Evaluation of Petrophysical Properties Using Imaging Techniques

Ahmad A. Ramadhan#, Hussien I.Z. Al-Sudani, Fadhil Sarhan Kadhim, Ayman Tariq, Muhammed Lutfy

Petroleum Technology Dept./University of Technology/Baghdad/Iraq

#Corresponding author’s e-mail address: 150073@uotechnology.edu.iq

Abstract The petrophysics science is concerned with the study and characterization of oil and gas reservoirs for the hydrocarbon potential availability and productivity through the quantitative of rock properties. Porosity is one of the most important property in petrophysics. Estimation of porosity values are classified into two techniques, direct and indirect methods. The direct method has been used to estimate the porosity from core analysis, because the well log records are considered as indirect technique, which depend on the measurements of the physical features related with the porosity values. In this study two methods are used to evaluate the porosity of carbonate reservoir. The first one has been applied to the well logging interpretation, while the second method uses imaging technique interpretation based on core slides. The result of the second method shows a more accurate results of porosity in comparison with first method. The porosity values are varied from 2% to 3% by using Neutron log, while the density and sonic logs recorded about 9%. The optical image results of the porosity are ranging from 6.2% to 19.1% at 40 X magnifications, and from 1.8% to 4.6% at 100X. The SEM image interpretation results are: 12.2%, 10.4, % 4.1%, 5.9% at 400X, 1.99KX, 5.01KX, and 10KX respectively. Finally, the results showed that accuracy of porosity values depends on the examined area of sample that the area of sample is changing with the magnification of microscopes types.

Key words: petrophysics, porosity, image process, well log

1. Introduction

The petrophysical properties and reservoir characterization are important issues in the study of hydrocarbons reservoirs. The specialty of the subject and its relationship to the identification of reservoirs and productivity wells. Therefore, the study of porosity is one of the fundamentals that based on the results of all other factors that are involved in the construction of the geological model of the reservoir which is used to estimate the reserve of reservoir and estimation of productivity. The uncertainty associated with the estimation of porosity will be reflected negatively on the decision makers in making the appropriate decision in the process of economic investment of the reservoir.

Porosity or void fraction is a calculation of the void spaces in a rock, ranging from 0 to 1, or a percentage pore from 0% to 100%. [1] There are many techniques to identify porosity in a rock, such as new technologies of imaging and developed microscopes. Porosity can be estimated from well logs results in addition to results from core data correlated to reservoir situation. [2] Porosity must be estimated
precisely because it is required for the estimation of saturation and permeability. Lithology of rocks that affect the porosity estimation is needed to be computed as part of the lithology identification. [3, 4]

While permeability is the ability of rocks to allow fluid to pass, and measured in Darcy. The rocks of a geological formations that pass fluids readily, for example sandstones, can be called permeable. [5] The formations, composed from fine grain sediments, the finer grained be less interconnected voids are called impermeable. Absolute permeability is the estimation of the connected void, when a single fluid is present in the rock. The permeability called effective when it is able to flow or pass a especially fluid in a porous rocks when other not unassailable fluids are exist in the reservoir. [6]

The computation of relative permeability gives the ability to correlate the various capabilities of liquids to pass in exist materials, since exist of more than one fluid generally stop the flow. [7]

Permeability concept is important to estimate the characteristics of hydrocarbons flow in reservoirs. A rock is considered to be exploited hydrocarbon reservoir without motivation when the permeability greater than approximately 100 md. Rocks with permeability significantly lower than 100 md can form efficient seals. Friable or loss sand may have permeability of over 5000 md. [6]

1.1 Porosity Measuring Methods
Conventional petrophysics is related to the characterization of reservoirs to assess the hydrocarbon availability and productivity, by the quantitative study of the properties of rock. The first interest is how naturally interconnected of voids and fractures that control movement and accumulation of hydrocarbon. The main groups methods used for measurements are, (a) core or crushed rock, (b) well logging results and (c) seismic prospecting survey results. Two groups will be reviewed concern, the core and well log that drive to evaluation of porosity from voids and fractures. [8]

In group (a) the methods is subdivide into direct measurements from imaging of a rock core, and group (b) methods are subdivided into indirect measurements from well log results. (Figure 1)

![Figure 1. Methods used to determine porosity and pore size distribution (PSD). [8]](image-url)

1.1.1 Conventional Methods
Several methods and techniques can be applied for direct measurement of rock porosity: (1) saturation or imbibition, (2) buoyancy, (3) gas expansion (He porosimeter), (4) gas adsorption (BET) and (5) mercury
intrusion porosimetry [1, 2]. The previous methods can measure the connected voids of the sample, like in a way to the contrast-match technique which is used in neutron scattering to evaluate connected voids. [8]

1.1.2 Imaging Microscopy

There are several techniques of imaging exist to identify the behavior of porosity and its related minerals in rock. For example, optical microscopy, SEM, NMR, FIB SEM.

1.1.2.1 Optical Image Microscope

Optical petrology is the most depending technique, precise and can be repeated to evaluate the void system and lithology of the reservoir rock outcrop, core and cutting samples. For better diagnosis pores and fractures, it is required to prepare the sample for testing by using epoxy solution, for imbibe the rock to identify the pore system. The slide is viewed by plane-polarized and cross-polarized or ultra-violet light to test the slide of cross section through a rock, to identify the lithology, fabric and texture by point counting or image analysis of the slide. In addition to texture, diagenesis, pore system and reservoir quality. However, despite the large amount of information available. [9]

The used of optical techniques in petrology is to study the minerals and rocks by computed their response to optical properties. It is used to evaluate the lithology composition of rocks in order to help identifying their origin and development. [6]

1.1.2.2 Scanning Electron Image Microscope

Through the application of SEM, geologist is now able to go up one step forward the slide analysis to study the void system. [6]. SEM have an advantage over optical petrography that it eases of preparation of sample, greater resolution, and a higher magnification range. When testing an SEM image for the first time, the scale is a major problem. However, with practice and training, the user can soon identify properties previously observed in slide thin section. The SEM replenish slide analysis by providing different type of information which when used with other techniques gives a new information to help characterized void features in sample. [10]

The electrons react with atoms in the rock sample, and send many signals that carry out an information about the sample's surface include topography and composition. The electron beam type is scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Samples situation can be detected in high and low vacuum or in dry or wet conditions in variable pressure or environmental SEM, and at a wide range of low or high temperatures with specialized instruments [8]. The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons that can be detected depends, among the other things, on the surface of sample. By scanning the sample and detected the secondary electrons that are released using a special detector, an image has been created representing the topography of the surface.

Historically, William Nicol had created Nicol prism, started to prepare slices of materials, and Henry Thronton Maire Witham (1831) applied his techniques by plant petrifactions study. This technique used in petrology, Sir David Brewster and many other used optical searches for thin sections of crystals. [8]

McMullan, presented the use of SEM. Although Max Knoll takes an image with a 50 mm showing the steering contrast using of an electron beam scanner. Manfred von Ardenne in 1937 created a microscope with high magnification by scanning a very small scanning with a de-magnified and finely focused electron beam. Ardenne used the scanning principle to achieve magnification in addition to purposefully eliminate the chromatic aberration otherwise inherent in the electron microscope. After that he had discussed the various detection modes, possibilities and theory of SEM together with the construction of the first high magnification SEM. Further work was reported by Zworykin's group, followed by the Cambridge groups in the 1950s and early 1960s headed by Charles Oatley, all of which finally led to the marketing of the first commercial instrument by Cambridge Scientific Instrument Company as the "Stereoscan" in 1965. [12]
2. Methods and Materials

Two methods have been applied in this research as follows:

2.1 Log Interpretation Method

The study was made across the Upper Cretaceous Mishrif Formation at Bazergan field. Interactive Petrophysics software IP, V3.5 is used to determine the porosity and permeability from well log data.

2.2 Imaging Interpretation Method

The first step in this method is sample preparation for image in microscope. Three samples of limestone were prepared for imaging by (1) optical microscope and (2) scanning electron microscope, the samples were prepared in three roughness of surface to explain the effect of roughness on porosity calculation. The samples are prepared according to Stutzman P.E., and Clifton J.R. 1999. [13]

3. Results and Discussions

3.1 Log results

The Interactive Petrophysics (IP) software is used to calculate the porosity and permeability from log results after environment corrections. These results will be used to be compared with the results of imaging method which will be used in this study. Fig. 2 and Fig. 3 show that the input data window which is used for porosity and permeability calculations. Fig 4 shows the results for those petrophysics. The results of porosity and permeability as follow:

Porosity at depth 3280m:
1- PHI Density: 9%
2- PHI Neutron: 2-3%
3- PHI Sonic: 9%
4- PHI Effective: 9%

Permeability at depth 3280m: By 3 defaults (Timur, Morris Oil, Schlumberger) all nearly the same readings: 500 md.

![Figure 2. Porosity input for IP.](image)

![Figure 3. Permeability input for IP.](image)
3.2 Imaging Methods Results
The 3 sample cores are used in this study from Buzurgan oil field, Mishrif formation. The depth of samples is at 3280m. Those samples are prepared as explained in section 3. And prepared in three roughness’s, the sample grinding to a flat surface, using 100, 260, and 600 mesh grit diamond paper.

3.3 Optical Results
Figure 5 shows the original image which taken from Optical Microscope before process in two magnifications lenses at 40X, and 100X. Figure 6 show the threshold image after processed by (Image J)
software to calculate the porosity. Figure 7 shows the processed image by image j software to show mapping of porosity. And the results are shown in table 1.

![Sample 1 a: 40X](image1.png) ![Sample 1 b: 100X](image2.png)
![Sample 2 a: 40X](image3.png) ![Sample 2 b: 100X](image4.png)
![Sample 3 a: 40X](image5.png) ![Sample 3 b: 100X](image6.png)

**Figure 5.** Optical image in two magnification enlargements for the studied samples.
Sample 1 a: porosity 8.209%       Sample 1 b: porosity 1.8%
Sample 2 a: porosity 19.157%     Sample 2 b: porosity 4.617%
Sample 3 a: porosity 6.238%     Sample 3 b: porosity 2.268%

**Figure 6.** Processed Optical image to determine porosity.
**Figure 7.** Processed Optical image for porosity mapping.
Table 1 Results of Optical image processing for porosity.

| Sample No. | Count | Total Area (μm²) | Average Pore size (μm) | % Area (porosity) |
|------------|-------|-------------------|------------------------|-------------------|
| Sample 1 a | 1072  | 61305.296         | 57.188                 | 14.155            |
| Sample 1 b | 504   | 2201.507          | 4.368                  | 1.821             |
| Sample 2 a | 1631  | 88226.807         | 54.094                 | 19.157            |
| Sample 2 b | 848   | 6830.234          | 8.055                  | 4.617             |
| Sample 3 a | 3381  | 11503.446         | 3.402                  | 6.238             |
| Sample 3 b | 515   | 2011.027          | 3.905                  | 2.268             |

3.4 SEM Results

Figure 8 shows the original image from SEM at magnification enlargement of 228X, 1.0 KX, 4.97 KX, 10 KX, 20 KX. And this magnification is applied to reach the nano scale porosity. Figure 9 shows the porosity of samples after being processed by image j software. Also, the SEM-EDS system provides the chemical composition of sample as CaCO₃, as shown in figure 10, and the results are shown in table 2.

Figure 8. SEM image for Sample 1 in five magnification enlargement 228X, 1.0 KX, 4.97 KX, 10 KX, 20 KX.
Figure 9. SEM image and processed for Sample 1 in five magnification enlargement: a: 400X, b: 1.99KX, c: 5.01KX, d: 10KX.
Figure 10. Shows the EDS of samples that reflect the chemical composition.

Table 2. Results of the SEM image processing for porosity.

| Sample No. | Count | Total Area (μm) | Area (porosity) | Average Pore size (μm) | Area% (porosity) |
|------------|-------|-----------------|-----------------|------------------------|-----------------|
| Sample 1 a | 7770  | 85916           | 11.057          | 12.186                 |                 |
| Sample 1 b | 2896  | 73402           | 25.346          | 10.411                 |                 |
| Sample 1 c | 1984  | 28916           | 14.575          | 4.101                  |                 |
| Sample 1 d | 2565  | 41734           | 16.271          | 5.920                  |                 |

3.5 Dissections
The result above has shown clearly that the use of image methods to calculate the petrophysical properties such as porosity is useful and accurate in determining the core samples properties and in addition to the pore structures. Table 3 represent the correlation between the IP results with results of imaging methods. These results are logical, but in SEM image the porosity has shown higher value because this technique has calculated the smallest size of pore.

Table 3. Correlation between the IP results with results of imaging methods.

| IP          | Optical image       | SEM image |
|-------------|---------------------|-----------|
| PHI Density: 9%       | 6.2-19.1% at 40X   | 12.186%   |
| PHI Neutron: 2-3%     | 1.8-4.6 % at 100X  | 10.411%   |
| PHI Sonic: 9%         |                     | 4.101%    |
| PHI Effective: 9%     |                     | 5.920%    |

4 Conclusion
It can be concluded:
1-The use of different techniques is important to verify the results of petrophysical properties.
2-The porosity are different at using different magnifications of Microscopes because of inhomogeneity of rock materials.
3- Porosity of SEM in sample (1) is greater in larger magnification than Optical image, due to the detailed surface of the SEM.
Acknowledgments

We extend our thanks and appreciation to the Department of Production and Metallurgy Engineering/University of Technology for providing support through the use of SEM and Optical Microscopes to complete measurements of this study.

References

[1] Tiab D and Donaldson EC 2004 Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties 2nd Edition. Elsevier
[2] Sondergeld C H Newsham K E, Comisky JT, Rice M C and Rai CS 2010 Petrophysical considerations in evaluating and producing shale gas Soc Petrol Eng SPE 131768
[3] Clarkson C R, Freeman M H L, Agamalian M, Melnichenko Y B, Mastalerz M, Bustin R M, Radlinski A P and Blach T P 2012a Characterization of tight gas reservoir pore structure using USANS/ SANS and gas adsorption analysis, Fuel 95 371–385 DOI: 10.1016/j.Fuel.2011.12.010
[4] Thomas, E C 1992 50th Anniversary of the Archie Equation: Archie Left More Than Just an Equation, Log Anal 199 12-90
[5] Horgan, G W 1998 Mathematical morphology for soil image analysis, European Journal of Soil Science 49 161-173
[6] Noiriel C 2015 Resolving time-dependent evolution of pore-scale structure, permeability and reactivity using X-ray microtomography, Rev Mineral Geochem 80 247–285
[7] Clarkson C R, Wood J M, Burgis S E, Aquini S D, Freeman M 2012b Nanopore-structure analysis and permeability predictions for a tight gas siltstone reservoir by use of low-pressure adsorption and mercury intrusion techniques. Soc Petrol Eng, Reservoir Eval Eng SPE 155537 648–661
[8] Anovitz L M and Cole D R 2015 Characterization and Analysis of Porosity and Pore Structures, Reviews in Mineralogy & Geochemistry, Mineralogical Society of America, 80:61-164.
[9] Beckingham L E, Peters C A, Um W, Jones K W, Lindquist W B 2013 2D and 3D imaging resolution trade-offs in quantifying pore throats for prediction of permeability, Adv. Water Resource 62 1–12
[10] Zhang S, and Klimentidis R E 2011 Porosity and permeability analysis on nanoscale FIB-SEM 3D imaging of shale rock, Presentation at the International Symposium of the Society of Core Analysts held in Austin, Texas, USA 18–21
[11] Welton J E 2003 SEM Petrology Atlas: methods in exploration series No.4 The American Association of Petroleum Geologists Tulsa, Oklahoma 74101, U.S.A.
[12] Stokes D J 2008 Principles and Practice of Variable Pressure Environmental Scanning Electron Microscopy (VP-ESEM), Chiohester: John Wiley & Sons
[13] Stutzman P E and Clifton J R 1999 Specimen preparation for scanning electron microscopy, Proceedings of the Twenty-First International Conference on Cement Microscopy, L Jany and A Nisperos, Eds., April 25-29, 1999, Las Vegas, Nevada, USA, 10-22