Course ME1100 (Module 3)

(Thermodynamics)

Course Grading and Exam Timing:

- Assignments: 40%
- Quizzes: 60%

  4 Quizzes and best 3 will be considered
- Quiz 3: 23rd june
- Quiz 4:

Ideal Gas

Part 1

Ideal Gases & Ideal Gas Mixtures

- **Properties of ideal gas-**

1. collisions between all molecules are perfectly elastic.
2. attractive (Van der Waals) forces between molecules are negligible.
3. An ideal gas follows the Boyle's and Charles' laws.

Boyle's and Charles' laws

- **Boyle's Law-**

  $V \propto 1/p$ at constant Temp.

- **Charles' law-**

  $V \propto T$ at constant P.

Ideal gas equation

- PV=nRT where R= 8.314$J/(Kmol)$

  R=(Universal gas constant)

- PV=mR_1T where R_1= R/M,

  R_1= (Specific gas constant)

  M= molecular weight of the gas (kg/kmol)

Joule's Experiment

- Joule's experiments proved that internal energy of an ideal gas depends on temperature alone.

=> If change in T=0

Then change in U(internal energy) will be zero.

Internal energy of a gas(U)

- $U_1=(1/2)kT$ where k is Boltzmann Constant and K=1.38 X 10-26kJ/K
  $k= R/N_A$ where N_A–Avogadro Number

- Total degrees of freedom =D
  U1(per molecule)=$(1/2)kTD$

- Molar internal energy(U)=$(D/2)RT$

- Molar enthalpy = $\boldsymbol{H}$=(($\boldsymbol{D}$+$\mathbf{2}$)/$\mathbf{2}$) $\boldsymbol{RT}$

We can write-

d$\boldsymbol{H}$=(($\boldsymbol{D}$+$\mathbf{2}$)/$\mathbf{2}$) $\boldsymbol{R}$d$\boldsymbol{T}$, where Cp= =(($\boldsymbol{D}$+$\mathbf{2}$)/$\mathbf{2}$)R

And

dU=($\boldsymbol{D}$/$\mathbf{2}$)$\boldsymbol{R}$d$\boldsymbol{T}$, where Cv= =($\boldsymbol{D}$/$\mathbf{2}$)$\boldsymbol{R}$

And

$\boldsymbol{\gamma}$=$\boldsymbol{Cp}$/$\boldsymbol{Cv}$=($\boldsymbol{D}$+2)/$\boldsymbol{D}$

Ideal Gas Mixture

- Consider a mixture of N constituents
- Number of moles of each species in mixture are n1, n2, ... nN
- Mass of each species are m1, m2, ... mN

So, Total number of moles n=n1+ n2+. . . . . . . +nN

And Total mass m=m1+ m2+. . . . . . . +mN

- Mole fraction = xi= $\boldsymbol{ni/n}$
- Mass fraction = yi=$\boldsymbol{mi/m}$

Conversion of Mole fraction to Mass fraction

Mass fraction $\boldsymbol{yi}=(\boldsymbol{xiMi})/\boldsymbol{M}$

where $\boldsymbol{xi}$=mole fraction

$\boldsymbol{Mi}$= molecular weight of ith species

$\boldsymbol{M}$ = molecular weight of all species

partial volume and partial pressure

- ***Dalton's law***

  $pV = n\,RT$

  If partial pressures are p1, p2, p3….

  Then xi=$ni/n = pi/p$

- ***Amagat's law***

  $pV = n\,RT$

  if partial volumes are v1, v2, v3…

  Then $xi = ni/n = Vi/V$

Properties of the mixture evaluated by mass basis or mole basis approach

- ***Mass basis approach***

-Internal energy $U = mu = m_1u_1 + m_2u_2 + ----$

Where $u = y_1u_i + y_2u_2 + y_3u_3 ......$

-Enthalpy $H = mh = m_1h_1 + m_2h_2 + ----$

Where $h = y_1h_1 + y_2h_2 + y_3h_3 ....$

-Volume $v = V/m = y_1v_1 + y_2v_2 + y_3v_3 ...$

- ***Mole basis approach***

-Replace y_i by x_i and apply same approach as mass basis approach

Gas constant of a mixture

- $Rmix = R/Mmix$
- $Rmix = y_A R_A + y_B R_B + \ldots.$

Second Law of Thermodynamics

Part 2

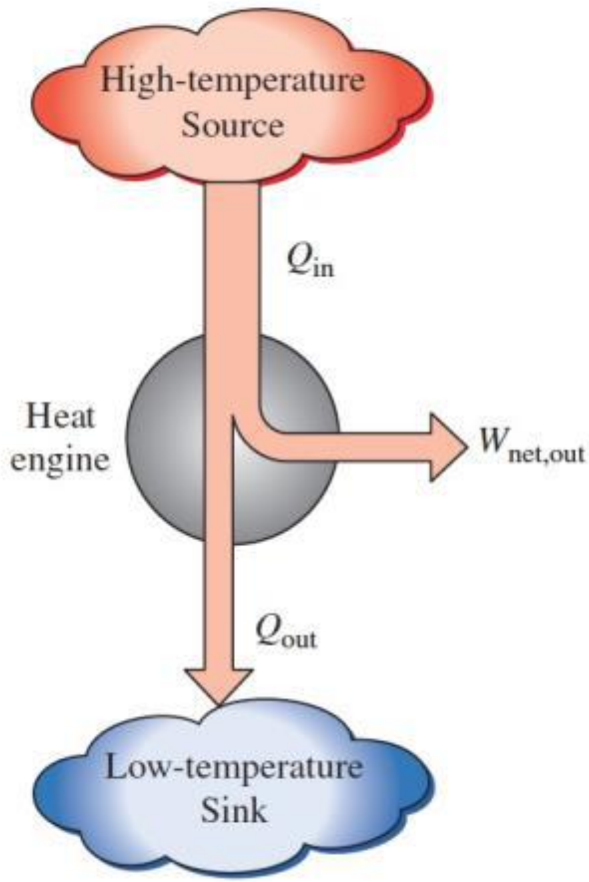
Introduction to 2nd Law

- First Law talks about conservation of energy in terms of its magnitude and not about the direction of energy flow, but 2nd law gives nice information regarding energy flow and its magnitude.
- And also it gives the knowledge of efficiency of a system/engine.

Heat Engines

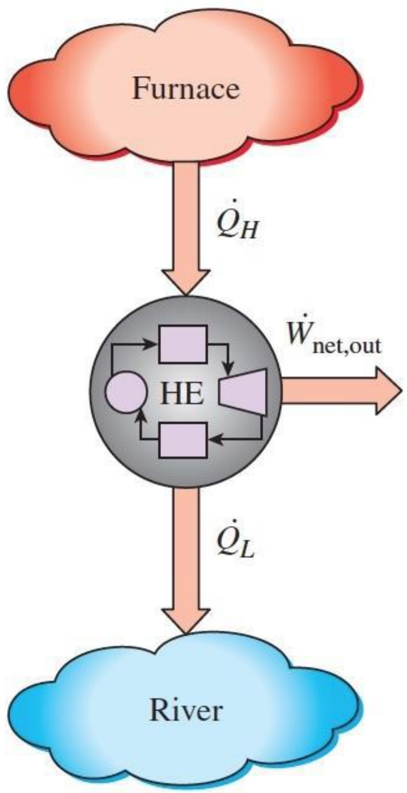
- Heat engine is a continuously operating device and operating in a thermodynamic cycle with heat and work interactions.
- The heat engine receives heat from the source, converts a part of it into work, and rejects the remaining to the sink.

Heat Engine Layout

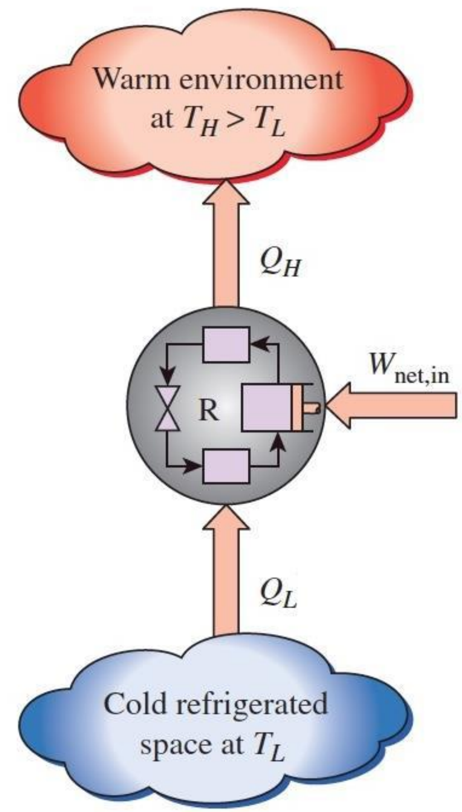


Direct Engines & Reverse Engines

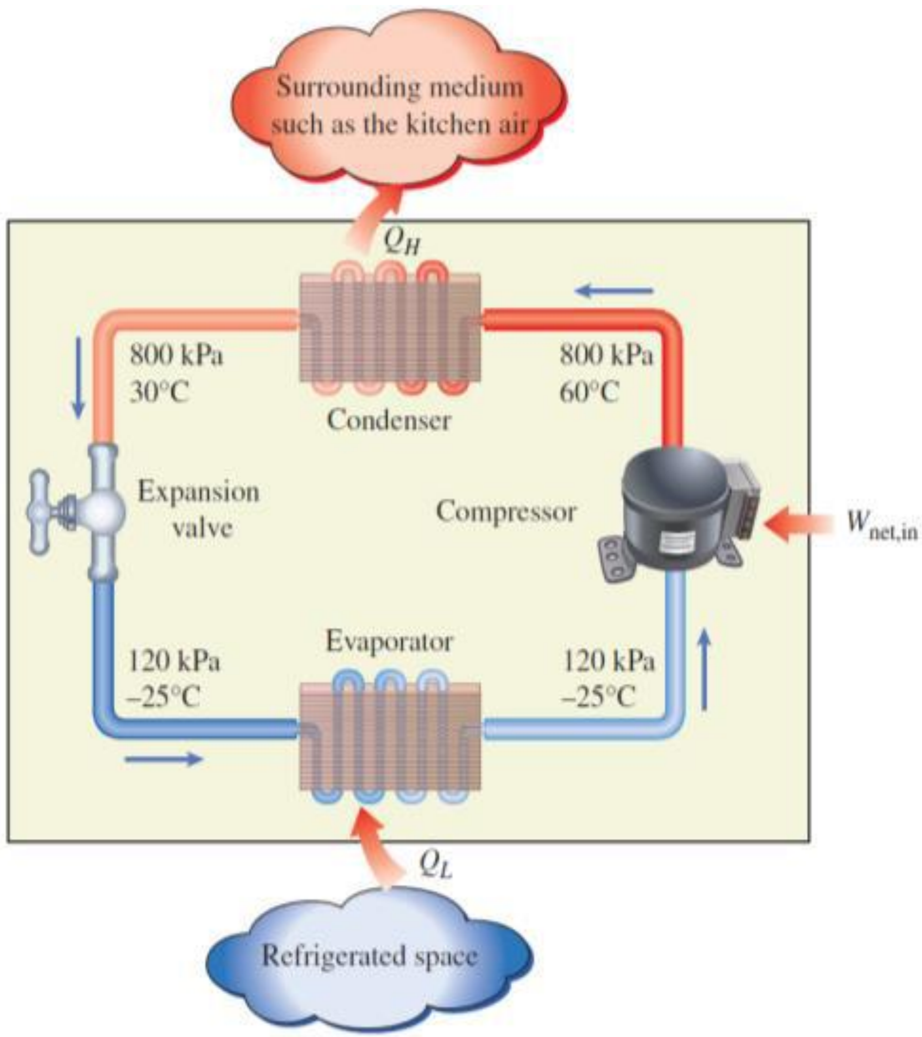
Direct Engines



Reverse Engines



Refrigerator



- In refrigerator the flow of heat is from a low-temperature device to a high-temperature device.

Quantification of the performance of heat engines

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_{\text{in}}}$$

$$W_{\text{net,out}} = Q_H - Q_L$$

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_H} \quad \text{or} \quad \eta_{\text{th}} = 1 - \frac{Q_L}{Q_H}$$

COP_{Ref} and $COP_{Heat\ Pump}$

1. If transferred heat is maximum
   - from the lower temp for Reg.
   - from the high temp for heat pump.
2. And minimize the work output

$\Rightarrow$Then the ratio can exceed 1 and it called "Coefficient of Performance"(COP)

COP_{Ref} and $COP_{Heat\ Pump}$

- $COP_{Ref} = (Desired\ Output/Required\ Input) = Q_L/W_{in}$
  $COP_{Ref} = Q_L/(Q_H - Q_L)$

- $COP_{HP} = (Desired\ Output/Required\ Input) = Q_H/W_{in}$
  $COP_{HP} = Q_H/(Q_H - Q_L)$

Kelvin-Planck Statement

- It refers to direct engines.
- It is impossible to construct a device that will operate in a thermodynamic cycle and produce a net amount of work by exchange of heat with a single source.
- its mean, there two sources are required, and the second one being the sink where some heat is to be rejected.

=> The thermal efficiency of 100% is unachievable.

Clausius Statement

- It refers to reverse heat engines.
- The main statement is “The reverse engine doesn't operate without external work .”

Difference Between Reversible and Irreversible Processes

- Main difference—

  -Reversible process delivers the maximum amount of work and consumes the least amount of work.

  -And Irreversible process delivers lesser work and consumes more work.

$\Rightarrow$ Therefore, a reversible engine is the best for a given pair of reservoirs (source and sink) rather than irreversible.

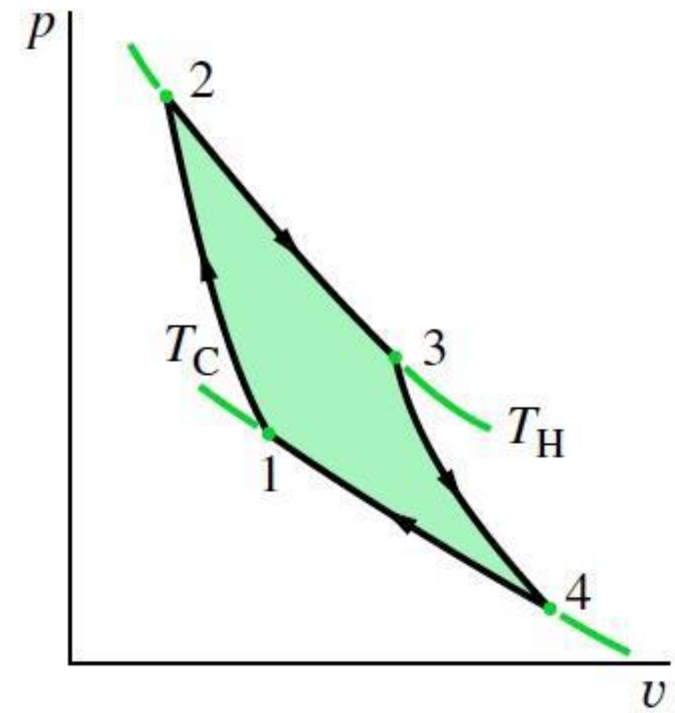
=> All reversible engines have the same and maximum efficiency.

Carnot Cycle

- All processes are reversible.
- Consists only isothermal and adiabatic process.
- Its efficiency is maximum.

Carnot Cycle: Representation

- 1-2: Adiabatic compression
- 2-3: Isothermal heat addition from a reservoir at temperature TH
- 3-4: Adiabatic expansion
- 4-1: Isothermal heat rejection to a reservoir at temperature TC



Some Calculations

Process	Equation	Q	W	ΔU
1 – 2 (adiabatic)	$P_1V_1^\gamma = P_2V_2^\gamma$	0	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$-\left(\frac{P_1V_1 - P_2V_2}{\gamma - 1}\right)$
2 – 3 (isothermal)	$P_2V_2 = P_3V_3$	$P_2V_2 \ln\frac{V_3}{V_2}$	$P_2V_2 \ln\frac{V_3}{V_2}$	0
3 – 4 (adiabatic)	$P_3V_3^\gamma = P_4V_4^\gamma$	0	$\frac{P_3V_3 - P_4V_4}{\gamma - 1}$	$-\left(\frac{P_3V_3 - P_4V_4}{\gamma - 1}\right)$
4 – 1 (isothermal)	$P_4V_4 = P_1V_1$	$P_4V_4 \ln\frac{V_1}{V_4}$	$P_4V_4 \ln\frac{V_1}{V_4}$	0

Carnot cycle efficiency

$$\boxed{\text{Carnot Efficiency} = 1 - \frac{T_1 \ln \frac{P_1}{P_4}}{T_2 \ln \frac{P_2}{P_3}} = 1 - \frac{T_1}{T_2} = 1 - \frac{T_C}{T_H}}$$

Thank You