Reservoir Saturation Profiling of Using Capillary Pressure Studies On Cores

Sharath Nair. S, Hemlata Agarwal and J.K. Basumatary
Regional Geoscience Laboratories, ONGC, Sivasagar

ABSTRACT

The paper discusses the characterization of a reservoir in terms of vertical oil-water saturation distribution using Leverett's 'J' function method.

The work depicted in the paper is a part of the extensive project work carried out for the estimation of effective porosity, permeability and pore size distribution of BMS sand of Geleky field of Upper Assam Shelf North, Assam & Assam Arakan Basin in the year 2017-18 with the objective of integration of Lab data with Log data by determining primarily the effective porosity of the core plugs. The studies were also intended to reveal the pore size distribution framework of the cores and their effects especially in variation in irreducible water saturation (Swirr) of different cores of the same sand.

The focus area of the paper is thedata derived from capillary pressure studies on the core plugs which are used to calculate the oil and water saturations at any height above the free liquid surface by incorporating Leverett's 'J' function.The profile thus drawn can be integrated with Logs for better characterization of reservoir and to fill up the gaps in the oil and water saturation profile wherever required.

INTRODUCTION

Welge and Bruce applied the equation derived from the vertical forces in a capillary tube for the calculation of vertical water-oil saturation distribution as a function of height for hydrocarbon reservoirs provided the capillary pressure and saturation data are available which is given as:

$$h(m) = \frac{0.102Pc}{\rho w - \rho o}$$

where:
h is the height of capillary rise in m;
pw and po are the densities of water and oil, respectively, in g/cm3 and capillary pressure Pc, is in kPa.

Thus Capillary pressure data of core plugs can be useful to calculate reservoir saturations provided a realistic average capillary pressure curve can be derived for a particular rock type.

Capillary pressure data are normally obtained on small core samples that represent an extremely small part of the reservoir and, therefore, it is necessary to combine all capillary data to classify a particular reservoir.

At first, Leverett made an attempt to convert all capillary pressure data to a universal curve. But, a universal capillary pressure curve does not exist because the rock properties affecting capillary pressures in reservoir have extreme variation with lithology (rock type). Realizing that capillary pressure should depend on the porosity, interfacial tension, and mean pore radius, Leverett defined a new dimensionless function of saturation called the J-function and represented as:

$$J = P_C * \frac{\sqrt{\frac{k}{\Phi}}}{\sigma * \cos(\theta)}$$

which is derived from $P_C = 2\sigma \frac{\cos\theta}{r}$ (Young-Laplace equation)

Where,
P_C is the capillary pressure in Pascal (N/m^2), k is the permeability in m^2, Φ is the porosity in fraction, σ is the interfacial tension in Newton/metre, θ is the contact angle in degrees.

The Leverett J-function is an attempt at extrapolating capillary pressure data for a given rock to rocks that are similar but with differing permeability, porosity and wetting properties.

The individual J values as obtained above is then averaged by performing statistical regression analysis to obtain Average 'J' value which is a function of saturation:

$$JSW\ (Avg.) = \left(\frac{A + BSw}{1 + CSw}\right)$$

The three constants A, B and C are determined by least square method.

The above calculated J(Average) is used to calculate average Capillary pressure value which takes into account the heterogenous rock characteristics in terms of Porosity and Permeability within the same formation:

$$Pc\ (Avg.) = J(Sw) * \sigma * \cos(\theta) * \sqrt{\frac{\Phi\ (avg.)}{k\ (avg.)}}$$

Where, $\Phi\ (avg.) = \Sigma\phi_i/n$ and $k\ (avg.) = (\Pi k_i)^{i/n}$

P_C (Avg.) is the capillary pressure in Pascal, k is the permeability in m^2, Φ is the porosity in fraction, σ is the interfacial tension in Newton/metre, θ is the contact angle in degrees.

Height of saturation above the free water level is calculated as follows:

$$h\ (m) = \frac{Pc}{pxg}$$

(another form of equation derived by Welge and Bruce)

Where,
h, is height in m, P_C is the capillary pressure in Pascal, ρ is the difference in densities between the reservoir fluids in Kg/m^3 = 200 Kg/m^3, g is acceleration due to gravity = 9.8 m/s^2.

Experımental and Methodology

Three conventional cores of BMS sand from three wells (WL-1, WL-2, WL-3) of Geleky field were identified for the studies and 41 cylindrical shaped core plugs of one inch diameter and about two inches in lengths were cut from the segments with reservoir facies. The core plugs were then polished to make the end faces parallel and then extracted with a mixture of suitable solvents by soxhlet extraction process to clean the pore spaces occupied by residual fluids. Cleaning was followed by drying at around 90^0C. After proper cooling, samples were placed in a desiccator with suitable desiccant such as fused calcium chloride to absorb excess moisture. The length, diameter and weight of the dried and cooled sample were accurately measured.

Basic studies

Porosity and Permeability data were generated by the equipment Poroperm (Vinci Make) which employs Boyle's law method for porosity determination and unsteady state pressure fall off method for permeability determination. The gas permeability was determined directly from the equipment and the inbuilt software performed Klinkenberg correction to calculate equivalent liquid permeability.

Capillary pressure studies

Capillary pressure studies were carried out on 12 selected core plugs to determine pore throat distribution and irreducible water saturation. The equipment used to measure these parameters is the Capillary pressure apparatus consisting of porous plates and works on Air-Brine system.

The plugs were saturated with brine and the same were placed on a porous plate. Certain minimum pressure was applied on top of the core specimen and the brine within the core specimen was allowed to drain through the porous plate. The capillary pressure, p_C is equal to the difference between the air pressure and the brine pressure. When equilibrium was achieved, the volume of brine expelled was read from the pipette which was fixed in the drainage line. The pressure was then increased and new equilibrium was attained. A capillary pressure curve was obtained by plotting the water saturation and the corresponding applied capillary pressure in the x- and y- axis, respectively. The experiments with the core plugs showed that Sw_{irr} was achievable at about 40-50 psi. From the Capillary pressure data, the pore throat distribution, irreducible water saturation were determined and the vertical saturation profile of the reservoir was drawn.

Findings/Results

The Basic petrophysical data obtained are as given in Table-1.

Vertical saturation profiling

The capillary pressure vs saturation curves of some of the individual plugs looked like as shown in Fig.1 The composite plot of capillary pressure vs saturation of all the studied plugs is shown in Fig.2

Capillary pressure data of all the studied plugs were assembled to reduce them into a single curve. Realizing that capillary pressure should depend on

Table 1:

Sl. No.	Well	Core No.	Porosity (%)	Permeability (mD)
1	WL-1	CC-1	9.9 - 16.8	1.2 - 83.7
2	WL-1	CC-2	5.2 - 13.4	0.4 - 13.8
3	WL-2	CC-2	7.2 - 17.1	0.2 - 94.5

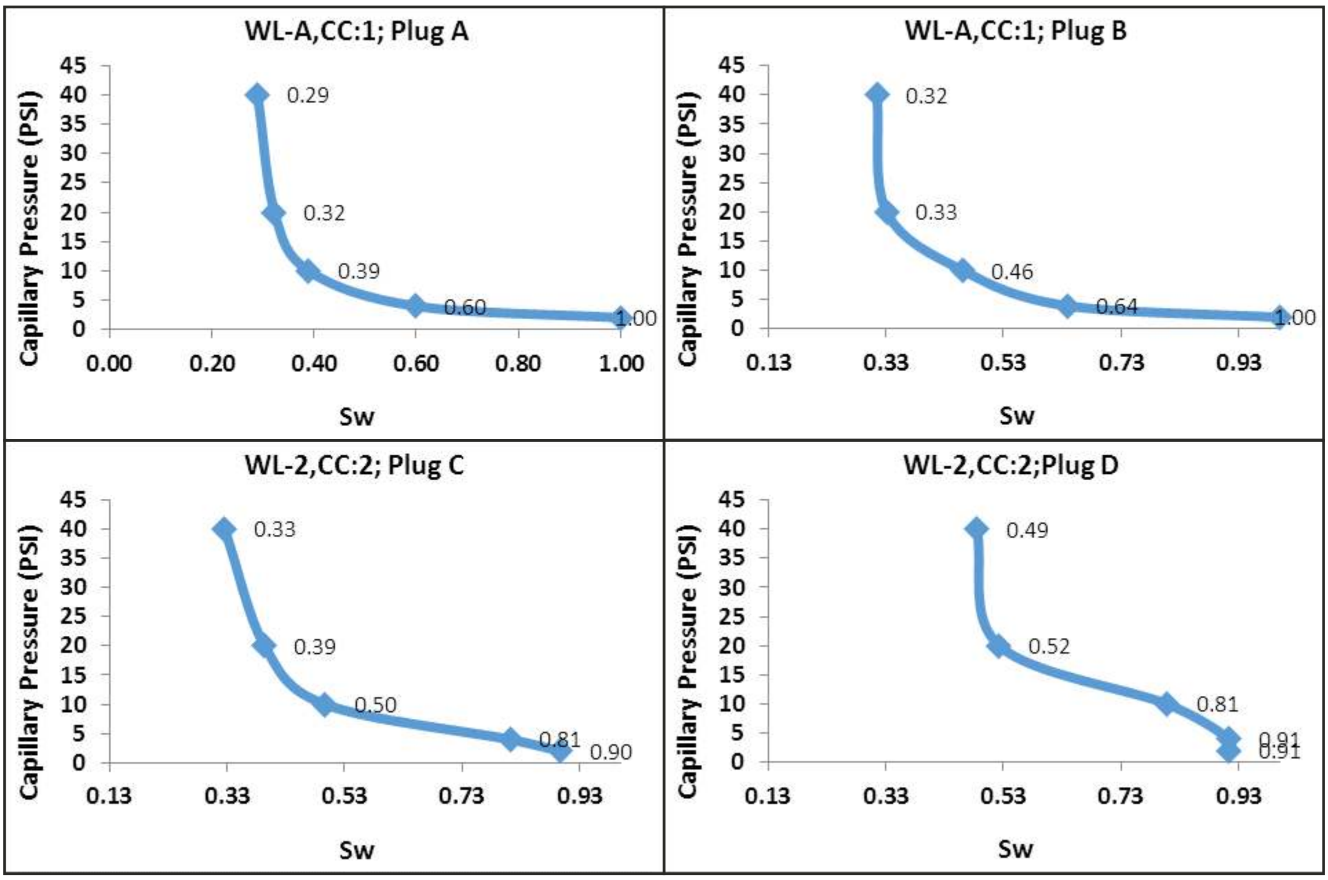


Fig. 1: Capillary pressure vs saturation curves of individual plugs

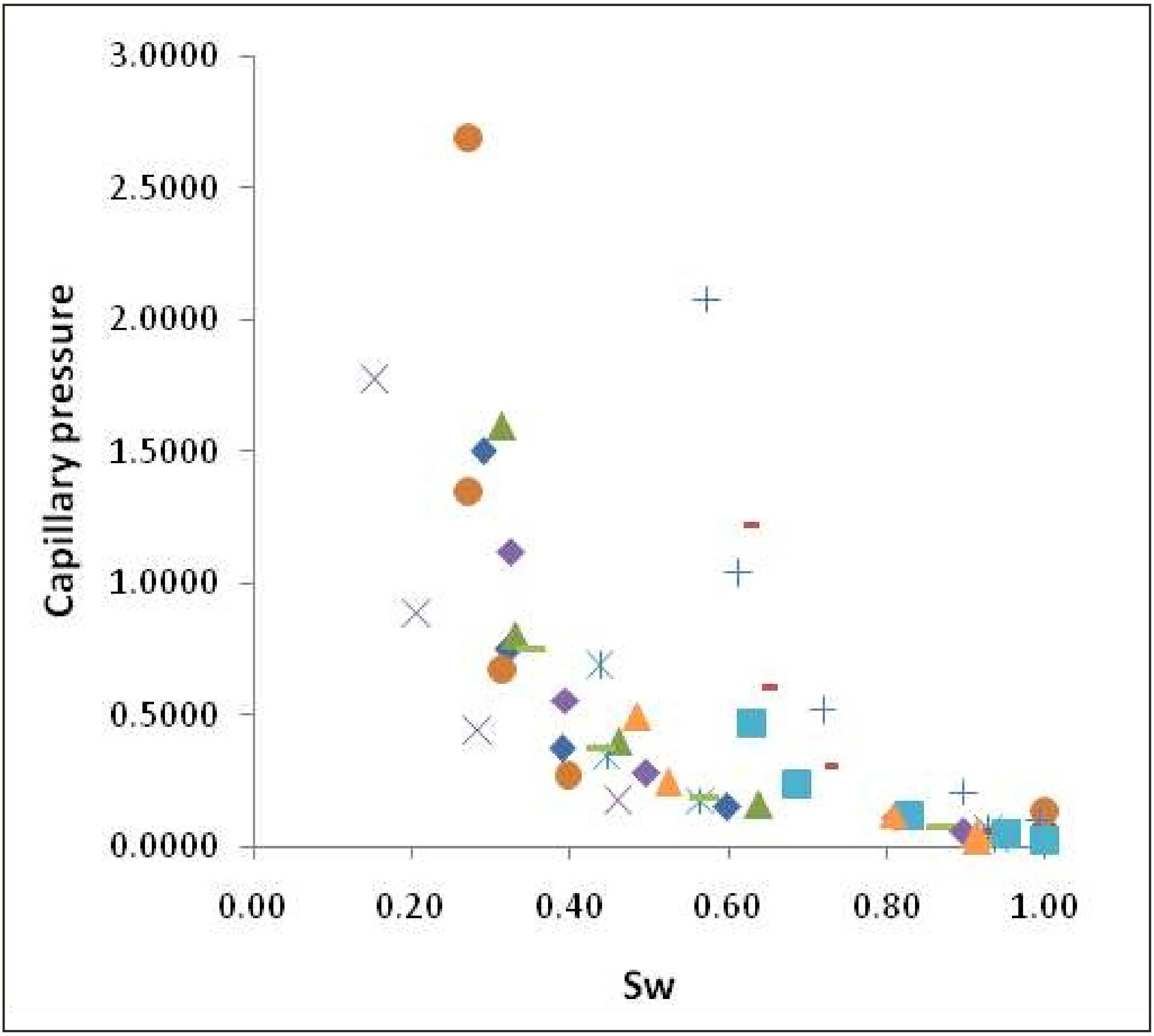


Fig. 2: Composite capillary pressure vs saturation plot of all studied plugs

the porosity, interfacial tension and mean pore radiuse, J function was introduced keeping all these factors.

The J function calculated for each capillary pressure data was plotted against water saturation (S_w) and is shown in Fig.3.

From the Individual J function values, average 'J' as a function of S_w was calculated and is presented in Fig. 4.

From The Average 'J' value, average capillary pressure and height above free water level was calculated and tabulated as shown in Table-2.

The capillary pressure and height above free water level were plotted against saturation and depicted in Fig. 5.

From Fig. 5, it is seen that the height from 3.5 m to 41 m above free water level might have been the transition zone. The average irreducible water saturation is expected to be around 45%.The Vertical saturation profile shown in Fig. 5 can be converted into actual drilled depth vs. saturation of water.

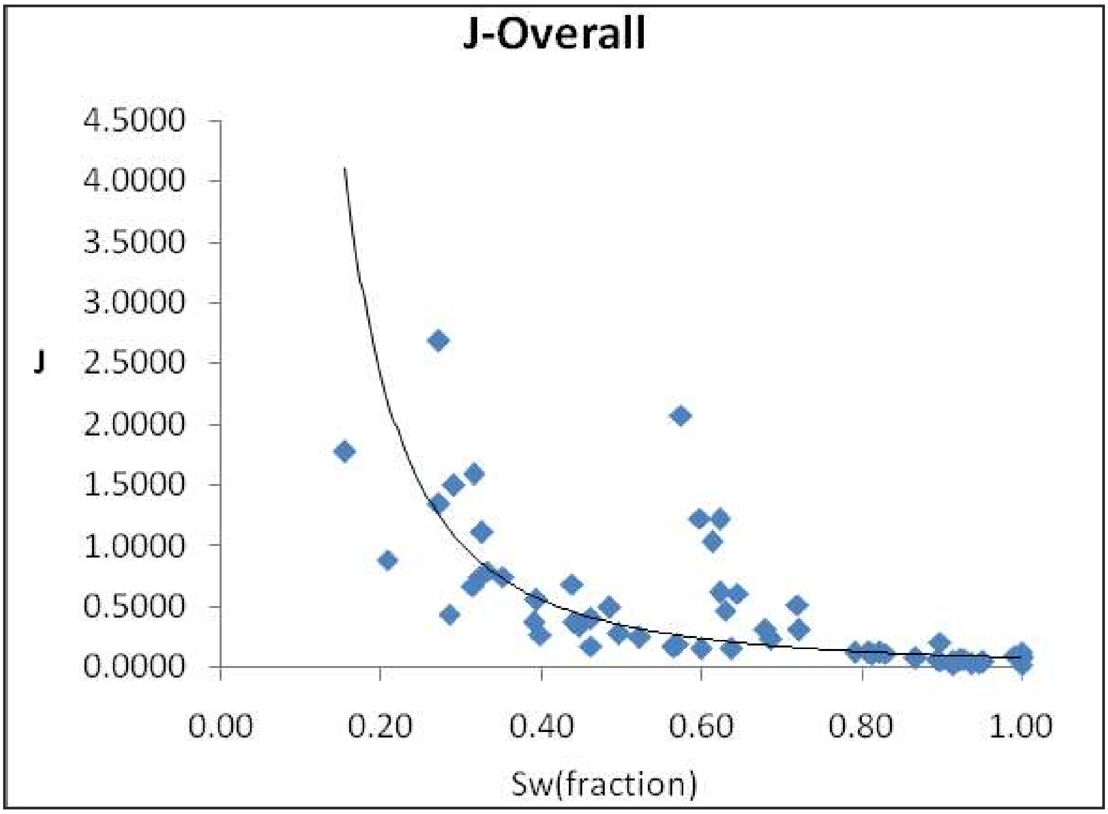


Fig. 3: J function vs saturation $J = P_c * \frac{\sqrt{\frac{k}{\Phi}}}{\sigma * \cos(\theta)}$

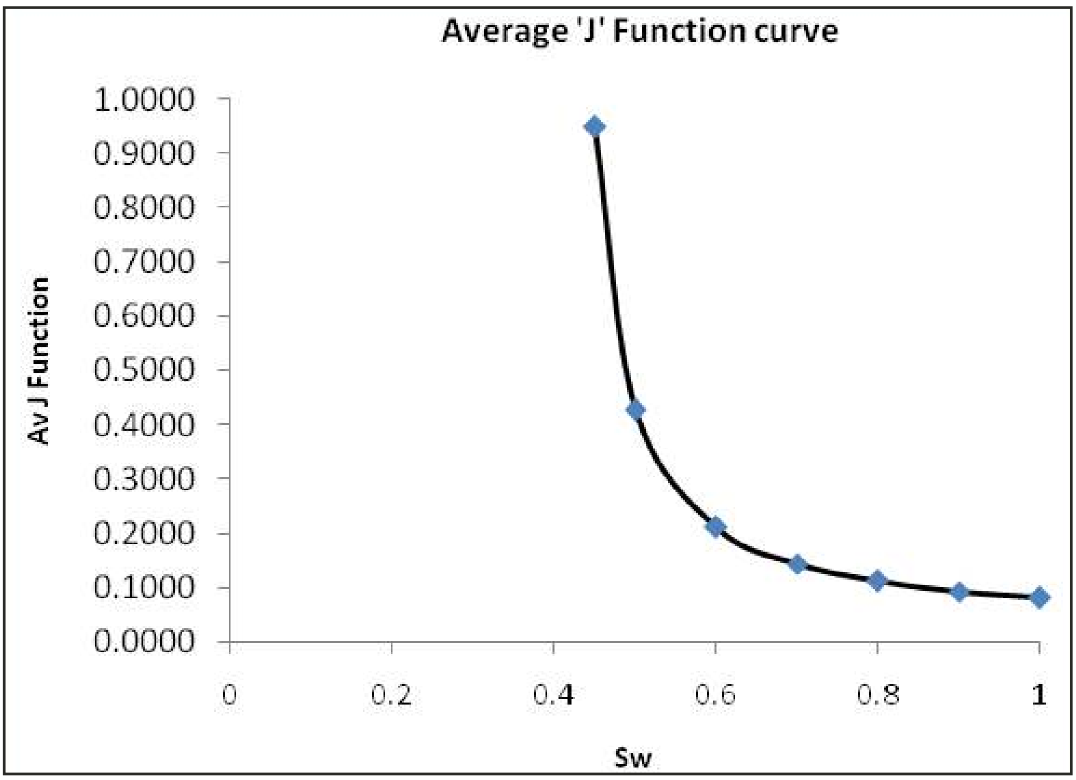
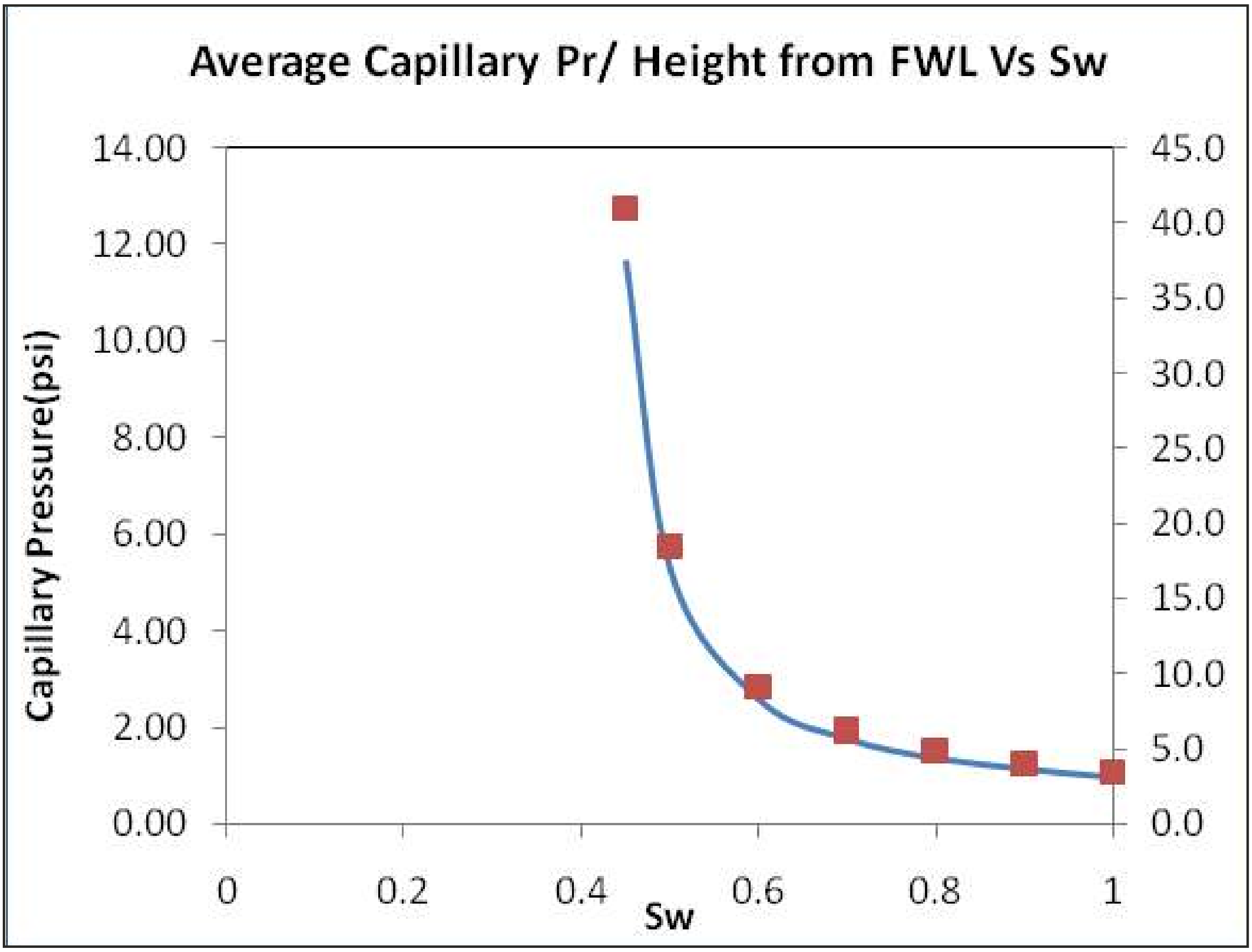


Fig. 4: Average 'J' as a function of S_w **Jsw (Avg.)** = $\left(\frac{A + BSw}{1 + CSw}\right)$

Table 2: Average 'J' value, average capillary pressure and height above free water level Oil-Water contact = 4074 m

Sw	J	Pc(psi)	h(m)	Ht from OWC	Depth
1	0.0806	0.9895	3.48	0.00	4074.00
0.9	0.0933	1.1453	4.03	0.55	4073.45
0.8	0.1125	1.3812	4.86	1.38	4072.62
0.7	0.1450	1.7801	6.26	2.78	4071.22
0.6	0.2119	2.6005	9.15	5.67	4068.33
0.5	0.4284	5.2582	18.50	15.02	4058.98
0.45	0.9498	11.6584	41.01	37.53	4036.47



$$P_C\,(Avg.) = J(S_w) * \sigma * \cos(\theta) * \sqrt{\frac{\Phi\,(avg.)}{k(avg.)}}$$

$$h\,(m)\ \frac{P_C}{pxg}$$

Fig. 5: The capillary pressure and height above free water level vs Sw

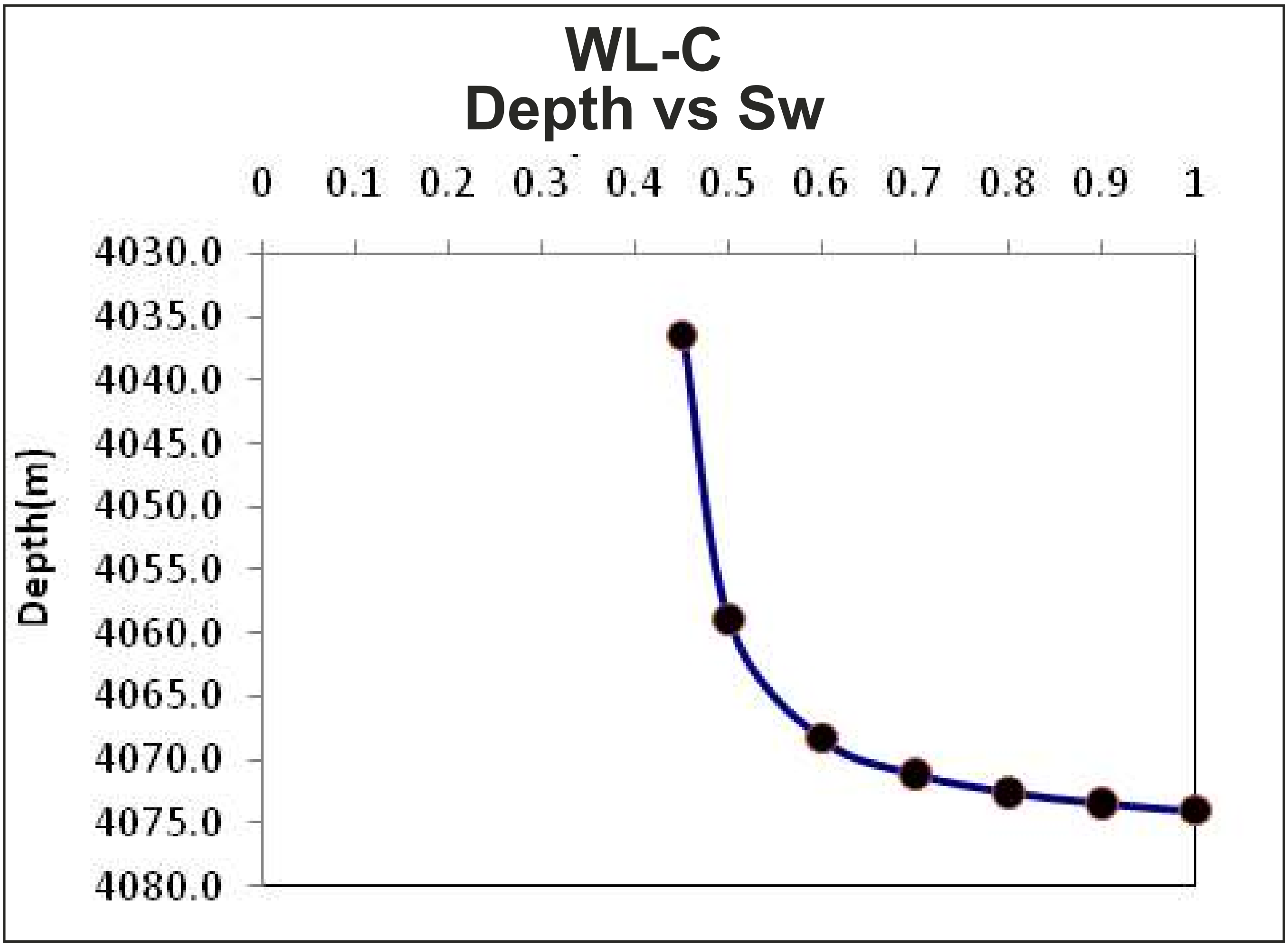


Fig. 6: Depth vs Sw

The depth vs saturation plot can be prepared as shown in Fig. 6 if OWC is known and from which depth at which water saturation is irreducible can be depicted.

CONCLUSIONS

- The average irreducible water saturation of 45% was obtained at a height of about 41 m above zero capillary pressure level
- The height upto 41m above zero capillary pressure level might have been the transition zone.
- The height above 41 m from free water level is the free oil zone provided the reservoir thickness extends upto that level
- The zone where were saturation of water is the lowest as per the plot is 4035 – 4060 m.

The view expressed in this paper are those of authors only.

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Capillary pressure techniques: Application to exploration and development Geology – Jeffry.B.Jennings (1987) The American association of Petroleum Geologists Bulletin, V.71, No.10(Oct 1987) P.1196-1209Fig.65 – Plot of J function (overall) vs Sw.

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