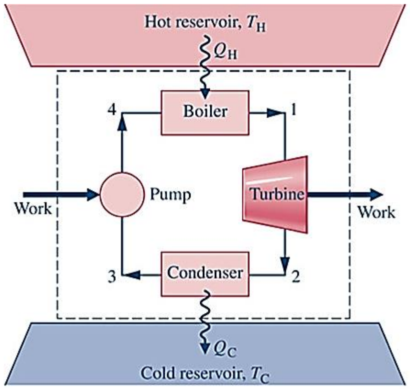
بسم الله الرحمن الرحيم

Thermodynamics (2)



Faculty of Engineering
Mechanical Engineering Dept.

Lecture (3)

on

Availability (Exergy) and Irreversibility

By

Dr. Emad M. Saad

Mechanical Engineering Dept.
Faculty of Engineering
Fayoum University

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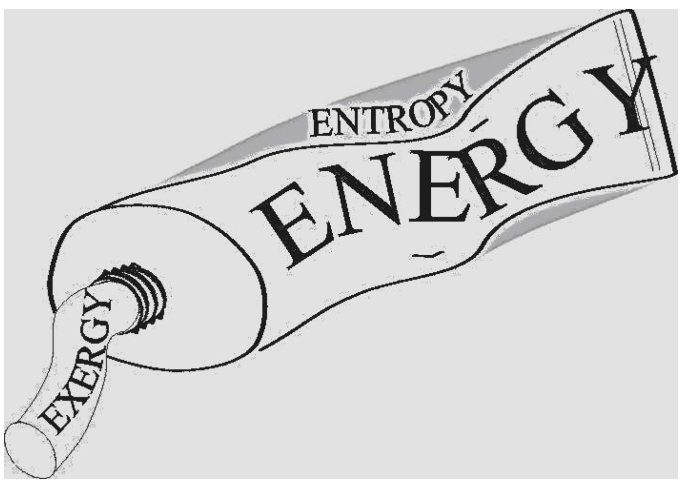
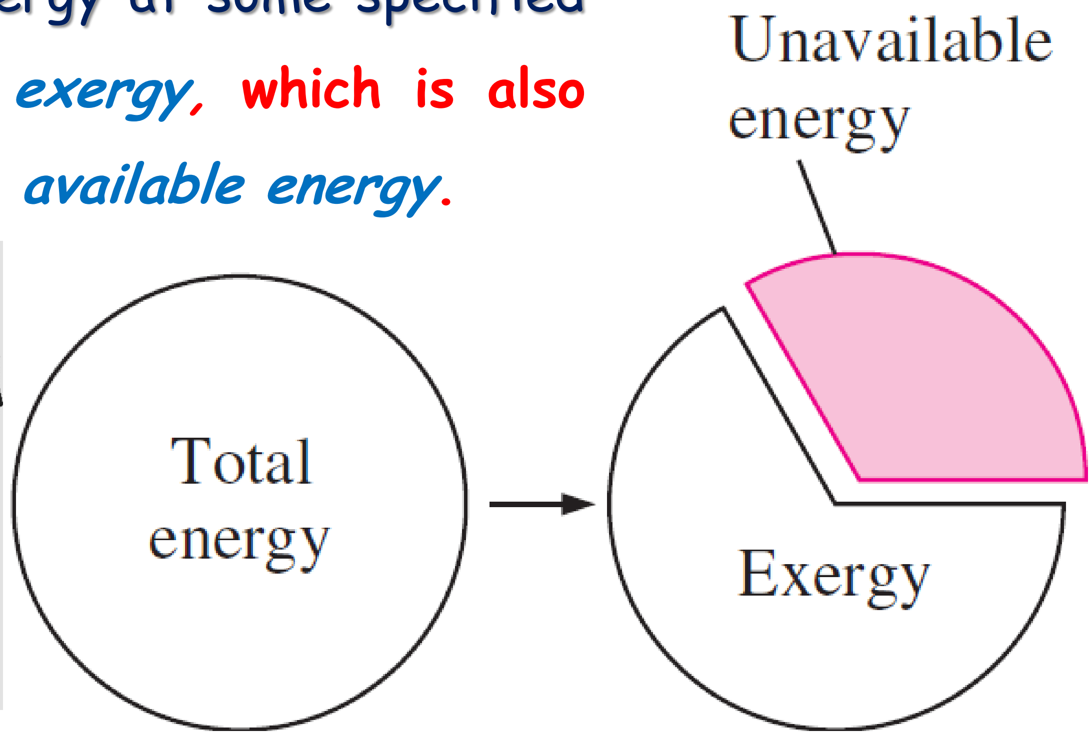
8–1 ▪ EXERGY: WORK POTENTIAL OF ENERGY

It would be very desirable to have a property to enable us to determine the useful work potential of a given amount of energy at some specified state. **This property is *exergy*, which is also called the *availability* or *available energy*.**





Example 1: Exergy Transfer from a Furnace

Consider a large furnace that can transfer heat at a temperature of 2000 R at a steady rate of 3000 Btu/s. Determine the rate of exergy flow associated with this heat transfer. Assume an environment temperature of 77°F.

The thermal efficiency of this reversible heat engine is

$$\eta_{th,max} = \eta_{th,rev} = 1 - \frac{T_L}{T_H} = 1 - \frac{T_0}{T_H} = 1 - \frac{537\text{ R}}{2000\text{ R}} = 0.732 \text{ (or } 73.2\%)$$

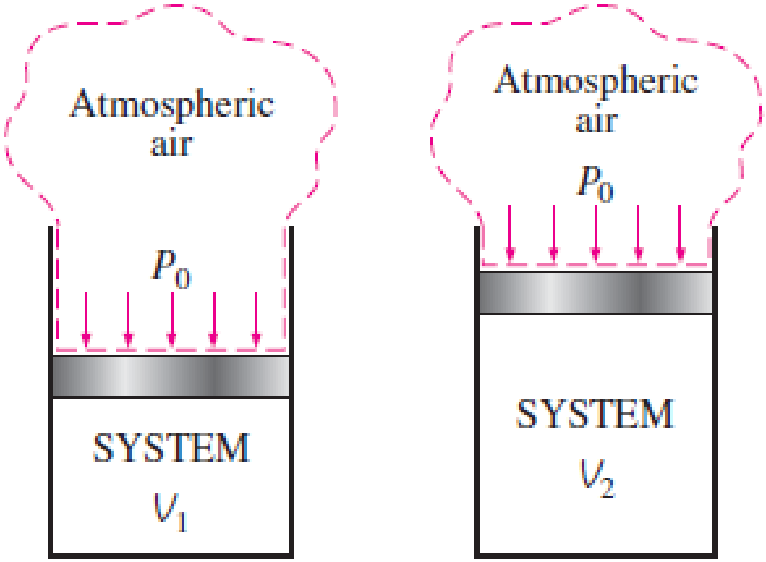
$$\dot{W}_{max} = \dot{W}_{rev} = \eta_{th,rev}\,\dot{Q}_{in} = (0.732)(3000\text{ Btu/s}) = \mathbf{2196\text{ Btu/s}}$$

Notice that 26.8% of the heat transferred from the furnace is not available for doing work. The portion of energy that cannot be converted to work is called unavailable energy

Surroundings work

This work, which cannot be recovered and utilized for any useful purpose, is equal to the atmospheric pressure P_0 times the volume change of the system,

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



Useful work

The difference between the actual work W and the surroundings work W_{surr} is called the useful work W_u:

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

Reversible work

W_{rev} 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.

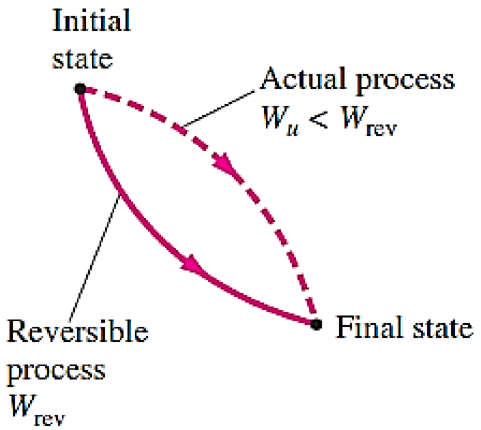
Any difference between the reversible work W_{rev} and the useful work W_u is due to the irreversibilities present during the process, and this difference is called **irreversibility** *I*. It is expressed as

$$I = W_{rev,out} - W_{u,out} \quad \text{or} \quad I = W_{u,in} - W_{rev,in}$$

The irreversibility is equivalent to the *exergy destroyed*,

$W_{rev} \geq W_u$ for work-producing devices

$W_{rev} \leq W_u$ for work-consuming devices.



$I = W_{rev} - W_u$

Example 2: The Rate of Irreversibility of a Heat Engine

A heat engine receives heat from a source at 1200 K at a rate of 500 kJ/s and rejects the waste heat to a medium at 300 K (Fig. 8–11). The power output of the heat engine is 180 kW. Determine the reversible power and the irreversibility rate for this process.

$$\dot{W}_{rev} = \eta_{th,rev}\,\dot{Q}_{in} = \left(1 - \frac{T_{sink}}{T_{source}}\right)\dot{Q}_{in} = \left(1 - \frac{300\text{ K}}{1200\text{ K}}\right)(500\text{ kW}) = \mathbf{375\text{ kW}}$$

$$\dot{I} = \dot{W}_{rev,out} - \dot{W}_{u,out} = 375 - 180 = \mathbf{195\text{ kW}}$$

Notice that 26.8% of the heat transferred from the furnace is not available for doing work. The portion of energy that cannot be converted to work is called unavailable energy

8–3 ▪ SECOND-LAW EFFICIENCY, η_{II}

Second-law efficiency η_{II} as the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions

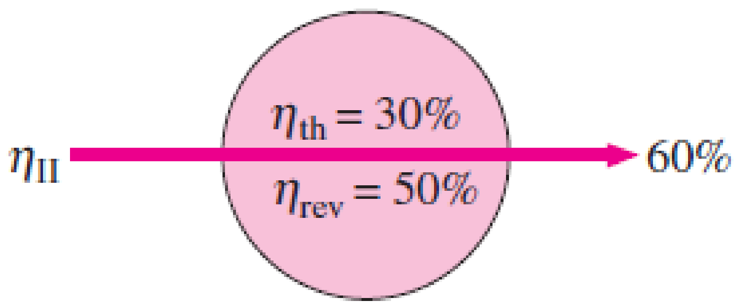
$$\eta_{II} = \frac{\eta_{th}}{\eta_{th,rev}} \qquad \text{(heat engines)}$$

Second-law efficiency is a measure of the performance of a device relative to its performance under reversible conditions.

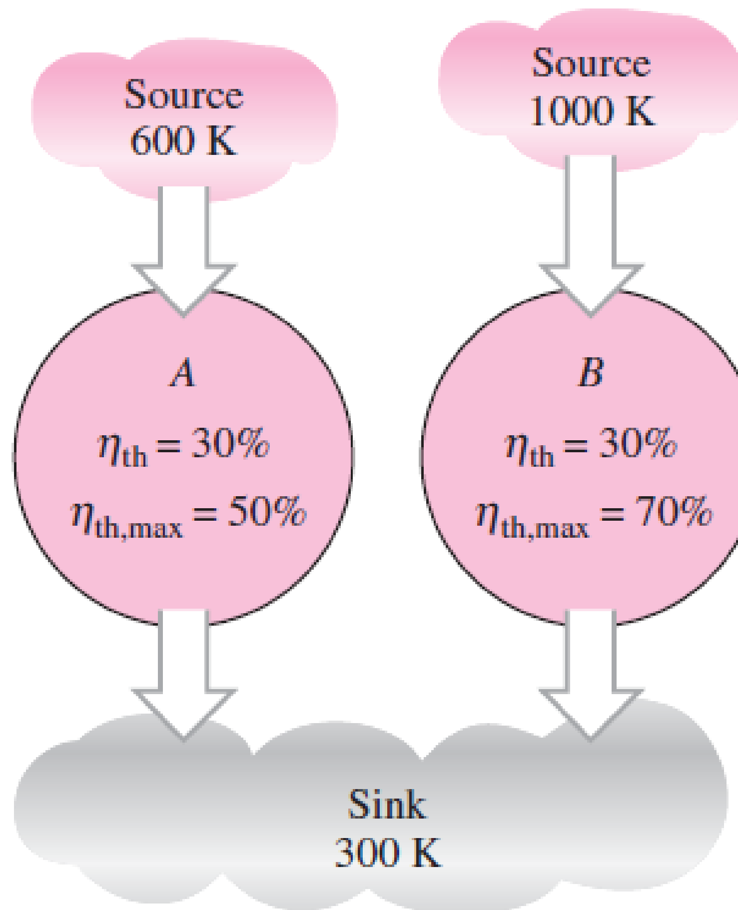
8–3 ▪ SECOND-LAW EFFICIENCY, η_{II}

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

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



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

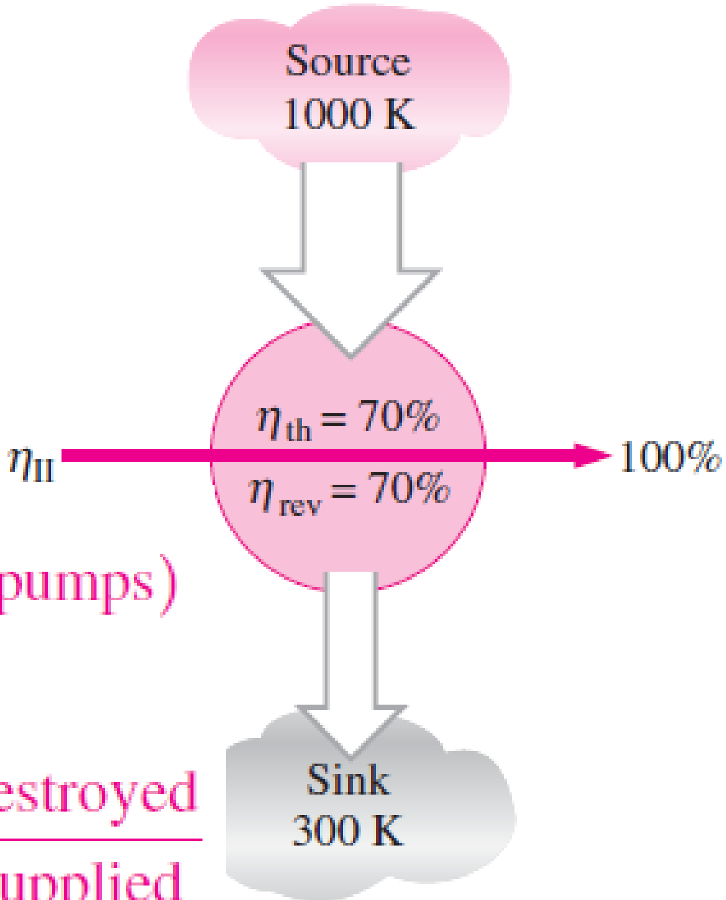


8–3 ▪ SECOND-LAW EFFICIENCY, η_{II}

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

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

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



$$\eta_{II} = \frac{\text{Exergy recovered}}{\text{Exergy supplied}} = 1 - \frac{\text{Exergy destroyed}}{\text{Exergy supplied}}$$

Thank you