Clausius Inequality

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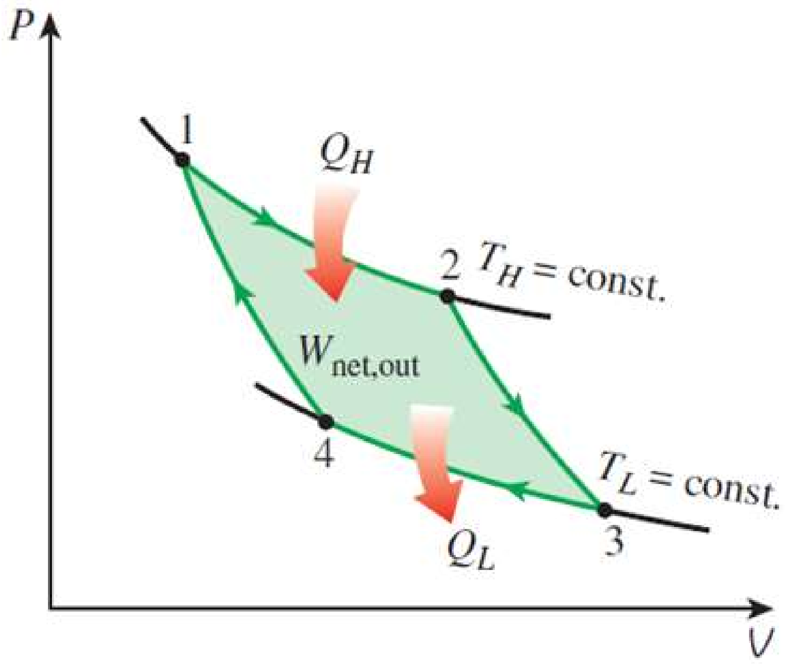
Previous lecture: Entropy as a State Function!



$$\left(\frac{Q_H}{Q_L}\right)_{\text{rev}} = \frac{T_H}{T_L}$$

$$\frac{Q_H}{T_H} + 0 - \frac{Q_L}{T_L} + 0 = 0$$

$$\sum_i \frac{Q_i}{T_i} = 0$$

$$\sum_i U_i = 0;\ \oint U = 0; U\ is\ a\ State\ Function$$

$$\sum_i \frac{Q_i}{T_i} = 0; S_i = \frac{Q_i}{T_i}; \sum_i S_i = 0;\ \oint S = 0; S\ is\ a\ State\ Function!!!$$

Fig: TD-Cengel & Boles

Clausius Inequality

$$\boxed{\text{All cycles:} \quad \oint \frac{\delta Q}{T} \le 0}$$

= reversible processes; < irreversible processes

Fig: TD-Borgnakke & Sonntag

Reversible heat engines

$$\oint \delta Q = Q_H - Q_L \geq 0$$

$$\oint (1/T)\, \delta Q = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

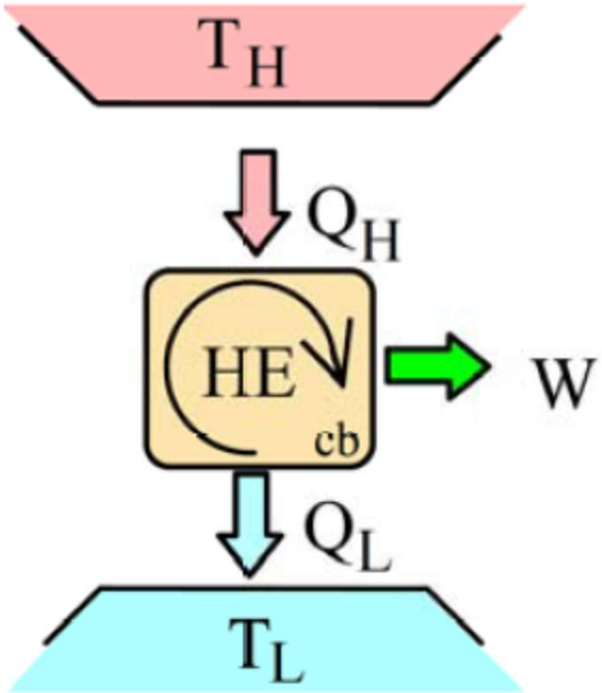


Fig: TD-Borgnakke & Sonntag

Irreversible: Less Work→More Heat rejection

- Irreversible/Actual HE: $W_{ac} < W_{rev} \quad \Rightarrow \quad Q_{L\,ac} > Q_L$

$$\oint \delta Q = Q_H - Q_L \geq 0$$

$$\oint \delta Q = Q_H - Q_{L\,ac} \geq 0$$

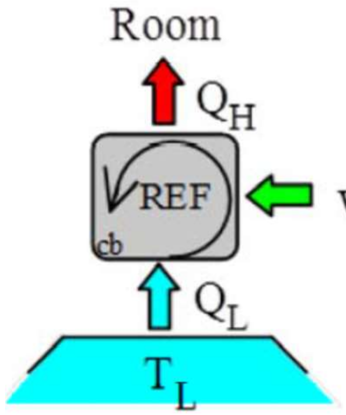
$$\oint (1/T)\, \delta Q = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

$$\oint (1/T)\, \delta Q = \frac{Q_H}{T_H} - \frac{Q_{L\,ac}}{T_L} < 0$$

Fig: TD-Borgnakke & Sonntag

Refrigerator

$$W_{ac} > W_{rev} \quad \Rightarrow \quad Q_{H\,ac} > Q_H$$



$$\oint \delta Q = Q_L - Q_H \leq 0$$

$$\oint \delta Q = Q_L - Q_{H\,ac} \leq 0$$

$$\oint (1/T)\, \delta Q = \frac{Q_L}{T_L} - \frac{Q_H}{T_H} = 0$$

$$\oint (1/T)\, \delta Q = \frac{Q_L}{T_L} - \frac{Q_{H\,ac}}{T_H} < 0$$

Fig: TD-Borgnakke & Sonntag

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$$\boxed{\text{All cycles:} \quad \oint \frac{\delta Q}{T} \leq 0}$$

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Fig: TD-Borgnakke & Sonntag

What's next?

- More & more Entropy!