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ME 209
Basic Thermodynamics (Lecture-13)

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Review of Lecture 12

- Understood TdS relations and their usefulness in evaluating entropy change between two states
- Appreciated the utility of T-S diagram.
- Appreciated solution of problems in II law.

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Agenda for Today

- Understand the concept of Availability
- Understand the development of Availability Balance equation

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Motivation for Second Law Analysis

- We have seen that when entropy production is there is a work penalty
- In technology, there is a constant quest for minimising this penalty
- To get a comparison between competing technologies, we need a method for assessment. This is commonly done by using second law efficiency
- While we can do everything by using the laws already defined, second law analysis or Availability/Exergy analysis helps in appreciating the interpretations better.

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Availability-I

- Availability, by definition, is the **maximum useful work** that can be extracted when a system at a given state is brought to equilibrium with the environment
- Since the reservoir with which the system most often interacts is atmosphere, the final state is in equilibrium with the surrounding. This state is called the Dead State
- 1 bar and 300 K, is the most commonly accepted dead state. However, it should be obvious that it can very much depend on the geographic location of the place and the season.

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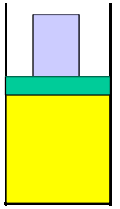
Availability-II

- First let us understand the term useful work
- Consider a piston moving dead weight as shown



- The work done by the system is used to lift weight as well as work against atmosphere
- The former is the useful work, while latter is the inevitable due to nature and cannot be extracted.
- Thus, of the total work $\int_1^2 pdV$, the unavailable work is $p_o \Delta V$.

$$\Rightarrow \int_1^2 pdV = p_0 \Delta V + W_U$$

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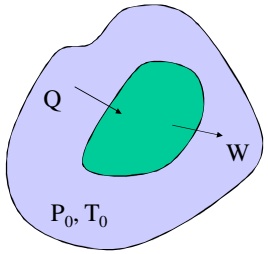
Availability-III

- First let a system and surrounding interact and have heat and work interactions as shown
- First law implies that

$$\Rightarrow \Delta E = Q - W$$

- If the heat interaction with the ambient be reversible, then

$$Q = T_0 \Delta S$$



$$\Rightarrow \Delta E = T_0 \Delta S - (W_u + p_0 \Delta V)$$

$$\Rightarrow W_u = -\Delta E + T_0 \Delta S - p_0 \Delta V$$

$$\Rightarrow W_u = -\Delta(E - T_0 S + p_0 V) = W_{u-max}$$ ← As there is no irreversibility

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Availability-IV

- Now, if we can define an availability function as

$$A = E - T_0 S + p_0 V$$

$$\Rightarrow W_{u-max} = -\Delta A$$

- Note that A is a property function and is dependent of system as well as environment properties
- Availability function can be viewed as a potential for doing work. As a consequence, for a process taking the present system state to the dead state, we can write

$$\Rightarrow W_{u\,max(1\to 0)} = A_1 - A_0 = (E - U_0) - T_0(S - S_0) + p_0(V - V_0)$$

- Availability would increase if work is done on the system and vice versa.

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Availability Balance Equation-I

- We can generate an availability balance equation by combining first and second laws.

$$\int_1^2 dQ - \int_1^2 dW = \Delta E \qquad \text{First Law} \qquad (1)$$

$$\int_1^2 \frac{dQ}{T} + S_p = \Delta S \qquad \text{Second Law} \qquad (2)$$

- Eq. (2) x T_0 implies

$$\int_1^2 T_0 \frac{dQ}{T} + T_0 S_p = T_0 \Delta S \qquad (3)$$

- Eq. (1) - Eq. (3) implies

$$\int_1^2 \left(1 - \frac{T_0}{T}\right) dQ - W - T_0 S_p = \Delta E - T_0 \Delta S = \Delta A - p_0 \Delta V \qquad (4)$$

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Availability Balance Equation-II

- Eq. (4) can be recast as

$$\Delta A = \int_1^2 \left(1 - \frac{T_0}{T}\right) dQ - (W - p_0 \Delta V) - T_0 S_p \qquad (5)$$

Change of availability

Availability transfer due to heat exchange

Availability transfer due to work exchange

Work Lost

Also called Irreversibility

- The above equation is useful to directly compute maximum useful work that can be extracted