A review on methods of oil saturation modelling using IRAP RMS

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Abstract. Oil saturation is one of the most important characteristics of the reservoir. In the process of geological modelling proper distribution of oil saturation is one of the main parameters for reserves assessment and further flow simulation. The paper presents methods of three-dimensional modelling of oil content of the reservoir based on the results of well log interpretation data, capillarimetry and 3D-trends and algorithms of their realization in reservoir characterization and modelling software suite IRAP RMS, their theoretical basis and application factors.

1. Introduction
Recently geological and hydrodynamic simulation has become an essential part of the reservoir estimation, engineering and exploitation process of oil and gas fields, it brings perceptible economic effect. The spatial distribution of oil in the reservoir plays one of the most important roles while the simulation of fluid displacement from the interstitial space of rock and reserves assessment.

2. Methods and theory
Existing approaches to oil saturation modelling include deterministic and stochastic methods and simulation based on Leverett J-function. The choice of the algorithm depends on geological conditions of the productive series, volume and quality of input data. The initial information for modelling consists of the well log interpretation data, core analyses and capillarimetry. The data should be taken especially before the start of reservoir exploitation, otherwise model would be incorrect. The paper presents various methods of saturation modelling, algorithms of their implementation with IRAP RMS software and the aspects of their application.

3. Results
In case of a rather small basin with an isotropic structure (slightly changing characteristics along the lateral and geologic profile), deterministic interpolation of the well data can give satisfactory results. In RMS interpolation of continuous and discrete parameters from the well logs is carried out by a Parameter Interpolation panel using a kriging – intellectual interpolation accompanied with weighing the determine values of the wells by their distance from the desired point. The panel settings include the choice of interpolation radiuses for X, Y and Z axes and horizontal or stratigraphic interpolation modes [1].

Stochastic models are aimed to show more natural distribution of reservoir characteristics, they may contain the multitude of equiprobable realizations. RMS includes the Petrophysical Modelling module that allows using the stochastic approach: 3D-model building is based on normalizing the probability
distribution of the modelled parameter and the fact that values of points depend on the distance between them. Petrophysical modelling operates with results of geostatistical analysis of initial data (variograms and correlations) and also with various trends. Figure 1 presents the results of interpolation and stochastic modelling. The choice of trends strongly affects the stochastic modelling process.

### 3.1. Variants of 1D, 2D and 3D trends application

One-, two- or three-dimensional trends are the functional dependences extracted from the statistical input data analyses or the concepts and experience of modeler. Trends are used as additional information for the calculation of saturation cube and other geological parameters.

![Figure 1. Oil saturation models calculated by interpolation (left) and stochastic approach (right).](image)

3.2. Vertical 1D trends

The most common vertical trend used to calculate the formation characteristic models is a vertical proportion curve that shows the probability to meet the collector on a certain depth [2]. RMS suggests special Vertical Proportion Curve tool, it works with continuous and discrete 3D parameters or averaged well data tied to grid cells - Blocked Wells. Figure 2 shows the two stochastic models of oil saturation: left one was built with the vertical proportion curve trend (based on averaged lithology log), right model was built without trend. Employment of monodimensional trend brings the good results in case of relatively isotropic reservoir in lateral direction [2].

![Figure 2. Stochastic distributions of oil saturation with 1D vertical proportion curve trend (left) and without it (right).](image)
3.3. Lateral 2D trends

Lateral 2D trends are maps of geological parameters in X, Y-coordinates. The map interpolated by well data serves as an essential source of extra information about the reservoir; it improves the objectivity of stochastic models (figure 3). In practice lateral trends for the oil saturation cube may include maps of oil saturation (or water saturation). The use of a net to gross ratio map that controls the lateral distribution of collector in modelled formation is also appropriate [2].

![Figure 3. Stochastic models built with the use of 2D trends: water saturation map (left) and net to gross ratio map (right).](image)

3.4. 3D trends

3D trends are more effective for the saturation modelling aims. 3D trend – calculated 3D parameter – may be extracted from the initial well data by the analyses of dependence between saturation and height over the oil-water surface for various intervals of porosity and permeability values. Firstly log data is divided into ranges by value: the more intervals mean the smoother changing of saturation as a result. Every range should include enough determine values otherwise the dependence would be uninformative. Then the saturation height functions are found for the ranges. Trend lines may be edited by modeler or chosen from existing functions. Impact of editor may add the subjective view on the character of ultimate model which is calculated by chosen saturation height functions. If the well data set is not sufficiently representative to divide it into intervals, the desirable dependence should be calculated for the whole reservoir.

Due to the high nonuniformity of geological conditions of subsurface well data interpolation may not be sufficient enough, so all existing knowledge about the distribution of hydrocarbons in the reservoir should be considered. If the results of core capillarimetry are available (capillarimetry results are residual water saturation ($S_w$) functions of capillary pressure in water wet rocks), Leverett J-function can be successfully employed. Modelling with a help of J-function is based on dependences of oil saturation on the height above the free-water surface and porosity and permeability. Here is Leverett J-function:

$$J = \frac{3.183 P_c \sqrt{k}}{\gamma \cos \theta}$$

where $J$ is Leverett function; $P_c$ – capillary pressure, $10^6$ Pa; $k$ – permeability, $10^{-3}$ μm$^2$; $m$ – porosity, u.f.; $\gamma$ – surface tension between hydrocarbons/water, kg·m$^2$/S$^2$; $\theta$ – contact angle, degrees. Capillary pressure is a function of pore channels radius:

$$P_c = 2\gamma \cdot \cos \theta/rt$$

where $rt$ is pore channel radius, m.
The function (2) shows that capillary pressure increases when the pore diameter and contact angle lower and surface tension grows [3]. But capillary pressure also depends on the height above the free-water level (according to the capillary-gravitational balance theory) [4]:

$$P_c = (\rho_w - \rho_{oil}) \cdot 0.098 \cdot \Delta h$$

(3)

where $\rho_w, \rho_{oil}$ – water and oil densities, kg/m³, $\Delta h$ - height above the free water level, m.

J-function involving method of oil saturation 3D modelling was firstly suggested by A.F. Gimlatdinova. Generally it consists of two steps: building of water-oil zone geometry and calculation of the saturation cube by interpolation with monodimensional trend – Leverett J-function.

Exact algorithm of oil saturation simulation with the water-oil zone includes a sequence of the following steps. The function $J = f(Sw)$ is extracted from the experimental data of capillarimetry (modeler finds an approximating function of a type $J = ASw^b$), then the value of J-function corresponding with the target water-oil surface $P_c$ is calculated by the expression (1), then expression (3) gives a height of water-oil contact level above the free-water surface. 3D parameter of $P_c$ is built for all heights above the free-water surface in a water-oil system, both $P_c$ and porosity cubes allow calculating J-function distribution in a reservoir volume. The extracted expression $J = f(Sw)$ helps to get tridimensional distribution of $Sw$ and oil saturation $Soil$ (as $Soil = 1 - Sw$) [5].

According to the researches [4, 6] comparison of the oil saturation values from the model with the well data showed that this method gives appropriate results. Both ranges of values presented the trend of growing oil saturation in a direction of maximal oil saturation zone, where the water saturation decreases and oil fills smaller and smaller pores [3, 7].

In RMS algorithm using J-function is carried out by Water Saturation Modelling panel of a Grid container. There are two variants of J-function: similar to the expression (1) and a simplified form:

$$J = H \sqrt{\frac{Perm}{Poro}}$$

(4)

where $H$ is height above the free water level, $Perm$ – permeability, $Poro$ – porosity.

In case of using J-function of form (1) the input variables include free-water surface, oil and water densities, gravity acceleration constant, oil-water surface tension, contact angle, cubes of porosity and permeability. In both cases the water saturation is calculated by the following expression:

$$Sw = Swirr + (Sw_{max} - Swirr)Sw_{jn}$$

(5)

where $Swirr$ is an irreducible water saturation, $Sw_{max}$ – the highest water saturation value, $Sw_{jn}$ – normalized water saturation:

$$Sw_{jn} = (\frac{1}{a})^\frac{1}{b}$$

(6)

where $a, b$ are petrophysical coefficients.

If the simplified J-function was chosen, essential input data includes permeability and porosity cubes and petrophysical constants $a, b$. A final result of the calculation is the 3D water saturation parameter, subtraction it from one in a Parameter Calculator panel leads to the cube of the oil saturation (figure 4).

Water Saturation Modelling panel allows applying different functions for the distributed by intervals data. These functions are found on a Scatterplot with a filter by values. Water saturation Modelling panel is supplied with the Look-up function for setting the trend found by modeler. Essential data for the Look-up function contains free-water level, irreducible water saturation cube, the highest water saturation value, petrophysical constant $a$ (provided by petrophysicist or taken as one) and the functional dependence obtained by user and saved in Trends container. Figure 5 presents the oil saturation model constructed according to described algorithm with a user trend taken from the dependence of normalized water saturation on the reservoir height.
4. Conclusions
There was a review on the various approaches to the 3D oil saturation distribution modelling based on the prioriy information in a form of well log data interpretation, 1D, 2D and 3D trends and results of capillarimery.

While the simulation of not very large fields with monotonous reservoir characteristics in lateral and vertical directions oil saturation can be efficiently described by the deterministic interpolation of the well data. The stochastic modelling accompanied with vertical proportion curve trends and maps also works well in this case. As the geological objects mostly have highly anisotropic structure, stochastic models allow getting more reliable and naturally-looking distributions of filtration parameters and oil content. Tridimensional trends are also useful as the functional dependences between the initial parameters serve as an additional source of information about the reservoir in case of lack of data. 3D trend should be created when there is a stable and informative relationship between the parameters. The trend choice depends on specific geological conditions of the reservoir.

Modelling with Leverett J-function helps to build model considering the physical forces applied to the fluid in a porous matrix. This approach corresponds to a more realistic conception of the reservoir filtration system, but it is actual only for the terrigenous water-wet rocks and in the condition of available capillarimetry results.
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