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TD Analysis in Carnot and Reverse Carnot Heat Engine

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ABSTRACT

The main purpose of the project is to perform thermodynamic analysis on Carnot and Reverse Carnot heat engine. In this project first of all we are going to discuss Carnot theorem, Kelvin-Planck and Clausius theorem using which we derive efficiencies of both Carnot and reverse Carnot engine. We are also going to discuss Carnot cycle in detail and derive efficiencies of both the engines. Later on we have calculated efficiencies for:

(i). Carnot Heat Engine while source temperature is kept constant,

(ii). Carnot Heat Engine while sink temperature is kept constant and

(iii). Reverse Carnot Engine while source temperature is kept constant

At the end we concluded by plotting different graph to study the nature of observation and graphs.

SYSTEM DESCRIPTION

The Kelvin-Planck Statement: It is impossible to construct a device which operates on a cycle and produces no other effect than the transfer of heat from a single body in order to produce work.

The Clausius Statement: It is impossible to construct a device which operates on a cycle and produces no other effect than the transfer of heat from a cooler body to a hotter body.

What is a Carnot Engine?

Carnot engine is a theoretical thermodynamic cycle proposed by Leonard Carnot. It gives the estimate of the maximum possible efficiency that a heat engine during the conversion process of heat into work and conversely, working between two reservoirs, can possess.

Carnot Theorem:

Any system working between two given temperatures T_1 (hot reservoir) and T_2 (cold reservoir), can never have an efficiency more than the Carnot engine working between the same reservoirs, respectively.

<u>Heat engine cycle and heat engine</u>

A device which can produce the work continuously at the expense of heat input is called a heat engine.

Example: - Steam engine, Steam turbine power plants, Petrol & Diesel engines, gas turbines etc.

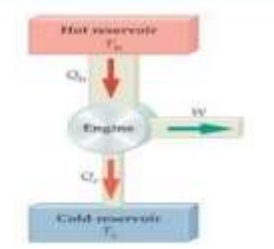


Fig. Heat Engine

$$Q_h = Q_c + W$$

$$\eta = \frac{Work\ output}{Heat\ supply}$$

$$= \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

Refrigerators & Heat Pumps:

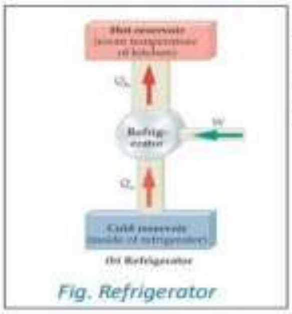


Fig. Refrigerator

A **Refrigeration** is a device operating on a cycle which removes heat form a low temperature body and reject it to a body at high temperature on the expense of external work supplied.

$$(COP)_{Ref} = \frac{Desire\ effect}{Energy\ input} = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c}$$

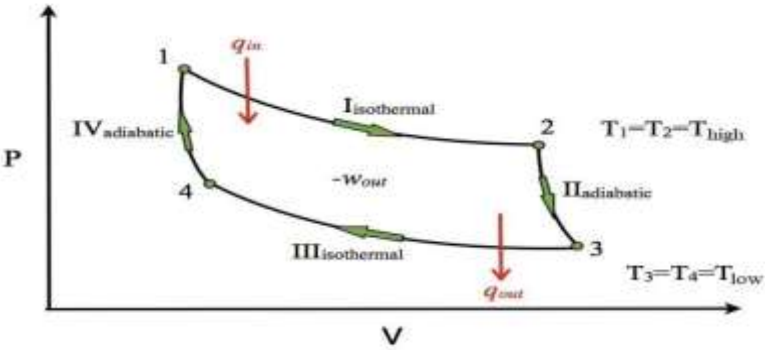
Heat pump :- If the objective the system is to deliver heat energy at higher temperature then the temperature corresponds to ambient temperature such a device is called heat pump.

$$(COP)_{pump} = \frac{Desire\ effect}{Energy\ input} = \frac{Q_h}{W} = \frac{Q_h}{Q_h - Q_c}$$

$$(COP)_{pump} - (COP)_{Ref} = 1$$

TD ANALYSIS OFCARNOT AND REVERSE CARNOT HEAT ENGINE

HEAT ENGINE:



Step 1:

Isothermal expansion: The gas is taken from P1, V1 and T1 to P2, V2 and T2. Heat Q1 is absorbed from the reservoir at temperature T1. Since the expansion is isothermal, the total change in internal energy is zero, and the heat absorbed by the gas is equal to the work done by the gas on the environment, which is given as:

W1→2=Q1=μ×R×T1×lnv2/v1

Step 2:

Adiabatic expansion: The gas expands adiabatically from P2, V2, T1 to P3, V3, T2.W2→3= μR (T1−T2)

γ−1

Step 3:

Isothermal compression: The gas is compressed isothermally from the state (P3, V3, T2) to (P4, V4, T2).

W3→4=μRT2lnv3/v4

Step 4:

Adiabatic compression: The gas is compressed adiabatically from the state (P4, V4, T2) to (P1, V1, T1).

W4→1= μR (T1−T2)

γ−1

Hence, the total work done by the gas on the environment in one complete cycle is given by:

W=W1→2+W2→3+W3→4+W4→1

W=μRT1lnv2/v1−μRT2lnv3/v4

$$Net\ efficiency = \frac{Net\ workdone\ by\ the\ gas}{Heat\ absorbed\ by\ the\ gas}$$

$$Net\ efficiency = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}\frac{ln\frac{v_3}{v_4}}{ln\frac{v_2}{v_1}}$$

Since the step 2−>3 is an adiabatic process, we can write $T_1V_2^{Y-1} = T_2V_3^{Y-1}$

Or,

$$\frac{v_2}{v_3} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}}$$

Similarly, for the process 4−>1, we can write

$$\frac{v_1}{v_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}}$$

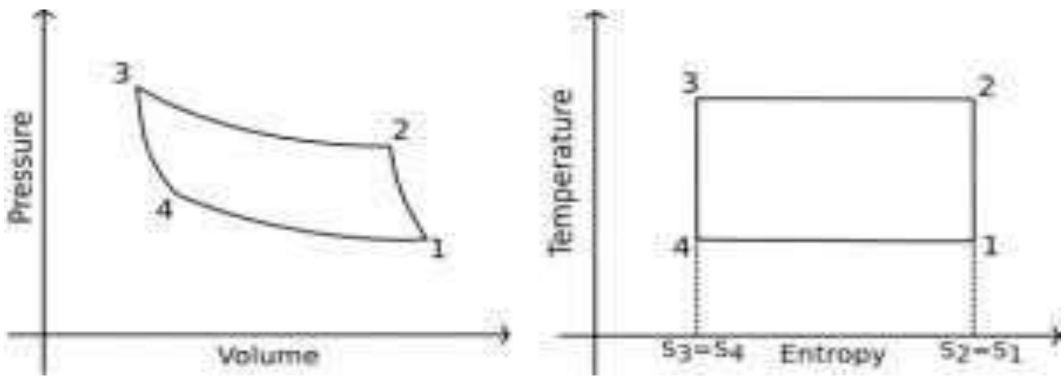
This implies,

$$\frac{v_2}{v_3} = \frac{v_1}{v_2}$$

So, the expression for net efficiency of carnot engine reduces to:

$$Net\ efficiency = 1 - \frac{T_2}{T_1}$$

REVERSE CARNOT CYCLE:



- In the reverse Carnot cycle, work is done to extract heat from one system and expel it into another via four processes, two isothermal and two isentropic.
- In process 1→2, the gas is isentropically compressed, and there is no heat flow into or out of the refrigerator.
- In process 2→3, heat is expelled into the sink (e.g. outside air) isothermally (T_2=T_3). The amount of heat ejected per unit mass of gas is Qc=T2 (S2−S3).
- In process 3→4, the gas is isentropically expanded. The pressure and temperature decrease to P_4, T_4. Heat transfer at this stage is zero.

- In process 4⟶1, the gas expands isothermally (T_4=T_1), extracting heat from the source (e.g. room). This is where the cooling takes place. The heat extracted from the source per unit mass of gas is QH=T1(S1−S4)=T1(S2−S3).–
- The work done during the process is simply W=QH−Qc=(T1−T2)(S2−S3).
- The efficiency of the reverse Carnot cycle is the heat removed from the cold reservoir / the amount of work input: ηcool=Qc/W so,
- ηcool=T2/T1−T2

RESULT AND DISCUSSION: -

CARNOT HEAT ENGINE

1. Carnot-vary sink temperature while keeping temperature of source constant

OBSERVATIONS: -

Q_{given} = 1000kJ

Tsource (kelvin)	T_{sink} (kelvin)	Work (KJ)	Efficiency (%)
1050	278	735.238	73.5238
1050	288	725.714	72.5714
1050	298	716.1905	71.61905
1050	308	706.66667	70.66667
1050	318	697.1429	69.71429

2. Carnot-vary source temperature while keeping temperature of sink constant

OBSERVATIONS: -

Q_{given} = 1000kJ

Tsource (kelvin)	Tsink (kelvin)	Work (KJ)	Efficiency (%)
825	295	642.42425	64.242425
875	295	662.857143	66.2857143
925	295	681.081081	68.1081081
975	295	697.435897	69.7435897
1025	295	712.195122	71.2195122

REVERSE CARNOT HEAT ENGINE

Varying sink temperature while keeping temperature of source constant.

OBSERVATIONS:-

$Q_{absorbed}$ = 1000kJ

Tsource (kelvin)	Tsink (kelvin)	COP (refrigerator)	COP (Heat Pump)	Work (KJ)
298	240	4.138	5.138	241.667
298	245	4.623	5.623	216.326
298	250	5.2083	6.2083	192
298	255	5.93	6.93	168.627
298	260	6.8421	7.8421	146.1538

Discussion

1. CARNOT HEAT ENGINE

a. Varying sink temperature while keeping source temperature constant

We can see from the above graph and observations, that as sink temperature rises, efficiency decreases linearly.

This is because of the decreasing linear relation between efficiency and sink temperature:

Efficiency = 1 - $\frac{T(sink)}{T(source)}$

Also, work done by the heat engine decreases with increase in sink temperature because

Work done = $Q_{given}\left(1 - \frac{Q(released)}{Q(given)}\right)$

Or, Work done = $Q_{given}\left(1 - \frac{T(sink)}{T(source)}\right)$

b.) Varying source temperature while keeping sink temperature constant

We can see from the above graph and observations, that as source temperature rises, efficiency increases non uniformly.

This is because of the non-linear relation between efficiency and source temperature:

Efficiency = 1 -$\frac{T(sink)}{T(source)}$

Also, work done by the heat engine increases with increase in source temperature because

Work done = $Q_{given}\left(1 - \frac{Q(released)}{Q(given)}\right)$

Or, Work done = $Q_{given}\left(1 - \frac{T(sink)}{T(source)}\right)$

2. REVERSE CARNOT HEAT ENGINE

Varying sink temperature while keeping source temperature constant

In reverse carnot engine, we see 2 types of systems, i.e refrigerator and heat pump.

Coefficient of performance (COP) of both systems increases with increase in sink temperature as is evident from the equations:

$COP_{refrigerator} = \frac{T(sink)}{T(source)-T(sink)}$ $COP_{heat\ pump}$ We $= \frac{T(source)}{T(source)-T(sink)}$

also observe that

$COP_{heat\ pump} - COP_{refrigerator} = 1$

C++ PROGRA TO FIND EFFICIENCY OF A HEAT ENGINE BY USING WORK OUTPUT AND HEAT SUPPLY-

```
#include<iostream.h> #include<conio.h> void main()

{

int a;

\\ a is considered as    work output
```

```
int b;

\\ b is considered as    heat supply clrscr();

cout<<"\nEnter two numbers:-"; cin>>a>>b;

int div=a/b;

\\ div is considered as efficiency cout<<"Division="<<div; getch();

}
```

CONCLUSION

The purpose of this research is to do the thermodynamic analysis of carnot and reverse carnot heat engine. From our study we conclude that the efficiency of both carnot heat engine and reverse carnot heat engine depends only on its temperature and not on the working substance.

We can improve the efficiency of any carnot heat engine either by increasing the temperature of sink or by decreasing the temperature of reservoir.

The coefficient of performance of reverse carnot heat engine also depends on the temperature of sink and source.

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