ESO 201A: Thermodynamics

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Exergy: part1

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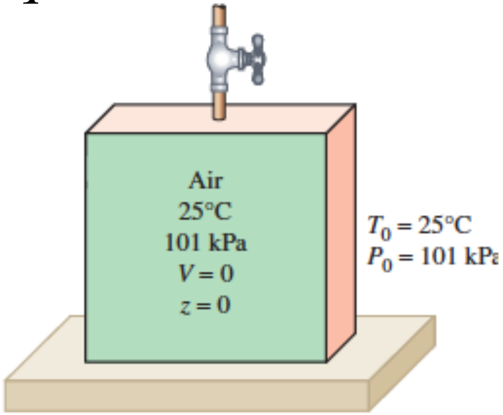
Learning objectives

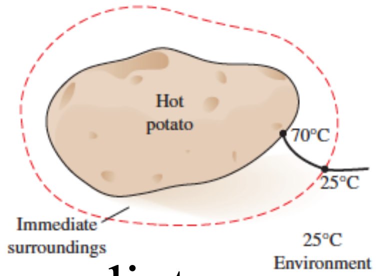
- Examine the performance of engineering devices in light of the second law of thermodynamics.
- Define *exergy*, which is the maximum useful work that could be obtained from the system at a given state in a specified environment.
- Define *reversible work*, which is the maximum useful work that can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

Exergy

Exergy (availability or available energy): useful work potential of a given amount of energy at some specified state.

Equilibrium state – dead state





Temperature of immediate surrounding changes from that of hot potato to environment. At the end of the process the system reaches a dead state

A *system delivers the maximum possible work as it undergoes a reversible process from the specified initial state to the state of its environment, that is, the dead state.*

This represents the *useful work potential* of the system at the specified state and is called exergy.

Exergy represents the upper limit on the amount of work a device can deliver without violating any thermodynamic laws.

Exergy transfer from a furnace

Consider a large furnace that can transfer heat at a temperature of 1100 ^{o}C at a steady rate of 3000 kJ/s. Determine the rate of exergy flow associated with this heat transfer. Assume an environment temperature of 25 ^{o}C

Exergy (work potential)

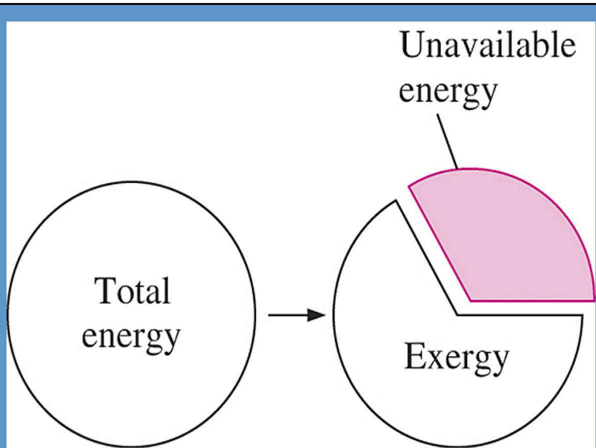
Kinetic energy and potential energy are forms of mechanical energy and thus can be converted to work entirely!

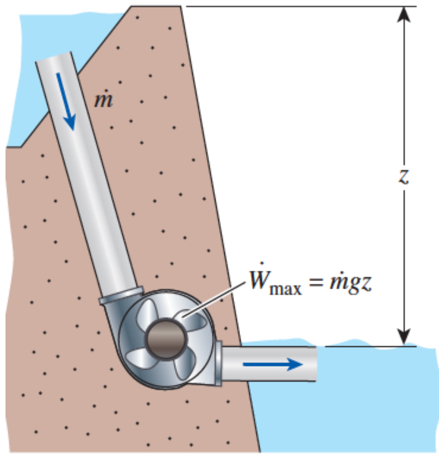
Exergy of kinetic energy: $x_{ke} = ke = \frac{V^2}{2} \quad (kJ/kg)$

Exergy of potential energy: $x_{pe} = pe = gz \quad (kJ/kg)$

Internal energy *u* and enthalpy *h* are not entirely available to work

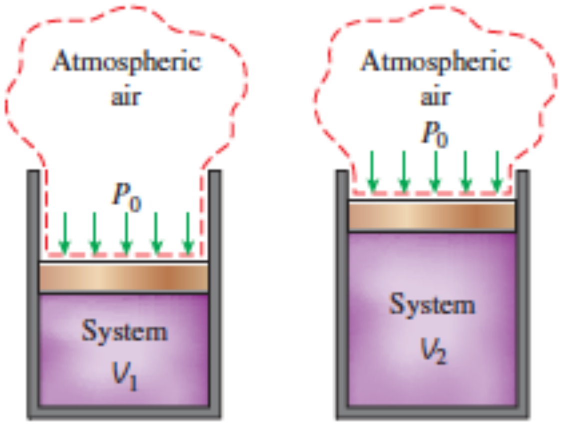
Unavailable energy is the portion of energy that cannot be converted to work by even a reversible heat engine.





The work potential or exergy of potential energy is equal to the potential energy itself.

Reversible work and Irreversibility



As a closed system expands, surrounding work (Wsurr) is needed to push the atmospheric air out of the way

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

Useful work = actual work – surrounding work

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

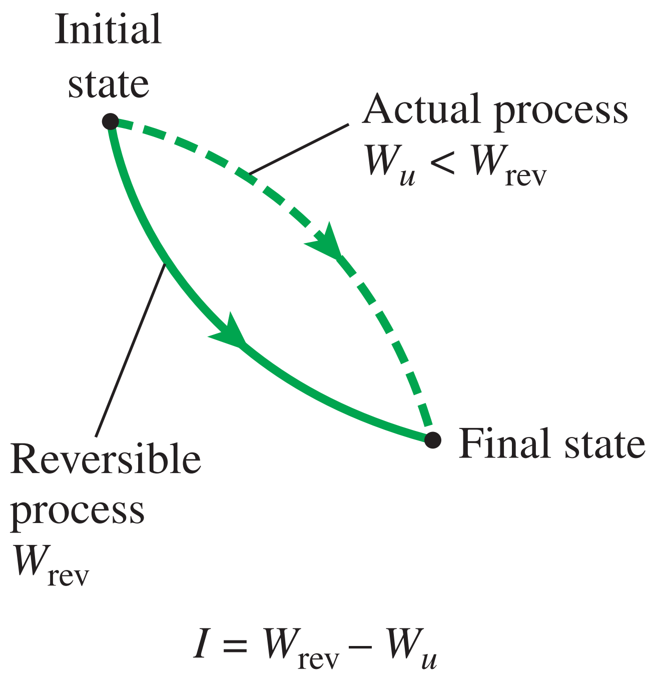
- W_{surr} can be loss or gain
- W_u=W for a constant volume system

Reversible work and Irreversibility

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

- **if the final state is dead, Wrev=exergy**
- The difference between Wrev and useful work is called irreversibility, which is equivalent to exergy destroyed.

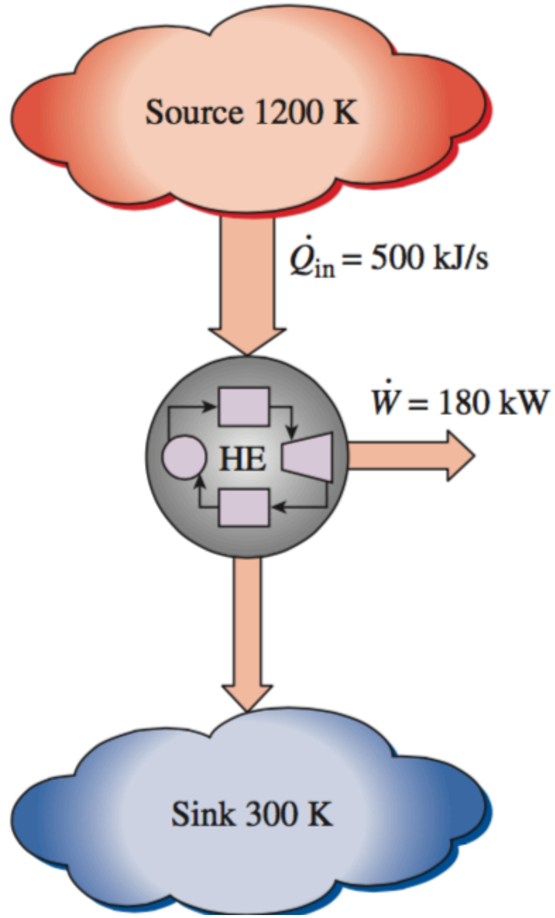
$$I = W_{\text{rev,out}} - W_{u,\text{out}} \quad \text{or} \quad I = W_{u,\text{in}} - W_{\text{rev,in}}$$



The performance of a system can be improved by minimizing the irreversibility

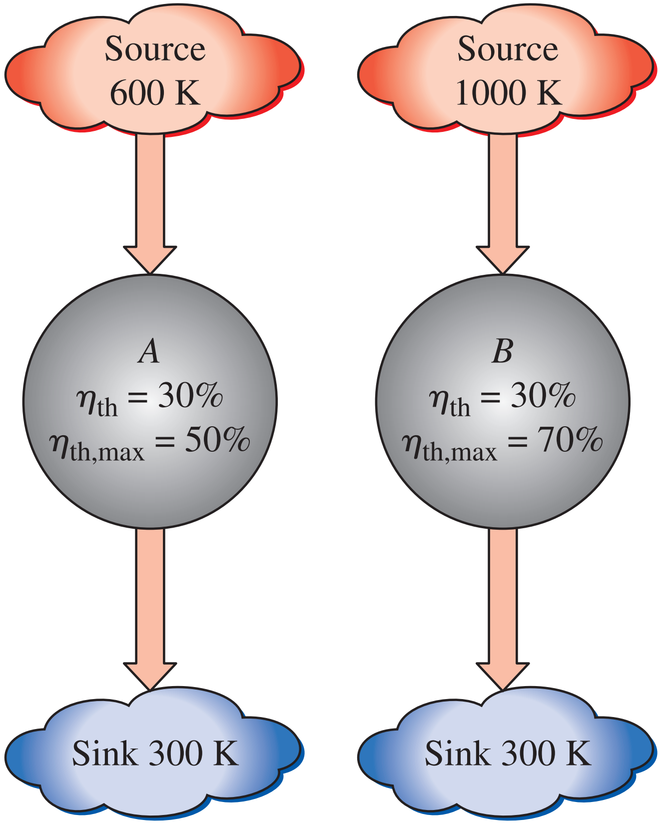
Example

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) The power output of the heat engine is 180 kW. Determine the reversible power and the irreversibility rate for this process.



Realistic measure of performance

Thermal efficiency or COP based on 1st law- doesn't address the best performance



$$\eta_{rev,A} = \left(1 - \frac{T_L}{T_H}\right)_A = 1 - \frac{300\text{ K}}{600\text{ K}} = 0.50 \text{ or } 50\%$$

$$\eta_{rev,B} = \left(1 - \frac{T_L}{T_H}\right)_B = 1 - \frac{300\text{ K}}{1000\text{ K}} = 0.70 \text{ or } 70\%$$

Though same thermal efficiency but have different reversible engine efficiency. B's performance seems to be inferior to A.

1st law is not sufficient to measure realistic performance of a device

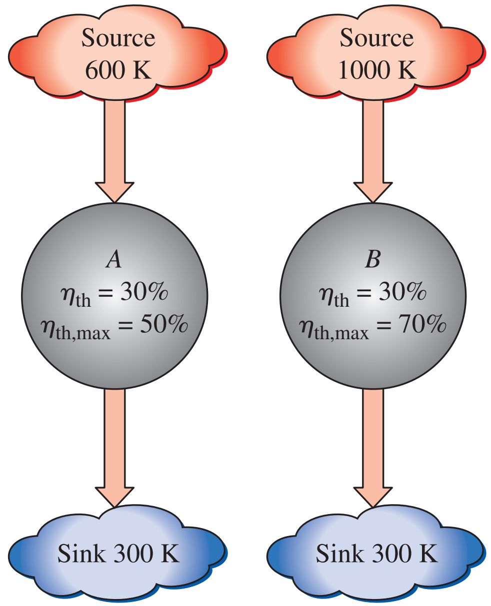
Second law efficiency

η_{II}: Second-law efficiency is a measure of the performance of a device relative to its performance under reversible conditions.

Defined as the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions

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

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



The second law efficiency can also be expressed as:

$$\eta_{II} = \frac{W_u}{W_{rev}}$$

General expression for work producing devices, turbine, piston-cylinder,

Note, it cannot exceed 100

Second law efficiency

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

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

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

The definitions for the second-law efficiency do not apply to devices that are not intended to produce or consume work. Therefore, we need a more general definition.

General expression: second law efficiency in terms of exergy or work potential

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

Next lecture

- Examine the performance of engineering devices in light of the second law of thermodynamics.
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