Sharif University of Technology
School of Mechanical Engineering
Center of Excellence in Energy Conversion

Advanced Thermodynamics

Lecture 14

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- Exergy analysis (2^{nd} law analysis), 2^{nd} law efficiency

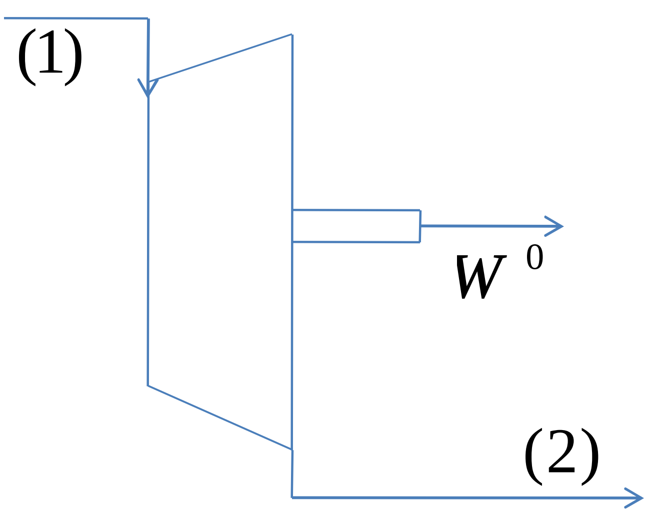
$$\text{Heat Engines: } h_{2^{nd}\ \text{law}} = \frac{W_{actual}}{W_{reversible}}$$

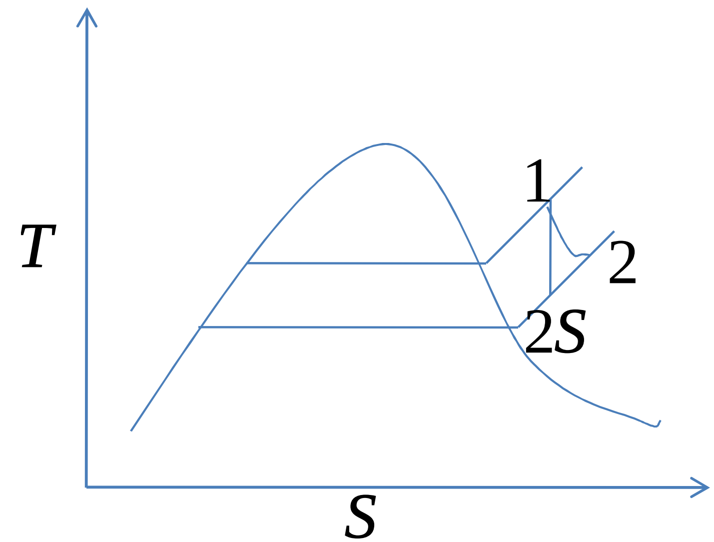
$$\text{Non-Cyclic Process: } h_{2^{nd}\ \text{law}} = \frac{W_{actual}}{-\Delta\Phi} = \frac{W_{actual}}{W_{rev_{1-2}}}$$

- Energy analysis (1^{st} law analysis), 1^{st} law efficiency

$$\text{Heat Engines: } h_{th} = \frac{W}{Q_H}$$

$$\text{Non-Cyclic Process: } h_{is} = \frac{W_{actual}}{W_{isentropic}}$$





- Assume the C.V. to be adiabatic, isentropic efficiency:

$$\eta_t = \frac{W_{act}}{W_{isent}} = \frac{h_1 - h_2}{h_1 - h_{2S}}$$

$$1^{st} \text{ law} \rightarrow h_1 - h_2 = \eta_t W_S$$

$$\left.\begin{aligned} &2^{nd} \text{ law} \rightarrow \frac{dS_{C.V.}}{dt} = \frac{\dot{Q}}{T} + \dot{m}(S_1 - S_2) + \dot{S}_{gen} \\ &SSSF \rightarrow \frac{dS_{C.V.}}{dt} = 0 \text{ and } \frac{\dot{Q}}{T} = 0 \end{aligned}\right\} \Rightarrow \frac{\dot{S}_{gen}}{\dot{m}} = S_2 - S_1$$

- Heat must be transformed to bring the working fluid from state 2 down to state 2S, $Q_a^0 = m^0(h_2 - h_{2S})$

- If the rejection temperature is T_0 , then additional irreversibilities caused by this heat transfer.

- Writing entropy balance for the turbine plus that part of condenser that handles the additional heat transfer

$$0 = \int \frac{dQ}{T} + \dot{m}\,\cancel{(S_1 - S_{2S})_0} + \sum \dot{S}_{gen} \Rightarrow \sum \dot{S}_{gen} = -\int \frac{dQ}{T} + \frac{Q_a^0}{T_0}$$

- $\sum \dot{S}_{gen}$ = sum of the turbine + heat rejection irreversibilities

$$\dot{S}_{gen\,,\,heat} = \frac{Q_a^0}{T_0}\left(1 - \frac{T_0}{T_{sA\,,\,a}}\right)$$

$$\dot{S}_{gen\,,\,\mathrm{turbine}} = \sum \dot{S}_{gen} - \dot{S}_{gen\,,\,heat}$$

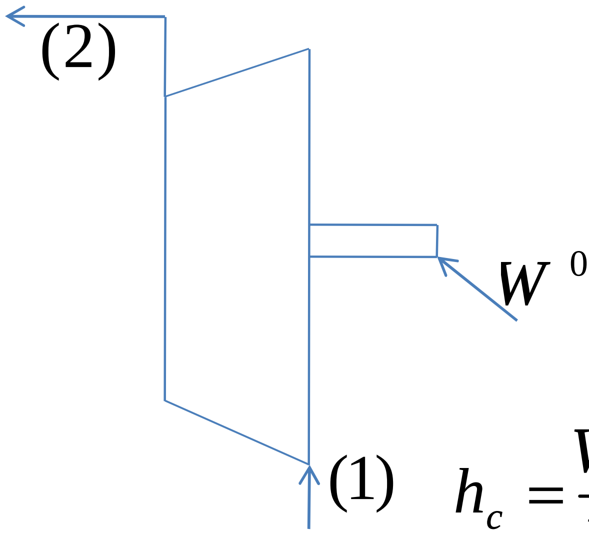
$$h_t = 1 - \dot{S}_{gen\,,\,\mathrm{turbine}} \frac{T_{sA\,,\,a}}{\dot{m}}$$

$$\dot{W}_{\mathrm{lost,\ a}} = Q_a^0\left(1 - \frac{T_0}{T_{sA\,,\,a}}\right)$$

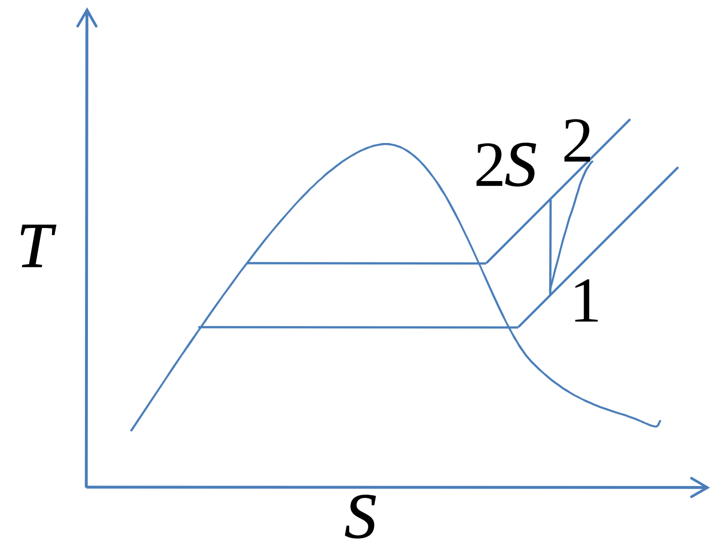
$$\dot{S}_{gen\,,\,\mathrm{turbine}} = \frac{Q_a^0}{T_{sA\,,\,a}}$$

- $T_{s\ A,\,a}$ is the average eutropic temperature between 2 and 2S.

Compressor



$$h_c = \frac{W_{isent}}{W_{act}} = \frac{h_{2S} - h_1}{h_2 - h_1}$$



$$1^{st} \text{ law} \rightarrow W_{act} = h_2 - h_1 = \frac{W_{isen}}{h_c}$$

$$2^{nd} \text{ law} \rightarrow \frac{dS_{C.V.}}{dt} = \frac{\dot{Q}}{T} + \dot{m}(S_1 - S_2) + \dot{S}_{gen}$$

$$SSSF \rightarrow \frac{dS_{C.V.}}{dt} = 0 \text{ and } \frac{\dot{Q}}{T} = 0$$

$$\Rightarrow \frac{\dot{S}_{gen}}{\dot{m}} = S_2 - S_1$$

- Heat must be rejected to bring the working fluid from state 2 down to state 2S, $Q_a^0 = m^0 (h_2 - h_{2S})$ assume rejected to T_0

- The additional entropy production due to this heat rejection is:

$$\dot{W}_{\text{lost, a}} = Q_a^0 \left(1 - \frac{T_0}{T_{sA,a}} \right)$$

$$\dot{S}_{gen,\text{a}} = \frac{Q_a^0}{T_0} \left(1 - \frac{T_0}{T_{sA,a}} \right)$$

- Entropy balance for the compressor plus that part of condenser that handles the additional heat rejection:

$$0 = \int \frac{dQ}{T} + \dot{m} \cancel{(S_1 - S_{2S})}_0 + \sum \dot{S}_{gen} \Rightarrow \sum \dot{S}_{gen} = -\int \frac{dQ}{T} + \frac{Q_a^0}{T_0}$$

$$0 = \int \frac{dQ}{T} + \dot{m}\,\cancel{(S_1 - S_{2s})}_0 + \sum \dot{S}_{gen} \Rightarrow \sum \dot{S}_{gen} = -\int \frac{dQ}{T} + \frac{Q_a^0}{T_0}$$

- Therefore,

$$\dot{S}_{gen,\,heat} = \frac{Q_a^0}{T_0}\left(1 - \frac{T_0}{T_{sA,\,a}}\right)$$

$$\dot{S}_{gen,\,\mathrm{comp}} = \sum \dot{S}_{gen} - \dot{S}_{gen,\,heat} = -\frac{Q_a^0}{T_0} - \frac{Q_a^0}{T_0}\left(1 - \frac{T_0}{T_{sA,\,a}}\right)$$

$$= \frac{Q_a^0}{T_{sA,\,a}} = \frac{\dot{m}\,(h_2 - h_{2s})}{T_{sA,\,a}} = \frac{\dot{m}\,(W_{act} - W_S)}{T_{sA,\,a}} = \frac{\dot{m}\,(W_S / h_c - W_S)}{T_{sA,\,a}}$$

$$\Rightarrow \dot{S}_{gen,\,\mathrm{comp}} = \frac{\dot{m} W_S \left(\frac{1}{h_c} - 1\right)}{T_{sA,\,a}}$$