EFFECT OF PORE SIZE DISTRIBUTION ON POROSITY MEASUREMENT BY COMPUTURIZED TOMOGRAPHY

DEMIR Murat, Turkish Petroleum Corporation
DEMIRAL Birol, Middle East Technical University

Although CT scanners were invented for medical purposes, they have been heavily used in petroleum engineering applications since 1980's when Harold Vinegar decided to apply CT techniques to rocks [1-4]. CT is mostly used for determination of porosity, internal structure of core and saturation changes during coreflood tests.

CT attenuation data are normally presented in an internationally standardized scale called Hounsfield unit (or CT number) that is defined by air at –1,000 (H) and water at 0 (H). In the experiments performed by Özgen et al [5] in the CT laboratory of METU Petroleum Research Center it was noticed that air CT number deviates from its theoretical value of –1,000. Deviation in air CT number causes to errors in the calculation of porosity and saturations. Was this deviation resulted from only artifact or was there any relation between pore size and deviation of air CT number? To find the answers of these questions experiments were conducted by X-ray CT scanner in our study.

To find a possible relation between pore size and air CT number, synthetic core sample made up of plexy-glass slices were prepared (Figure 1). Each slice was 10 cm in diameter and 1 cm in width and each one had artificial pores in different diameters changing from 1.5 mm to 15 mm on it. Total 19 slices were prepared. These slices were glued to each other to create synthetic plexy-glass core sample.

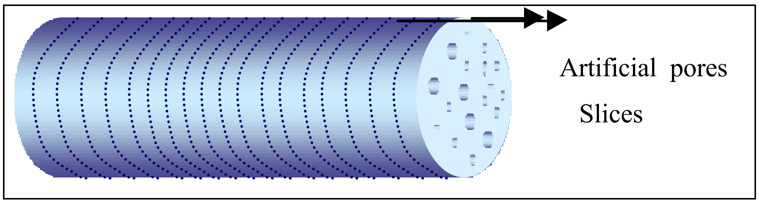


Figure 1.
Figure of synthetic core sample

Synthetic core sample was placed into the water bath then scanned by CT to reduce beam hardening artifact. CT data for each slice were evaluated. Data showed that air CT number was not constant as used in classic approach (-1,000) but changing with pore size (Figure 2): as the pore size getting bigger, air CT number was getting closer to value to –1,000. Air CT number and pore size data obtained from CT experiments were evaluated and correlation equation for air CT number and pore size was obtained for both 100 KeV and 130 KeV energy levels.

back to contents

In the evaluation of the air CT number and pore size data (Figure 2), when air CT data for pores below 4-4.5 mm in diameter were included for curve fitting, much deviation in air CT number for small pores was observed. This deviation caused to lower porosity calculation than its value of obtained from helium porosimeter. In addition to this reason, standard deviations for 4-4.5 mm and below diameter pores were higher, so, air CT number data for these small pores were not included to curve fitting.

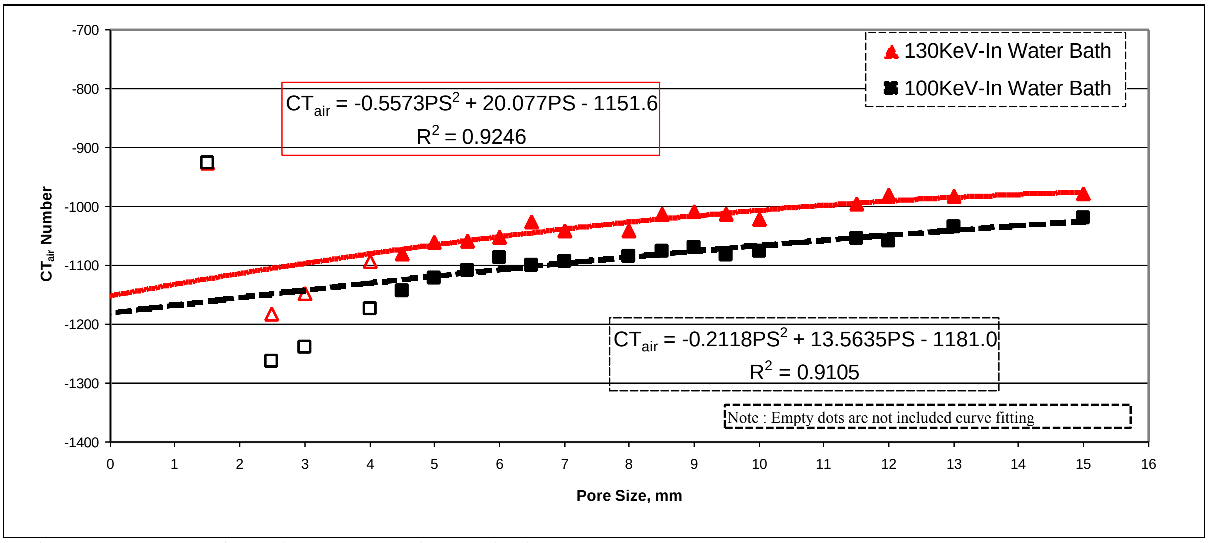


Figure 2. Pore size air-CT number relation

Porosity can be determined from X-ray CT measurements using either single scan or multiple-scan (dual scan) techniques. Single scan porosity technique is applied to generally homogeneous or native-state samples, because variations in mineralogy affect porosity measurement. To obtain porosity of a sample from single scanning method, matrix CT number of core sample and saturates and saturation should be known or they should be measured.

Relationship between CT readings and porosity in standard single scan method [3] is:

$$CT_{average} = CT_{matrix}\,(1-\phi) + CT_{air}\,\phi \qquad \ldots\ldots\ldots\ldots\ldots \qquad (1)$$

where, $CT_{average}$ is average CT number of scanned section, CT_{matrix} is the matrix CT number, CT_{air} is air CT number and ϕ is porosity.

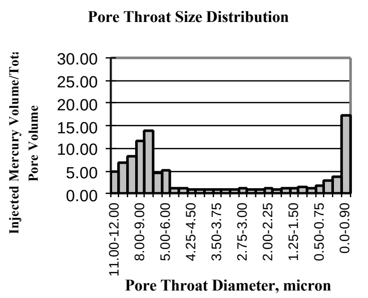
Air CT number is accepted as constant, –1,000, and in classic CT applications and CT related calculations. According to our observations in CT experiments, air CT number can change due to both beam hardening and pore size. So, if the air CT number is known in a certain sized pore and the partial porosity of that sized pores, and if the beam hardening effect can be reduced, then the equation 2 can be integrated to get:

$$CT_{average} = CT_{matrix}\,(1-\phi) + \Sigma[(CT_{air})_r\,\phi_r] \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

where, r is the pore size , $(CT_{air}.)_r$ is the air CT number in "r" sized pore and ϕ_r is the partial porosity of the "r" sized pores. For this equation be applicable, the trend of CT air readings changing due to pore sizes must be known.

In the second part of the study, effect of air CT number deviation on porosity determination by CT was studied. Four core plug samples, Berea, 2 limestone samples and dolomite, were used for the second part of the study. Correlation equations obtained from tests explained above and newly developed single scan CT method were used to determine porosity of rock plug samples by use of CT. To use new single scan method, pore size distribution of scanned core plug sample has to be known. Pore/pore throat size distributions of core plug samples were determined by both capillary pressure experiments and thin section analysis. Then, these samples were scanned using CT and porosities of the samples were calculated by both classic single scan CT technique and new approach method applying correlation equations as shown below.

Table 1. Partial air CT of Berea sandstone sample with pore throat size data



Pore Throat Diameter, micron	Partial Porosity %	CT_{air} (100 KeV)	Partial Air CT (100 KeV)	CT_{air} (130 KeV)	Partial Air CT (130 KeV)
0.18	2.591	-1181.028	-30.595	-1151.600	-29.833
0.5	0.896	-1181.027	-10.577	-1151.599	-10.314
1	0.659	-1181.027	-7.784	-1151.598	-7.590
1.5	0.386	-1181.026	-4.564	-1151.597	-4.450
....	....	....	....	....	....
16	2.640	-1181.006	-31.174	-1151.568	-30.397
18	2.347	-1181.004	-27.713	-1151.564	-27.022
20	1.801	-1181.001	-21.266	-1151.560	-20.736
22	1.473	-1180.998	-17.400	-1151.556	-16.966
24	1.114	-1180.995	-13.153	-1151.552	-12.825
Sum=	19.130	$S(CT_{air})_r\ f_r$ =	-225.928	$S(CT_{air})_r\ f_r$	-220.297

Average porosity (by mercury injection), % = 19.13
For Berea sandstone; CT_{matrix} (@ 100 KeV) = 2392.15 CT_{matrix}(@ 130 KeV) = 2128.19

Table 2. Porosity of Berea obtained by new single scan method

Slice No	**100 KeV**			**130KeV**		
	CT_{mean}	**Porosity of Slice, % (by new method)**	**Porosity of Slice, % (by old method)**	**CT_{mean}**	**Porosity of Slice, % (by new method)**	**Porosity of Slice, % (by old method)**
1	1696.54	19.63	20.51	1486.25	19.81	20.52
2	1677.49	20.43	21.07	1469.87	20.58	21.04
3	1666.23	20.90	21.40	1462.19	20.94	21.29
…	...	...	...	...	...	...
13	1682.49	20.22	20.92	1476.83	20.25	20.82
14	1639.74	22.01	22.18	1440.03	21.98	22.00
	Average =	**20.37**	***21.02***		**20.49**	***20.98***

Pore size distribution of samples were also determined by thin section analysis and same procedure applied to find porosity of plugs. Porosity values of samples obtained by different methods are given below in Table 3.

Table 3. Comparison of porosity values of samples by different methods

		Sample No	Berea Sample	Limestone Sample-85	Limestone Sample-109	Dolomite Sample-106
AVERAGE PORSITY, %		By helium porosimeter	20.57	13.35	12.54	15.91
		By Hg Injection	19.13	12.62	11.51	15.16
		by thin section analysis	19.85	13.43	12.73	15.24
	Using CT and Thin Section Data	by new method @ 100 KeV	20.01	13.17	12.35	15.28
		by new method @ 130 KeV	20.10	13.21	12.40	15.25
	Using CT and Pc Data	by new method @ 100 KeV	20.37	13.46	12.78	15.31
		by new method @ 130 KeV	20.49	13.54	12.89	15.28
	Using Single Scan CT Method	by classic mtd. @ 100 KeV	21.02	13.79	12.96	15.97
		by classic mtd. @130 KeV	20.98	13.80	12.99	15.89

In rock core samples because pore sizes were so small that air CT number calculated for these pores was nearly constant, but different from –1,000. Porosity results obtained using new developed single scan CT method was lower about 5 % (relative) than results obtained from classic single scan CT approach.

REFERENCES

1. Liu D., Castanier L.M. and Brigham W.E.: "Analysis of Transient Foam Flow in 1-D Porous Media With CT", SPE 20071, presented at the 60th SPE California Regional Meeting in Ventura, California, April 4-6, 1990
2. Huang Y., Ringrose P.S. and Sorbie K.S.: "X-Ray Imaging of Waterflood Fluid Saturations in Heterogeneous Rock Slabs", SPE 30000, presented at the International Meeting on Petroleum Engineering in Beijing, PR China, November 14-17, 1995
3. Saner S.: "A Review of Computer Tomography and Petrophysical Applications", Sabbatical Research, 1993-1994
4. Vinegar H.J.: "X-Ray CT and NMR Imaging of Rocks", SPE 15277, J. Pet. Tech. (March 1986), 257-259
5. Karacan C. Ö.: "Modeling of Sorption and Investigation of Flow Mechanism of Coalbed Gas", Ph.D. Thesis-METU, 228 pages, July 1998