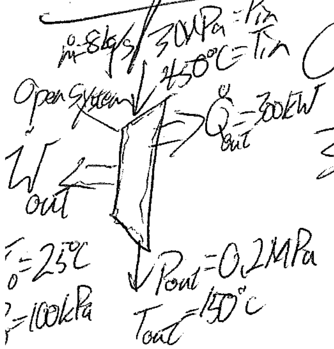
Exergy Balancing for Open Systems

Until now we have shown that Exergy is a property of an energy resource that describes the available work. We showed that Exergy flows via: 1) Mass: $(m\psi)$, 2) Heat: $\left(1-\frac{T_0}{T}\right)Q$, 3) Work: W

Moreover, we can balance exergy on a system knowing it cannot be produced, only destroyed via: IN + ~~PRODUCED~~ = OUT + DESTROYED + STORED

We've then applied this to analyze resources & closed systems. Let's try an open system.

Example: 8 kg/s of Steam enters a turbine at 3MPa, 450°C & exits at 0.2MPa & 150°C. The turbine is <u>not</u> adiabatic & loses 300kW to the surroundings @ 100kPa & 25°C. Find: A) The actual power output, B) maximum possible work, C) the isentropic efficiency, D) the exergy destroyed, E) the exergy of the inlet stream.



Assumptions: 1) Steady, Open system, 2) $\Delta PE, \Delta KE$ negligible, 3) Heat out, 4) T_0, P_0, 5) real fluid

Balances: Energy: $\dot{E}_{in}=\dot{E}_{out}+\frac{dE_{stored}}{dt}^{0} \Rightarrow \dot{Q}_{in}^{0}+\dot{W}_{in}^{0}+\dot{m}\left(h_{in}+\frac{V_{in}^2}{2}^{0(2)}+gz_{in}^{0(2)}\right)=\dot{Q}_{out}+\dot{W}_{out}+\dot{m}(h_{out})$

$$\Rightarrow \dot{W}_{out}=\dot{m}(h_{in}-h_{out})-\dot{Q}_{out} \Rightarrow 8\tfrac{kg}{s}\left(3344.9\tfrac{kJ}{kg}-2769.1\tfrac{kJ}{kg}\right)-300kW \Rightarrow$$

$$\Rightarrow \underline{\dot{W}_{out}=4306kW}$$

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Entropy: $\dot{S}_{in} + \dot{S}_{GEN} = \dot{S}_{out} + \cancelto{0}{\frac{dS_{stored}}{dt}} \Rightarrow \dot{m}s_{in} + \dot{S}_{GEN} = \dot{m}s_{out} + \frac{\dot{Q}_{out}}{T_0} \Rightarrow$

$$\dot{S}_{GEN} = 8\,\text{kg/s}\,(s_{out} - s_{in}) + \frac{\dot{Q}_{out}}{T_0} \Rightarrow 8\,\text{kg/s}\left(7.279\,\tfrac{\text{kJ}}{\text{kg·K}} - 7.083\,\tfrac{\text{kJ}}{\text{kg·K}}\right) + \frac{300{,}000\,\text{W}}{298.1\,\text{K}}$$

$$\dot{S}_{GEN,T} = 2573\,\text{W/K}$$

Exergy on reversible Turbine: $\dot{X}_{IN} = \dot{X}_{out} + \cancelto{0}{\dot{X}_{DESTROYED}} + \cancelto{0}{\frac{dX_{stored}}{dt}} \Rightarrow$

$$\cancelto{0}{\left(1 - \frac{T_0}{T}\right)\dot{Q}_{in}} + \cancelto{0}{\dot{W}_{in}} + \dot{m}\psi_{in} = \cancelto{0}{\left(1 - \frac{T_0}{T_B}\right)}\dot{Q}_{out} + \dot{W}_{out,max} + \dot{m}\psi_{out} + \cancelto{0}{\dot{X}_{DESTROYED}}$$

$$\dot{m}\left[(h_{in} - h_0) - T_0(s_{in} - s_0) + \cancelto{0}{\frac{V_{in}^2}{2}} + \cancelto{0}{gz_{in}}\right] = \dot{m}\psi_{in}$$

$$\dot{W}_{out,max} = \dot{m}(\psi_{in} - \psi_{out})$$

$$\dot{m}\left[(h_{out} - h_0) - T_0(s_{out} - s_0) + \cancelto{0}{\frac{V_{out}^2}{2}} + \cancelto{0}{gz_{out}}\right] = \dot{m}\psi_{out}$$

$$\Rightarrow \dot{W}_{out,max} = \dot{m}\left[(h_{in} - h_{out}) - T_0(s_{in} - s_{out})\right] \Rightarrow$$

$$\Rightarrow 8\,\text{kg/s}\left[\left(3{,}344\,\tfrac{\text{kJ}}{\text{kg}} - 2769\,\tfrac{\text{kJ}}{\text{kg}}\right) - 298.1\,\text{K}\left(7.083\,\tfrac{\text{kJ}}{\text{kg·K}} - 7.279\,\tfrac{\text{kJ}}{\text{kg·K}}\right)\right]$$

$$\dot{W}_{out,Max} = 5072\,\text{kW}$$

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$$\eta_{Turbine} = \frac{\text{What you got}}{\text{What you could've}} = \frac{\dot{W}_{actual}}{\dot{W}_{MAX}} = \frac{4306\,kW}{5072\,kW} = \underline{\underline{84.9\%}}$$

$$\dot{X}_{DESTROYED} \stackrel{?}{=} \dot{W}_{MAX} - \dot{W}_{actual} = 5072\,kW - 4306\,kW = \underline{\underline{766\,kW}}$$

$$\dot{X}_{IN} = \dot{m}\psi_{in} = 9894\,kW$$