Problem solving technique

1. Problem statement

2. Schematic
    a. Control mass or control volume
    b. Find system boundary

3. Assumptions

4. Physical laws

5. Properties
    a. What are the initial and final states
    b. Is anything constant, zero, related
    c. Represent the process on a T-v or P-v diagram

6. Calculations
    a. Energy balance; which equation applies
    b. Simplification; can anything be ignored
    c. Substitution; can any qualities be replaced

7. Conclusion

Thermodynamics Laws

Zeroth law; if A and B are both in thermal equilibrium with C, then A and B are also in thermal equilibrium with each other.

First law; Energy cannot be created nor destroyed

- In an isolated system, total energy is constant with time
- Flow of heat is a form of energy transfer
- Performing work is a form of energy transfer

Second Law; Heat will not spontaneously flow from a cold body to hot body and conversion of heat to work is always less than 100%

Third Law; Can't get to absolute zero, as approaching absolute zero, entropy approaches a constant value

Definitions

Control mass; (closed system)

- Fixed amount of mass
- Energy transfer, no mass transfer
- Closed tank, piston cylinder

Control volume; (open system)

- Fixed region in space
- Energy transfer and mass transfer
- Turbine, pump, water heater

Intensive properties;

- Independent of size and mass
- E.g. temperature, pressure, density

Extensive properties;

- Dependent on size and mass
- E.g. mass, volume, momentum

Specific properties;

- Extensive properties expressed as per unit mass
    - Therefore intensive property
- Density, specific volume, specific gravity

State postulate; the state of a simple compressible system is completely specified by two independent intensive properties

- E.g. temperature and density

Quasi-equilibrium;

- Slow change, e.g. slow moving piston
- System remains infinitely close to equilibrium at all times.

Steady; no change with time

Uniform; no change with location

Vapour power cycle characteristics

- Pressure drops during heat input & output processes
- Irreversible compression & expansion
- Isentropic efficiencies of turbine and compressor

$$\eta_p = \frac{W_s}{W_a} = \frac{h_{s2}-h_1}{h_{2a}-h_1} \qquad \eta_T = \frac{W_a}{W_s} = \frac{h_3-h_{4a}}{h_3-h_{4s}}$$

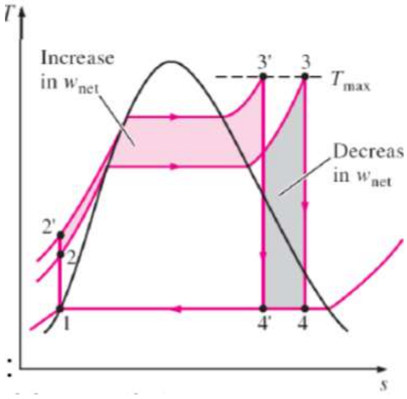
Consequences of deviations

Pressure drops

- Larger work input – pump to higher pressure to compensate

Irreversibility's

- Heat loses – larger heat input to compensate



Reheat Rankine cycle

- Multistage expansion with heating between stages
  - Allows use of higher boiler pressure (Keeps lower T_3)
  - Maintains safe temperatures at turbine inlet
  - Avoids low quality steam
  - Total heat input; $q_{in} = q_{2-3} + q_{4-5}$
  - Total heat output; $q_{out} = h_6 - h_1$
  - Total work output; $W_{out} = W_{turbine,1} + W_{turbine,2}$

$$\eta_{th} = \frac{W_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

- Superheating is similar
  - Both increase average heat input temperatures & net work outputs
  - Both avoid low quality steam
  - Reheating enable similar increase in work for lower turbine inlet temperature

Reheat parameters

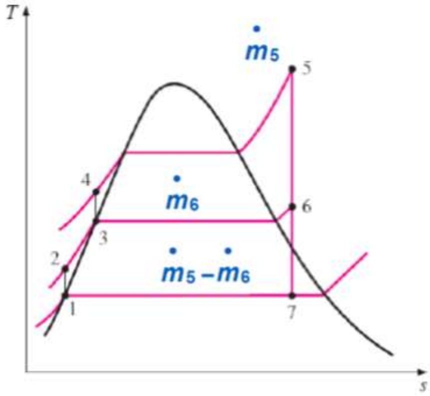
- Optimum temperature; maximum possible high-pressure turbine inlet temperature
- Optimum pressure of reheat; ¼ of boiler pressure

Regeneration Rankine cycle

- Use hot fluid in cycle to preheat colder fluid before boiler
  - Increase average heat input temperature
- Unlike Brayton cycle, turbine exhaust from Rankine cycle is colder than boiler inlet
  - Use of hot turbine steam (rather than exhaust) to preheat cold feedwater entering pump

Methods of regenerative heat transfer

- Ideal regeneration; Transfers heat within turbine
    - Circulate feedwater
    - Cool turbine exhaust to saturation point
- Feedwater heating; Bleed some steam from turbine to heat feedwater in separate heater



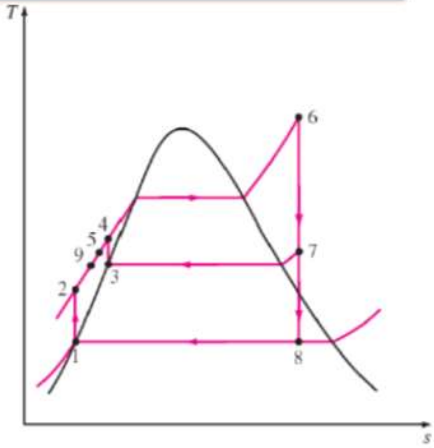
Open feedwater mixing chamber

- Extracted steam is directly mixed with boiler feedwater
- Mixture; will be saturated liquid at extraction pressure
- 5-6; isentropic expansion to extraction pressure P_6
- 6-7; isentropic expansion of remaining steam
- Pump 1; isentropic compression to extraction pressure
- Pump 2; isentropic compression to boiler pressure P_4

Extracted steam fraction; $\boldsymbol{y = \frac{\dot{m}_6}{\dot{m}_5}}$

- heat input; $\dot{m}_{boiler} = \dot{m}$ $q_{in} = q_{boiler}$
- heat output; $\dot{m}_{condenser} = (1-y)\dot{m}$ $q_{out} = (1-y)q_{condenser}$
- work input; $W_{in} = (1-y)W_{pump,1} + W_{pump,2}$
- Work output; $W_{out} = W_{turbine,1} + (1-y)W_{turbine,2}$

Open feedwater heater



- Extracted steam transfer heat to boiler feedwater
- Feedwater (9); compressed liquid at steam temperature T_7 & boiler pressure P_5
- Steam (3); cooled to saturated liquid at extraction pressure P_7
- pump 1; raises feedwater to boiler pressure
- pump 2; raises condensed steam to boiler pressure
- condensed steam and feedwater mix at the same pressure

choice of feedwater design

- Open feedwater heater
  - Simple, inexpensive, good heat transfer (mixing)
  - Pumps for each mixing chamber
- Closed feedwater heater
  - More complex & expensive
  - One need one feedwater pump

Cogeneration and combines cycles

- Power cycle heat output
  - Gas powered cycles; heat is rejected to air in exhaust
  - Vapour power cycles; heat is rejected to a cooling substance in condenser

Cogeneration

- Industrial process heating; hot water steam
  - Traditionally supplied by combustion
  - Food processing, pulp & paper mills, oil refineries, steel production
  - Traditionally supplied by electricity or combustion

Ideal vapour cogeneration plant

- Condenser replaced by process heater
- Supply of process heat is linked to net power output
  - $Q_{in} = W_{out} + Q_{out}$