Automated workflow for Core Saturation experiment

1. Introduction

This tutorial will detail how to develop and use an automated workflow for a core flooding experiment.

The workflow consists of a recipe including all image processing operations.

Optionally, a python or TCL script defining the data access and output results in order to apply the workflow automatically to a series of acquisitions can be developed.

Data name:	Dry.am				
Data info:	3D Image, grayscale, 16-bit signed				
Dimension:	512 x 512 x 735, uniform coordinates				
Physical Size:	89.8241, 89.8241, 220.2 [mm] from -45, -45, -351.45 [mm]				
Voxel size:	0.175781 x 0.175781 x 0.3 [mm]				
Memory size:	367.5 MB				
Histogram:	-3024 3071				
Preview:					

Figure 1 Original core data

2. Samples and workflow definition

The samples consist of multiple series of 10cm plugs CT scans acquired at different levels of imbibition. For each series, we have :

- 1 water-saturated sample
- 1 oil-saturated sample
- multiple plugs with different degrees of saturation

The image processing workflow consists of:

- Registration of the water-wet sample against the oil-wet sample

For every plug:

- Removing the core barrel and correcting the tilted orientation with Crop Core
- Beam hardening correction
- Automated bulk volume mask computation
- Registration of the plug against the wet sample
- Computation of the saturation with an Arithmetic module and the formula:
 - o (data Oil) / (Wet Oil)*1000



3. Workflow implementation

The implementation will be defined once, and saved as a recipe, so that it can be applied to multiple samples.

Removing the core barrel and correcting the tilted orientation The crop core module will remove the core barrel, re-center and re-align the core



Crop Core	
Data:	2143.am 💌
Core Diameter [mm]:	75
4 Registration Step:	ON ON
Disable Rotation:	
> Other Parameters	

Figure 2 Original Core (not centered with barel) - corrected core

Beam hardening correction

The Beam hardening correction module will correct the beam hardening. A validation of the intensity correction is obtained by comparing the cylindrical intensity profiles.

Beam Hardening Correction				
Data:	2143.to-ushort			
Rotation Axis:	© X © Y ◉ Z			
Axis Angle:	\odot straight \bigcirc sheared	Cylindrical Intensity Profile		
Middle Point [px]:	213 213 367 options	Data:	2143.BHC 🔹	
Average Radius [px]:	▲ 53	Rotation Axis:	⊙ x ⊙ γ ⊚ z	
Max Radius [px]:	▲ ▶ 213			
Threshold:	168 4071	 Middle Point [px]:	213 213	367 options 🔻
Smooth Histogram:	smooth sigma: 1.00	Max Radius [px]:		▲ 213





Figure 3 Cropped Core vs Beam Hardening corrected core, and associated cylindrical intensity profiles

Mask computation

The mask is computed with an *Auto thresholding* module followed by a *Fill Holes* module, and a 2D erosion with a circular kernel, in order to remove the bordering pixels, often the cause of artefacts.



Figure 4 Computed mask on top of the greyscale image



Registration of the oil-wet sample against the water-wet sample This automatic operation is only done once, with a *Register Images* module.

Register Images	A (
Model:	Oil-Wet.am 🔻
Reference:	Water-Wet.am 🔻
Transform:	🛛 Rigid 🔲 Iso-Scale 📄 Aniso-Scale 🔲 Shear
Disable Rotation:	
Register:	② 2D ③ 3D
Prealign:	Align centers Align principal axes
Metric:	Normalized Mutual Information 🔻
> Localizers:	

Note : although the samples seems properly aligned to each other, there is always a tiny displacement that needs to be corrected



Figure 5 Water, Oil wet samples and arithmetic difference with bordering pixels highlighting the displacement

Registration of each sample against the water-wet sample

In order to correctly compute the saturation, every sample is registered to the water-wet sample, prior to the saturation computation.

Note: since the Arithmetic module supports transformations, there is no need to Resample the data after the registration step



Computation of the saturation

An Arithmetic module with the formula (data - Oil) / (Wet - Oil)*1000 is applied to the corrected sample.

Arithmetic				
Input A:	2153.crop.BHC.reg			
Result Type:	input A			
Options:	☑ ignore errors			
4 Result Channels:	like input A 💌			
Expression:	(A-B)/(C-B)*1000			
4 Optional Connections				
Input B:	Oil-Wet.crop.BHC.reg 🔻			
Input C:	Water-Wet.crop.BHC 🔻			

Masking the result

The saturation result can optionally be masked by either a fixed mask for all different sample, or computed every time with the workflow described above.

Mask	
Input Image:	2143.result 💌
Input Binary Image:	2143.MASK 🔻

Saving the recipe

Note : prior to saving the recipe, the models (water-wet, oil-wet) need to have a cleared history. This can be achieved through the *Clear History* button of the home panel, resulting in no log of the Crop Core and Beam Hardening Correction.

The recipe is saved and stored in order to be applied further

Recipes	s					Β×
2153-	Sat		- Ø			8 🛍
	•	Input (data)	2153	•		
	\mathbf{I}	Input (reference)	Water-Wet.crop.BHC	¥		
	•	Input (inputB)	Oil-Wet.crop.BHC.reg	v		
(þ	Module:Crop Core			-⁄É•	
(þ	Module:Convert Image Type			-ڃ+	
(þ	Module:Beam Hardening Correction			-ڃ ~	
(þ	Register Images:Register			-⁄≦•	
(5	Module:Arithmetic				

Figure 6 Saturation recipe



4. Application to multiple series

Application to multiple series requires a bit of scripting. The image processing is handled via recipes, and the script just focuses on loading/unloading the data.

Many possibilities exist for outputting results :

- Saving the computed saturation cores as a 3D tiff data
- Saving snapshots of 2D slices or 3D volume renderings
- Saving intensity profiles as .csv files. The intensity profiles can be obtained after applying a *Global Analysis* module in XY mode on the binary mask and greyscale core data.



Figure 7 Saturation results at different levels of imbibition

