Thermo Midterm 2

- Ch. 5 → Control Volumes and Conservation of Mass
  - Mass and Volume Flow Rates
    - $\underset{\frac{kg}{s}}{\dot{m}} = \rho A v = \underset{\frac{kg}{m^3}}{\rho} \underset{\frac{m^3}{s}}{\dot{V}}$
      - In steady flow, mass flow rate = const
  - Flow Work and Energy
    - $W_{flow} = PV$; $w_{flow} = P\nu$
    - θ = Total energy for flow, per unit mass
      - $\theta = P\nu + e = P\nu + (u + ke + pe)$

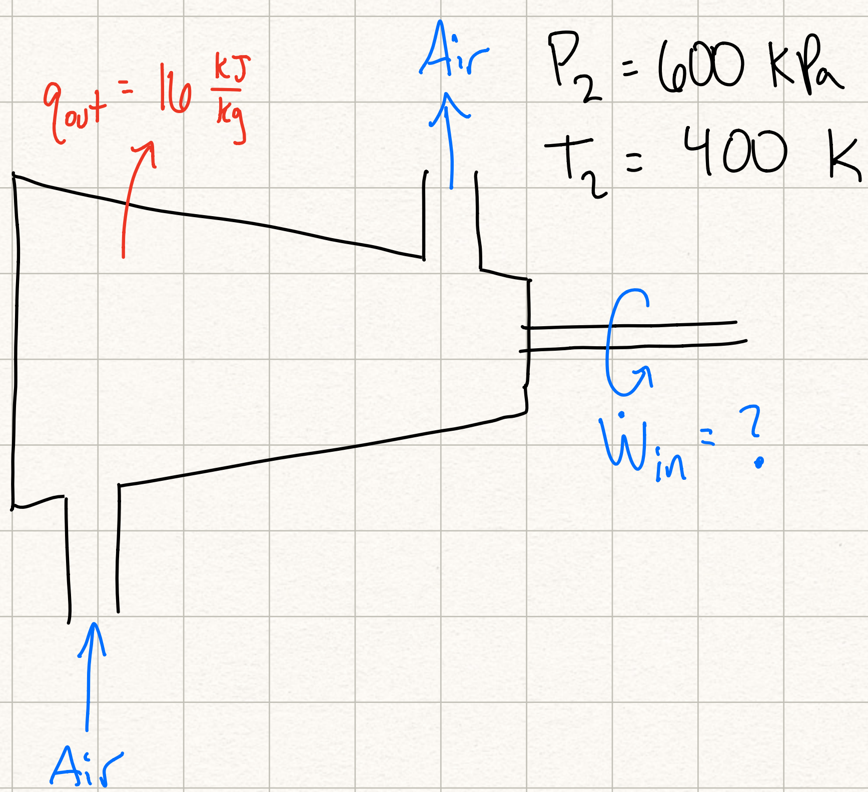
        $\theta = h + \frac{v^2}{2} + gz$
    - $\dot{E}_{mass\ flow} = \dot{m}\,\theta$
  - Energy analysis for control volumes

- $E_{in} - E_{out} = \Delta E_{system}$

- $\dot{E}_{in} - \dot{E}_{out} = \frac{d}{dt}(E_{system})$

S-6

Air in a steady compressor



$P_1 = 100$ kPa

$T_1 = 280$ K

$\dot{m}_1 = 0.02 \frac{kg}{s}$

- $\dot{E}_{in} - \dot{E}_{out} = \frac{d}{dt}(E_{system}) = 0$ (steady)

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{E}_{mass\ in} = \dot{Q} + \dot{E}_{mass\ out}$$

$$\dot{W}_{in} = \dot{Q} + \dot{E}_{mass\ out} - \dot{E}_{mass\ in}$$

$$\dot{W}_{in} = \dot{Q} + \dot{m}_{out}\,\theta_{out} - \dot{m}_{in}\,\theta_{in}$$

$\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

$$\dot{W}_{in} = \dot{Q} + \dot{m}\left(\theta_{out} - \theta_{in}\right)$$

$$\dot{W}_{in} = \dot{m}\,q_{out} + \dot{m}\left(\theta_{out} - \theta_{in}\right)$$

$$\dot{W}_{in} = \dot{m}\left(q_{out} + \theta_{out} - \theta_{in}\right)$$

$$\dot{W}_{in} = \dot{m}\left(q_{out} + \underbrace{h_{out} + \cancel{ke_{out}} + \cancel{pe_{out}}}_{\theta_{out}} - \underbrace{\left(h_{in} + \cancel{ke_{in}} + \cancel{pe_{in}}\right)}_{\theta_{in}}\right)$$

$$\dot{W}_{in} = \dot{m}\left(q_{out} + \underbrace{h_{out} - h_{in}}\right)$$

Table A 17

$T_{out} \rightarrow h_{out} = 400.98\ \frac{kJ}{kg}$

$T_{in} \rightarrow h_{in} = 280.13\ \frac{kJ}{kg}$

$$\dot{W}_{in} = \left(0.02\ \frac{\cancel{kg}}{s}\right)\left(16\ \frac{kJ}{\cancel{kg}} + 400.98\ \frac{kJ}{\cancel{kg}} - 280.13\ \frac{kJ}{\cancel{kg}}\right)$$

$$\boxed{\dot{W}_{in} = 2.74\ kW}$$

Chapter 6 Review

Second Law of Thermodynamics

Limitations of 1st Law of Thermodynamics:

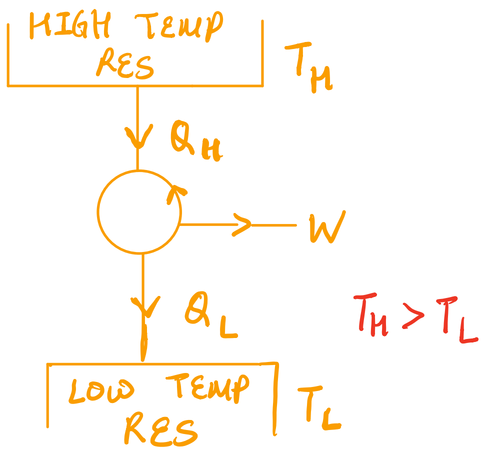
i] Direction of Heat Transfer
ii] Mutual transformation of heat & work

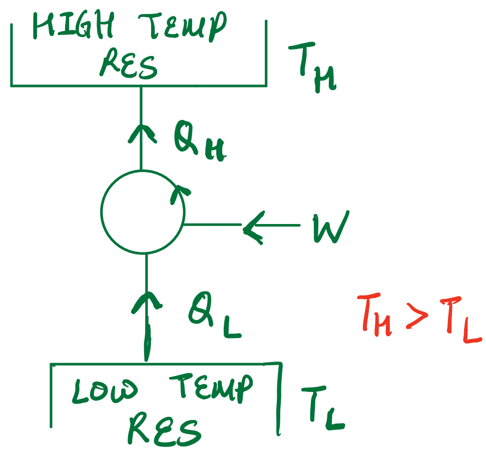
2nd Law answers these two.

iii] The rate of heat transfer

Heat Engine & Refrigerator/Heat Pump

thermal energy to work





$Q_H = Q_L + W$

or, $Q_H - Q_L = W$

$Q_H = Q_L + W$

or, $Q_H - Q_L = W$

e.g. internal combustion engine, steam power plant

refrigerator ⇒ extract heat from sink

heat pump ⇒ dump heat to source

Efficiency of heat engine,

$$\eta_{HE} = \frac{W}{Q_H} \quad \frac{[\text{output}]}{[\text{input}]}$$

$$= \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_L}{Q_H}$$

*

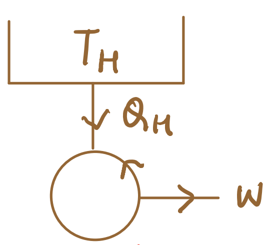
Coefficient of Performance,

$$COP = \frac{\text{Desired effect produced}}{\text{Energy supplied}}$$

$$COP_R = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{HP} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L}$$

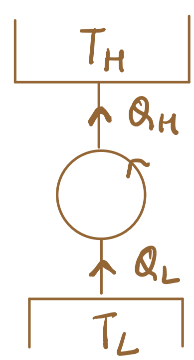
It is impossible to construct a heat engine which will operate in a cycle and will transfer heat only with a single reservoir.



X not possible

you cannot convert full amount of thermal energy from a reservoir solely into work. You have to deposit into another reservoir

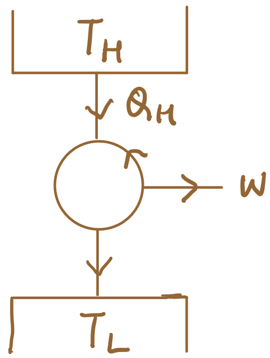
It is impossible to construct a device which will operate in a cycle and will produce no effect other than transfer of heat from a low-temp body to a high-temp one.



$T_H > T_L$

X not possible

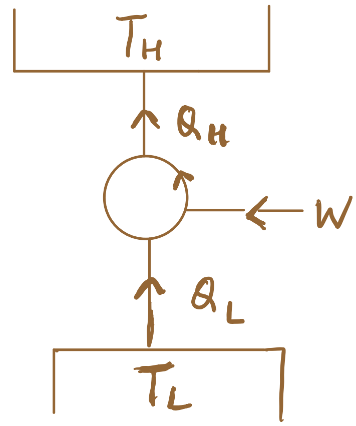
heat will not flow from low temp to high temp, until & unless you supply external work



correct

$$\eta_{HE} = 1 - \frac{Q_L}{Q_H}$$

If $Q_L \neq 0$, then,
η is always less than 1



correct

$T_H > T_L$

$$COP_R = \frac{Q_L}{Q_H - Q_L} \qquad COP_{HP} = \frac{Q_H}{Q_H - Q_L}$$

Since, $Q_H \neq Q_L$, so COP will never be ∞.

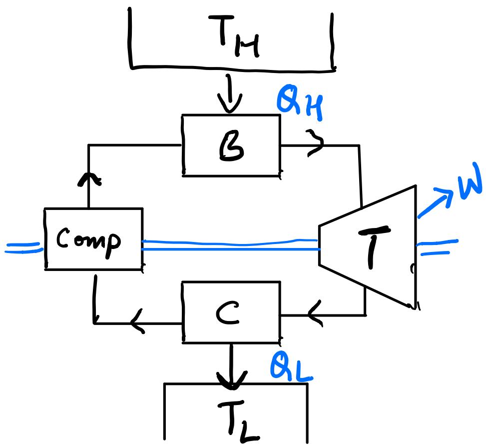
WHAT IS THE MAXIMUM POSSIBLE EFFICIENCY ?
HOW CAN WE GUARANTEE MAXIMUM POSSIBLE EFFICIENCY ?

REVERSIBLE PROCESS

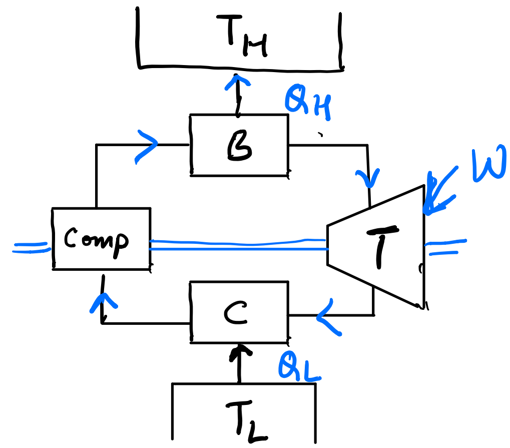
We make a cycle reversible by avoiding irreversible processes.

- friction
- unconstrained expansion
- mixing
- heat transfer
- chemical rxn

To create an engine that



Forward Carnot Cycle
(HE Carnot Cycle)



Reversed Carnot Cycle
(REF Carnot Cycle)

For Reversible cycles

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

6–28 A coal-burning steam power plant produces a net power of 300 MW with an overall thermal efficiency of 32 percent. The actual gravimetric air–fuel ratio in the furnace is calculated to be 12 kg air/kg fuel. The heating value of the coal is 28,000 kJ/kg. Determine (*a*) the amount of coal consumed during a 24-hour period and (*b*) the rate of air flowing through the furnace. *Answers:* (*a*) 2.89×10^6 kg, (*b*) 402 kg/s

Here, steam-power plant ⇒ heat engine

$\dot{W}_{net,out} = 300\ MW = 300 \times 10^6\ W$

$\eta_t = 0.32$

$$\eta_t = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}} \Rightarrow \dot{Q}_{in} = \frac{300}{0.32} = 937.5\ MW$$

$$\therefore\ Q_{in} = \dot{Q}_{in}\,\Delta t = 937.5 \times (24 \times 3600) = 8.1 \times 10^7\ MJ$$

$$m_{coal} = \frac{Q_{in}}{q} = \frac{8.1 \times 10^7}{28} = 2.893 \times 10^6$$

An irreversible heat engine extracts heat from a high temperature source at a rate of 100 KW and rejects heat to a sink at a rate of 50 KW. The entire work output of the heat engine is used to drive a reversible heat pump operating between a set of independent isothermal heat reservoirs at 17°C and 75°C. The rate (in KW) at which the heat pump delivers heat to its high temperature sink is

A] 50

B] 25

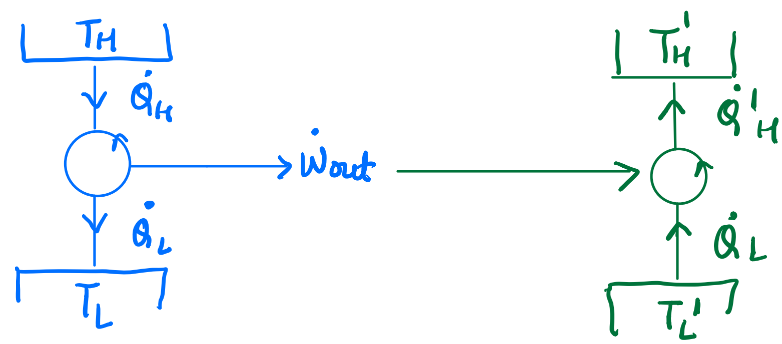
C] 300

D] 360

HINT: $\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$, for reversible process

Here,

For irreversible H.E — For reversible H.P.



$\dot{Q}_H = 100\ KW$

$\dot{Q}_L = 50\ KW$

$T_L' = 17°C = 290\ K$

$T_H' = 75°C = 348\ K$

$\dot{W}_{out} = \dot{Q}_H - \dot{Q}_L$

$COP = \frac{T_H'}{\quad}$

$= 100 - 50$

$= 50 \text{ KW}$

$\overline{T_H' - T_L'}$

$= \frac{348}{348 - 290}$

$= 6$

But, $COP = \frac{\dot{Q}_H'}{\dot{W}_{out}}$

or $\dot{Q}_H' = COP\ (\dot{W}_{out})$

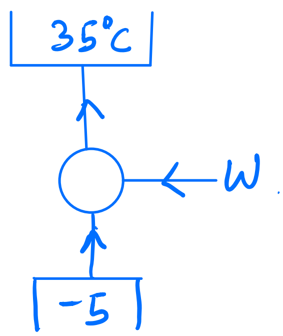
$= 6\ (50)$

$= 300 \text{ KW}$

$\therefore$ 300 KW is supplied to the high temperature reservoir of the heat pump.

A reversed Carnot cycle refrigerator maintains a temp of $-5°C$. The ambient air temperature is $35°C$. The heat gained by the refrigerator at a continuous rate is 2.5 KJ/s. The power (in watt) required to pump this heat out continuously is ____ ?

Here,



$T_L = -5 = 268\,K$

$T_H = 35 = 308\,K$

$$COP = \frac{T_L}{T_H - T_L} = \frac{268}{308-268} = 6.7$$

Also,

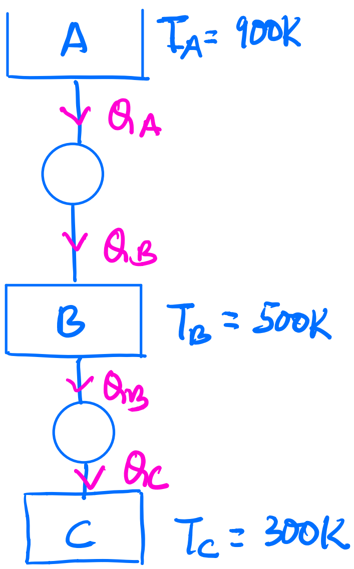
$$COP = \frac{\dot{Q}_L}{\dot{W}}$$

$$\Rightarrow \dot{W} = \frac{\dot{Q}_L}{COP} = \frac{2500}{6.7} = 373.134\ W$$

Carnot engine (CE-1) works between two temperature reservoirs A and B, where $T_A = 900K$ and $T_B = 500K$. A second Carnot engine (CE-2) works between temperature reservoir B and C, where $T_c = 300K$.

In each cycle of CE-1 and CE-2, all the heat rejected by CE-1 to reservoir B is used by CE-2. For one cycle of operation, if net Q absorbed by CE-1 from reservoir A is 150 MJ, the net heat rejected to reservoir C by CE-2 (in MJ) is ______ ?

A] 100 MJ B] 50 MJ C] 75 MJ D] 25 MJ



$$\eta_1 = 1 - \frac{500}{900} = 1 - \frac{Q_B}{150}$$

$$\Rightarrow Q_B = 83.33 \text{ MJ}$$

$$1 - \frac{300}{500} = 1 - \frac{Q_C}{83.33}$$

$$Q_c = 50 \text{ MJ}$$