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Comparison of Petrophysical Properties Measurement Methods in Sandston Rocks

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Abstract

This paper displays a survey about the laboratory routine core analysis study on ten sandstone core samples taken from Zubair Reservoir/West Quarna Oil Field. The Petrophysical properties of rock as porosity, permeability, grain's size, roundness and sorting, type of mineral and volumes of shales inside the samples were tested by many apparatus in the Petroleum Technology Department/ University of Technology such as OFITE BLP-530 Gas Porosimeter, PERG-200™ Gas Permeameter and liquid Permeameter, GeoSpec2 apparatus (NMR method), Scanning Electron Microscopy (SEM) and OFITE Spectral Gamma Ray Logger apparatus. By comparing all the results of porosity and permeability measured by these instruments, it is clear a significant variation in the values with the depth within same formation. The porosity by gas, liquid and NMR are varied (15.4 - 35.9) %, (4.6 - 22.3) % and (2.4-13.5) % respectively, While the permeability by gas, liquid and NMR were altered (0 - 512) md, (0-139.6) md and (1.577 x10^{-6} – 492) md respectively.

Keywords: Porosity, Permeability, Routine core analysis

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1- Introduction

Routine core analysis is essential in the petroleum industry. It determines the petrophysical properties of samples that improved from the surface of revelation by the geologic data. The core assessing involve lithology as carbonates, sandstones shales and coal etc. The samples usually are recovered in the vertical or horizontal direction with respect to the surface [1]. The cores are necessary for identification the system of pores among the reservoir unit and that will improves the ability to predict the performance of reservoir and therefore this helps in selection the methods to increase the profit of hydrocarbon recovery to the maximum value. The core analysis in the early life was an art and from such initiation this art developed using the modern development in empirical methods of physical and chemical analyses. Nowadays, different tools as NMR analysis (Nuclear Magnetic Resonance), SEM (Scanning Electron Microscopy), mass spectrometry, high frequently phase analysis; gas chromatography, etc. are used in the core testing [2].

2- Core Preparation

Ten sandstone core samples were taken from well number (2) of Zubair formation (West Qurna Oil Field) at depths (3219-3266) meters [3].

By using each of Rock well (cutting device) and Grinder apparatus, the plugs were cut in the horizontal direction which was parallel to the bedding plane in a special dimensions length about 2.54 cm (1 inch) and diameter about 3.8 cm (1.5 inch).

3- Core Measurements

3.1. Routine Core Analysis

a. Porosity Measurement

Each of the OFITE BLP-530 Gas Porosimeter and GeoSpec2 equipment were used to determine effective porosity for samples. All samples were evacuated from air by vacuum equipment and then the effective porosity was measured first by the Porosimeter. The Porosimeter measurement is based on Boyle's law ($P_1V_1 = P_2V_2$)

The second equipment that was used to measure the effective porosity (ϕE) and (ϕT) is GeoSpec2 Fig. 1. The Principle of analyses the rock core is NMR (Nuclear Magnetic Resonance). (NMR) is commonly applied in well logging measurements and for routine laboratory core analysis.

The Petrophysical properties of the rock core that can be evaluated by the NMR are porosity, permeability, pore size distribution, producible fluid type, free fluid index and oil viscosity.

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The NMR information gained for rock reflects electrical signal distribution created by hydrogen protons found in the fluids that gratify the rock. Another device used to measure effective porosity was the vacuum pump, by liquid saturation method.

The fresh water was used to cool and clean cutting edge, then the fluids in the samples were extracted using Soxhelt extractor.

Toluene (C_7H_8), Benzene (C_6H_6) and Methanol (CH_3OH) were used to remove the residual fluids and salts. After that, the oven was used for drying the samples at temperature (230 C˚).

Fig. 1. GeoSpec2 apparatus

b. Permeability Measurement

Absolute permeability of the prepared samples was measured using core lab PERG-200^{TM} Gas Permeameter apparatus before saturation the samples with the fresh water. Then the permeability was calculated by using the liquid Permeameter and GeoSpec2 apparatuses for these samples after saturation process. The results of air permeability were corrected for gas slippage employing klinkenberg correction. Darcy's law for gas and liquid was used to calculate permeability.

3.2. Mineralogical Analysis

Minerals inside the samples were specified by OFITE Spectral Gamma Ray Logger Fig. 2 and Scanning Electron Microscopy. The device (figure 2) determines the radiation quantity that sends out from a core sample and then computes the quantity of each of the elements. The quantities of each of these elements are counted.

Ten thin sections "slides" Fig. 3 from core samples were go run in the University of Baghdad, Department of Geology and were checked by microscope to detect the mineral components, heavy minerals types, diagentic process and its influence on structure of rocks and mineral synthesis, in addition to study the changes in lithology to define formation depositional environment in order to form an obvious image about reservoir behavior through the enhanced recovery processes. According to the microscope examination for slides and Wentworth classification [4], the average grains' size, shape and roundness and sorting degree were determined.

Grain's roundness is a significant property for sample characteristic due to its represents a guide to the substantial geological standards (Porosity and permeability) [5]. Degree of sorting reflects the nature of depositional environment.

Fig. 2. OFITE Spectral Gamma Ray Logger

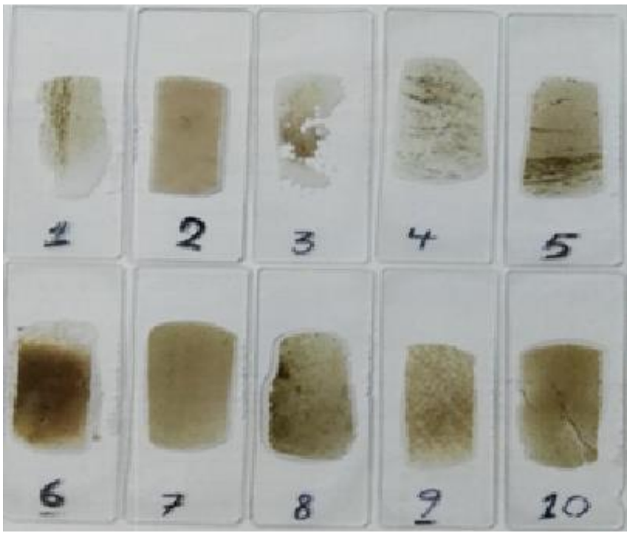

Fig. 3. Thin sections for all core samples

4- Experimental Work

Before beginning the experiments all pressure gauges, pumps, and all instruments were calibrated. The experiments were implemented as following:

4.1. Measurement the Gas Porosity

Length and diameter of plugs were measured in order to calculate the bulk volume (VB) and then the pore volume (Vp).

After that the plugs were placed into the core holder of gas Porosimeter to calculate inlet and outlet pressure and volume of gas inside the core holder to be then applied first in Boyle's law ($P_1V_1 = P_2V_2$) and after that in the porosity equation, we see that as follow:

$$VB = \frac{\pi D^2 L}{4} \quad (1)$$

$$V2 = \frac{P1V1}{P2} \quad (2)$$

$$VG = V3 - V2 \quad (3)$$

$$\phi\ eff. = \frac{Vp}{VB} * 100 \quad (4)$$

4.2. Measurement the Liquid Porosity by the Saturation Method

Weighting of dry sample before and after the saturation by water was determined to calculate the pore volume using (quation5) and then calculation the liquid porosity by the equation 4:

$$Vp = \frac{Ws - Wd}{\rho s} \quad (5)$$

4.3. Measurement the Gas Permeability

Using several values of upstream pressures in the gas Permeameter, gas flow rate was recorded and Darcy's law for gas was used to calculate permeability as follow:

$$k = \frac{C\,Q\,\mu\,L}{A\,(P1^2 - P2^2)} \quad (6)$$

4.4. Measurement the Liquid Permeability

The plugs were saturated 100% with the fresh water for a period of time about 24 hours. Absolute permeability of the liquid was defined by using GeoSpec2 and core lab liquid Permeameter. The inlet pressure in the liquid Permeameter was constant (range to 25 psig), the time of 10 cc of fresh water passed through samples was recorded to practice after that in Darcy's law.

5- Results and Discussion

According to the classification of folk [6], grain's size, roundness and sorting were detected. Table 1 shows the grain range for each core sample.

The average grains size of quartz ranging from medium to very fine.

Most of the grains are sub-angular with a few rounded grains according folk.

The grains have a well sorting and in some cases very well to moderately sorting. All these indicate that the samples have a good porosity and permeability with the exception of some samples.

The percentage of mineral for each core sample was determined, as given in Table 2.

Table 1. Size, roundness and sorting degree of grains for all plugs

Slide No.	Average Grains Size, µm	Type of grain	Roundness	Sorting Degree
1	0.9-1	very coarse sand	Sub angular-high& low Sphericity	Well sorted
2	1.5	Pebble	Sub angular-low Sphericity	Very well sorted
3	0.25	Medium	Sub angular-high& low Sphericity	Well sorted
4	0.4-0.5	medium coarse sand	Sub angular-high Sphericity	Well sorted
5	0.8-1	coarse to very coarse sand	Sub angular -low Sphericity	Well sorted
6	0.125-0.0625	Fine to very fine sand	Sub angular-low Sphericity	Well sorted
7	0.4-0.5	medium coarse sand	Sub angular-high& low Sphericity	Well sorted
8	0.25	Medium	Sub angular-high Sphericity	Well sorted
9	1-2	very coarse sand to pebble	Sub angular-low Sphericity	Moderately sorted
10	0.5	Coarse sand	Sub angular-low Sphericity	Well sorted

Table 2. Percentage of mineral for all core sample

Slide No.	Quartz,%	Feldspar,%
1	50	25
2	65	25
3	60	30
4	10	10
5	70	25
6	90	5
7	70	25
8	20	20
9	30	25
10	60	30

The rates of potassium, thorium and uranium minerals were counted by the OFITE Spectral Gamma Ray Logger as shown in Fig. 4 for one sample (sample no.1). Table 3 shows the results of all samples.

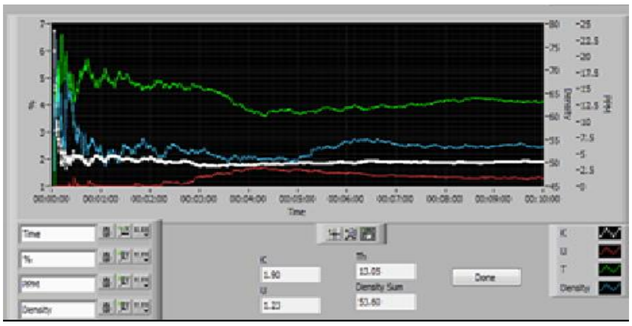

Fig. 4. Rates of potassium, uranium & thorium minerals for core no. (1)

Table 3. Results of Gamma Ray analysis for all plugs

Core No.	K (%)	U (ppm)	Th(ppm)
1	1.9	1.23	13.05
2	1.58	3.6	12.54
3	1.8	2.63	12.3
4	1.96	1.17	13.08
5	1.75	2.16	13.62
6	1.71	2.21	13.56
7	1.83	0.45	15.49
8	1.63	1.87	15.63
9	1.89	1.18	13.89
10	1.83	1.61	13.52

Using the ratio of thorium/ potassium (Th/K) and another technique by plotting the values of thorium verses potassium [7], the volume of shale and types of clays in the samples were detected. The results listed in Table 4.

Table 4. Final results of potassium, uranium, and thorium minerals

Core No.	Volume of shale (%)	Minerals according to potassium content	Minerals according to uranium content	Minerals according to thorium content
1	12	Shales	betonies	Biotite
2	12	Shales	granite	Grandiorite to biotite
3	57	andesite	Grandiorite	Grandiorite to biotite
4	42	Feld spathic	betonies	Biotite
5	12	Carbonates& andesite	biotite	Biotite
6	75	andesite	Granodioritr	Biotite
7	35	Carbonate	Andesite & basalt	Biotite
8	35	Shales	basalt	Granite
9	35	andesite	clays	Granite to granite
10	35	andesite	Carbonate and clays	Schist (Biotite)

Both of diameter, length, bulk volume, grain volume, weight of dry and wet plugs were measured to be applied in equation (4) in order to calculate the gas and liquid porosity; as shown in Table 5 and Table 6.

Table 5. Results of gas porosity for all samples

Core No.	VB, cm^3	VG, cm^3	V3, cm^3	P1, Psi	P2, Psi	(ØG), %
1	19.2	14.4	139.2	77.6	29.6	25.1
2	19.2	12.8	140.8	77.7	29.3	33.4
3	19.2	13.9	139.7	77.6	29.5	27.5
4	19.2	13.7	139.9	77.7	29.5	28.4
5	19.2	12.3	141.3	77.7	29.2	35.9
6	19.2	16.2	137.4	77.6	30	15.4
7	19.2	15.3	138.3	77.6	29.8	20.2
8	19.2	14.8	138.8	77.6	29.7	22.6
9	19.2	12.9	140.7	77.6	29.3	32.5
10	19.2	15.8	137.8	77.6	29.9	17.8

Table 6. Results of liquid porosity for all samples

Core No.	Dry weight, gm	wet weight, gm	Liquid Porosity (Ø) %
1	40.5	43.5	15.5
2	39.3	41.8	12.9
3	41.2	43.1	9.8
4	40.2	44.5	22.3
5	37.7	40.7	15.5
6	52.2	53.1	4.6
7	40.2	42.6	12.4
8	38.8	41.3	12.9
9	39.8	42.5	14
10	41	44.6	18.7

Each of porosity and permeability rates are measured in GeoSpec2 device as shown in Fig. 5 for one sample (no. 1).

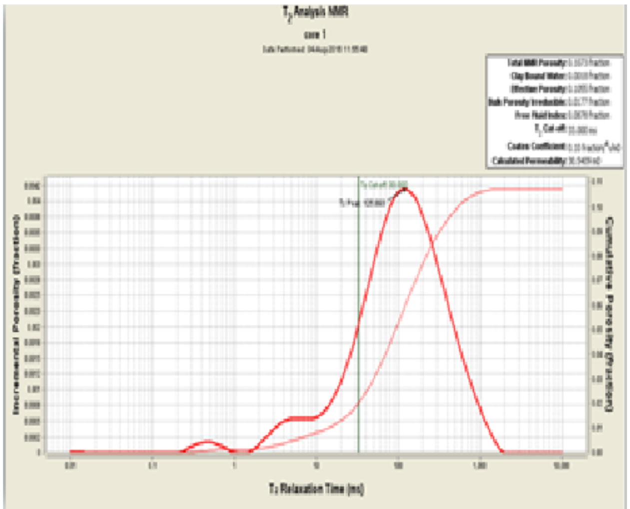

Fig. 5. Porosity &permeability results by the geospec2 apparatus for core no. (1)

The flow rates of gas at different pressures were measured by PERG-200^{TM} Permeameter apparatus of gas and then tabulated in Table 7 for sample no (1). The values of flow rates were differed extremely from core sample to another because of existing fractures and cracks in some samples. Results of reciprocal mean pressure were plotted versus permeability as shown in Fig. 6 and then corrected to eliminate the gas slippage effect by using klinkenberg correction to be then applied in Darcy's law.

Table 7. Results of gas permeability for core no. (1)

Q (cc/sec)	P_1,atm	mean press.(p-)	1/P$^-$,(atm.)	KG ,(md)
18	1.34	1.170	0.854	597.2
37	1.68	1.340	0.746	535.9
62	2.02	1.510	0.662	531.3
71	2.36	1.680	0.595	410.1

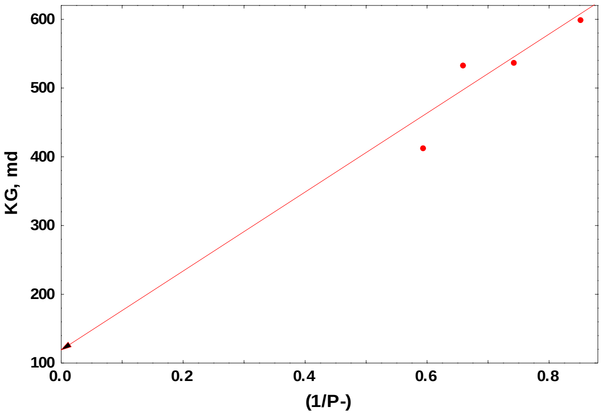

Fig. 6. Permeability vs. (1/P-) for core no.(1)

In this way the permeability of other samples were calculated and tabulated in Table 8.

Table 8 shows permeability results by liquid Permeameter when (10) cc of fresh water was passed through samples. Final results of gas and liquid porosity and permeability measured by the gas and liquid Permeameter, gas Prosimeter, vacuum pump in addition to the GeoSpec2 equipment are tabulated in Table 9.

Table 8. Results of liquid permeability measurments

Core No.	Time, sec	Press. ,atm.	Differential pressure ,atm	Flow rate, cc/sec
1	74.4	2.46	1.462	0.13
2	118	2.49	1.49	0.08
3	100	2.54	1.54	0.1
4	40	2.47	1.47	0.25
5	80	2.49	1.49	0.125
6	0	1	0	0
7	110	2.46	1.46	0.09
8	40	2.61	1.61	0.25
9	58	2.46	1.46	0.17
10	158	2.41	1.41	0.06

Table 9. Final Results of Porosity and Permeabilty

Core No.	Ø Gas ,%	Ø Liquid, %	Ø GeoSpec, %	KG_C, md	KL, md	K GeoSpec, md
1	25.1	15.5	11.4	120	75.1	341
2	33.4	12.9	12.4	130	47.3	192
3	27.5	9.8	13.5	54	53.2	36
4	28.4	22.34	9	140	139.6	492
5	35.9	15.5	12	200	69.8	90
6	15.4	4.6	2.4	0	0	1.57×10^{-6}
7	20.2	12.4	7.5	140	50.7	49
8	22.6	12.9	6.5	180	139.6	19.9
9	32.5	14.02	7.1	512	96.3	21.9
10	17.8	18.7	11.4	42	35.3	28.7

6- Conclusions

1- The tests results that have been presented in this paper show the petrophysical properties such as gas porosity and permeability values higher than results of liquid and less than results by GeoSpec2, this refer to capability of leak of gas in the gas Porosimeter and high content of hydrogen ions in most samples using GeoSpec2 device, therfore the results of liquid are going to be certified.

2- The gas and liquid permeability of core sample number (6) were zero. By return to the scanning electrical microscope, the sample contained very small grains in addition to exist grains of iron in addition to its structure where it seems a limestone.

3- From the results it is clear that the samples have a high rate of shale and type of clay was Illite-montmorillonite, this indicates to probability of swelling the shale if the water injection process employ in the future causing the damage in the formation.

Nomenclature

KG	:permeability of gas, md
L	:Length of core samples, cm
D	:Diameter of core samples, cm
A	:Cross sectional area, cm^2
VG	:Grain volume, cc
V_1&V_3	:Constants of Prosimeter, cc
V2	:Volume of gas inside the core holder, cc
ϕeff.	:Effective porosity,%
ρs	:Density of liquid (water), gm/cc
Ws	:Weight of saturated samples, gm
Wd	: Weight of dry samples, gm
C	: Conversion factor equal 2000
µ	:Viscosity of fluids equal 0.0176, cp
P1	:Upstream pressure, psi
P2	:Downstream pressure, psi
ϕT	:Total porosity,%
(1/P-)	:Adverse of mean pressure, Psi^{-1}

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