Study of downscaling sandstone rock porosity by x-ray microtomography

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Abstract- Dimensional microtomography metrology is a new approach in the petroleum and gas industry. Petrophysical characterization can be achieved by quantitative properties, such as porosity, which is one of the main parameter for the knowledge of reservoir potential. For example, the microporosity is a major factor of control water saturation in oil and gas reservoir. The smaller the pixel size the better the spatial resolution of the system, which leads to the investigation of the micropore network. The goal of this work is to investigate the impact of different pixel sizes on the characterization of internal rock porosity. For that purpose, sandstone rock samples were used in three different dimensions, which were achieved by trimming the edges of the samples. The total porosity results were not equivalent for the used spatial resolutions and the comparison among the microtomography images datasets and pore size distributions showed differences that enhances the importance of the spatial resolution for a complete characterization of the rock sample internal microstructure.

I.   Introduction

X-ray microcomputed tomography (µCT) can be used in a non-destructive way to characterize microstructures, such as internal damages and total porosity [1-3]. The information on the internal structures can be qualitative characterized by longitudinal, sagittal and transverse views. Basically, µCT image quality depends on contrast, spatial resolution and signal ratio noise. One of the most important parameter in µCT is the scanning pixel size, which is linked with spatial resolution of the system. This last parameter is equipment dependent and with unsatisfactory values small voxels are not accurately quantified in the reconstruction image. The understanding all these image quality parameters remain key issues to fully optimized the µCT quantifications. In this way, image quality is essential to perform suitable measurements, which can be studied by downscaling samples.

Since various techniques are combined together with different areas of knowledge, the µCT has been widely used in the petroleum and gas industry [4]. One of the most remarkable aspects in reservoir field is the petrophysics of the productive sandstones, which are consolidated clastic sedimentary rock. Porosity is one of the most important physical characteristics of sedimentary rocks and its knowledge helps to know the reservoir potential because it is the pore system that permits sandstone to store and transmit fluids. Fluid invading techniques, such as, mercury porosimetry simply evaluate the open (or effective) porosity, which is defined as the ratio of the part of the pore volume where the fluid can circulate to the total volume of a representative sample of the medium. Generally does not provide satisfactory information because the pore volume occupied by the pore fluid that can circulate through the porous medium is smaller than the total pore space, and, consequently, the effective porosity is always smaller than the total porosity. µCT can be used in order to evaluate the entire network porosity related to open and closed (residual) porosities.

In this context, the goal of this work is to investigation the relationship between rock porosity and it's downscaling, which leads to image quality with different pixels size and consequently several spatial resolutions applications.

II.   Materials and Methods

µCT technique is based on Beer's Law of X-ray attenuation from a series of radiographies at different angular positions, which are combined in order to give the spatial distribution of the local absorption coefficients [5]. The apparatus used in this work was a high-energy µCT system, which consists of a microfocus X-ray source (spot size ≤ 5 µm), microposition stage and a flat panel detector (2240 x 2240 pixels). The equipment was calibrated to operate at 80 kV, 100 µA, with thin metal sandwiches of aluminum (1.0 mm of thickness) and cooper (0.15 mm of thickness) in order to reduce beam-hardening effects. It was used a common sandstone rock sample, which was trimmed down in order to reduce the size and consequently able to perform µCT with better pixel size (Figure 1). It can be noted that the scan was done on the entire sample (a) and on two more subsamples (b,c). It is also possible to see the region of the samples that was resized and quantified represented as a dot cylinder line.

All the samples were placed at the microposition stage inside acrylic tube in order to avoid their movement during the acquisition procedure. InstaRecon® and CTAn® were used in order to quantify the porosity parameter. µCT image contrast is related to the range of brightness levels in the image of one object.
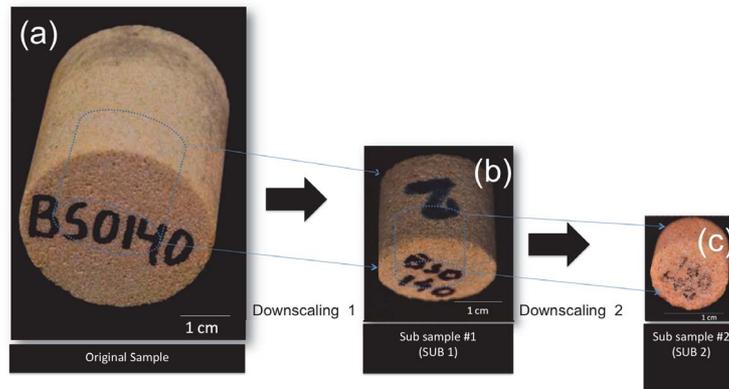

Figure 1: Photos of used sandstones: (a) original sample µCT pixel size of 20 µm, (b) subsample #1 (SUB1) µCT pixel size of 12 µm, (b) subsample #2 (SUB2) µCT pixel size of 6 µm.

One of the biggest issue in the image processing analyze is the choice of the threshold level, which influence directly on the quantification results. In this work, this issue was not evaluated, e. g., it was used the same segmentation procedure in all samples in order to decrease the amount of variable parameters. This procedure can be viewed in figure 2, which can be noted an example of one slice of each sample (b) and the entire pore network (d) that was quantified based on the binary images (c). In this case it global threshold was used in order to obtain binary images and quantified porous network. Global is the simplest to apply an applicable to the most µCT images. In order to improve the quality of the segmentation procedure, before threshold choice 2d smoothing plug-in (Kuwahara and Gaussian filters) was applied to grey-level images. Filters application is important in order to remove noise presented in the images without take away any important information, such as edges. Kuwahara and Gaussian are a non linear and a traditional linear filters respectively. The first one maintain edges while the second one remove noise by replacing each pixel by an average or weighted average of its spatial neighbors. This two filters combination provide a good final image result because it can be achieved a stack of µCT images with noise reduction without edge loss of information. In this step it is important to say that the boundary of the region of interest (ROI) of each of one of the samples correspond exactly the boundary of the solid binarised object (rock sample), which allow to use the rock's perimeter as the reference ROI.
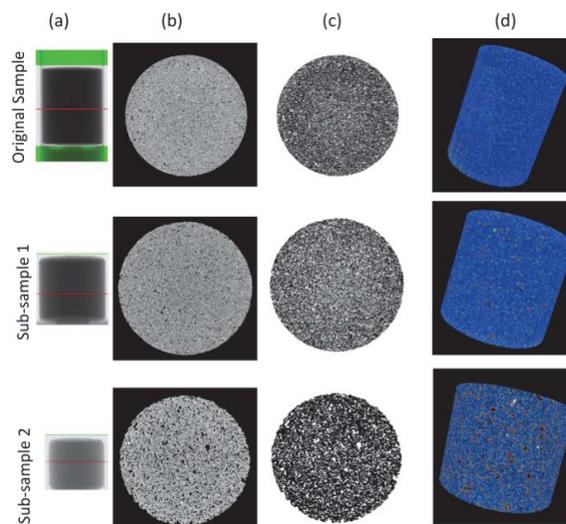

Figure 2: µCT views of porosity network: (a) Radiography images, (b) an example of one µCT slice and their binary images (c), (d) µCT 3D visualization of the entire pore network.

III. Results and Discussion

Table 1 and Figure 3 present the assembly of the proposed quantification respectively.
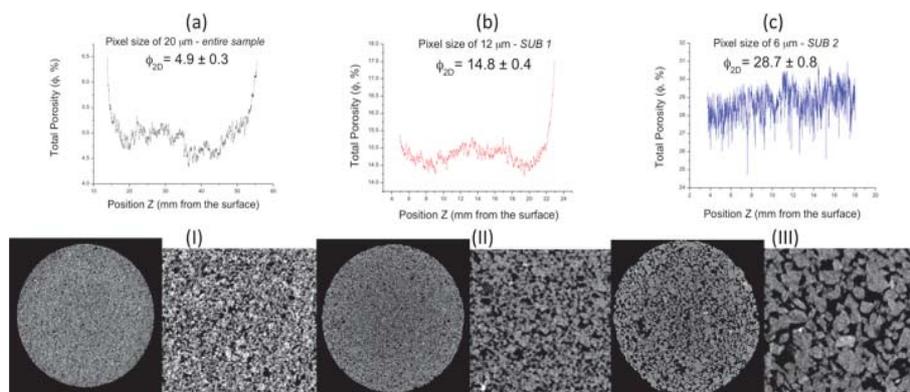

Figure 3: 2D μCT porosity results: (a) original sample, (b) SUB 1, (c) SUB 2, (I-III) cross-sections μCT examples of porous media identifications.

Table 1: 3D μCT porosity results.

Samples	Pixel size (μm)	VOI volume (mm^3)	3D Porosity (%)		
			Closed	Open	Total
Original	20	47106.17	4.85	0.16	5
SUB 1	12	8752.25	1.38	13.81	15
SUB 2	6	886.74	0.03	29.02	29

The total porosity and the pore size distribution were the structural parameters studied. The quantification procedure was performed isolating the rock matrix from the porous network. Figure 3 shows 2D total porosity distribution slice by slice. In this case the porosity parameter was calculates in 2D from individual binarised cross-section images. It is possible to note the smaller the pixel size the greater the 2D total porosity with a heterogeneous behavior. This kind of approach can be studied together with conventional porosimetry techniques, which also evaluate 2D dataset but with the disadvantage of being slower, tedious, and less accurate and user dependence. Shape and roundness (Figure 3 (I-III)) are very helpful properties of sand grains because they have significance for the study of the effect of the transport process in the debris furnished by the source area.

Table 1 shows a summary of 3D μCT porosity results. Total porosity was evaluated as the volume of all open plus closed pores as a percent of the total VOI (volume of interest) volume. A closed pore in 3D is a connected assemblage of space (black) voxels that is fully surrounded on all slides in 3D by solid (white) voxels while an open pore is defined as any space located within a solid object or between solids objects, which has any connection in 3D to the space outside the object or objects. Both 2D and 3D analyzes were performed over the same selected region for each sample. It was possible to observe the same behavior shown in Figure 3, besides being possible to note a significant increase in open porosity values when highest spatial resolutions are employed. In other words, the higher the μCT spatial resolution the better the identification of the differences between the empty space and rock matrix regions leading a decrease in the amount of closed porosity, which is overestimated for larger pixel sizes values. Figure 4 shows other 3D μCT visualizations. It can be note that the pores are small and not connected for both largest 2D pores (a) and of the pore network in the first 2 mm of each sample (b).

It is important to say that the size of sandstone sample was changed in order to enable the maximum accuracy and reliability of porosity measurement by μCT. The results show that 3D μCT does not provide the information about pores with the diameter smaller than the used pixel size imaging, but every method has some limitation. The great advantage of μCT is the possibility of study pore network directly in 3D, which provide the knowledge of the connectivity of the pores.
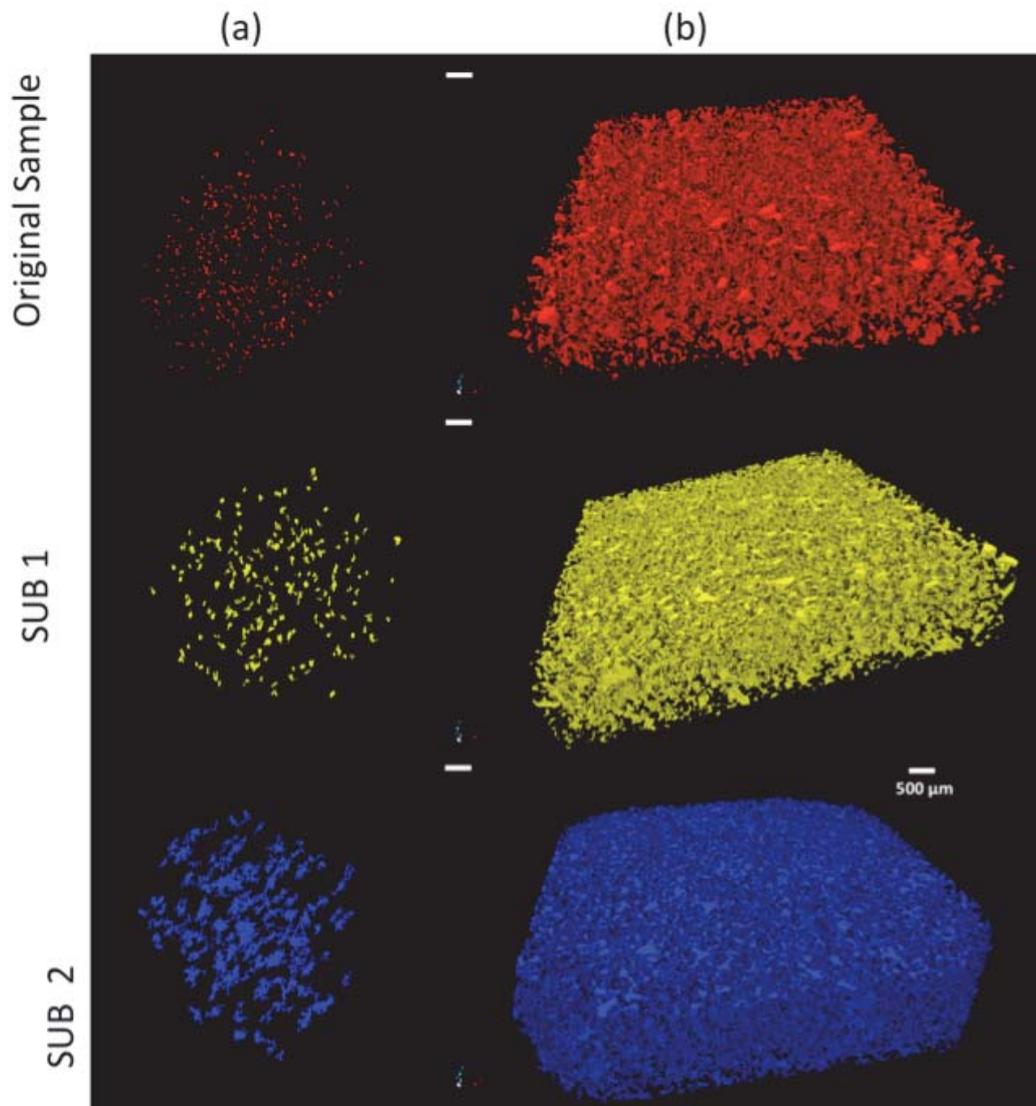
Figure 4: Pore sizes µCT results: (a) pore size distribution, (b) the largest 2D pore of the entire VOI volume of each sample, (c) pore network in the first 2 mm of each sample.

The results show zones of porosity not well connected. The smaller the pixel size the better the spatial resolution of the µCT system, which leads to the knowledge of smaller porosities. This issue is important because since microporosity is some time below the µCT resolution, it is not included in the porosity evaluattion. Therefore, resizing the sample can make an estimation of this microporosity. In this context, we can say that µCT metrology is an interesting issue for pore network quality of reservoir rocks performing dimensional measurements, such as porosity distribution.

IV. Conclusions

The total porosity results were not equivalent for the used spatial resolutions and the comparison among the µCT images datasets and pore size distributions showed differences that enhances the importance of the spatial resolution for a complete characterization of the rock sample internal microstructure.

Acknowledgments

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