EFFECTS OF MANUAL THRESHOLD SETTING ON IMAGE ANALYSIS RESULTS OF A SANDSTONE SAMPLE STRUCTURAL CHARACTERIZATION BY X-RAY MICROTOMOGRAPHY

Anderson C. Moreira¹, Jaquiel S. Fernandes², Leonardo C. Marques², Carlos R. Appoloni², Celso P. Fernandes¹ and Rodrigo Nagata²

¹Laboratório de Meios Porosos e Propriedades Termofísicas (LMPT), PGMAT/EMC
Universidade Federal de Santa Catarina
Florianópolis, P.O. Box 476, 8040-900, Brazil
anderson@lmpt.ufsc.br
celso@lmpt.ufsc.br

²Laboratório de Física Nuclear Aplicada, Depto de Física, Centro de Ciências Exatas
Universidade Estadual de Londrina
Londrina, P.O. Box 6001, 86051-990 Brazil
jaquielfernandes@yahoo.com.br
leocarma@yahoo.com.br
appoloni@uel.br
rodrigo_nagata@yahoo.com.br

ABSTRACT

X-ray microtomography is a nondestructive nuclear technique widely applied for samples structural characterization. This methodology permits the investigation of materials porous phase, without special sample preparation, generating bidimensional images of the irradiated sample. The images are generated by the linear attenuation coefficient mapping of the sample. In order to do a quantitative characterization, the images have to be binarized, separating porous phase from the material matrix. The choice of the correct threshold in the grey level histogram is an important and discerning procedure for the binary images creation. Slight variations of the threshold level led to substantial variations in physical parameters determination, like porosity and pore size distribution values. The aim of this work is to evaluate these variations based on some manual threshold setting. Employing Imago image analysis software, four operators determined the porosity and pore size distribution of a sandstone sample by image analysis. The microtomography measurements were accomplished with the following scan conditions: 60 kV, 165 µA, 1 mm Al filter, 0.45º step size and 180.0º total rotation angle with 3.8 µm and 11 µm spatial resolution. The global average porosity values, determined by the operators, range from 27.8 to 32.4 % for 3.8 µm spatial resolution and 12.3 to 28.3 % for 11 µm spatial resolution. Percentage differences among the pore size distributions were also found. For the same pore size range, 5.5 % and 17.1 %, for 3.8 µm and 11 µm spatial resolutions respectively, were noted.

Keywords: X-ray microtomography, threshold, porosity and pore size distribution.

1. INTRODUCTION

Conventional methodologies for materials structural characterization like mercury injection porosimetry [1,2], Helium pycnometry [3], optical metallography [4] and scanning and transmission electron microscopy [5] are easily found in the literature. However, a great part of these methodologies is destructive and require sample preparation.
The X-ray microtomography is a non-destructive technique and allows the visualization of materials' internal structure. This visualization is done by images with good spatial resolution ranging from micro to nanometer scale. Don't require sample preparation and analyze microstructures by 2D sections or 3D volume rendered investigation. These 2D sections (images in grey level) represent the linear attenuation coefficient mapping of the sample in study.

In order to do a microstructural characterization, the images in grey level must to be segmented in a binary form discriminating matrix from porous phase. The image segmentation procedure is based in a threshold set using its grey level histogram.

The manual threshold setting can be a relevant source of error because it is somewhat arbitrary and subjective [6,7]. Mathematical models adopted in routine procedures to find the optimal threshold value, for a given acquisition condition, are reported in the literature [8,9,10,11]. However, in some specific cases, the operator intervention is strongly necessary. The sandstones petroleum reservoirs are a noticeable example. They are generally heterogeneous and its characterization is complicated by the heterogeneity of porous phase. The processes of sedimentation cause a complex pore space in its structure containing a wide range of pore sizes, microporous grains, and an unusual spatial distribution and connectivity of the pores [12,13].

Any microtomography images of sandstones samples present considerable brightness non uniformity, making very difficult the threshold decision. The models can adjust an inadequate threshold value for the description of the intrinsic structural parameters of these samples.

This work presents the determination of physical and structural parameters, from microtomography images of a sandstone sample, and the marked differences among them. These parameters (porosity, pore size distribution and permeability) were determined with IMAGO image analysis software based on manual thresholds setting of four different operators.

2. MATERIALS AND METHODS

2.1. Sandstone Sample

The sample studied was a Botucatu sandstone. This kind of rock is a quartzarenite in composition, presenting almost only detrital quartz grains, entirely coated with a fringe of microcrystalline quartz (small and discrete quartz crystals) and iron oxide cements [14].

2.2. Physical and Structural Parameters

Porosity, pore size distribution and permeability were the physical and structural parameters determined for the sandstone sample. On image analysis technique, these parameters are highly influenced by threshold value choice and spatial resolution of the cross sections.
Porosity is one of the most fundamental parameters describing porous media [15]. Correct porosity determination, of great interest in oil and natural gas extraction procedure, is considered essential for characterization of sedimentary porous media like sandstone.

Pore-size distribution is other critical parameters to characterize porous structures, and is often employed to describe many transport phenomena, such as water transmission and storage functions of soil [16] and evolution of soil and rocks [17].

Permeability expresses the ability of fluids to pass through the pore system, hence it is related to pore characteristics. Several studies determined the relation between pore structure and permeability properties at various petroleum reservoirs [18].

2.3. X-Ray Microtomography

X-ray microtomography technique permits the investigation of the internal structure of samples. The linear attenuation coefficient, of the specimen in study, is mapping under different scanning positions generating several projections of the sample. These projections are used as an input for the images reconstruction algorithm. The Fourier transformed was the adopted algorithm, based on the filtered back projection method.

The scanner system used was a SkyScan 1072 with an air cooled sealed microfocus X-ray tube, a CCD camera detector (1K x 1K resolution) and system for sample and detector movement. The spatial resolutions achieved of the studied images were 3.8 µm and 11 µm. The operation conditions were 60kV, 165µA, 1 mm Al filter and total rotation angle of 180.0° with rotation step size of 0.45°, for both resolutions. A total of 956 cross-sections and 976 cross-sections, were obtained for the spatial resolution of 3.8 µm and 11 µm, respectively. The images were generated using a cone-beam (Feldkamp) reconstruction algorithm.

2.4. Segmentation

Five different operators analyzed the images from the sandstone sample. Some central images from the cross sections stack, in sequence, were selected for analysis (105 and 113 cross sections for 3.8 µm and 11 µm spatial resolutions, respectively). In order to select a section inside the images to perform the characterization, initially a region of interest was determined. The cropped images were then segmented into binary images based on a manual threshold setting using their grey level histogram. Fig 1 shows a grey level histogram, ranging from 0 to 255 grey tones.

The threshold setting consists of finding the grey level of the histogram which best separated the classes associated to solids and pores, creating binary black and white images. Image filters were not used. Fig. 2 presents a cropped image from the sandstone sample before and after segmentation.
The choice of the threshold, selected by the operators, was personal and individual. No one of those was convinced or influenced by anyone.

The binary images set were modeled to determine porosity, pore size distribution and permeability for each section and their respective mean value. The porous phase characterization was performed using the Imago image analysis software. This software was 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 ESSS and PETROBRAS.

3. RESULTS AND DISCUSSION

Thresholds values set by the operators and mean porosities determined for the two spatial resolutions are summarized in Table 1. Values of threshold and porosity from Appoloni et al., [14] is showed also (same sample with 3.8 µm spatial resolution).
A considerable divergence on the average porosity values was found. These values range from 27.8 to 32.4 % for 3.8 µm spatial resolution and 12.3 to 28.3 % for 11 µm spatial resolution. Op. 2 and Op. 3 chose identical value for the threshold but different porosity values were determined. This disagreement indicates the operators assumed different areas inside cross sections for the cropped images set.

Table 1. Mean porosity values

<table>
<thead>
<tr>
<th>Operators</th>
<th>3.8 µm</th>
<th>11 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold</td>
<td>Porosity (%)</td>
</tr>
<tr>
<td>Op. 1</td>
<td>202</td>
<td>28.31</td>
</tr>
<tr>
<td>Op. 2</td>
<td>205</td>
<td>27.78</td>
</tr>
<tr>
<td>Op. 3</td>
<td>205</td>
<td>28.26</td>
</tr>
<tr>
<td>Op. 4</td>
<td>182</td>
<td>32.39</td>
</tr>
<tr>
<td>[14]</td>
<td>180</td>
<td>32.20a</td>
</tr>
</tbody>
</table>

a. Mean porosity for 14 sets of 50 images of the same sample.

The pore size distributions of all operators are rather similar. Fig. 3 and 4 shows the average pore size distributions. The operators found the same frequency peak in the 30.4 µm size for 3.8 µm. For 11 µm, only Op. 2 found a different frequency peak (32.6 µm) from the others (43.4 µm).

Table 2 presents the quantification of the porous phase in relationship to the pore size. For the same pore size range, percentage differences of 5.5 % (15.2-45.6 µm pore radius range) and 17.1 % (21.7-54.3 µm), for 3.8 µm and 11 µm spatial resolutions respectively, were found among the pore size distributions.
Figure 3. Pore size distribution for 3.8 µm (a) Op. 1, (b) Op. 2, (c) Op. 3 and (c) Op. 4.

Table 2. Percentage of pore size.

<table>
<thead>
<tr>
<th>Operators</th>
<th>3.8 µm (15.2-45.6 µm pore radius)</th>
<th>11 µm (21.7-54.3 µm pore radius)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold</td>
<td>Pore size dist. (%)</td>
</tr>
<tr>
<td>Op. 1</td>
<td>202</td>
<td>62.33</td>
</tr>
<tr>
<td>Op. 2</td>
<td>205</td>
<td>63.36</td>
</tr>
<tr>
<td>Op. 3</td>
<td>205</td>
<td>62.19</td>
</tr>
<tr>
<td>Op. 4</td>
<td>182</td>
<td>57.87</td>
</tr>
<tr>
<td>[14]</td>
<td>180</td>
<td>52.75</td>
</tr>
</tbody>
</table>

The relative permeability regarding the mean values for the stack of cross sections is summarized in Table 3. The sample comes from a quarry and has a porosity of 30% and permeability of 5,000 mD [19].

The permeability values present the biggest discrepancies among the data. For the 11 µm spatial resolution, the value determined by the operator 2 is one order of magnitude lower than operator 4 value.
Figure 4. Pore size distribution for 11 µm (a) Op. 1, (b) Op. 2, (c) Op. 3 and (c) Op. 4.

Table 3. Permeability values.

<table>
<thead>
<tr>
<th>Operators</th>
<th>3.8 µm</th>
<th>11 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold</td>
<td>Permeability (mD)</td>
</tr>
<tr>
<td>Op. 1</td>
<td>202</td>
<td>1461.22</td>
</tr>
<tr>
<td>Op. 2</td>
<td>205</td>
<td>1484.78</td>
</tr>
<tr>
<td>Op. 3</td>
<td>205</td>
<td>1420.51</td>
</tr>
<tr>
<td>Op. 4</td>
<td>182</td>
<td>2282.86</td>
</tr>
</tbody>
</table>

As shown in the Tables 1 to 3, the values of porosity, pore size distribution and permeability are strongly influenced by the spatial resolution, besides the threshold setting. Noises and artifacts are commonly found in microtomography images. This occurrence is inherent from the X-ray microtomography technique. Due to these artifacts, an extreme care in the threshold choice has to be assumed. In comparison to the original image, the binary images have to preserve the boundaries of the rock grains. Slight variations on the threshold value can preserve these artifacts in the binary images, underestimating or overestimating the quantification of the structural parameters.
4. CONCLUSIONS

The characterization of a porous media, by image analysis, is directly influenced by the threshold setting. The great differences among the porosity values show the difficulty on threshold manual setting. The same behavior is shown by the permeability and pore size distribution values. The regions of interest also play an important role on porous phase characterization. For the same threshold value different values of structural and physical parameters were determined. The software operator has to be carefully for the threshold setting, wrong decisions can quantify incorrect data of the sample characterization.

REFERENCES