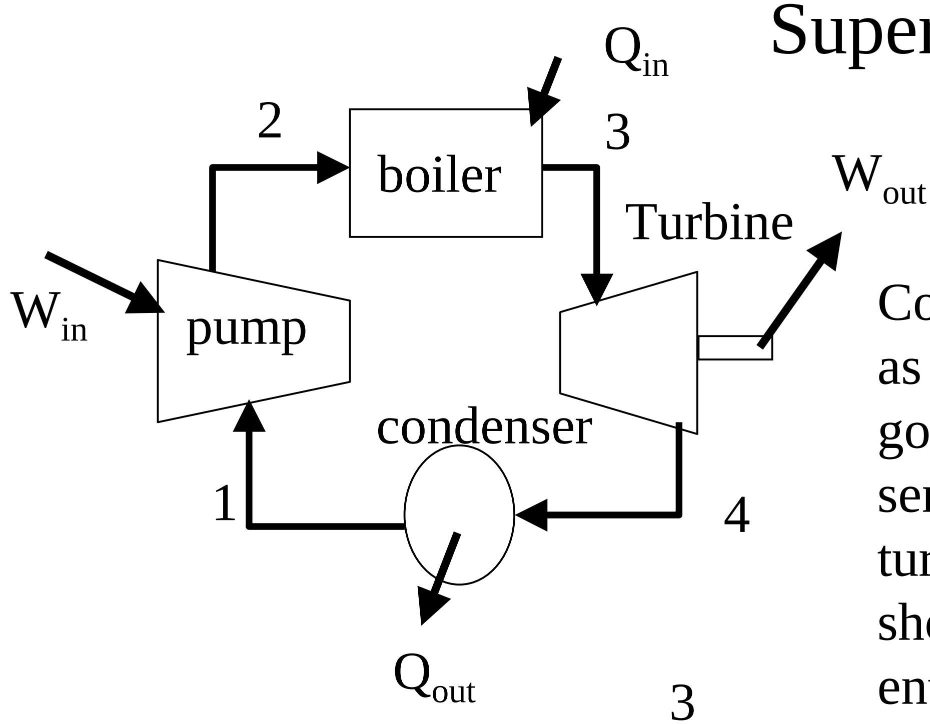
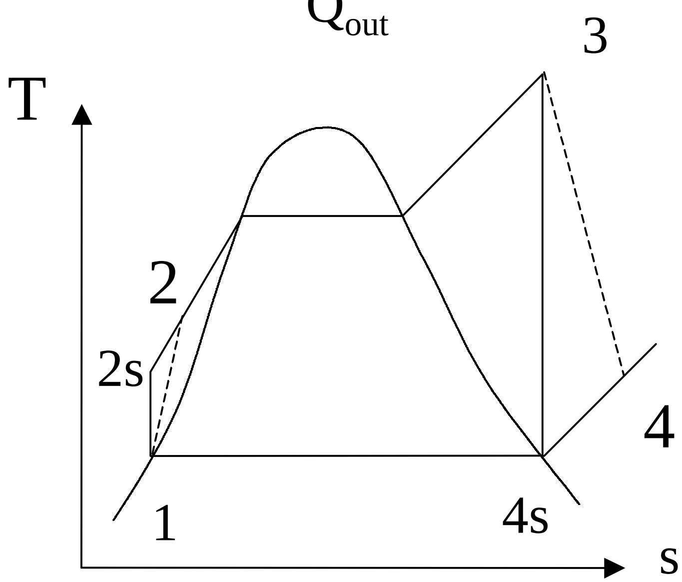
Superheat Rankine Cycle Example





Consider the superheat Rankine power cycle as we analyzed before. But this time we are going to look at the system at a more practical sense. As before, the steam exits from the turbine will be 100% saturated vapor as shown. After condensing, saturated liquid enters the pump at a pressure of 0.1 MPa. However, both the turbine and the pump are operating at an isentropic efficiency of 80%. Determine (a) the rate of heat transfer into the boiler per unit mass, (b) the net power generation per unit mass. (c) the thermal efficiency,

Discussion

- Irreversibilities and losses are always associated with the operation of a real mechanical system. The existence of these unwanted effects is accompanied by an increase of entropy as required from the second law. (ex: 3 ➔4s isentropic process, 3 ➔4, entropy increases for a real process)
- The efficiency of the turbine (η_t) will decrease as a result of these losses:

$$\eta_t = \frac{\dot{W}_t}{\left(\dot{W}_t\right)_s} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

- The isentropic expansion work $(W_t)_s = h_3 - h_{4s}$ is the ideal process and $W_t = h_3 - h_4$ is the actual work done in a real process
- Similarly, the isentropic pump efficiency can be expressed as

$$\eta_p = \frac{\dot{W}_p}{\left(\dot{W}_p\right)_s} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

- Because of inefficiency, $h_2 - h_1 > (h_2 - h_1)_s$ it required more work to pump and compress the liquid.

Solution

(4) Let us analyze state 4s first, that is when the steam exits from the turbine isentropically (ideal case) $P_4 = 0.1(MPa)$, From saturated steam table ~~C-2~~ A-5

$$s_{4s} = s_g = 7.3602(kJ/kgK), h_{4s} = h_g = 2675.5(kJ/kgK)$$

(1) Now look at the state 1 when the steam enters the pump, again use ~~C-2~~

$$s_1 = s_f = 1.3029(kJ/kgK), h_1 = h_f = 417.4(kJ/kgK)$$

$$v_1 = v_f = 0.001043(m^3/kg)$$

(2) From 1-2s, an ideal pump is used to compress the saturared liquid into compressed liquid. The process is isentropic, that is, s=constant, therefore, from the Tds equation

$$Tds = dh - vdP,\ ds = 0,\ dh = vdP,\ \text{int}\,egrate\ \ h_{2s} - h_1 = \int_1^2 vdP$$

Since the substance is compressed liquid, v=constant

$$h_{2s} - h_1 = \int_1^2 vdP = v_1(P_2 - P_1) = (0.001043)(6000 - 100) = 6.15(kJ/kg) = \left(W_{pump}\right)_S$$

$$\left(W_{pump}\right) = \frac{\left(W_{pump}\right)_S}{\eta_P} = \frac{6.15}{0.8} = 7.69(kJ/kg) = h_2 - h_1 = h_2 - 417.4$$

$$h_2 = 425.09(kJ/kg)$$

Solution (cont.)

(3) If the turbine is going through an isentropic expansion

$$s_3 = s_{4s} = 7.36(kJ/kgK),\ P_3 = 6\,MPa$$

We can determine the thermodynamic properties of this superheated vapor using superheated table $\cancel{C-3}$ A-6 through interpolation

$$T_3 = 674^\circ C,\ h_3 = 3832.9(kJ/kg)$$

(a) The rate of heat transfer into the boiler

$$\mathrm{q_{in}} = \dot{m}(h_3 - h_2) = (1)(3832.9 - 425.09) = 3407.8(kW) \text{ per kg of steam}$$

(b) The net power generation

$$\dot{\mathrm{W}}_{\mathrm{net}} = \dot{W}_{turbine} - \dot{W}_{pump} = \dot{m}[(h_3 - h_4) - (h_2 - h_1)]$$

$$\dot{m}[\eta_t(h_3 - h_{4s}) - \frac{(h_{2s} - h_1)}{\eta_P}] = 925.9 - 7.69$$

= 918.2(kW) net power generation per kg of steam

(c) Thermal efficiency

$$\eta = \dot{\mathrm{W}}_{\mathrm{net}} / q_{in} = 918.2 / 3407.8 = 26.9\%$$