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Experimental Study of Brine Concentration Effect on Reservoir Porosity and Permeability Measurement

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Authors' contributions

This work was carried out in collaboration between both authors. Author ANO designed the study, analyzed the results and supervised important intellectual content in the manuscript. Author UBE managed the literature searches, wrote the protocol and the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Reservoir rock properties such as permeability and porosity can be determined using routine core analysis. However, the optimum brine concentration to determine these petrophysical properties with fluid saturation method has remained unattainable. Therefore, brine concentrations of 0.292 mol/L to 1.752 mol/L were used to assess the effect on reservoir porosity and permeability determination. Six (6) core samples with different diameters and lengths ranging from 2.51 cm to 3.78 cm and 4.48 cm to 10.81 cm respectively were used in the study. Result obtained depicts the effect of brine concentration has on reservoir porosity and permeability; as increased brine concentration resulted in decreased porosity and permeability values. However, stable porosity values were obtained from brine concentration of 1.168 mol / L in all the core plugs. The result further reveals a stable permeability value for core diameter and length of about 3.80 cm and 6.0 cm respectively from a brine concentration of 0.876 mol / L. Therefore, for routine core analysis, brine concentration range of 0.876 mol/L to 1.168 mol / L and core diameter and length of 3.80 cm and 6.0 cm can be used for the determination of reservoir rock porosity and permeability.

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1. INTRODUCTION

Hydrocarbon reservoirs are subset of a regional brine-bearing formation representing the parts of formation where geometry and fluid migration coincided so that economically significant hydrocarbon accumulated [1]. Among the petrophysical parameters necessary for the characterization and evaluation of petroleum reservoirs potential; porosity and permeability are the most important. These two are the backbones of reservoir rock functionality. While porosity depicts the storativity - measure of the rock's capacity to contain or store fluids such as gas, oil or water, permeability indicates the transmissivity potential - the ease with which the fluids flow through the interconnected pores of the rock. These parameters can be determined in various ways either directly through well test and well log data core analyses or directly by mathematical models. For an explorationist, the most effective reservoir rock property is permeability. High porosity values indicate high capacities of the reservoir rocks to contain these fluids, while low porosity values indicate the opposite [2]. Core plug analysis depends on fluid extraction or saturation of reservoir core plug to evaluate these reservoir's parameters, others use reservoir rock response to correlate these properties. On the other hand, the nature and interaction of the injected fluid in the voids of the reservoir core plug is not almost important; as it attempt to represent the hydrocarbon occurred in the pore space. Porosity measurement is done by measuring the bulk volume of the reservoir rock and its related pore volume or space (empty spaces in a rock). The bulk volume is gravimetrically determined when the core-sample has irregular shape [3]. The permeability of reservoir rock samples are often measured using constant-flow equipment [4]. In permeability measurement, most routine core analysis method use gas as the flowing phase for convenience as it does not react with the rock. However, correction must be made to account for the mean free path slippage of the gas through the pores because gas molecules do not collide as often as liquid molecules. This effect is referred to as the Klinkenberg effect. Regrettably, limited or no literatures has established the range or optimum brine concentration for routine core analysis. This paper assesses the effect of brine concentration on reservoir porosity and permeability measurement. In addition, establish the range and/or optimum brine concentration for routine core analysis.

1.1 Geology of Niger Delta Region

The cores used in this study were obtained from a formation in the Niger Delta region. The Niger Delta Basin, also referred to as the Niger Delta province is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the western coast of Nigeria [5]. It is one of the largest subaerial basins in Africa that covers about 75000 km^2, with total area and sediment fill volume of 300,000 km^2 and 500,000 km^3, respectively. The sediment fill in the Niger Delta basin is characterized by three major depobelts; which indicate it experienced an overall regression throughout time as the sediments go from deep sea mud sized grains to fluvial denser sand sized grains. The lithology of Niger Delta region is presented in three lithostratoigraphic units: the Benin formation - Oligocene and younger in age, the Agbada formation - Eocene in age, and Akata formation - Paleocene in age. The Akata formation composed of thick marine shale, turbidite sands, and small amounts of silt and clay. It is estimated to be up to 7000m thick; Doust and Omatsola [6] in Ajaegwe et al. [7]. The Agbada formation is the lithology of interest, as it is the major hydrocarbon-bearing unit in the Niger Delta region. It consist mostly of shore face and channel sands with minor shales in the upper part, and alternation of sands shales in equal proportion in the lower part [7]. It is estimated to be about 3700m thick. Finally, the Benin formation is composed of continental flood plain sands and alluvial deposits. It is estimated to be up to 2000m thick [5].

2. MATERIALS AND METHODS

2.1 Brine Preparation

As indicated in Table 1, six (6) brine samples were prepared using water of 1000 cm^3 equivalent of one (1) litre. Sodium Chloride (NaCl) of different weight ranging 20 g to 120 g was weighed with digital balance (Fig. A-2) and dissolved in the distilled water. The corresponding brine concentration (C_b) was evaluated using the equation 1.

$$C_b = \frac{W_{NaCl}}{(M_{NaCl})(V_{water})} \quad (1)$$

where:

W_{NaCl} = Weight of Sodium Chloride (g)
M_{NaCl} = Molar Weight of Sodium Chloride (g/mol)
V_{water} = Volume of Water (L)
C_b = Brine Concentration (mol/L)

In addition, the brine density (ρ_b) was determined using pycnometer. The pycnometer was weighed without brine and its weight was noted. Afterward, it was filled to the scribed mark with the brine to be measured. The weight of the pycnometer with its content and the content temperature were noted and recorded. Also, the brine density was evaluated using the expressed equation 2, as presented in Table 1.

$$\rho_b = \frac{W_f - W_e}{V_b} \quad (2)$$

where:

W_f = Weight of Pycnometer filled with Brine
W_e = Weight of Pycnometer without Brine
V_b = Volume of solution filled in Pycnometer
ρ_b = Brine Density

2.2 Experimental Procedure

The cores used in this study are obtained within the sandstone facies of the Agbada formation in the Niger Delta region. The core plugs (Fig. A-1) were labelled A through F. Their length and diameter were determined using digital venier caliper (Fig. A-6). In addition, the dry cores were weighed weight recorded (Table 2). Thereafter, the permeability of the sample was determined with an air permeameter (Fig. A-3) and corresponding Tiny Perm value (T) was noted and converted to permeability value, using the expanded equation 6. Thereafter, the cores were put in desiccator (Fig. A-4) and saturated with de-ionized water for 24 hours. They were removed (one after another) from the desiccator and weighed. This weight was recorded in Table 3. Furthermore, the wet core plugs permeability was determined with air permeameter, as noted in the Table 3. Then, the cores were dried in vacuum oven (Fig. A-5) for 5 hours at 65°C to ensure that the de-ionized water is completely driven off the pore. The dry cores were again weighed to establish the absence of de-ionized water in the pore. This was ascertained by ensuring the obtained core weight was the same as the initial weighed core weight before it was saturated with de-ionized water. When this was established, the cores were put in desiccator again and saturated with 0.292 mol/L brine concentration for 24 hours. Afterwards, they were removed from the desiccator and weighed. Also, Tiny Perm values of the brine saturated cores were obtained using air permeameter. Then, the brine saturated cores were placed in a water bath for 24 hours and de-saturated of the brine content. Thereafter, they were placed in the vacuum oven for 5 hours to dry up water content in the cores' pore space. Subsequently, the core plugs were placed in the desiccator and saturated with 0.584 mol/L brine concentration for 24 hours. Then, the same procedures were followed to obtain the brine saturated cores weight and its Tiny Perm values. In the nutshell, the overall experimental procedures were repeated for brine concentrations of 0.876 mol/L, 1.168 mol/L, 1.460 mol/L and 1.752 mol/L. The overall results of which are shown in Figs. 3 and 8, for brine saturated porosity and permeability the results are presented in Tables 4 and 5.

2.2.1 Porosity determination

The effective porosity of the six (6) core plugs were determined using liquid saturation approach. Thence, the cores' bulk volume was evaluated using equation 3, given as:

$$V_b = \frac{\pi D^2 L}{4} \quad (3)$$

where:

L = Core Length (cm)
D = Core Diameter (cm)
V_b = Core Bulk Volume (cm^3)

Secondly, the cores' pore volume (V_p) was established using the expanded equation 4;

$$V_p = \frac{(W_{sat} - W_{dry})}{\rho_b} \quad (4)$$

where:

W_{sat} = Weight of Saturated Core (g)
W_{dry} = Weight of Dry Core (g)
ρ_b = Brine Density

Then, the effective porosity of the core plugs was calculated using the expressed equation 5;

$$\varphi = \left[\frac{4(W_{sat} - W_{dry})}{\pi \rho_b D^2 L}\right] \quad (5)$$

the parameters in equation 5 were defined in equations 3 and 4.

2.2.2 Permeability measurement

The absolute permeability of the cores was determined using portable air permeability (Fig. A-5). The plunger of the permeameter was pulled out until the attached screen displayed zero value (i.e. standardized). Then, the rubber nozzle of the permeameter was placed on the core surface. When adequate contact was ascertained between the permeameter nozzle and the core surface, the plunger was pressed in to release air into the core. The air flow through the core was monitored on the attached screen, as the status bar on the screen indicated when the measurement was completed. The displayed value on the attached screen was recorded as the Tiny Perm value (T). This value was used to calculate the permeability of the core plugs using the equation 6;

$$K = 10^{\left(\frac{12.8737-T}{0.8206}\right)} \tag{6}$$

where:

T = Tiny Perm value
K = Absolute Permeability (md)

3. RESULTS AND DISCUSSION

3.1 Brine Concentration Effect on Porosity Measurement

Tables 3 shows the porosity values obtained from the different core plugs saturated with de-ionized water. The results were used as the reference porosity to assess the effect of brine concentration on core plug porosity measurement. Fig. 1 depicts the cores' porosity values at different brine concentrations. From the Figure, it was observed that all the core plugs' porosity values reduced from their referenced porosity value (i.e. porosity value obtained with de-ionized water saturation), except in core sample 'D'. This observation is attributed to the sodium chloride (NaCl) content in the de-ionized water; as it saturates the core pore space resulted in decreased pore volume. This accounted for the less porosity value; as observed. However, from brine concentration of 1.168 mol/L, all the obtained core plugs' porosity values were almost constant; as indicated in the Fig. 1. This implies that from 1.168 mol/L brine concentration, the presence of NaCl will no longer affect the measured core porosity; an indication of stability between the core pore volume - brine interaction.

3.2 Brine Concentration Effect on Permeability Measurement

Tables 2 and 3 present the cores' air permeability (K_{air}) and de-ionized water saturated permeability (K_w) respectively. The comparison of the Tables (i.e. 2 and 3) results indicates that the cores' permeability reduces when they were saturated with liquid. This means that the core permeability is sensitive to fluid content; as permeability depicts the transmissive capacity of the porous media. Furthermore, Fig. 2 presents the cores' permeability (K_{cb}) at different brine concentration. The obtained results indicate significant decrease and unstable permeability values for all the core plugs, except for Core C. The stable permeability values in Core C were established from brine concentration of 0.876 mol/L; as indicated in the Fig. 2. The unstable permeability values for the other core plugs may be attributed to their core length. This assertion is based on the fact that the established equation by Darcy to evaluate permeability depends on core diameter, length and other flow parameters: fluid viscosity, flow rate and pressure drop. Additionally, aside from Core A, other cores have about the same diameter but different length; as presented in Table 2. Therefore, if the flow rate, brine viscosity, pressure drop and flow area are the same, then, core length becomes the determining factor for the unstability of the obtained permeability values. This means that the core plug length should be considered when using brine for routine core analysis.

Furthermore, Figs. 3 through 8 shows the surface plot of the brine concentration and the cores' permeability and porosity values. Ideally, stability in the obtained cores' parameters: porosity and permeability would result in flat surface plot. However, these figures depict the various disparities of the core parameters; as observed on the depressed and/or twisted portions on the plots. Additionally, the surface plot reveals that the obtained permeability and porosity values from Core F (Fig. 8) were not greatly affected by brine concentration compared to other core plugs' values (Figs. 3 – 7).

Table 1. Brine composition

Brine	Salt weight (g)	Temp. (°C)	Density (g/cm^3)	Conc. (mol/L)
I	20	27.5	0.990	0.292
II	40	26.0	1.003	0.584
III	60	27.0	1.015	0.876
IV	80	27.5	1.040	1.168
V	100	26.5	1.041	1.460
VI	120	27.5	1.053	1.752

Table 2. Core samples' properties before saturation

Core	Length, L (cm)	Diameter, D (cm)	Bulk volume V_b (cm^3)	Dry weight W_{dry} (g)	Permeability K (md)
A	4.48	2.51	22.17	44.61	33.60
B	4.77	3.76	52.97	107.14	12.94
C	5.99	3.78	67.23	143.18	8.99
D	7.40	3.72	80.44	163.46	15.75
E	10.70	3.70	115.06	235.02	55.68
F	10.81	3.69	115.02	232.39	60.57

Table 3. Core samples' properties saturated with de-ionized water

Core	Wet weight W_{sat} (g)	Pore volume V_p (cm^3)	Porosity, φ (%)	Permeability K (md)
A	48.12	3.58	16.14	20.28
B	114.93	7.95	15.01	7.60
C	151.31	8.30	12.34	4.46
D	169.60	6.27	7.79	97.59
E	247.40	12.64	10.98	28.40
F	252.69	20.73	17.92	19.17

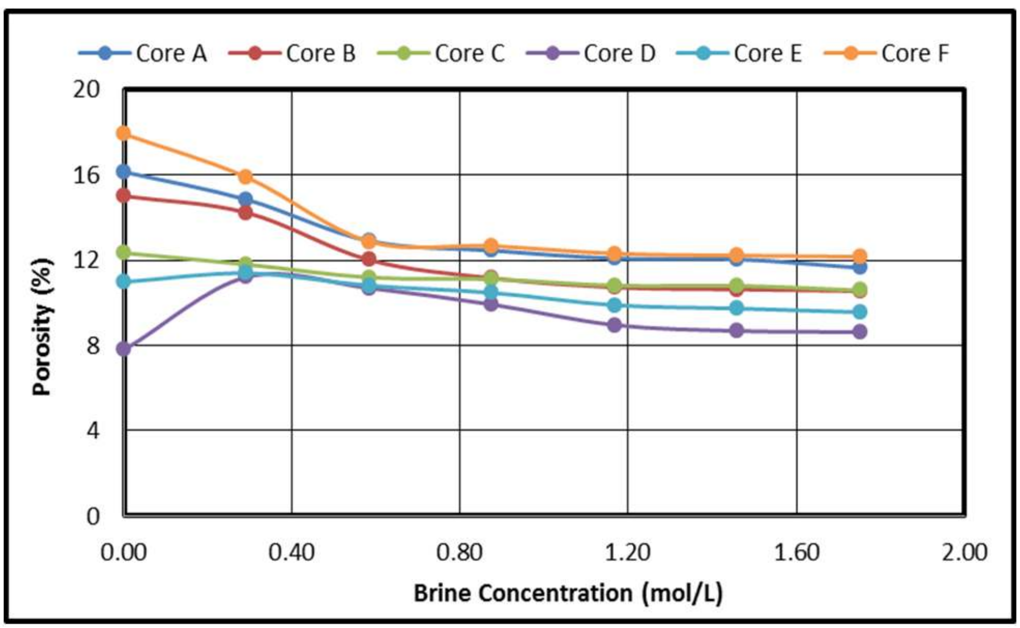

Fig. 1. Porosity profile at different brine concentration

Table 4. Cores' porosity values at different brine concentrations

Conc. (mol/L)	Porosity values (%)					
	Core A	Core B	Core C	Core D	Core E	Core F
0.292	14.84	14.23	11.80	11.21	11.39	15.89
0.584	12.90	12.01	11.19	10.69	10.81	12.87
0.876	12.45	11.16	11.11	9.92	10.47	12.67
1.168	12.08	10.72	10.81	8.96	9.89	12.31
1.460	12.04	10.63	10.80	8.68	9.73	12.22
1.752	11.64	10.55	10.58	8.63	9.56	12.16

Table 5. Cores' permeability values at different brine concentrations

Conc. (mol/L)	Permeability values (md)					
	Core A	Core B	Core C	Core D	Core E	Core F
0.292	22.06	12.03	6.42	15.75	18.12	16.66
0.584	13.10	8.79	6.14	15.31	13.84	16.29
0.876	10.70	4.66	2.42	12.44	12.87	12.17
1.168	9.56	4.63	2.23	7.94	12.51	9.04
1.460	5.52	2.03	2.10	5.33	9.09	6.45
1.752	4.03	1.46	2.07	4.61	5.67	5.06

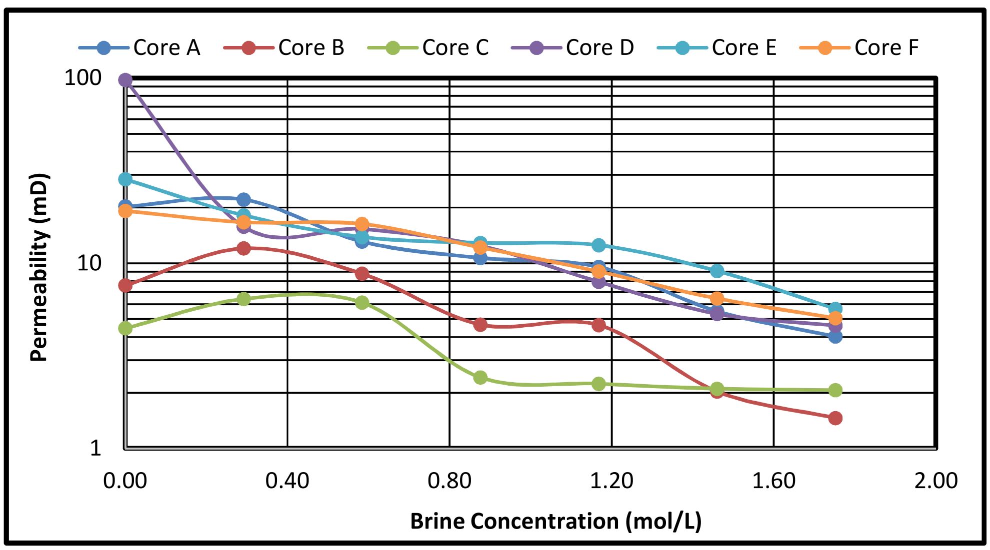

Fig. 2. Permeability profile at different brine concentration

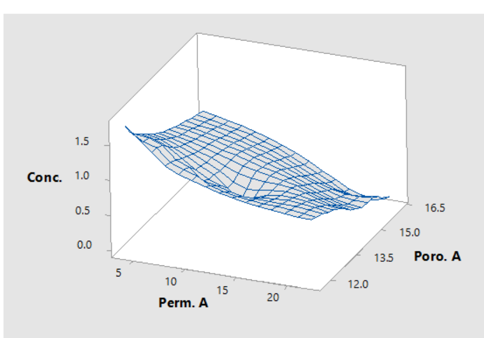

Fig. 3. Surface plot core A

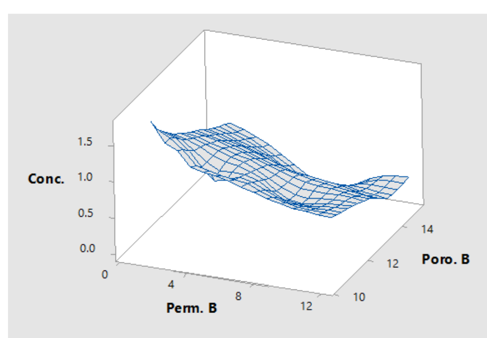

Fig. 4. Surface plot core B

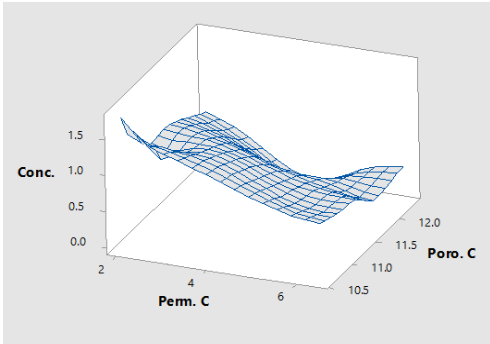

Fig. 5. Surface plot core C

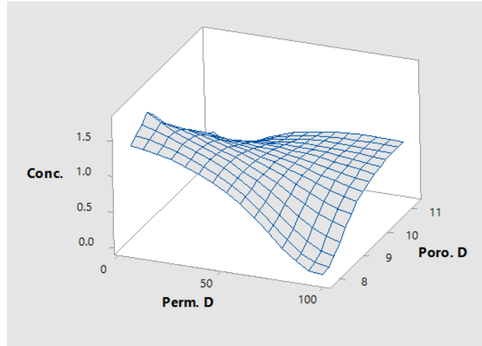

Fig. 6. Surface plot core D

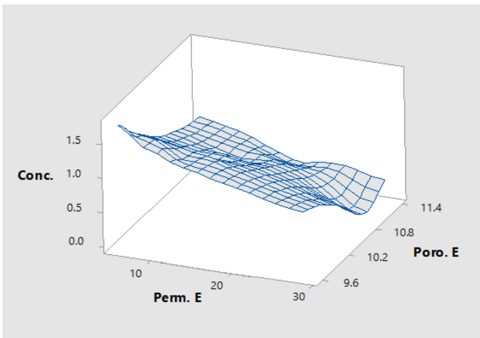

Fig. 7. Surface plot core E

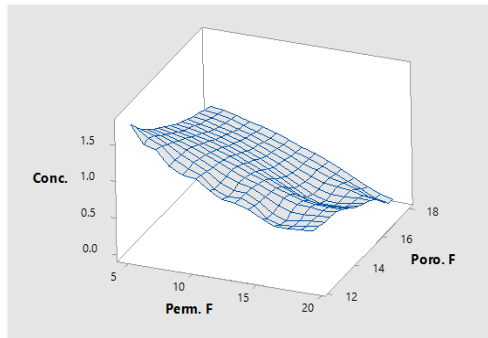

Fig. 8. Surface plot core F

4. CONCLUSION

Routine core analysis provides the basic means of evaluating reservoir petrophysical properties such as permeability and porosity. However, the missing link in reservoir routine core analysis is the optimum brine concentration to obtain the mentioned petrophysical properties. In the course of this study, different brine concentrations were used to determine its effect on reservoir rock porosity and permeability measurement using liquid saturating method. Based on the results obtained from the study, the following conclusions are drawn:

1. In routine core analysis, the brine concentration used affects the obtained porosity and permeability values of the reservoir core;
2. Brine concentration of 1.168 mol/L can be used to determine reservoir core porosity;
3. For core permeability measurement, the brine concentration of 0.876 mol/L and core diameter and length of 3.80 cm and 6.0 cm respectively are required; and
4. The dimension of core plugs affect the permeability more than the porosity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hovorka SD, Choi J, Meckel TA, Trevino RH, Zeng H, Kordi M, Wang FP, Nicot J. Comparing carbon sequestration in an oil reservoir to sequestration in a brine formation – field study. Journal of Energy Procedia. 2009;1: 2051-2056. DOI: 10.1016/j.egypro.2009.01.267
2. Nnaemeka JG, Coalson EB. The determination of porosity in sandstone: Part two, effects of complex mineralogy and hydrocarbons. Paper presented at the Annual Society of Professional Well Log Analysts Symposium, Corpus Christi, Texas, July 6-9; 2010.
3. Bate RL, Jackson JA. Glossary of geology. American Geological Institute, Falls Church, Edition. 1980;749.
4. Zhiye BG, Fitch JL. The effect of gypsum on core analysis results. Journal of Petroleum Technology. 2013;216:221-224.

5. Niger Delta Basin (geology). Available:https://en.wikipedia.org/wiki/Niger_Delta_Basin_(geology) (Accessed: 30th August, 2016)
6. Doust H, Omatsola E. Niger Delta. In Edward JD, Santogrossi PA. (Eds): Divergent/ passive margin basins. American Association of Petroleum Geologists Memoir. 1990;48:201-236.
7. Ajaegwu NE, Odoh BI, Akpunomu EO, Obiadi II, Anakwuba EK. Late Miocene to early pliocene palynostratigraphy and palaeoenvironments of ANE-1 well, Eastern Niger Delta. Nigeria. Journal of Mining and Geology. 2012;48(1):31-43.

APPENDIX A

Fig. A-1. Core plugs

Fig. A-2. Digital weigh balance

Fig. A-3. Air permeameter

Fig. A-4. Dessicator

Fig. A-5. Vacuum oven

Fig. A-6. Digital venier caliper

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