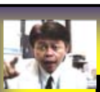


Thermodynamics Lecture Series

Assoc. Prof. Dr. J.J.

Second Law – Quality of Energy - Carnot Engines

Applied Sciences Education Research Group (ASERG)
Faculty of Applied Sciences
Universiti Teknologi MARA

email: drjjlanita@hotmail.com
http://www3.uitm.edu.my/staff/drjj/

Quotes

- It does not matter how slowly you go, so long as you do not stop.
  --Confucius
- To be wronged is nothing unless you continue to remember it.
  --Confucius

Introduction - Objectives

Objectives:

1. *State factors of irreversibilities in real cyclic processes.*
2. *Explain how each of the irreversibility factor causes energy to degrade.*
3. *State what is the purpose to introduce a dream engine*
4. *Describe and explain the processes in a Carnot engine.*

Introduction - Objectives

Objectives:

5. *Apply the first law in each of the process of the Carnot engine.*
6. *Sketch a pressure-volume diagram representing a Carnot cycle and label all the energy interaction for a steam power plant.*
7. *Sketch a pressure-volume diagram representing a reversed Carnot cycle and label all the energy interaction for a refrigerator or heat pump.*

Introduction - Objectives

Objectives:

8. *State the Carnot principles.*
9. *Use result of Carnot principles to obtain performances for a Carnot steam power plant, Carnot refrigerator and a Carnot heat pump.*
10. *Compare performances of Carnot engines to performances of real engines.*
11. *Solve problems related to Carnot engines.*

Review - First Law

- All processes must obey energy conservation
- Processes which do not obey energy conservation cannot happen.
- Processes which do not obey mass conservation cannot happen

Piston-cylinders, rigid tanks
Turbines, compressors,
Nozzles, heat exchangers

Review - First Law

Energy Entering a system	-	Energy Leaving a system	=	Change of system's energy

Energy Balance

$E_{in} - E_{out} = \Delta E_{sys}$, kJ or

$e_{in} - e_{out} = \Delta e_{sys}$, kJ/kg or

$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys}, kW$

Review - First Law

Mass Entering a system	-	Mass Leaving a system	=	Change of system's mass

Mass Balance

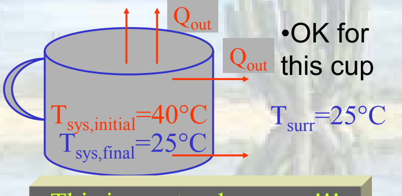
$m_{in} - m_{out} = \Delta m_{sys}$, kg or

$\dot{m}_{in} - \dot{m}_{out} = \Delta \dot{m}_{sys}, kg/s$

Second Law

- First Law involves quantity or amount of energy to be conserved in processes

$0 - q_{out} + 0 - 0 = -\Delta u = u_1 - u_2$, kJ/kg

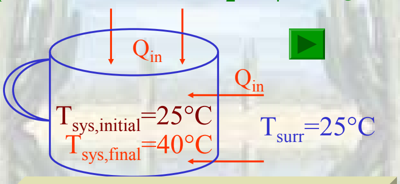


•OK for this cup

This is a natural process!!! Q flows from high T to low T medium until thermal equilibrium is reached

Second Law

$q_{in} - 0 + 0 - 0 = \Delta u = u_2 - u_1$, kJ/kg



This is NOT a natural process!!! Q does not flow from low T to high T medium. Never will the coffee return to its initial state.

Second Law

- First Law is not sufficient to determine if a process can or cannot proceed

•Introduce the second law of thermodynamics – processes occur in its natural direction.

- Heat (thermal energy) flows from high temperature medium to low temperature medium.
- Energy has quality & quality is higher with higher temperature. More work can be done.

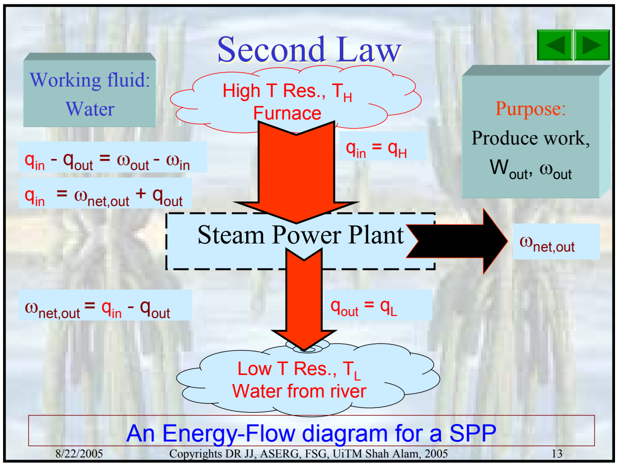
Second Law

Considerations:

•Work can be converted to heat directly & totally.

•Heat cannot be converted to work directly & totally.

- Requires a special device – heat engine.



Second Law

Thermal Efficiency for steam power plants

$$\eta = \frac{\text{desired output}}{\text{required input}} = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}}$$

$$\eta = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{Q}_{in}} = \frac{\dot{Q}_{in}}{\dot{Q}_{in}} - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}$$

$$= 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}$$

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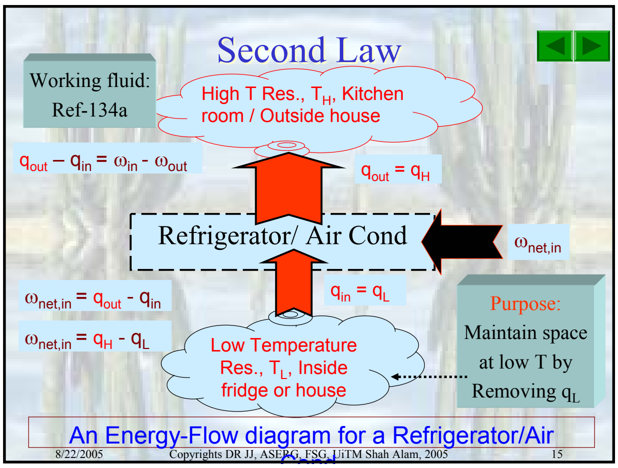

Second Law

Coefficient of Performance for a Refrigerator

$$COP_R = \frac{\text{desired output}}{\text{required input}} = \frac{q_{in}}{\omega_{net,in}}$$

$$COP_R = \frac{q_{in}}{\omega_{net,in}} = \frac{q_{in}}{q_{out} - q_{in}}$$

Divide top and bottom by q_{in}

$$= \frac{1}{\frac{q_{out}}{q_{in}} - \frac{q_{in}}{q_{in}}} = \frac{1}{\frac{q_{out}}{q_{in}} - 1} = \frac{1}{\frac{q_H}{q_L} - 1}$$

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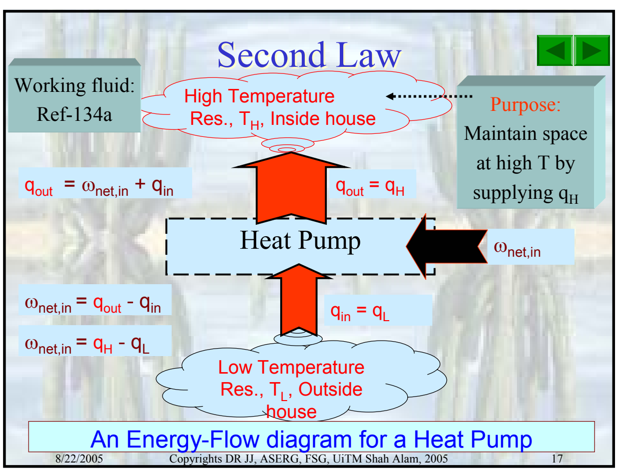

Second Law

Coefficient of Performance for a Heat Pump

$$COP_{HP} = \frac{\text{desired output}}{\text{required input}} = \frac{q_{out}}{\omega_{net,in}}$$

$$COP_{HP} = \frac{q_{out}}{\omega_{net,in}} = \frac{q_{out}}{q_{out} - q_{in}}$$

$$= \frac{1}{\frac{q_{out}}{q_{out}} - \frac{q_{in}}{q_{out}}} = \frac{1}{1 - \frac{q_{in}}{q_{out}}} = \frac{1}{1 - \frac{q_L}{q_H}}$$

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Second Law – Energy Degrade

What is the maximum performance of real engines if it can never achieve 100%??

•Processes in real devices are irreversible

Factors of irreversibilities

- less heat can be converted to work
  - Friction between 2 moving surfaces
  - Processes happen too fast
  - Non-isothermal heat transfer

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Second Law – Energy Degrade

What is the maximum performance of real engines if it can never achieve 100%??

Factors of irreversibilities

- Friction between 2 moving surfaces
  - Heat generated during compression causes wall of cylinder to increase
  - Work supplied by surrounding is lost to warming of cylinder walls.
  - At end of cycle, if piston can be returned to original state, surrounding cannot be returned to original state (work in not equal to work out).

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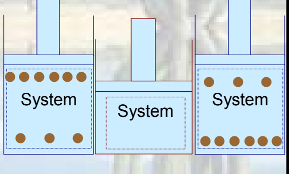
Second Law – Energy Degrade

What is the maximum performance of real engines if it can never achieve 100%??

Factors of irreversibilities

- Processes happen too fast
  - Fast compression causes pressure near piston to be higher than pressure at bottom due to molecules near piston not enough time to react.
  - Hence more work is required to compress system. (work in bigger than work out)



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Second Law – Energy Degrade

What is the maximum performance of real engines if it can never achieve 100%??

Factors of irreversibilities

- Heat transfer at finite temperature difference
  - Surrounding loses Q during warming of coke.
  - Surrounding loses W but supply Q during return process.
  - After cycle, surrounding not returned to original state since the work supplied by surrounding was not returned to the surrounding.

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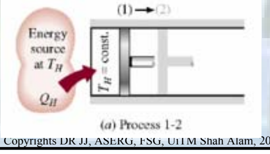
Second Law – Dream Engine

Carnot Cycle-All processes in cycle is completely reversible. Hence performance is the highest.

- **Isothermal expansion**
  - ❖Slow adding of Q resulting in work done by system (system expand)
  - ❖$Q_{in} – W_{out} = \Delta U = 0$. So, $Q_{in} = W_{out}$. Pressure drops.



(a) Process 1-2

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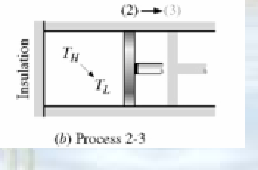
Second Law – Dream Engine

Carnot Cycle

- **Adiabatic expansion**
  - ❖$0 – W_{out} = \Delta U$. Final U smaller than initial U.
  - ❖T & P drops.



(b) Process 2-3

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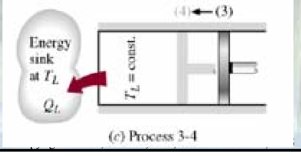
Second Law – Dream Engine

Carnot Cycle

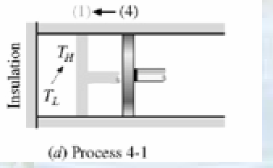
- Isothermal compression
  - ❖Work done on the system
  - ❖Slow rejection of Q
  - ❖- $Q_{out} + W_{in} = \Delta U = 0$. So, $Q_{out} = W_{in}$.
  - ❖Pressure increases.



Second Law – Dream Engine

Carnot Cycle

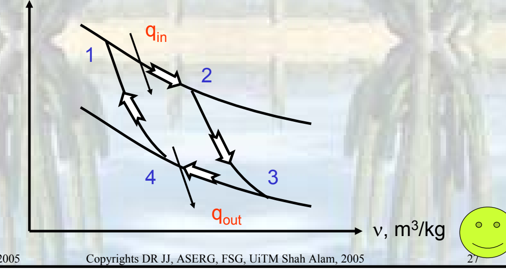
- Adiabatic compression
  - ❖$0 + W_{in} = \Delta U$. Final U higher than initial U.
  - ❖T & P increases.



Second Law – Dream Engine

Carnot Cycle

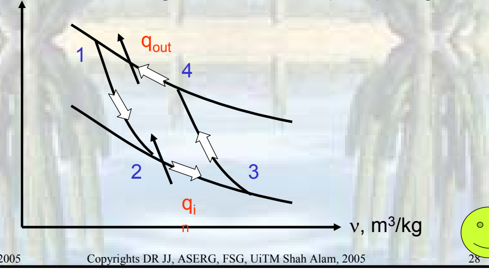
P - v diagram for a Carnot (ideal) power plant



Second Law – Dream Engine

Reverse Carnot Cycle

P - v diagram for a Carnot (ideal) refrigerator



Second Law – Dream Engine

Carnot Principles

- For heat engines in contact with the same hot and cold reservoir
  - ❖All reversible engines have the same performance.
  - ❖Real engines will have lower performance than the ideal engines.

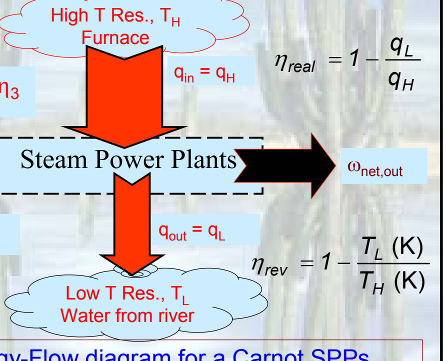
$$\left(\frac{q_H}{q_L}\right)_{rev} = \frac{T_H\ (K)}{T_L\ (K)}$$

Second Law

Working fluid: Not a factor

P1: $\eta_1 = \eta_2 = \eta_3$

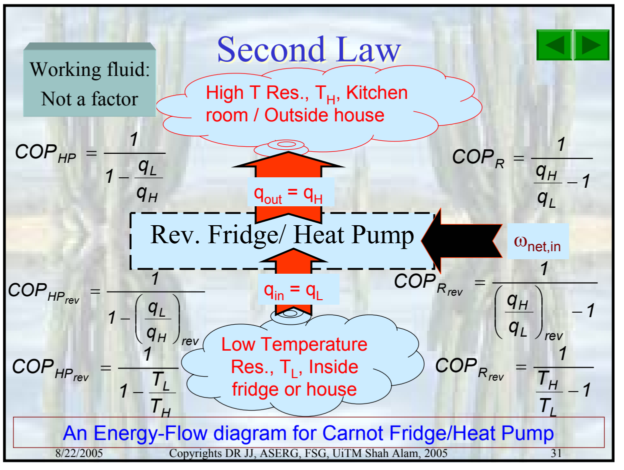
P2: $\eta_{real} < \eta_{rev}$



$$\eta_{real} = 1 - \frac{q_L}{q_H}$$

$$\eta_{rev} = 1 - \frac{T_L\ (K)}{T_H\ (K)}$$

An Energy-Flow diagram for a Carnot SPPs


Second Law
Working fluid: Not a factor
High T Res., T_H, Kitchen room / Outside house
q_out = q_H
Rev. Fridge/ Heat Pump
ω_net,in
q_in = q_L
Low Temperature Res., T_L, Inside fridge or house
COP_HP = 1 / (1 − q_L/q_H)
COP_R = 1 / (q_H/q_L − 1)
COP_HP_rev = 1 / (1 − (q_L/q_H)_rev)
COP_R_rev = 1 / ((q_H/q_L)_rev − 1)
COP_HP_rev = 1 / (1 − T_L/T_H)
COP_R_rev = 1 / (T_H/T_L − 1)
An Energy-Flow diagram for Carnot Fridge/Heat Pump
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