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MICROSTRUCTURE PARAMETERS EVALUATION OF BOTUCATU FORMATION SANDSTONE BY X-RAY MICROTOMOGRAPHY

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ABSTRACT

Microstructural parameters evaluation of reservoir rocks are very important to petroleum industry. This work presents total porosity and pore size distribution measurement of a silicified sandstone sample from the Botucatu formation, collected at municipal district of Faxinal, Paraná, Brazil. Porosity and ~~pores~~ size distribution were determined using X-Ray microtomography and imaging techniques. Acquired images had 2.9 μm spatial resolution. 800 2-D images where reconstructed for the microstructure analysis. The determined average porosity was 6.1 ± 2.1 %. 95 % of the porous phase refers to pores with radius ranging from 2.9 to 167.4 μm, presenting the larger frequency (6 %) at 5.9 μm radius. The 3-D volume of the sample was reconstructed and compared with the 3-D model obtained through the autocorrelation functions from the 2-D images analysis.

1. INTRODUCTION

X-ray computed microtomography (μ-CT) is a relatively new technique, which has found potential applications in petroleum industry research. The technique allows visualization and analysis of the architecture of cellular materials with an axial and lateral resolution down to a few micrometers, and without sample preparation or chemical fixation. It is a nondestructive technique that measures variations in material density. The technique uses a set of two-dimensional shadow X-ray images of an object to reconstruct its three-dimensional structure using a mathematical algorithm [1–4]. An illustrative scheme of the acquisition, reconstruction and generation of the image and 3-D model is presented in Figure 1.

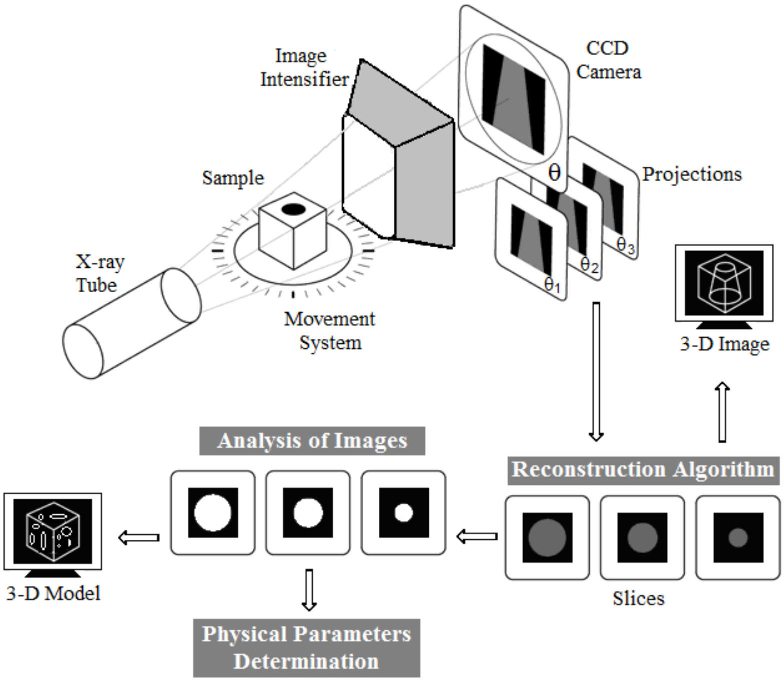

Figure 1 – Illustrative scheme of the acquisition, reconstruction and generation of the images and three-dimensional models.

When X-rays pass through the object being scanned, the signal is attenuated by scattering and absorption. The basic equation for attenuation of a monoenergetic beam through a homogeneous material is Beer's Law:

$$I = I_0 \exp[-\mu x] \tag{1}$$

where I_0 is the initial X-ray intensity, μ is the linear attenuation coefficient for the material being scanned, and x is the length of the X-ray path through the material. If the scan object is composed of a number of different materials, the equation becomes:

$$I = I_0 \exp\left[\sum_i (-\mu_i x_i)\right] \tag{2}$$

where each increment i reflects a single material with attenuation coefficient μ_i over a linear extent x_i.

Two-dimensional and three-dimensional samples imaging of reservoir rocks using computerized tomography (CT) and/or X-ray computerized microtomography (μ-CT) is becoming a standard practice in the petroleum industry. Generally, water injection is used for the extraction of petroleum in reservoir rocks where CT and μ-CT are being used to determine important parameters in this process, such as, porosity, pore size distribution, and permeability.

Until now the petroleum industry uses more often other methods to determine these parameters, where the more spread are mercury intrusion porosimetry [5] and Arquimedes' method. However, many times, the use of these methods make infeasible the use of the samples for future analyses, because they are destructive methods. Therefore, CT and μ-CT techniques, besides facilitate futures analyses of the measured sample, they also provide three-dimensional visualization of the sample.

2. MATERIALS AND METHODS

2.1. Used Equipments

Measurements were carried out with a Skyscan 1172 μ-CT scanner (Figure 2), at the Research and Development Center (CENPES)/PETROBRAS, Rio de Janeiro, RJ. The μ-CT images were reconstructed by the NRecon software [6]. Porosity and pore size distribution were obtained through the Imago software [7], developed at the Laboratory of Porous Media and Thermophysical Properties (LMPT), Department of Mechanical Engineering, Federal University of Santa Catarina, Brazil, in association with the Brazilian software company Engineering Simulation and Scientific Software (ESSS). Other used software was CTan [6], with which the sample 3-D reconstructions were performed.

Figure 2 – Skyscan 1172 μ-CT scanner, 20 – 100 kV X-ray tube, 10 W maximum power.

X-ray tube possesses a 10 W maximum power, using a tungsten anode and operated at 70 kV and 142 μA (spot size <5μm). The tube was positioned the 4.42 cm of the sample, that meets to 34.5 cm of the CCD camera (2 000 x 1 048 pixels).

2.2. Studied Sample

The studied sample was silicified sandstone from the Botucatu Formation, collected at municipal district of Faxinal, Paraná, Brazil, with dimensions 5 x 5 x 15 mm, as it can be observed in Figure 3. The sample was rotated from 0^o to 360º, in steps of 0.25º, resulting in 1,440 projections. These projections were reconstructed by the NRecon software, resulting 560 two-dimensional images. For acquisition of these data a 1 mm thickness aluminum filter was used, with the objective of decreasing the beam hardening effect in the sample [8].

Figure 3 - Sandstone sample from the Botucatu Formation.

2.3. Image Processing

Figure 4 shows two projections, 0º and 180º, made in the CCD camera. These projections are reconstructed by the NRecon software using a cone-beam reconstruction algorithm [9], result in 2-D images in gray scale, as it can be seen in the Figure 5a. After the generation 2-D images, they are analyzed by the Imago software, where it is defined a region of interest (ROI) and creating binary black and white images, where the black is the solid and the white is the pore. Figure 5b shows the same image yet with selected ROI. These images possess spatial resolution of 2.9 μm.

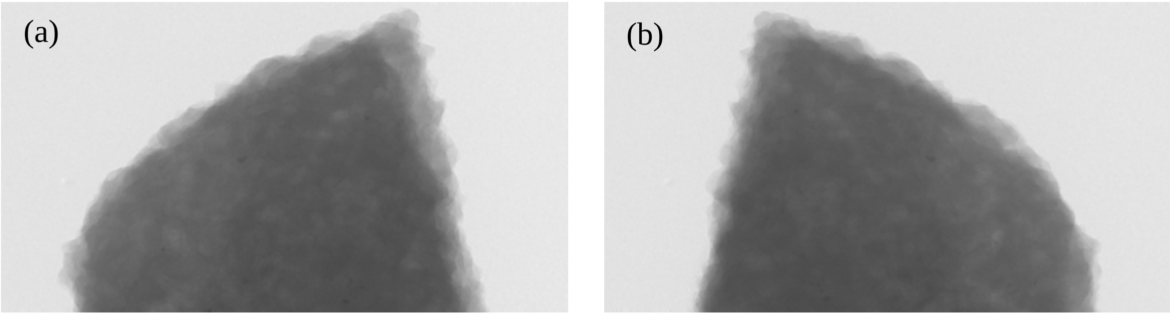

Figure 4 – Projections of the Botucatu formation sandstone sample. (a) image obtained at 0º position; (b) image obtained at 180º position.

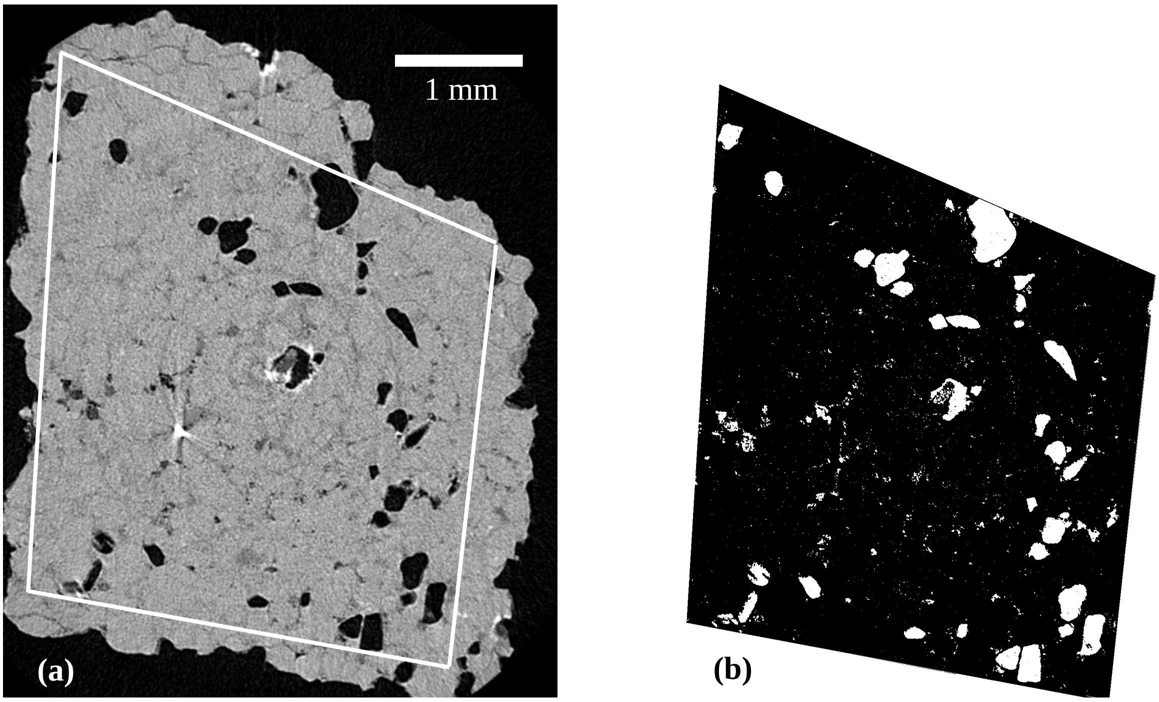

Figure 5 – (a) 2-D image in grey scale; (b) 2-D binary image, black is a solid phase and the white is the porous phase.

With the 2-D images, it was also possible the creation of a 3-D image, where the CTan software was used for reconstruct solid phase (light gray in Figure 6) and porous phase of the sample (dark gray in Figure 6). In this figure we can observe that the pores are isolated, not offering permeability for the rock.

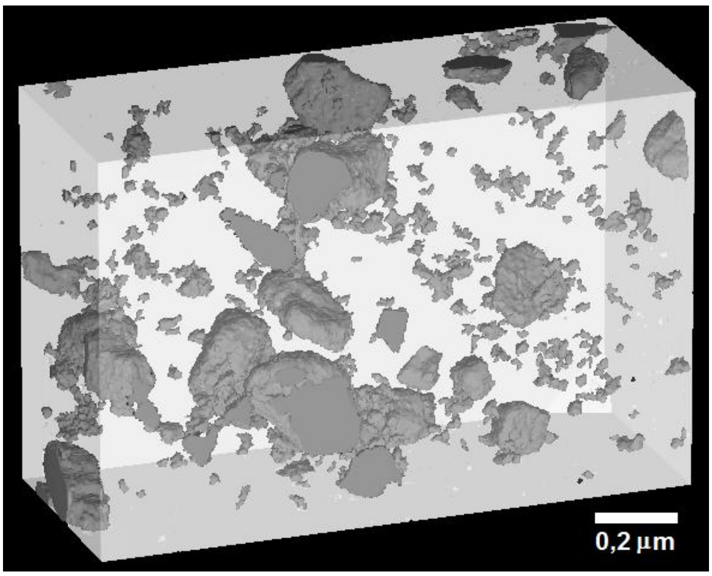

Figure 6 – 3-D volume Botucatu formation sandstone sample; light gray is reconstructed solid phase and dark gray is porous phase.

3. RESULTS

The porosity of the sample, obtained by Imago software, for each 2-D slice is represented in the graph of Figure 7, where the black line indicates the average porosity (6.1 %) and red lines indicate the variability (2.1 %), with 95 % confidence level.

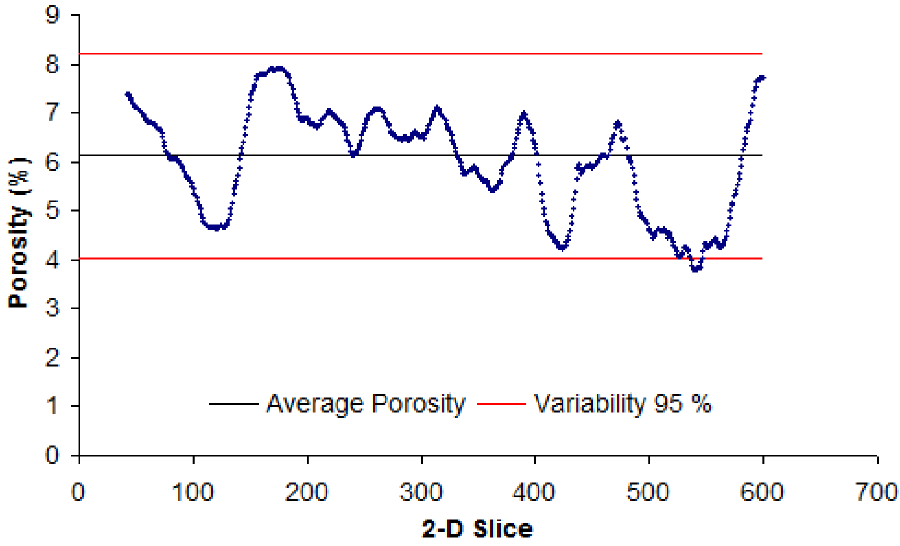

Figure 7 – Porosity 560 2-D slices of the Botucatu formation sandstone sample.

In the Figure 8 it can be seen the average pore size distribution, for the 560 2-D slices. It can also be observed that two different distributions exist, one around 5.9 μm and another in 58.7 μm, and presenting larger frequency (5.85 %) in 5.9 μm radius.

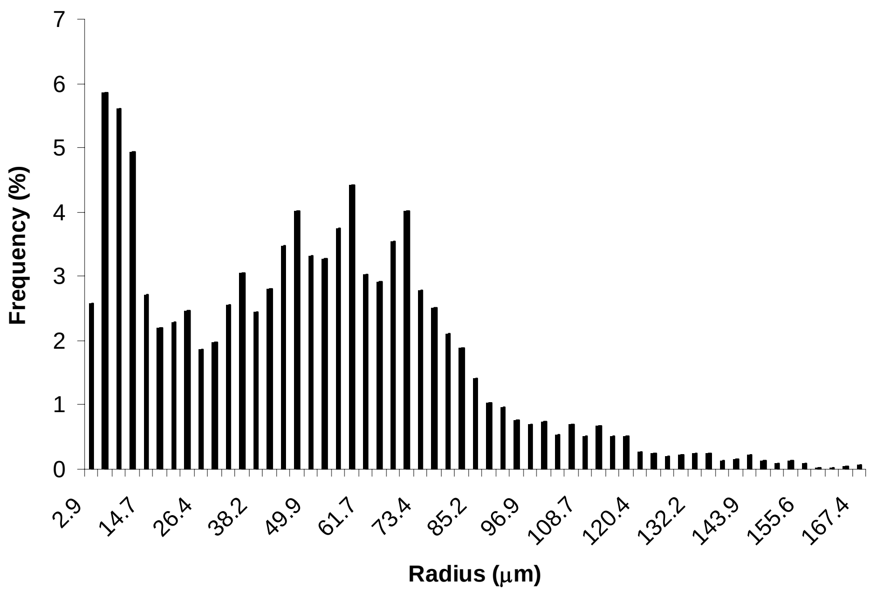

Figure 8 – Average pore size distribution for the 560 2-D slices.

4. CONCLUSIONS

Reservoir rocks characterization, such as the studied sandstone, are of great importance for the petroleum industry. These data are generally measured through destructive methods, such as mercury intrusion porosimetry and Arquimedes' method.

Computed microtomography technique provides detailed non-destructive characterization of the core geometry, porosity and pore size distribution. Pore interconnectivity can be visualized and characterized analyzing the 3-D images. This characterization provides valuable data for the understanding and modeling of fluid transport and mechanical processes occurring in real porous media systems. Given microtomographic characterization of any core material, at sufficient spatial and contrast resolution, and occupying fluid properties, any transport property can be modeled and simulated.

Due to the fact of the sandstone be a silicified one, the pores are isolated, not offering permeability for the rock, as it can be observed in the Figure 6.

The total porosity of the Botucatu formation sandstone sample, calculated by the Imago software, was of 6.1 % ± 2.1 %. Among the found pores, we can observe pores 2.9 μm (μ-CT spatial resolution) to 167.4 μm (radius), where the largest frequency occurs in pores of 5.9 μm, as it can be seen in the Figure 8.

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