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Research Article

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Capillary Pressure Determination Using the Centrifuge Method

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Abstract The centrifuge method of capillary pressure determination is a unique method of capillary pressure determination in the laboratory in that the core plug is spun at discrete rotational speed which necessitate a force which pushes out fluid from the pores of the rock sample.

In this paper the method was carried out by preparing the cores and saturate them with brine and crude oil and spun at a rotation speed ranging from 500RPM to 3000RPM, an interval of 500RPM using a centrifuge and the displaced fluid Vcoll is collected in the test tube inserted in the core holder and the capillary pressure was determined.

As seen in fig 6 through to fig. 9, saturation decreases as capillary pressure increases and vice versa. The effect of core length on capillary pressure is shown on fig.10.0 .The longer the length of the core the higher the capillary pressure.

Advantages of the centrifuge method are that; it is a rapid approach, and a full drainage and imbibition cycle are being complete in a matter of days. Centrifuges can also be operated at elevated temperatures (up to 150°).

Keywords Capillary, Centrifuge, Pressure, Reservoir

Introduction

The study of capillary pressure is relevant in the petroleum industry, since it is a major factor that controls the distribution of fluid in a reservoir rock. This study is aim to determine capillary pressure using the centrifuge method. The objective of this work is to determine the saturation of the core samples with respect to the measured capillary pressure.

As defined by the petroleum dictionary, capillary pressure in a rock formation or core sample is the pressure of water or the contained fluid which causes it to rise or adhere to the surface of a small pore space than to larger one.

Capillary pressure is grossly important in reservoir engineering studies since it a major factor controlling the distribution of fluid in the reservoir rock. The small pores in a reservoir rock are similar to capillary tubes and they usually contain two immiscible fluid phases in contact with each other.

When two immiscible fluids are in contact with each other in a capillary tube, a clear interface exists between them. This interface is due to interfacial tension. The interface is a curved surface and the pressure on the concave side exceeds the pressure on the convex side. The resultant pressure difference existing on either side of the meniscus (concave or concave) gives rise to capillary pressure. In the presence of two immiscible fluids, one of them preferentially wets the tube surface and is called the "wetting" fluid, while the other is the "non-wetting" fluid [1].

Mathematically and implicitly, the capillary pressure can be expressed as;

$$P_c = P_{nw} - P_w \qquad (1)$$

Where P_{nw}= pressure of non-wetting phase

P_w= pressure of wetting phase

Although, there exist numerous techniques of obtaining capillary pressure such as the Laplace equation, the use of the interfacial tension correlation, the porous plate method, the mercury injection method etc. this research work deals exclusively on the use of the centrifuge method.

The centrifuge method is increasingly favored for measuring capillary pressure; this is not to say it is as easy as the mercury method. The centrifuge measurements are much faster than the porous plate method [2].

Capillary pressure can be viewed as the necessary pressure to force non-wetting fluid to displace wetting fluid in a capillary rock matrix. Imagine water wet reservoir rock which is saturated by oil and water. By capillary effect, the water tends to rise inside the rocks pores due to the rocks surface preference to the water. The height of displacement is largely dependent on the capillary pressure between the oil and the water. It is important to add that the capillary pressure is dependent on the interfacial tension, pore size and wetting angle [3].

It is impossible to use the Laplace and capillary tube equations to calculate the capillary pressure on porous media due to the complexity of the pore structure. However, capillary pressure is measured in the laboratory as a function of the saturation of the wetting phases. Rocks usually have pores of different radii; therefore a particular capillary pressure will be associated with a specific set of pores having the same radius. Consequently, lower capillary pressure will displace water out of bigger pores, while higher capillary pressure will displace water out of smaller pores.

Capillary pressure can be used to delineate the displacement of wetting fluid in a non-wetting fluid and vice versa, such that when two curves are plotted as a function of water saturation for a water-oil system, one for the drainage process (the displacement of the wetting phase by the non-wetting phase) and the other for the imbibition process (the displacement of the non-wetting phase by the wetting phase). The imbibition curve presents lower capillary pressures for a fixed saturation than drainage curves because of the natural tendency of the wetting fluid to saturate the rock.

It is important to state that for the drainage curve, a capillary pressure greater than zero is required to force the non-wetting fluid into the rock (entry pressure). The difference between the saturations at the end points of both curves is the residual saturation of the non- wetting fluid that is trapped inside the rock (e.g. oil).

Water flood efficiency significantly affected by the capillary pressure of the rock [4].

Hasser and Brunner (1945) proposed a centrifuge methods to determine capillary pressure saturation data from small core plugs [5]. In this method which will are going to be discussing explicitly, a fluid saturated core plug, contained in a special core-holder, is rotated at different rotational speeds.

Research Methodology

The centrifuge method for determining capillary pressure is a rapid approach to achieving a full drainage and imbibition cycle being completed in a matter of days and from which oil-brine data can be obtained, hopefully, under representative wetting conditions. It is important to add that the centrifuge can also be operated at elevated temperature (up to 150°C).The summary of this experimental work is to measure the capillary pressure in a core sample and consequently plot the capillary pressure versus water saturation curve. In this experiment, two core samples of different length and diameters were used. The samples were tagged sample A and sample D. The experiments on both samples were conducted at a room (laboratory) temperature of 31°C (87.8°F)

Apparatus/Equipment/Materials

The following are the apparatus used in this experiment.

(i) A Vernier caliper. A weighing balance. (ii) A volumetric flask 1000ml. (iii) A beaker. (iv) An electric dryer. (v) An electric centrifuge. (vi) Piece of paper. (vii) Crude oil sample (0.823359, 38°API). (viii) Distilled water. (ix) Sodium chloride salt (Nacl).(x)Test tube/ centrifuge tube core holder(xi) Thermometer.(xii)Density bottle.

Procedure:

The two samples were skillfully sharpened to avoid different contours on the core sample and the core length and diameter was then measured using a Vernier caliper and recorded. The core samples were then placed in a dryer to dry it up. This was achieved after drying the samples at an interval of four hours and weigh until a constant weight was obtained. This gives the dry weight (W_{dry}) of the core samples. A standard solution of brine was prepared by dissolving 58.44g of Nacl in 1000ml of distilled water, using a volumetric flask. The core samples were submerge in the standard solution for one day as the samples were weighed at an interval of four hours until a constant saturated weight (W_{sat}) was obtained. It is important to state that the density of brine/water (ρ_w) was obtained using a density bottle prior to the preceding procedure. Then the saturated core sample was placed in a calibrated test tube which was then inserted into a centrifuge core holder. The centrifuge was powered and made to rotate at rotation speed of 500rpm, subsequently at 1000, 1500, 2000,2500, 3000RPM respectively and the resultant volume of displaced fluid (i.e. volume collected, V_{coll}); recorded at each rotary speed. This was done at an interval of six minutes and the strobe light frequency was turned off when the volume of collected fluid shows no further changes. The above procedures were carried out on the two core samples. Similarly a crude oil (0.8235SG, 38°API measured at standard condition of 60°F) sample of 1000ml was measured using a volumetric flask of 1000ml. The core samples were likewise submerged into the oil sample and allowed to saturate for one day which was monitored (weigh) at an interval of four hours to obtain a constant weight. Also, the density of the crude oil was measured using the density bottle. The saturated core sample (with oil) was placed in a calibrated test tube which was then inserted into a centrifuge as before and rotated at a rotation speed of 500RPM, 1000,1500, 2000, 2500, 3000RPM, recorded at each rotary speed. This was also conducted at an interval of six minutes and the strobe light frequency was turned off when the volume of collected fluid shows no further changes.

Calculations and Report

The pore volume of the core samples (V_p) was obtained using the relation:

$$v_p = \frac{W_{sat} - W_{dry}}{\rho_l} \quad 2$$

The speed of the rotation of the centrifuge was converted from revolution per minute (RPM) to rad/s using:

$$w = \frac{2\pi(RPM)}{60} \quad 3$$

Then the capillary pressure (P_{cl}) at each step was obtained as:

$$p_{cl} = \tfrac{1}{2}\rho_l w^2 (r_2^2 - r_1^2) \quad 4$$

where:

r_2= o.145m

r_1= r_2-L

L= Length of the core sample.

The average water saturation $\overline{S_w}$ in the core sample based on the volume of the fluid collected (V_{COLL}) at corresponding capillary pressure (P_{CL}) was calculated using the relations.

$$\overline{S_w} = 1 - \frac{V_{coll}}{V_p} \quad 5$$

Then $\overline{S}P_{CL}$ was plotted against P_{CL} .At this point, tangents are drawn to the plot of the curve at each point and the slope of each tangent is calculated. These slopes are the water saturation values S_w at the corresponding capillary pressure. The capillary pressures are plotted as a function of the liquid saturations to delineate the point of imbibition, drainage, transition, residual oil saturation. As earlier noted, two core samples of different length and diameter were used in this experiment (sample A & sample D).

Table 1: parameters of sample A and D

Parameters	Sample a	Sample d
Length (cm)	1.935	1.227
Diameter (cm)	0.6	0.58
Weight of dry sample (g)	5.5	4.2
Weight of sturated sample with brine (g)	6.6	5.1
Weight of saturated sample with crude oil (g)	6.0	5.0

The following are the volumes collected (V_{COLL}) in the test tube after saturating the core samples of brine (i.e 38.44g in 1000ml of distilled water) at the different rotary speed of the centrifuge.

Table 2: Speed, time and volume collected ***FOR SAMPLE A***

Speed Of Rotation (RPM)	Time of Revolution (min)	Volume Collected V_{coll} (mL)
500	6	0.30
1000	6	0.35
1500	6	0.37
2000	6	0.39
2500	6	0.42
3000	6	0.43

Table 3: Speed, time and volume collected ***FOR SAMPLE D***

Speed of Rotation (RPM)	Time of Revolution (min)	Volume Collected V_{coll} (mL)
500	6	0.25
1000	6	0.27
1500	6	0.30
2000	6	0.32
2500	6	0.35

3000	6	0.39

The following below are the volume collected after saturating the core samples using an equal volume (1000ml) of crude oil (38°API) at the different rotary speed of the centrifuge.

Table 4: Speed, time and volume collected ***FOR SAMPLE A***

Speed of Rotation (RPM)	Time of Revolution (min)	Volume Collected V_{coll}(mL)
500	6	0.167
1000	6	0.250
1500	6	0.270
2000	6	0.275
2500	6	0.281
3000	6	0.281

Table 5: Speed, time and volume collected **FOR SAMPLE D**

Speed of Rotation (RPM)	Time of Revolution (min)	Volume Collected (V_{COLL})(min)
500	6	0.110
1000	6	0.113
1500	6	0.115
2000	6	0.125
2500	6	0.127
3000	6	0.129

NB: 1000 cm^3 = 1L

1 cm^3 = 1mL

1g/ cm^3 = 1000kg/m

Density of brine (ρ_b) = 1.132g/cm^3

Specific gravity of oil = 0.8235

Density of oil (ρ_0) =0.8235g/cm^3

Precautions

- It was ensured that the centrifuge jacket, the test tube and the core sample were adequately positioned to withstand both centripetal and centrifugal forces to avoid jumping off the orbit.
- It was also ensured that error necessitated by parallax was strictly avoided when reading off the volume collected from the calibrated test tube as well as the Vernier caliper.
- It was also ensured that zero error was achieved in using the measuring balance i.e. the scale was zeroed before weighing.
- It was ensured that the apparatus were cleaned and dried before and after use.

Data Presentation and Analysis

Capillary pressure curves can tell us much about the variation of saturation across a reservoir.

Table 6: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample A saturated with brine.

For Sample a, Saturated With Brine.

CORE NO:A D = 0.6cm L = 1.935cm (0.01935m)

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	$\overline{S_W}$ (%)	$\overline{SP_{CL}}$ (bar)
500	52.37	8130	0.30	0.69	5610
1000	104.73	32512	0.35	0.64	20808
1500	157.10	73157	0.37	0.62	45357
2000	209.47	130062	0.39	0.60	78037
2500	261.83	203210	0.42	0.57	115830
3000	314.20	292629	0.43	0.56	163872

Table 7: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample A saturated with oil.

For Sample A Saturated With Oil

CORE A D = 0.6cm L = 1.935cm (0.01935m)

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	S_O(%)	$\overline{S_W}$ (%)	$\overline{SP_{CL}}$ (bar)
500	52.37	5910	0.167	0.13	0.87	5142
1000	104.73	23650	0.250	0.19	0.81	19157
1500	157.10	53220	0.270	0.20	0.80	42576
2000	209.47	94620	0.275	0.21	0.79	74750
2500	261.83	147830	0.281	0.21	0.79	116786
3000	314.20	212880	0.281	0.21	0.79	168175

For Sample A

It should be noted that the pore volume of the core was obtained from equation 2 above. $v_p = \frac{W_{sat} - W_{dry}}{\rho_b}$ =

$\frac{(6.6-5.5)g}{1.132g/cm^3}$ = 0.9717cm^3

For the oil system,

$$v_p = \frac{(6.6-5.5)g}{0.8235g/cm^3} = 1.336\text{cm}^3$$

and the average water saturation was obtained from

$$\overline{S_W} = 1 - \frac{V_{COLL}}{V_P}$$

It is important to recall that: 1mL = 1cm^3

$$w = \frac{2\pi(RPM)}{60}$$

$p_{cl} = \frac{1}{2}\rho_l w^2 (r_2^2 - r_1^2)$, As defined earlier.

For Sample D, Saturated With Brine

CORE D, D=0.58cm L= 1.227cm (0.01227m)

Table 8: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample D saturated with brine.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	$\overline{S_W}$ (%)	$\overline{SP_{CL}}$ (bar)
500	52.37	5290	0.25	0.69	3650
1000	104.73	21156	0.27	0.66	13963
1500	157.10	47603	0.30	0.62	29514
2000	209.47	84631	0.32	0.60	50779
2500	261.83	132228	0.35	0.60	79337
3000	314.20	190413	0.39	0.51	97111

For Sample D, Saturated With Crude Oil

CORE D, D=0.58cm L= 1.227cm (0.01227m)

Table9: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample D saturated with oil.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	S_O(%)	$\overline{S_W}$ (%)	$\overline{SP_{CL}}$ (bar)
500	52.37	3848	0.110	0.101	0.899	5142
1000	104.73	15390	0.113	0.103	0.897	19157
1500	157.10	34630	0.115	0.105	0.895	42576
2000	209.47	61567	0.125	0.114	0.886	74750
2500	261.83	96192	0.127	0.116	0.884	116786
3000	314.20	138520	0.129	0.118	0.882	168175

For Sample D

It should be noted that the pore volume of the core was obtained from the relation when using Brine.

$$v_p = \frac{(5.1-4.2)g}{1.132g/cm^3} = 0.795\text{cm}^3$$

For The Oil System

$$v_p = \frac{(5.1-4.2)g}{0.8235g/cm^3} = 1.0929\text{cm}^3$$

For Sample a, Saturated With Brine.

CORE NO:A D = 0.6cm,L = 1.935cm (0.01935m)

Table 10: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample A saturated with brine.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	$\bar{S}_W$ (%)	$\bar{S}P_{CL}$ (bar)	S_W (%) from plot
500	52.37	8130	0.30	0.69	5610	0.69
1000	104.73	32512	0.35	0.64	20808	0.62
1500	157.10	73157	0.37	0.62	45357	0.60
2000	209.47	130062	0.39	0.60	78037	0.57
2500	261.83	203210	0.42	0.57	115830	0.52
3000	314.20	292629	0.43	0.56	163872	0.54

Table 11: showing the product of average saturation and capillary pressure, and the corresponding capillary pressure for sample A saturated with brine.(extracted from Table10.)

$\bar{S}P_{CL}$ (bar)	P_{CL}(bar)
5610	8130
20808	32512
45357	73157
78037	130062
115830	203210
163872	292629

For Sample A Saturated With Oil

CORE NO:A D = 0.6cm L = 1.935cm (0.01935m)

Table 12: Showing the rotation rate and the corresponding capillary pressure, volume collected and saturations obtained during a capillary pressure investigation using the centrifuge for sample A saturated with oil.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	S_O	$\bar{S}_W$ (%)	$\bar{S}P_{CL}$ (bar)	S_W (%)
500	52.37	5910	0.167	0.13	0.87	5142	0.87
1000	104.73	23650	0.250	0.19	0.81	19157	0.79
1500	157.10	53220	0.270	0.20	0.80	42576	0.79
2000	209.47	94620	0.275	0.21	0.79	74750	0.78
2500	261.83	147830	0.281	0.21	0.79	116786	0.79
3000	314.20	212880	0.281	0.21	0.79	168175	0.79

Table13: Showing product average saturation and capillary pressure, and the corresponding capillary pressure for sample A saturation with oil.

$\bar{S}P_{CL}$ (bar)	P_{CL}(bar)
5142	5910
19157	23650
42576	53220
74750	94620
116786	147830
168175	212880

For Sample D, Saturated With Brine (CORE D, D=0.58cm L= 1.227cm (0.01227m)

Table14: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample D saturated with brine.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	$\overline{S_W}$	$\overline{SP_{CL}}$ (bar)	S_W from plot
500	52.37	5290	0.25	0.69	3650	0.69
1000	104.73	21156	0.27	0.66	13963	0.65
1500	157.10	47603	0.30	0.62	29514	0.59
2000	209.47	84631	0.32	0.60	50779	0.57
2500	261.83	132228	0.35	0.60	79337	0.60
3000	314.20	190413	0.39	0.51	97111	0.31

Table15: Showing product average saturation and capillary pressure, and the corresponding capillary pressure for sample D saturated with brine.

$\overline{SP_{CL}}$ (bar)	P_{CL}(bar)
3650	5290
13963	21156
29514	47603
50779	84631
79337	132228
97111	190413

For Sample D, Saturated With Crude Oil (CORE D, D=0.58cm L= 1.227cm (0.01227m)

Table 16: Showing the rotation rate and corresponding capillary pressure, volume collected and the average saturation obtained during a capillary pressure investigation using the centrifuge method for sample D saturated with oil.

RPM	ω(rad/s)	P_{CL}(bar)	V_{COLL}(cm^3)	S_O	$\overline{S_W}$	$\overline{SP_{CL}}$ (bar)	S_W from Plot
500	52.37	3848	0.110	0.101	0.899	3459	0.90
1000	104.73	15390	0.113	0.103	0.897	13805	0.90
1500	157.10	34630	0.115	0.105	0.895	30994	0.89
2000	209.47	61567	0.125	0.114	0.886	54548	0.87
2500	261.83	96192	0.127	0.116	0.884	85034	0.88
3000	314.20	138520	0.129	0.118	0.882	121898	0.87

Table 17: Showing product average saturation and capillary pressure, and the corresponding capillary pressure for sample D saturation with oil.

$\overline{SP_{CL}}$ (bar)	P_{CL}(bar)
3459	3848
13805	15390
30994	34630
54548	61567
85034	96192
121898	138520

The following are the curves obtained using Table 11, 13, 15 and 17

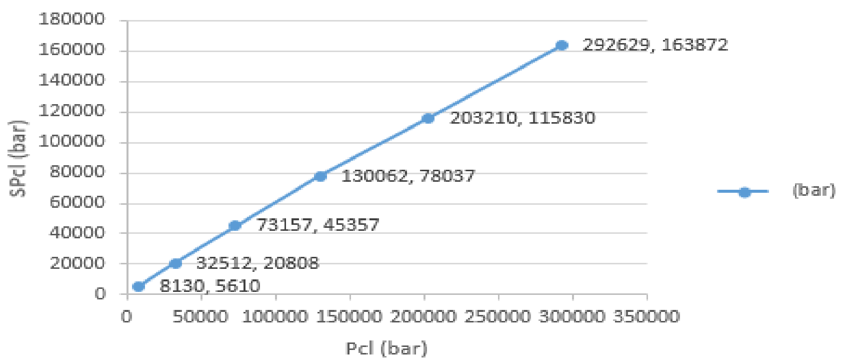

Figure 1: capillary pressure and average saturation against capillary pressure for sample A saturated with Brine.

This curve is necessary to obtain the saturation of the core sample when saturated with brine taking slopes at strategic locations.

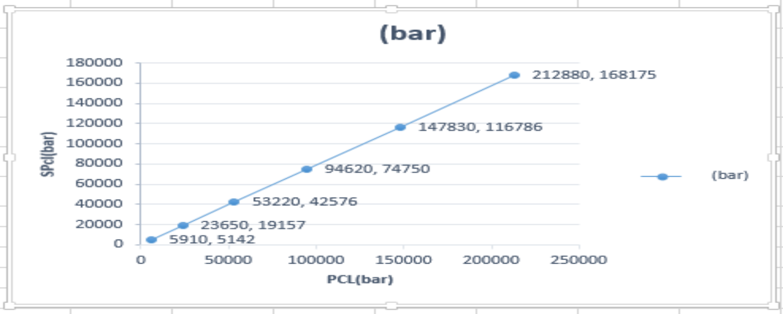

Figure 2: capillary pressure and average saturation against capillary pressure for sample A saturated with oil.

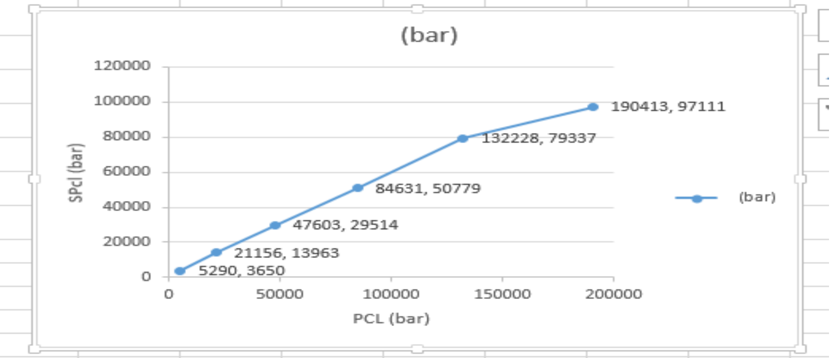

Figure 3: capillary pressure and average saturation against capillary pressure for sample D saturated with Brine.

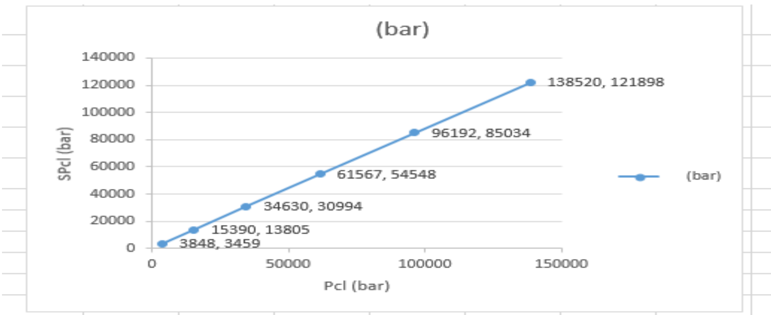

Figure 4: capillary pressure and average saturation against capillary pressure for sample D, saturated with oil.

Taking a slope at strategic positions as shown in fig 5 below:

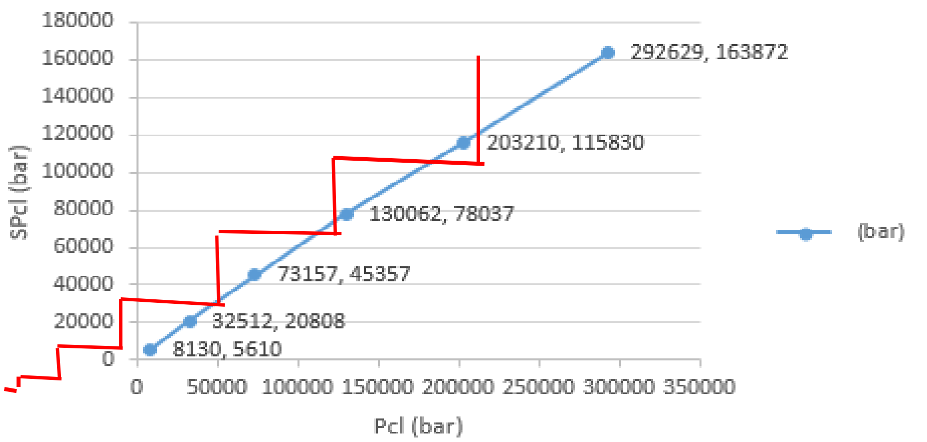

Figure 5: Showing the slope of capillary pressure and average saturation against capillary pressure for sample A saturated with brine at different positions of P_{cl}.

Similarly for other plots, the slopes were obtained as Fig 5 and the following calculations proceeds.
To obtain the slope considering a P_{cl} value of 4065 bar,
Slope of the triangle $1A_1$ at 4065 bar is given by:

$$m_1A_1 = \frac{\Delta \bar{S}_{PCL})}{\Delta P_{cl}}$$

$$= \frac{5610-0}{8130-0}$$

=0.69

To obtain the slope considering a P_{cl} value of 20321 bar

$$= \frac{20808-5610}{32512-8130}$$

=0.62

To obtain the slope considering a P_{cl} value of 52835bar

$$m_1A_3 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}} = \frac{45357-20808}{73157-32512}$$

$$m_1A_3 = \frac{24549}{40645} = 0.60$$

To obtain the slope considering a P_{cl} value of 101610bar

$$m_1A_4 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}} = \frac{78037-45357}{130062-73157}$$

$$m_1A_4 = \frac{32680}{56905} = 0.57$$

To obtain the slope considering a P_{cl} value of 166636bar

$$m_1A_5 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}} = \frac{115830-78037}{203210-130062} = \frac{37793}{73148} = 0.52$$

To obtain the slope considering a P_{cl} value of 247920bar

$$m_1A_6 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}} = \frac{163872-115830}{292629-203210}$$

m_1A_6 = 0.54

Hence, the table

Table 18: showing the assumed capillary pressure against saturation of core sample A saturated with brine.

P_{cl}(bar)	S_w(%)
4065	0.69
20321	0.62
52835	0.60
101610	0.57
166636	0.52
247920	0.51

To obtain the slope considering a P_{cl} value of 2955bar, the slope of the triangle $2A_1$ at 2955bar is given as

$$m_2A_1 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$$= \frac{5142-0}{5910-0} = 0.87$$

To obtain the slope considering a P_{cl} value of 14780bar

$$m_2A_2 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$$= \frac{19157-5142}{23650-5910} = 0.79$$

To obtain the slope considering a P_{cl} value 38435bar

$m_2A_3 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}}$

$= \frac{42576 - 19157}{53220 - 23650} = 0.79$

To obtain the slope considering a P_{cl} value of 73920bar

$m_2A_4 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}}$

$= \frac{74750 - 42576}{94620 - 53220} = 0.78$

To obtain the slope considering a P_{cl} value of 121225bar

$m_2A_5 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}}$

$= \frac{116786 - 74750}{147830 - 94620} = 0.79$

To obtain the slope considering a P_{cl} value of 180355bar

$m_2A_6 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}} = \frac{168175 - 116786}{212880 - 147830} = 0.79$

Hence,

Table 19: showing the assumed capillary pressure against saturation of the core sample A saturated with oil

P_{cl}(bar)	S_w(%)
2955	0.87
14780	0.79
38435	0.79
73920	0.78
121225	0.79
180355	0.79

To obtain the slope considering a P_{cl} value of 2645bar, the slope of triangle m_1D1 is given as

$m_1D_1 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}} = \frac{3650 - 0}{5290 - 0} = 0.69$

To obtain the slope considering a P_{cl} value of 13223bar

$m_1D_2 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}} = \frac{13963 - 3650}{21156 - 5290} = 0.65$

To obtain the slope considering a P_{cl} value of 34380bar

$m_1D_3 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}} = \frac{29514 - 13963}{47603 - 21156} = 0.59$

To obtain the slope considering a P_{cl} value of 57073bar

$m_1D_4 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}}$

$= \frac{50779 - 29514}{84631 - 47603}$

=0.

To obtain the slope considering a P_{cl} value of 108430bar

$m_1D_5 = \frac{\Delta \bar{S}_{P_{CL}}}{\Delta P_{cl}}$

$= \frac{79337-50779}{132228-84631}$

= 0.60

To obtain the slope considering a P_{cl} value of 161321bar

$$m_1D_6 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{97111-79337}{190413-132228}$

= 0.31

Table 20: showing the assumed capillary pressure of core sample D saturated with brine.

P_{cl}(bar)	S_w(%)
2645	0.69
13223	0.65
34380	0.59
57073	0.57
108430	0.60
161321	0.31

To obtain the slope considering a P_{cl} value of 1924bar, the slope of the triangle $2D_1$ at 1924bar

Hence,

$$m_2D_1 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{3459-0}{3848-0}$

=0.90

To obtain the slope considering a P_{cl} value of 9619bar

$$m_2D_2 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{13805-3459}{15390-3848}$

=0.90

To obtain the slope considering a P_{cl} value of 25010bar

$$m_2D_3 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{30994-13805}{34630-15390}$

= 0.89

To obtain the slope considering a P_{cl} value of 48099bar

$$m_2D_4 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{54548-30994}{61567-34630}$

= 0.87

To obtain the slope considering a P_{cl} value of 78880bar

$$m_2D_5 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$= \frac{85034-54548}{96192-61567}$

= 0.88

To obtain the slope considering a Pcl value of 117356bar

$$m_2D_6 = \frac{\Delta \bar{S}_{PCL}}{\Delta P_{cl}}$$

$$= \frac{121898 - 85034}{138520 - 96192}$$

$= 0.87$

Table 21: Showing the assumed Capillary pressure against saturation of the core sample D saturated with oil

P_{cl}(bar)	S_w(%)
1924	0.90
9619	0.90
25010	0.89
48099	0.87
78880	0.88
117356	0.87

N.B. The capillary pressure used in the table (18– 21) is an average of the calculated pressures from Table (7 – 10) respectively since there was no need for tangent (in this, a straight line was involved not a curve hence a constant saturation value on the straight line).

Analysis of Presented Data

Figure1. and 3, shows when the core is saturated with brine, as the capillary pressure and the volume of fluid collected in the tube in the core holder increases, the lower the water saturation in the core. This in a nut shell practically indicates that the higher the overburden pressures of the earth on a reservoir rock, the higher the tendency for drainage (i.e an increase in the saturation of the non-wetting phase). Fig. 2 and 4, shows that as the capillary pressure and volume collected increases, the crude oil saturation increases as well. This is partly due to the density of the fluid which affects the fluid pressure and the grain pressure which collectively are affected by the overburden pressure. Hence the saturation level of a core sample at a given capillary pressure can be obtained as clearly presented from fig 1 through to fig.4.

The following are the resultant plot from Table 10 to Table 21

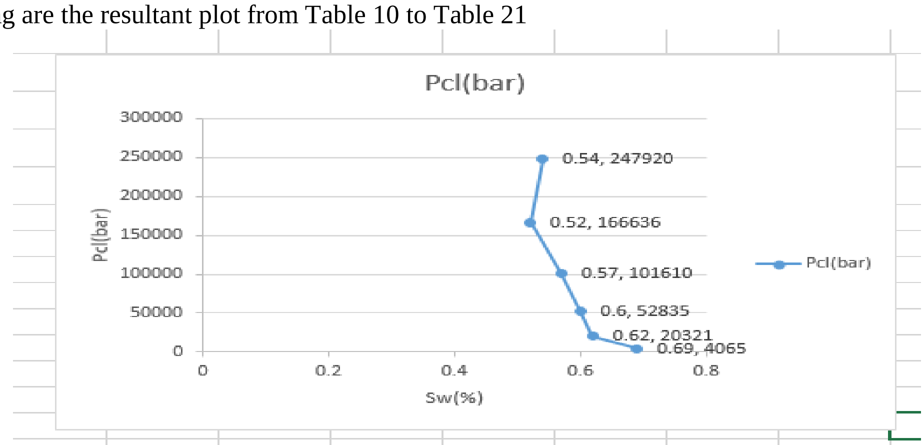

Figure 6: showing saturation against capillary pressure for sample A saturated with Brine.

From fig 6.0, it seen as capillary pressure decreases, the saturation increases almost steadily.

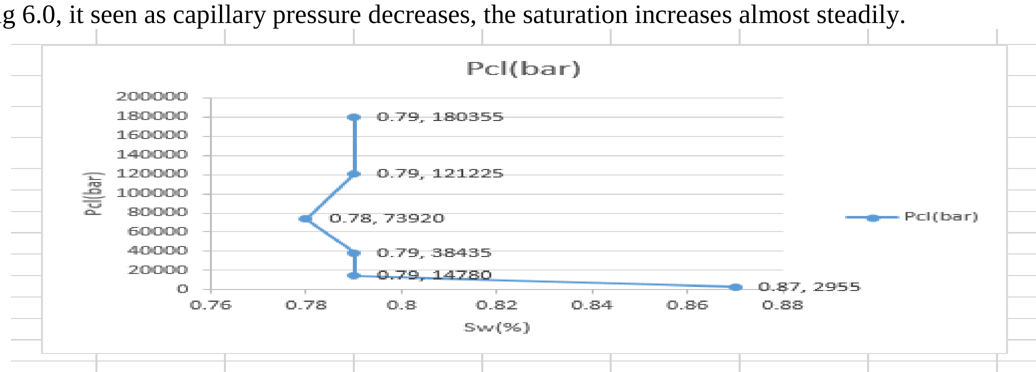

Figure 7: showing the capillary pressure against saturation for sample A saturated with oil.

In fig.7, the saturation of oil in the core sample is higher than that of brine and as capillary increase, saturation decreases.

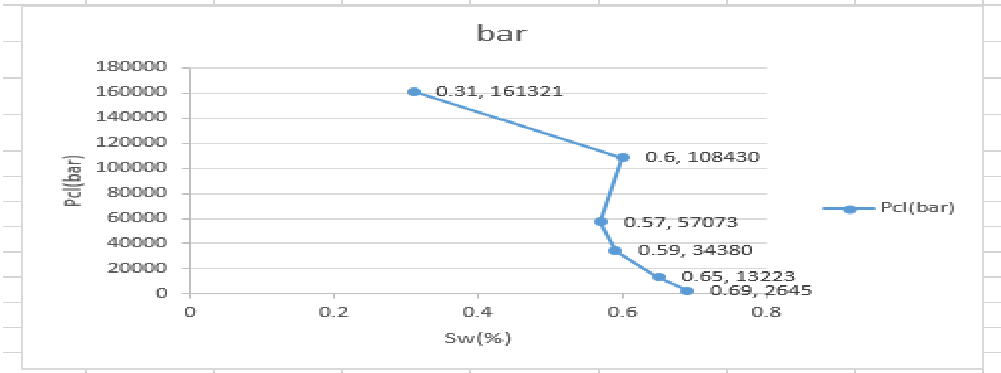

Figure 8: showing the capillary pressure against saturation for sample D saturated with Brine.

Although, the saturation in this case increases with decreasing capillary pressure, there is an abnormality between 161321bar and 108430bar

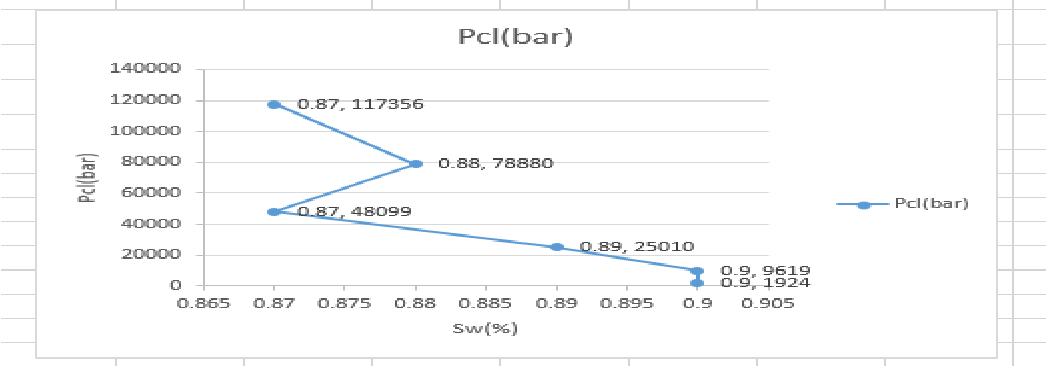

Figure 9: showing the capillary pressure against saturation for sample D saturated with oil.

Although, the saturation in this case is fairly constant but the plots are not regularly scattered.

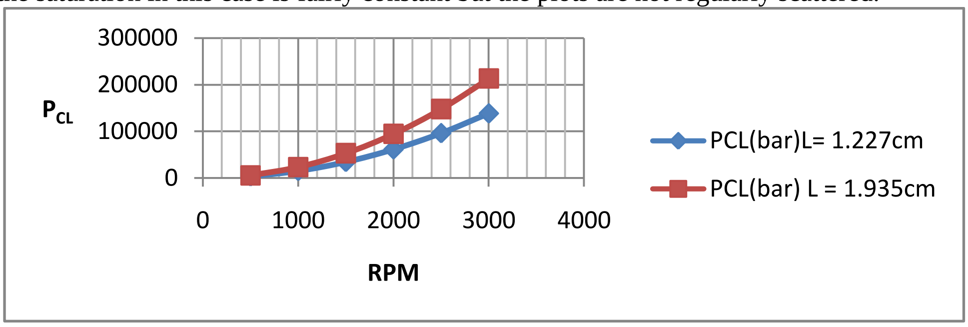

Figure 10: Effect of core length on capillary pressure

The effect of core length on capillary pressure is shown on fig.10.0 above. The longer the length the higher the capillary pressure.

Conclusion

This research work encompasses the investigation of the capillary pressure of two core samples using brine and crude oil as the saturating fluid for both samples. The experiment was conducted in a room temperature (laboratory temperature of 31^0 (87.8^0F), and atmospheric pressure of 14.7psi. This research work was able to review some literatures which borders around the concept –capillary pressure. Several plots of capillary pressure and saturations were obtained which shows clearly that as capillary pressure increases, the connate water saturation of the rock matrix decreases. The capillary pressure no doubt is a handy tool for investigating the oil/water, gas/oil contact of a reservoir from the relation: P=(dP/dD)*D + constant. Hence facilitating the decision of *where to complete in the reservoir*.

From the Fig 6 to Fig 9 it is clear that core sample A which is of a greater length (1.935cm) had a more reasonable plot both when saturated with brine and when saturated with oil than sample D. This is with reference to the various literatures reviewed .

The advantages of the centrifuge method are that; it is a rapid approach, and a full drainage and imbibition cycle are being complete in a matter of days. Also, oil-brine data can be obtained, hopefully, under representative wetting conditions and centrifuges can also be operated at elevated temperatures (up to 150°).

In particular, it is beneficial for low permeability rocks as these rocks require high centrifugal speed and low equilibrium time. Centrifuges are readily available in different sizes.

This research work opines that even though the centrifugal method is a rapid and an approximate method of obtaining capillary pressure and consequently the saturation of a core sample, the core sample to be used should be of a reasonable length so that more pore spaces will be considered. Also, it is recommended that a similar approach as the Magnetic Resonance imaging method (MRI) which combines the principles of centrifugal method and the porous plate method be adopted when the duration of completion of the test is not a major factor of consideration.

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