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Permeability estimation using flow zone indicator from Well log data

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Summary

Permeability has been estimated making use of the concept of Flow Zone Indicator (FZI). Flow Zone Indicator has been obtained from the combined use of the well log data. Well logs are evaluated for porous and permeable sand layers from a total depth interval of 220 m. Permeability values have been calculated for four sand layers varying thicknesses from 3 to 4 m. Flow zone indicator (FZI) for porous and permeable layers from a well are calculated from transformation of Gamma Ray, neutron porosity, density, deep resistivity logs. Calculated permeability value ranges from 30.64 md to 231.05 md for hydrocarbon bearing layers.

Introduction

The hydraulic flow unit (HFU) approach has been used for classification of rock types and prediction of flow properties, as an integrating tool for petrophysical description of the reservoir. Development and application of the HFU approach is stimulated by the common problem of permeability prediction in uncored but logged wells (Svirsky et al., 2004). Classical approaches for estimation of permeability are based either on simple logarithmic regressions evaluating permeability from log-derived porosity (Eq. 1) or on empirical correlations which relate permeability to various log responses.

$\ln K = a.\varphi + b$…………………………. (1)

a and b are constants.

The hydraulic unit is defined as the representative elementary volume of total reservoir rock within which geological and petrophysical properties that control fluid flow are internally consistent and predictably different from properties of other rocks (Amaefule et al., 1993). The fundamental petrophysical units in a reservoir (rock types) can be determined by flow zone indicators for routine core plug analysis. The variation in the petrophysical properties (porosity & permeability) should be small for a given rock type implying that knowledge of any porosity or permeability will enhance the prediction of the other properties. This technique of calculating FZI from core data has been introduced by Amaefule et al., 1993, which involves normalized porosity index (NPI) and reservoir quality index (RQI) through equation 2.

Flow Zone Indicator (FZI): Flow Zone Indicator is a unique and useful value to quantify the flow character of a reservoir and one that offers a relationship between petrophysical properties at small-scale, such as core plugs, and large-scale, such as well bore level. In addition, the term of FZI provides the representation of the flow zones based on the surface area and tortuosity. It is mathematically represented as (Al-Dhafeeri et al., 2007)

$FZI = RQI / NPI = \{(.0314\sqrt{K/\Phi})\} / \{\Phi / (1- \Phi)\}$ ……………………...…………. (2)

Where,
FZI=Flow Zone Indicator, µm.
K=Permeability, md.

Φ=Porosity, volume fraction.

Methodology

To obtain FZI (Flow Zone Indicator) for uncored interval / well, the various log parameters such as GR (gamma Ray), φ_n (neutron porosity), ρ_b (density), R_t (true resistivity) are obtained for depth intervals: X133 - X136 m, X161 – X164 m, X312 – X316 m and X330 – X334 m. FZI is calculated for these selected porous and permeable depth intervals using a technique given by Xue and Dutta Gupta, 1997. This technique is based on the transformation of gamma ray (GR), neutron porosity (NPHI), density (RHOZ) and resistivity (LLD) logs as given below:

$$\mathbf{GR\_Tr = 4.7860E\text{-}03\ GR^2 - 1.7320E\text{-}01\ GR + 1.0614E{+}00} \quad \text{------------ (3)}$$

$$\mathbf{NPHI\_Tr = -8.1102E{+}00\ NPHI^2 + 9.6676E\text{-}01\ NPHI + 1.7170E\text{-}01} \quad \text{--------- (4)}$$

$$\mathbf{RHOZ\_Tr = 7.1926E{+}00\ RHOZ^2 - 3.6727E{+}01\ RHOZ + 4.5873E{+}01} \quad \text{-------- (5)}$$

$$\mathbf{LLD\_Tr = -1.6859E\text{-}04\ HLLD^2 - 3.8016E\text{-}02\ LLD + 4.3712E\text{-}01} \quad \text{-------- (6)}$$

$$\mathbf{SUMTr = GR\_Tr + NPHI\_Tr + RHOZ\_Tr + LLD\_Tr} \quad \text{--------------------- (7)}$$

$$\mathbf{FZI = 4.4306E\text{-}01\ SUMTr^2 + 6.08575E\text{-}01\ SUMTr + 3.8229E\text{-}01} \quad \text{-------------- (8)}$$

SUMTr is the sum of all transform given by equations (3-6). Equation (8) gives the relation between the log motifs and FZI.

Calculations

From the well log data four zones are considered for FZI estimation using equation (8). The porous and permeable clean sand layers are identified from X134-X136m, X161-X166m, X312-X316m and X330-X334m for depth intervals; X130-X140 m, X160-X180m, X310-X320m and X330-340m respectively. The sand layer corresponding depth intervals from X134-X136m, X161-X166m are characterized by high gamma ray (139.9-142.8) gAPI and resistivity (4-6) Ω-m. The crossover between neutron porosity and density logs is observed at the depth interval X134-X136m. The layer is gas-bearing. The second zone X161-X166m is oil bearing, which is characterized by small separation between neutron porosity and density logs. The other two sand layers are water bearing where neutron porosity and density logs are coinciding each other. Tables 1, 2, 3, 4 are listing the well log parameters, FZI and permeability values for four depth intervals.

Interpretation

Table 1. Well log parameters, FZI and permeability values for Depth interval (X130-X140) m

Depth(m)	GR (Normalized) (gAPI)	PHIN (m^3/m^3)	RHOZ (gm/cm^3)	LLD (Ω-m)	FZI (μm)	Permeability (md)
130	.58	.48	2.16	.75	.55	125.48
131	.55	.45	2.17	.70	.68	141.27
132	.61	.48	2.15	.70	.60	149.33
133	.66	.35	2.33	.90	.54	30.01
134	.93	.18	2.21	2.5	1.68	24.83
135	.86	.12	1.92	4.0	7.0	110.89
136	.66	.18	2.13	2.5	2.59	59.00
137	.64	.37	2.16	1.5	1.22	192.64
138	.62	.46	2.16	.90	.67	151.97
139	.55	.46	2.11	.95	1.0	338.54
140	.57	.48	2.14	.90	.65	175.25

Table 2. Well log parameters, FZI and permeability values for Depth interval (X160-X180) m

Depth(m)	GR(gAPI) (Normalized)	PHIN(m^3/m^3) (Neutron Porosity)	RHOZ(density) (gm/cm^3)	LLD (Ω-m) (Deep Resistivity)	FZI(μm)	Permeability (md)
160	.62	.49	2.18	.70	.39	69.77
161	.75	.38	2.31	1.0	.46	30.64
162	.95	.28	2.21	1.75	1.31	73.70
163	.69	.29	2.09	6.0	2.17	231.05
164	.81	.24	2.14	4.0	1.29	40.39
165	.63	.29	2.21	2.0	1.32	85.49
166	.54	.15	2.59	2.0	.76	2.736
167	.75	.40	2.36	1.25	.29	15.16
168	.83	.48	2.41	2.0	.18	13.43
169	.87	.24	2.35	2.5	.77	14.39
170	.89	.21	2.45	3.0	.54	4.39
171	1.0	.26	2.49	1.5	.49	7.82
172	1.0	.28	2.31	1.5	.79	26.80
173	1.0	.39	2.26	1.0	.53	45.42
174	.96	.18	2.60	4.0	.58	2.96
175	1.0	.36	2.24	1.0	.75	48.60
176	.81	.36	2.28	1.0	.62	44.41
177	.67	.40	2.31	1.25	.39	27.42
178	.78	.32	2.29	1.25	.75	40.43
179	.67	.25	2.28	.95	1.13	35.97
180	.67	.31	2.26	1.25	.95	57.27

Table 3. Well log parameters, FZI and permeability values for Depth interval (X310-X320) m

Depth(m)	GR (Normalized) (gAPI)	PHIN (m^3/m^3)	RHOZ (gm/cm^3)	LLD(Ω-m)	FZI(μm)	Permeability (md)
310	.75	.37	2.21	.8	.91	107.2
311	.63	.46	2.25	.9	.33	36.87
312	.67	.36	2.29	.9	.61	42.99
313	.44	.31	2.19	.8	1.48	139.0
314	.49	.28	2.17	.75	1.82	142.26
315	.42	.24	2.23	1	1.52	56.08
316	.56	.30	2.19	.7	1.51	127.42
317	.59	.48	2.10	.6	.91	343.49
318	.54	.51	2.19	.7	.31	53.85
319	.56	.51	2.21	.75	.27	40.85
320	.54	.53	2.19	.7	.39	103.96

Table 4. Well log parameters, FZI and permeability values for Depth interval (X330-X340) m

Depth(m)	GR (Normalized) (gAPI)	PHIN (m^3/m^3)	RHOZ (gm/cm^3)	LLD (Ω-m)	FZI (μm)	Permeability (md)
330	.50	.30	2.23	1.25	1.21	81.8
331	.48	.27	2.19	.90	1.68	105.73
332	.50	.30	2.22	.85	1.27	90.14
333	.45	.30	2.16	.85	1.77	175.08
334	.47	.28	2.14	.90	2.12	193.02
335	.61	.36	2.16	.70	1.40	226.43
336	.67	.36	2.19	1.0	1.09	137.25
337	.55	.36	2.48	1.5	.47	25.52
338	.64	.49	2.25	.90	.24	26.42
339	.54	.45	2.21	.70	.51	79.46
340	.56	.52	2.21	.80	.24	35.65

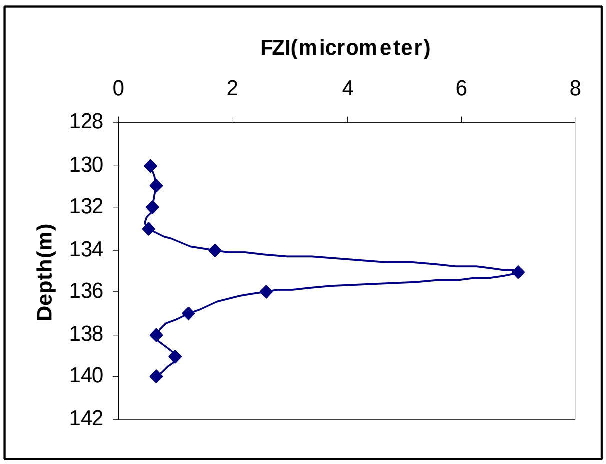


Fig. 1 FZI vs. Depth plot for (X130 - X140) m

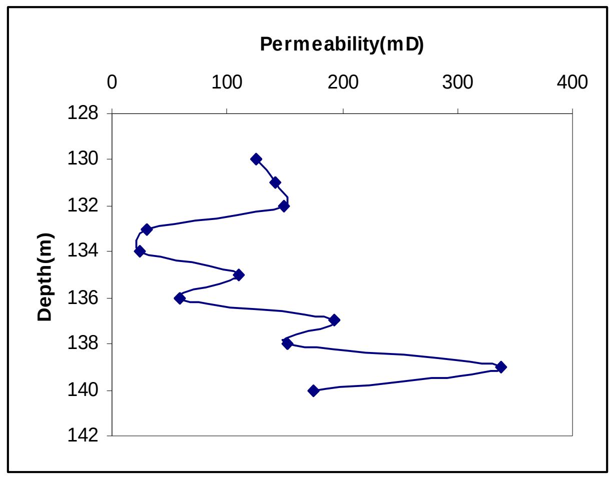


Fig. 2 Permeability Vs Depth plot for (X130-X140) m

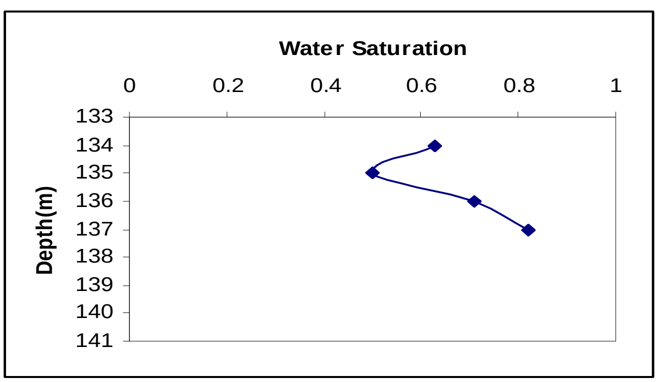


Fig. 3 Water Saturation Vs Depth plot for (X130-X140) m

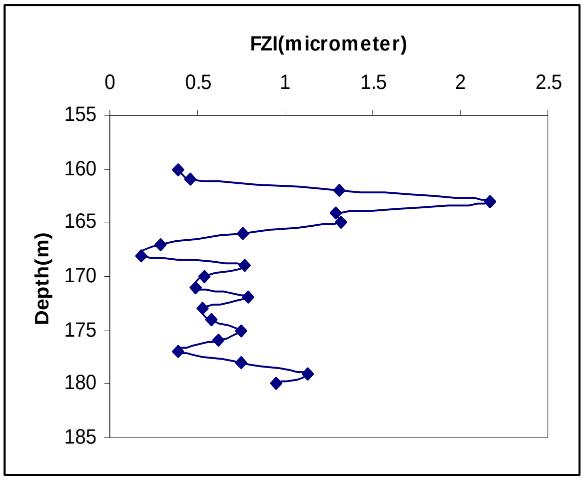


Fig. 4 FZI vs. Depth plot for (X160 - X180) m

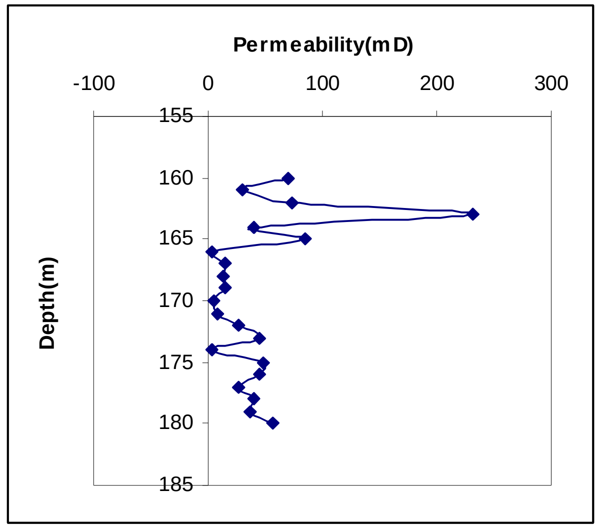


Fig. 5 Permeability Vs Depth plot for (X160-X180) m

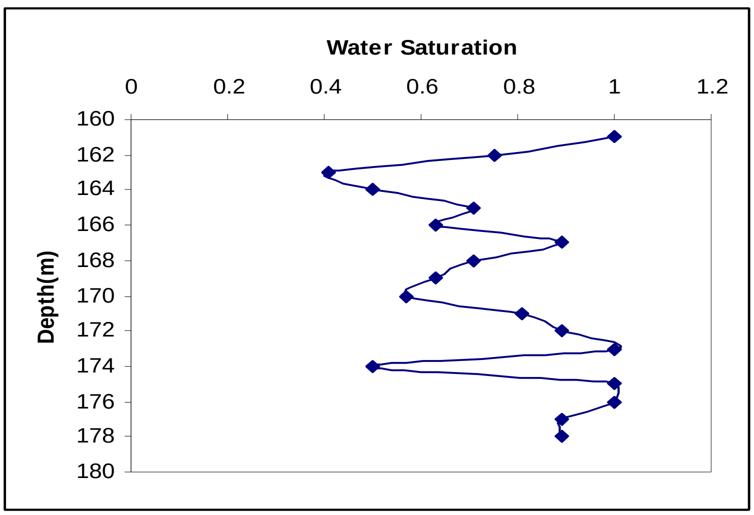
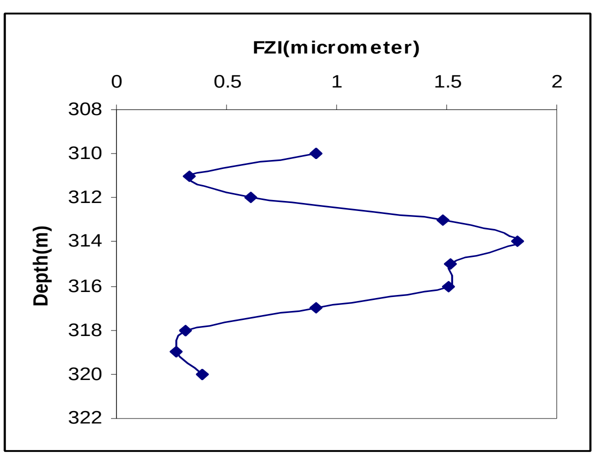


Fig. 6 Water Saturation Vs Depth for (X160-X180) m



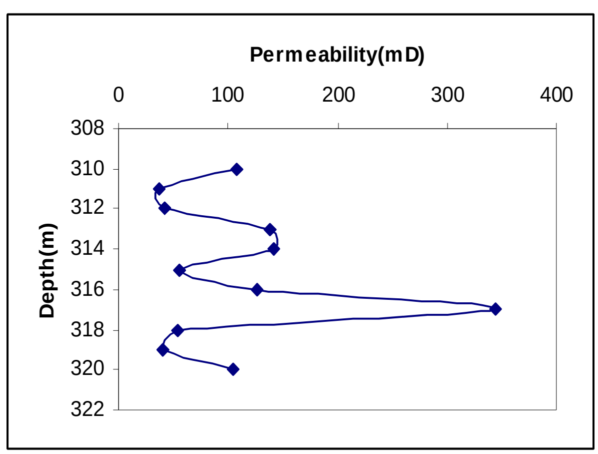


Fig. 7 FZI vs. Depth plot for (X310 – X320) m

Fig. 8 Permeability Vs Depth plot for (X310-X320) m

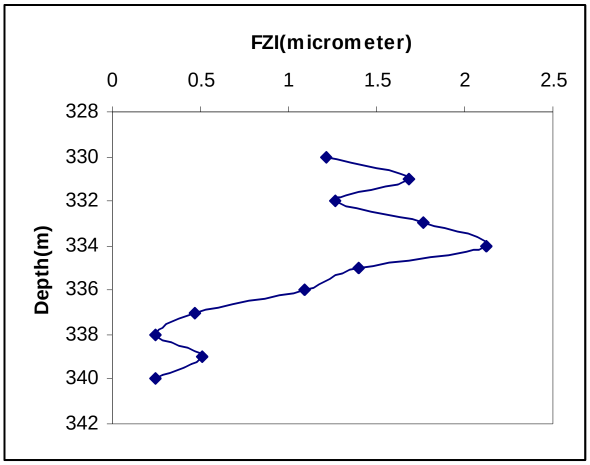


Fig.9 FZI vs. Depth plot for (X330 – X340) m

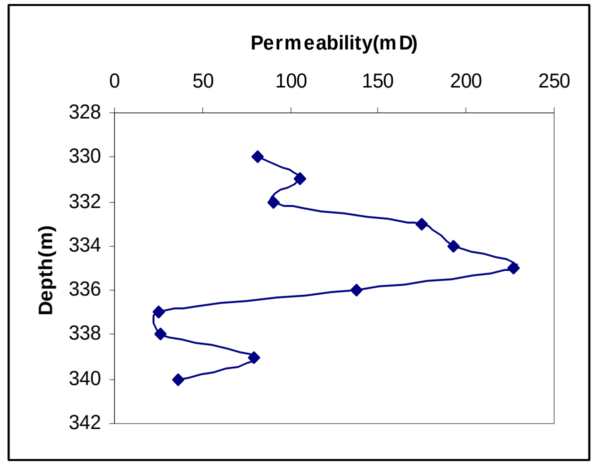


Fig. 10 Permeability Vs Depth plot for (X330-X340) m

Figs. 1, 4, 7 and 9 represents the variation of FZI with the depth interval of (X130 - X140) m, (X160-X180) m, (X310 – X320) m and (X330-X340) m respectively. From fig.1 it is noticed that the FZI is showing high values within the depth interval (X134-X137) m. At a depth of 135m gas bearing sand layer has the highest FZI value of about 7. That means sand layer has high FZI values. It also indicates that shale has low FZI values above and below the sand layer. From fig.4 we see high values of FZI vary within X162-X165 m. At 163m the highest value of FZI at oil bearing layer of about 2.17 is observed. Fig. 7 shows high values of FZI between X313-X316 m. Highest FZI value for water bearing layer is about 1.82 at X314 m depth. Fig. 9 shows high values of FZI from depth X330 to X336 m. At X334m depth the highest value of FZI is representing porous and permeable water bearing clean sand layer. For shale layer low values of FZI are observed. Figs. 2, 5, 8 and 10 represent the variation of permeability values with depth intervals (X130 - X140) m, (X160-X180) m, (X310 – X320) m and (X330-X340) m respectively. Fig. 5 indicates high permeability values between X161-X165 m depth interval due to porous and permeable clean oil bearing sand. Again for the depth interval of X332-X336 m high values of permeability are showing the presence of porous and permeable sand. Figs. 3 and 6 represent the plotting of water saturation with depth. Water saturation (S_W) for clean sand can be calculated using the formula given as:

$$S_W = \sqrt{R_0/R_t}$$

(R_0 is read from deep resistivity log for 100 %water bearing sand)

From the log data we get

R_0 =1 Ωm

R_t = True resistivity listed in Tables

For the first zone of interest for depth interval X130-X140 m the water saturation value is less at a depth of 135m because this zone is gas bearing. Again from the fig.6 we see that water saturation value is less in the depth interval X162-X164 m because this zone is oil bearing. High value of water saturation exists between X160-X162 m and X176-X178 m.

Conclusions

The use of well data for calculating FZI for logged depth interval is found to be an important tool to find out permeability. FZI and Permeability values are obtained for hydrocarbon bearing as well as water bearing layers. The high FZI values indicate high permeability values in hydrocarbon as well as water bearing layers. Though there are little mismatch of FZI and permeability values at depths X130-140m and X310-X320m. The water saturation value ranges from 40 to 50% in oil and gas bearing layers respectively.

References

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