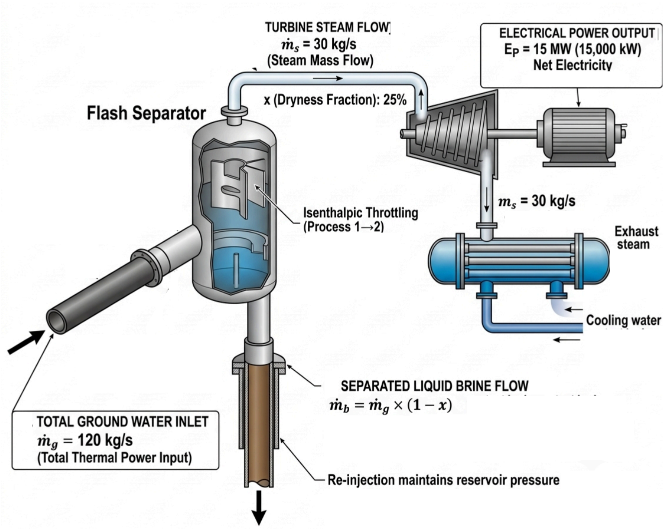
In geothermal power plant design, evaluating overall thermal performance requires identifying how geothermal fluid (brine or ground water) from a production well converts into net electrical energy. In a wet-steam (flash steam) geothermal system, high-pressure ground water undergoes an isenthalpic throttling process as it rises or passes through a flash vessel. This pressure drop causes a portion of the fluid to flash into dry saturated steam, which is then separated and directed into a steam turbine to drive the electrical generator.



The **Overall Plant Efficiency** (η_o) represents the ratio of net useful electrical power output (P_{net} or EP) to the total thermal power entering the plant boundaries from the geothermal resource (Q_{in}).

The general equation is stated as: $\eta_o = \frac{Net\ Electrical\ Power\ Output}{Total\ Thermal\ Power\ Input} = \frac{EP}{m_g h_1}$

Where:

- EP is the electrical power output (kW).
- m_g is the total mass flow rate of the ground water or geothermal fluid drawn from the well (kg/s)
- h_1 is the initial enthalpy of the ground water or geothermal fluid (kJ/kg).

<u>Step 1:</u> Analyze Given Parameters and System Units

We begin by establishing the properties provided in the problem statement. To ensure dimensional consistency across our energy equations, we convert all power expressions to kilowatts (kW):

- Net Electrical Power Output (EP) = 15MW = 15,000 kW
- Mass flow rate of steam entering the turbine (m_s) = 30 kg/s
- Steam quality or dryness fraction after flash throttling (x) = 25% = 0.25
- Initial specific enthalpy of ground water (h_1) = 750 kJ/kg

Step 2: Determine the Total Mass Flow Rate of Geothermal Fluid

The steam quality (x) represents the mass fraction of dry vapor separated from the flashed mixture. It acts as a direct proportionality factor between the useful steam driving the turbine (m_s) and the total raw geothermal fluid mass flow extracted from the earth (m_g):

$$x = \frac{m_s}{m_g}$$

$$0.25 = \frac{30\ kg/s}{m_g}$$

$$m_g = 120\ kg/s$$

This reveals that for every 120 kg of ground water pulled from the geothermal well, 30 kg flashes into dry steam while the remaining 90 kg is separated as liquid brine.

Step 3: Calculate the Total Thermal Power Input

The thermal energy rate entering the system boundary is the product of the total mass flow rate of geothermal fluid and its initial specific enthalpy:

$$Q_{in} = m_g h_1 = \left(120\ \frac{kg}{s}\right)\left(750\ \frac{kJ}{kg}\right) = 90,000\ kW\ (or\ 90\ MW)$$

Step 4: Compute the Overall Plant Efficiency

Using our definition for overall thermodynamic efficiency, we evaluate the ratio of converted electrical work to total available resource energy:

$$\eta_o = \frac{15,000\ kW}{90,000\ kW} x\ 100\% = 16.67\%$$

An efficiency of 16.67% might seem low compared to modern combined-cycle gas plants that exceed 60%. However, geothermal energy operates at inherently lower fluid temperatures and enthalpies than fossil-fueled systems. Because its fuel source (earth's heat) is free and continuous, a low thermodynamic efficiency is perfectly acceptable as long as capital and maintenance costs are balanced.

The mass balance reveals that 75% of the extracted fluid (90kg/s) remains liquid after flashing. This hot brine contains a significant amount of thermal energy. In modern engineering practice, this fluid is safely re-injected back into the reservoir to maintain reservoir pressure, or passed through a secondary heat exchanger in a **binary-cycle configuration** to extract additional power.

The efficiency is highly sensitive to the steam quality after flashing. If the reservoir pressure drops over years of operation, the flash quality may decrease, lowering the turbine steam mass flow rate (m_s) and reducing the plant's net electrical output unless remediation steps are taken.