X-Ray Micro-CT Investigation of Sandstones with SkyScan 1172

D.A. Koroteev, A.N. Nadeev

Schlumberger Technology Company, 101000, 5a, Ogorodnaya Sloboda lane, Moscow, Russia, dkoroteev@slb.com

Aims

We studied different regimes for scanning rock samples at the highest resolution using the SkyScan 1172 tomograph to find optimal conditions with respect to 3D image quality and scanning duration. Critical characteristics of the reconstructed images include high contrast of the grain-pore boundary and the boundary between grains with different X-ray absorption coefficient. The ideal case is when a histogram of a reconstructed 3D image represents a set of separate peaks responsible for pore space and grains of different density and element composition. This allows us to create a segmented digital 3D model which would reproduce the original sample with maximal accuracy.

Method

We used the SkyScan 1172 X-ray microtomograph (version A) with a camera mode of the highest resolution (4,000×2,096 pixel^2). The X-ray tube voltage varied from 50 kV to 100 kV. The tube's power is constant and equals 10 W. Usually, we use a 360^0 scan with a rotation step of 0.3^0 and an average within four frames. We performed scans with built-in Al and Al+Cu filters and a 0.125-mm Cu filter. Each time, the flat field correction was applied prior to scanning.

A reconstruction of back-projection images is performed by NRecon shell with InstaRecon software.

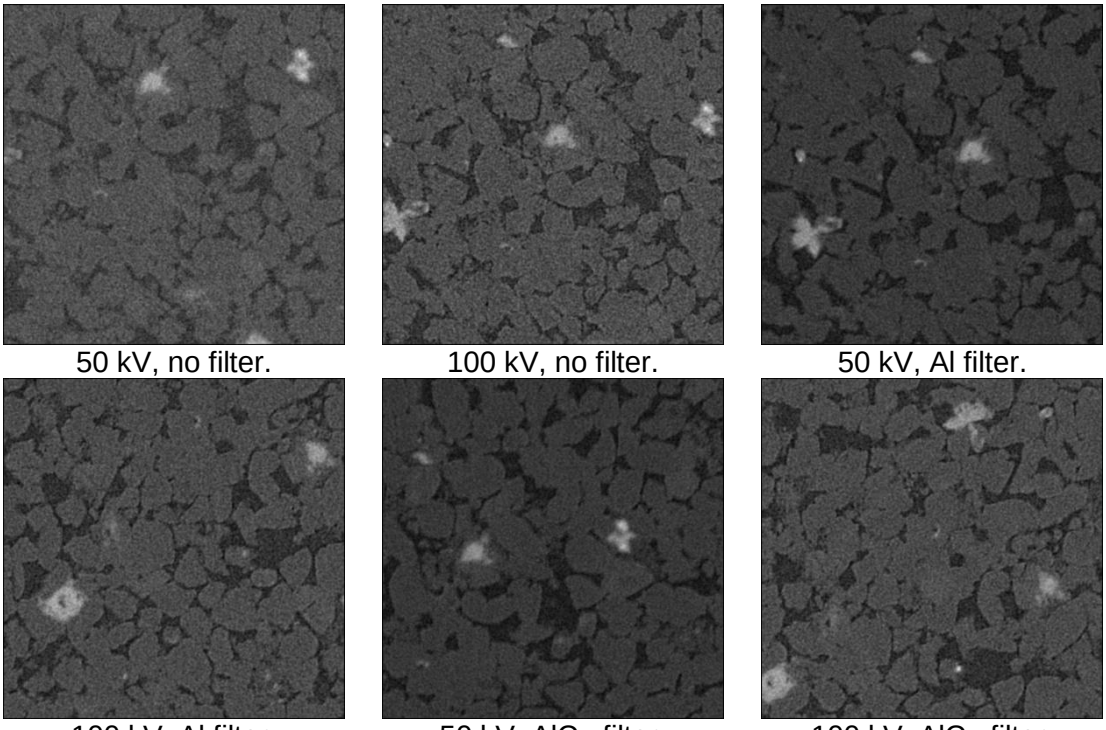
To process the reconstructed 3D images we used CTan and AvizoFire software. And for visualization purposes we used CTvol, CTvox, and AvizoFire technology.

Results

We performed a series of scans on a natural sandstone sample of cylindrical form with an 8-mm diameter. Resolution was 2.2 um/pixel. Porosity of the sample was measured by means of classical porosimetry. The experimental value of the porosity is used as a reference point for choosing the most adequate threshold value to split pores from grains during the binarization procedure.

To make images from different configurations comparable, we converted them from a 16-bit TIF format to an 8-bit JPG format with the same gray-scale range; see Fig. 1 for cropped examples. The images at 50 kV appear darker, but this does not affect the high contrast value. In Fig. 2 we provide the histograms of the uncropped images. Peaks on the histograms correspond to air (left) and grains (right). There is quite a significant difference in contrast between the first and second peaks for all cases. Al and Al+Cu filter cases at 50 kV demonstrate a strong dip between the peaks, while for the 100-kV cases the dip is much smoother. The gray-scale value corresponding to the dip might be considered as a threshold value to separate pores from grains. This characterizes 50 kV cases as most useful for binarization purposes. However, even zero-filter scans might be useful, as they result in quite clear separation in histogram peaks and are about 2–4 times faster than scans with filters. Porosimetry

data is applicable here for correcting the threshold value. But in the no-filter scans, the outer layer of the sample should be removed from the consideration due to noncorrectible beam hardening in this zone. If we zoom in to the right ends of the right peaks to investigate the gray-scale range responsible for small, bright areas (Fig. 1), we see that all cases are equivalent and the histogram features do not allow us to determine the value for further segmentation directly.



50 kV, no filter. 100 kV, no filter. 50 kV, Al filter.

100 kV, Al filter. 50 kV, AlCu filter. 100 kV, AlCu filter.

Figure 1: Reconstructed slices of sandstone sample at different acquisition regimes.

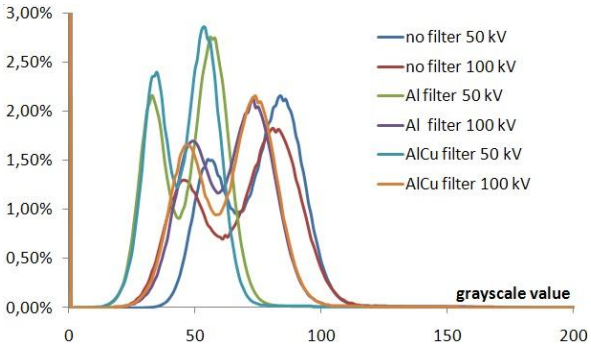


Figure 2: Histograms.

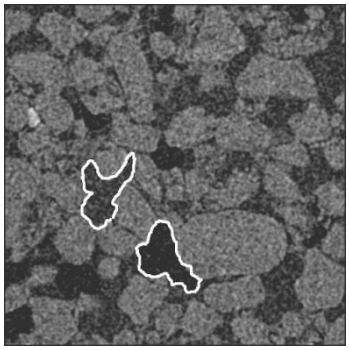


Figure 3: Sandstone saturated with clay. Upper highlighted pore filled with clay, lower one is empty.

We also performed scans of sandstones partially saturated with clay which has similar absorption properties to the quartz grains. But the shape and porous microstructure of the clay allows us to split it from the quarts grains, as shown in Fig. 3.

Another interesting issue discovered during the investigation of sandstones is anisotropy in the binarized model. Using CTan functionality we have noted that binarized models with open porosity corresponding to measured value, demonstrate

quite noticeable anisotropy in the direction colinear with the axis of the sample rotation. To investigate the nature of this phenomenon we prepared a cubic sandstone sample and performed three scans at three orthogonal orientations. Stereology analysis of different spherical volumes of interest for all three cases delivered anisotropy mainly along the vector colinear to the rotation axis, and the degree of anisotropy was about 1.6. With help from the SkyScan researchers we found an artificial way to exclude the anisotropy by applying a smoothing procedure for 2D slices before thresholding, although this operation reduces the adequacy of the reconstructed porous space with respect to the original one.

Conclusion

We carried out a series of XmCT experiments with sandstone samples. The main issues to conclude are

- the lower the voltage and the stronger the filter, the better the contrast achieved between the grains and pores
- in case of time limitations, scans with no filter are quite reasonable even for high-density materials such as sandstone. In this case, the outer layers of the sample should be removed from consideration
- there is no characteristic feature on the histogram allowing us to separate dominating quarts grains from others automatically
- some substances, such as clay, might be separated from grains by its characteristic morphological structure
- quite noticeable artificial anisotropy might be introduced at the scanning or reconstruction stage. To overcome this problem, presmoothing should be applied to gray-scale images before binarization.