ABE 201
Biological Thermodynamics 1

Module 12: 2^{nd} Law Balances

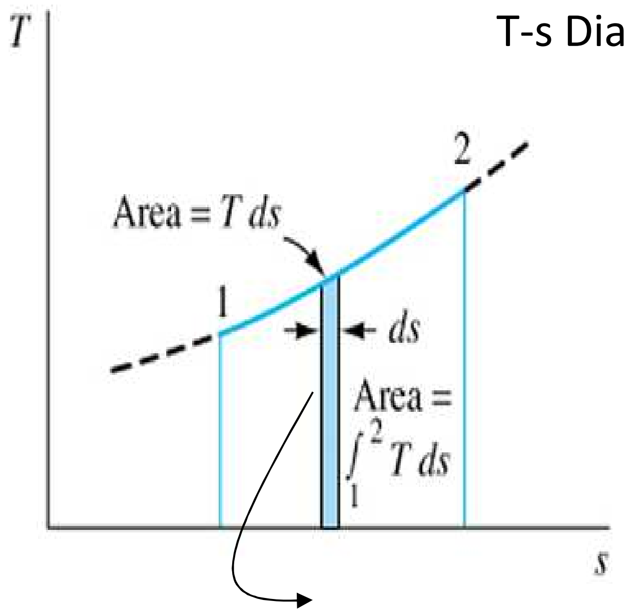
Outline

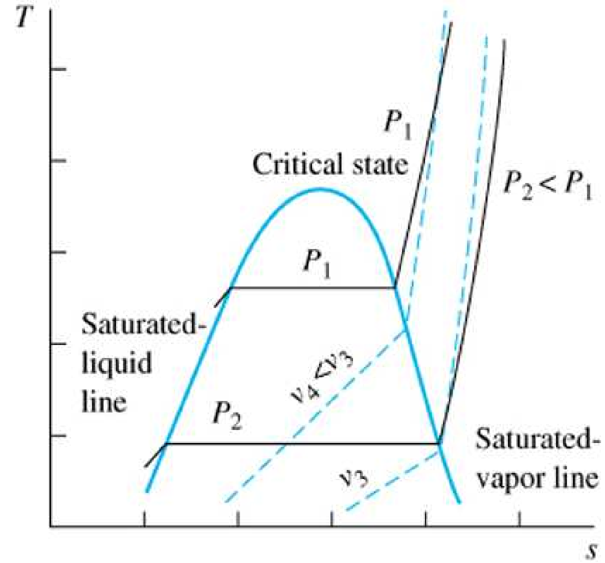
- Relationships between entropy and other state properties
- Developing 2nd Law Balance equation.
- Applications of 2nd Law Equation
  - Closed systems
  - Open systems
- Isentropic systems

T-s Diagram

$$ds = \left(\frac{\delta q}{T}\right)_{rev} \rightarrow \delta q_{rev} = T\,ds \rightarrow Q_{rev} = \int_1^2 T ds$$

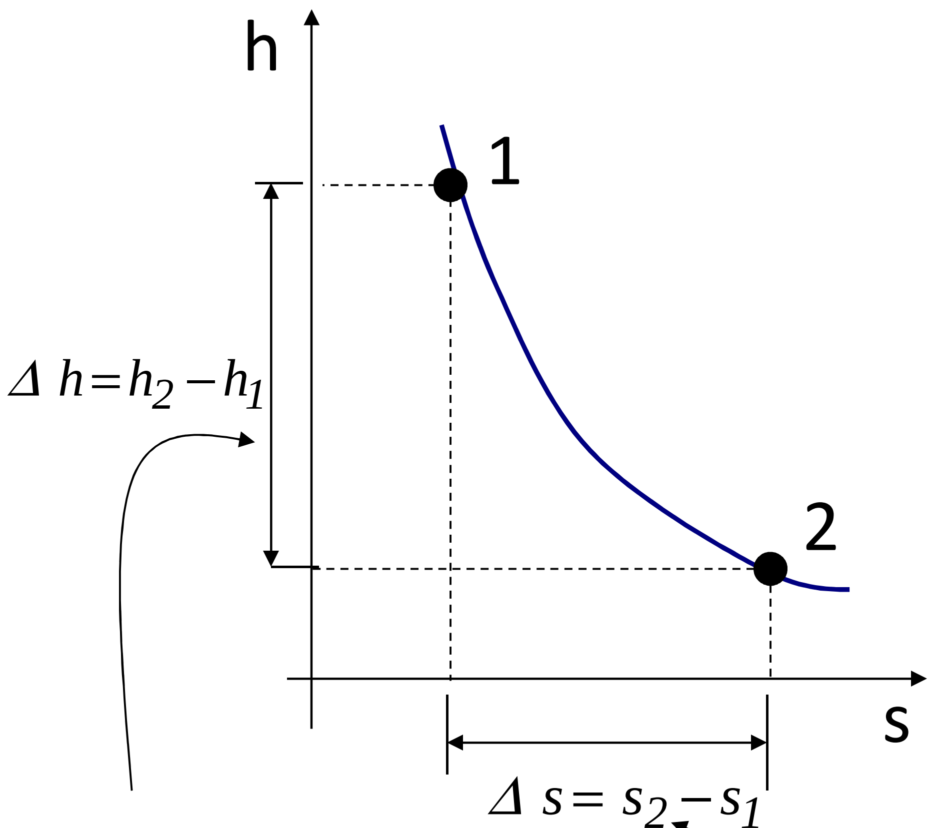
T-s Diagram

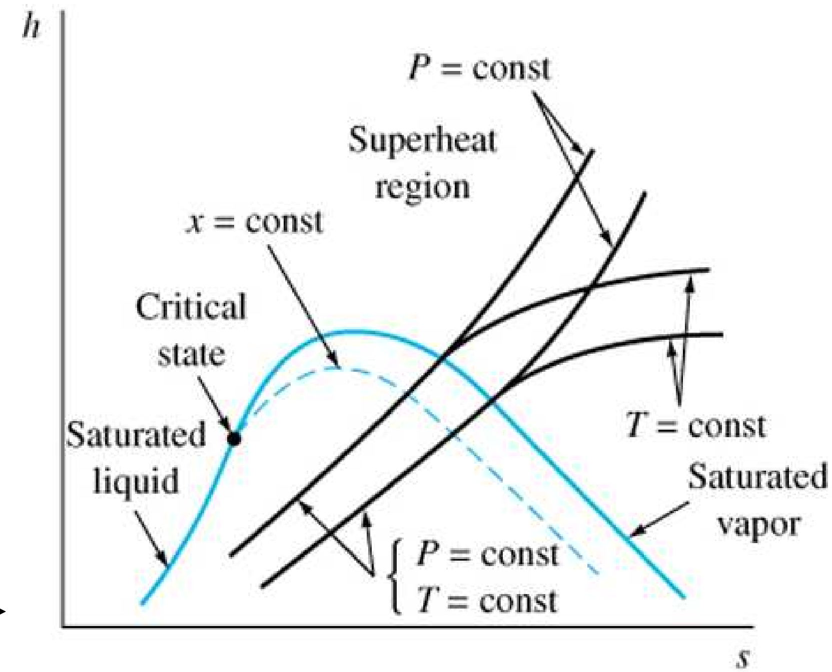




Area under the curve gives
the heat exchanged in the process

h-s Diagram



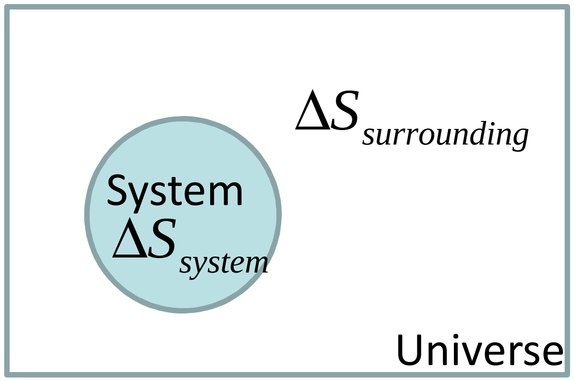


Change related to energy balance of the process.
A measure of work

Change related to the irreversibility of the process.
A measure of irreversibilities.

Entropy Change for Universe

- Entropy change of universe



$$\Delta S_{universe} = \sum_{i=1}^{N} \Delta S_i = S_{gen} > 0$$

- Entropy of universe (isolated, closed system) will always increase.

$$\Delta S_{univ} = \Delta S_{system} + \Delta S_{surroundings} > 0$$

Entropy of System Can Decrease Only If…

$$\Delta S_{univ} = \Delta S_{system} + \Delta S_{surroundings} > 0$$

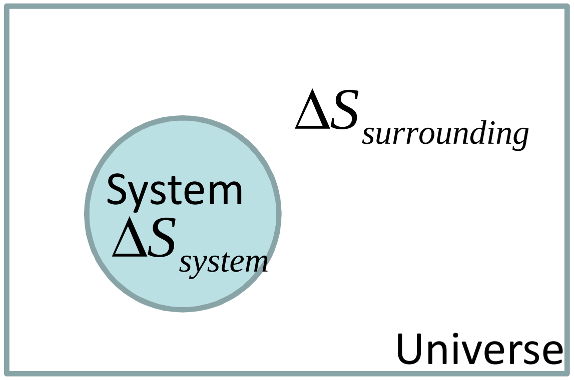
+ +, -, 0 +, -, 0

- Entropy of a system can decrease if the system is not isolated from its surroundings.

  ($S_1 > S_2 \rightarrow \Delta S = S_2 - S_1 < 0$).

- But this is only possible when there is a greater entropy increase in the surroundings so that the entropy change of universe (sum of the entropy change of system and surroundings) is greater than zero.

2^{nd} Law of Thermodynamics and Entropy

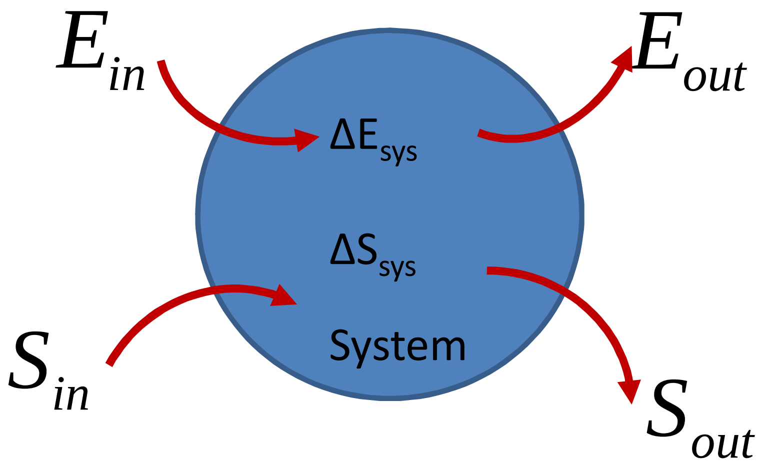


$$\Delta S_{universe} = \sum_{i=1}^{N} \Delta S_i > 0 \qquad S_{gen} \geq 0$$

- Entropy is a non-conserved property.
- The entropy of the **system plus the surroundings** (also called **the universe**) always increases.
- A process must proceed in the direction that increases the entropy of universe.
- In an ***Isolated System*** (i.e. a system that does not exchange mass and energy with the surroundings) every <u>change within the system increases the entropy.</u>
- If the system **<u>is not isolated</u>** from the surroundings, then the entropy **<u>in the system</u> can decrease** but at the expense of a greater entropy increase in surroundings so that the entropy of universe increases.

Entropy Balance

Accumulation=In- Out + Generation - Consumption



$$\Delta E_{sys} = E_{in} - E_{out} \quad \Delta U + \Delta E_K + \Delta E_P = Q - W$$

1st Law!

$$\Delta S_{sys} = S_{in} - S_{out} + S_{gen}$$

2nd Law!

$$\frac{dS_{sys}}{dt} = \dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} \quad \text{(rate form)}$$

$$S_{gen} \geq 0$$

$S_{gen} = 0$ for a reversible process

$then, \; S_{in} - S_{out} = \Delta S_{sys}$

S_{in} and S_{out}

1. Entropy transfer associated with heat transfer

$$S_{heat} = \frac{Q}{T} \quad \text{(T=constant)} \quad \text{for adiabatic, } S_{heat} = 0$$

$$S_{heat} = \int_1^2 \frac{\delta Q}{T} \approx \sum \frac{Q_k}{T_k} \quad \text{(when T is not constant)}$$

2. Entropy transfer associated with mass flow

$$\dot{S}_{mass} = \dot{m}\hat{s}$$

$$\dot{S}_{mass} = \dot{m}\hat{s} = 0 \quad \text{(for no mass flow, closed system)}$$

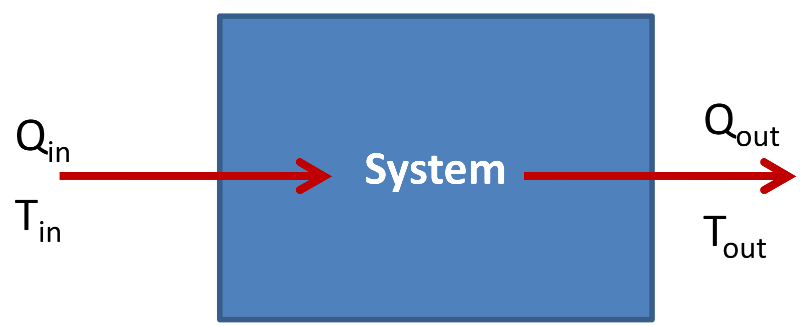
Entropy Balance for Closed Systems

Closed system=no mass flow

$$S_{in} - S_{out} + S_{gen} = \Delta S_{sys}$$

$$\sum \frac{Q_k}{T_k} + \sum m_{in}\hat{s} - \sum m_{out}\hat{s} + S_{gen} = \Delta S_{sys}$$

$$\left(\frac{Q_{in}}{T_{in}} + \cancelto{0}{m_{in}\hat{s}_{in}}\right) - \left(\frac{Q_{out}}{T_{out}} + \cancelto{0}{m_{out}\hat{s}_{out}}\right) + S_{gen} = \Delta S_{sys}$$



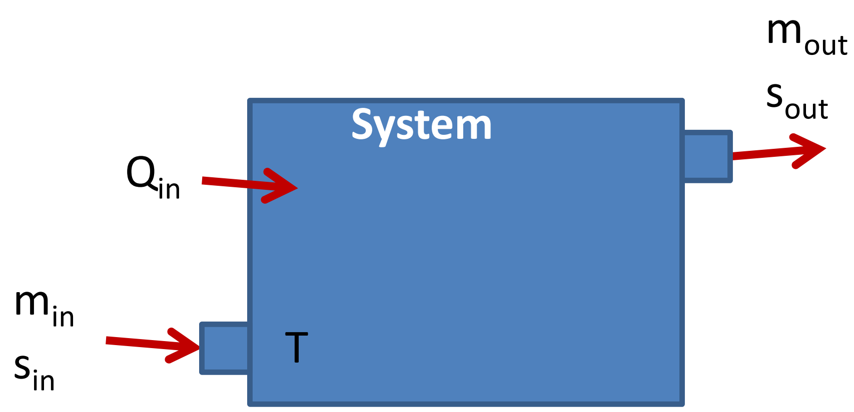
Entropy Balance for Open Systems with Control Volumes

Control vol.= a fixed vol. in space through which fluid flows.

$$S_{in} - S_{out} + S_{gen} = \Delta S_{sys}$$

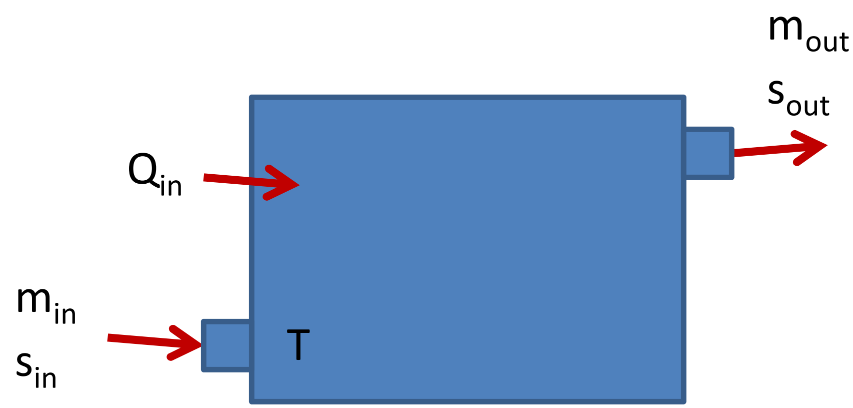
$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_{in}\hat{s}_{in} - \sum \dot{m}_{out}\hat{s}_{out} + \dot{S}_{gen} = \frac{dS_{sys}}{dt}$$

$$\left(\frac{\dot{Q}_{in}}{T_{in}} + \dot{m}_{in}s_{in}\right) - \left(\frac{\dot{Q}_{out}}{T_{out}} + \dot{m}_{out}s_{out}\right) + \dot{S}_{gen} = \Delta\dot{S}_{sys}$$



Entropy Balance for Open Systems with Control Volumes

<u>Steady State or Steady Flow</u>:
a process during which a fluid flows steadily through a control volume.
Turbines, compressors, nozzles, diffusers, heat exchanges, pipes, ducts usually operate steadily so they experience no entropy change.

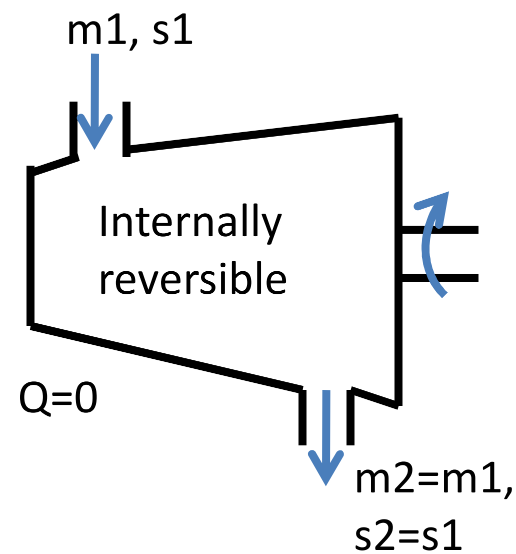


$$\frac{dS_{sys}}{dt} = 0 \quad \text{for steady flow process,}$$

$$\dot{S}_{gen} = \sum \dot{m}_{out} s_{out} - \sum \dot{m}_{in} s_{in} - \sum \frac{\dot{Q}_k}{T_k}$$

Isentropic Process

Entropy of a fixed mass does not change during a process that is internally reversible and adiabatic.

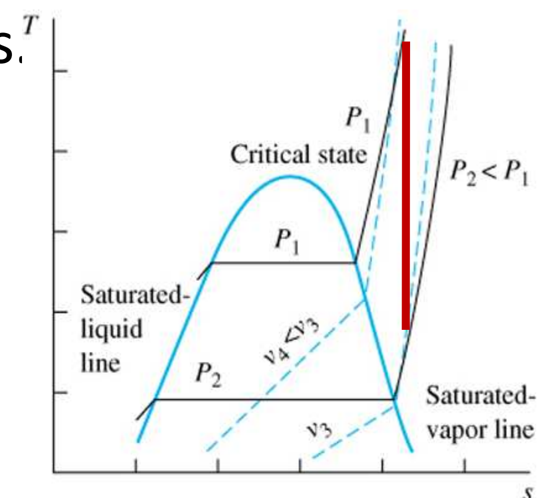


Entropy remains constant.

$$\Delta S = S_2 - S_1 = 0$$

$$S_{gen} = 0$$

- Pumps, turbines, nozzles and diffusers are essentially adiabatic.
- Serves as an idealized model for actual process.
- Defines efficiencies for processes to compare the actual performance of these devices to the performance under idealized conditions.



Summary

- Entropy is **not** conserved ($s_{gen} \geq 0$)

- Entropy balances

- Steady state/flow: $$\frac{dS_{sys}}{dt} = 0$$

- Isentropic: $$\Delta S = S_2 - S_1 = 0, \text{ closed system}$$
$$S_{gen} = 0, \text{ open system}$$