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A new reference-sample-guided computed-tomographic method for porosity quantification of reservoir sandstones

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Summary

One of the main interests in petroleum geology and engineering is to quantify the porosity of reservoir beds as accurately as possible. A variety of direct measurements, including methods of mercury intrusion, helium injection and petrographic image analysis, have been developed; however, their application frequently yields equivocal results because these methods are different in theoretical bases, means of measurement, and causes of measurement errors. Here we present sets of Berea Sandstone porosities measured by a new method using computed tomography and reference samples, which are also compared to results of other measurement methods. The data show a marked correlativeness between different methods and suggest that the new method of the reference-sample-guided computed tomography is more effective than the previous methods when accompanied merits such as providing porosity network information are taken into account.

Introduction

One of the main interests in petroleum geology and engineering is to quantify the porosity of reservoir beds as accurately as possible. Researchers have developed different means of a direct porosity measurement such as mercury intrusion[1, 2] (MI), helium injection[3] (HI), petrographic image analysis[4,5] (PIA), and even computed-tomographic (CT) method (e.g. [6-10]), which yield equivocal results because of obvious differences in principle and procedure between the methods. The CT method has an apparent merit in that it enables us to perform a direct calculation of porosity and visualize the 3D structure of porosity network using an almost limitless numbers of tiny voxels of the rock volume which are segmented into either side of matrix or pores[11]. However, the thresholding step for the segmentation in the CT method is observer-dependent thus somewhat arbitrary [7]. We adopt a new computed tomographic method using a reference material[12] and show an improved quality of porosity measurement using the CT method.

Method

In order to adopt Jin et al.'s concept[12] using a reference sample in computed-tomographic porosity measurement, we paired two different Berea Sandstone samples during CT scanning, putting the measurement sample (MS) at top and the reference sample (RS) at bottom on the rotary sample stage. We scanned the paired MS and RS concurrently with application of X-ray tube (160 kV or 225 kV) and detector (pixel binning 1024*1024 or 2048*2048) to apply the same scanning conditions to both MS and RS. These configuration and input parameters made us ensure 15 microns resolution of the tomogram voxels for the low resolution CT method (CT_LR) or 5 microns resolution of those for the high resolution CT method (CT_HR). We could drew out CT porosity (ϕ_{CT}) for the extracted sub-volume, using the equation (1).

$$\phi_{CT} = \frac{\Sigma\, pore\ volume\ voxels}{(\Sigma\, matrix\ volume\ voxels + \Sigma\, pore\ volume\ voxels)} \quad (1)$$

Examples

As shown in Fig. 1, porosity measurements using multiple methods yielded results that are matched with each other on a large scale but under some discrepancies when inspect in detail. It is noteworthy that the values of the CT_HR porosities are fairly coincident with those of the mercury intrusion (MI) porosities, both showing having the narrowest range of porosity variations amounting only 2-3% within each group of the sample set.

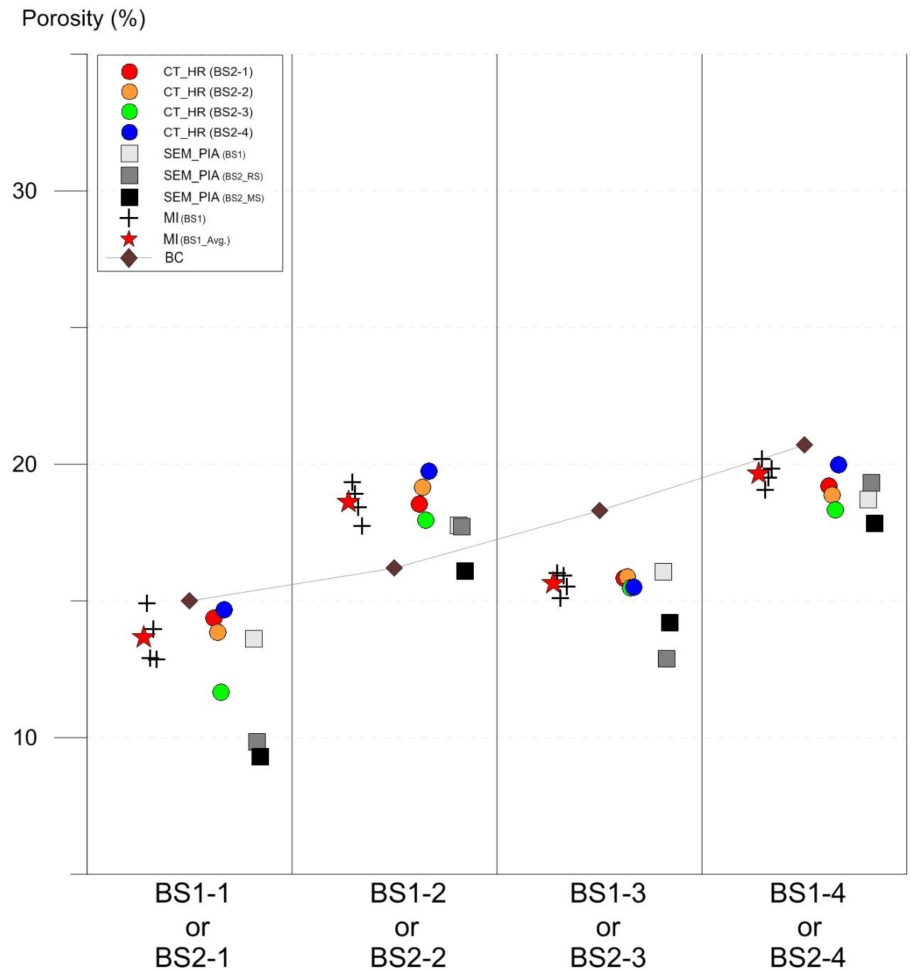

Figure 1. Results of multiple porosimetries that are plotted along with the arranged sample group numbers belonging to either the first or the second sample set (Courtesy of Scientific Reports[13]). The results are based on methods of computed tomography of high resolution (CT_HR; circle, reference sample no. in parenthesis), petrographic image analysis on scanning electron microscopic images (SEM_PIA; square, further sample information in parenthesis), mercury intrusion (MI; plus with star for average) method, while the BC (diamond) in the figure inset means porosities notified from the company selling the Berea Sandstone samples. Note a zigzagging trend of porosities along with the arranged sample group numbers, i.e., porosities are low in BS*-1 and BS*-3, and high in BS*-2 and BS*-4.

In Fig. 2, we can appreciate the effect of resolution controls on the CT scanning that addresses possible cause of the wrong estimation of porosities under a low resolution control. The phenomenon is well explained by the pore networks of the MS visualized on the basis of the newly derived porosities. The pore network of the MS is very rough in the tomograms of low resolution (Fig. 2A), whereas that is surely compact at the high resolution controls (Fig. 2B) while the MI and CT_HR porosities show a marked coincidence under the high-resolution control (Fig. 1). Hence we can infer that some pores in the MS would possibly be overlooked or overweighed under low resolution controls. These observations further suggest that the reference-sample-guided CT method could be a good means for porosity measurement provided the CT system satisfies the necessary resolution.

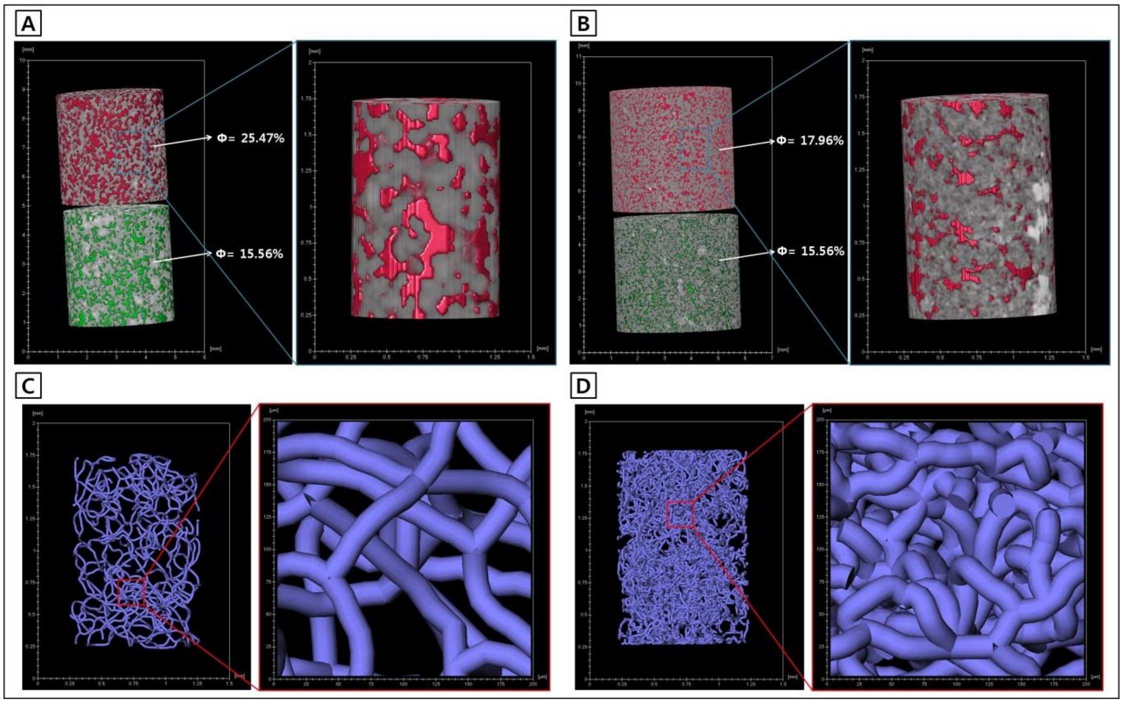

Figure 2. Examples of porosity measurement and pore visualization using the reference-sample-guided computed tomography of either low-resolution control or high-resolution control for the same Berea Sandstone sample (Courtesy of Scientific Reports[13]). Note probable simplification of the original pore networking under low-resolution controls, evinced by large pore segmentations (A) and loose centerlines of filamentous pores (C). Note also a proper pore networking under high-resolution controls showing sufficiently small pore segmentations (B) and compact centerlines of filamentous pores (D).

Conclusions

The CT_HR method yields a high-quality data matched well with that of the MI porosity thus the reference-sample-guided computed-tomographic method is surely appropriate for porosity measurement of reservoir rocks if it is under an adequate resolution control. A lower resolution control in the CT method would result in over- or under-estimation in porosity measurements thus further researches are necessary to determine an optimum resolution for a specified rock type.

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