Chapter 7

EXERGY(*availability or available energy*)

- **exergy is the measure of work potential of energy**
- the *useful work potential* of the system at the specified state and is called **exergy.**
- A system that is in equilibrium with its surroundings has zero exergy and is said to be at the *dead state.*
- The difference between the actual work W and the surroundings work W is called the **useful work** Wu

Dead state

- A system is said to be in the **dead state when it is in thermodynamic equilibrium** with the environment.
- At the dead state, a system is at the temperature and pressure of its environment (in thermal and mechanical equilibrium); it has no kinetic or potential energy relative to the environment
- (zero velocity and zero elevation above a reference level).

Cont..

- it does not react with the environment (chemically inert). Also, there are no unbalanced magnetic, electrical, and surface tension effects between the system and its surroundings.
- At the dead state, the useful work potential (exergy) of a system is zero

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$$W_u = W - W_{surr} = W - P_0(V_2 - V_1)$$

$$W_{surr} = P_0(V_2 - V_1)$$

Reversible work W is defined as *the maximum amount of useful work that can be produced (or the minimum work that needs to be supplied) as a system undergoes a process between the specified initial and final states.*

Any difference between the reversible work W_{rev} and the useful work W is due to the irreversibilitys present during the process, and this difference is called **irreversibility** I.

SECOND-LAW EFFICIENCY

- The *second-law efficiency* is a measure of the performance of a device relative to the performance under reversible conditions for the same end states.
- **second-law efficiency** h as the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions
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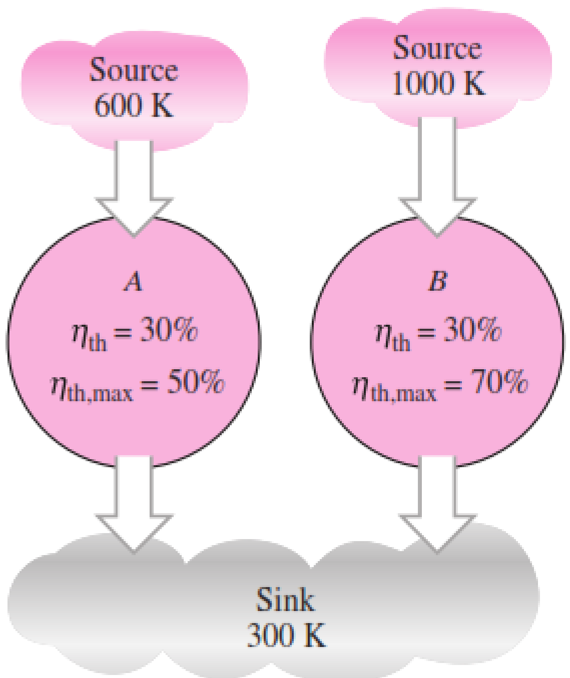


$$\eta_{rev,A} = \left(1 - \frac{T_L}{T_H}\right)_A = 1 - \frac{300\text{ K}}{600\text{ K}} = 50\%$$

$$\eta_{rev,B} = \left(1 - \frac{T_L}{T_H}\right)_B = 1 - \frac{300\text{ K}}{1000\text{ K}} = 70\%$$

$$\eta_{II} = \frac{\eta_{th}}{\eta_{th,rev}} \qquad \text{(heat engines)}$$

Based on this definition, the second-law efficiencies of the two heat engines discussed above are

$$\eta_{II,A} = \frac{0.30}{0.50} = 0.60 \quad \text{and} \quad \eta_{II,B} = \frac{0.30}{0.70} = 0.43$$

cont....

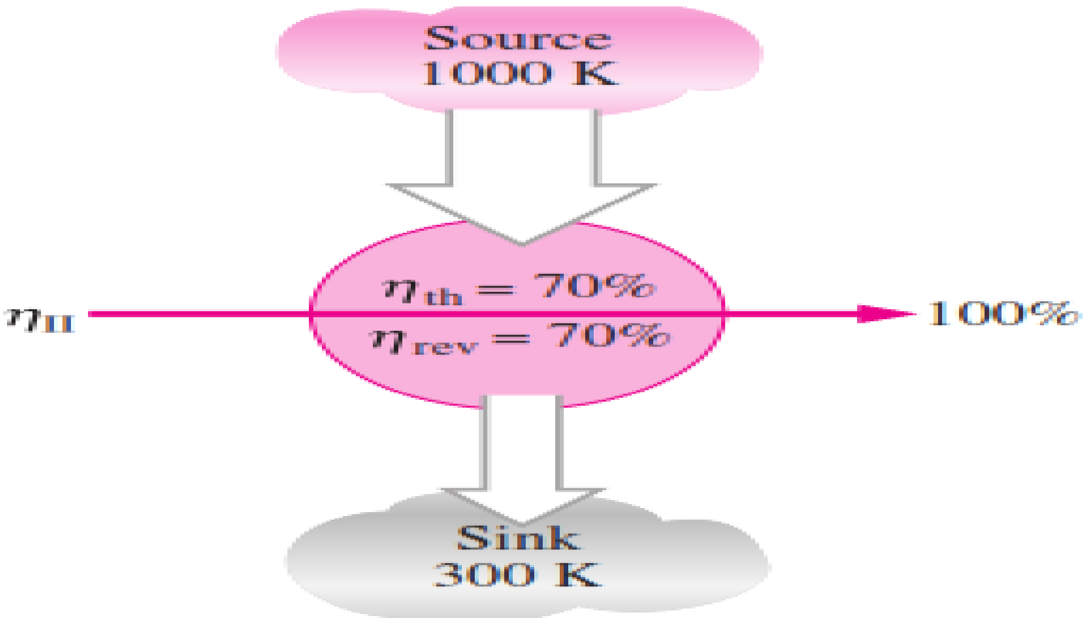
The second-law efficiency can also be expressed as the ratio of the useful work output and the maximum possible (reversible) work output:

$$\eta_{II} = \frac{W_u}{W_{rev}} \qquad \text{(work-producing devices)}$$

$$\eta_{II} = \frac{W_{rev}}{W_u} \qquad \text{(work-consuming devices)}$$

For cyclic devices such as refrigerators and heat pumps, it can also be expressed in terms of the coefficients of performance as

$$\eta_{II} = \frac{\text{COP}}{\text{COP}_{rev}} \qquad \text{(refrigerators and heat pumps)}$$



EXERGY TRANSFER BY

1. Heat
2. Work
3. Mass

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- Exergy, like energy, can be transferred to or from a system in three forms: *heat, work,* and *mass flow.* Exergy transfer is recognized at the system boundary as exergy crosses it, and it represents the exergy gained or lost by a system during a process. The only two forms of exergy interactions associated with a fixed mass or closed system are *heat transfer* and *work.*

Exergy transfer by heat: $X_{heat} = \left(1 - \frac{T_0}{T}\right)Q$ (kJ)

Exergy transfer by work: $X_{work} = \begin{cases} W - W_{surr} & \text{(for boundary work)} \\ W & \text{(for other forms of work)} \end{cases}$

Exergy Transfer by Mass, *m*

Mass contains *exergy* as well as energy and entropy, and the exergy, energy, and entropy contents of a system are proportional to mass. Also, the rates of exergy, entropy, and energy transport into or out of a system are proportional to the mass flow rate. Mass flow is a mechanism to transport exergy, entropy, and energy into or out of a system. When mass in the amount of m enters or leaves a system, exergy in the amount of $m\psi$, where $\psi = (h - h_0) - T_0(s - s_0) + V^2/2 + gz$, accompanies it. That is,

Exergy transfer by mass: $X_{mass} = m\psi$

EXERGY DESTRUCTION

- which is the wasted work potential during a process as a result of irreversibilities.
- Exergy destroyed represents the lost work potential and is also called the *irreversibility or lost work..*
- No exergy is destroyed during a reversible process ($X_{destroyed,rev}=0$)

EXERGY BALANCE: CLOSED SYSTEMS

- the *exergy change of a system* during a process is less than the *exergy transfer* by an amount equal to the *exergy destroyed during the process within the system boundaries.*
- the **exergy balance can be stated as *the*** *exergy change of a system during a process is equal to the difference between the net exergy transfer through the system boundary and the exergy destroyed within the system boundaries as a result of irreversibilities.*

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$$\begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{entering}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{leaving}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{destroyed}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total exergy}\\ \text{of the system}\end{pmatrix}$$

$$X_{\text{in}} - X_{\text{out}} - X_{\text{destroyed}} = \Delta X_{\text{system}}$$

General:

$$\underbrace{X_{\text{in}} - X_{\text{out}}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{X_{\text{destroyed}}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{\text{system}}}_{\substack{\text{Change}\\ \text{in exergy}}} \qquad (\text{kJ})$$

or, in the **rate form,** as

General, rate form:

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{\text{destroyed}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{dX_{\text{system}}/dt}_{\substack{\text{Rate of change}\\ \text{in exergy}}} \qquad (\text{kW})$$

EXERGY BALANCE: CONTROL VOLUMES

- The exergy balance relations for control volumes differ from those for closed systems in that they involve one more mechanism of exergy transfer: *mass flow across the boundaries.*
- taking the positive direction of heat transfer to be to the system and the positive direction of work transfer to be from the system, the general exergy balance relations

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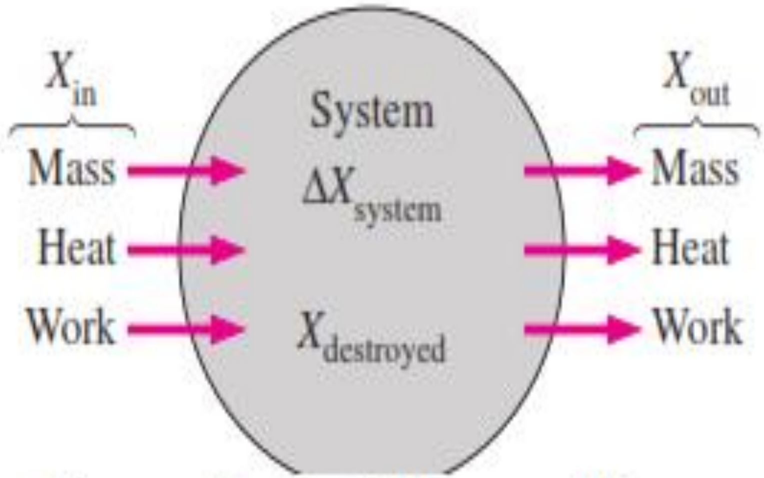

$$X_{heat} - X_{work} + X_{mass,in} - X_{mass,out} - X_{destroyed} = (X_2 - X_1)_{CV}$$

$$\sum\left(1 - \frac{T_0}{T_k}\right)Q_k - [W - P_0(V_2 - V_1)] + \sum_{in} m\psi - \sum_{out} m\psi - X_{destroyed} = (X_2 - X_1)_{CV}$$