EXAMPLE

Given: A steam power plant has a steam engine has operating temperatures of 680°C and 260°C. The heat of combustion of coal is 2.8x10^7 J/kg. The plant needs to produce 850 MW of power, and the plant is 60% of the ideal efficiency.

Required:
a. Rate at which coal must be burned.
b. Rate at which cooling water must pass through the plant if the water temperature cannot increase by more than 5°C.

Solution:

a. Carnot efficiency: \[ \eta = 1 - \frac{T_c}{T_h} = 1 - \frac{260 + 273}{680 + 273} = 0.441 \]

Actual efficiency = 0.6(0.441) = 0.264

\[ \eta = \frac{W}{Q_h} = \frac{\dot{W}}{\dot{Q}_h} \Rightarrow \dot{Q}_h = \frac{\dot{W}}{\eta} = \frac{850MW}{0.264} = 3214MW \]

where the overdot indicates a rate, or derivative with respect to time.

Set power equal to energy/time, with energy/time calculated as (energy/mass)(mass/time)

\[ \dot{Q}_h = 3214x10^6 W = \frac{2.8x10^7 J}{kg} \dot{m} \Rightarrow \dot{m} = 115 kg / sec \]

115 kg of coal must be burned every second.

b. \[ \dot{Q}_c = \dot{Q}_h - \dot{W} = 3214MW - 850MW = 2364MW \]

Write heat capacity equation in terms of rate.

\[ \dot{Q}_c = \dot{m}c_{water}\Delta T \Rightarrow 2364x10^6 J / s = \dot{m}(1cal / g \cdot ^{\circ}C)(5^{\circ}C)(4.186J / cal) \]

Solving, \[ \dot{m} = 1.130x10^8 g / s = 1.130x10^5 kg / s \]