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* Second law of thermodynamics.

1. Kelvin planck's statement of second law of thermodynamics
It is impossible to get a continuous supply of work by cooling a body below the coldest to its surrounding.

Explanation: The heat engine will work only when the temperature of engine is greater than the temperature of surroundings. For example, petrol or diesel engine will work continuously only when the temperature of engine is greater than the temperature of surrounding air. The temperature of engine is made high by burning petrol or diesel in petrol engine and design engine respectively.

2. Claussin's statement of second law of thermodynamics:-
Heat cannot of itself flow from a hot body to a cold body.

Explanation:- We know that heat always flows from a hot to a cold body itself. But if we want to send heat from a cold body to a hot body, we will have to do some external work to force heat from cool to hot body. For example, in refrigator heat is transferred from cool to hot body by doing external work by electricity.

3. In terms of entropy: 'every physical and chemical change occuring in nature takes place in such a way that the total entropy of universe is increasing'.

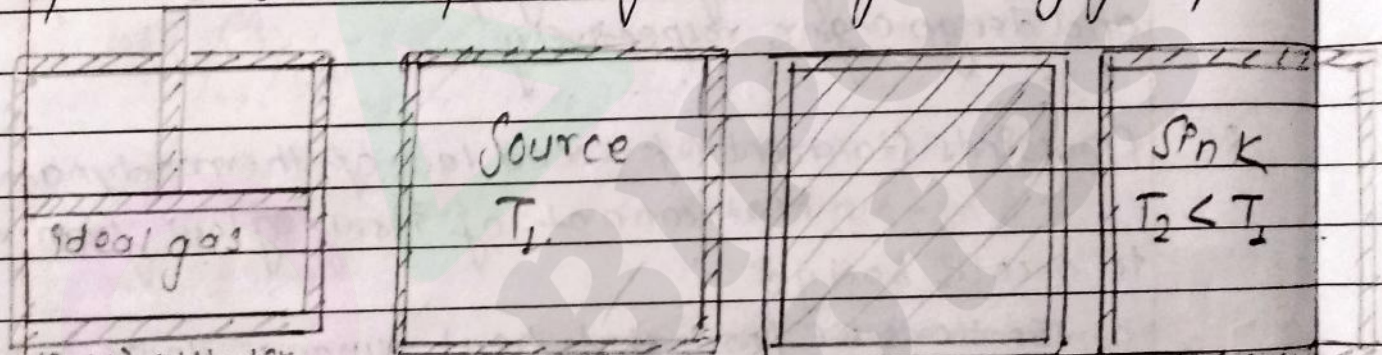
Entropy (s):- Entropy is the measure of disorder. Entropy is defined as the ratio of heat change to constant temperature in going from one adiabatic to another adiabatic. Thus, the change in entropy may be written as,

$$\boxed{dS = \frac{dQ}{T}}$$

Its unit is Joule K^{-1} or cal K^{-1}.

* Carnot's heat engine

It is an ideal theoretical engine which can not be constructed practically. It has following four parts.



fig(1) cylinder fig(2) source fig (3) Insulating stand fig :-(4) sink.

1. cylinder fitted with movable frictionless piston. perfectly ideal gas inside the cylinder is the working substance. Lower surface is perfectly good conducting whereas other surfaces are perfectly insulating (fig-1)

2. source of heat of infinite heat capacity at constant temperature T_2 (fig 2)

3. perfectly insulating stand (fig 3)
4. sink of infinite heat capacity at lower temperature T_2 (fig 4)

Working:-

Step I - Isothermal expansion:- cylinder is placed on source and the gas is expanded isothermally from (P_1, V_1, T_1) to (P_2, V_2, T_1). During this the gas draws heat Q_1 from source at constant temperature T_1. This is shown by curve AB of p-v diagram (fig 5).

Step II:- Adiabatic expansion:- Now cylinder is placed on insulating stand and gas is expanded adiabatically from (P_2, V_2, T_1) to (P_3, V_3, T_2) as shown by curve BC of fig (5).

Step III:- Isothermal compression:- Now cylinder is placed on sink and compressed isothermally from (P_3, V_3, T_2) to (P_4, V_4, T_2) as shown by curve CD of fig (5). During this, heat Q_2 is rejected to sink.

Step IV:- Adiabatic compression:- Now cylinder is again placed on insulating stand and compressed adiabatically from (P_4, V_4, T_2) to initial point (P_1, V_1, T_1) as shown by curve DA of fig (5)

This completes one cycle ABCDA called carnot cycle. Now similar cycles are repeated

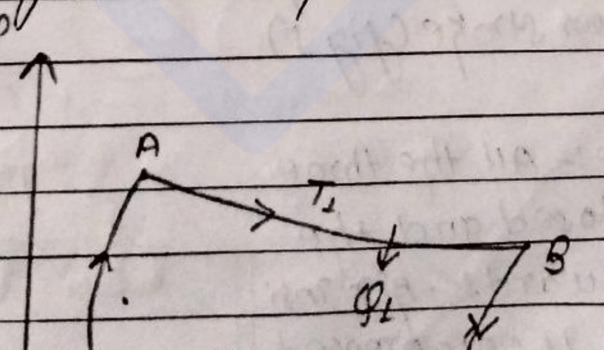


fig (5) P.V diagram of carnot's engine.

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Efficency of engine is denoted by n and is defined as the ratio of total work done to the heat taken from source. thus,

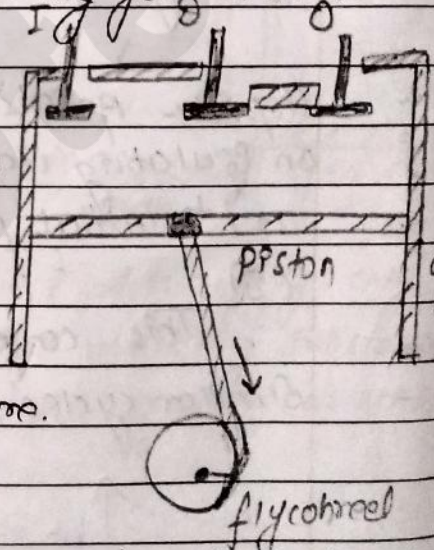
$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \left(1 - \frac{Q_2}{Q_1}\right) = \left(\frac{T_1 - T_2}{T_1}\right)$$

$$\text{or, } \eta = \left(1 - \frac{Q_2}{Q_1}\right) = \left(1 - \frac{T_2}{T_1}\right) = \left(1 - \frac{Q_2}{Q_1}\right) \times 100\% = \left(1 - \frac{T_2}{T_1}\right) \times 100 \quad \text{--(1)}$$

Note:-
From eqn (1) it is clear that efficency of Carnot's engine cannot be 100%.

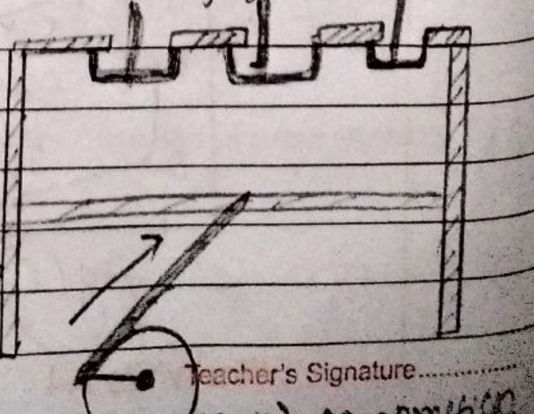
* Diesel engine:- (Designed by Rudolf Diesel in 1892).
Diesel engine is a four stroke internal compustion engine. This engine does not require spark plug. The working of diesel engine perform's in the following four strokes.

(i) Suction stroke:-
In the first step of the working of diesel engine, the inlet value 'I' is open and diesel value 'D' and outlet value 'O' are closed. The piston moves outwards and air is sucked into the cylinder (fig 1) at atmospheric pressure. AB show's suction stroke (fig 5).



fig(1) Suction stroke

(ii) Compression stroke:- All the three valves are now closed and the piston moves inwards. Air inside the cylinder is compressed adiabatically to about one-seventh of its initial volume. The temp of air is raised about 1000°C


fig(2) compression

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curve BC of fig (5) shows adiabatic compression.

(iii) Working stroke:- At the end of compression stroke the diesel value 'D' opens (with I and O still closed) and diesel is sprayed on compressed air in the cylinder. Due to high temp the oil burns simultaneously at constant pressure. Line CD in fig (5) shows combustion. The temp raises to about 2000°c The motion of piston is very rapid hence doesnot work. fig (3) shows working stroke.

iv) Exhaust stroke:- The outlet value 'O' is now opened and burnt mixture and smoke is forced out and the cylinder becomes ready for next similar cycle. Fig (4) shows exhaust stroke. BA represent exhaust in fig (5).

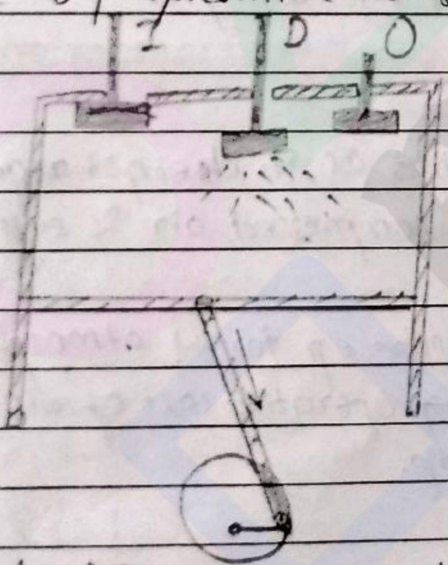

fig (3) working stroke.

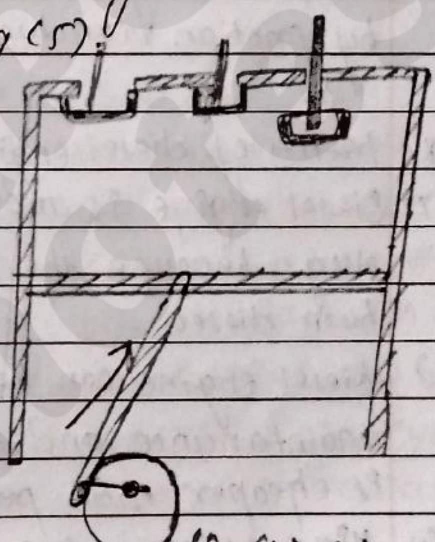

fig (4) Exhaust stroke

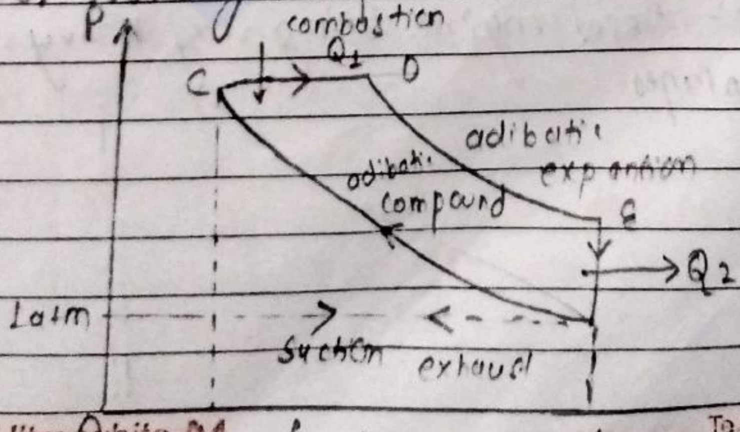

fig (5) Indicator diagram for disel engine (P-V diagram)

* ~~of~~ efficency of η diesel engine:

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right) = 1 - \left(\frac{1}{\rho}\right)^{\gamma - 1} \quad \text{---- (1)}$$

where, ρ = compression ratio.

For a typical diesel engine $\begin{cases} \rho = 12.6 \\ \gamma = 1.4 \end{cases}$

$$\therefore \eta = 1 - \left(\frac{1}{12.6}\right)^{1.4-1}$$

$$= 1 - \left(\frac{1}{12.6}\right)^{0.4} = 0.62 = 62\%.$$

But practically it is less than 62%. due to loss of energy by friction, conduction and radiation.

* Merits of diesel engine:-

(1) Diesel engine is more reliable as it doesnot require spark plug, because the temp of compressed air is sufficient to burn diesel.

(2) Diesel engine can bear pressure up to 34 atmosphere.

(3) Maintanance and ~~reporating~~ operating cost of diesel engine is cheaper than petrol engine.

(4) High efficency (η).

* Demeritis:- Desel engine being very heavy, cannot be used in air planes.

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Numerical:-

(*) A diesel engine performs 2200 J of mechanical work and discard 4300 J of heat per cycle (i) How must heat must be supplied to an engine per cycle (ii) what is the thermal efficiency of engine.

Soln;

(i) Work done per cycle $= W = Q_1 - Q_2$

$$\therefore Q_1 = W + Q_2 = (2200 + 4300) J$$
$$= 6300 \text{ Joules}$$

ii) Efficiency of engine is

$$\eta = \frac{W}{Q_1} = \frac{2200}{6300} = 0.349$$
$$= 0.349 \times 100\%$$
$$= 34.9\%$$

(*) Petrol engine: (Developed by Ott van in 1876).

It is an internal combustion engine which uses a mixture of 2% petrol vapour and 98% air as working substance. It has a cylinder fitted with a piston that can move inwards and outwards in the cylinder with a ~~flywheel~~ flywheel. The spark plug (sp), inlet value (I) and outlet value (O) are fitted at the other end of the cylinder. The inlet and outlet values can open and close when required.

Working:- Petrol engine is a four stroke engine. The four strokes are as follows.

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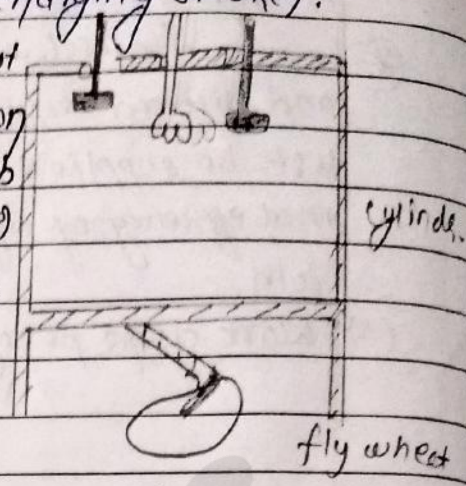
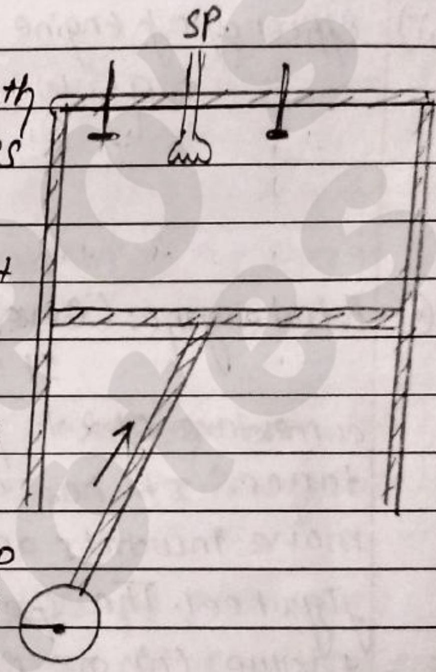
(i) Suction stroke (or Induction or charging stroke).

The inlet valve I opens (without let valve 'O' closed) and the piston move outwards and the working sub stance (petrol vapour and air mixture) is sunked into the cylinder at atmo spheric pressure (fig 1). This is shown by curve AB of P-V diagram fig (5)



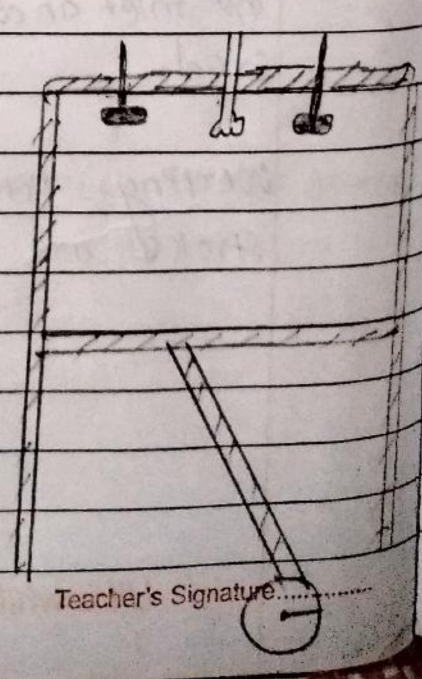
(ii) Compression stroke:-

Now the values I and O both are closed and the piston moves inwards such that the temp of compressed mixture rises to about 600°c and pressure about 7 atm At the end of this stroke spark plug (SP) produces fire sparks and the compressed mixture is burnt curve BC of fig(5) shows the compression. and curve CD shows burning of mixture.



(iii) working stroke:-

Due to burning of the mixture the temp of gas is raised to 2000°c and pressure about 15 atm. Due to such high pressure the piston is pushed outward with very large force. & this force does work in moving the wheel of the petrol vehicle. this is represented by curve DE of fig (5). Both 'I' and 'O' are closed.



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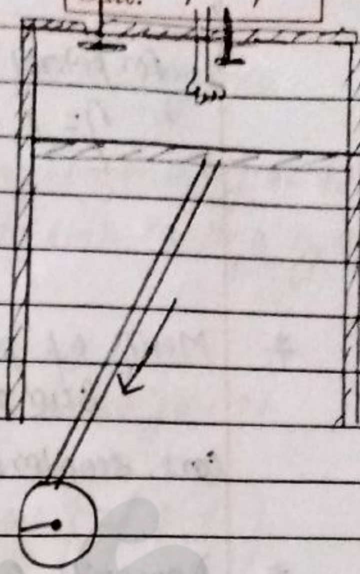
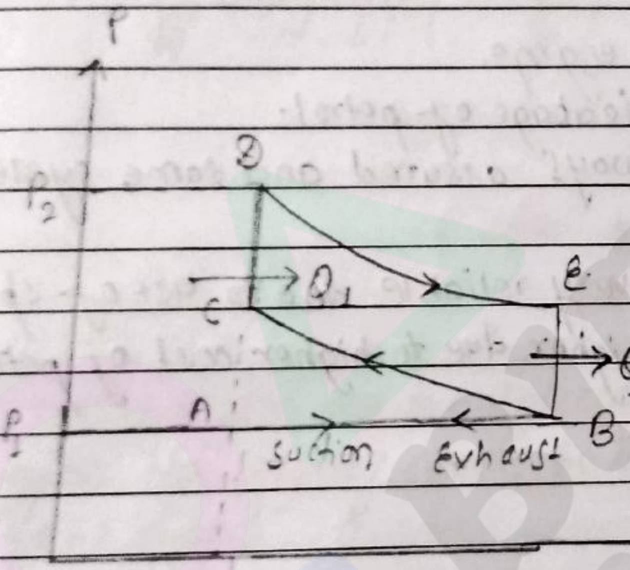
iv. Exhaust stroke:- At the end of working stroke outlet value (O) get opened (with I closed) and unburnt gas mixture is forced out of cylinder. Now the engine is ready for next similar cycle and so on.





fig(5):- P-V diagram of petrol engine.

Efficiency of peterol engine:-

$$\eta = \frac{W}{Q'} = \frac{\text{work done by engine}}{\text{heat supplied to engine}} = \frac{Q_1 - Q_2}{Q_1}$$

$$\therefore \eta = \left(1 - \frac{Q_2}{Q_1}\right) \text{— i}$$

If $\rho = \frac{V_2}{V_1}$ = compression ratio, then

$$\eta = 1 - \left(\frac{1}{\rho}\right)^{\gamma - 1} \text{— ii}$$

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For peterol engine $S=5$ hence eqn iii) gives

$$\eta = 1 - \left(\frac{1}{5}\right)^{1.4-1} \quad [\gamma = 1.4 \text{ for air}]$$

$$= 0.52$$

$$= 52\%$$

* Merits of petrol engine.

Due to light weight, petrol engines are used in cars, scooters and air planes.

* Demerits of peterol engine.

1. Risk of fire due to leakage of petrol.
2. Sparking is not always assured and same cycle loss fuel without burning.
3. Petrol engine is not very reliable due to use of spark plug.
4. Operational cost is higher due to higher cost of petrol.

* Numerical based on carnot engine and petrol engine.

1.) What will be the thermal efficency of an engine if it take 8 kJ heat from source and rejects 6 kJ to sink in one cycle? [2072 set E]

here,

Q_1 = heat taken from source = 8kJ = 8000 Joules.

Q_2 = heat rejects to sink = 6kJ = 6000 Joules.

$\therefore$ Efficency $(\eta) = \left(1 - \frac{Q_2}{Q_1}\right) = \left(1 - \frac{6000}{8000}\right) = \left(1 - \frac{6}{8}\right)$

$= \frac{8-6}{8} = \frac{2}{8} = 0.25$

$= 25\%$ Ans.

2) A carnot engine has 50% efficency with a sink at 9°C. By how degress the temp of source be increase to make efficency 70%? [2071 supp]

Given,

$\eta = 50\% = \frac{50}{100} = 0.5$

when, $T_2 = 9^\circ C$ = sink temp

$= 273 + 9 = 282$ K.

ΔT_1 = ? to make

$\eta' = 70\% = \frac{70}{100} = 0.7$.

Soln

$\eta = \left(1 - \frac{T_2}{T_1}\right) = \left(1 - \frac{282}{T_1}\right)$

$\therefore \frac{282}{T_1} = 1 - \eta$

or, $\frac{282}{T_1} = 1-0.5$

or, $\frac{282}{T_1} = 0.5$

or, $T_1 = \frac{285}{0.5}$

$\therefore T_1 = 564 K$

and

$\eta' = \left(1 - \frac{T_2}{T_1'}\right)$; where T_1' = new temp of source

or, $0.7 = \left(1 - \frac{282}{T_1'}\right)$

or, $\frac{282}{T_1'} = 1-0.7$

or, $\frac{282}{T_1'} = 0.3$

or, $T_1' = \frac{282}{0.3}$

$\therefore T_1' = 940 K$

$\therefore$ Increase of temp of source $(\Delta T_1) = T_1' - T_1$

$= (940 - 564) K$

$= 376 K$.

3. A petrol engine consume 25 kg of petrol per hour. The calorific value of petrol is 11.4×10^6 cal/kg^{-1}. Calculate the efficency of engine if its power is 99.75 kw [2070 set ②]

$\Rightarrow$ Given $P = 99.75 kw$ = Power

$= 99.75 \times 10^3$ watt.

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time $(t) = 1$ hrs $= 3600$ sec.
Mass of petrol consumed by engine in 1 hours $(m) = 25$ kg
calorific value of petrol $= 11.4 \times 10^6$ cal kg^{-1}.

Soln

φ_1 = total heat produced in 1 hour $= 11.4 \times 10^6 \frac{cal}{kg} \times 25$ kg

$= 285 \times 10^6$ cal
$= 285 \times 10^6 \times 4.2$ Joules.

Now efficiency will be

$$\eta = \frac{w}{\varphi_1}$$

$$\text{or, } \eta = \frac{P \times t}{\varphi_1} \left[\because P = \frac{w}{t}\right]$$

$$\text{or, } \eta = \frac{99.75 \times 10^3 \times 3600}{285 \times 10^6 \times 4.2}$$

$$\text{or, } \eta = 0.30$$

$$\therefore \eta = 30\%$$

4. A carnot engine works betn $800°c$ and $400°c$. If it is possible either to increase the source temp by $50°c$ or to decrease sink temp by $50°c$, which of these actons will be causing more increase in efficency? [2069 supp]

Given

$T_1 = (800 + 273)k = 1073k$ = source temp.
$T_2 = (400 + 273)k = 673k$ = sink temp.

case I.

when source temp is increased by $50°c$ then

$$T_1' = (1073 + 50)k = 1123k$$

$$\text{then } \eta = \left(1 - \frac{T_2}{T_1}\right) = \left(1 - \frac{673}{1123}\right)$$

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$$= \frac{1123 - 673}{1123}$$

$$= 0.40$$

$$= 40\%$$

Case II and when temp. of sink is decreased by $50°C$, then,

$$T_2' = (673 - 50\ K) = 628\ K.$$

$$\therefore \eta' = \left(1 - \frac{T_2'}{T_1'}\right)$$

$$= \left(1 - \frac{623}{1073}\right)$$

$$= \left(\frac{1073 - 623}{1073}\right)$$

$$= 0.419$$

$$\simeq 0.42$$

$$= 42\%$$

Thus, the second case give more efficiency.

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A carnot engine works betn the source and the sink with efficency 40%. How much temp of the sink be lowered keeping the source temp constant so that its efficiency is increased by 10%? [2072 set C]

Soln

Initially,

$$\eta = \left(1 - \frac{T_2}{T_1}\right)$$

$$\text{or, } 0.4 = \left(1 - \frac{T_2}{T_1}\right)$$

$$\text{or, } \frac{T_2}{T_1} = 1 - 0.4$$

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or, $\frac{T_2}{T_1} = 0.6$

or $T_2 = 0.6T_1$ ——— 1}

And when sink temp is decreased at constant source temp then

$\eta' = (40+10)\% = 50\% = 0.5$

then,

$$\eta' = \left(1 - \frac{T_2'}{T_1'}\right)$$

or, $0.5 = \left(1 - \frac{T_2'}{T_1}\right)$

or, $\frac{T_2'}{T_1'} = 1 - 0.5$

or, $\frac{T_2'}{T_1'} = 0.5$

$\therefore T_2' = 0.5T_1$ ——— 2}

Hence, decrease in sink temp. will be.

$\Delta T_2 = (T_2 - T_2') = (0.6T_1 - 0.5T_1) = 0.1T_1$ ——— 3}

$\therefore$ percentage decrease in sink temp $= \frac{\Delta T_2}{T_2} \times 100\%$

$= \frac{0.1T_1}{0.6T_1} \times 100\%$ [from eq 1} and 3}]

$= \frac{100}{6}\%$

$= 16.66\%$

Bipin Khatri

(Bipo)

Class 12 complete notes and paper collection.

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- maths
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