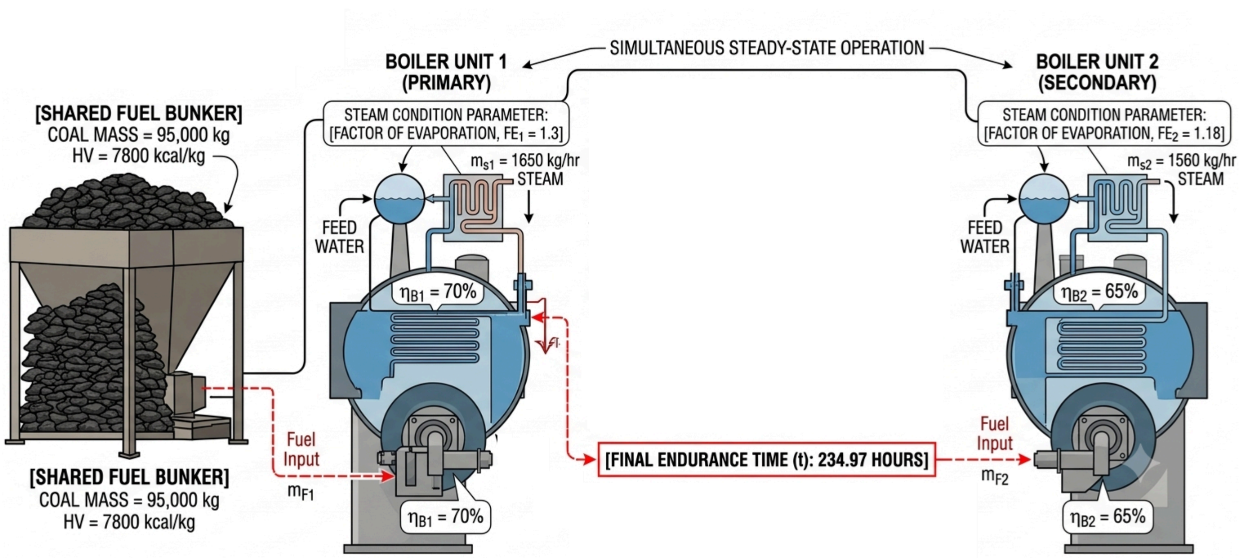
In steam power engineering, the thermal performance of a steam generator (boiler) is quantified by its thermal efficiency (η_B). This efficiency represents the ratio of the energy absorbed by the working fluid (water changing state into steam) to the total chemical energy released via fuel combustion within the furnace.



The fundamental relationship is expressed as:

$$\eta_B = \frac{m_s(h_s - h_f)}{m_F HHV} x\ 100\%$$

Where:

- m_s = Steam generation mass flow rate (kg/hr)
- h_s = Enthalpy of the leaving steam (kJ/kg)
- h_f = Enthalpy of the entering feedwater (kJ/kg)
- m_F = Fuel consumption mass flow rate (kg/hr)
- HHV = Higher Heating Value of the fuel (kJ/kg or kcal/kg)

The Concept of Factor of Evaporation (FE)

Historically and in standard power plant testing codes, comparing boilers operating at widely different operating pressures and temperatures requires a standardized base. This baseline is established by the **Factor of Evaporation (FE)**, which is defined as the ratio of the heat required to generate one kilogram of steam under actual conditions to the latent heat of vaporization of water at standard atmospheric boiling point (100ºC), which is exactly 2257 kJ/kg (or 539 kcal/kg).

The relationship is formulated as:

$$FE = \frac{h_s - h_f}{2257}\ x\ 100\%$$

Consequently, the net heat absorbed by the fluid per kilogram, $h_s - h_f$), can be directly evaluated if the factor of evaporation is known: ($h_s - h_f$) = (FE)(2257 kJ/kg).

Step 1: Establish Unit Uniformity for Heating Value

The heating value of the coal is given in metric thermal units (kcal/kg) whereas standard steam table calculations are evaluated in SI units (kJ/kg). Let us convert the higher heating value (HHV) of the coal into kJ/kg using exact standard conversion factors (1 kcal = 4.1868 kJ):

$$HHV = \left(7800\ \frac{kcal}{kg}\right)\left(4.1868\ \frac{kJ}{kcal}\right) = 32,657.04\frac{kJ}{kg}$$

Step 2: Analyze Boiler 1 Fuel Consumption (m_{F1})

For Boiler 1: m_{S1} = 1650 kg/hr, FE_1 = 1.3, and η_{B1} = 0.70.

First, find the net enthalpy change of the fluid:

($h_{s1} - h_{f1}$) = (1.3)(2257 kJ/kg) = 2934.1 kJ/kg.

Next, apply the efficiency equation to solve for the hourly fuel demand (m_{F1}):

$$\eta_{B1} = \frac{m_{s1}\left(h_{s1} - h_{f1}\right)}{m_{F1}HHV}\ x\ 100\%$$

$$0.70 = \frac{\left(1650\ \frac{kg}{hr}\right)\left(2934.1\frac{kJ}{kg}\right)}{m_{F1}\left(32,916\frac{kJ}{kg}\right)}$$

$$m_{F1} = 210.1134\ \frac{kg}{hr}$$

Step 3: Analyze Boiler 2 Fuel Consumption (m_{F2})

For Boiler 2: m_{S2} = 1560 kg/hr, FE_2 = 1.18, and η_{B2} = 0.65.

First, find the net enthalpy change of the fluid:

($h_{s2} - h_{f2}$) = (1.18)(2257 kJ/kg) = 2663.26 kJ/kg.

Next, solve for the hourly fuel demand (m_{F2}):

$$\eta_{B2} = \frac{m_{s2}\left(h_{s2} - h_{f2}\right)}{m_{F2}HHV} \; x\; 100\%$$

$$0.65 = \frac{\left(1560\ \frac{kg}{hr}\right)\left(2663.26\frac{kJ}{kg}\right)}{m_{F2}\left(32{,}916\frac{kJ}{kg}\right)}$$

$$m_{F2} = 194.1859\ \frac{kg}{hr}$$

<u>Step 4:</u> Calculate Total Fuel Consumption Rate and Operating Duration

Since both boilers draw steadily from the same shared coal bunker storage, their individual consumption rates add up to a combined total fuel consumption rate ($m_{F,\ total}$):

$$m_{F,\ total} = m_{F1} + m_{F2} = 210.1134\ \frac{kg}{hr} + 194.1859\ \frac{kg}{hr} = 404.2993\,\frac{kg}{hr}$$

Given a total storage capacity inside the bunker of 95,000 kg, the operational endurance time (t) is calculated as:

$$t = \frac{Total\ Fuel\ Available}{m_{F,\ total}} = \frac{95{,}000\ kg}{404.2993\frac{kg}{hr}} = 234.9749\ hours$$

Calculating fuel depletion rates is vital for managing utility operations and fuel logistics. An endurance time of approximately 235 hours tells the plant plant engineers that the facility can run continuously for nearly **9.8 days** before requiring a new delivery of coal. This provides a clear window for scheduling fuel supply chains without risking unexpected plant shutdowns.

Notice that Boiler 2 has a lower operational efficiency (65%) compared to Boiler 1 (70%). Even though Boiler 2 produces less steam overall (1560 kg/hr compared to 1650 kg/hr), its fuel consumption rate (194.2 kg/hr) is disproportionately close to Boiler 1's consumption (210.1 kg/hr). In practical industrial settings, evaluating these metrics helps plant engineers determine which unit to prioritize for base-load power and which to flag for maintenance or efficiency upgrades.