Some Comparisons Between Virtual Computations and Laboratory Estimations of Rock Physics Parameters

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Abstract

Physical measurements of rock properties such as permeability, porosity, formation factor and acoustic properties are important to both geophysicists and to engineers. These parameters are important to help understand the reservoir characteristics and to make better production management decision in the petroleum as well as the groundwater industry.

The usual way to achieve these data sets is to conduct physical experiments on formation core samples. These experiments consume a great amount of time to be performed. The simulation of fluid flow is also a time consuming task and could alter the fabric and therefore the properties of, for example, carbonates percolated by acids.

Three-dimensional (3D) X-ray micro-tomography allows geologists to study the geometry, the fabric and mineralogy of the rock, along with its petrophysical properties, whether it is a clastic or a carbonate sample. The images can be viewed not only in 3D as a complete volume but also in 2D, and correlated with thin sections viewed using a petrographic microscope. The digital data reproduces the rock fabric and computational methods produce realistic petrophysical properties. With this new technology, parameters can be computed from any rock sample including cuttings. The paper will explore some differences between conventional physical lab measurements and the new computational approach.

Here we show that the parameters obtained from virtual computational experiments are comparable to those obtained in the laboratory attesting for the reliability of this new technology.

Introduction

Current laboratory methods for estimation of rock physics parameters are slow and cumbersome. Yet, we need to understand our reservoirs as more wells are drilled and more oil needs to be discovered. Computational methods are the key for obtaining more rock parameters in less time while obtaining data that cannot be acquired in the physical labs, such as from rock cuttings. Virtual computations can be performed on any sample, core, side-wall or cuttings, in less time while still obtaining reliable parameters.

The result is increased efficiency and more data available to be interpreted.

Method

One of the purposes of imaging a rock and producing 3D digital data is to calculate absolute and relative permeabilities. Here, we solve Darcy's equation using the Lattice- Boltzmann method.
It is important to understand the primary definition of absolute permeability based on Darcy's equation because permeability is related to the size of the pores and their connectivity.

$Q = -k \frac{A}{\mu}\frac{\Delta P}{L}$; where Q is Volume flux, A is Area, ΔP is difference in pore pressure, μ is dynamic viscosity of the fluid and L is the length of the sample.

Experiments performed in physical labs are complex and subjected since the rock can undergo physical deformation or alteration from the physical experiment itself. In comparison, virtual computations are non-destructive and do not disrupt the rock's integrity. Imaging rocks with a MicroXCT creates a digital rock volume from the physical rock that directly translates density into gray scale: pores are represented by black to dark grey and grains are represented by all lighter shades of grey to white. A 3D digital volume is created following the scan (Figure 1b, 1d) and is made up of 2D slices (Figure 1a, 1c) that are seamlessly connected to complete the digital rock volume. This volume is an exact recreation of all details pertaining to the rock's texture and fabric and is limited only by the scans resolution.

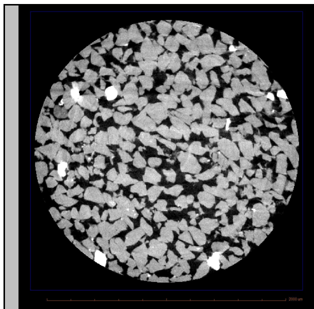

Figure 1a: 2D slice from a clean quartz sandstone.

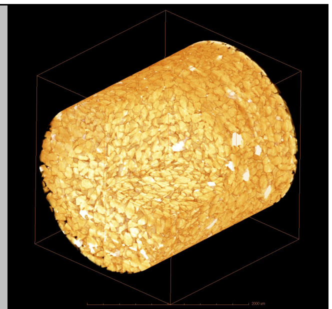

Figure 1b: 3D image from a clean quartz sandstone.

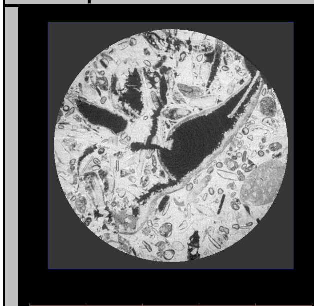

Figure1c: 2D slice from a fossil carbonate.

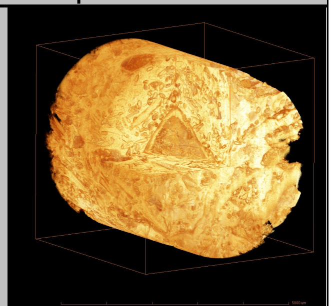

Figure 1d: 3D image from a fossil carbonate.

Figure 1: Images show examples of 2D slices obtained through CT scanning and the re-creation of the rock's pore space in 3D.

The results achieved with our methodology include:

- **Elastic Moduli using the FEM (Finite Element Method)**
- **Total Porosity**
- **Relative Permeability in three axis**
- **Absolute Permeability**
- **Formation Factor in three axis**

All these properties are obtained by virtual experiments. Together they provide an understanding of the relationship between these properties.

An example of parameters computed by our computational method is shown in Table 1 for the well-consolidated sandstone imaged in Figure 2.

The main operational steps for the virtual computations are the scanning which acquires the image, the reconstruction, and the grain and pore segmentation. The segmented, or binary representation of the rock volume is then used to compute the rock properties.

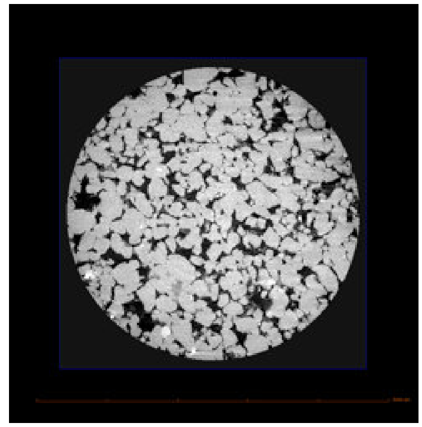

Figure 2: 2D image slice obtained through CT scanning of a well consolidated sandstone (Sample A). Its rock properties, calculated using computational methods are shown in Table 1.

Sample Name	A
Porosity	
Total Porosity (%)	19
Permeability (mD)	
Directional Permeability (X)	459
Directional Permeability (Y)	488
Directional Permeability (Z)	454
Formation Factor	
Formation Factor (X)	20
Formation Factor (Y)	20
Formation Factor (Z)	23
Elastic Properties	
Compressional Velocity V_P Km/s	4.8
Shear Velocity V_S Km/s	3.2
Bulk Modulus K Gpa	20
Shear Modulus G Gpa	22
Youngs Modulus E Gps	48
Poisson Ratio	0.09

Table 1: Rock properties for sample A (Figure 2) calculated using computational methods.

Laboratory versus Computational Parameters

Simulating rock properties using virtual computations differs from physical laboratory method, but results have shown that the values obtained from physical measurements are not compromised. Although the experimental method gives results that are close to the physical measurements, like any other tools there are some limitations regarding the interpretation and computation of the data. Segmentation of the image into pores (black) and grain (white) is an interpretative process and is performed on the digital rock volume. Tables 1, 2, 3 and Figure 4 show comparisons between parameters computed from physical laboratory experiments and those from our virtual computations for samples A, B and C. These samples come from a formation predominately arenaceous and present a complex succession of various sedimentary facies, interpreted as being from glaciomarine environments.

Porosity values obtained by our virtual method present the same range of values as the ones obtained from laboratory measurements.

The difference in the range of permeability and Formation Factor values is due to the difference in methodology. Physical laboratory measures permeability on a entire core and takes an average value, while our method measures it on sub-samples of the core that have been chosen based on the unique heterogeneities of the rock. The heterogeneities are identified using a low resolution scan that images the entire core. The low resolution scan is analyzed and sub-samples are taken to capture the variation within the rock. Thus, the subsamples are not an average of permeability, but show the end members included in the physical labs average permeability values.

Sample	Lab Porosity (%)	Digital Porosity (%)
A	18-20	25-20-19
B	12-13	12-11-12
C	15-16	16-14-16

Table 2: Porosities from samples A, B and C measured in a physical lab and using our virtual method.

Sample	Lab FF	Digital FF
A	15	15
B	40	65
C	30	35

Table 3: Formation factor (FF) from samples A, B and C measured in a physical lab and using our virtual method.

Sample	Lab Perm (mD)	Digital Perm (mD)
A	50	500
B	200	10
C	1000	500

Table 4: Permeabilities from samples A, B and C measured in a physical lab and using our virtual method.

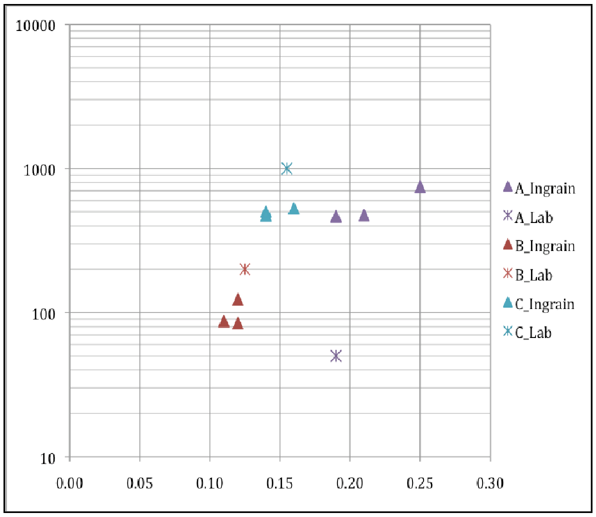

Figure 3: Porosity versus Permeability values from samples A, B and C measured in a physical lab and our digital lab.

Conclusions

The comparisons presented in this paper show that our methodology in which the rock sample (core, side-wall or cutting) is imaged and rock parameters are computed from a 3D virtual rock can provide values that are close to those from a physical laboratory and in much lesser time. However, the more homogeneous the rock, the closer the values will be to physical laboratory measurements.

Also, physical laboratory procedures measure the core through the main axis and the advantage of digital analysis is the freedom to analyze all axes for rock properties. In addition, it provides the ability to see different phases of mineral density, rock fabric, texture and porosity, to give a real tangible feel to what was previously only mathematical numbers.

Our examples show that our computational technology can provide vast amounts of data that will be extremely important for the understanding of the reservoirs.

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