Permeability estimation using Flow zone indicator (FZI) from Well log data and comparison with permeability obtained from CMR log. Case study: Field of ONGC, Ahmedabad Asset.

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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. Permeability values have been calculated for three sand layers varying thicknesses from 4 to 9 m. Flow zone indicator (FZI) for porous and permeable layers from different wells are calculated from transformation of gamma ray, neutron porosity, density, deep resistivity logs. Calculated permeability value ranges from 11 md to 24 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), NPHI (neutron porosity), RHOZ (density), LLD (true resistivity) are obtained for depth intervals: (X876-X880m) for well KL-XXX, (X161-X169m) for well AM-XX1, and (X537-X544m) for well AM-XX2. 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:

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

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

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

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

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

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

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

Calculations:

The FZI values using equation (8) are estimated for porous and permeable zones from well log data. The porous and permeable sand layers are identified from depth intervals; X871.5-X883.0m for well KL#XXX, X161-X170m for well AM#XX1 and X536.5-X549.5m for well AM#XX2 respectively. The hydrocarbon bearing sand layers corresponding to the above depth intervals are respectively from X161-X169m for well AM#XX1 and X537-X544m for well AM#XX2. The layer in the interval X161-X169m in well AM#XX1 is having resistivity value of around 1 Ω-m and is of fine grained in nature. The layer in the interval X537-X544m in well AM#XX2 is having resistivity value of 10-12 Ω-m and is siltstone reservoir in nature. The layer in the interval X876-X880m in well KL#XXX is having resistivity value of 3-8 Ω-m and is water bearing. The well log parameters like gamma ray (GR), neutron porosity (NPHI), density (RHOZ), resistivity (LLD), FZI and permeability values are listed in Tables 1, 2 and 3 for depth intervals X876-X880m, X161-X169m, and X537-X544m respectively.

Depth(m)	GR (Normalized) (gAPI)	NPHI (m^3/m^3)	RHOZ (gm/cm^3)	LLD (Ω-m)	FZI (μm)	Permeability (md)
X876.0	0.22	0.36	2.54	4.54	0.26	7.56
X876.5	0.19	0.35	2.53	5.93	0.26	6.73
X877.0	0.20	0.32	2.52	4.93	0.34	8.13
X877.5	0.20	0.34	2.57	4.49	0.30	8.16
X878.0	0.19	0.33	2.56	6.49	0.28	6.45
X878.5	0.20	0.32	2.54	6.97	0.29	6.12
X879.0	0.21	0.32	2.44	7.03	0.33	7.93
X879.5	0.19	0.33	2.46	5.73	0.33	8.69
X880.0	0.22	0.37	2.53	3.50	0.25	8.30

Table 1. Well log parameters, FZI and permeability values for Depth interval (X876-X880)m for well **KL#XXX**

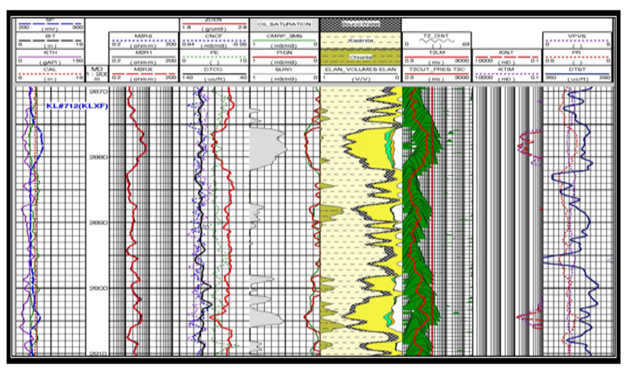
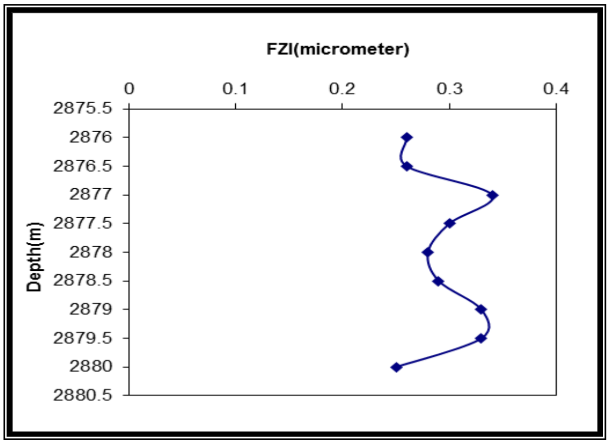
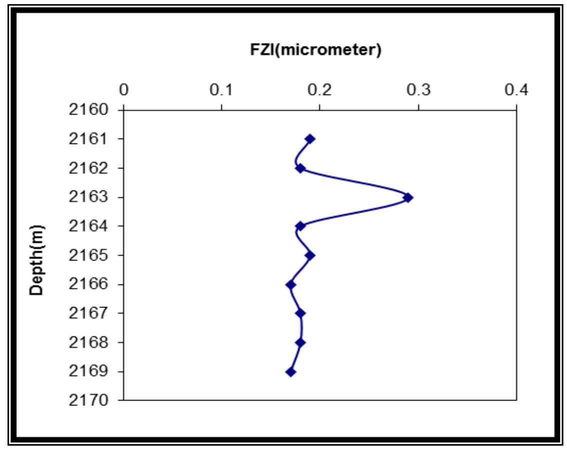


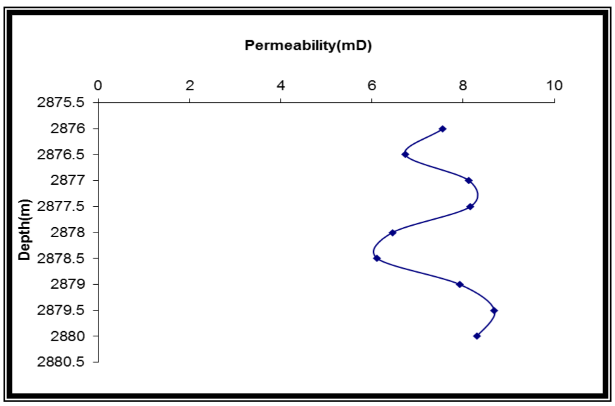
Fig 1. KTIM for well **KL#XXX**



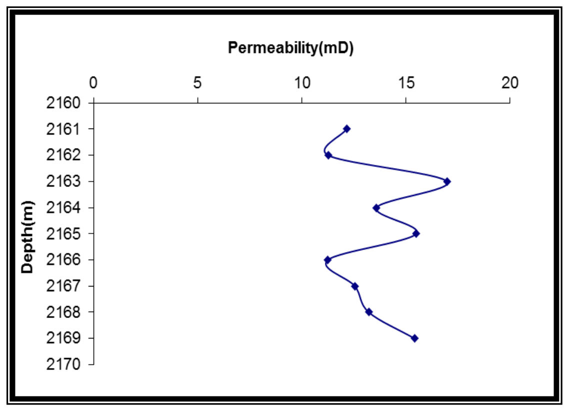
Plot. Ia: FZI Vs Depth plot for (X876-X880)m



Plot. IIa: FZI Vs Depth plot for (X161-X169)m



Plot. Ib: Permeability Vs Depth plot for (X876-X880)m



Plot. IIb: Permeability Vs Depth plot for (X161-X169)m

Depth(m)	GR (Normalized) (gAPI)	NPHI (m^3/m^3)	RHOZ (gm/cm^3)	LLD (Ω-m)	FZI(μm)	Permeability (md)
X161.0	0.20	0.46	2.40	0.50	0.19	12.16
X162.0	0.27	0.46	2.42	0.53	0.18	11.28
X163.0	0.24	0.43	2.43	0.55	0.29	16.99
X164.0	0.30	0.48	2.36	0.64	0.18	13.60
X165.0	0.23	0.48	2.34	0.69	0.19	15.51
X166.0	0.20	0.47	2.47	0.51	0.17	11.26
X167.0	0.28	0.47	2.38	0.45	0.18	12.56
X168.0	0.28	0.48	2.37	0.44	0.18	13.23
X169.0	0.24	0.50	2.38	0.44	0.17	15.43

Table 2. Well log parameters, FZI and permeability values for Depth interval (X161-X169) m for well **AM#XX1**

Depth(m)	GR (Normalized) (gAPI)	NPHI (m^3/m^3)	RHOZ (gm/cm^3)	LLD(Ω-m)	FZI(μm)	Permeability (md)
X537.0	0.27	0.50	2.33	9.11	0.20	20.35
X538.0	0.25	0.52	2.27	10.81	0.20	24.55
X539.0	0.23	0.50	2.30	10.72	0.19	18.64
X540.0	0.25	0.51	2.30	9.89	0.20	22.40
X541.0	0.26	0.50	2.31	9.79	0.19	18.72
X542.0	0.32	0.48	2.26	13.72	0.17	12.61
X543.0	0.31	0.50	2.24	13.76	0.18	16.04
X544.0	0.26	0.49	2.35	4.86	0.18	14.07

Table 3. Well log parameters, FZI and permeability values for Depth interval (X537-X544)m for well **AM#XX2**

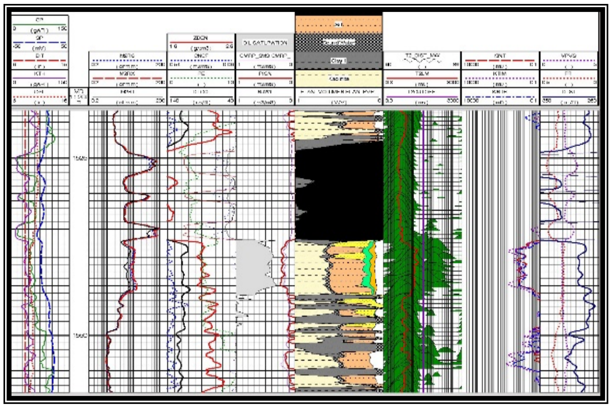
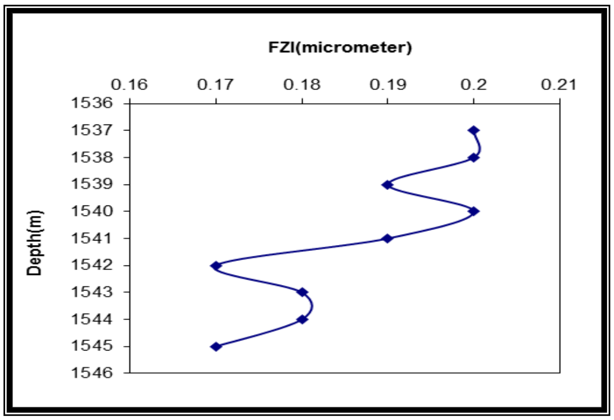
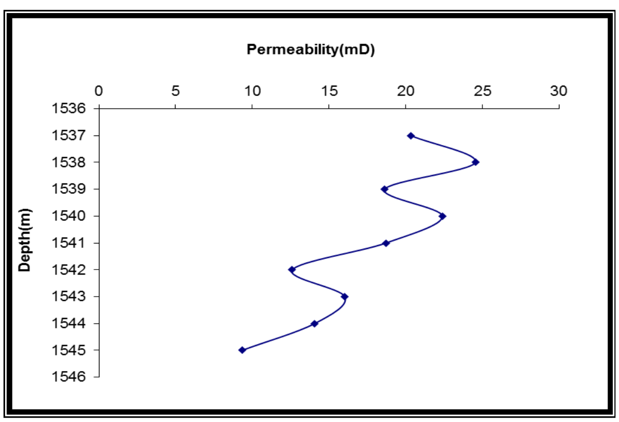


Fig 3. KTIM for well **AM#XX2**



Plot. IIIa:: FZI vs. Depth plot for (X537-X544)m



Plot. IIIb:: Permeability Vs Depth plot for (X537-X544)m

Interpretation:

Plots. Ia-IIIb represent the variation of FZI within the depth intervals of (X876-X880)m, (X161-X169)m and (X537-X544)m for wells KL#XXX, AM#XX1 and AM#XX2 respectively. FZI vs depth plots for three sand layers are indicating peak amplitude FZI with lows at either sides. The minimum FZI values are representing shales above and below these sand layers. The FZI is showing high value within the depth interval X876.5-X877.5m, X162.0-X164.0m and X537.0-X539.0m. We observe oscillating FZI variation within depth interval X537-X544m (Plot. IIIa), which matches with laminated shaly sand gamma ray log response. Among the two hydrocarbon bearing sand layers the highest FZI value (.29) has occurred at depth X163m (Plot. IIa) for oil bearing layer. The peak FZI value for water bearing sand layer is .34 at depth X877m (Plot. Ia). For shale layer, low values of FZI are observed. Plots. Ib, IIb and IIIb represent the variation of permeability values with depth intervals (X876-X880)m, (X161-X169)m and (X537-X544)m for wells KL#XXX, AM#XX1 and AM#XX2 respectively. The low permeability values are representing shales above and below the sand layers. The permeability is showing high value within the depth intervals X876.5-X877.5m, X162.0-X164.0m and X537.0-X539.0m respectively. The peak values of permeabilities are 16.99md and 24.55md at a depth of X163m and X538m for hydrocarbon bearing sand layers respectively.

Conclusions:

The use of well logs 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 clean sand and shaly sand layers as well as for water bearing layer. The high FZI values indicate high permeability values in hydrocarbon reservoir. The permeability of the hydrocarbon reservoir increases with the increase of FZI value. FZI as well as permeability decreases in shale layers. The FZI plot vs. depth serves as a lithological indicator because it differentiates permeable zone from impermeable zone. This result also matches with the variation of core permeability of sandstone samples with laboratory derived FZI values provided by previous author (Prasad, 2003).

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The permeability values computed from FZI, also matches with the permeability value obtained from CMR log wherever available (Fig.1 & Fig.3).

Acknowledgements

The authors are grateful to the management of ONGC. The authors are indebted to Asset Manager, Ahmedabad, ONGC for the motivation and permission to publish this paper. The authors also acknowledge the support and guidance rendered by their colleagues. The views presented in this paper belong to the authors only and do not necessarily represent the view of the organization to which they belong.

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