भारतीय प्रौद्योगिकी संस्थान
(भारतीय खनि विद्यापीठ)
धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY
(INDIAN SCHOOL OF MINES)
DHANBAD

GPC510 - Well logging

Semester - Winter 2024; Lecture - 6

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TEACHING OUTLINE

Week 4

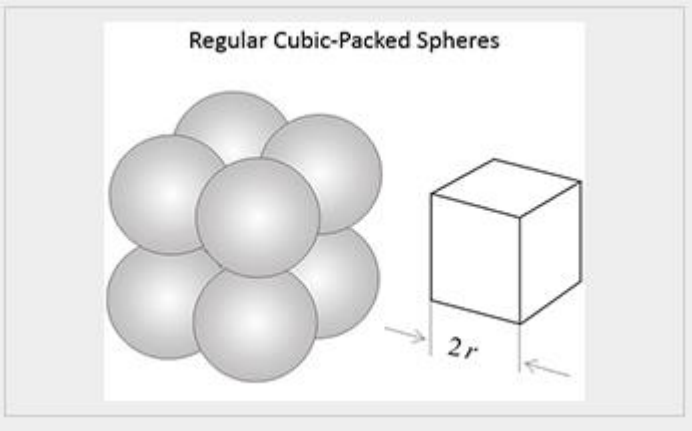
Tutorial 8 – Core porosity, porosity variation with depth, permeability

AGENDA

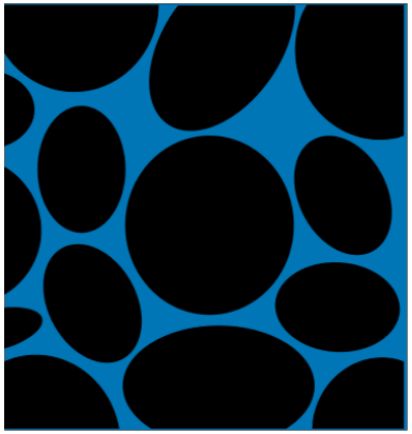
- Porosity measurement techniques (lab scale)
- Darcy's law of fluid flow
- Permeability (k) definition and permeability ranges of different rock
- Effective and relative permeability

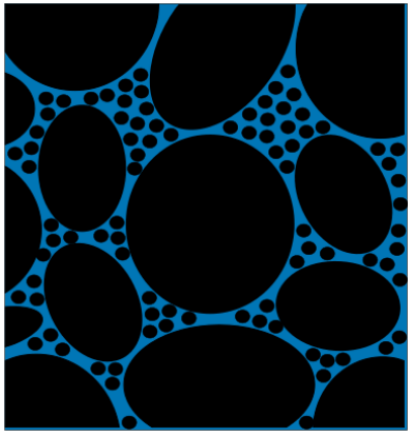
POROSITY OF IDEALIZED GRAINS

- Calculate porosity of regular cubic-packed sphere?



- Which section has larger porosity?





Serra, 1985; Wikipedia, 2021

POROSITY FROM CORE SAMPLE

- Measurement of porosity in the laboratory is part of Routine Core Analysis (RCA). Several methods exist for intergranular porosity measurement
- **Bulk volume** (V_b) – physical measurement (dimensions of a cylindrical shape) and displacement method for irregular shape sample
- The fluid volume that the sample displaces can be determined volumetrically or gravimetrically in three different ways:

- Coating the sample with paraffin
- Saturating the rock with same fluid into which it is to be immersed
- By using mercury, generally not enter the pore space

Regular geometry

Irregular geometry

POROSITY FROM CORE SAMPLE

- Gravimetric determination of bulk volume either by loss of weight when immersed in fluid or change in weight of pycnometer filled with mercury
- **Grain volume** (V_g) – require dry weight of sample and grain density. Crushed powder sample is required to determine grain volume by displacement method

Gas Pycnometer

CSIRO; PERM TIPM Lab, 2021

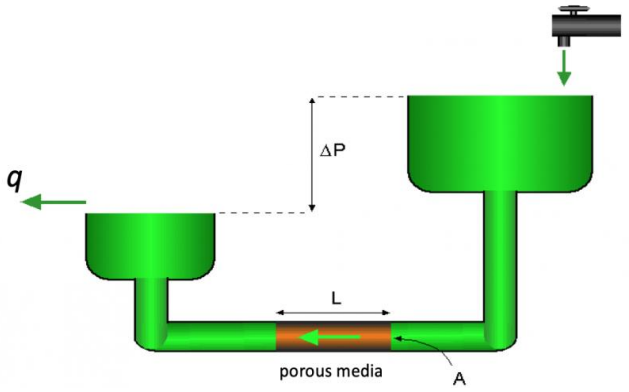
POROSITY VARIATION WITH DEPTH

- Beside the mechanism of grain packing, the degree of compaction with the depth of burial is an important factor
- Porosity decreases with increasing depth in a predictable manner for a normal pressurized subsurface reservoir such as

$\varphi = \varphi_0 e^{-z\alpha}$ in which φ_0 is the porosity at surface and α is the compact constant (1/m or 1/ft) for a particular geological area

DARCY'S LAW OF FLUID FLOW

- Darcy's law is the fundamental law of fluid motion in porous media of single fluid under steady state flow with constant fluid compressibility and temperature
- Darcy's law is $q = \frac{k}{\mu}\frac{A}{L}(P_1 - P_2)$ which is similar to Fourier's law of heat conduction/ Ohm's law of electricity

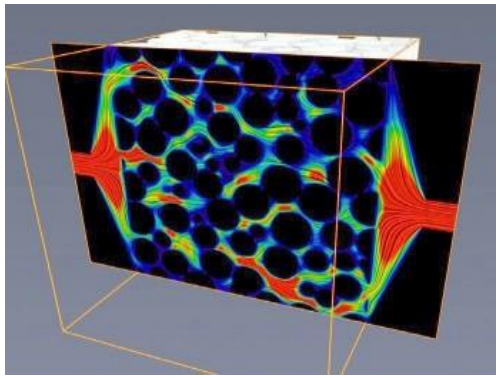


in which k = absolute permeability (Darcy); A= cross-sectional area (cm^2); L = length (cm); P_1, P_2 – pressure in atm at up and downflow faces; μ = fluid viscosity (centipoise)

- If the flow is changed from linear to radial, the above equation will change accordingly

PERMEABILITY

- A measure of ability of the rocks to transmit fluids
- Permeability (petroleum industry) is expressed in millidarcy (1 Darcy = 1000 mD)
- Model based approach can be used to derive continuous permeability profile from well logs
- Similar to porosity, permeability is part of RCA
- Permeability is a directional dependent property (anisotropic in nature)



Ref: Geomore.com

PERMEABILITY CHART OF ROCKS

Permeability	Pervious				Semi-Pervious				Impervious				
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel		Very Fine Sand, Silt, Loess, Loam								
Unconsolidated Clay & Organic					Peat		Layered Clay		Unweathered Clay				
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	
κ (cm^2)	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}
κ (millidarcy)	10^{+8}	10^{+7}	10^{+6}	10^{+5}	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001

Source: modified from Bear, 1972

EFFECTIVE AND RELATIVE PERMEABILITY

- Effective permeability refers to flow of fluid through a rock in presence multiple pore fluids. It depends not only rock but also to the percentage of fluids presents in the pores [i.e., saturation]
- Multiphase fluid flow is described by relative permeability (k_{rw}, k_{ro}, k_{rg}). It is expressed as ratio of effective permeability ((k_w, k_o, k_g) to their absolute permeability k as below

$$k_{ro} = \frac{k_o}{k}$$ for oil

$$k_{rg} = \frac{k_g}{k}$$ for gas

$$k_{rw} = \frac{k_w}{k}$$ for water

EFFECTIVE AND RELATIVE PERMEABILITY

- **Effective permeability** is the ability to preferentially flow or transmit a particular fluid through a rock when other immiscible fluids are present in the reservoir (for example, effective permeability of gas in a gas-water reservoir).
- The **relative saturations** of the fluids as well as the nature of the reservoir affect the effective permeability.
- Relative permeability is the ratio of **effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation.**
- Basically, absolutely permeability for a particular rock-fluid pair will be specific. That's why there are **different absolute permeabilities for gas and brine.**
- Generally, we choose **brine-rock pairs** for measuring absolute permeability and then take that as a reference for calculating relative permeabilities for other phases.

END OF LECTURE