PS Analysis of the Relations between Porosity and Permeability in Non-Consolidated Granular Media*

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Abstract

Few natural rock properties have received more attention than porosity and permeability. The variation of these two properties is associated with some factors as pore space geometry and distribution, textural parameters, pore throat size and capillary pressure. In this sense, the study of the pore throat radii distribution, through Pittman's equations, is useful in reservoir characterization. The aim of this study was to establish empirical relations and their applications in the dynamic and static flow properties, through the characterization of simple granular materials. In order to accurately describe the microstructural parameters of these media 16 samples were studied, and three relations were proposed after analyzing the 2D distribution of the pore throat radii in monodisperse and spherical granular samples, with diameters ranging between 1.5 mm and 7.5 mm. The permeability was calculated using both, a falling-head permeameter for the volumetric media, and the Pittman's equations for the 2D images of the samples. The porosity was estimated with an image-processing algorithm. Using the regression analysis, it was found that pore throat radii of 70%, 80% and 85% yield the best correlation for permeability, porosity and pore throat size for monodisperse granular samples. This study indicates that higher pore throats than those proposed by Pittman are the best representatives for estimating permeability from 2D images of coarse-grained granular media.

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Abstract

Porosity | Storage Capacity | Flow Capacity | Permeability

Controlled by pore size and pore geometry

Methods

Embedding Method — Falling Head Permeameter

Image Analysis — Pore Throat Radii Distribution

Φ ≈ 30-38% — K ≈ 10^3 Darcies

Pittman's and Windland's equation utility in permeability estimation from 2D images

Introduction

Sedimentary Rocks → Granular Materials → Economical Resources

Faraday (1831) → Convective instability in vibratory containers

Windland (1975) &Pittman (1992) → Empirical relations between ϕ, *k* and P_c

Kameda (2004) → Porous space description through 2D images

Alberts (2005) → Porosity analysis in random speherical packages

Granular Matter

Discrete clusters of mesoscopic particles

Elastic Repulsion — *Behave similar to* — Friction

Liquids: Take the shape of their container and are able to flow

Solids: Resist strain and stress (shear and compressional)

Highlights

Static Friction — $E_p+E_k>>E_{internal}$ — Inelastic collisions

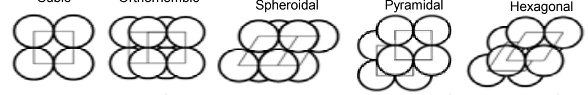

Figure 1. Superior view of regular spheric arrays, with the minimum number of spheres needed to form them(Modified from Alberts, 2005).

Falling Head Permeameter

Darcy's Law

$$k=\frac{a\mu L}{A\rho g\Delta t}\ln\left(\frac{h_2}{h_1}\right)$$

g=gravity constant
ρ =fluid density
L =sample length
A =sample cross sectional area
a=sample cross sectional area
μ=fluid viscosity

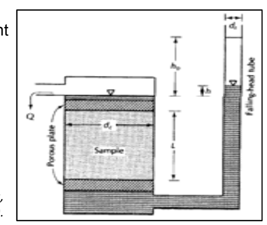

Figure 2. Falling head permeameter. (Modified from Espinoza, 2004).

Empirical Relations between k and ϕ

Pittman's equation for r_{70} (1992) →

$$Log(r_{70}) = 1,664 + 0,627Log(k) - 2,314Log(\phi)$$

Samples Used

K and Φ were measured over 5 steel spherical samples

Sample	Diameter (mm)	Length (mm)
Sample 1	1.5	80.0
Sample 2	3.5	90.0
Sample 3	4.0	74.0
Sample 4	6.0	80.0
Sample 5	7.5	80.0

Samples were combined to evaluate relations between k and Φ in heterogeneous media

Methodology

Permeability Measurements

1. Falling head permeameter construction

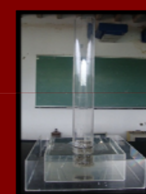

Figure 3. Falling head permeameter

2. Pore Throat Radii Distribution Analysis

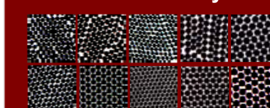

Figure 5. Samples images selected for throat radii distribution analysis.

Figure 6. Pore filling process for throat radii distribution analysis.

Porosity Measurements

1. Embedding porosity measurements

Figure 4. Vpores=Vsample+Vwater-Vfinal

2. Optical Porosity Measurements

Take 25 pictures for each sample.

Convert RGB images to Black and White using a computational algorithim.

Images are transformed into matrices of 1 (white-pores) and 0 (black-grains).

Calculate total and porous areas.

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Results, Analysis and Discussion

Identify pore throat radii which dominates the flow

Generate new equations for r_{80} and r_{85}

Substitute 80 and 85 in the polynomial equations for Pittman's coefficients

$$Log(r_{80}) = 4{,}8910 + 0{,}3300 Log(k) - 3{,}3710 Log(\phi)$$

$$Log(r_{85}) = 4{,}1986 + 0{,}4266 Log(k) - 3{,}0088 Log(\phi)$$

K and Φ characterization on monodisperse granular media

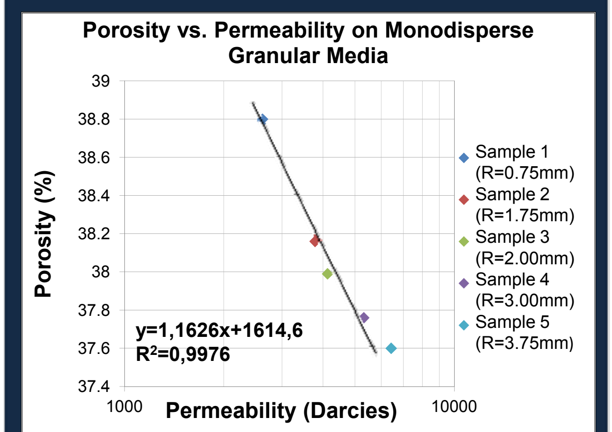

Figure 7. Linear relation between k and Φ, when k values are graphed on a logarithmic scale. Note that k is higher for samples with bigger radii, while Φ increases as the radius size decreases.

K and Φ characterization on bidisperse granular media

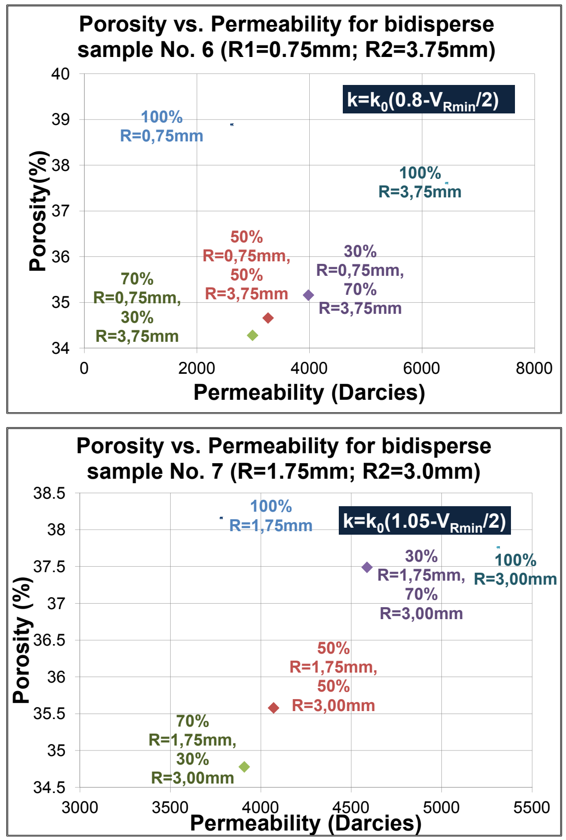

Figure 8. Porosity vs. Permeability for two bidisperse samples. Note that the high porosity of the smaller monodisperse media is responsible for the decreasing tendency at the beginning of the curve.

K and Φ characterization from two dimensional images

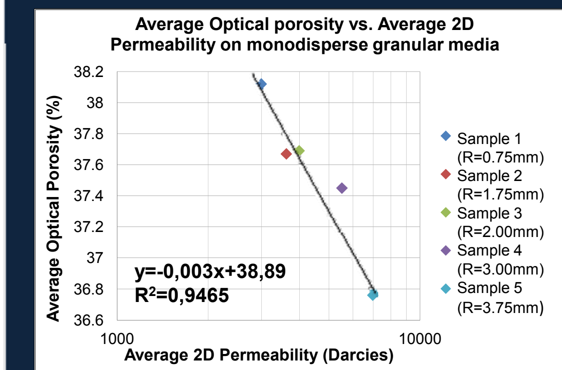

Figure 9. Optical Porosity vs. 2D Permeability on monodisperse granular media. Note that the curve is similar from one shown on figure 7, which validates the proposed methodology .

Conclusions and Recommendations

- Permeameter is a cheap and easy method to measure permeability.
- Permeability can be accurately determined from 2D images by using the empirical approximations of Pittman's equations.
- It would be useful to estimate permeability from real thin sections.

Acknowledgments

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