Fluid Mechanics: Fluid Properties

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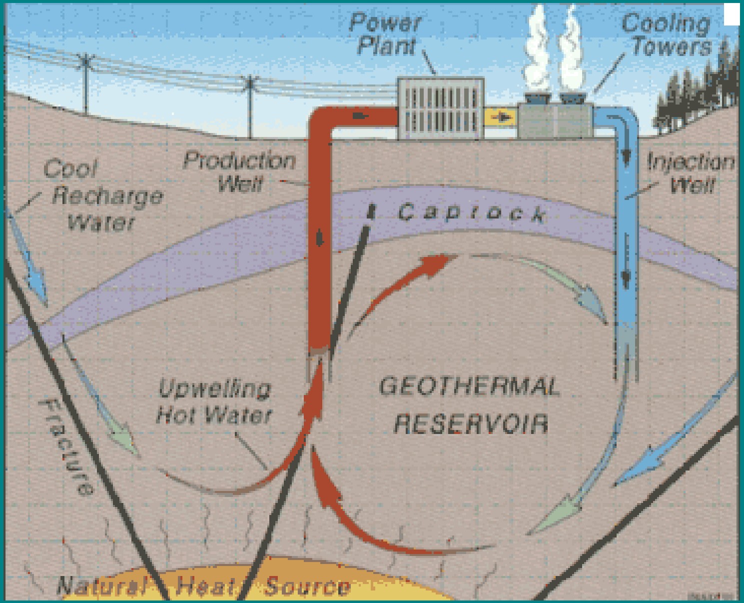
Training for Engineers on
Geothermal Power Plant
Yogyakarta, 9-13 October 2017

Classification of geothermal reservoir

- It is usual to categorize geothermal reservoir according to how much steam they contain, if no steam is present, how far they are away from boiling.
- There is a whole range of geothermal reservoir and the exact nature depends on temperature, depth, gas content and permeability structure.
- In one hydrothermal system there may be more than one permeable zone or reservoir at different depths.



1. Warm water reservoir

- It includes systems with temperatures in the range 90 – 180^0C.
- Boiling will not occur in the reservoir even during exploitation.
- Usually they are useful only for non-electrical purposes.

2. Hot water reservoir

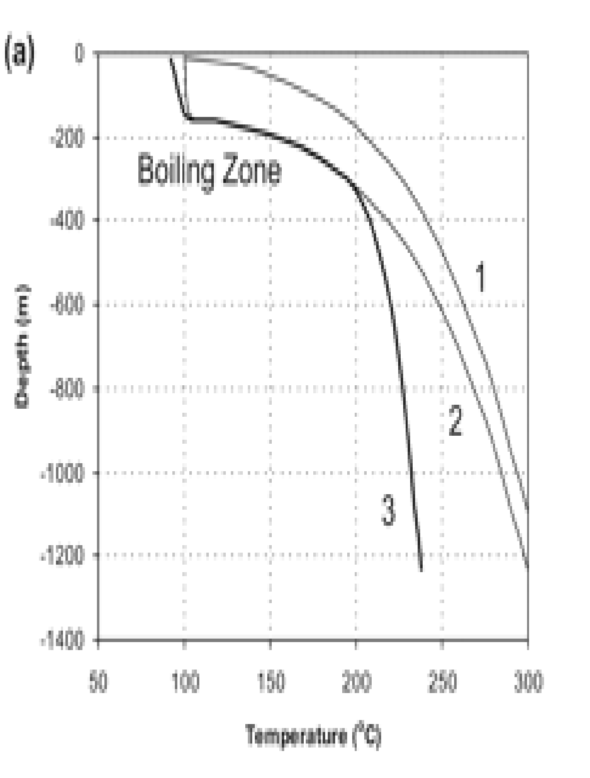
- The system is all hot water in its pre-production state but may boil after extensive production.
- Temperature is usually in the range 200 – 250^{0}C (the presence of gas may cause some reservoirs in this temperature range to boil).

3. Two-phase liquid-dominated reservoir

- In this reservoir a two phase region containing a mixture of steam and liquid water overlying a deeper hot liquid layer is present in the natural state.
- Temperatures vary (220 – 300^{0}C) with the presence of gas causing boiling at lower temperatures.

4. Two-phase vapor-dominated reservoir

- It also contains an upper two-phase layer.
- In this case, the liquid phase is sparse, widely dispersed and immobile and it produces only steam.
- Temperatures vary (230-320^{0}C) depending on depth and gas content.
- When drilling first occurs in a geothermal reservoir, it may be classified into one of the above categories.



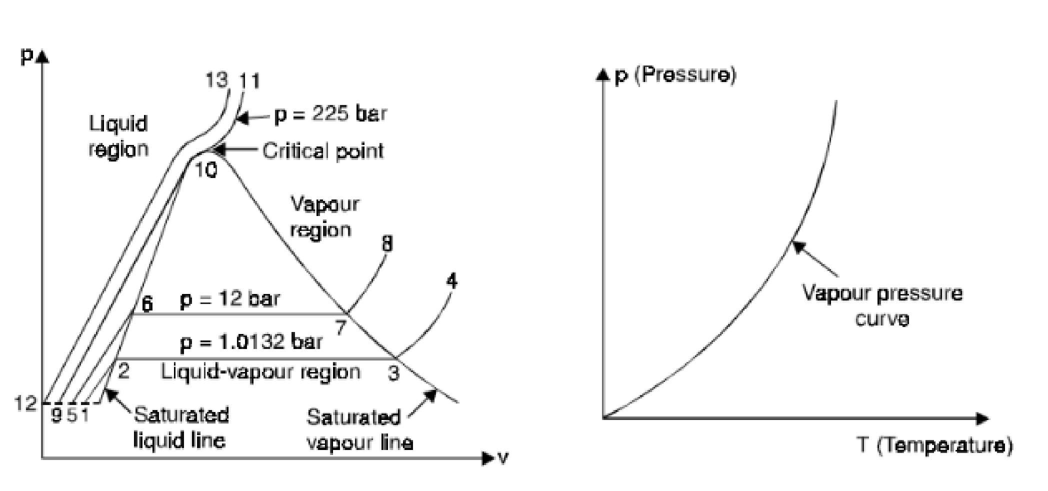
Properties of water

1. Variation of boiling temperature with pressure (saturation temperature)

- As pressure increases, the temperature at which water boils increases – this temperature is known as the saturation temperature.
- Some examples (1 bar = 10^5 Pa and 1 Pa = 1 N/m^2)

Pressure (bar)	Temperature (^{0}C)
1.0	99.6
1.01325	100
20	212.4
100	311.0
200	365.7
221.2	374.15 (critical point)

- At the saturation temperature and pressure both liquid (water) and gas (steam) phases may be present.
- The amount of each present is measured by the liquid saturation (S_ℓ) and the vapour saturation (S_v).
- These are defined as the fraction, by volume, of each phase present (dimensionless).



$$S_\ell + S_v = 1$$

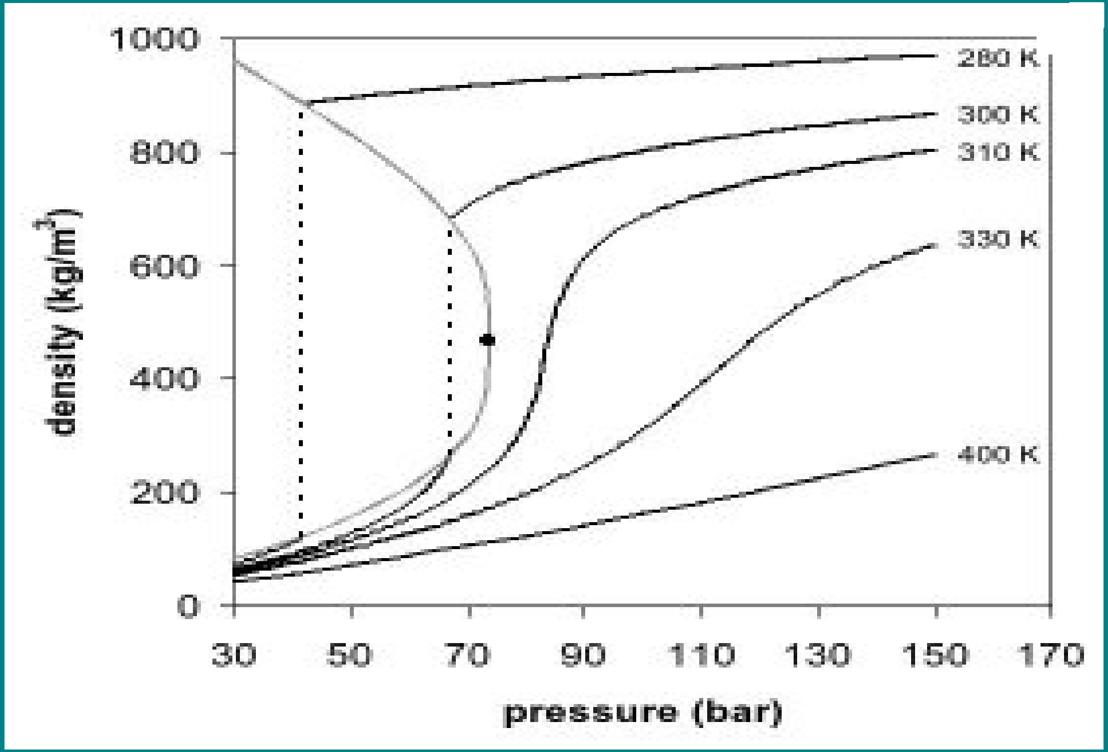
2. Water and steam density (ρ_ℓ, ρ_v)

- The unit is of the form mass/volume, usually kg/m^3.
- At saturation temperature and pressure, i.e. on the saturation line.
- The densities of each phase are different.

p (bar)	T (^{0}C)	$\rho_\ell=\rho_w$ (kg/m^3)	$\rho_v=\rho_s$ (kg/m^3)
1	99.6	958	0.59
20	212.4	850	10.0
100	311.0	688	55.5
200	365.7	491	171.0
221.2	374.15	315	315.0

- The mixture density, ρ:

$$\rho = \rho_v S_v + \rho_\ell S_\ell$$



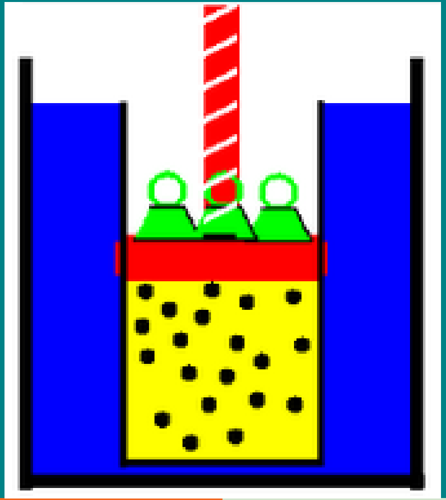
1000
800
600
400
200
0
density (kg/m3)
30
50
70
90
110
130
150
170
pressure (bar)
280 K
300 K
310 K
330 K
400 K

3. Internal energy, u and enthalpy, h

- The specific internal energy is a measure of the total amount of heat stored in a material per unit mass (u_v, u_ℓ).
- The enthalpy measures the sum of the internal energy and an amount due to work stored by the action of pressure (specific enthalpies h_v, h_ℓ).
- The two types of energy measure are related by

$$h_v = u_v + p / \rho_v$$

$$h_\ell = u_\ell + p / \rho_\ell$$



- The units: J/kg, kJ/kg, MJ/kg

4. Viscosity, μ

- The dynamic viscosity of steam μ_v and water μ_ℓ depend mainly on temperature and vary only slightly with pressure.
- Units often used are Pa.s (kg/ms), Ns/m^2.
- The kinematic viscosity ν_s, ν_w are the quotient of dynamic viscosity divided by density ($\nu=\mu/\rho$).
- Some typical examples:

T(^{0}C)	μ_wx10^{-6} (Pas)	μ_sx10^{-6} (Pas)	ν_wx10^{-6} (m^2/s)	ν_sx10^{-6} (m^2/s)
100	283	12.0	0.295	20.2
150	180	13.9	0.196	5.47
200	134	15.7	0.155	2.00
300	90	19.8	0.127	0.427

Mixtures quantities

- Mixture density, ρ:

$$\rho = \rho_s S_v + \rho_w S_\ell$$

- Specific internal energy, u:

$$\rho u = \rho_s u_s S_v + \rho_w u_w S_\ell$$

- Mixture enthalpy, h:

$$\rho h = \rho_s h_s S_v + \rho_w h_w S_\ell$$

- In case where the saturation S_v, S_ℓ of a two-phase mixture are unknown, they can be determined from given pressure and mixture enthalpy h as follows.
- The state of the mixture is first determined by finding h_v and h_ℓ, where

$$\boxed{h_v = h_s(p)}$$

$$\boxed{h_\ell = h_w(p)}$$

i.e., the saturation line.

- The mixture can be classified as:

$h \leq h_\ell$, hot water

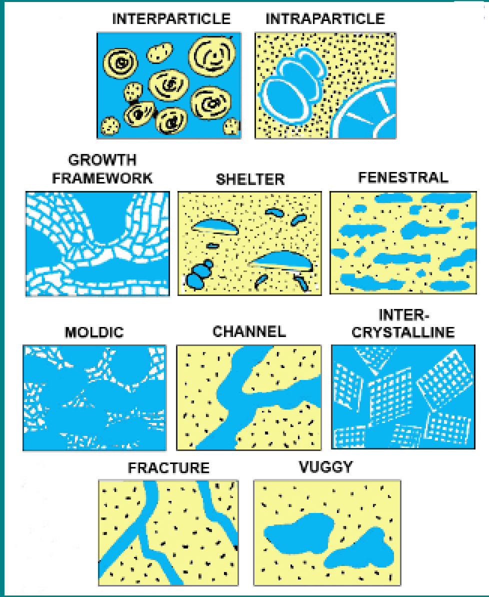
$h_\ell < h \leq h_v$, two phase

$h > h_v$, superheated steam

Other Related Properties

1. Porosity, ϕ

- It is defined as the ratio of volume of pore space (i.e., the volume that can be occupied by the fluid).
- On a microscopic scale, porosity may vary greatly throughout a system.
- In fractured rock, ϕ may vary from little more than 0 in the rock itself, to 1 in the fractures.
- On a large scale, an average porosity is defined, and it is this value which is usually used.
- Generally, porosities are of the order 5 – 30%.
- Porosity is in the form of a ratio, and is thus a dimensionless parameter.



$$\phi = \frac{\text{volume of pore space}}{\text{total volume of material}}$$

2. Fluid velocities, v, u

- There are two kinds of velocity; the flux velocity (**v**) and the interstitial velocity (**u**).
- The flux velocity or Darcy velocity (v) is the average volume flux or flow rate per unit cross-sectional area of the porous medium. This may be visualized as the rate at which fluid flows out of a surface of the material when cut by a plane.
- The interstitial velocity (u) is the average velocity at which the fluid actually flows through the porous medium. This is the particle velocity.
- v has the unit of distance/time. Typically the flux velocity is the order 10^{-6} m/s.

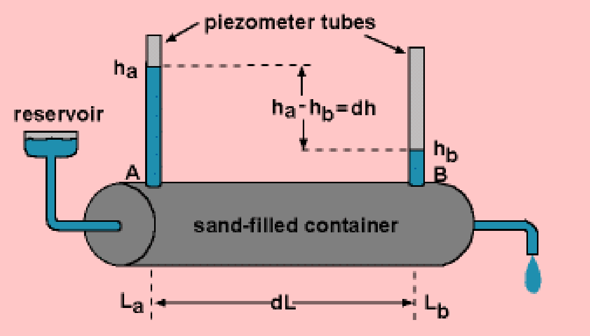
$$v = \phi u$$

3. Permeability, k

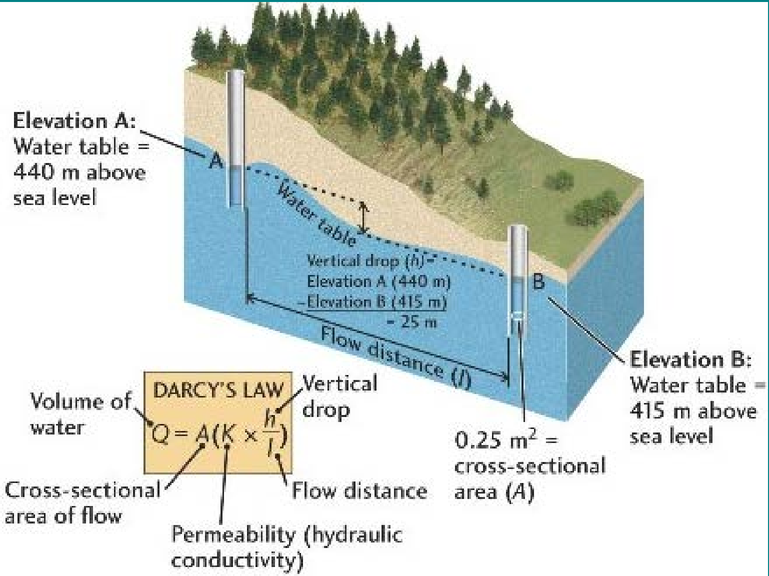
- It tells us how easy it is for the fluid to flow through a porous medium.
- It is defined by an empirical relationship known as Darcy's law.

$$\mathrm{v} = \frac{k}{\mu}\left(-\frac{dp}{dx}\right)$$

that is, the flux velocity is proportional to the pressure gradient.

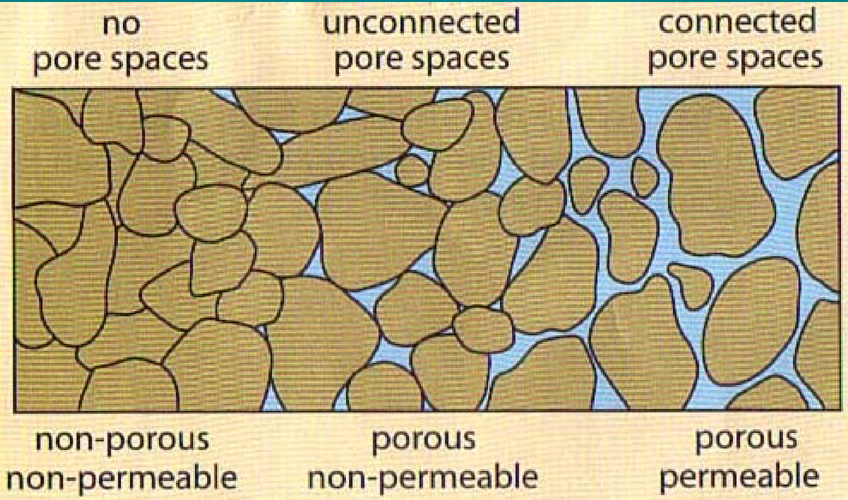


Horizontal pipe demonstrating Darcy's experiment



- For the same pressure gradient, a medium with a high permeability will allow a higher flux velocity than one with a lower permeability.
- k/μ is sometimes called the mobility.

- It is important not to confuse permeability with porosity.
- A glass block with a bubble inside has porosity but no permeability.
- A glass block with a hole drilled through it has low porosity, but quite high permeability.
- Porosity is a measure of pore space, while permeability is a measure of how well-connected that pore space is.



Thank You