Module 5

Basics of energy conversation cycles

Heat Engines and Efficiencies

- The objective is to build devices which receive heat and produce work (like an aircraft engine or a car engine) or receive work and produce heat (like an air conditioner) in a sustained manner.

- All operations need to be cyclic. The cycle comprises of a set of processes during which one of the properties is kept constant (V,p,T etc.)

Heat Engines (contd…)

- A minimum of 3 such processes are required to construct a cycle.
- All processes need not have work interactions (eg: isochoric)
- All processes need not involve heat interactions either (eg: adiabatic process).

Heat Engines (Contd…)

- A cycle will consist of processes: involving some positive work interactions and some negative.

- If sum of +ve interactions is > -ve interactions the cycle will produce work

- If it is the other way, it will need work to operate.

- On the same lines some processes may have +ve and some -ve heat interactions.

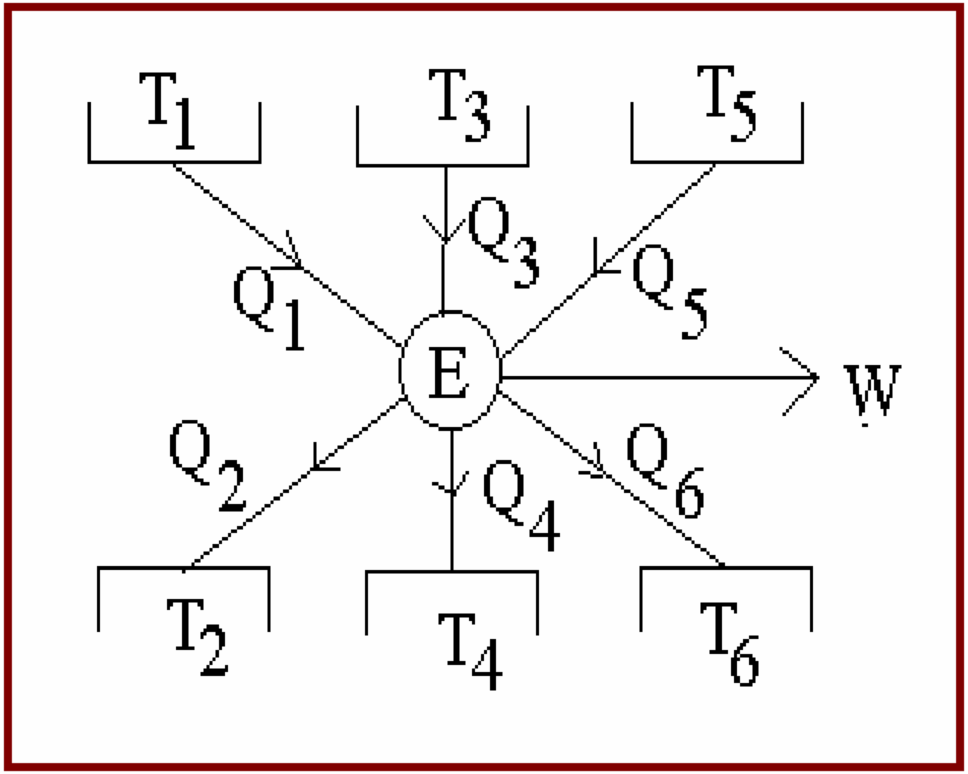
Heat Engines (Contd…)

- Commonsense tells us that to return to the same point after going round we need at one path of opposite direction.
- I law does not forbid all heat interactions being +ve nor all work interactions being -ve.
- But, we know that you can't construct a cycle with all +ve or
- All -ve Q's nor with all +ve or all -ve W's
- Any cycle you can construct will have some processes with
- Q +ve some with -ve.

Heat Engines (Contd…)

- Let Q_1, Q_3, Q_5 …. be +ve heat interactions (Heat supplied)
- Q_2, Q_4, Q_6 …. be -ve heat interactions (heat rejected)
- From the first law we have
- $Q_1+Q_3+Q_5$ ..- $Q_2-Q_4-Q_6$ -... = Net work delivered (W_{net})
- $\Sigma Q_{+ve} - \Sigma Q_{-ve} = W_{net}$
- The efficiency of the cycle is defined as $\eta = W_{net} / \Sigma Q_{+ve}$
- Philosophy → What we have achieved ÷ what we have spent to achieve it

Heat Engines (Contd…)

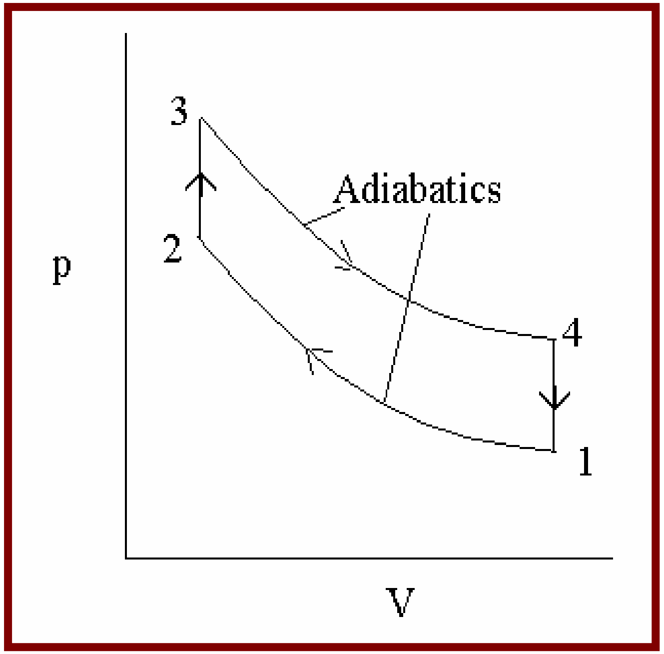


Otto Cycle

Consider the OTTO Cycle (on which your car engine works)

It consists of two isochores and two adiabatics

- There is no heat interaction during 1-2 and 3-4
- Heat is added during constant volume heating (2-3) Q2-3= cv (T3-T2)
- Heat is rejected during constant volume cooling (4-1) Q4-1= cv (T1-T4)
- Which will be negative because T4 >T1



Otto Cycle (Contd…)

- Work done = cv (T3-T2) + cv (T1-T4)

- The efficiency = [cv(T3-T2)+cv(T1-T4)]/[cv(T3-T2)]

  = [(T3-T2) + (T1-T4)]/[(T3-T2)]

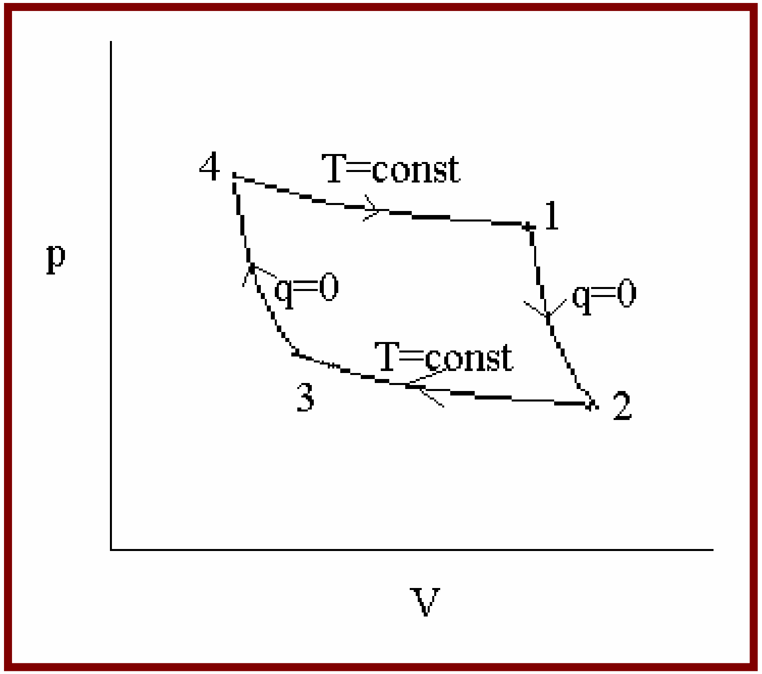
  =1 - [(T4-T1) / (T3-T2)]

Carnot Cycle

Consider a Carnot cycle - against which all other cycles are compared

It consists of two isotherms and two adiabatics

- Process 4-1 is heat addition because v4 < v1
- Process 2-3 is heat rejection because v3 < v2



Carnot Cycle (contd..)

Process	Work	Heat
1-2	(p1v1-p2v2)/(g-1)	0
2-3	p2v2 ln (v3/v2)	p2v2 ln (v3/v2)
3-4	(p3v3-p4v4)/(g-1)	0
4-1	p4v4 ln (v1/v4)	p4v4 ln (v1/v4)
Sum	(p1v1-p2v2 + p3v3-p4v4)/(g-1) + RT2 ln (v3/v2) + RT1ln (v1/v4)	RT2 ln (v3/v2) + RT1ln (v1/v4)

But,p1v1 = p4v4 and p2v2 = p3v3

Therefore the first term will be 0

!!We reconfirm that I law works!!

Carnot Cycle (contd..)

We will show that (v2/v3) = (v1/v4)

1 and 2 lie on an adiabatic so do 3 and 4

p1v1g = p2v2g p4v4g = p3v3g

Divide one by the other (p1v1g /p4v4g) = (p2v2g /p3v3g) (A)

(p1/p4) (v1g / v4g) = (p2/p3) (v2g /v3g)

But (p1/p4) = (v4/ v1) because 1 and 4 are on the same isotherm

Similarly (p2/p3) = (v3/ v2) because 2 and 3 are on the same isotherm

Carnot Cycle (contd..)

Therefore A becomes $(v1 / v4)g-1 = (v2/v3)g-1$

which means $(v2/v3) = (v1/v4)$

Work done in Carnot cycle = $RT1 \ln (v1/v4) + RT2 \ln (v3/v2)$

$= RT1 \ln (v1/v4) - RT2 \ln (v2/v3)$

$= R \ln (v1/v4) (T1 - T2)$

Heat supplied $= R \ln (v1/v4)\, T1$

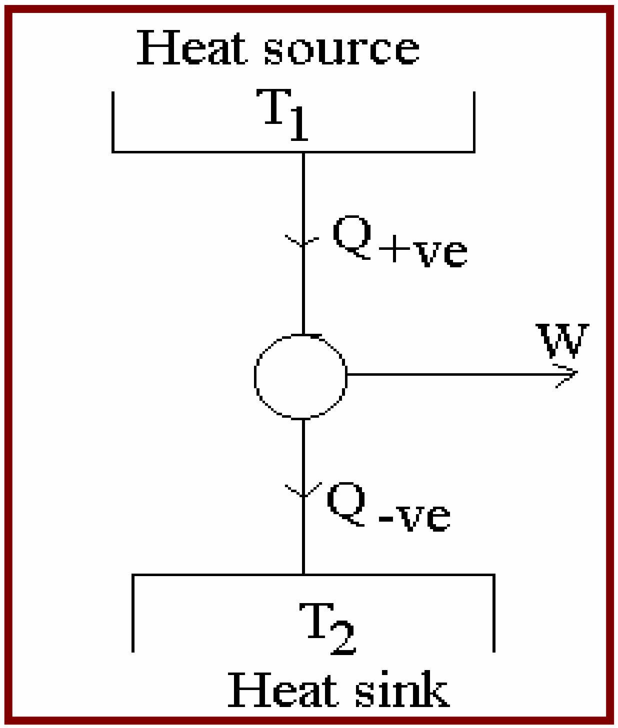
The efficiency $= (T1 - T2)/T1$

In all the cycles it also follows that Work done=Heat supplied - heat rejected

Carnot Cycle (contd..)

Carnot engine has one Q +ve process and one Q -ve process.This engine has a single heat source at T_1 and a single sink at T_2.

If Q +ve > Q -ve; W will be +ve It is a heat engine



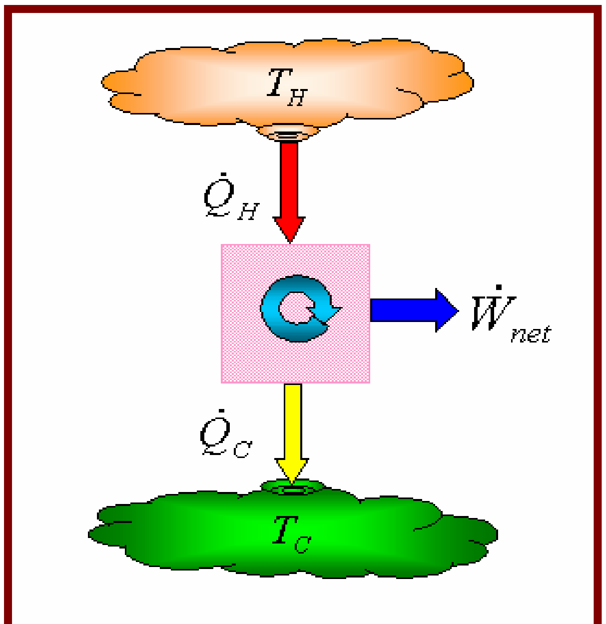


Fig. 1. Heat Engine

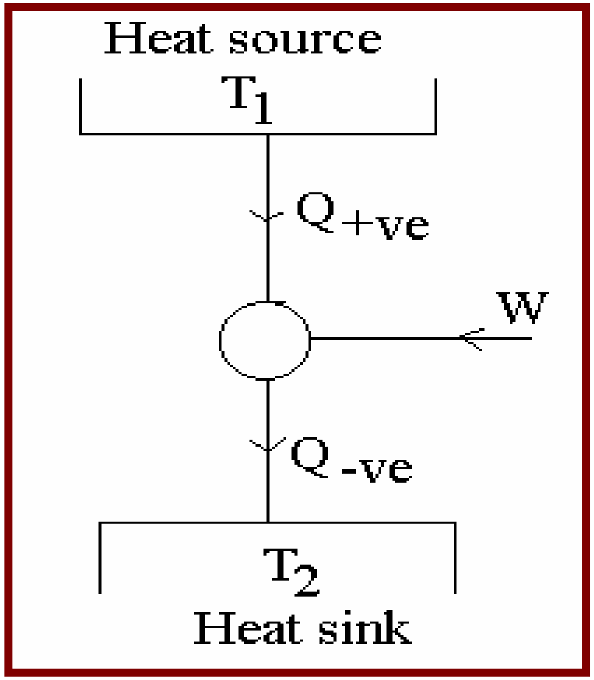
Carnot Cycle (contd..)

It will turn out that Carnot efficiency of $(T1- T2)/T1$ is the best we can get for any cycle operating between two fixed temperatures.

Carnot Cycle (contd..)

Q +ve < Q -ve W will be - ve It is not a heat engine

Efficiency is defined only for a work producing heat engine not a work consuming cycle



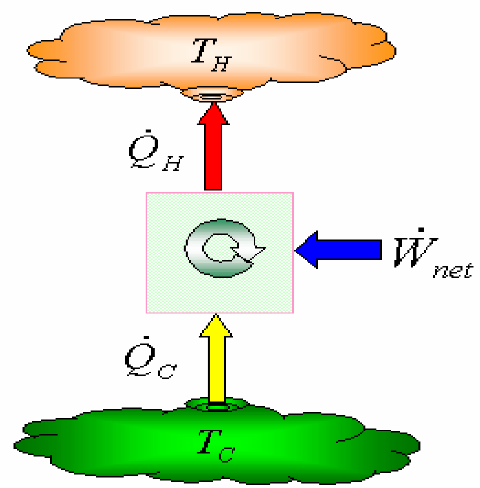


Fig. 1 . Refrigerator/Heat Pump.

Carnot Cycle (contd..)

Note: We can’t draw such a diagram for an Otto cycle because there is no single temperature at which heat interactions occur