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

Advanced Thermodynamics

Lecture 13

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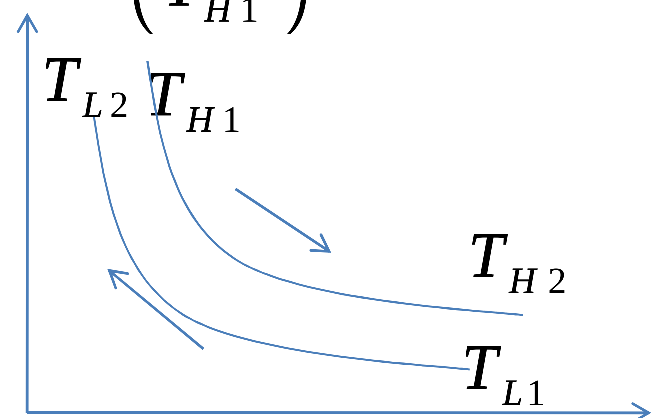
Heat Exchanger

- For simplification, consider an average temperature for hot and cold flows, namely eutropic average temperature.

$$T_{SA,\,\mathrm{H}} \equiv \frac{\dot{Q}_H}{\int \frac{d\dot{Q}_H}{T_H}} = \frac{-\dot{m}_H c_H (T_{H2} - T_{H1})}{-\dot{m}_H c_H \int \frac{dT_H}{T_H}} \Rightarrow T_{SA,\,\mathrm{H}} = \frac{(T_{H2} - T_{H1})}{\ln\left(\frac{T_{H2}}{T_{H1}}\right)}$$

$$T_{SA,\,\mathrm{L}} = \frac{(T_{L2} - T_{L1})}{\ln\left(\frac{T_{L2}}{T_{L1}}\right)}$$



- 2nd Law of thermodynamics:

$$\eta = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H} = 1 - \frac{T_{SA,\,L}}{T_{SA,\,H}} - \frac{T_{SA,\,L}\dot{S}_{gen}}{\dot{Q}_H}$$

$$\dot{S}_{gen} = \frac{-\dot{Q}_H}{T_{SA,\,H}} + \frac{\dot{Q}_L}{T_{SA,\,L}} \rightarrow \dot{S}_{gen} = \dot{Q}_L \left[\frac{1}{T_{SA,\,L}} - \frac{1}{T_{SA,\,H}}\right]$$

Exergy Analysis of a System

- Investigation of exergy Eq. terms at different situations:
  - If a system is in contact with only one source:

$$\left.\begin{aligned}\Delta u &= q - w\\ \Delta s &= \frac{q}{T} + s_{gen}\end{aligned}\right\} \Rightarrow \Delta u - T_0 \Delta s = q\left(1 - \frac{T_0}{T}\right) - w - T_0 s_{gen}$$

$$\Rightarrow \Delta u + P_0 \Delta v - T_0 \Delta s = q\left(1 - \frac{T_0}{T}\right) - (w - P_0 \Delta v) - T_0 s_{gen}$$

$$\Delta(u + P_0 v - T_0 s) = \Delta \Phi \quad \text{Exergy or Availability}$$

$$\Delta u + P_0 \Delta v - T_0 \Delta s = (u_2 - u_1) + P_0 (v_2 - v_1) - T_0 (s_2 - s_1) = \Phi_2 - \Phi_1$$

$$\Rightarrow W_{\underset{1-2}{rev}} = \Phi_1 - \Phi_2 = -\Delta \Phi$$

$$\underbrace{\frac{dy}{dt}}_{I}=\underbrace{\sum_{i=1}^{n}\left(1-\frac{T_0}{T}\right)\dot{Q}_i}_{II}-\underbrace{\left(\dot{W}_{C.V.}-P_0\frac{dV}{dt}\right)}_{III}+\underbrace{\sum_{in}\dot{m}b-\sum_{out}\dot{m}b}_{IV}-\underbrace{T_0\dot{S}_{gen}}_{V}$$

- $\sum_{in}\dot{m}b-\sum_{out}\dot{m}b$: Net availability convected into the C.V. with mass flow, also called physical exergy, can be split into thermal and pressure components.

- For an ideal gas with constant heat capacity, c_P

$$E_{Ph.}=c_P\left[(T-T_0)-T_0\ln\left(\frac{T}{T_0}\right)\right]+RT_0\ln\left(\frac{P}{P_0}\right)$$

- For solids and liquids $(c_P=c_v=c)$

$$E_{Ph.}=-c(T-T_0)\ln\left(\frac{T}{T_0}\right)+v_m(P-P_0)$$

- v_m is the specific volume determined at T_0

- The chemical exergy, Ex_{chem} at P_0 can be calculated by bringing the pure component in chemical equilibrium with the environment.

$$Ex_{chem} = RT_0 \ln\left(\frac{P_0}{P_{ref}}\right)$$

- When a substance does not exist in the environment, it must first react to references substances in order to get in equilibrium with the environment.

- The reaction exergy of reference condition needs Gibbs free energy changes.

$$\Delta G^0 = \Delta H^0 - T_0 \Delta S^0$$

$$Ex_{chem} = \sum_{i=1}^{n} \nu_i Ex_{chem,ref} - \Delta G^0$$

- Exergy analysis (2nd law analysis), 2nd law efficiency

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

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

- Energy analysis (1st law analysis), 1st law efficiency

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

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