Introduction to Geothermal Power Plant Components (1)

Prepared by: Geocap Team & PPSDM EBTKE

Presented by: Khasani

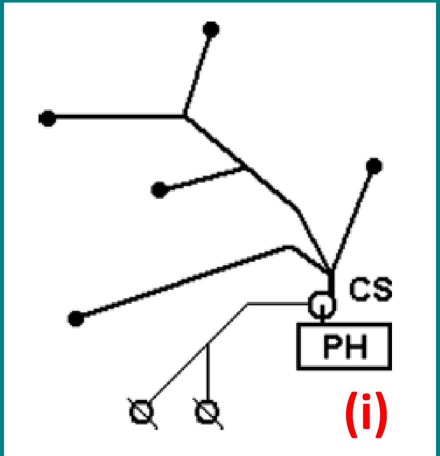
Training for Engineers on
Geothermal Power Plant
Yogyakarta, 9-13 October 2017

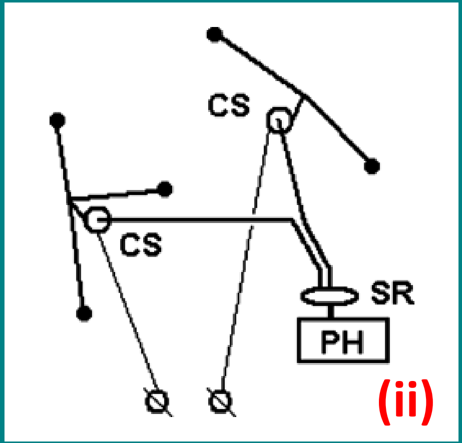
Basic concept of fluid separation and gathering

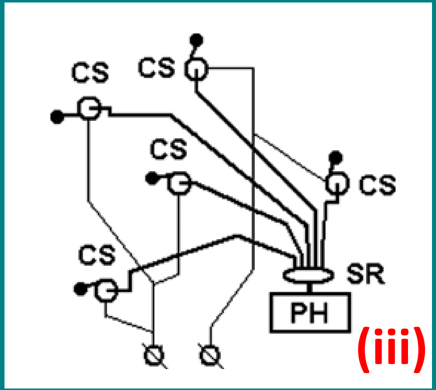
- When geothermal wells produce a mixture of steam and liquid, they must be separated using e.g. cylindrical cyclonic pressure vessel (separator).
- A piping system is needed to gather the geofluids from the production wells and transport them to the power house and to the points of disposal.

- Where the separator should be located is the challenging task for engineers.
- In general, the separator can be placed either close to the wellhead or power plant.

Piping layouts







●	production wells
⦰	injection wells
CS	cyclone separator
SR	steam receiver
PH	powerhouse

Pressure losses

- One of the main concern in the design of the gathering system is the pressure loss in the steam lines from the wellhead to the powerhouse.
- The steam pressure drop is a function of the diameter, length, steam density, mass flow rate and configuration of the steam piping.
- The most critical variable is the pipe diameter, as indicated by the following equation.

$$\Delta P_f = 0.8 \frac{L\dot{m}^{1.85}}{\rho D^{4.97}}$$

- L = length of the pipe (ft)
- m = mass flow rate (lbm/h)
- ρ = density (lbm/ft^3)
- D = inside diameter (ft)

- The pressure drop in the liquid lines is less of a concern since the liquid is going to disposed by injection.
- The frictional pressure drop depends on the same variables as in steam pipes plus friction factor which is a function of pipe diameter, internal roughness and the viscosity of the liquid.

$$\Delta P_f = 1.75 \times 10^{-4} \frac{f L \dot{m}^2}{\rho D^5}$$

$$f = \frac{0.25}{\left\{ \log_{10}\left[\frac{\varepsilon / D}{3.7} + \frac{5.74}{\mathrm{Re}^{0.9}} \right] \right\}^2}$$

$$\mathrm{Re} = \frac{4}{\pi} \frac{\dot{m}}{\mu D}$$

- ΔP_f = pressure loss (lbf/in^2)
- ε = pipe internal roughness (ft)
- μ = absolute viscosity (lbm/ft.s)
- D = inside diameter (ft)

- If there is a change in the elevation of the pipe, the gravity head must be included.

$$\Delta P_g = \rho g \Delta H$$

  - g = local gravitational acceleration (ft/s^2)
  - ΔH = change in elevation (ft)

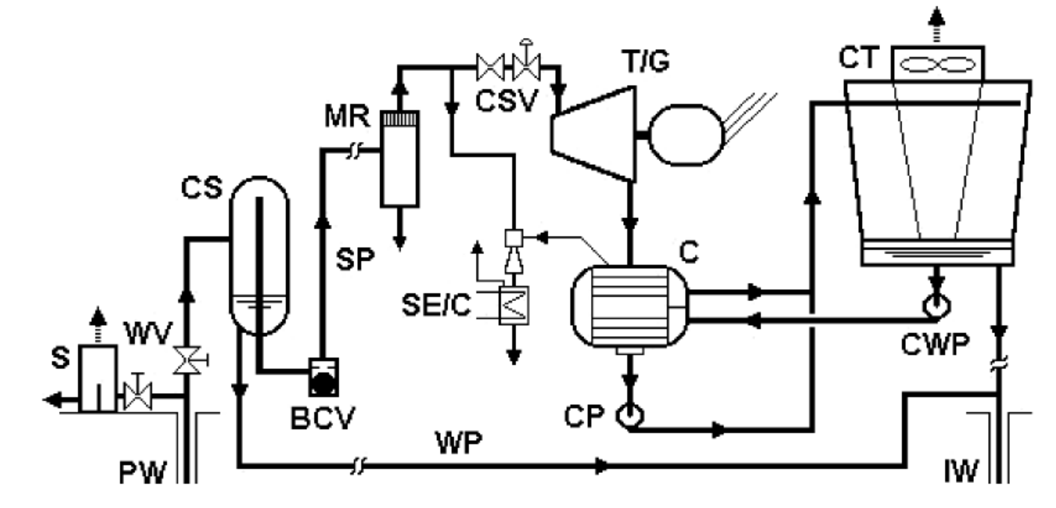
- The pressure loss in a two-phase, steam-liquid pipeline is complex, and the empirical correlations are used to estimate the pressure drop.
- Sometimes, fields test are conducted to determine the losses experimentally.

- The pressure drop in the two-phase pipelines can be larger than that in single-phase pipelines.
- The presence of unsteady flow patterns such as slug flow can cause excessive vibrations and should be avoided by proper selection of the pipe diameters.
- The liquid leaving from the separator is in a saturated state, so any loss in pressure can cause it to flash into vapor and results in vibration, for example if the liquid is conveyed upward immediately after the separator.

- If the liquid is conveyed horizontally over significant distance, the frictional pressure drop may lead to flashing in the pipeline before the fluid reaches the injection well (vapor barrier).
- It is necessary to bleed vapor or to install booster pump.
- It is preferable to have the injection piping run downhill.

Energy conversion system

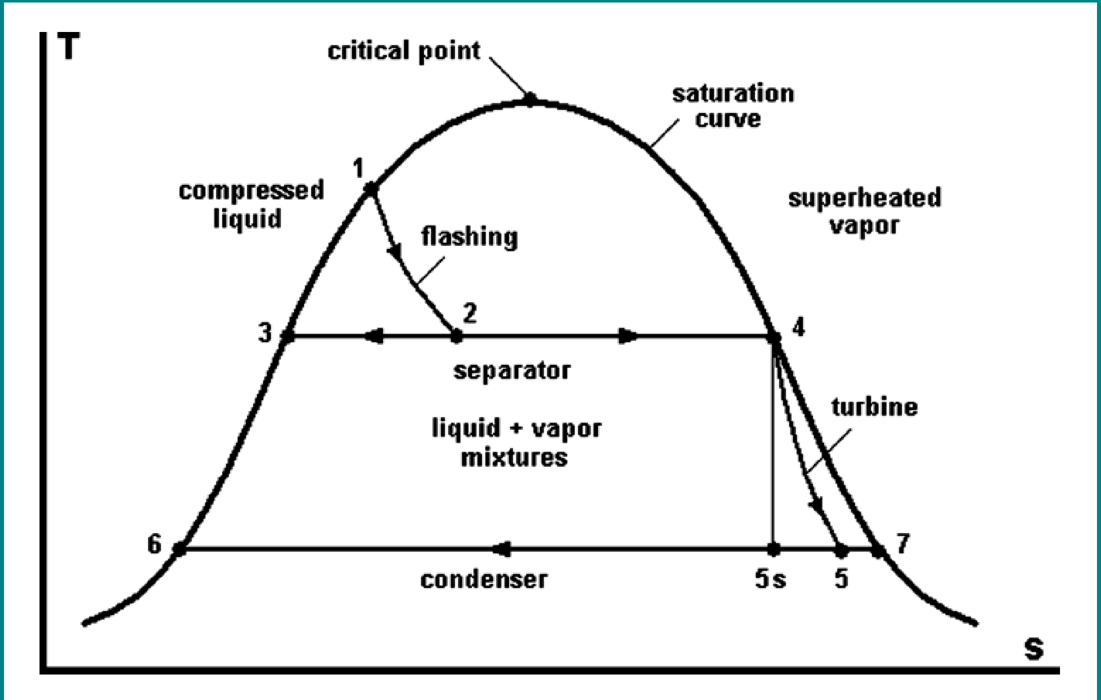
- The flash process may occur in a number of places:
  - In the reservoir as the fluid flows through the permeable formation with an accompanying pressure drop
  - In the production well anywhere from the entry point to the wellhead as the result of pressure loss due to friction & gravity head
  - In the inlet to the cyclone separator as a result of throttling process by control valve or orifice.



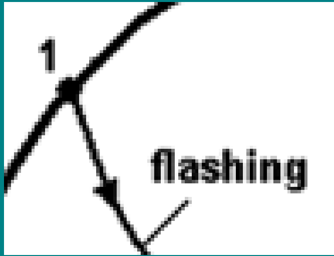
- It is assumed that the geofluid starts off as a compressed liquid somewhere in the reservoir.
- It experiences flashing process somewhere, that the two-phases are separated.
- The steam is used to drive a turbine which in turn drives the electric generator.

Thermodynamic of the conversion process

Temperature-entropy process diagram



Flashing process



- **State 1**
  - Geofluid under pressure close to the saturation curve.
  - Flashing process is modeled as one at constant enthalpy ,i.e., isenthalpic (steadily, spontaneously, adiabatically with no work involvement).
  - We neglect any change in the kinetic or potential energy.

$$h_1 = h_2$$

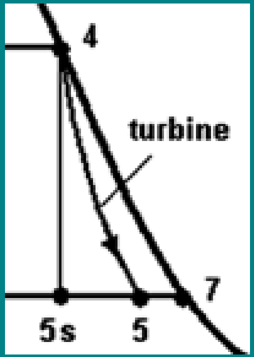
Separation process

- State 2
  - The separation is modeled as one at constant pressure (isobar).
  - The quality (dryness fraction), x, of the mixture is found from

$$x_2 = \frac{h_2 - h_3}{h_4 - h_3}$$

  - This gives the steam mass fraction of the mixture and is the amount of steam that goes to the turbine per unit total mass flow.

Turbine expansion process (4-5)



- State 4
  - o The work produced by the turbine per unit mass of steam

$$w_t = h_4 - h_5$$

assuming no heat loss from the turbine and neglecting kinetic and potential energy.

  - o The isentropic turbine efficiency η_t, as the ratio of the actual work to the isentropic work

$$\eta_t = \frac{h_4 - h_5}{h_4 - h_{5s}}$$

- The power developed by the turbine:

$$\dot{W}_t = \dot{m}_s w_t = x_2 \dot{m}_{total} w_t$$

- The gross electrical power:

$$\dot{W}_e = \eta_g \dot{W}_t$$

- All auxiliary power requirements (parasitic loads: pumping power, cooling tower fan power, etc.) for the plant must be subtracted from this to obtain the net, salable power.

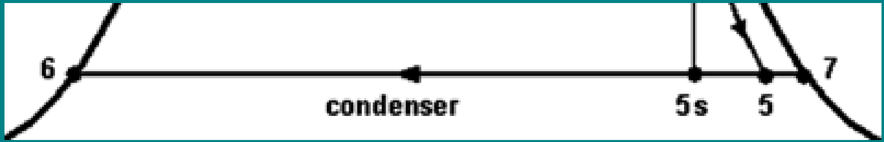
- Since geothermal turbines generally operate in the wet region, we must account for the degradation in performance.
- The isentropic efficiency for a wet turbines:

$$\eta_{tw} = \eta_{td}\left[\frac{x_4 + x_5}{2}\right]$$

$$\eta_{td} = 0.85 \ \text{(dry turbine efficiency)}$$

- State 5
  - o The state depends on the turbine efficiency.
  - o For the ideal turbine outlet state:

$$h_{5s} = h_6 + [h_7 - h_6] \times \left[\frac{s_4 - s_6}{s_7 - s_6} \right]$$



  - o For the actual turbine outlet state:

$$h_5 = \frac{h_4 - A\left[1 - \dfrac{h_6}{h_7 - h_6}\right]}{1 + \dfrac{A}{h_7 - h_6}}$$

$$A \equiv 0.425(h_4 - h_{5s})$$

- The above equations are based on the assumption that the quality at the turbine inlet, $x_4 = 1$, the steam is saturated vapor.
- If the inlet is wet:

$$h_5 = \frac{h_4 - A\left[x_4 - \dfrac{h_6}{h_7 - h_6}\right]}{1 + \dfrac{A}{h_7 - h_6}} \qquad (\text{for } x_4 < 1)$$

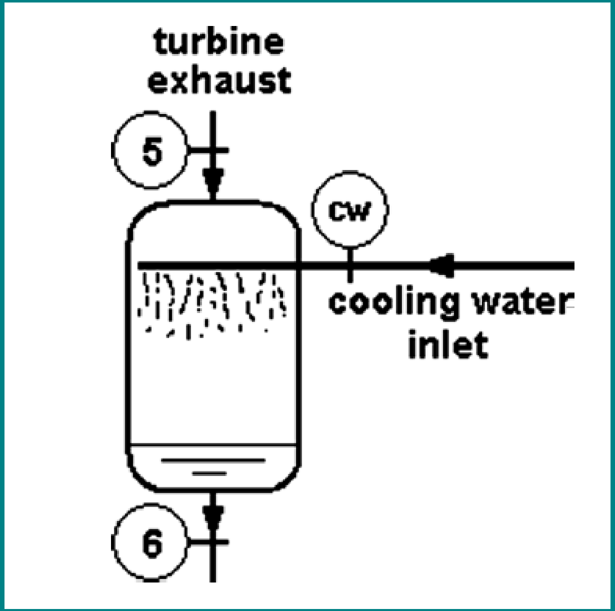
Condensing process (5-6)

- State 6
  - The required flow rate of cooling water, m_{cw}, to the steam flow rate, x_2m_{total}:

$$\dot{m}_{cw} = x_2\dot{m}_{total}\left[\bar{c}\Delta T\right]$$

where c is the assumed constant specific heat of cooling water, ΔT is the rise in cooling water temperature as it passes through the condenser.

- For a direct contact condenser, the appropriate equation:

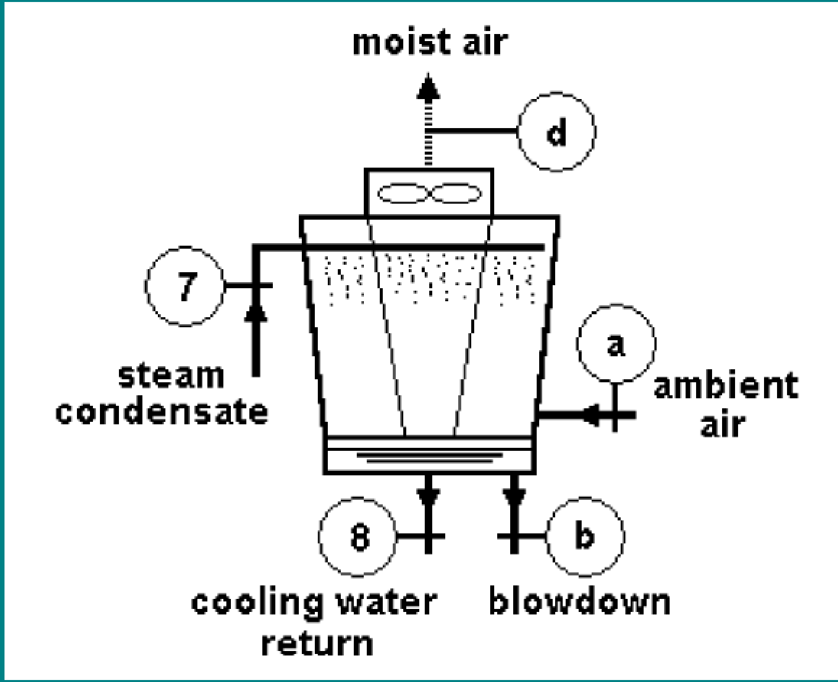


$$\dot{m}_{cw} = x_2 \dot{m}_{total} \left[\frac{h_5 - h_6}{\bar{c}\left(T_6 - T_{cw}\right)} \right]$$

Cooling tower process (7-8)

- State 7
  - The steam condensate that has been pumped from the condenser hotwell is sprayed into the tower where it falls through an air stream drawn into the tower by a motor driven fan at the top of the tower.
  - The internal process involves the exchange of both heat and mass between the air and the water.

- The overall operation of the tower, excluding the fan and assuming steady flow and overall adiabatic conditions:



$$\dot{m}_7 h_7 - \dot{m}_8 h_8 = \dot{m}_d h_d - \dot{m}_a h_a + \dot{m}_b h_b$$

- Conservation of water equation:

$$\dot{m}_7 - \dot{m}_{wa} = \dot{m}_8 + \dot{m}_b + \dot{m}_{wd}$$

- Conservation of dry air equation:

$$\dot{m}_{ad} = \dot{m}_{aa}$$

$$\dot{m}_{wa} = \text{water content of incoming air stream}$$

$$\dot{m}_{wd} = \text{water content of leaving air stream}$$

- The humidity of the air stream, ω:

$$\dot{m}_{wa} = \omega_a \dot{m}_a \qquad \dot{m}_{wd} = \omega_d \dot{m}_d$$

Thank You