Lecture 21

Second Law Analysis of Closed Systems
The Laws of the Universe

**Conservation of Mass – The Continuity Equation**

\[ \sum_i m_i - \sum_e m_e = \frac{dm_{sys}}{dt} \]

**Conservation of Energy – The First Law of Thermodynamics**

\[ \dot{Q} - \dot{W} + \sum_i \dot{m}_i \left( h_i + \frac{V_i^2}{2g_c} + \frac{g}{g_c} z_i \right) - \sum_e \dot{m}_e \left( h_e + \frac{V_e^2}{2g_c} + \frac{g}{g_c} z_e \right) = \frac{dE_{sys}}{dt} \]

**The Entropy Balance – The Second Law of Thermodynamics**

\[ \sum_k \frac{\dot{Q}_k}{T_k} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{S}_p = \frac{dS_{sys}}{dt} \]
Isolated System – First Law

Recall that neither mass or energy cross the boundary of an isolated system. Therefore,

\[ \Delta E_{\text{isol}} = 0 \]

Energy is conserved.

Inside an isolated system, there can be subsystems interacting with the surroundings. Therefore,

\[ \Delta E_{\text{isol}} = \Delta E_{\text{sys}} + \Delta E_{\text{surr}} = 0 \]
Isolated System – Second Law

Recall that neither mass or energy cross the boundary of an isolated system. Therefore,

\[ \Delta S_{isol} = S_{P,isol} \]

For real-world processes the entropy change of the isolated system must increase.

Inside an isolated system, there can be subsystems interacting with the surroundings. Therefore,

\[ \Delta S_{isol} = \Delta S_{sys} + \Delta S_{surr} = S_{P,isol} \]

The Principle of Increase of Entropy
Die Energie der Welt ist constant. Die Entropie der Welt strebt einem Maximum zu.

Translation …
The energy of the world is constant. The entropy of the world tends towards a maximum.

Something to think about …
Is the world, as we know it, an isolated system?
What if we replace the word ‘world’ with ‘universe’?
The Principle of Increase of Entropy

\[ \Delta S_{isol} = \Delta S_{sys} + \Delta S_{surr} = S_{P,isol} \]

\[ \Delta S_{sys} \] May be positive or negative
\[ \Delta S_{surr} \] Must be big enough to ensure \( S_P \geq 0 \)

What are several examples where a system experiences a decrease in entropy?

What is the ‘entropy cost’ to the surroundings for each of these cases?
An operating gearbox has 200 hp at its input shaft while 190 hp are delivered to the output shaft. The gearbox has a steady state surface temperature of 140 F.

a) Sketch this system, showing all heat and work transfers along with their correct sign.

b) Write the 2\textsuperscript{nd} Law for this system. Begin with the general statement of the 2\textsuperscript{nd} Law and cancel terms that can be neglected.

c) Determine the entropy production rate. How does this change with surface temperature?
Piston-Cylinder Problem (w/Ideal Gas)

Neon undergoes a two-step process in a piston-cylinder assembly. The first process is isothermal compression from (1 atm, 80 F) to 100 psia. The second process is reversible and adiabatic expansion back to the initial pressure (1 atm). The gas constant for Neon is .0984 Btu/lbm-R. The isochoric heat capacity for Neon is .246 Btu/lbm-R.

a) Sketch this sequence of processes on Pv and Ts diagrams. Show how to use these diagrams to estimate the sign and relative magnitude of heat transfer and work transfer for each process.

b) Find the entropy change for each process.

c) Find the final temperature for each process.

d) Find the heat transfer and work transfer for each process.

e) Find the overall heat transfer and work transfer.
Sealed Vessel Problem (w/real fluid)

A closed, sealed, rigid container is filled with \(0.0583\ \text{ft}^3\) of liquid water and \(0.9417\ \text{ft}^3\) of water vapor in equilibrium at 1.00 \text{psia}. The vessel is then heated until its contents become saturated vapor.

a) What is the quality in the vessel at the initial state? Is this a mass fraction or a volume fraction?
b) What is the final temperature and pressure?
c) What heat transfer is required for this process?
d) Determine the total entropy produced for this process if the surface temperature of the vessel is maintained constant at 300 F. Is this process possible?
e) Sketch this process on \(Pv\) and \(Ts\) diagrams. Show lines of constant \(T\) and \(x\) on the \(Pv\) diagram. Show lines of constant \(P\) and \(x\) on the \(Ts\) diagram.
Diffusional Mixing
(w/incompressible fluid)

See Section 8.4 and Example 8.15 in your text.