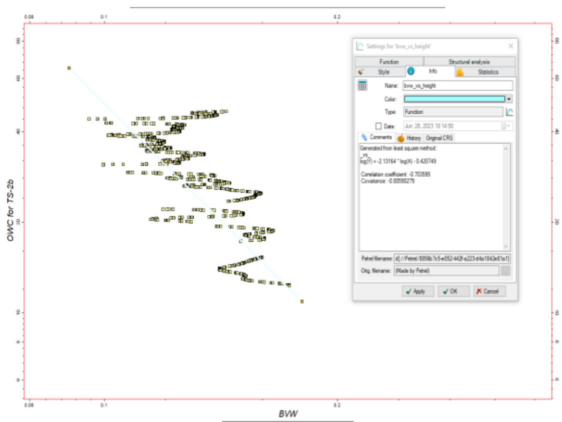

Figure 9: **Height vs BVW relationship of reservoir Y5** in log-log scale. A correlation of 0.7 is there in the relationship.

A good correlation of 0.70 was achieved in BVW vs Height function in log log scale which was used to generate the empirical constants a and b in the equation **log(BVW) = alog (Hfwl) + b)**. Using the relation, saturation model was carried out in the reservoir Y5.

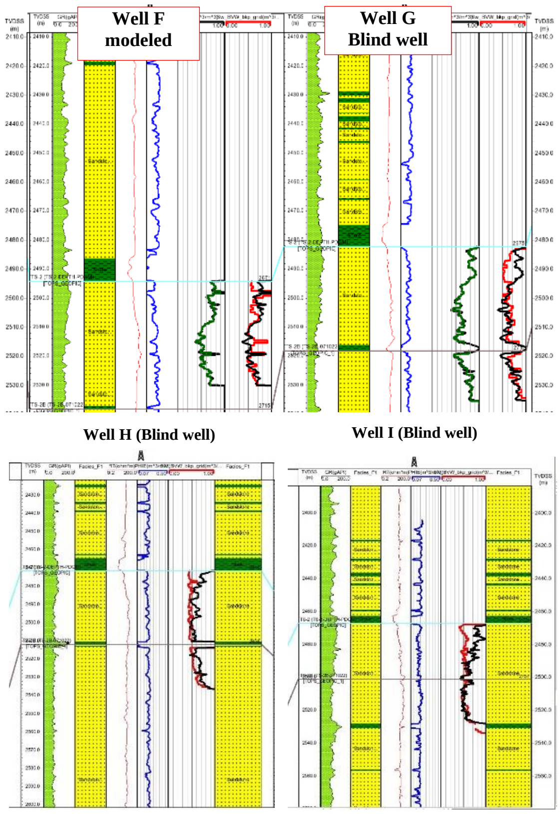

Figure 10: Saturation modelling results in **blind well G,H,I** and **modelled well F. Black colour line** represents the **processed log**. **Red colour line** represents the **modelled saturation log** using **BVW method**. In **well F and well G** which were blind wells, **dark green** colour represents the **modelled saturation using Geo-statistical method** which shows a good match

In case of reservoir Y5, where there is fining upward sequence with deteriorating reservoir facies at top of the reservoirs, BVW method had very good results

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within the reservoir at lower heights as shown in Fig.10 . However in **blind well G,H and I we can see that as we move away from the contact at structurally higher positions BVW methodology (red) is over predicting the saturation as compared to processed log saturation**. This is because BVW model takes into the account the height above Free water level while calculating the saturation. In fining upward sequence, due to tightness at upper parts the hydrocarbon, saturation decreases which can be seen in the resistivity logs too. Although BVW methodology is dependent on porosity and height, it is highly biased towards height above free water level. Thus, application of BVW methodology in such cases may lead to erroneous results. In such scenarios, saturation modelling can be done using geo-statistical propagation despite its limitations. Overall geo-statistical model (Fig. 11) will give a better a saturation model compared to BVW method in such cases.

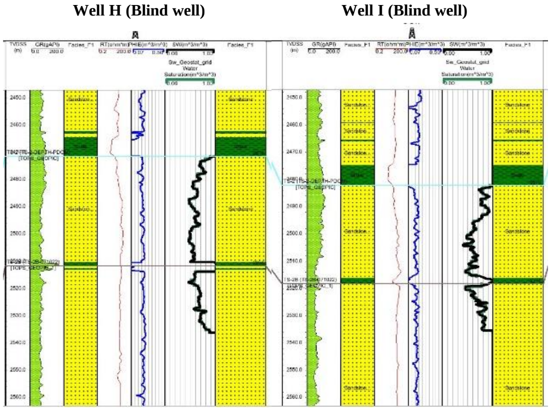

Figure 11: Saturation modelling results in blind well H and well I. **Black colour line** represents the well log. Dark **Green colour** represents the modelled saturation log using **geo-stats method** which shows a good match.

Limitations of the methods:

Although both methods are useful in propagation of saturation, there are certain limitations for each method:

The BVW method has certain limitations and assumptions that should be considered:

- **Simplistic Assumptions**: The BVW method makes several simplifying assumptions about the rock and fluid properties, for instance, it presumes that the rock is homogeneous and isotropic.

- **Limited Applicability in Thinly Layered and Complex Reservoir Models**: The BVW approach is too simple to offer reliable estimates of water saturation when dealing with layered reservoirs with different FWL. In such scenarios a single BVW function will lead to erroneous saturation estimation. The BVW method is also not suitable for unconventional reservoirs (shale reservoirs) that do not follow capillarism sensu-stricto.

Geostatistical saturation modelling is often used in geo-modelling studies to estimate the spatial distribution of water saturation in subsurface formations. While it can provide valuable insights, it also has several limitations:

- **Data Availability, Density and Uncertainty**: The accuracy and reliability of geo-statistical water saturation models depend on the quality and density of input data. The data mentioned here may frequently be incomplete or contain errors or uncertainties, such as measurement & processing errors, drilling inaccuracies, or bias in the sample process. The dependability of the results may be impacted by these uncertainties as they spread throughout the modelling process.
- **Spatial Stationarity**: Geo-statistical models often assume spatial stationarity, meaning that the statistical properties of water saturation are constant over the entire study area. This assumption may not be accurate because subsurface formations can be extremely heterogeneous in nature.
- **Model Complexity**: The choice of geo-statistical model and parameters (e.g. variogram models, covariance structures) can be complex and require expertise. Selecting the appropriate model and parameterization is not always straightforward.
- **Boundary Effects**: Modelling near the boundaries of the study area can be challenging. Geo-statistical models frequently make the unrealistic assumption that spatial processes continue indefinitely beyond the boundary.
- **Computational Resources**: Running geo-statistical models can be computationally demanding and demand significant computational resources, especially for big and high-resolution datasets.
- **Neglects Capillary Pressure**: The geo-statistical method does not account for capillary pressure effects, which play a significant role in determining the distribution of fluids in reservoir rocks.

Conclusion:

The paper presents a comparative study of two methods of saturation modelling, namely the BVW method and the geo-statistical method employing collocated co-kriging, in the absence of SCAL (Special Core Analysis Laboratory) data. The study

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evaluates the applicability of the aforementioned approaches based on the depositional history and hydrocarbon distribution and focuses on the reservoirs of the Upper Assam Shelf region. Basic conventional saturation modelling techniques that rely on capillary pressure data usually cannot be applied in cases where there is no core data. The study demonstrates that in such scenarios, log-based saturation propagation techniques can be trustworthy, albeit with uncertainties that need to be carefully analysed.

While the geo-statistical technique requires the population of upscaled saturation logs using the SGS algorithm, the BVW method which assumes that the product of porosity and saturation can be a function of height alone, utilizes well porosity and saturation data to predict saturation volumes. In order to compare the strengths and weaknesses of the two approaches, considerations including structural disposition and stratigraphic framework were taken into account. The Geo-statistical method performs better for strati-structural entrapment while the BVW method works better for structural entrapment. The BVW method performs well in clean and blocky sand scenarios, while the Geo-statistical method surpasses the BVW method in heterogeneous sand sequences. Overall, the study emphasizes the relevance of choosing suitable saturation modelling techniques based on the reservoir's characteristics and offers insights into their benefits and drawbacks.

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