GEO India 2018

PaperID **AU364**

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Permeability modeling through Integration of electrofacies from logs & core reservoir facies in laminated reservoirs: A case study

Abstract:

Understanding reservoir dynamics is an important part for taking hydrocarbon production from any field. One of the parameter that controls it, is the permeability of the reservoir apart from porosity, pressure, reservoir extension etc. Various methods are in place to get permeability of the reservoir in the interpretational process. One of them is reservoir pressure build up study which is used to know flow behavior of the reservoir. Petro physics data/logs such as formation pressure points, NMR etc. are also helpful in determining permeability of the reservoir. There are fields where NMR logs or pressure points are scarce & limited only in one or two wells. These wells data may give erroneous picture about the permeability & hence producibility behavior of other wells in the field. Simple porosity, permeability correlation to get permeability from porosity may also fails in the reservoirs where variation of porosity is not much but permeability variations is of the higher degree.

Uncertainties in computing permeability thru simple porosity permeability relationship further enhanced in sand shale laminated sequences formation. Uncertainty can be reduced by picking up variations in the facies due to depositional & digenetic processes through logs and their integration with reservoir facies derived from core. Reservoir facies discrimination can be obtained from the lab measurement study on core plugs and the data can also be used in establishing relationship of porosity with permeability for each facie.

This is a case study of the shale sand laminated sequence of Kamalapuram formation of Eocene age encountered in Kamalapuram & Vijayapuram fields of Cauvery basin. Only Conventional logs have been recorded in all wells drilled in these fields except in two wells, where high resolution image log is available in one well and in another well NMR has been recorded. In absence of high resolution data viz NMR or formation pressure data, robust methodology is discussed in this paper to compute permeability in laminated shale sand sequences from conventional logs by integrating reservoir facies from core data & electrofacies from log data. This approach of integrating core and Petro physical data for these complex reservoirs add value in designing effective well completions and can be utilized as a workflow for evaluating such type of reservoirs.

Introduction:

Shale sand laminated sequence reservoirs are often encountered globally in hydrocarbon producing fields. Permeability is an important parameter to assess the producibility of reservoirs which hampers the predictability if proper evaluation is not made especially in shaly sand sequences reservoirs where it is highly affected due to facies variations.

Kamalapuram & Vijayapuram fields are located on the South Western part of Karaikal high in Nannilam saddle at the tri-junction of Tanjavur, Tranquebar and Nagapattinam sub-basins (Fig-1). The Kamalapuram Formation occurs within the submarine canyon network on top of Cretaceous, originating from Tanjore sub-basin in the west and running parallel to the Karaikal high. The field consists of multilayered oil and gas pay sands belonging to Kamalapuram Formation of Paleocene and Eocene age.

Eocene reservoirs of Kamalapuram & Vijayapuram have various degree of laminations of sand shale sequence and its frequency increases in Vijayapuram field where thin laminations of sand & shale are more. Shale sand laminations are visible on cores taken in few wells (Fig-2) and also on electro logs. Laminations in some wells are very thin which are not in the resolvable limit of the logging tools and could not be identified through logs.

Challenges:

Depositional and diagenetic processes tends to alter the petrophysical/ reservoir properties such as porosity, permeability etc. Rock typing based on porosity & permeability is a process for classifying flow zones of a reservoir rock having deposited in similar geological conditions & has undergone similar diagenetic process. Permeability variation due to depositional processes is an inherent property in shale sand laminated reservoir. Testing results of zones in wells of studied fields have also shown variability in production due to variability in permeability. It thus makes essential to determine permeability to understand producibility behavior of the reservoir. Workflow/methodology is presented in this paper for permeability modeling with the help of logs & core measurement in shale sand laminated Eocene reservoirs of Kamlapuram & Vijapuram fields

Permeability modeling methodology:

An utmost care has been taken to derive reliable permeability log in these shaly sand reservoirs which is necessary to define the precise rock types. Methodology was developed for permeability modeling in a key well where core data is available. Workflow adopted for permeability modeling is given below.

- Electro facies generation & propagation.
- Reservoir facies generation through core measured porosity & permeability.
- Generation of regression for each facie with porosity.
- Tagging of electro facies with reservoir facies.
- Computing porosity with multi-mineral model.
- Computing permeability with porosity obtained from processed output and regression.

Electro Facies generation

Key well, where core measured porosity, permeability is selected for electro facies generation. Electrofacies have been generated using SOM (Self organized map) module. These electrofacies are generated with convention logs like density, Neutron porosity, GR & sonic travel time log. Different combination of input logs are utilized to get best representative known lithofacies.

Self-organized neural network is used to cluster high dimensional input pattern into group of pattern. It was started from unsupervised learning to allow network to find its own solution in a key well with conventional log curves.

SOM involves ***m*** nodes units arranged in matrices with vectors of ***n*** input signal. The weight vector define each nodes. Each node has weight of same dimension as input vector. Input patterns are compared and each node is associated to the node it best matches with (Fig.3).

Comparison is based on square of the min Euclidean distance. When the best match is found, the associated node get its weight and its neighboring unit is updated.

Training occur in many steps and iterations.

1. Each node weights are initialized. It set to small standardized random value $0 < w < 1$.
2. A vector is chosen at random from the set of input signal and presented to the matrix.
3. Every node is examined to calculate which ones weight are most likely with input vector and the node is called as BMU (best matching unit).
4. The radius of neighborhood of BMU is calculated which diminishes each time step. Nodes found within this radius are deemed to be inside BMU's neighborhood.
5. Each neighborhood node weights are adjusted to make them more like input vector.

BMU is chosen when Euclidean distance between each node vector and current input vector is minimum

$$Dist = sqrt(\Sigma_{i=0} \text{ to } n\ (vi-wi)**2)$$

V= current input vector, w= nodes weight vector

After determining BMU, next step is to determine BMU's local neighborhood. All these nodes will have their weight vector altered in next step. It calculates radius of neighborhood and the area of the neighborhood shrinks over time.

$\sigma_{(t)}=\sigma,\ \exp(-1/\lambda),\ \ t=1,2,3$—

σ= width of lattice at time t

λ= time constants

t= current time step (iteration of the loop)

Most of the wells of this field have conventional log curves viz resistivity, porosity and sonic travel time. High resolution log such as resistivity mage & NMR is available only in one well. Resistivity recorded in these wells are induction type which has poor resolution shallow resistivity (LL3). In absence of high-resolution logs Electrofacies are generated with the help of conventional logs only which sometime fail to resolve the facies. To capture variation in facies, one more curve with the porosity difference between neutron & density porosity generated and used in electrofacies generation (Fig.4).

The facies are generated with GR, MSFL/LL3, NPHI, RHOB, Diff PHIN-PHID & DT log curves in key wells (KMP-A & KMP-B) where core data is available. Total 6 nos of electrofacies have been generated, out of 6 facies, four facies belongs to reservoir having different character and two facies belongs to non-reservoir part.

The different electrofacies (Fig.5) identified using conventional logs are linked with the reservoir facies identified from core studies and a transform between Porosity-Permeability for each facie is generated in key wells. The facies identified also reflect the gran size variations as seen on Neutron-Density separations. The finalized facies model has been propagated to the other wells and found to be representative.

Generation of reservoir facies & Transforms:

Two wells of this field are chosen as model well and measured core porosity and permeability on core plugs in lab. Core measured porosity & permeability are used to determine reservoir facies. Porosity vs permeability plot and winland overlay was plotted to understand facies and their pore throat sizes. Four types of reservoir facies are identified from crossplot with different pore throat size.

Pore throat size may be estimated from core porosity and permeability data at ambient conditions. Combining these data with mercury injection capillary pressure results, Winland (1972) developed an empirical relationship between porosity, air permeability and pore aperture corresponding to a mercury saturation of 35% (R35). This analysis suggests the possible presence of 4-5 rock types (Fig.6).

An exponential regression for each facie is generated to derive permeability from porosity.

Linking of reservoir & electroafacies

After proper depth matching of core plugs with logs, reservoir facies from core measured data are linked with the electro facies from conventional logs in the model wells. Transforms between cores measured porosity & permeability are generated for individual electro facie. A programme in Python script was written for linking electofacie from conventional logs & reservoir facies from core studies to compute permeability of individual facie from porosity.

Propagation of electrofacies & Permeability computation:

Electro facies in other wells were propagated using the modeled well facies. Cores were also studied for presence of mineralogical components. Accordingly a multimineral model was developed by integrating cores studies & other inputs. Wells were processed with developed multimineral model for porosity estimation. Generated transforms are used to compute permeability level by level in other wells constraining with electrofacies where cores are not available. The generated permeability curve is validated with NMR derived in well-C & core measured permeability in well-D (Fig-8 & 9).

Conclusions

- Electrofacies generation is an important tool in reservoir characterization for the laminated shale sand sequence reservoir where conventional tool fails to resolve lamination due to vertical resolution constrained.
- The different electrofacies could be identified using combination of conventional logs which could be further linked with the reservoir facies identified from core studies.
- Generated transform between Porosity-Permeability for each reservoir facie can be used for Permeability modelling curve after linking reservoir facies with electrofacies.
- The modelled permeability has good match with the NMR permeability and core permeability showing efficacy of the methodology.

Acknowledgement

Authors express their sincere gratitude to ONGC management for allowing to publish this study. Authors also indebted to all the data providing units for acquiring quality data and providing us to accomplish the study. Authors expresses their sincere thanks to all the CEWELL colleagues for their suggestions, support and help.

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