Thin Section Analysis and Effects of Geothermal Gradient to Determine Porosity and Permeability in Sandstone Rocks

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Abstract

All of the reservoir assets including oil, gas, and geothermal energy are all depended upon the pore volume and the permeability of the reservoir rock. In this study, these parameters were determined by applying capillary pressure approach through digitally scanned microscopic images. Especially the existence of steam and liquid water in the reservoir make the capillary pressure approach more accurate for the determination of rock properties. The geothermal gradient may also participate in this approach, since the pore diameters of the rock masses change with the changing temperature. After 1500ft in Termin region where the samples were collected the pore diameter increased in 0.8% resulting in 2-5% increase in porosity values and thus converting more absolute permeability into effective permeability. By applying image analysis technique, the sandstone permeabilities were found as around 18%. In this study capillary pressure was considered as a function of the pore diameter. Each scanned pore area per total area was considered as saturation parameter. At least ten scans were performed for each thin section and at least 95% of all thin sectioned are was examined under microscope and 600 data were recorded for each field scan of the sample.

INTRODUCTION

Thin section analysis to determine permeability and the effect of geothermal gradient effect on the pore size distribution were considered in this study. There are two basic approaches for analyzing raw rock samples such as preparation of core plugs of required dimensions and making maintenance work and producing thin section plates. In this study, the application is focused on the second approach. During the experiments, the glass plate over which thin section of the rock sample exists, was moved several times until the "Percentage Area" item reaches to a maximum point and then starts decreasing. The porosity is indicated by this "Percentage Area" item. For the determination of porosity, after each motion of the glass plate under the microscope, the image on screen is shot. The points indicated by black colour which are suspected to be pore spaces are selected by the computer. Nevertheless, while choosing these black points as pore spaces, it is very common to confuse minerals existing in the section as pore space. In order to eliminate this confusion, after every shot, the filter of the microscope should be inserted. The minerals display lustring and shiny view under the filter. Thus minerals are distinguished from the pore spaces. After being sure that the chosen dots are of pore space, the shot image is scanned by the set-up.[1]

On the other hand an instrument called CMS 300 (Core Measurement System 300) was also used to see the effect of geothermal and pressure gradient effect in the determination of porosity and permeability.

EXPERIMENTAL SET-UP AND PROCEDURE

The raw rock sample taken from the field is cut to a dimension that it can be easily studied in laboratory conditions. Rectangular glass plates which are appropriate for microscopic studies are cleaned with methyl alcohol in a very detailed manner. The rock particles which are cut into smaller dimensions are sticked over the glass plates. The redundant part of the rock is cut by diamond teeth electric cutter. The part which stays on the glass plate is shaved so that the thickness on the glass plate should not exceed 3 cm. The prepared sections are examined by using Integrated Image Analysis Device. Thin sections are placed to the microscope. By the help of the computer assisted camera, the section is seen on the video monitor in a magnified scale (Figure 1). The parameters of the device are set. The glass plates are moved very slowly under the microscope by hands. Meanwhile the view on the screen moves, too. This motion is continued until a large portion of the section has been scanned. Finally porosity information is obtained fractionally. Other values like relative permeability can be obtained by working on the raw data.[2]. In order to determine the geothermal or the temperature effect, all the prepared thin sectioned plates were heated sensitively at digital temperature controlled oven. After reaching the required temperature the plates were placed into adiabatically insulated transparent cases. Thermally insulated systems are called adiabatic.

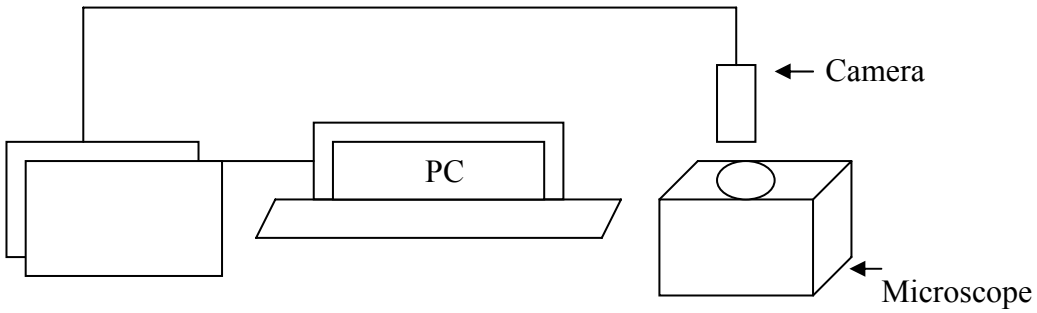

Figure 1 Integrated Image Analysis Device

CMS-300 device was also used for the 1.5 inch limestone and sandstone core plugs to see the effect of pressure and temperature on porosity and permeability. This device enables to measure the porosity and permeability of the core plugs under different pressure and temperature conditions. The device is an integrated automated computer directed, unsteady state pressure and temperature decay and increase controlled permeameter and porosimeter. The system is capable of 0.01 to 40 % pore volume, air permeability and equivalent Klinkenberg permeability.

RESULTS AND DISCUSSION

By looking at the “Percentage Area” of each scan, namely each table below, it is seen that the porosity value indicated by average value of “Percentage Area”, increases in field scan 1 and decreases back and stabilises at that value. Thus the porosity of the sample studied is determined as 23.65 %. “Percentage Area” is the ratio of the “Detected Area” to the sum of “Detected Area” and “Undetected Area”. After each scan these parameters are accumulated and their arithmetical mean due to the number of scan is given. The average value after the final scan is the percentage porosity of the sample used.[3]

In Figure-3, the coloured section displays the total area scanned. The black coloured section is the porous part. The shiny part near the porous zone is the mineral accumulation zone. The blue zone is the “Blue Volume”, red zone is the “Red Volume”. The striped lines may be considered as the fractures within the sample. The colours except black are the conventions of the device or the chemical used to have a better idea.

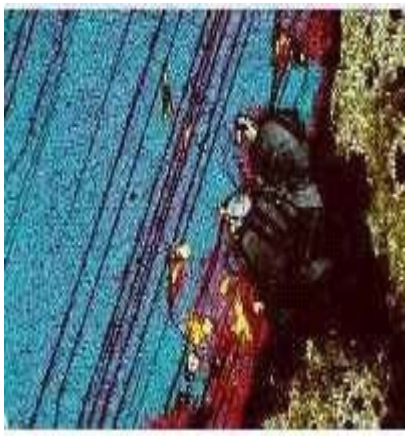

Figure -3 On screen display of thin section shots for sandstone 2

On the other hand by using thin section analysis, it is possible to determine relative permeability of the wetting phase. In this procedure capillary pressure approach is used. [4]. The equations used in permeability applications are as follows:

$$\frac{S_b}{S_{binf}} = e^{Fg/(\log Pc/Pd)} \quad \text{.....Equation 1}$$

$$\bar{Fg} = \frac{\sum_{i=1}^{n} F_{gi}}{n} \quad \text{.....Equation 2}$$

After each field scan shot, another table including raw data is supplied by the system. As long as the scans are increased by the operator, the raw data comes into screen as a cumulative of form. To determine how many scans to do, porosity values are observed. When the porosity item stays fixed or reaches a peak point, it is understood that the required number of scans has been reached. When the relevant experiment is finished, more than seven hundred data are obtained in column and row wise. For the sake of demonstration, a portion of this raw data is given in Table 1 and in Table 2 where sandstone 2 is the sample used. Table 3 shows field scan for porosity determination.[3]

Table – 1
A selected number of raw data for sandstone 2.

No. of Data	Area	Perimeter	Max.Diameter	Min. Diameter	Angle
1	213.21	15.79	6.11	5	-17
2	213.21	9.36	4.09	2.62	0
3	157.77	7.02	3.51	2.11	0
4	157.77	6.43	2.98	2.34	79
5	135.52	17.55	7.07	4.22	66
6	135.52	39.78	10.37	7.4	74
7	108.14	6.43	2.98	1.85	-11
8	107.12	16.38	6.85	3.15	-20
9	107.12	49.72	17.95	10.22	-71
10	99.93	18.13	5.39	4.14	13
11	86.58	7.02	2.98	2.11	11
12	86.58	15.79	4.82	4.46	76
13	77.69	14.62	6.02	4.46	-61
14	77.69	11.11	4.72	3.56	-83
15	68.1	10.53	4.82	1.85	76

Table - 2
A selected number of raw data for sandstone 2.

No.of Data	Volume	Average	Farctor X	Factor Y	Circularity	Enclosed Area	Equivalent Circular Diameter
1	2557	54.4	481	114	0.85	15.74	8.54
2	576	57.6	480	119	0.7	3.76	8.54
3	505	63.13	648	131	0.67	2.4	7.5
4	394	65.67	429	135	0.78	1.71	7.5
5	2843	54.67	685	143	0.7	17.11	6.68
6	5262	47.84	664	162	0.73	37.99	6.68
7	402	67	695	158	0.88	2.4	5.99
8	2662	66.55	680	167	0.63	13.69	5.88
9	13769	47.15	444	206	0.51	100.27	5.88
10	1672	50.67	631	295	0.96	11.29	5.65
11	551	68.88	640	305	0.98	2.74	5.35
12	1426	62	479	332	0.92	7.53	5.35
13	2345	53.3	578	359	0.83	15.06	5.19
14	1398	60.78	579	376	0.8	7.53	5.19
15	1050	65.63	534	391	0.62	5.13	4.76

Table -3
Field Scan 1 to determine porosity of Sandstone 2

Measurement	This Scan	Total	Average
Detect Area	6977.97	7006.37	3503.19
UnDetect Area	10828.68	28606.93	14303.46
Percentage Volume	39.19	39.95	19.67
Red Volume	2514360	2522209	1261104.5
Green Volume	2480958	2488206	1244103
Blue Volume	2425631	2434103	1217051
Red Ave Interval	123	217	108.5
Green Ave Interval	121	208	104
Blue Ave Interval	118	220	110
Perimeter	4200	4273	2136.5

The capillary pressure values (P_c) are determined by Equation 3. Then capillary pressure vs. wetting phase saturation plotted. The minimum radius was determined as 0.33 mm.

$$P_c = \frac{214}{d} \quad \text{Equation 3}$$

Since capillary pressure is inversely proportional with the diameter of the pore due to Equation 3, the maximum capillary pressure value can be reached at the minimum diameter. By using Equation 3, the capillary pressure value at the minimum diameter 0.66 is 324 psi. [4] This graph has been plotted to determine pressure value at horizontal asymptote and saturation value at the highest possible pressure.(Figure 4) The capillary pressure value as horizontal asymptote is 25 psi which is P_d value. Since the maximum possible capillary pressure is 324 psi, the relevant saturation value is obtained from the equation of the capillary pressure versus wetting phase saturation equation, Equation-4.

$$Pc = 24.023 * e^{2.504 S_b} \quad \text{.....4.}$$

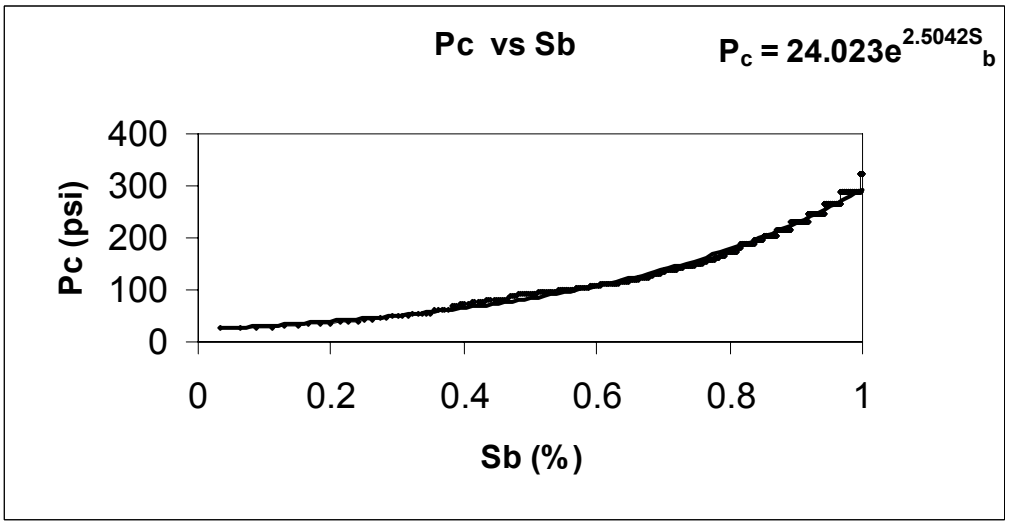

Figure-4 Capillary pressure versus wetting phase saturation of sandstone1

Thus, the required saturation value S_{binf} is determined as 1. After the determination of these parameters, the pore geometric factor F_g should be determined for every data point. In this calculation Equation 1 was used. But unfortunately, the required pore geometric factor is in exponential variable in this equation. To eliminate this problem the natural logarithm is applied to right hand side and left hand side of Equation 1. Thus, pore geometric factor for each data point can be determined by elementary mathematics. Since the basic aim in doing this study is to obtain relative permeability data. The parameters in equation should be identified. In Equation-4, there is an integral portion. To determine this part, the square of the capillary pressure column is taken, and than the reciprocal of square of capillary pressure is

$$S_{bi} = \frac{A_i}{\sum_{i=1}^{n} A_i} \quad \text{.....Equation 5}$$

calculated for every capillary pressure data. This is calculated by Equation-5.

$$k = \frac{\bar{F_g} * \varphi}{2} * (\sigma * \cos\theta o^2 * \int_0^1 ds/(Pc)^2 \quad \text{..... Equation 6}$$

$$\int_0^1 ds/(Pc)^2 \quad \text{.....Equation 7}$$

$$(1/P_c)^2 = 0.0017e^{-5.0084S_b} \quad \text{……..Equation 8}$$

To evaluate the integral part in Equation 4, a numerical integral is applied between 0 and 1. An integral stepwise incremental is chosen starting from 0. The smaller the increment is the more accurate is the integral. In this study the increment was chosen as 0.0012. For every data point calculations are performed and thus relative permeability is obtained. It is also possible to determine the average pore geometric by Equation 2. The total integral from 0 to 1 is calculated by summing up every individual data. This average pore geometric factor and the total integral is put in Equation 4. The absolute permeability is obtained as 0.062 D.
It is seen the values obtained from different methods are consistent with each other. Porosity values from thin section analysis are higher than those obtained from Helium Porosimeter except Sandstone 2. This may be due to experimental error. The permeability values from the both methods are very close. Nevertheless, the permeability value from thin section analysis for the sample Sandstone 2, is almost four times the value from Helium Porosimeter. (Amyx, J.W,1976)[5] This may be due to the effects of vugular structure and the applied capillary pressure technique.

By using Core Measurement System 300 CMS device all the limestone and sandstone samples were analyzed under different pressure and temperature values as in core plug dimensions. A sample output table is given for samples and Sandstone 1. All the values in Table -4 are computer out put of the device.

Table -4 Computer output of Sandstone 2 by CMS-300

Net Stress Pressure (psi)	Pore Volume (cc)	Porosity (%)	k(D)	ka (D)	B(He)	Temperature (^oF)	Depth (ft)
1000	9.546	16.4	0.0234	0.0169	0.019	100	1000
2500	9.15	15.7	0.0101	0.0118	0.134	150	1500
4000	8.9936	15.4	0.0084	0.0103	0.011	200	2000

The device was set as geothermal gradient 0.1 ^oF/ft. It is possible to set the depth interval upon the preferences of the study.

CONCLUSION

The increase in temperature as the depth increases decreases permeability significantly. Nevertheless the porosity displays a sudden increase after a critical temperature value. Before and after this critical value the porosity generally decreases. However if the temperature effect combined with pressure reaches higher values, a fractionation in the reservoir may take place leading a high increase in both porosity and permeability.

The increase in temperature causes an increase in capillary pressure. Thus permeability decreases.

Both porosity and permeability decrease with increasing pressure and depth unless no hatching of the cores take place.

Determination of permeability by thin section and image analysis method gives close values obtained from conventional core plug methods. Thin section analysis is cheaper and less time consuming compared to conventional techniques.

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