ESTIMATION OF HEIGHT OF OIL -WATER CONTACT ABOVE FREE WATER LEVEL USING CAPILLARY PRESSURE METHOD FOR EFFECTIVE CLASSIFICATION OF RESERVOIRS IN THE NIGER DELTA

E.C. Okolie[1] **and O. Ujanbi**[2]

[1] *Department of Physics, Delta State University,Abraka, Delta State, Nigeria*

[2] *Department of Physics, Ambrose Alli University, Ekpoma, Delta State, Nigeria*

(Submitted: 31 March, 2007; Accepted: 17 September, 2007)

Abstract

An estimate of oil-water contact (OWC) and the understanding of the capillary behaviour of hydrocarbon reservoirs are vital for optimum reservoir characterization, hydrocarbon exploration and production. Hence, the height of oil-water contact above free water level for different rock types from some Niger Delta reservoirs were estimated here. Data obtained from oil-displacing brine (drainage) capillary pressure tests using refined oil as simulated brine formation or reservoir fluid on various rock samples were utilized to illustrate the basic capillary behaviour of ten hydrocarbon reservoirs within Niger Delta of Nigeria and to estimate the (OWC) above Free Water Level. Almost all the samples show plateau prominence and high permeabilities of (422-4110) x 10^{-12} Hm^{-2} at very low displacement pressures with well sorted grains which is indicative of good reservoirs This is further confirmed by their low heights of 100% water saturation above free water level of 2.11m, 1.41m, 2.46m, 1.05m, 2.07m, 1.72m, 1.79m, 1.76m, and 1.05m, and corresponding to a depth range of 3030 to 3261 m which indicate good quality reservoirs. Only one sample showed evidence of low yield reservoir with high height of 5.62m at a depth of 3266 m. The derived knowledge of water density, oil density and saturation height function adequately estimates the quality of reservoirs and classify them in terms of prominence of the plateaux and channels. The results show that the typical Niger Delta reservoirs are of good quality as confirmed by the relatively low shale presence.

Keywords: *Oil-water contact, capillary pressure, reservoir characterization, saturation height function and permeabilities*

Introduction

Capillary behavior is one of the most important factors which determine the distribution of hydrocarbon. Detailed understanding of the capillary force of a reservoir is therefore vital for effective reservoir characterization. The rise of water in the capillary tube experiment is initiated by a capillary force. This force is balanced by the weight of the rising liquid. The same principle governs the migration of hydrocarbons in porous reservoirs which may be viewed as a bundle of straight cylindrical capillaries with varying diameters. In this model, the oil water contact (OWC) is the depth at which oil and water start entering the pores in the rock. Thus, it is the depth below which water saturation is 100%.The zone of 100% water saturation exists above the free water level (FWL). The (OWC) in a reservoir is dependent on lithology or formation strata of the field.

Estimate and recognition of fluid contacts such as oil water contact OWC) in reservoirs are essentials for reservoir characterization and evaluation of hydrocarbon in place (Acher, 1986) and (Adam, 1993).

A particular difficulty in evaluating hydrocarbon water contacts in most reservoirs in Niger Delta is as a result of increased shaliness which is manifested in small pore throats as high capillary pressure and high water saturation. Fluid contacts are represented as depth ranges in well test intervals until data from several reservoirs are correlated due to gradient extrapolation uncertainties in fluid properties.

There are numerous reasons for predicting, determining, confirming and exploring a reservoir saturation profile. Unfortunately well logs do not provide a complete picture due to insufficient column penetration and reservoir inhomogeneity. This calls for other profiling approaches. Hence, the capillary tube model is used to illustrate the basic capillary behaviour of hydrocarbon reservoirs. Here capillary curves of some reservoir rocks in Niger Delta were obtained using laboratory capillary measurements. The influence of wettability and fluid saturation are treated with a view to estimating and improving reservoir characterization. Results show that (i) the Oil Water Contact (OWC) varies with depth in water- wet reservoir where the OWC is relatively close to the free water level (FWL). Conversely, as pore radius reduces, the OWC above FWL increases. Thus, lower permeability results in a larger separation between OWC and FWL. Hence, one effective approach in estimating height of oil -water contact above free water level of rocks for effective classification of reservoirs is the capillary curves profile which shows capillary pressure as a function of fluid saturation. This is the thrust of this work. To effectively carry out the work, the oil and water densities as well as saturation height function for a particular reservoir were obtained by capillary pressure analysis (Catalan, 1992). The capillary pressure and water saturation curve was then used to deduce rock types and properties such as permeability and grain size distribution and to evaluate hydrocarbon in place using the height of OWC above FWL.

Materials and Methods

Materials:

1. Ten cleaned and prepared drilled core samples from study field for Capillary pressure test
2. Simulated brine formation (Ammoniacal brine solution NaCl + NH3 in water)
3. Specially designed centrifuge receptacle 4. Refined mineral oil Oil and brine (drainage) Centrifuge.

Capillary Pressure Test

The ten cleaned and prepared core samples used for the study are reservoir rock samples for identification and lithological description (Appendix 1a and 1b). They were drilled from points that were as close as possible to the wells of interest. The simulated brine is used to represent the real reservoir water formation since its behaviour in the laboratory is very similar to that of the reservoir fluid formation and it has been used to predict the reservoir characteristics correctly over a long time. Thus its reliability in serving as the wetting fluid has been tested and is trusted.

Reservoir rock types are classified into three:-

1. The upper shore face (USF) which has high permeability and porosity because of its uniform large grain size. This is the main sand stone
2. The lower shore face which has lighter grains which are brown/grey fine grained and may contain iron minerals.
3. The shale which is fine grained and impermeable rock is highly compact and cemented.

The specially designed centrifuge receptacle is an apparatus that holds core samples that are already saturated with brine in an oil environment while spinning or rotating at high speed which is proportional to a given pressure. Under this condition, the oil forces the water out due to the pressure exerted by the centrifuge receptacle. Refined oil is used as the non wetting phase displacing wetting phase. In a reservoir capillary and buoyancy forces are balanced. The buoyancy forces are initiated by gravity with density differences of the reservoir fluids. The capillary force is a function of pore throat radii, interfacial tension and wettability.

Each sample was then replaced in a specially designed centrifuge receptacle that was filled with a low viscosity refined mineral oil, and the core plugs were increased incrementally to generate equivalent pressures ranging up to 82.8 x 10 3 Nm^{-2} or greater in an oil-displacing-brine system. Sufficient time was allowed at each rate or rotation for equilibrium within the samples to be established, and the volume of water displaced from each sample at each rate was recorded (Archer, 1986).

Displacement volume and equivalent pressure data obtained were used to calculate the capillary pressure saturation relationship. In analyzing the data obtained from the tests, capillary curves were drawn for each of the samples from the various rock types. Using the knowledge of the saturation height function, oil and water densities, water saturation above free water level, the rock samples were estimated to about 95% accuracy.

The height of OWC above FWL for each site is calculated using the equation (Archer 1986)

$$H = \frac{Pct}{g(l_w - l_o)} = \frac{2\sigma Cos\theta}{r(l_w - l_o)g} \qquad (1)$$

Where, H = height of OWC above FWL, = threshold capillary pressure (read from the graphs); lw = water density (1.0 x10^3 kg/m^3), lo = oil density (0.7 x 10^3 kg/m^3) σ = interface tension, = acceleration due to gravity (9.81 m/s^2) and from equilibrium situation, where capillary force per unit area P is given by

$$P = \frac{2\sigma Cos\theta}{r} \qquad (2)$$

and is balanced by gravity initiated force, $h((l_w - l_o)$ where r = pore radius,

Table 1: Capillary pressure test data; oil displacing brine drainage

Pressure (psi)			0.5	1	1.5	2	4	6	8	10	12
Pressure x 1000 (N/m²)			3.5	6.9	10.4	13.8	27.6	41.4	55.2	69.0	82.8
Sample number	Test depth (feet)	Depth (metres)	Drainage: Oil Displacing Water (Sample Ammoniac Brine saturation % por								
1	9940.2	3029.8	-----	38.3	----	23.0	16.0	12.8	12.5	11.8	---
2	9975.2	3040.4	21.1	17.3	----	12.2	8.9	7.6	5.8	5.6	5.6
3	10040.1	3060.2	-------	27.5	----	18.3	14.0	13.6	13.2	13.0	12.5
4	100709	3069.6	42.7	26.2	----	17.5	11.2	8.6	7.1	5.6	4.3
5	10110.1	3081.6	-----	12.5	-----	8.6	5.7	4.4	4.0	3.6	3.3
6	10129.9	3087.6	85.7	63.5	----	38.8	25.5	19.8	17.1	14.4	13.5
7	10140.7	3090.9	100.0	77.1	----	52.0	34.7	26.7	23.2	20.7	18.9
8	10650.3	3246.2	30.0	24.4	----	18.1	13.1	10.4	9.0	8.1	7.9
9	10699.9	3261.3	58.2	46.0	----	30.9	17.1	15.7	14.9	14.4	14.0
10	10714.9	3265.9	-----	----	98.1	88.5	65.4	54.6	48.5	42.0	---

Table2: Estimated height of 100% water saturation above free water level (m)

Sample number	Depth (feet)	Depth (metres)	Permeability to air x 10 $^{-12}$ H/m^2	Percentage porosity	Height of 100% saturation abo (metres) H=Pc/g(e$_w$
1	9940.2	3029.8	855	21.0	2.11
2	9975.2	3040.4	3410	23.2	1.41
3	10040.1	3060.2	419	23.2	2.46
4	100709	3069.6	1030	22.8	1.05
5	10110.1	3081.6	4110	25.2	2.07
6	10129.9	3087.6	512	14.9	1.72
7	10140.7	3090.9	243	24.4	1.79
8	10650.3	3246.2	1570	21.4	1.76
9	10699.9	3261.3	422	23.8	1.05
10	10714.9	3265.9	44	20.7	5.62

lo = oil density l_w = water and θ =contact angle.

Results and Discussion

The capillary tube pressure test is used to illustrate the basic capillary behavior of hydrocarbon reservoirs. The results obtained are displayed on Tables 1 and 2 below.

Prominent plateau at a very low pressure is indicative of a good reservoir. From the capillary curves of the various samples, it is evident that the more prominent the plateau the higher the permeability of the rock types. The capillary curves for samples 2, 4, 5, and 8, reflect high permeabilities of (3411, 1030, 4110 and 1570) x 10^{-12} H/m^2, respectively, with plateau prominence at very low displacement pressures of 0.59 Psi, 0.40 Psi, 0.50 Psi and 0.30 Psi ie 4071Nm^{-2}, 2760 Nm^{-2}, 3450 Nm^{-2} and 2070 Nm^{-2} respectively and the capillary curves are indicative of wells with sorted coarse grains. Their high permeabilities, percentage porosity and grain size distribution are further confirmed by the low values of height of 100% water saturation above FWL obtained as 2.07 m, 1.41 m, 1.76 m and 1.054 m respectively. These are properties exhibited by canals and upper shore face. The properties are indicative of good quality reservoirs. The capillary curves for samples 2, 3, 6, 7 and 9 indicate lower permeabilities than those of the samples discussed above. Their grains are not poorly sorted although the relatively low permeabilities of this set of reservoirs indicate higher clay content than the first set. The prominence of their plateaux is good enough for good quality reservoirs. Channels with these properties and low height of 100% water saturation above free water level are good quality reservoirs (Figs 1-4) (Adams, 1993).

Conversely, the shape of the capillary curve for sample 10 has a plateau that is not prominent, with a relatively higher entry of displacement pressure (Fig. 5). This reflects its low permeability (44 x 10^{-12} H/m^2) and a relatively higher height of 5.60 m of 100% water saturation above FWL. The shape of the capillary curve shows that the grain distribution consists

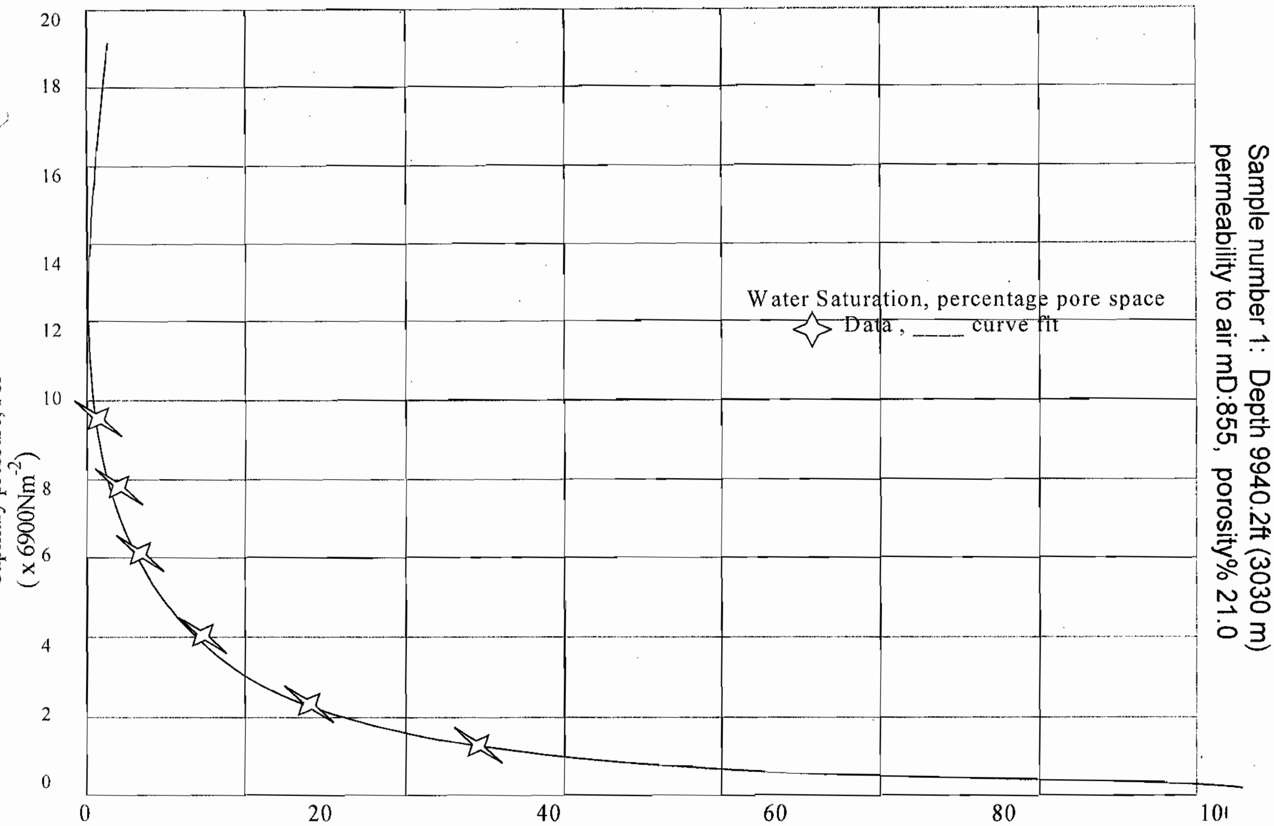

Fig 1: Oil-brine centrifuge capillary pressure system plot
Sample 1

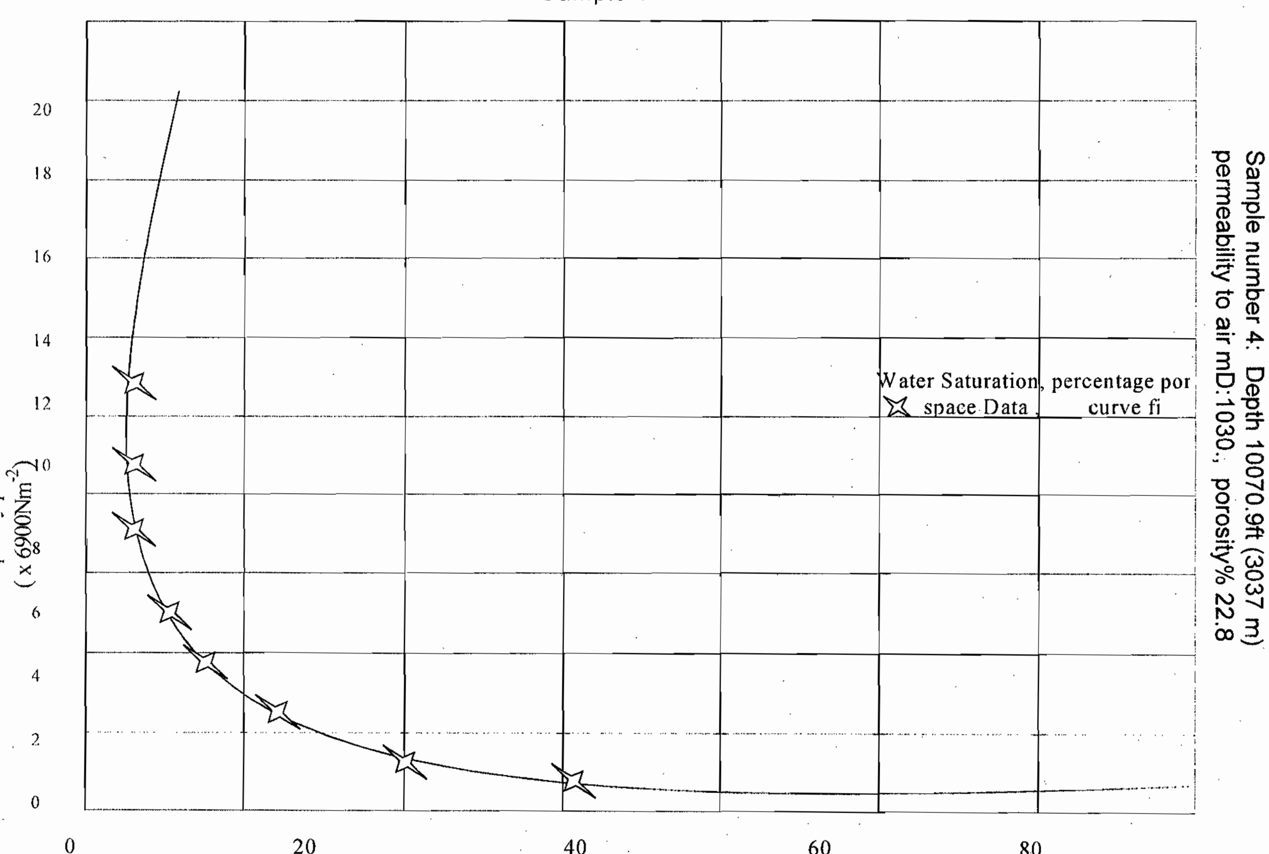

Fig 2: Oil-brine centrifuge capillary pressure system plot
Sample 4

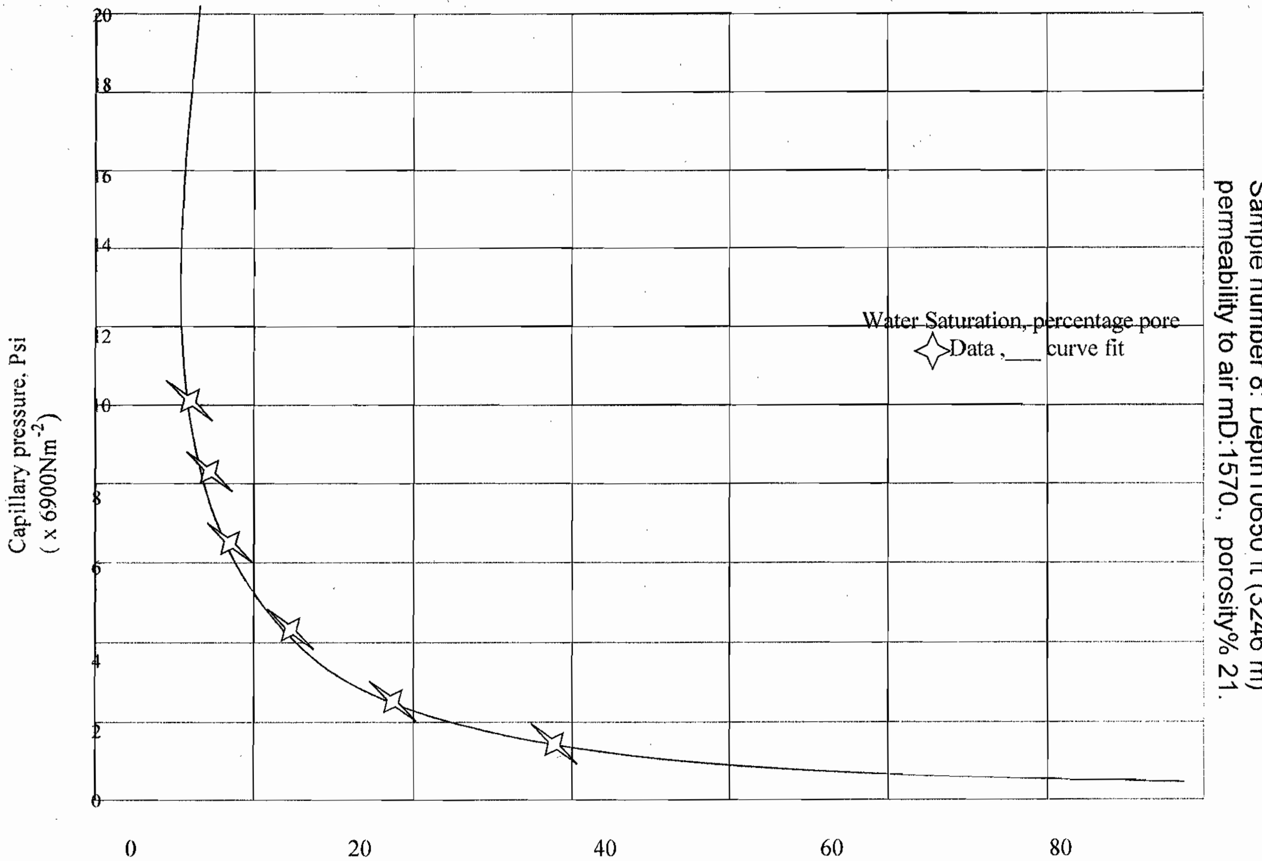

Fig 3: Oil-brine centrifuge capillary pressure system plot
Sample 8

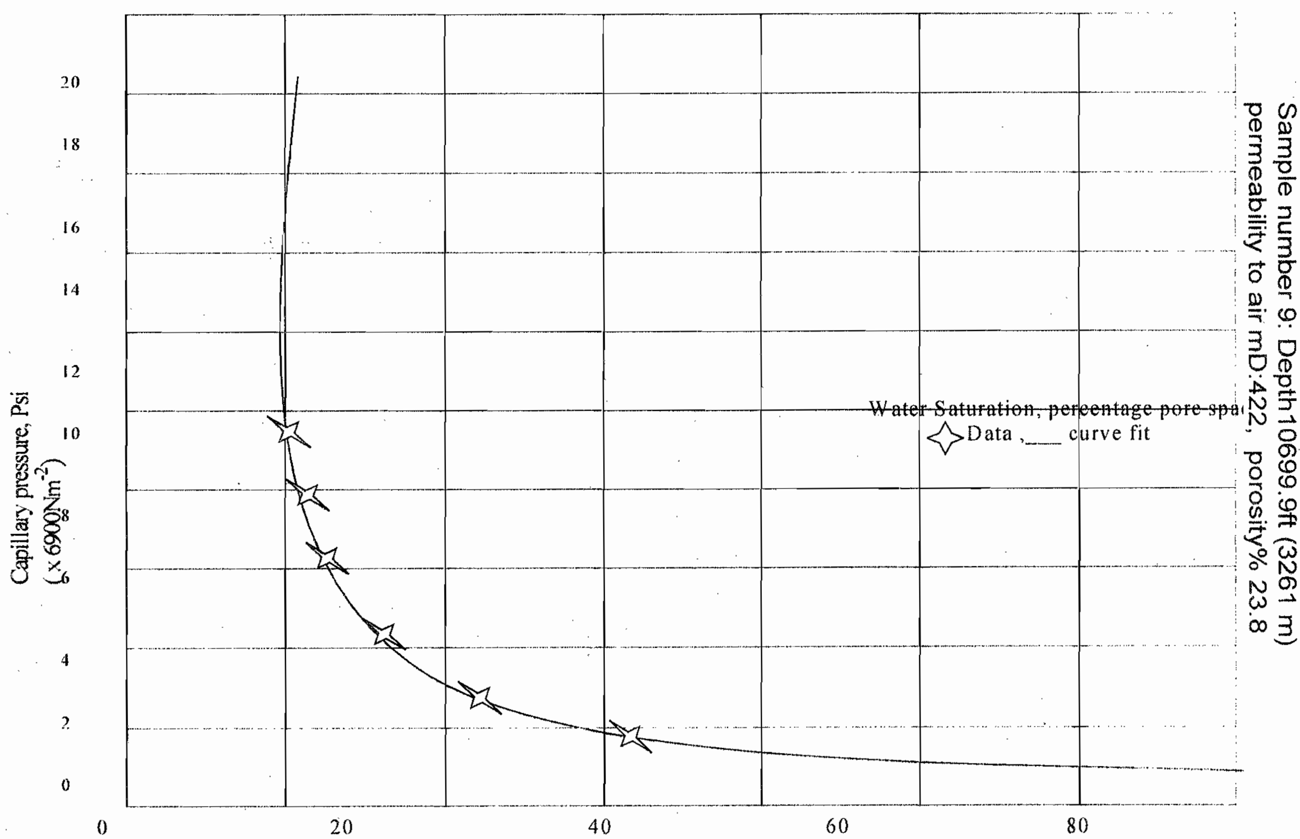

Fig 4: Oil-brine centrifuge capillary pressure system plot
Sample 9

of poorly sorted to medium size formation with a lot of clay which is indicative of upper and lower shore face with shale.
The variation in the height of OWC which is equivalent to the height of 100% water saturation above FWL, in this typical Niger Delta reservoir ranges of 1.0m to 2.5m corresponding to a depth range of

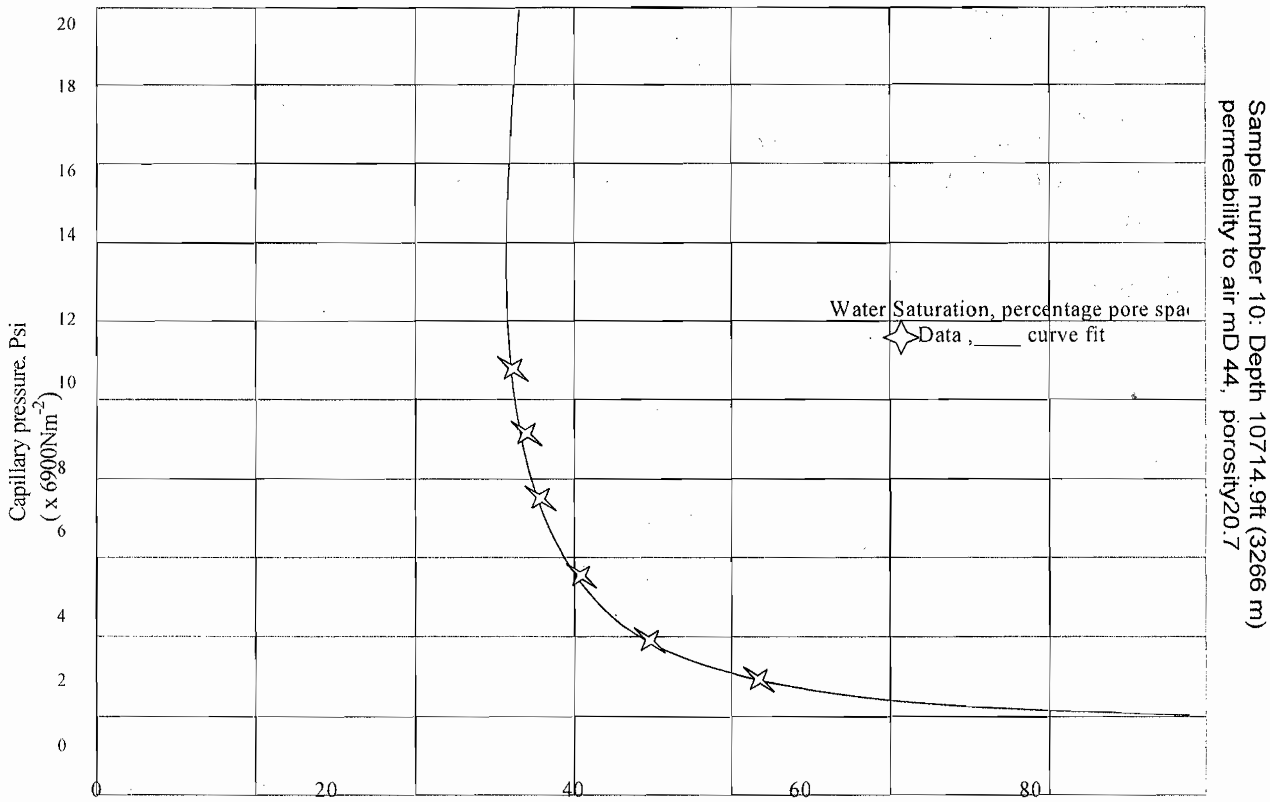

Fig 5: Oil-brine centrifuge capillary pressure system plot
Sample 10

3030 to 3261 metres with a sharp rise of 5.6m at a depth of 3266 m

In reconciliation with log data from wells that cut through the field, the various rock types are found to be from good quality reservoirs (Table A 1).

Conclusion and Recommendation

The hydrocarbon water content in a reservoir will vary in depth depending on the reservoir quality. In general lower permeability results in larger separation between the OWC and the FWL.
Given the various core samples (1-10) the height of 100% water saturation above FWL is estimated to be 2.11m, 1.41m, 2.46m, 1.05m, 2.07m, 1.72m, 1.79m, 1.76m, 1.05m, and 5.62m respectively) by capillary pressure analysis of oil displacing brine centrifuge drainage using the knowledge of oil density, water density and the saturation height function. The results discussed above indicate that the field consists of good quality reservoirs. This is further confirmed by the relatively low shale content in the reservoir. This is indeed typical of a typical Niger Delta oil field or reservoir.

The following recommendations are made:
Quality control capillary curve measurements using Computer Tomography (CT scan) are necessary to enhance assessment of reservoirs and oil wells.

Understanding of the fluid behavior

around the gas-oil contact needs to be improved. For example interaction between capillary forces (wettability, interfacial tension) and gas dissolution into oil and/or water are poorly understood near the gas oil contact.

References

Abdulin, F (1985): Production of Oil and Gas. MOSCOW Mir Publishers, 8 - 10.

Adams, S. J (1993): Capillary Pressure and Saturation Height Functions. Shell International Petroleum Maatschappij B.V. The Hague 5-6, 51-53, 76-79.

Allington. A.V. (1982): Capillary Consideration in Field Appraisal. Grouy Prod. Geology Petrophysics Conference; The Hague

Anderson W. C. (1987): Wettability Literature Survey Part 4: The Effect of Wettability Capillary Pressure; JPT

Archer J. S (1986): Petroleum Engineering Principles and Practice. London: Grayer and Trotman, Pages 10, 92 -100.

Catalan, L (1992): An Experimental Study of Secondary Oil Migration. America Association of Petroleum Companies (AAPC) Bulletin, 76 (5)

Hoaken G.A, (1991): Reservoir Engineering Usage of Capillary Pressure, EP 0775 European Petroleum.

Appendix

APPENDIX 1a: Standard Abbreviation for Lithological Description
1. sst- sandstone, 2. brn- brown, 3. gry- grey, 4. gr- grain, 5. cmt- cemented,
6. lam- laminated. 7. fe- iron, 8. min- mineralo, 9. mod- moderately, 10. m- medium, 11.
- fine, 12. crs- coarse 13. carb- carbonaceous, 14. mic- mica.

Table A1. Sample identification and lithological description.

Sample number	Depth (feet)	Depth (Metres)	Lithological descriptions of formations
1	9940.2	3029.8	Sst ,brn ,f ,m, mod ,cmt
2	9975.2	3040.4	Sst ,brn ,f ,m, mod ,cmt
3	10040.1	3060.2	Sst, brn, f, gr, lam, carb, mic, wl, cmt
4	100709	3069.6	Sst ,brn ,f, gr mod ,cmt
5	10110.1	3081.6	Sst, brn, f, m, gr, fe, min, mod, cmt,
6	10129.9	3087.6	Sst, brn/gry. F, gr, carb, lam, wl. mod, cn
7	10140.7	3090.9	Sst, brn/gry. F, gr,miccarb wl. mod, cmt,
8	10650.3	3246.2	Sst, brn, m-crs, gr, mod, wl, cmt,
9	10699.9	3261.3	Sst, brn/gry, f, gr, lam, car, mic, mod, cmt
10	10714.9	3265.9	Sst, brn/gry. F, gr, carb, lam, wl. mod, cn

Conversion Guide
Pressure 1psi = 6900 Nm -2
Permeability 1D = 1X10 -12 m -2 Where (D = åE)
Pressure Gradient 1psi/ft = 22600 Nm -3