Tikrit University

The College of Petroleum Processes Engineering

Petroleum and Gas Refining Engineering Department

An Introduction to Petroleum Technology

First Class

Lecture (5)

By

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Permeability:

Permeability is a property of the porous medium that measures the capacity and ability of the formation to transmit fluids. The rock permeability, k, is a very important rock property because it controls the directional movement and the flow rate of the reservoir fluids in the formation.

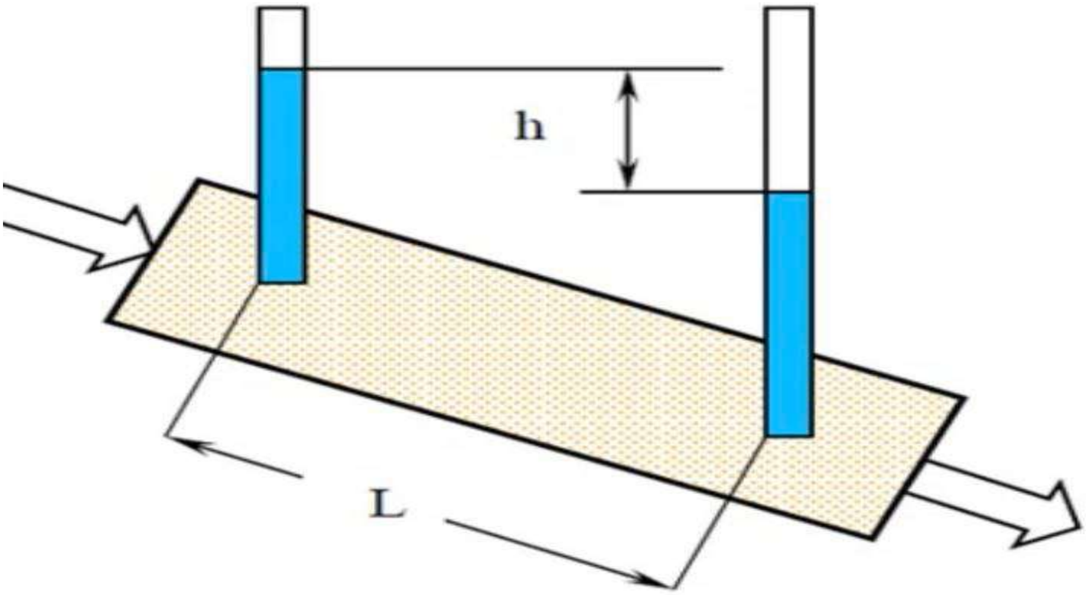
This rock characterization was first defined mathematically

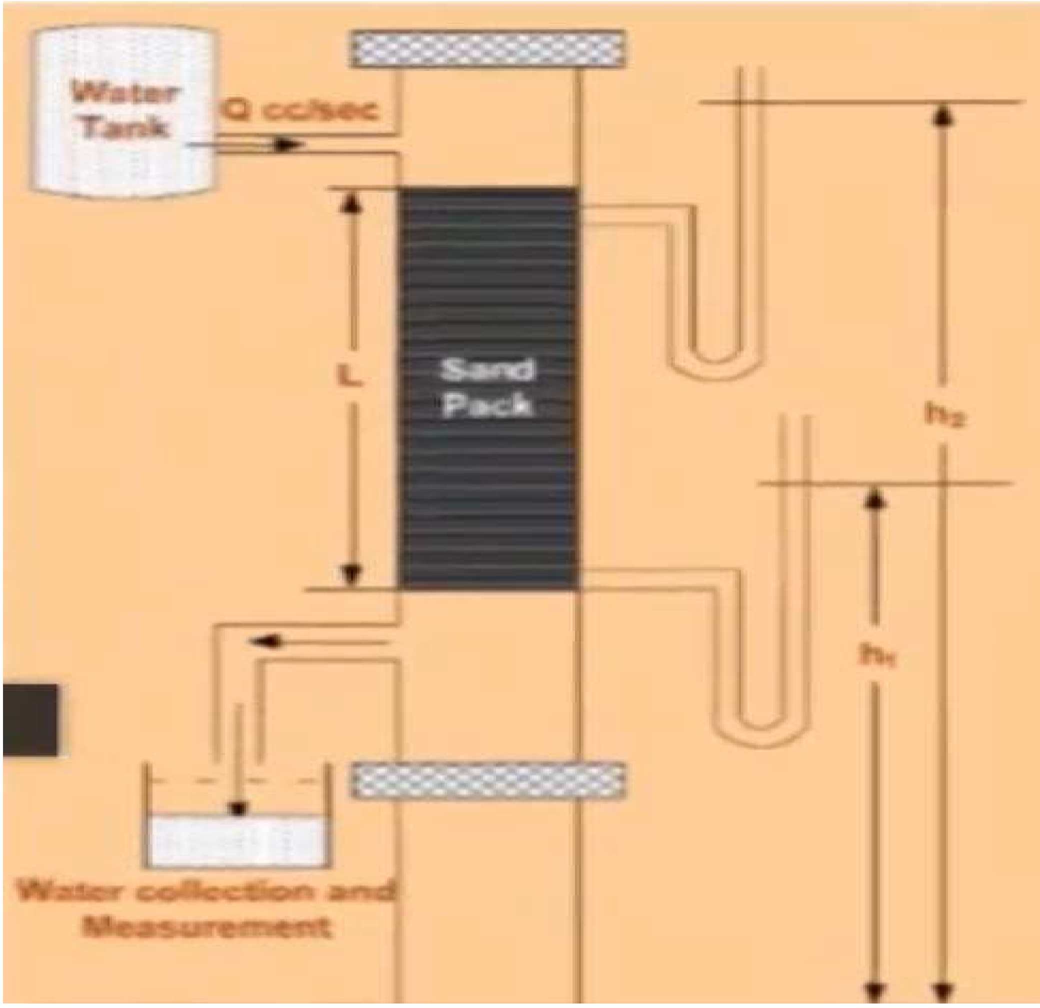
By Henry Darcy in 1856. In fact, the equation that defines permeability in terms of measurable quantities is called

Darcy’s Law.

Darcy developed a fluid flow equation that has since become one

of the standard mathematical tools of the petroleum engineer.





$V \propto \Delta h$

$V \propto \frac{1}{L}$

$V \propto \frac{\Delta h}{L}$

$V = K \frac{\Delta h}{L}$

$Q = A \cdot V$

$Q = KA \frac{\Delta h}{L}$

Other scientists used other liquids instead of water, and found that the speed of flow is inversely proportional to the viscosity of the liquid, so the relationship became:

$$V = \frac{K\ \Delta P}{\mu \Delta L} \qquad 5\text{-}1$$

Where V =apparent fluid flowing velocity, cm/sec

k = proportionality constant, or permeability, Darcys

μ =viscosity of the flowing fluid, cp.

dp/dL = pressure drop per unit length, atm/cm

The velocity, V, in Equation 5-1 is not the actual velocity of the flowing fluid but is the apparent velocity determined by dividing the flow rate by the cross-sectional area across which fluid is flowing. Substituting the relationship, q/A, in place of V in Equation 5-1 and solving for q results in:

$$q = \frac{K\ A\ \Delta P}{\mu \Delta L} \qquad 5\text{-}2$$

where q = flow rate through the porous medium, cm /sec

A = cross-sectional area across which flow occurs, cm3

One Darcy is a relatively high permeability as the permeabilities of

most reservoir rocks are less than one Darcy. In order to avoid the use of fractions in describing permeabilities, the term millidarcy is used. As the term indicates, one millidarcy, i.e., 1 md, is equal to one-thousandth of one Darcy or,

1 Darcy = 1000 md

Equation 5-2 can be integrated when the geometry of the system through which fluid flows is known. For the simple linear system shown in Figure 5-1, the integration is performed as follows:

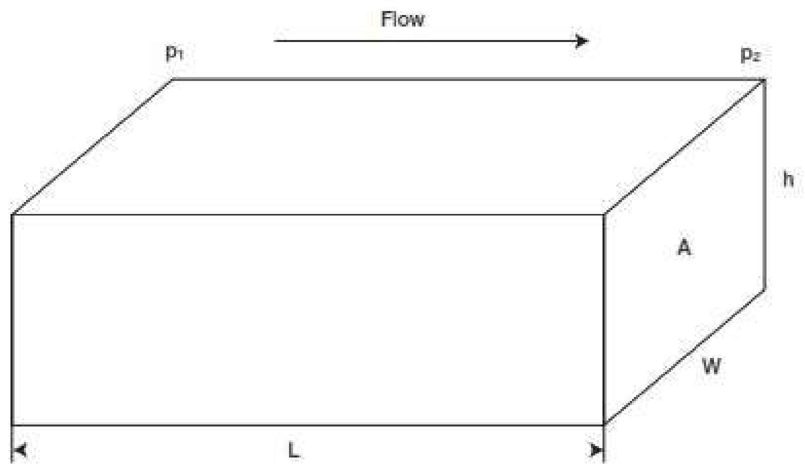


Figure 5-1

$$q \int_0^L \Delta L = \frac{K\,A}{\mu} \int_{P1}^{P2} \Delta P \qquad 5\text{-}3$$

t should be pointed out that the volumetric flow rate, q, is constant for liquids because the density does not change significantly with pressure.

Since p1 is greater than p2, the pressure terms can be rearranged, which will eliminate the negative term in the equation. The resulting equation is:

$$q = \frac{K\,A\,(p2-p1)}{\mu L} \qquad 5\text{-}4$$

Equation 5-4 is the conventional linear flow equation used in fluid flow calculations.

$$k = \frac{q\mu L}{A\,(p2-p1)} \qquad 5\text{-}5$$

Where L = length of core, cm

A = cross-sectional area, cm2

The following conditions must exist during the measurement of permeability:

(Condition applies Darcy's law):

1- No reaction occurs between the rock and fluid.

2- Laminar flow exist.

3- Incompressible fluid .

4- One fluid completely saturation the core .

5- Permeability a constant

6- Flow system steady – state

Only single phase present at 100% pore space saturation

This measured permeability at 100% saturation of a single phase is called the absolute permeability of the rock.

Example 5-1

Brine is used to measure the absolute permeability of a core plug.

The rock sample is 4 cm long and 3 cm in cross section. The brine has a viscosity of 1.0 cp and is flowing a constant rate of 0.5 cm2/sec under a 2.0 atm pressure differential. Calculate the absolute permeability.

Solution:

Applying Darcy's equation, i.e., Equation 5-5, gives:

$$k = \frac{q\mu L}{A\,(p2-p1)} = \frac{0.5\,(1)(4)(4\,)}{(4x3)(2)}$$

k = 0.333 Darcys

Example 5-2

Rework the above example assuming that an oil of 2.0 cp is used to measure the permeability. Under the same differential pressure, the flow rate is 0.25 cm3/sec

Solution:

Applying Darcy's equation yields:

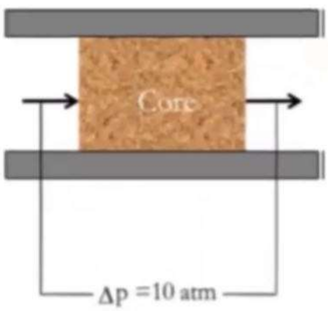
$$k = \frac{q\mu L}{A\,(p2-p1)} = \frac{0.25\,(2)(4)}{(3)(2)}$$

k = 0.333 Darcys

Example 5-3

Determine core permeability with a flow of water given the following: μ = 1 cp; L = 85 cm; r_{core} = 3 cm; Δp = 10 atm; Q = 0.05 cm^3/s.

Plot relationship between pressure drop (Δp) versus flow rate ranges from 0.05 to 0.5 cm^3/s.

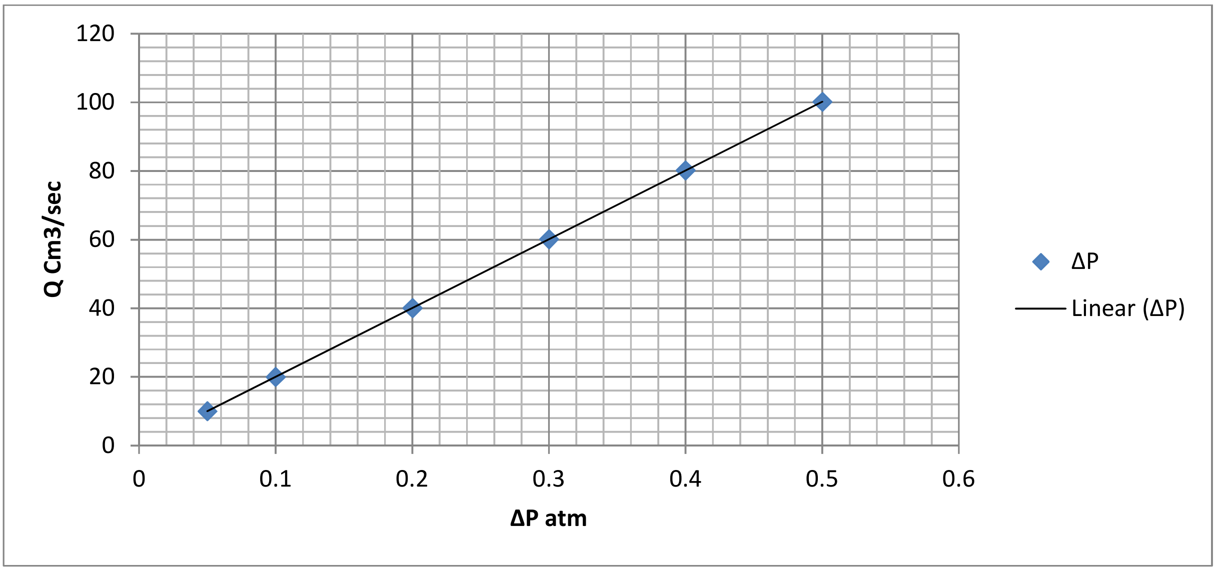


Solution:

A = r^2 л = 3^2 x 3.14 = 28.274 cm^2

k = $\frac{q\mu L}{A\,(p2-p1)}$ = $\frac{0.05\,(1)\,(85)}{(28.274)(10)}$ = 0.015 Darcy= 15 md.

Q cm3/s	0.05	0.1	0.2	0.3	0.4	0.5
ΔP atm	10	20.04173	40.08347	60.1252	80.1669	100.2087



Note:

To convert units from the units that Darcy used in his experiment to field units:

unit conversions you must memorize:

30.48 cm/ft ,

14.7 psi/atm,

5.615 ft3/bbl,

0.3048 m/ft ,

7.48 gal/ft3,

42 gal/bbl.

Field Units:

q [bbl/day]	μ [cp]	A [ft^2]
k [md]	Δp [psi]	L [ft]

Darcy Units: $q = \frac{kA}{\mu}\frac{\Delta p}{L}$

q [cm^3/sec]	μ [cp]	A [cm^2]
k [Darcy]	Δp [atm]	L [cm]

$$q = \frac{K\,A\,(p2-p1)}{\mu L}$$

Left side:

$$\left[\frac{bbl}{day}\right]\left[5.615\,\frac{ft^3}{bbl}\right]\left[30.48\,\frac{cm}{ft}\right]^3\left[\frac{day}{24\ hr}\right]\left[\frac{hr}{3600\ sec}\right]$$

$$\left[\frac{\cancel{bbl}}{\cancel{day}}\right]\left[5.615\,\frac{\cancel{ft^3}}{\cancel{bbl}}\right]\left[30.48\,\frac{cm}{\cancel{ft}}\right]^3\left[\frac{\cancel{day}}{24\,\cancel{hr}}\right]\left[\frac{\cancel{hr}}{3600\,sec}\right]$$

Right side:

$$= \frac{[md]\left[\frac{d}{1000\,md}\right][ft^2]\left[30.48\,\frac{cm}{ft}\right]^2[psi]\left[\frac{atm}{14.7\,psi}\right]}{[cp][ft]\left[30.48\,\frac{cm}{ft}\right]}$$

$$= \frac{[\cancel{md}]\left[\frac{d}{1000\,\cancel{md}}\right][\cancel{ft^2}]\left[30.48\,\frac{cm}{\cancel{ft}}\right]^2[\cancel{psi}]\left[\frac{atm}{14.7\,\cancel{psi}}\right]}{[cp][\cancel{ft}]\left[30.48\,\frac{cm}{\cancel{ft}}\right]}$$

$$\frac{(5.615)(30.48)^3}{(24)(3600)} = \frac{(30.48)^2}{(1000)(14.7)(30.48)}$$

$$= \frac{(24)(3600)}{(5.615)(1000)(14.7)(30.48)^2}$$

$$q = -1.127 \times 10^{-3} \frac{kA}{\mu B_o} \frac{\Delta p}{\Delta L}$$