PROCEEDINGS OF SCIENCE

Application of the X-ray microtomography for the Visualization of Fluid Multi-phasic in Glass Beads Samples

Leonardo Carmezini Marques[1]
E-mail: leocarma@yahoo.com.br

Carlos Roberto Appoloni[1]
E-mail: appoloni@uel.br

Rodrigo Nagata[1]
E-mail: rodrigo_nagata@yahoo.com.br

Celso Peres Fernandes[2]
*E-mail:*celso@lmpt.ufsc.br

[1]*Universidade Estadual de Londrina*
P.O. Box: 6001, Zip code: 86051-990, Londrina, Paraná, Brazil

[2]*Universidade Federal de Santa Catarina*
P.O. Box: 476, Zip code: 88040-900, Florianópolis, Santa Catarina, Brazil

The X-ray microtomography has showed to be a useful tool for studies of inner structure of reservoir rocks. Moreover recent works have used this methodology to visualize different fluid phases present in these microstructures. In this work, X-ray microtomography was used to visualize three-phase fluid, separately or simultaneously, in addition to a solid phase (glass beads). Two samples were manufactured and scanned, one of them with glass beads of 0.8 mm (GB1) and other one with 0.6 mm (GB2) diameter, respectively. The three fluid phases used were air, oil and a water-salt-potassium iodine solution. Two Skyscan scanners, 1172 model, were used. It employs an X-ray tube with W anode, cone beam and a CCD camera. This laboratory equipment is able to provide images of until 1 μm spatial resolution. The 2D images show a clear presence of the solution in addition to the air and solid phase. They also show that the presence of oil phase is less clear than the solution. When all the phases are present together in the sample is possible to differentiate all of them. Individual 3D images are shown for each phase present in the sample. The 3D image containing all the phases is also shown.

XXXIV edition of the Brazilian Workshop on Nuclear Physics,
Foz de Iguaçu, Parana state, Brasil
5-10 June 2011

Leonardo Carmezini Marques
[1] Speaker

1. Introduction

The thorough understanding of the multi-phase fluid characteristics is a important for applications in environmental preservation, groundwater management and also in energetic field with the recovery of petroleo[1].

In the X-ray tomogrphy, a sample is illuminated from many different directions by a X-ray beam, generating a set of maps of linear attenuation coefficients. These projections are used by a mathematical algorithm to create cross sections of scanned object. Such cross sections have the same thickness as the spatial resolution chosen to perform the scanning.

This methodology have recently been used to study different fluid phases within reservoir rocks[2]. In this sense, this work presents results of the investigation of three phases fluid flowing through glass beads samples by X-ray microtomography.

2. X-ray Microtomography Fundamentation

X-ray microtomography is based on heterogeneous attenuation suffered by an X-ray beam transmitted through matter. The characterization of this transmission is a linear attenuation coefficients map. Such attenuation is written by Lambert-Beer law, as following:

$$I = I_0 e^{-\mu x} \tag{1}$$

The attenuation of the X-ray beam as it passes through the matter originates a projection in the CCD camera, and the set of projections is reconstructed in 2D images by a backprojection algorithm[3]. This procedure is performed by the NRecon software of the Skyscan series[4].

Each 2D section is binarized with the Imago software (image analysis software)[5], so that only pixels corresponding to porous ou matrix phase are considered. This procedure is based on the gray-level histogram, where the user selects the threshold for binarization[5]. This threshold is selected within a range of 0 to 255 gray tones and thus the porous phase becomes free of noise without damaging the solid phase[5,6]. The Imago software was developed at the Laboratory of Porous Media and Thermophysical Properties (LMPT), Department of Mechanical Engineering, Federal University of Santa Catarina, in association with Engineering Simulation and Scientific Software (ESSS)[5].

After the binarization process, 3D images of a scanned volume part and relative to one or more phases can be generated by the CTAn software. This software is an application for deriving quantitative parameters and constructing visual models[6]. The visualization and manipuling of the 3D images is performed by the CTvol software[7]. Both CTAn and CTvol are softwares of the Skyscan series.

3. Materials and Methods

The experiments were performed with two scanners Skyscan, 1172 model, which employs X-ray tube and W anode and cone beam. One microtomograph is located at CENPES/Petrobras (Research Center Leopoldo Américo Miguez de Mello/Petrobras) and has a CCD camera of 10 mega pixels resolution. The other one is locate at LAMIR/UFPR (Laboratory analysis of Minerals and Rocks/Federal University of Parana) and has a CCD camera of 11 mega pixels resolution.

Two glass beads samples were used to perform the experiments. The GB1 sample was manufactured with glass beads of 0.8 mm diameter and was measured with the CENPES's scanner. The GB2 sample possesses glass beads of 0.6 mm diameter and was measured with the LAMIR's scanner. Both type of glass beads were packed in glass tubes with 6.7 mm inner diameter and 1.0 mm wall thickness. Table 1 shows the main selected parameters for each performed experiment.

Table 1. The scanning parameters chosen for each measurement.

Sample	Condition	Spatial Res. (μm)	Tension/ Current (kV/μA)	Exposure Time (ms)	Angular Steps (degree)	Rotation (degree)	Grid Size (pixels)
GB1	Dry	4,84	80/124	2000	0,40	180	1048 x 2000
	Solution/ Oil	4,84	80/124	2000	0,40	360	1048 x 2000
GB2	Dry	4,99	70/141	1800	0,25	360	1336 x 2000
	Solution	4,99	80/124	2000	0,25	360	1336 x 2000
	Oil	4,99	70/141	1800	0,25	360	1336 x 2000
	Oil	4,99	60/167	1800	0,25	360	1336 x 2000

The same solution was used for both samples: H_2O-NaCl-KI at proportion of 70 %, 17 % and 13 %, respectively. KI was chosen as dopant in order to increase the X-ray attenuation of the solution. For the GB1 sample it was used an oil of 0.97 g/cm^3 density supplied by CENPES. For the GB2 sample it was used a commercial oil: Lubrax SJ (BR) SAE 20W50-Petrobras Distribuidoras S.A.. Fluid phases were injected or removed by rubber membranes placed on the ends of the glass tube that contained the glass beads. First, each sample was measured dry, then removed from the microtomographic camera to filling with the fluids and then it was put back, aproximately, in the same angular and vertical position.

4. Results and Discussions

Figure 1 shows projections for the GB1 sample before and after of fluid phases presence. The dark region at (b) shows the location of solution.

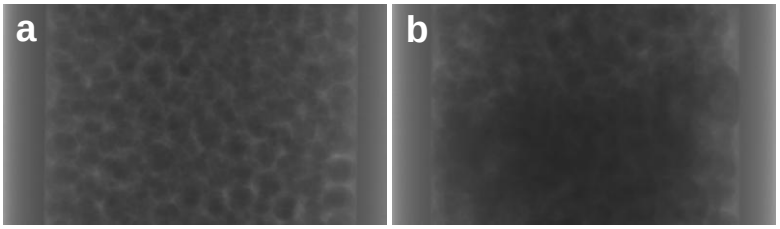

Figure 1- Projections for the GB1 sample: (a) dry and (b) with multi-phase presence.

A total of 947 2D images were reconstructed for the GB1 sample. Figure 2 (a) shows a example of these images. On this figure is possible to visualize four phases: glass (tube and beads); solution; oil and air. A detail of this section is shown on (b), and (c) shows its colored version.

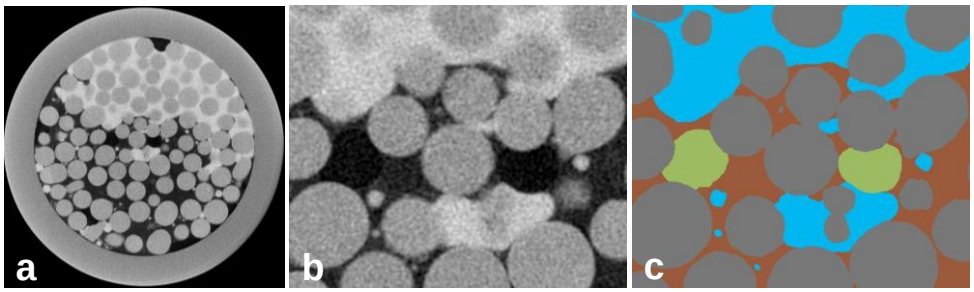

Figure 2- (a) Image of the slice number 684 for the GB1 sample with multi-phase presence, (b) central zoom and (c) colored multi-phase (the glass beads are represented in gray, the solution in blue, oil in brown and air in green).

Figure 3 shows 3D images for the GB1 sample with the suitable threshold range to allow visualization of the phases. It was not possible to separate completely glass beads from the solution. The oil phase is not very clear. The oil phase appears like a pinch of pepper in the center of the pores and, like a bark at the border of the grains.

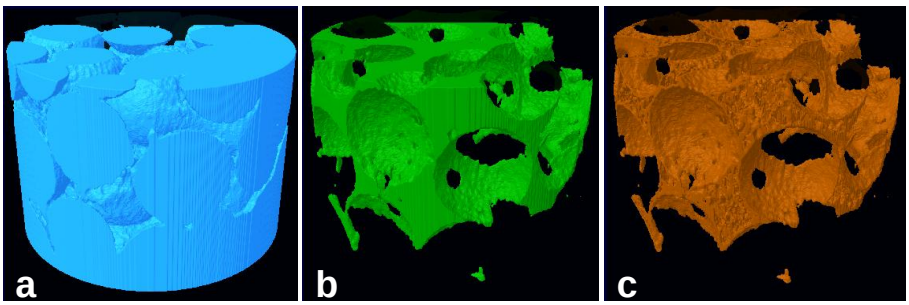

Figure 3- 3D images for the GB1 sample (a) glass beads and solution (88 – 255 threshold); (b) oil and air (0 – 88 threshold) and (c) oil (44 – 88 threshold).

Figure 4 shows the projections for the GB2 sample before and after fluid phases injection, like for the GB1 sample. However, in this case, the solution and oil were used separately. The attenuation of the employed solution is greater than that of the oil phase.

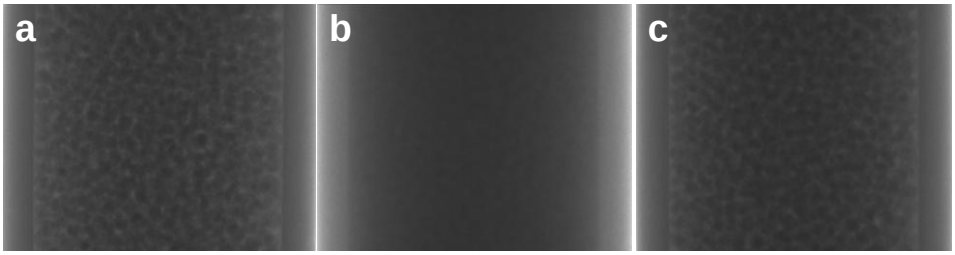

Figura 4- Projections for the GB2 sample: (a) dry; (b) with solution and (c) with the commercial oil.

Figure 5 shows the 2D images for the GB2 sample. At (c) the oil phase has changed the gray scale level when compared with (a) image. This fact resulted in a more clear visualization of glass phase.

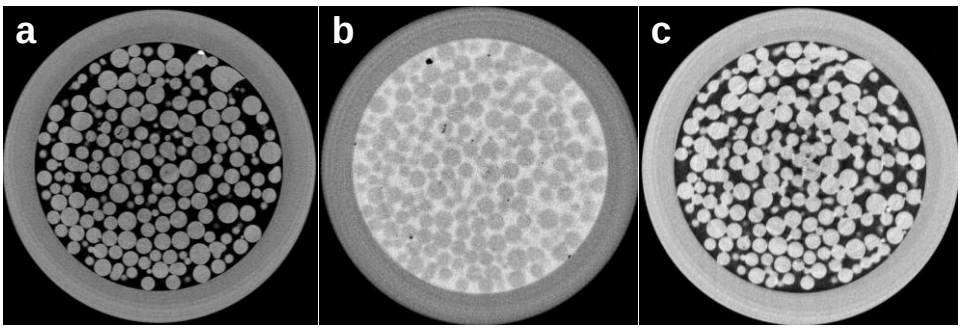

Figure 5- Images for the GB2 sample: (a) Slice number 580 for dry sample; (b) Slice number 585 for sample with solution and (c) Slice number 584 for sample with commercial oil.

Figure 6 shows 3D images for the GB2 sample. The threshold range was chosen to allow visualization of the solution in the pores among glass beads at (a) and oil at (b). Like for the GB1 sample, it was not possible separate completely the solution from the glass beads. The oil phase is not clear enough.

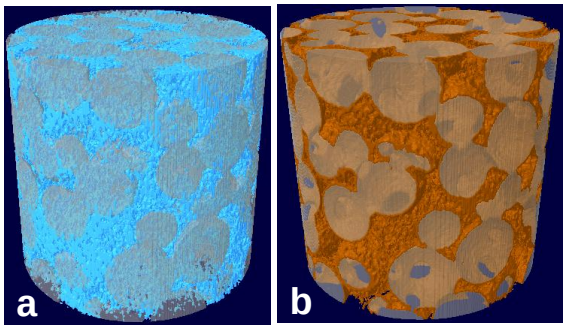

Figure 6- 3D images for the GB2 sample (a) 128 – 255 threshold for glass beads and 60 – 255 threshold for solution and (b) 56 – 128 threshol for oil and 128 – 255 threshold for glass beads.

5. Conclusions

Under the conditions in which the X-ray microtomographies were performed, it was possible to visualize three fluids in samples of glass beads.

Preliminary tests showed that the water phase does not provide sufficient attenuation, compared to the solid phase, in order to provide good contrast in the reconstructed 2D images. The dopant used in addition to the water-salt solution allowed the identification of this phase. Measurements will be performed with a higher percentage of KI (or another dopant) in the solution, in order to allow the complete separation of the glass beads from the solution phase.

The results for the oil phase are satisfactory, despite the low contrast, since no dopant was used to increase the attenuation of this phase.

Acknowledgments

The authors thank CNPq and Capes/MEC for the scholarships and to CENPES and LAMIR for providing the equipments used in the measurements.

References

[1] C. J. Landry, Z. T. Karpyn & M. Piri, *Pore-scale analysis of trapped immiscible fluid structures and fluid interfacial areas in oil-wet and water-wet bead packs*, Geofluids [doi: 10.1111/j.1468-8123.2011.00333.x], 2011.

[2] M. Prodanovic, W. B. Lidquist, R. S. Seright, *3D image-based characterization of fluid displacement in a Berea core*, Advances in Water Resources [doi:10.1016/j.advwatres.2005.05.015], 2007.

[3] A. C. Kak & M. Slaney, *Principles of computerized tomographic imaging*, IEE Press, 2001.

[4] NRecon, *NRecon User Guide*, Skyscan, 2010.

[5] IMAGO®, *Scientific Manual*, Version 2.1.4, ESSS – Engineering Simulation and Scientific Software Ltda, 2002.

[6] CT-Analyser, *The user's guide*, version 1.6.1, Skyscan, 2010.

[7] CT-Volume, *The user´s guide*, version 2.0, *Skyscan, 2010.*