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DIGITAL CORE ANALYSIS OF CAPILLARY PRESSURE IN SANDSTONE

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Abstract
This research aimed to obtain the petrophysical parameters of the capillary pressure in a sandstone from 3D modelling of high-resolution images. By integrating a number of 2D slice results, a plot of capillary pressure vs water saturation was built. When performing digital simulations using 512 x 512 x 512 pixels, the effect on the resulting image was clearly seen using adaptive thresholding. The obtained porosity was 29.5% while the permeability was obtained through iteration was 3942 mD. This quite large value is because the synthetic core was made from coarse sand grains. It was found that at the depth of free water level of 984 ft, the obtained capillary pressure is 167.36 psi with water saturation at 4%.

Introduction

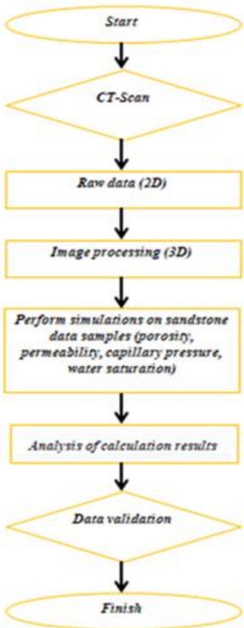
Digital Rock Physics or (DRP) is a method based on digital images because it is an alternative method for finding physical quantities from rocks with more effective and efficient and non-destructive properties. Physical properties of rocks that are usually sought are porosity, specific surface area, permeability, capillary pressure, and saturation. In its development, Digital Rock Physics can show the physical properties of rocks on a micro scale with microstructural parameters such as rock pores, grain size, pore network and surface area. The main goal of rock physics or Rock Physics itself is to find and provide an understanding of model relationships between field data and data transformations obtained from geophysical surveys.

Capillary pressure analysis is one method that is often used in the validation process of a parameter. Rock physical quantities such as porosity, permeability, capillary pressure, and so on are important aspects in petroleum because they are especially useful in determining the quality of a reservoir. The application of DRP applications has been widely used in several sandstone samples from sample data analysis.

Digital images (3D images) on rocks can be obtained by scanning using a CT-Scan tool and combined with simulation software to obtain digital images of the reservoir rock. The projection is then reconstructed into a cross-sectional or incision image. The reconstructed image will then be processed to obtain the desired physical quantity, to obtain this digital image, it is necessary to adjust the physical parameters that can affect the resulting image. Using the help of imaging methods, complex pore geometries can be represented. Therefore, digital rock physics is developing very quickly and has become a potential and valuable resource in determining the relationships between rock properties. This method relies on imaging techniques to obtain high resolution rock representations with 3D samples. The pore spaces and mineral matrices of natural rocks are digitized and then numerically simulated to obtain estimates of various macroscopic rock properties. The volume depiction was obtained using high-resolution micro-scale computer tomography (CT) which was used to capture and visualize the three-dimensional pore geometry structure of the reservoir rock.

Data and Method

The research carried out is pure research or basic research by performing software simulations. The data collection method used is the literature method. The digital simulation used is a DRP software which is used to process data and to iterate over the core samples in order to visualize the core samples in 3D, and also to see how the fluid flows and the direction of the fluid flow. While the data used are digital core data from sandstone originating from synthetic samples or artificial samples made using a mixture of cement and sand.



At the beginning of doing this research by doing a micro CT-scan on a sample of sandstone cores. Then from this data will form a digital core data called raw data which is still in 2-dimensional form through an incision on each core slice. Furthermore, the raw data is processed in A DRP software for image processing so that it can visualize in 3-dimensional form, then from the digital core sample data we initiate and impose limits on the data by segmenting so that the data reads as solids and the data is read as pivot then you can immediately find out the porosity and permeability values obtained, while the capillary pressure and water saturation values are obtained through calculations from the formula discussed in the previous chapter. And the last one is validating the data to find out whether the results that have been studied with the results of digital rock core carbonate data are valid or not.

Result and Discussion

- *Sandstone in Digital Rock Physics*

This type of reservoir has quite high variations in the value of porosity and permeability, so it is very good to be a good quality reservoir. In the sandstone sample in the 3D model it is very important to know to see the microstructure parameters of the rock in the form of pores and rock matrix in detail and to be able to model the pore structure and to be able to know the fluid flow velocity model in the sandstone core sample or sandstone. In this sandstone sample, digital simulation calculations are carried out to calculate the values of porosity, permeability, capillary pressure and water saturation.

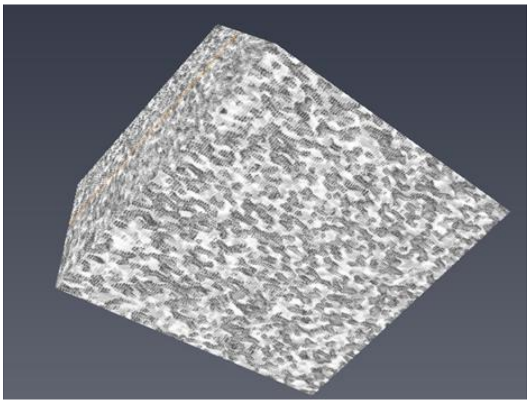


Figure 1. 3D image of a digital core sample

Rock pores are indicated by color (black / white), whereas rock dense matrix is indicated by color (white and gray). This color difference is due to the different density of each mineral.

- DRP Images

To obtain petrophysical data from the micro ct-scan image of core rocks, it is also necessary to verify with laboratory results. For 1 complex core sample it takes 8-12 hours rather than laboratory measurements which take 1-2 days even for relative permeability it may take several months. From this data, it can also be done in parallel for various kinds of petrophysical analysis and also various types of EOR.

By performing simulations using a DRP software from micro ct-scan data, which focuses on visualizing 3-dimensional depictions and to be able to analyze, we must know data properties such as lattice info used, namely 512 x 512 x 512 pixels or in a number of 512 pieces in the form 2 dimensions and voxel size, namely 1 x 1 x 1 to determine the area on the slice so that the results are made into 3 dimensions, then a threshold process is carried out to distinguish between rock pores and the matrix in the sandstone sample. At 512 x 512 x 512 pixels it greatly affects the quality of the resulting digital image because when processing the digital image data it looks clearer than 256 x 256 x 256 pixels.

In a digital image, a set of matrix data is usually called a pixel. Each pixel contains an intensity value with a certain scale so that it can indicate the color in the original image. A digital image that has an increasing number of pixels will produce a good image. From a set of pixel matrices with an intensity value on a gray scale, namely from 0 - 255. Where the value scale of 0 means black this is to show hollow rocks while the 255 value scale means white this is to show its cementation. From the rendering of the information regarding the percentage of the pore content to the total material or the pore with solids / grains to be extracted, then from the digital image it is necessary to convert it with the thresholding stage, which is to determine which rocks have cavities with those without cavities in the rock.

Judging from the porosity and permeability results obtained from the 3D visualization results with the Digital Rock Physics (DRP) method, it can be concluded that the results from rock samples are included in the porous sandstone category and this rock has the ability to pass through fluids to accumulate oil, water, and gases which usually have very good relations between the matrices. With high porosity and permeability values, it can interpret the ideal sandstone layer as reservoir rock.

- *Calculation of Capillary Pressure (Pc) from DRP*

To obtain the value of calculating capillary pressure from free water level 0 - 300 meters by doing trial and error, the capillary pressure formula will be obtained from the following equation (Gibrata, 2019):

$$Pc = Diff\ water\ and\ oil\ Gradient\ x\ HAFWL\ (ft)$$

Where:

Pc = capillary pressure, psi.

Water gradient = 0.495, psi/ft

Oil gradient = 0.320, psi/ft

HAFWL = Height above free water level, ft

Table 1. Capillary pressure calculation results

water gradient=			0.495	psi/ft	
hydrocarbon gradient=			0.33	psi/ft	
wg-hg =			0.165	psi/ft	
HAFWL (m)	HAFWL (ft)	CAPILLARY PRESSURE (Psi)	HAFWL (m)	HAFWL (ft)	CAPILLARY PRESSURE (Psi)
0	0	0	100	328	59.12
0.1	0.328	5.05412	110	360.8	64.532
0.2	0.656	5.10824	120	393.6	69.944
0.3	0.984	5.16236	130	426.4	75.356
0.4	1.312	5.21648	140	459.2	80.768
0.5	1.64	5.2706	150	492	86.18
1	3.28	5.5412	160	524.8	91.592
1.5	4.92	5.8118	170	557.6	97.004
1.7	5.576	5.92004	180	590.4	102.416
2	6.56	6.0824	190	623.2	107.828
4	13.12	7.1648	200	656	113.24
6	19.68	8.2472	210	688.8	118.652
8	26.24	9.3296	220	721.6	124.064
10	32.8	10.412	230	754.4	129.476
20	65.6	15.824	240	787.2	134.888
30	98.4	21.236	250	820	140.3
40	131.2	26.648	260	852.8	145.712
50	164	32.06	270	885.6	151.124
60	196.8	37.472	280	918.4	156.536
70	229.6	42.884	290	951.2	161.948
80	262.4	48.296	300	984	167.36
90	295.2	53.708			

It can be seen from the results of the above calculations that the difference in pressure at HAFWL (Height Above Free Water Level) is within 300 meters or equivalent to 984 ft, the difference in pressure obtained is 167.36 psi. It can be concluded that the height above free water level has an influence on capillary pressure because from the results obtained above, the deeper the free water level is, the greater the pressure difference is obtained, the smaller the HAFWL, the smaller the pressure difference given will be.

- *Calculation of Water Saturation (Sw) from DRP*

One of the very important properties in rocks to know the calculation is the saturation value. After knowing the results of Pc data, then to obtain water saturation (Sw) the formula will be obtained from the following equation (Gibrata, 2019):

$$Sw_{RRT} = \left[\frac{\frac{a}{Water\ gradient - hydrocarbon\ gradient}\ HAFWL\ x\ 3.28}{\left(\frac{k}{\emptyset}\right)^{0.5}}\right]^{\left(\frac{1}{b}\right)}$$

Where:

Sw_RRT = *Water saturation of reservoir rock type*, v/v

a = 5 (constant RRT)

b = 2,65 (constant RRT)

HAFWL = *Height above free water level*, ft

k = Permeability, mD

∅ = Porosity, v/v

Table 2. The results of the calculation of water saturation

WHERE:			
a=		5	
b=		2.65	
water gradient=		0.495	psi/ft
hydrocarbon gradient=		0.33	psi/ft
wg-hg =		0.165	psi/ft
Porosity		0.295	
Permeabillity (mD)		3942	
HAFWL (ft)	WATER SATURATION (%)	HAFWL (ft)	WATER SATURATION (%)
0	0	328	0.067794476
0.328	0.918903232	360.8	0.0653995
0.656	0.707413843	393.6	0.063287012
0.984	0.607049384	426.4	0.061404022
1.312	0.544599614	492	0.058176123
1.64	0.500619213	524.8	0.056776406
3.28	0.385399626	557.6	0.055492265
4.92	0.330720988	590.4	0.054308156
5.576	0.315463728	623.2	0.053211349
6.56	0.296698304	656	0.052191296
13.12	0.228411959	688.8	0.051239174
19.68	0.196005974	721.6	0.050347534
26.24	0.175842	754.4	0.049510035
32.8	0.161641472	787.2	0.048721244
65.6	0.124439017	820	0.047976467
98.4	0.106784211	852.8	0.047271631
131.2	0.095798862	885.6	0.046603177
164	0.088062403	918.4	0.045967981
196.8	0.082207382	951.2	0.045363285
229.6	0.0775618	984	0.044786647
262.4	0.073750356		
295.2	0.070544195		

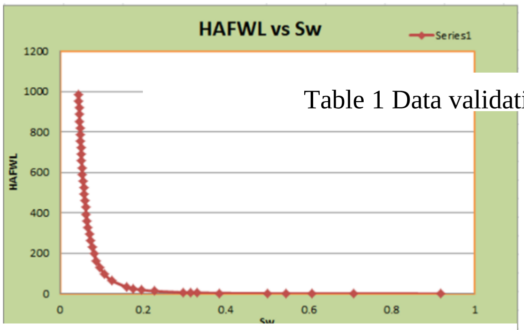


Figure 2. HAFWL vs Sw

In the graph in Figure 2, we can find out how the vertical distribution of saturation is. And from Figure 1.2 it can also be proven that the minimum water saturation value is 0.04 or about 4% which causes the liquid that sticks to the rock grains so that it can no longer flow due to capillary pressure.

- *Curve of the Pc vs Sw parameters of the DRP*

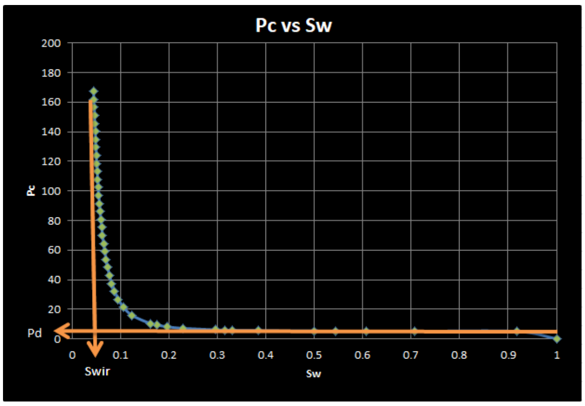
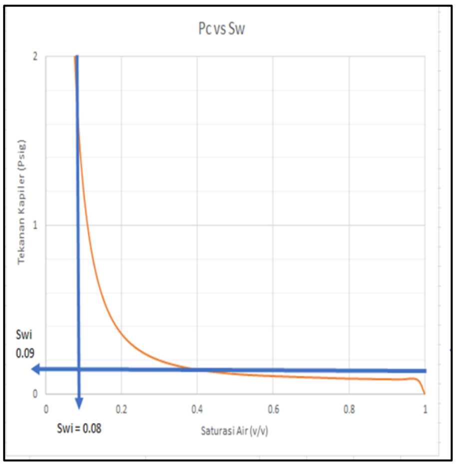


Figure 2. Pc vs Sw

Initially the oil migrates from the source rock to the reservoir. With a Pd of 5 psi to replace the water in the reservoir because initially the water contains 100% Sw and when the oil enters, the Sw will gradually decrease so the oil will increase, when the oil enters there needs to be pressure (Pd) to push the water out from pores. The pressure (Pd) is getting smaller or easier because the values of porosity and permeability are good so that when the water cannot come out again even though the Pc pressure is increased however much, Sw remains at that value. The remaining Sw that cannot come out again is called Swir.

In validating the data in this study using simulation results on carbonate rocks that were examined by researchers using simulation results on sandstone. The core samples used in sandstone are synthetic core samples from a homogeneous mixture of cement and sand, while the core samples used in carbonate rocks are non-homogeneous carbonate rock sample data. Following are the calculation results obtained from the simulation results for carbonate rock and sandstone:



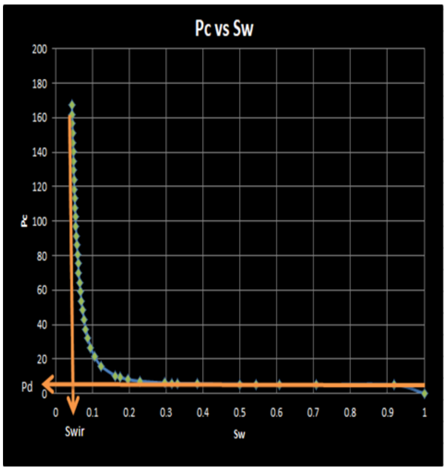


Figure 3. Comparison of carbonate curves and sandstone curves

Perhitungan berdasarkan batuan karbonat				Perhitungan berdasarkan batuan pasir			
Porositas	Permeabilitas (mD)	Pc (Psi)	Sw (%)	Porositas	Permeabilitas (mD)	Pc (Psi)	Sw (%)
0,18	8,10	0	1	0,295	3942	0	1
		0.08646321	0.98			5.05412	0.918903
		0.08835644	0.93403809			5.10824	0.707414
		0.09016986	0.8736958			5.16236	0.607049
		0.09202329	0.8257283			5.21648	0.5446
		0.09387671	0.78145728			5.2706	0.500619
		0.11243096	0.55257574			5.5412	0.3854
		0.13094521	0.45117857			5.8118	0.330721
		0.14947945	0.39072864			5.92004	0.315464
		0.1680137	0.34947832			6.0824	0.296898
		0.18654795	0.3190286			7.1648	0.228412
		0.20508219	0.29536309			8.2472	0.196006
		0.22361644	0.27628687			9.3296	0.175842
		0.24215068	0.26048576			10.412	0.161641
		0.26068493	0.24711840			15.824	0.124439
		0.27921918	0.23561823			21.236	0.106784
		0.29775342	0.22558728			26.648	0.095799
		0.31628767	0.21673725			32.06	0.088062
		0.33482192	0.20885324			37.472	0.082207
		0.35335616	0.2017714			42.884	0.077562
		0.37189041	0.19536432			48.296	0.07375
		0.39042466	0.18953123			53.708	0.070544
		0.4089589	0.18419125			59.12	0.067794
		0.42749315	0.17927859			64.532	0.065399
		0.4460274	0.17473916			69.944	0.063287
		0.46456164	0.17052796			75.356	0.061404
		0.48309589	0.16660725			80.768	0.059711
		0.50163014	0.16294511			86.18	0.058176
		0.52016438	0.1595143			91.592	0.056776
		0.53869863	0.15629146			97.004	0.055492
		0.55723288	0.15325638			102.416	0.054308
		0.57576712	0.15039152			107.828	0.053211
		0.59430137	0.14768154			113.24	0.052191
		0.61283562	0.14511297			118.652	0.051239
		0.63136986	0.14267393			124.064	0.050348
		0.64990411	0.14035387			129.476	0.04951
		0.66843836	0.13814343			134.888	0.048721
		0.6869726	0.13603425			140.3	0.047976
		0.70550685	0.13401882			145.712	0.047272
		0.7240411	0.13209039			151.124	0.046603
		0.74257534	0.13024288			156.536	0.045968
		0.76110959	0.12847078			161.948	0.045363
		0.77964384	0.12676911			167.36	0.044787

From the results of the validation of the carbonate data and the sandstone data that have been studied, this uses the same concept and method of work, but the results of the calculations are slightly different because of differences in digital core data on the rocks being studied respectively. The most visible difference from the results of the comparison above is that the permeability value obtained for the carbonate data itself has a value of 8.10 mD, while for the sandstone data it is obtained a value of 3942 mD, the difference in this value is far enough that it also affects the calculation on Pc and Sw. the shape of the curve is a little different. So it can be concluded that the data under study is valid.

Conclusions

The conclusions in this study are as follows:

1. The 2D image results from the digital core sample data are processed and simulated using DRP software, so a digital core image is formed in 3D using the Digital Rock Physics (DRP) approach.
2. The threshold used is Interactive Thresholding because later the data obtained will be more accurate in processing it so that it can calculate capillary pressure.

3. The calculation results show that the average porosity value of the sandstone sample is 29.5% and the total permeability value is 3942 millidarcy, the permeability value is large because the cores used are synthetic or artificial cores. From the core samples that have been made, the capillary pressure value is 167.36 psi, and the result is a Swir value of 4% and a

Pd value of 5 psi with a free water level range of 0-300 meters.

4. From the results of the analysis and comparing with the carbonate data, the results show that the curves that are compared are almost the same, there is only a slight difference in values between the 2 data samples.

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