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 Roll- 21 ME 8076 Sec-A Course- MEC04
 Dept.- Mechanical Engineering. Assignment - 2

1. A Carnot Cycle is defined as an ideal reversible closed thermodynamic cycle.

It consists of four successive operations :

- i) Reversible Isothermal Expansion.
- ii) Adiabatic Expansion.
- iii) Reversible Isothermal Compression.
- iv) Reversible Adiabatic Compression.

It estimates the maximum possible efficiency that a heat engine can possess during the conversion process of heat into work and conversely working between two reservoirs.

2. The Kelvin-Plank's statement of second law states: It is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.

The Clausius' statement of second law states: It is impossible to construct a device which operating in a cycle will produce no effect other than the transfer of heat from a cooler to a hotter body.

It can be shown that they are virtually two parallel

statements of the second law and are equivalent in all respects. The equivalence of the two statements will be proved if it can be shown that the violation of one statement implies the violation of the second and vice-versa.

First, let us consider a heat pump P which transfers heat from a low temperature reservoir (t_2) to a high temperature reservoir (t_1) with no other effect, i.e., with no expenditure of work, violating Clausius's statement.

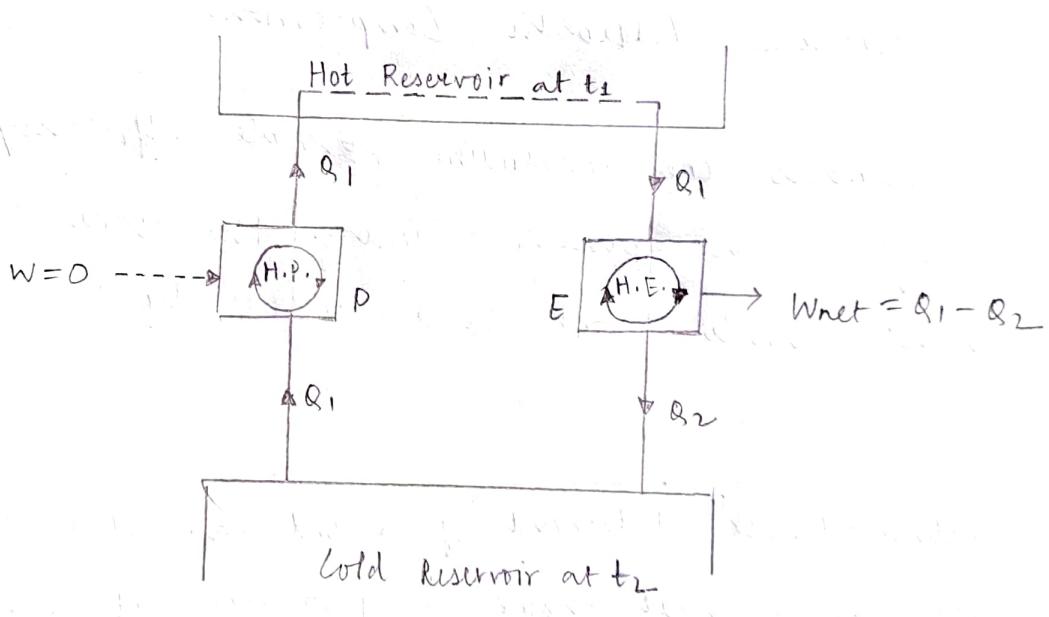


Fig: Violation of Clausius Statement.

Let us assume a cyclic heat engine E operating between the same thermal energy reservoir, producing W_{net} in one cycle. The rate of working of the heat engine is such that it draws an amount of heat Q_1 from the hot reservoir equal to that

discharged by the heat pump, then the hot reservoir may be eliminated and the heat Q_1 discharged by the heat pump is fed to the heat engine. So, we see that the heat pump P and the heat engine E acting together constitute a heat engine operating in cycles and producing net work while exchanging heat only with one body at a single fixed temperature. This violates the Kelvin-Planck statement.

(b) Let us know consider a perpetual motion machine of second kind (E) which produces net work in a cycle by exchanging heat with only one thermal energy reservoir (at t_1) and this violates the Kelvin-Planck statement.

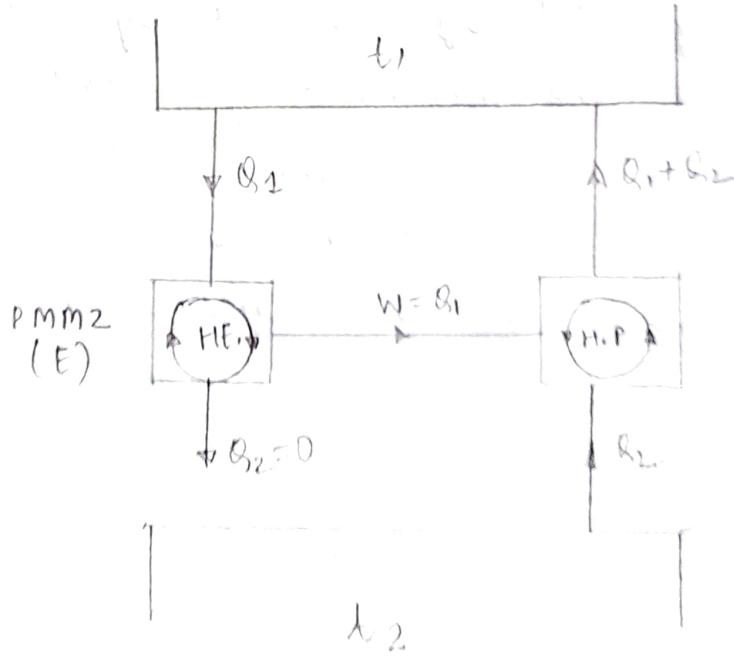


Figure - Violation of Kelvin-Planck Statement.

Let us assume a cyclic heat pump (P) extracting heat (Q_2) from a low temperature reservoir at t_2 and discharging heat to the high temperature reservoir at t_1 with the expenditure of work W equal to what the PMM2 delivers in a complete cycle. So E and P together constitute a heat pump working in cycle and producing the sole effect of transferring heat from a lower to higher temperature body, thus violating the Clausius statement.

3. Since the entropy of an isolated system can never decrease, it follows that only those processes are possible in nature which would give an entropy increase for the system and the surroundings together. All spontaneous processes in nature occur only in one direction from a higher to a lower potential, and these are accompanied by an entropy increase of the universe. When the potential gradient is infinitesimal the entropy change of the universe is zero, the process is reversible. The second law indicates the direction as to cause an increase in the entropy of the universe. The macroscopic change ceases only when the potential gradient disappears and the equilibrium is reached when the entropy of the universe attains the maximum value. To determine the equilibrium state of an isolated system, it is necessary to express the entropy as a function of certain properties of the system and then render the function a maximum.

4. The criteria for a process to be reversible are:-
- The conditions for mechanical, thermal and chemical equilibrium are satisfied.
 - The dissipative effects are not present.
 - The system is at all times infinitesimally near a state of thermodynamic equilibrium.
 - All the work done by the system during the performance of a process in one direction must be returned to the system.

5. i) Thermal Efficiency of a Carnot Heat Engine: The thermal efficiency of a heat engine cycle is defined as follows:

$$\eta = \frac{\text{Net Work Output of cycle}}{\text{Total heat input to cycle}} = \frac{W_{\text{net}}}{Q_1}$$

We know that,

$$W_{\text{net}} = W_{\text{Turbine}} - W_{\text{Pump}}$$

$$\text{Also, } W_{\text{net}} = Q_1 - Q_2 \quad [\text{Conservation of Energy}]$$

$$\therefore \eta = \frac{W_{\text{net}}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

$$\Rightarrow \boxed{\eta = 1 - \frac{Q_2}{Q_1}}$$

(ii) Coefficient of Performance of Heat Pump: The coefficient of performance of heat pump is a performance parameter that is a ratio of useful heating provided to the work required. It is defined as:

$$COP = \frac{Q_1}{W}$$

$$[COP]_{H.P.} = \frac{Q_1}{Q_1 - Q_2},$$

(iii) Coefficient of Performance of Refrigerator: The coefficient of performance of refrigerator is a performance parameter that is the ratio of useful cooling provided to the work required. It is defined as:

$$COP = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

6. The thermal efficiency of a Carnot Engine working between the heat reservoir at constant temperature of T_1 and T_2 ($T_1 > T_2$) is:

$$\boxed{\eta = 1 - \frac{T_2}{T_1}}, \quad T_1 > T_2$$

7. Carnot's Theorem states that all heat engines operating between a given constant temperature source and a given constant temperature sink, none has a higher efficiency than a reversible engine.

Corollary of Carnot's Theorem: The efficiency of all reversible heat engines operating between the same

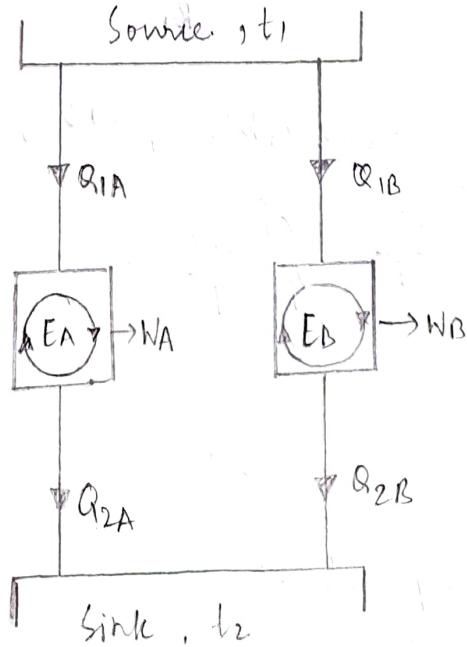
temperature levels is the same.

Let both the heat engines E_A and E_B be reversible.

Let us assume $\eta_A > \eta_B$. Similar to the procedure outlined in the preceding article, if E_B is reversed to run, say, as a heat pump, using some part of the work output (W_A) of engine E_A , we see that the combined system of heat pump E_B and engine E_A becomes as PMM2 (Perpetual Motion Machine 2). So, η_A cannot be greater than η_B . Similarly, we assume that $\eta_B > \eta_A$ and reverse the engine E_A , we observe that η_B cannot be greater than η_A .

Therefore, $\boxed{\eta_A = \eta_B}$.

Since, the efficiencies of all reversible heat engines operating between the same two heat reservoirs are the same, the efficiency of a reversible engine is independent of the nature or amount of the working substance undergoing the cycle.



8. The internal irreversibility is caused by the internal dissipative effects like friction, turbulence, electrical resistance, magnetic hysteresis, etc., within the system.

The external irreversibility refers to the irreversibility occurring at the system boundary like heat interaction with the surroundings due to a finite temperature gradient.

9. Let the system be taken from an initial equilibrium state i to a final equilibrium state f by following the reversible path R_1 . The system is brought back from f to i by following another reversible path R_2 . Then the two paths R_1 and R_2 together constitute a reversible cycle.

From Clausius' theorem,

$$\oint_{R_1 R_2} \frac{dQ}{T} = 0$$

The above integral may be replaced as the sum of two integrals, one for path R_1 and the other for path R_2

$$\int_{R_1}^f \frac{dQ}{T} + \int_{R_2}^f \frac{dQ}{T} = 0 \quad \text{or} \quad \int_i^f \frac{dQ}{T} = - \int_f^i \frac{dQ}{T}$$

Since, R_2 is a reversible path,

$$\int_{R_1}^f \frac{dQ}{T} = \int_{R_2}^f \frac{dQ}{T}$$

Since R_1 and R_2 represent any two reversible paths, $\int_R \frac{dQ}{T}$ is independent of the reversible path

Connecting i and f . Therefore, there exists a property of a system whose value at the final state f minus its value at the initial state i is equal to $\int_i^f \frac{dQ}{T}$. This property is called entropy and is denoted by S . Entropy is an extensive property.

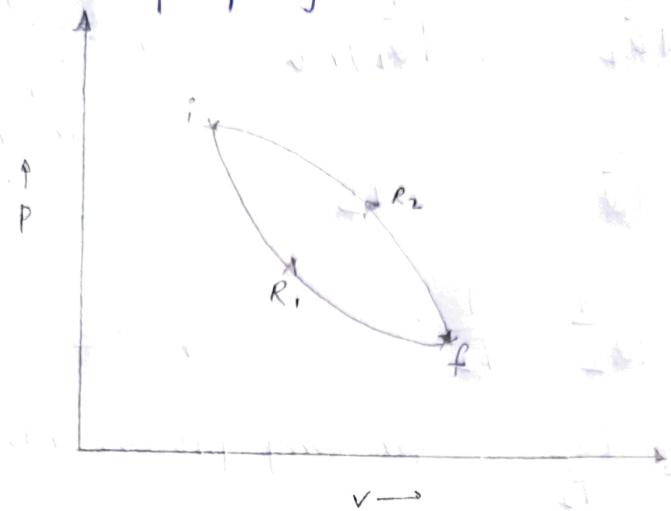


Fig: Two Reversible Paths R_1 and R_2 Between Two Equilibrium States i and f .

10. Let us consider a cycle $ABCD$. Let AB be a general process, either reversible or irreversible, while the other processes in the cycle are reversible. Let the cycle be divided into a number of elementary cycles, as shown. For one of these elementary cycles,

$$\eta = 1 - \frac{dQ_2}{dQ}$$

where dQ is the heat supplied at T_1 , and dQ_2 , the heat rejected at T_2 .

Now, the efficiency of a general cycle will be equal to or less than the efficiency of a reversible cycle.

$$\therefore 1 - \frac{dQ_2}{dQ} \leq \left(1 - \frac{dQ_2}{dQ}\right)_{\text{rev.}}$$

$$\Rightarrow \frac{dQ_2}{dQ} \geq \left(\frac{dQ_2}{dQ}\right)_{\text{rev.}}$$

$$\text{since} \Rightarrow \frac{dQ}{dQ_2} \leq \left(\frac{dQ}{dQ_2}\right)_{\text{rev.}}$$

$$\text{Since, } \left(\frac{dQ}{dQ_2}\right)_{\text{rev.}} = \frac{T}{T_2}$$

$$\Rightarrow \frac{dQ}{dQ_2} \leq \frac{T}{T_2}$$

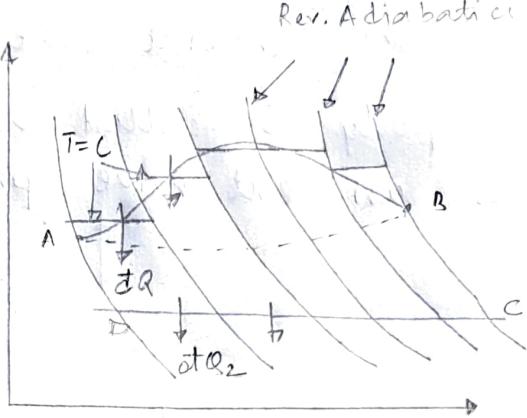


Fig: Inequality of Clausius.

or $\frac{dQ}{T} \leq \frac{dQ_2}{T_2}$, for any process AB, reversible

or irreversible.

For a reversible process,

$$ds = \frac{dQ_{\text{rev}}}{T} = \frac{dQ_2}{T_2}$$

Hence, for any process AB

$$\frac{dQ}{T} \leq ds$$

Then for any cycle

$$\oint \frac{dQ}{T} \leq \oint ds$$

Since entropy is a property and the cyclic integral of any property is zero, i.e., $\oint \frac{dQ}{T} \leq 0$

This equation is known as the inequality of Clausius.

It provides the criterion of the reversibility of cycle.

11.

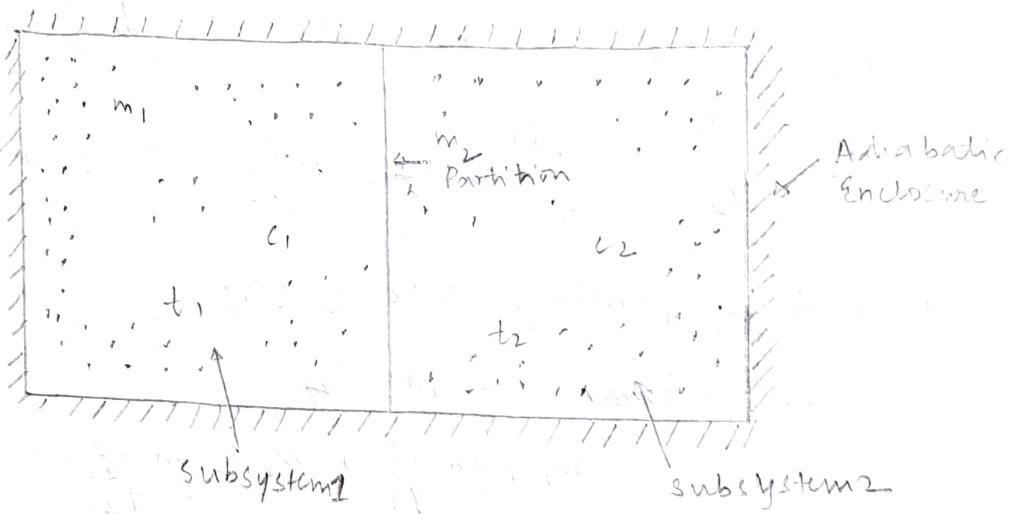


Figure: Mixing of Two Fluids.

Subsystem 1 and 2 having a fluid of mass m_1, m_2 , specific heat c_1, c_2 and temperature t_1, t_2 respectively. When the partition is removed, the two fluids mix together, and at equilibrium let t_f be the final temperature, and $t_2 < t_f < t_1$. Since energy interaction is exclusively confined to the two fluids, the system being isolated

$$m_1 c_1 (t_1 - t_f) = m_2 c_2 (t_f - t_2)$$

$$\therefore t_f = \frac{m_1 c_1 t_1 + m_2 c_2 t_2}{m_1 c_1 + m_2 c_2}$$

Entropy change for the fluid in subsystem 1

$$\begin{aligned} \Delta S_1 &= \int_{T_1}^{T_f} \frac{\partial Q_{\text{rev}}}{T} = \int_{T_1}^{T_f} \frac{m_1 c_1 dT}{T} = m_1 c_1 \ln \frac{T_f}{T_1} \\ &= m_1 c_1 \cdot \ln \left(\frac{T_f + 273}{T_1 + 273} \right) \end{aligned}$$

This will be negative, since $T_1 > T_f$.

Entropy change for the fluid in subsystem 2

$$\Delta S_2 = \int_{T_2}^{T_f} \frac{m_2 c_2 dT}{T} = m_2 c_2 \ln \frac{T_f}{T_2} = m_2 c_2 \ln \left(\frac{T_f + 273}{T_2 + 273} \right)$$

This will be positive, since $T_2 < T_f$

$$\therefore \Delta S_{\text{univ}} = \Delta S_1 + \Delta S_2 \\ = m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2}$$

ΔS_{univ} will be positive definite, and the mixing process is irreversible.

12. For any infinitesimal process undergone by a system, we have for total mass,

$$dS \geq \frac{dT}{T}$$

For an isolated system which does not undergo any energy interaction with the surroundings $dQ=0$.

Therefore, for an isolated system,

$$dS_{\text{iso}} \geq 0$$

For a reversible process,

$$dS_{\text{iso}} = 0$$

$$\Rightarrow S = \text{constant}$$

or For an irreversible process,

$$dS_{\text{iso}} > 0$$

It is thus proved that the entropy of an isolated system can never decrease. It always increases and remains constant only when the process is reversible. This is known as the principle of increase of entropy.

13. High Grade Energy is the energy that can be completely transformed into work without any loss, i.e., exempted from limitations of the second law. Examples are:

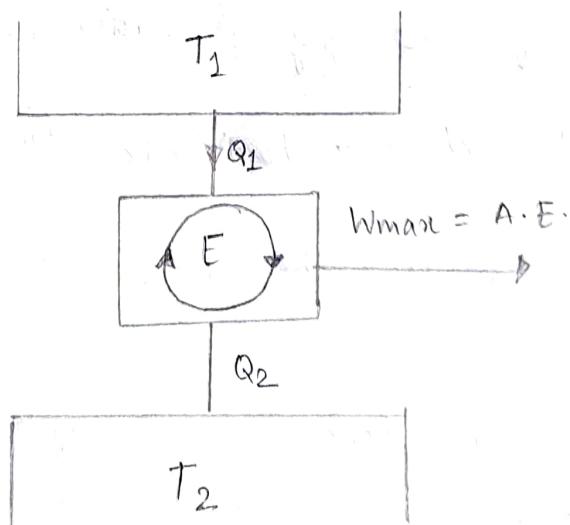
- i) Mechanical work.
- ii) Electrical Energy.
- iii) Water Power.
- iv) Wind Power.
- v) Kinetic Energy of a Jet.
- vi) Tidal Power.

Low Grade Energy is the energy that cannot be completely transformed into work by virtue of second law of thermodynamics. Examples are:

- i) Heat or Thermal Energy.
- ii) Heat derived from nuclear fission or fusion.
- iii) Heat derived from combustion of fossil fuels.

14. The maximum work output obtainable from a certain heat input in a cyclic heat engine is called Available Energy.

For example:



Here, W_{max} is the available energy.

15. Helmholtz function is a thermodynamic function which is defined as the decrease in the function and is equal to the maximum amount of work which is available during reversible isothermal process.

Helmholtz function F can be defined by the relation:

$$F = U - TS.$$

Gibbs Function is a thermodynamic function which is used to measure the maximum ~~work~~ amount of work done in a thermodynamic system when the temperature and pressure are kept constant.

Gibbs function G can be defined by the relation:

$$G = H - TS.$$

16. The Guoy-Stodola ^{theorem} states that the rate of loss of available energy or energy in a process is proportional to the rate of entropy generation, \dot{S}_{gen} .

$$\dot{I} = \dot{W}_{lost} = T_0 \dot{S}_{unir} = T_0 \dot{S}_{gen}.$$

This is known as the Guoy-Stodola equation.

The actual work done by a system is always less than the idealized reversible work, and the difference between the two is called irreversibility of the process.

$$I = W_{max} - W$$

This is also sometimes referred to as 'degradation' or 'dissipation'.

For a non-flow process between the equilibrium states, when the system exchanges heat only with the environment,

$$\begin{aligned}
 I &= [(V_1 - V_2) - T_0(S_1 - S_2)] - [(V_1 - V_2) + Q] \\
 &= T_0(S_2 - S_1) - Q \\
 &= T_0(\Delta S)_{\text{system}} + T_0(\Delta S)_{\text{sur.}} \\
 &= T_0[(\Delta S)_{\text{system}} + (\Delta S)_{\text{sur.}}] = T_0(\Delta S)_{\text{univ.}}
 \end{aligned}$$

∴ $I > 0$,

Similarly, for the steady flow process,

$$\begin{aligned}
 I &= W_{\text{max}} - W \\
 &= \left[(B_1 + \frac{mv_1^2}{2} + mgz_1) - (B_2 + \frac{mv_2^2}{2} + mgz_2) \right] \\
 &\quad - \left[(H_1 + \frac{mv_1^2}{2} + mgz_1) - (H_2 + \frac{mv_2^2}{2} + mgz_2) + Q \right] \\
 &= T_0(S_2 - S_1) - Q \\
 &= T_0(\Delta S)_{\text{sys}} + T_0(\Delta S)_{\text{sur.}} \\
 &= T_0(\Delta S_{\text{sys}} + \Delta S_{\text{sur.}}) = T_0\Delta S_{\text{univ.}}
 \end{aligned}$$

Hence, this equation when written in rate form
is the Quoy-Stodola Equation.

17. Given, $Q = 420 \text{ kJ}$

$$N = 20$$

$$\cancel{T_h} = 273 + 30 = 303 \text{ K}$$

$$T_c = 273 - 2 = 275 \text{ K}$$

$$\text{Cost} = \text{Rs } 2.5 / \text{kWh}$$

$$COP = 0.15$$

$$COP_{\max} = \frac{T_c}{T_h - T_c} = \frac{275}{303 - 275} = \frac{275}{28}$$

$$COP = 0.15 \times \frac{275}{28} = 1.473$$

$$\text{Also, } COP = \frac{Q}{W} \Rightarrow W = \frac{420}{1.473} = 285.13 \text{ kJ}$$

So, each time the door is opened, 285.13 kJ of work is to be done by fridge and that much electrical energy is consumed. The fridge is opened 20 times a day = 600 times a month.

$$\therefore \text{Monthly consumption} = 285.13 \times 600 \\ = 171079.4 \text{ kJ}$$

$$\therefore \text{Cost} = \text{Rs } 2.5 / \text{kWh} = \text{Rs } \frac{2.5}{3600} / \text{kJ}$$

$$\therefore \text{Bill} = \frac{2.5}{3600} \times 171079.4 = \text{Rs } 118 \quad \underline{\text{Ans}}$$

$$18. \text{ Carnot Efficiency } (\eta) = 1 - \frac{273 + 60}{273 + 671} = 1 - \frac{333}{944} = 0.64725$$

$$\text{Actual } (\eta_a) = 0.323623 = 1 - \frac{Q_2}{Q_1}$$

$$\Rightarrow \frac{Q_2}{Q_1} = 0.6764$$

$$\text{Ideal COP} = \frac{305.2}{305.2 - 266.4} = 7.866$$

$$\text{Actual COP}_a = 3.923 = \frac{Q_3}{W}$$

if $Q_3 = 1 \text{ kJ}$

$$\Rightarrow W = \frac{Q_3}{3.923} = \frac{1}{3.923}$$

= 0.25426 kJ/kJ, heat input to block

$$W = Q_1 - Q_2 = Q_1 - 0.6764 Q_1 \\ = 0.3236 Q_1$$

$$\therefore Q_1 = \frac{0.25426}{0.3236}$$

= 0.7857 kJ/kJ, heat input to block.

Direct heating is thermodynamically more wasteful because no process can be 100% efficient and as heat get degraded into lower temperature it and becomes less useful thus waste heat is inevitable.

19. The temperature of the heat engine source is 800K (T_1)
 The temperature of the second reservoir is 300K (T_2)

The heat extracted by the pump from reservoir at 300K is $2Q_2$.

The rate of heat supply to the engine is 40kW

$$\eta_{\text{actual}} = 30\% \text{ of } \eta_{\text{max}}$$

$$\eta_{\text{max}} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{800} = \frac{500}{800} = \frac{5}{8} = 0.625 \\ = 62.5\%$$

$$\eta_{\text{actual}} = 0.3 \times 0.625 = 0.1875$$

$$\therefore (\text{COP})_{\text{actual}} = (\text{COP})_{\text{max}} \times 0.4$$

But,

$$\eta_{\text{actual}} = \frac{W_E}{Q_1} = 0.1875$$

$$\therefore W_E = 0.1875 \times 40 = 7.5 \text{ kW}$$

$$\text{We know, } W_E = Q_1 - Q_2$$

$$\Rightarrow 0.1875 Q_1 = Q_1 - Q_2$$

$$\Rightarrow Q_2 = \cancel{0.72 Q_1} 0.8125 Q_1$$

Now,

$$(\text{COP})_{\text{actual}} = 0.4 \left(\frac{T_p}{T_p - T_2} \right)$$

$$(\text{COP})_{\text{max}} = \frac{Q_3}{Q_3 - 2Q_2}$$

$$\text{Now, } Q_3 = 2Q_2 + WE$$

$$\Rightarrow Q_3 = 2(0.8125 Q_1) + (0.1875) Q_1$$

$$\Rightarrow Q_3 = 1.8125 Q_1$$

So,

$$(COP)_{actual} = 0.4 \left(\frac{1.8125 Q_1}{0.1875 Q_1} \right) = 3.86$$

Now,

$$3.86 = 0.4 \left(\frac{T_p}{T_p - T_2} \right)$$

$$\Rightarrow 1.544 \frac{9.65}{T_p - T_2} = T_p$$

$$\Rightarrow 0.544 T_p = 1.544 T_2$$

$$\Rightarrow 8.65 T_p = 9.65 T_2$$

$$\Rightarrow T_p = \frac{9.65}{8.65} \times 300$$

$$= 334.68 \text{ K}$$

So, the ^{rate of} heat rejection from the heat pump is:

$$\begin{aligned} Q_3 &= 1.8125 Q_1 \\ &= 1.8125 \times 50 \\ &= 90.625 \text{ kW} \end{aligned}$$

Hence, the temperature of the reservoir is 334.68 K and the heat rejection from the heat pump is 90.625 kW.

20. (a) $\oint \frac{dQ}{T} = \frac{+420}{(327+273)} - \frac{-210}{(27+273)} = 0$

\therefore Cycle is reversible, Possible. Ans.

(b) $\oint \frac{dQ}{T} = \frac{420}{(327+273)} - \frac{105}{300} = 0.35$

\therefore Cycle is impossible. Ans

(c) $\oint \frac{dQ}{T} = \frac{+420}{327+273} - \frac{315}{300} = -0.35$

\therefore Cycle is irreversible and possible. Ans

21. (a) $(\Delta S)_{\text{system}} = + \frac{1 \times 335}{273} \text{ kJ/K}$

$$= 1.227 \text{ kJ/K} \quad \underline{\text{Ans}}$$

(b) $(\Delta S)_{\text{system}} = \int_{273}^{273} mC_p \frac{dT}{T} = 0 \text{ kJ/K} \quad \underline{\text{Ans}}$

22. Heat absorbed by ice & from the atmosphere
 $=$ Heat absorbed in solid phase + latent heat +
 Heat absorbed in liquid phase

$$\begin{aligned} &= 1 \times 2.093 \times (0 - (-5)) + 1 \times 333.3 + (1 \times 4.187) \times (20 - 0) \\ &= 427.5 \text{ kJ} \end{aligned}$$

Entropy change of the atmosphere

$$(\Delta S)_{\text{atm}} = -\frac{Q}{T} = -\frac{427.5}{293} = -1.46 \text{ kJ/K}$$

Entropy of the system (ice) as it gets heated from -5°C to 0°C .

$$(\Delta S_I)_{\text{system}} = \int_{268}^{293} m C_p \frac{dT}{T} = 1 \times 2.093 \ln \frac{273}{268}$$

$$= 2.093 \times 0.0186 = 0.0389 \text{ kJ/K}$$

Entropy change of the system as ice melts at 0°C to become water at 0°C

$$(\Delta S_{II})_{\text{system}} = \frac{333.3}{273} = 1.22 \text{ kJ/K}$$

Entropy change of water as it gets heated from 0°C to 20°C

$$(\Delta S_{III})_{\text{system}} = \int_{273}^{293} m C_p \frac{dT}{T} = 1 \times 4.187 \ln \frac{293}{273}$$

$$= 0.296 \text{ kJ/K}$$

Total entropy change of ice as it melts into water

$$(\Delta S)_{\text{total}} = \Delta S_I + \Delta S_{II} + \Delta S_{III}$$

$$= 0.0389 + 1.22 + 0.296$$

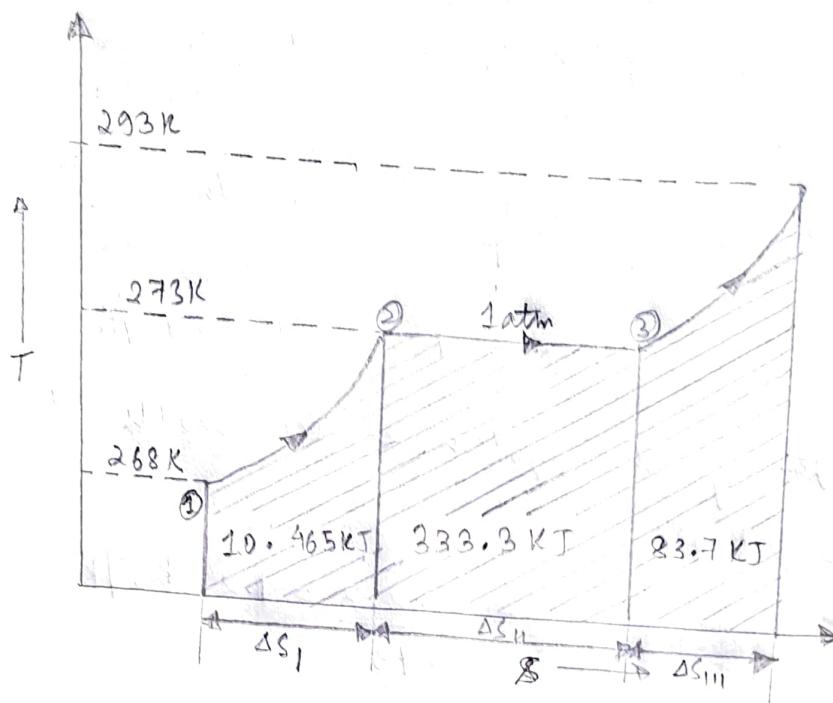
$$= 1.5549 \text{ kJ/K}$$

The entropy - temperature diagram for the system as ice at -5°C converts to water at 20°C is shown.

\therefore Entropy increase of universe

$$\Rightarrow \Delta S_{\text{univ}} = \Delta S_{\text{system}} + \Delta S_{\text{atmospheric}}$$

$$= 1.5549 - 1.46 = 0.0949 \text{ kJ/K}$$



To convert 1 kg of water at 20°C to ice at -5°C, 427.5 kJ of heat have to be removed from it, and the system has to be brought from state 4 to state 1. A refrigerator cycle, as shown is assumed to be accomplished. The entropy change of the system would be the same, i.e., $S_1 - S_4$, with the only difference that its sign will be negative, because heat is removed from the system.

$$(\Delta S)_{\text{system}} = S_1 - S_4 \text{ (negative)}$$

The entropy change of the working fluid in the refrigerator would be zero, since it is operating in a cycle, i.e., $(\Delta S)_{\text{ref}} = 0$,

The entropy change of the atmosphere (positive)

$$(\Delta S)_{\text{atm}} = \frac{Q + W}{T}$$

∴ Entropy change of the universe

$$\begin{aligned} (\Delta S)_{\text{univ}} &= (\Delta S)_{\text{system}} + (\Delta S)_{\text{ref}} + (\Delta S)_{\text{atm}} \\ &= (S_1 - S_4) + \frac{Q + W}{T} \end{aligned}$$

By the principle of increase of entropy

$$(\Delta S)_{\text{univ}} \text{ or } \geq 0$$

isolated system

$$\therefore [(S_1 - S_4) + \frac{Q + W}{T}] \geq 0$$

$$\therefore \frac{Q + W}{T} \geq S_4 - S_1$$

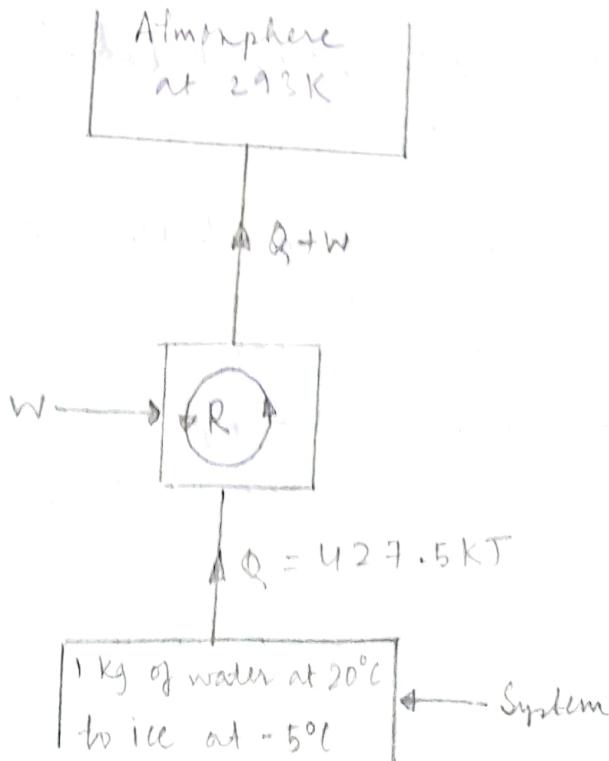
$$\therefore W \geq T(S_4 - S_1) - Q$$

$$\Rightarrow W_{(\min)} = T(S_4 - S_1) - Q$$

$$\text{Here, } Q = 427.5 \text{ kJ; } T = 293 \text{ K}$$

$$\Rightarrow S_4 - S_1 = 1.5549 \text{ kJ/K}$$

$$\Rightarrow W_{\min} = 293 \times 1.5549 - 427.5 = 28.5 \text{ kJ}$$



23. For maximum work obtainable the process should be reversible

$$(\Delta S)_{\text{body}} = \int_{T_1}^{T_0} C_v \frac{dT}{T} = C_v \ln\left(\frac{T_0}{T_1}\right)$$

$$(\Delta S)_{\text{reso}} = \frac{Q-W}{T_0}$$

$$(\Delta S)_{\text{cycle}} = 0$$

$$\therefore (\Delta S)_{\text{minv}} = C_v \ln\left(\frac{T_0}{T_1}\right) + \frac{Q-W}{T_0} \geq 0$$

$$\therefore C_v \ln\left(\frac{T_0}{T_1}\right) + \frac{Q-W}{T_0} \geq 0$$

$$\text{or } C_v T_0 \ln\left(\frac{T_0}{T_1}\right) + Q - W \geq 0 \quad \therefore Q = C_v (T_1 - T_0)$$

$$\text{or } W \leq Q + C_v T_0 \ln\left(\frac{T_0}{T_1}\right)$$

$$\text{or } W \leq C_v (T_1 - T_0) + C_v T_0 \ln\left(\frac{T_0}{T_1}\right)$$

$$\text{or } W \leq C_v \left\{ (T_1 - T_0) + T_0 \ln\left(\frac{T_0}{T_1}\right) \right\}$$

$$\therefore \text{Maximum work } W_{\text{max}} = C_v \left\{ (T_1 - T_0) + T_0 \ln\left(\frac{T_0}{T_1}\right) \right\} \text{ Ans}$$

23(a) As the temperature of the resistor is constant, its entropy does not change. The entropy is a function of state. Hence, the change in the entropy of the resistor is zero, i.e., $\Delta S_1 = 0$.

(b) The heat that flows from the resistor to the external world (a heat source of constant temperature)

is

$$I^2 R t = (10)^2 \times (250) \times (1)$$

$$= 25000 \text{ J} = 25 \text{ kJ}$$

The increase in entropy of the heat source is ΔS_2 .

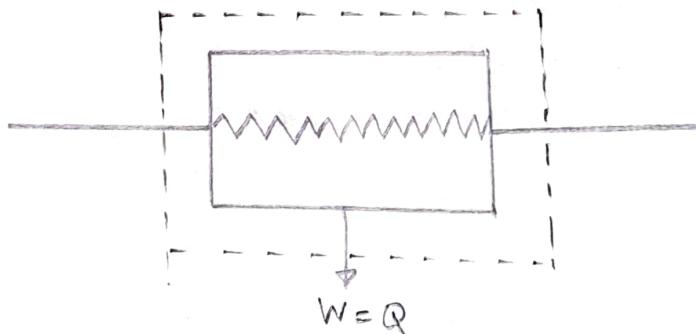
$$\Delta S_2 = \frac{25000 \text{ J}}{(27+273) \text{ K}} = 83.33 \text{ J/K}$$

Thus the total change in entropy is $\Delta S = \Delta S_1 + \Delta S_2$

$$= 83.33 \text{ J/K}$$

(c) If the resistor is thermally insulated, then no heat flow to surroundings,

$$\text{So, } (\Delta S)_{\text{surroundings}} = 0$$



(d) Temperature of resistor (δt) = $\frac{Q}{mc}$

$$= \frac{(10)^2 \times (250) \times (1)}{0.84 \times 1000 \times 0.01} = 2976.19 \text{ K}$$

$$\therefore \text{Final temperature } (T_f) = 2976.19 \text{ K} + 300 \text{ K}$$

$$= 3276.19 \text{ K}$$

$$\therefore \text{Initial Temperature } (T_0) = 300 \text{ K}$$