6.1

• Consequences of interactions : on

$\boxed{\text{mass balance equation :}}$

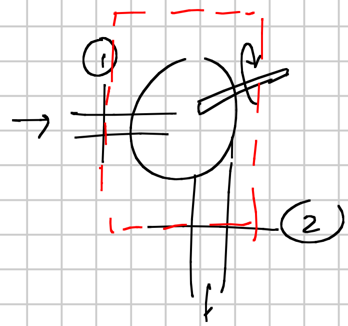
$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$$

for an open, unsteady system.

Energy balance equation :

0, steady state   0 Adiabatic

$$\cancel{\frac{dE}{dt}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \cancel{\dot{Q}} - \dot{W}_{ext}$$



$$0 = \dot{m} j_1 - \dot{m} j_2 - \dot{W}_{ext}$$

$$\dot{W}_{ext} = \dot{m}\,(j_1 - j_2)$$

We need animations in Chapter 2 to derive the mass & energy balance equations

6.2

$$s = \frac{S}{m}$$

$$\dot{S} = \dot{m}\, s$$

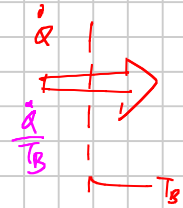
Entropy can be transferred by mass, we call it entropy transport. $\dot{S} = \dot{m} s$.

Entropy is not transferred by work as work is transferred in an organized manner.

Entropy is transferred by heat as heat transfer involves transfer of disorder.

Entropy transferred by heat is given by

$$\frac{\dot{Q}}{T_B} \qquad \left[\frac{kW}{K}\right]$$



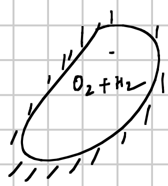
It is possible for entropy to be generated in a system whenever a gradient is destroyed.

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$$

$$\frac{dE}{dt} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \dot{Q} - \dot{W}_{ext}$$

$$\frac{dS}{dt} = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}.$$

$$\underbrace{\boxed{\dot{S}_{gen} \geq 0}}_{\text{2nd law of thermo}}$$



No mass, heat, or work transfer.

$$\frac{dm}{dt} = \sum \cancel{\dot{m}_i}^{\,0} - \sum \cancel{\dot{m}_e}^{\,0}$$

$$\Rightarrow \quad \frac{dm}{dt} = 0$$

$$\Rightarrow \quad m = \text{constant.}$$

$$\frac{dE}{dt} = \cancel{\sum \dot{m}_i j_i}^{\,0} - \cancel{\sum \dot{m}_e j_e}^{\,0} + \cancel{\dot{Q}}^{\,0} - \cancel{\dot{W}_{ext}}^{\,0}$$

$$\Rightarrow \quad \boxed{E = \text{constant.}}$$

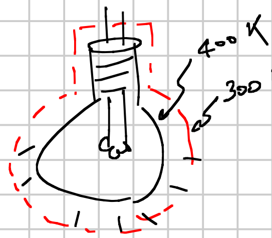
$$KE + PE + U = \text{constant.}$$

$\Rightarrow \quad U = \text{const}$ as KE & PE are not going to change w/o external force.

$$\frac{dS}{dt} = \cancel{\sum \dot{m}_i s_i}^{\,0} - \cancel{\sum \dot{m}_e s_e}^{\,0} + \cancel{\frac{\dot{Q}}{T_B}}^{\,0} + \dot{S}_{gen}$$

$$\Rightarrow \quad \frac{dS}{dt} = \dot{S}_{gen} \geq 0$$

$$\Rightarrow \quad \frac{dS}{dt} \geq 0$$



7.1

$$\dot{W}_{ext} = \cancel{\dot{W}_{sh}}^{\,0} + \dot{W}_{el} + \cancel{\dot{W}_{B}}^{\,0}$$

$$= -0.2 \text{ kW}$$ Ans

$$\cancel{\frac{dE}{dt}}^{\,0,\text{ steady state}} = \dot{Q} - \dot{W}_{ext}$$

$$\Rightarrow \quad \dot{Q} = \dot{W}_{ext}$$

$$= -0.2 \text{ kW}$$ Ans

$$\cancel{\frac{dS}{dt}}^{\,0,\text{ steady}} = \cancel{\sum \dot{m}_i s_i}^{\,0} - \cancel{\sum \dot{m}_e s_e}^{\,0} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen,univ}$$

$$\Rightarrow \quad \dot{S}_{gen,univ} = -\frac{\dot{Q}}{T_B}$$

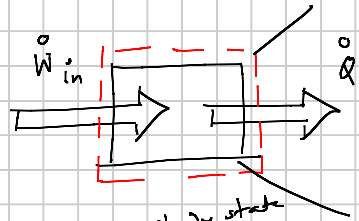
$$= -\frac{[-0.2]}{300}$$

$$= \frac{0.2}{300} \frac{\text{kW}}{\text{K}}$$ Ans

Energetic efficiency

$$= \frac{\text{Desired energy output/outcome}}{\text{Required energy input}}$$

// A work → heat conversion device



Energy :

$$\cancel{\frac{dE}{dt}}^{\,0,\ \text{steady state}} = \sum \cancel{\dot m_i j_i}^{\,0} - \sum \cancel{\dot m_e j_e}^{\,0} + \dot Q - \dot W_{ext}$$

$$\Rightarrow \quad \dot Q = \dot W_{ext}$$

$$\Rightarrow \quad \left[-\dot Q_{out}\right] = \left[-\dot W_{in}\right]$$

$$\Rightarrow \quad \dot Q_{out} = \dot W_{in}$$

Energetic efficiency is also called the first - law efficiency

$$\eta_I \ \left[\text{pronounced eta - I}\right] = \frac{\dot Q_{out}}{\dot W_{in}} = 1$$

$$= 100\% \quad \underline{\text{Ans}}$$

$$\cancel{\frac{dS}{dt}}^{\,0} = \sum \cancel{\dot m_i s_i}^{\,0} - \sum \cancel{\dot m_e s_e}^{\,0} + \frac{\dot Q}{T_B} + \dot S_{gen}$$

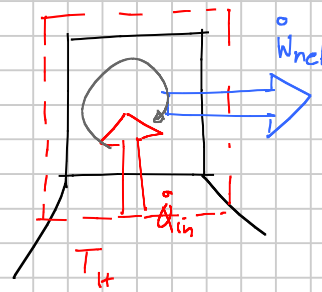
$$0 = \frac{\left[-\dot Q_{out}\right]}{T_0} + \dot S_{gen,\,univ}$$

$$\Rightarrow \quad \dot S_{gen,\,univ} = \underbrace{\frac{\dot Q_{out}}{T_0}}_{\text{positive}}$$

Such a device, therefore, is possible.

// A heat → work conversion device

[heat engine]



mass : $\frac{dm}{dt} = \cancel{\sum \dot{m}_i}^{\,0} - \cancel{\sum \dot{m}_e}^{\,0}$

$\Rightarrow \quad m = \text{constant.}$

energy : $\cancel{\frac{dE}{dt}}^{\,0} = \dot{Q} - \dot{W}_{ext}$

$$0 = [\quad] - [\quad]$$

$$= [\dot{Q}_{in}] - [\dot{W}_{net}]$$

$$= \dot{Q}_{in} - \dot{W}_{net}$$

$\Rightarrow \quad \dot{W}_{net} = \dot{Q}_{in}$

$\Rightarrow \quad \eta_I$, which is also known as thermal efficiency η_{th}

$$= \frac{\dot{W}_{net}}{\dot{Q}_{in}} = 1 = 100\%$$

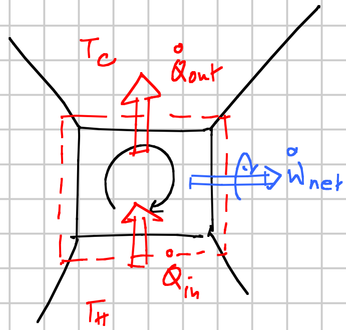
Ans

$$\cancel{\frac{dS}{dt}}^{\,0} = \cancel{\sum \dot{m}_i s_i}^{\,0} - \cancel{\sum \dot{m}_e s_e}^{\,0} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen,\,univ.}$$

$$0 = \underbrace{\frac{\dot{Q}_{in}}{T_H}}_{>0} + \underbrace{\dot{S}_{gen,\,univ}}$$

$\Rightarrow \quad \dot{S}_{gen,\,univ} < 0$: Violation of second law of thermodynamics

In the last class we saw that a heat engine violates second law if it produces net work by exchanging heat with a single reservoir. This was recognized by Kelvin & Planck and is known as the first statement of the second law of thermodynamics.



$$\cancel{\frac{dE}{dt}}^{\,0} = \dot{Q} - \dot{W}_{ext}$$

$$0 = \left[\dot{Q}_{in} - \dot{Q}_{out}\right] - \left[\dot{W}_{net}\right]$$

$$\Rightarrow \quad \dot{W}_{net} = \dot{Q}_{in} - \dot{Q}_{out}$$

$$\eta_{I} = \eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{Q}_{in}}$$

$$// \quad \boxed{\eta_{th} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}}$$

$$\cancel{\frac{dS}{dt}}^{\,0} = \frac{\dot{Q}}{T_B} + \dot{S}_{gen,univ.}$$

$$0 = \left[\frac{\dot{Q}_{in}}{T_H} - \frac{\dot{Q}_{out}}{T_C}\right] + \dot{S}_{gen,univ}$$

$$\Rightarrow \quad \frac{\dot{Q}_{out}}{T_C} = \frac{\dot{Q}_{in}}{T_H} + \dot{S}_{gen,univ}$$

$$\Rightarrow \quad \dot{Q}_{out} = \frac{T_C}{T_H}\dot{Q}_{in} + T_C\,\dot{S}_{gen,univ.}$$

$$\Rightarrow \quad \boxed{\dot{Q}_{out} \geq \frac{T_C}{T_H}\dot{Q}_{in}}$$

$$\dot{W}_{net} = \dot{Q}_{in} - \dot{Q}_{out}$$

If the engine is made perfect so that all friction is eliminated, the engine is called REVERSIBLE &

$$\dot{S}_{gen,univ} = 0$$

For a reversible engine

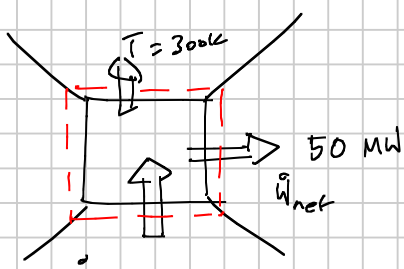
$$\dot{Q}_{out} = \frac{T_C}{T_H}\dot{Q}_{in}$$

$$\Rightarrow \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = \frac{T_C}{T_H}$$

[ETA]

Therefore, $\eta_{th,\,reversible} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{T_C}{T_H}$

$$\boxed{\eta_{th,\,Carnot} = 1 - \frac{T_C}{T_H}}$$



$\dot{Q}_{in} = 200$ MW

T = 1000 K

(a) 150 MW

(b) $\frac{50}{200} = 25\%$

(c) $1 - \frac{T_C}{T_H} = 1 - \frac{300}{1000}$

$= 1 - 0.3 = 70\%$

Determine the (a) waste heat and

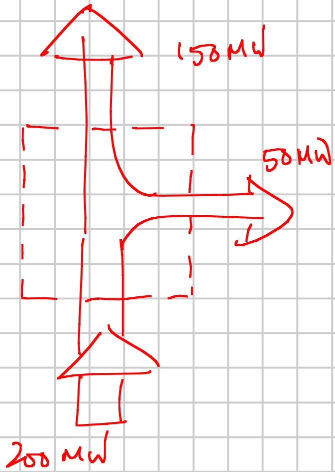
(b) η_{th}, (c) $\eta_{th,\,Carnot}$ (d) $\dot{S}_{gen,\,univ.}$

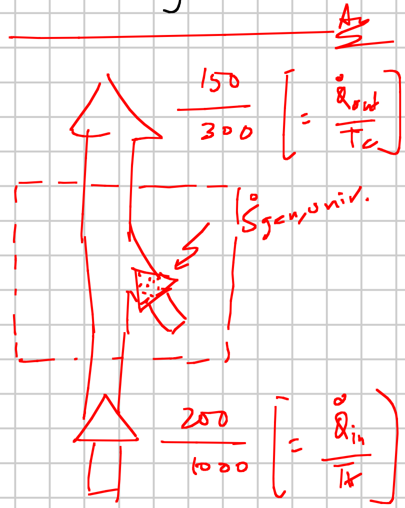
$$\cancel{\frac{dS}{dt}}^{\,0} = \cancel{\sum \dot{m}_i s_i}^{\,0} - \cancel{\sum \dot{m}_e s_e}^{\,0} + \frac{\dot{Q}}{T_b} + \dot{S}_{gen,univ}$$

$$\Rightarrow 0 = \left[\frac{\dot{Q}_{in}}{T_H} - \frac{\dot{Q}_{out}}{T_C}\right] + \dot{S}_{gen,univ}$$

$$\Rightarrow \quad 0 = \left[\frac{200}{1000} - \frac{150}{300}\right] + \mathring{S}_{gen,univ}$$

$$\Rightarrow \quad \mathring{S}_{gen,univ} = \left[\frac{150}{300} - \frac{200}{1000}\right] \frac{MW}{K}.$$





Energy Flow
Diagram.