DARCY'S LAW (1856)

WHAT IS DARCY'S LAW?

Darcy's law states the principle which governs the movement of fluid in the given substance. Darcy's law equation that describes the capability of the liquid to flow via any porous media like a rock. The law is based on the fact according to which, the flow between two points is directly proportional to the pressure differences between the points, the distance and the connectivity of flow within rocks between the points. Measuring the interconnectivity is known as permeability.

"The volume of water which passes through a bed of sand of a given nature is proportional to the pressure and inversely proportional to the thickness of the bed traversed"

In analyzing the sub surface movement of water, the actual paths of the water molecules as they flow through pores, cracks and crevices of the soil or other aquifer material are taken as smooth paths. If the water molecules move right through the solid particles. The resulting smooth lines of travel of the water molecules are called stream line.

DARCY'S LAW APPLICATION

One application of Darcy's law is to flow water through an aquifer. Darcy's law with the conservation of mass equation is equivalent to the groundwater flow equation, being one of the basic relationships of hydrogeology. Darcy's law is also applied to describe oil, gas and water flows through petroleum reservoirs.

The liquid flow within the rock is governed by the permeability of the rock. Permeability has to be determined in horizontal and vertical directions. For instance, shale consists of improbabilities which are less vertically. This indicates that it is not easy for liquid to flow up and down via shale bed but easier to flow side to side.

Darcy's Law Equation

To understand the mathematical aspect behind liquid flow in the substance, Darcy's law can be described as:

Darcy's law describes the relationship among the instantaneous rate of discharge through porous medium and pressure drop at a distance.

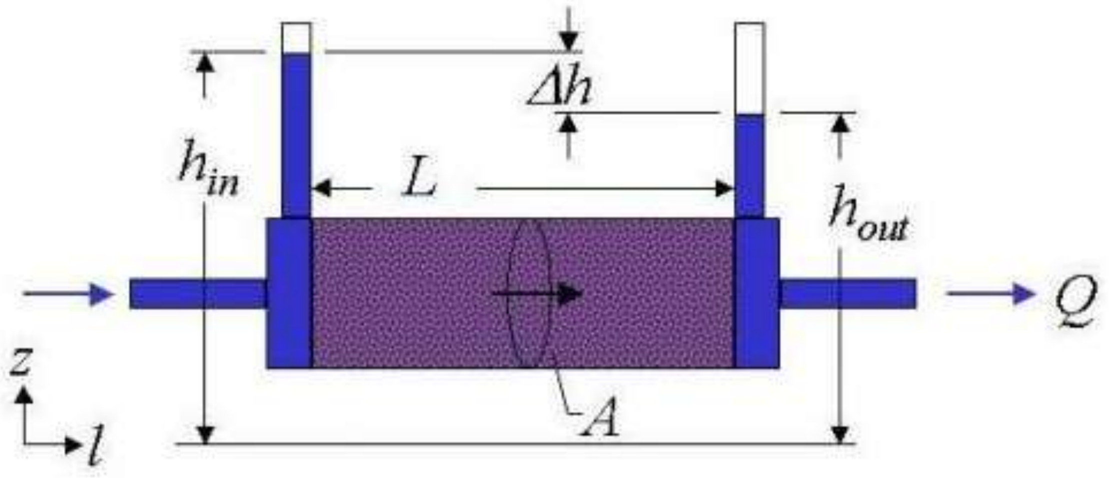
Using the specific sign convention, Darcy's law is expressed as:

$$Q = -KA\, dh/dl$$

Wherein:

Q is the rate of water flow
K is the hydraulic conductivity
A is the column cross section area
dh/dl indicates hydraulic gradient.

Darcy's Law diagram is as shown below:



Darcy's refers to many unit systems. A medium that has a permeability of 1 Darcy allows a flow of 1 cm^3/s of a liquid with viscosity 1 cP under 1 atm/cm pressure gradient acting across an area of 1 cm^2.

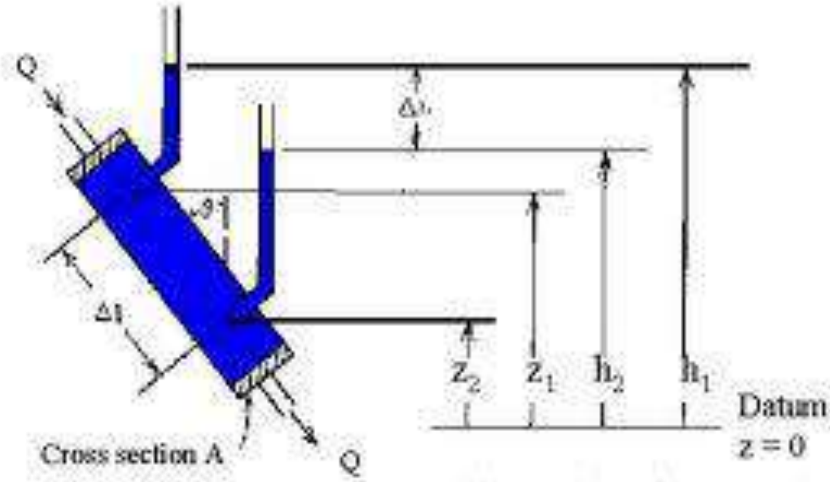
Darcy's law is critical when it comes to determining the possibility of flow from a hydraulically fractured to a freshwater zone because it creates a condition where the fluid flow from one zone to the other determines whether hydraulic fluids can reach fresh water zone or not.

LIMITATIONS OF DARCY'S LAW

Darcy's law can be applied to many situations but do not correspond to these assumptions.

- Unsaturated and Saturated flow.
- Flow in fractured rocks and granular media.
- Transient flow and steady-state flow.
- Flow in aquitards and aquifers.
- Flow in Homogeneous and heterogeneous systems.

EXPERIMENTAL SETUP



Experimental apparatus for the illustration of Darcy's law.
After Freeze and Cherry, 1979

The experimental setup Shows a system of lines, parallel streamlines below a water table in a vertical cross section of an aquifer parallel to the direction of flows. Since the streamlines are straight and parallel, The flow of water does not change with distance. This is called uniform flow. In a non uniform flow, where the flow changes with distance and streamlines may curve, diverge or converge.

If piezometer are placed at two points on a stream line (point 1&2)then the velocity of that stream line flow can be calculated by,

V=K (h1+z1)-(h2+z2)/L

Where V-darcy 's velocity of water

h1-pressure head at point 1

h2-pressure head at point 2

z1-elevation head at point 1

z2-elevation head at point 2

L-Distance of flow between points 1 and 2 as measured along stream line.

K- hydraulic conductivity of soil or aquifer material.

EXPERIMENTAL VERIFICATION

The experimental verification of Darcy's law can be performed with water flowing at a rate ‘Q’ through a cylinder of cross sectional area ‘A' packed with sand and having piezometer a distance ‘L’ a part. Total energy heads ,or fluid potentials above a datum plane may be expressed by,

$$P1/\rho + V1^2/2g + Z1 = P2/\rho + V2^2/2g + Z2 + hL \quad \ldots\ldots..(1)$$

Where p-pressure

ρ -specific weight of water

V-velocity of flow

g-acceleration due to gravity

Z-elevation

hL-head loss

Because velocities in porous media are usually low, velocity heads may be neglected without appreciable error. Hence by rewriting, the head loss becomes,

$$hL = (P1/\rho + Z1) - (P2/\rho + Z2) \quad \ldots\ldots..(2)$$

Hence the resulting head loss is defined as the potential loss within the sand cylinder ,this energy being lost by frictional resistance dissipated as heat energy. It is independent on the inclination of the cylinder.

Now Darcy's measurement showed that the proportionalities, Q~hL and Q~1/L exist. Introducing a proportionality constant's leads to the equation,

$$Q = -KA\ hL/L \quad \ldots\ldots..(3)$$

Expressed in general terms

$$Q = -KA\ dh/dl \quad \ldots\ldots..(4)$$

or

$$V = Q/A = -K\ dh/dl \quad \ldots\ldots.(5)$$

where,

V-Darcy's velocity or specific discharge

K-hydraulic conductivity

dh/dl-hydraulic gradient

The – sign of the equation indicates that the flow of water is in the direction of decreasing head.

DARCY'S VELOCITY

The velocity,

V=Q/A=-K dh/dl

This is referred to as Darcy's velocity because it assumes that flow occurs through the entire cross section of the material without regard to solids and pores.

VALIDITY OF DARCY'S LAW

Darcy's law applies to laminar flow in pores media, such as water flowing in a capillary tube. For flow in pipes and other large sections, the Reynolds number which expresses the dimensionless ratio of inertial to viscous forces, serves as a criterion to distinguish between laminar and turbulent flow.

Reynolds number is expressed as

$$Re = \frac{\rho v d_{30}}{\mu}$$

Where,

ρ is the density of the fluid

v is the specific discharge

*d*30 is a representative grain diameter for the porous medium

μ is the dynamic viscosity of the fluid.

If Re<1 then Darcy's law is valid and it does not depart upto Re=10 then this represents an upper limit to the validity of Darcy's law. Fortunately most natural underground flow occurs with Re<1 so Darcy's law is applicable. Deviation from Darcy's law can occurs where steep hydraulic gradients exist, such as near pumped wells, also turbulent flow can be found in rocks such as limestone that contain large underground openings.