ESO 201A: Thermodynamics

2016-2017-I semester

Exergy: part 2

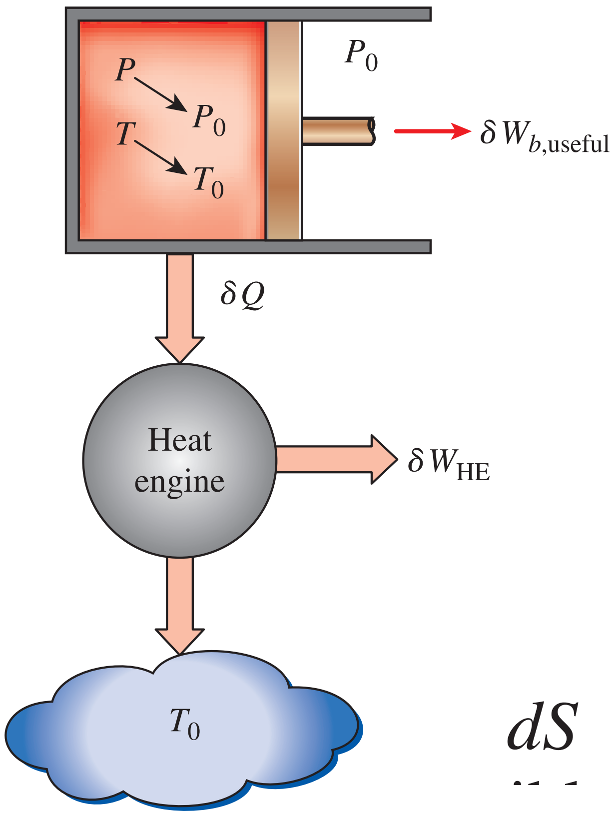
Dr. Jayant K. Singh
Department of Chemical Engineering
Faculty Building 469,
Telephone: 512-259-6141
E-Mail: jayantks@iitk.ac.in
home.iitk.ac.in/~jayantks/ESO201/index.html

Learning objectives

1. Examine the performance of engineering devices in light of the second law of thermodynamics.
2. Define *exergy*, which is the maximum useful work that could be obtained from the system at a given state in a specified environment.
3. Define *reversible work*, which is the maximum useful work that can be obtained as a system undergoes a process between two specified states.
4. Define the exergy destruction, which is the wasted work potential during a process as a result of irreversibilities.
5. Define the *second-law efficiency*.
6. Develop the exergy balance relation.
7. Apply exergy balance to closed systems and control volumes.

Exergy of a fixed mass (closed system)

System



Energy balance of the system

$$\underbrace{\delta E_{in} - \delta E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$-\delta Q - \delta W = dU$$

$$\delta W = P\,dV = (P - P_0)\,dV + P_0\,dV = \delta W_{b,\text{useful}} + P_0\,dV$$

A reversible process cannot involve heat transfer through finite temperature. It must occur through a reversible heat engine.

$$dS = \delta Q/T$$ For a reversible process

$$\eta_{th} = 1 - T_0/T,$$ Thermal efficiency of reversible HE operating between T and To

$$\delta W_{HE} = \left(1 - \frac{T_0}{T}\right)\delta Q = \delta Q - \frac{T_0}{T}\delta Q = \delta Q - (-T_0\,dS)$$

or

$$\delta Q = \delta W_{HE} - T_0\,dS$$

Exergy of a fixed mass (closed system)

Substituting expressions in the energy balance:

$$\delta W_{\text{total useful}} = \delta W_{\text{HE}} + \delta W_{b,\text{useful}} = -dU - P_0\, dV + T_0\, dS$$

Integrating from the given state to the dead state (with subscript 0)

$$W_{\text{total useful}} = (U - U_0) + P_0(V - V_0) - T_0(S - S_0)$$

where $W_{\text{total useful}}$ is the total useful work delivered as the system undergoes a reversible process from the given state to the dead state, which is *exergy* by definition.

Exergy of a fixed mass (closed system)

$$W_{\text{total useful}} = (U - U_0) + P_0(V - V_0) - T_0(S - S_0)$$

In general, the closed system may posses K.E or P.E, thus general expression of exergy :

$$X = (U - U_0) + P_0(V - V_0) - T_0(S - S_0) + m\frac{V^2}{2} + mgz$$

Unit mass basis:

$$\phi = (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

The exergy change for a closed system

$$\Delta X = X_2 - X_1 = m(\phi_2 - \phi_1) = (E_2 - E_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$$

$$= (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1) + m\frac{V_2^2 - V_1^2}{2} + mg(z_2 - z_1)$$

Unit mass basis

$$\Delta\phi = \phi_2 - \phi_1 = (u_2 - u_1) + P_0(v_2 - v_1) - T_0(s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

$$= (e_2 - e_1) + P_0(v_2 - v_1) - T_0(s_2 - s_1)$$

Exergy of a fixed mass (closed system)

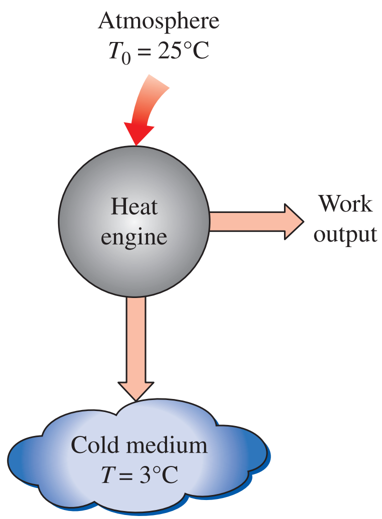
When properties of the system is not uniform

$$X_{\text{system}} = \int \phi \, \delta m = \int_V \phi \rho \, dV$$

Note exergy is a state property.

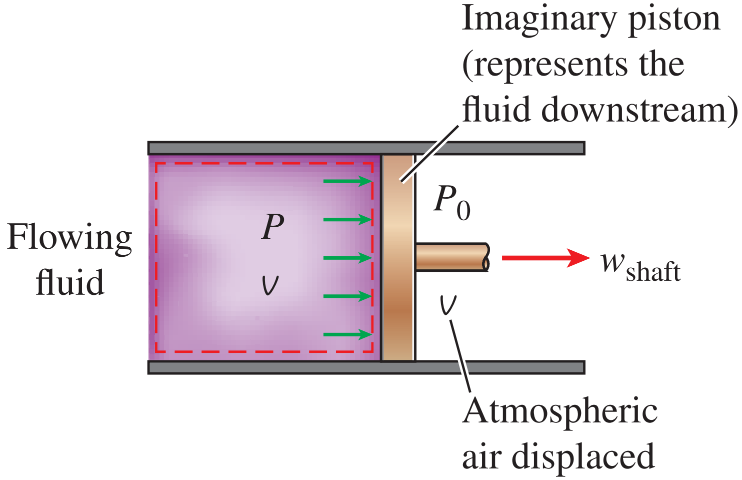
- Exergy for nozzles, compressors, turbine, pumps, heat exchange during, in a given environment, during steady state condition =0

- Exergy for a closed system can be positive or zero, never negative!
- A cold system with $T < T_{surr}$ (or $P < Po$) can contain exergy, as it can act as a sink



Exergy of a flow stream: Flow(stream) exergy

- Flow work is equivalent to boundary work by a fluid on the fluid downstream
- Exergy associated with flow work is equivalent to the exergy associated with the boundary work
- Flow work PV, work done against the atm $P_o V$



$$Pv = P_0 v + w_{shaft}$$

Exergy associated with flow energy

$$x_{flow} = Pv - P_0 v = (P - P_0)v$$

Exergy of a flow stream

$$x_{flowing\ fluid} = x_{nonflowing\ fluid} + x_{flow}$$

$$= (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz + (P - P_0)v$$

$$= (u + Pv) - (u_0 + P_0 v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

$$= (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

Exergy of a flow stream: Flow(stream) exergy

Flow exergy: $$\psi = (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

Exergy change:

$$\Delta\psi = \psi_2 - \psi_1 = (h_2 - h_1) - T_0(s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

- Exergy change of a closed system of fluid stream represents the maximum amount of useful work that can be done or minimum amount of useful work that is needed as the system changes from state 1 to state 2
- Represents the reversible work, Wrev
- Exergy of a closed system cannot be negative
- Exergy of a flow system can be negative at pressures below the environment pressure Po

Example

A 200-m^3 rigid tank contains compressed air at 1 MPa and 300 K. Determine how much work can be obtained from this air if the environment conditions are 100 kPa and 300 K.

Next lecture

1. Examine the performance of engineering devices in light of the second law of thermodynamics.
2. Define *exergy*, which is the maximum useful work that could be obtained from the system at a given state in a specified environment.
3. Define *reversible work*, which is the maximum useful work that can be obtained as a system undergoes a process between two specified states.
4. Define the exergy destruction, which is the wasted work potential during a process as a result of irreversibilities.
5. Define the *second-law efficiency*.
6. Develop the exergy balance relation.
7. Apply exergy balance to closed systems and control volumes.