Steam Turbine Generator

Example of Power Generation Steam Turbine

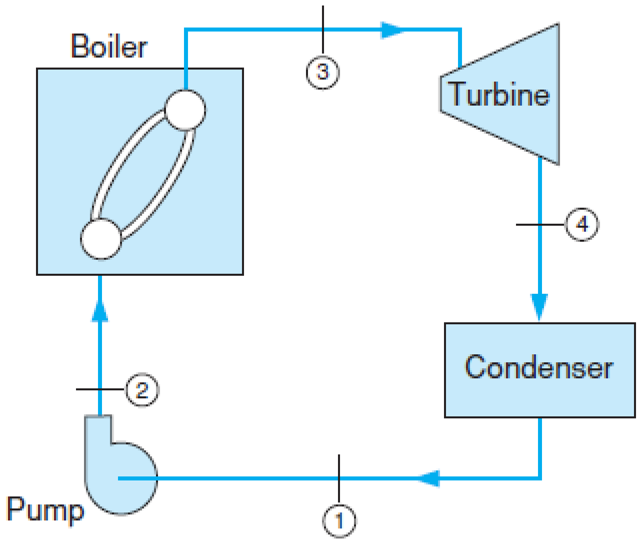
Rankine Cycle

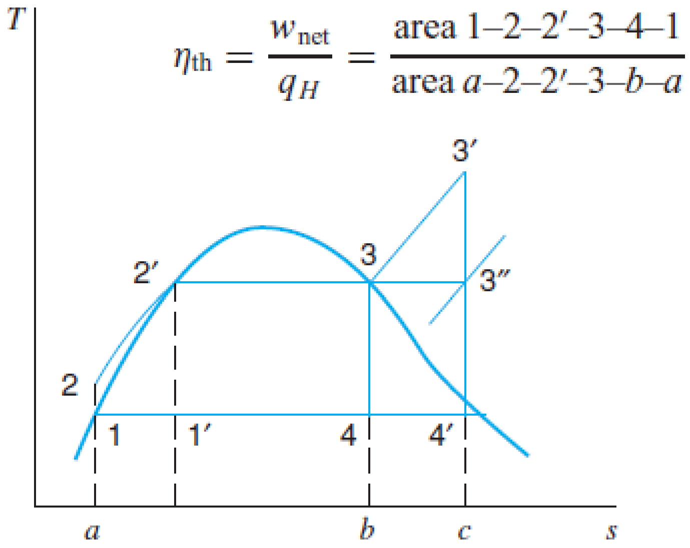
1–2: Reversible adiabatic pumping process in the pump

2–3: Constant-pressure transfer of heat in the boiler

3–4: Reversible adiabatic expansion in the turbine (or another prime mover such as a steam engine)

4–1: Constant-pressure transfer of heat in the condenser





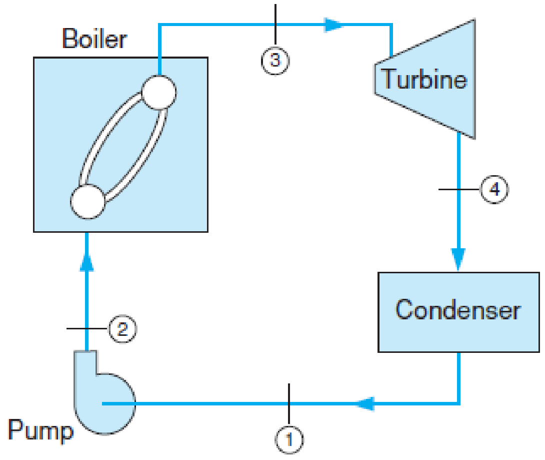
$$\eta_{th} = \frac{w_{net}}{q_H} = \frac{\text{area } 1\text{–}2\text{–}2'\text{–}3\text{–}4\text{–}1}{\text{area } a\text{–}2\text{–}2'\text{–}3\text{–}b\text{–}a}$$

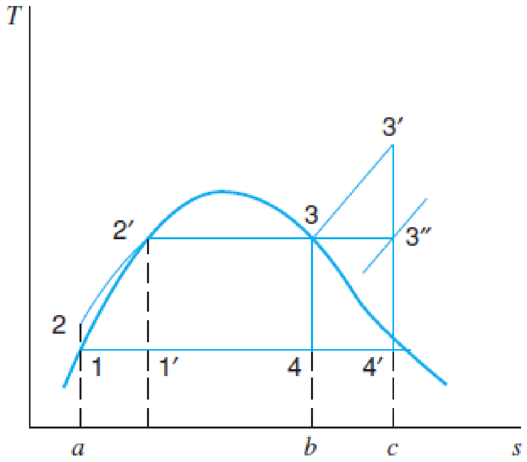
- Adiabatic Process- Process that does not leave or take any heat
- No Heat loss/gain
- Thermal Eff= Net Work/Heat Input

What is the difference between Pump and compressor?
Pump-- > for incompressible Liquid
Compressor→ for Gas, air, compressible fluid

Example Problem

Determine the efficiency of a Rankine cycle using steam as the working fluid in which the condenser pressure is 10 kPa. The boiler pressure is 2 MPa. The steam leaves the boiler as saturated vapor.





Given:
P3= 2 Mpa
P2 is known=2 MPa
P1=10kPa

Steam leaves boiler at point 3
Determine thermal Eff.

Pump work, Wp=h2-h1, h2=h1+wp

Wp=v(P2-P1)=Sp. Volume*(P2-P1)=0.001*(2000-10)=2 kJ/kg

Go to steam table and find
enthalpy of saturated water at P1 and P2,
h1= 191.75 kJ/kg
h2= h1+Wp kJ/kg=191.75+2=193.8 kJ/kg

Boiler and Turbine Work

Here we will determine boiler heat input and turbine work
And thermal efficiency

Now consider the boiler:

Control volume: Boiler.
Inlet state: P_2, h_2 known; state fixed.
Exit state: P_3 known, saturated vapor; state fixed.

Analysis

$$\text{Energy Eq.:} \quad q_H = h_3 - h_2$$

Solution

Substituting, we obtain

$$q_H = h_3 - h_2 = 2799.5 - 193.8 = 2605.7 \text{ kJ/kg}$$

Turning to the turbine next, we have:

Control volume: Turbine.
Inlet state: State 3 known (above).
Exit state: P_4 known.

Analysis

$$\text{Energy Eq.:} \quad w_t = h_3 - h_4$$

$$\text{Entropy Eq.:} \quad s_3 = s_4$$

Solution

We can determine the quality at state 4 as follows:

$$s_3 = s_4 = 6.3409 = 0.6493 + x_4 7.5009, \qquad x_4 = 0.7588$$

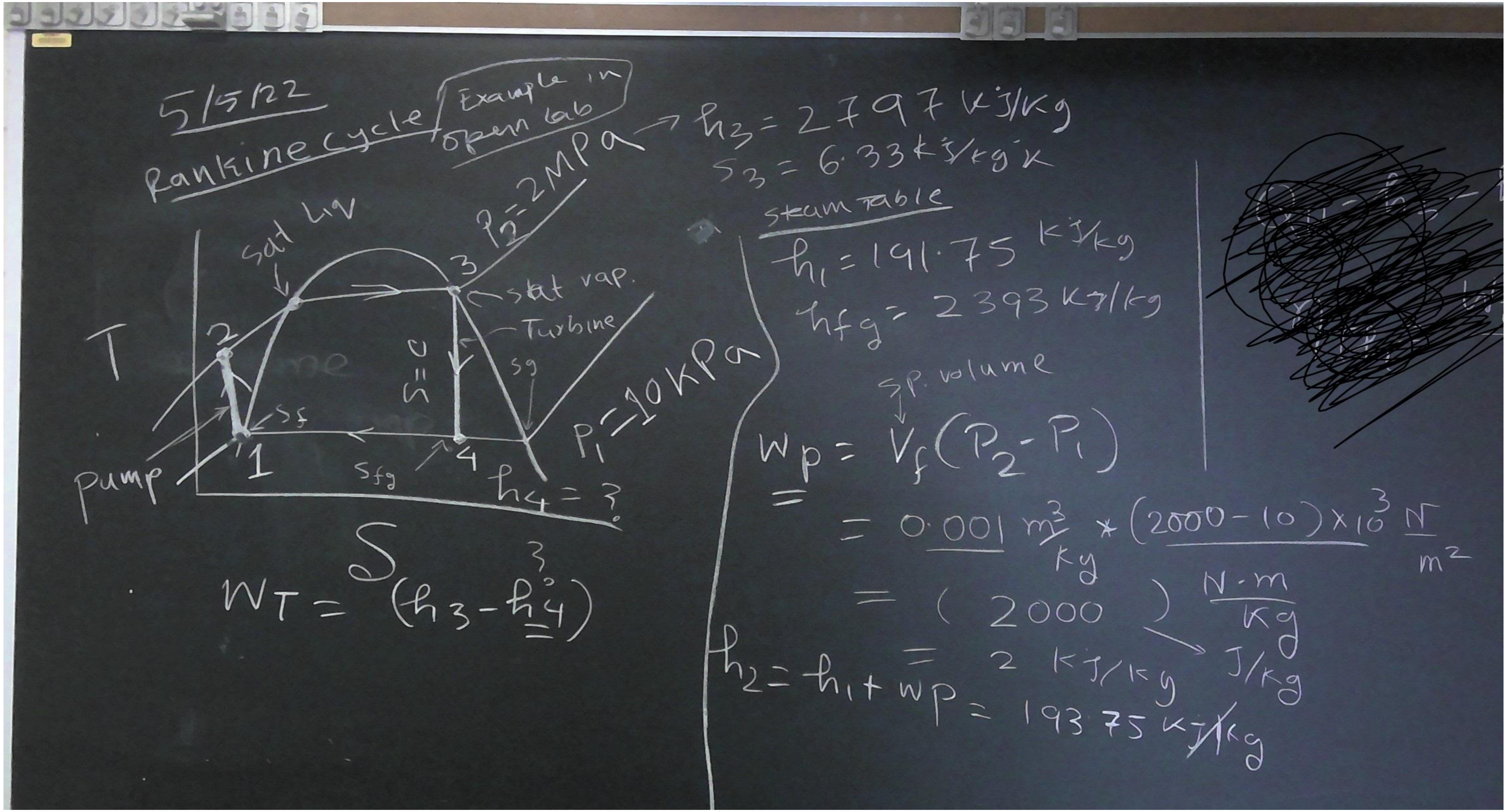
$$h_4 = 191.8 + 0.7588(2392.8) = 2007.5 \text{ kJ/kg}$$

$$w_t = 2799.5 - 2007.5 = 792.0 \text{ kJ/kg}$$

Net work= Turbine work-Pump work=792-2=790 kJ/kg
qH=Boiler heat input=2605kJ/kg

Efficiency= 790/2605=30.3%

Solution to Rankine Cycle



$$Q_H = h_3 - h_2 = (2797 - 193.75)$$
$$= 2603 \text{ kJ/kg}$$

$$\eta_{Th} = \frac{W_T - W_P}{Q_H}$$

$h_4 \rightarrow S_2 = S_4 =$

$$s = s_f + x * s_{fg}$$

Quality of steam, x

$$h = h_f + x * h_{fg}$$

$$h_4 = h_1 + x_4 * h_{fg}$$

$$S_4 = S_1 + x_4 * S_{fg}$$
$$= S_3 = 6.33$$

$$S_4 = 6.33 = S_1 + x_4 S_{fg} = 0.65 + x_4 * 7.5$$
$$\Rightarrow x_4 = 0.76 \text{ or } 76\%$$

$$h_4 = h_1 + x_4 * h_{fg}$$
$$= 191.75 + 0.76 * 2393$$
$$= 2010 \text{ kJ/kg}$$

at state 1

$s_f = 0.65$

$s_g = 8.15$

$s_{fg} = 7.5$

$$W_T = 2797 - 2010$$
$$= 787 \text{ kJ/kg}$$

$$\eta_{Th} = \frac{787 - 2}{2603}$$
$$= 0.3 \simeq 30\%$$

How to calculate Turbine Generator power?

Turbine work= Delta h= h2-h1= kj/kg
How about kw? Turbine power= m(h2-h1)=
Partial Rankine Cycle Problem→
For example, steam mass flow rate, m=10 kg/s, from steam table h2=3445 kj/kg, h1=2115 kj/kg
Then Turbine power=10 kg/s*(3445-2115)=13300 kJ/s=13300 kW=13.3 MW
For example, a power generator has a 13.3 MW turbine, how much electricity you can produce if generator efficiency is 80%?
Electricity generated= 13.3*0.8=10.6 MW.