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Development of Saturation Height Functions for a Multilayered Carbonate Reservoir of an Indian Offshore Field

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Summary

Layer-wise saturation height functions are developed by establishing relationships between height above the free water level and bulk volume of water (BVW). The scatter in the BVW plot has been reduced by further classifying the data for different porosity facies. These porosity intervals are treated as rock types for that layer. Since each layer has a particular range of porosity, different porosity based rock types are identified. Height above the free water level versus water saturation plots are then generated for different rock types using the relationship developed for each geological layer. These equations were used to assign initial water saturation in the reservoir simulation model of a multilayered carbonate reservoir.

Keywords*: Saturation Height Function, Bulk Volume of Water, Porosity, Free Water Level, Water Saturation*

Introduction

The distribution of water saturation within a 3-D reservoir model is a key task of an integrated reservoir description. Possible ways of distributing water saturation values to the various layers in a reservoir simulation model are,

1. By mapping, so each grid cell has an assigned initial water saturation, calculated by integrating porosity-weighted water saturation values over the mapped zone for each well. This entails the use of "pseudo capillary pressures" at each grid cell to maintain initial equilibrium.

2. By the use of relationship such as bulk volume of water (BVW) versus depth curve. BVW has the added advantage of compensating to a certain extent for different average porosity levels within comparable zones.

A significant amount of work to generate saturation height functions is available in the literature 1-7. A methodology for identifying different rock types based on the variation of porosity in each layer in a multi-layered carbonate reservoir using saturation height function concept is discussed in the present paper.

The reservoir under consideration is a heterogeneous, multi- layered carbonate reservoir interbedded by thin shale bands and argillaceous limestones. The main producing reservoir consists of elevan main reservoir sub-layers designated as A1, A2-I to A2-VII, B, C & D separated by shales/shaly or tight limestones. The porosity range in different layers broadly vary as A1 (13-29%), A2I (11-22%), A2II (12-27%), A2III (13-28%), A2IV (12-28%), A2V (13-30%), A2VI (10-26%), A2VII (14-29%), B (14-29%), C (15-24%) and D (12-22%).

The reservoir under consideration is a saturated oil reservoir with gas cap and edge water. The free water levels varies from 1408m to 1362m for different sub-layers.

Methodology and Discussion of Results

A water saturation-height function can be used in the volumetric calculation of the hydrocarbons in place using the porosity and water saturation values from well logs. This function is based on the bulk volume of water, which is the product of porosity and water saturation. To apply this approach in this multi-layered carbonate reservoir, a total number of 53 wells were selected. All of

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these wells were drilled prior to the commencement of water injection and were covering the entire field.

Height above the free water level (free water level depth minus the mean MSL depth of well), Hfwl of all the wells versus BVW (i.e. product of well averaged Phi and Sw values from logs) on log-log scale were plotted for each layer. Established a regressed straight line of the type,

log (BVW) = a log (Hfwl) + b

as depicted in Fig.1 for A1 layer. Using this equation, height above the free water level (Hfwl) versus BVW plot for this layer was made on linear scale as shown in Fig. 2. In this figure, water saturation BVW calculated from both using conventional log water saturation values, BVW(log) and derived from saturation height function, BVW(shf) approach have been plotted against Hfwl. It is seen that scattering in the variation of conventional log values with height from the free water level is reduced by using the one derived from saturation height function approach.

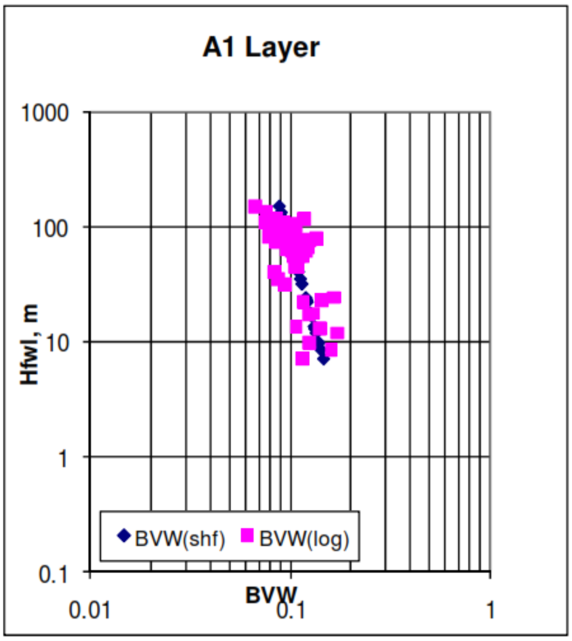

Fig.1

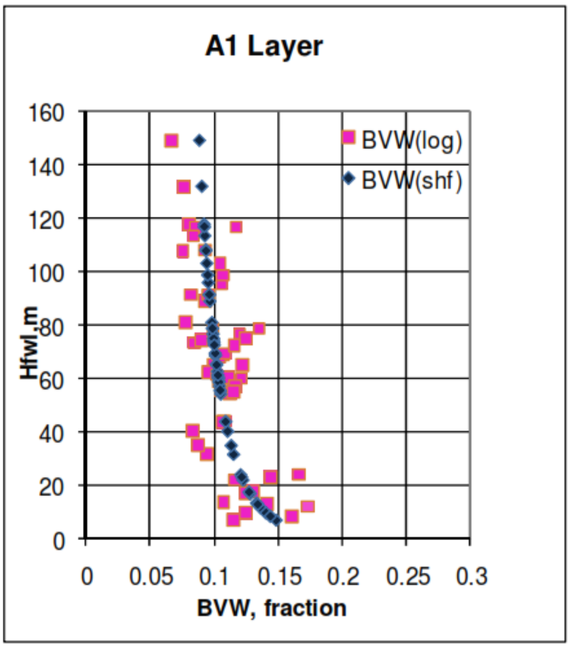

Fig.2

Similar relationships for all the layers have been developed. The values of the constants a and b of the regressed straight lines for all the layers are given in Table-1. Saturation height functions so derived for all the layers with respect to single free water level are shown in Fig.3. This gives the estimate of different capillary pressure threshold values for different

Table-1: Regression line Constants for Different Layers

BVW = 10**(-a*LOG(Hfwl)-b)

Layer	fwl	a	b
A1	1408	0.1685	0.685
A2I	1408	0.1375	0.723
A2II	1408	0.1877	0.618
A2III	1408	0.3319	0.477
A2IV	1408	0.1874	0.812
A2V	1398	0.2278	0.645
A2VI	1398	0.1435	0.710
A2VII	1398	0.4462	0.270
B	1379	0.2909	0.648
C	1379	0.4870	0.322
D	1362	0.2293	0.726

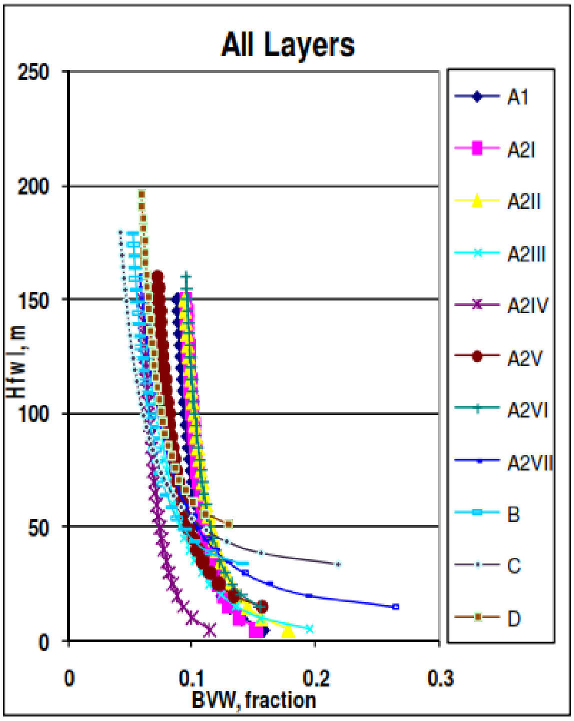

Fig.3

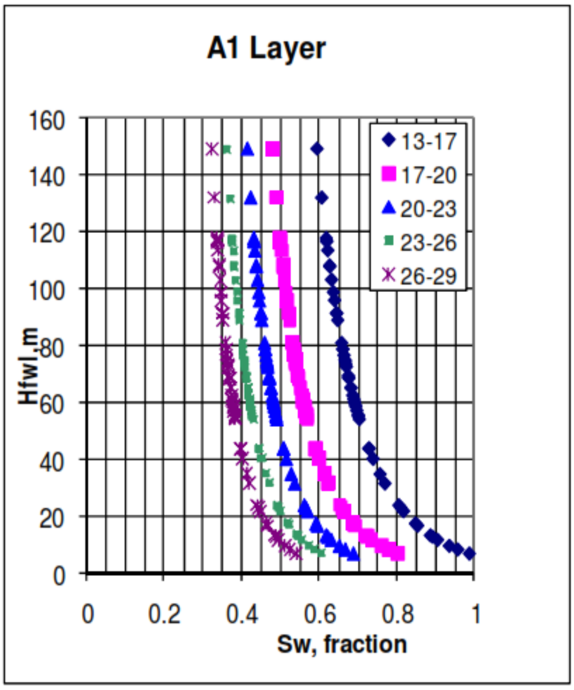

Fig.4

layers. It is seen that in case of all the layers, as Hfwl decreases, Sw increases. From top to bottom in the reservoir i.e. from layer A1 to D, Sw increases at a much faster rate as Hfwl decreases in some of the bottom layers. In other words, the shape of the saturation-height curve tends to tilt towards higher Sw values from nearly straight line portion of the curve from top to bottom in the reservoir. This indicates that relatively higher saturation values will be obtained in bottom layers in comparison to upper layers upto few meters above their respective free water levels.

In order to distribute the Sw values in a more accurate manner within the layer rather than distributing Sw values corresponding to averaged value of porosity, different curves were mae for different porosity classes depending on the variation of porosity in each layer have been generated. These curves for A1 layer for 5 different porosity classes are depicted in Fig.4. It is observed that as the porosity class interval increases, Sw decreases at all values of Hfwl.

Similar porosity classes based curves are generated for all the layers and these different rock types in each geological layer are presented in Table 2.

As the porosity class interval increases, Sw decreases at all values of Hfwl. Therefore, the curves corresponding to different porosity ranges would distribute the Sw values in a more accurate manner rather than distributing Sw values corresponding to averaged value of porosity.

Table-2: Porosity Based Rock Types for Different Layers						
Layer	Porosity Range %	Rock Types				
		I	I	III	IV	V
A	13-29	13-17	17-20	20-23	23-26	26-29
A2I	11-22	11-14	14-16	16-17	17-20	20-22
A2II	12-27	12-16	16-18	18-20	20-22	22-27
A2III	13-28	13-18	18-20	20-22	22-24	24-28
A2IV	12-28	12-17	17-19	19-22	22-24	24-28
A2V	13-30	13-18	18-21	21-23	23-26	26-30
A2VI	10-26	10-15	15-17	17-19	19-21	21-26
A2VII	14-29	14-19	19-21	21-23	23-25	25-29
B	14-29	14-17	17-19	19-21	21-24	24-29
C	15-24	15-17	17-19	19-20	20-21	21-24
D	12-22	12-14	14-16	16-17	17-19	19-22

Conclusions

Layerwise porosity based rock types have been identified using saturation height function approach. This technique has been found very suitable to calculate initial inplace reserves for a multi-layered carbonate reservoir. It also helped for enhancing the quality of description of the reservoir.

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