Velammal Institute of Technology, Panchetti
Department of Mechanical Engineering

ME8351- ENGINEERING THERMODYNAMICS

Focused question

UNIT II SECOND LAW AND AVAILABILITY ANALYSIS

PART –A (2 marks)

1. State the Kelvin – Plank statement of second law of thermodynamics
Ans: Kelvin – Plank states that it is impossible to construct a heat engine working on cyclic process, whose only purpose is to convert all the heat energy given to it into an equal amount of work.

2. State Clausius statement of second law of thermodynamics.

Ans: It states that heat can flow from hot body to cold without any external aid but heat cannot flow from cold body to hot body without any external aid.

3. State Carnot's theorem.

Ans: No heat engine operating in a cyclic process between two fixed temperature, can be more efficient than a reversible engine operating between the same temperature limits.

5. What are the Corollaries of Carnot theorem.

Ans: (i) In all the reversible engine operating between the two given thermal reservoirs with fixed temperature, have the same efficiency.

(ii) The efficiency of any reversible heat engine operating between two reservoirs is independent of the nature of the working fluid and depends only on the temperature of the reservoirs.

6. Define – PMM of second kind.

Ans: Perpetual motion machine of second kind draws heat continuously from single reservoir and converts it into equivalent amount of work. Thus it gives 100% efficiency.

7. What is the difference between a heat pump and a refrigerator?

Ans: Heat pump is a device which operating in cyclic process, maintains the temperature of a hot body at a temperature higher than the temperature of surroundings.

A refrigerator is a device which operating in a cyclic process, maintains the temperature of a cold body at a temperature lower than the temperature of the surroundings.

8. What is meant by heat engine?

Ans: A heat engine is a device which is used to convert the thermal energy into mechanical energy.

9. Define the term COP?

Ans: Co-efficient of performance is defined as the ratio of heat extracted or rejected to work input.

$$COP = \frac{\text{Heat extracted or rejected}}{\text{Work input}}$$

10. Write the expression for COP of a heat pump and a refrigerator? Ans: COP of heat pump

$$COP_{HP} = \frac{\text{Heat Supplied}}{\text{Work input}} = \frac{T_2}{T_2 - T_1}$$

COP of Refrigerator

$$COP_{HP} = \frac{\text{Heat extrated}}{\text{Work input}} = \frac{T_1}{T_2 - T_1}$$

11.What is the relation between COP_{HP} and COP $_{ref}$?

Ans: $COP_{HP} = COP_{ref} + 1$

12.Why Carnot cycle cannot be realized in practical?

Ans: (i) In a Carnot cycle all the four process are reversible but in actual practice there is no process is reversible.

(ii) There are two processes to be carried out during compression and expansion. For isothermal process the piston moves very slowly and for adiabatic process the piston moves as fast as possible. This speed variation during the same stroke of the piston is not possible.

(iii) It is not possible to avoid friction moving parts completely.

13.Name two alternative methods by which the efficiency of a Carnot cycle can be increased.

Ans: (i) Efficiency can be increased as the higher temperature T_2 increases. (ii) Efficiency can be increased as the lower temperature T_1 decreases.

14. Why a heat engine cannot have 100% efficiency?
Ans: For all the heat engines there will be a heat loss between system and surroundings.

Therefore we can"t convert all the heat input into useful work.

15. When will be the Carnot cycle efficiency is maximum?
Ans: Carnot cycle efficiency is maximum when the initial temperature is 0°K.

16.What are the processes involved in Carnot cycle.
Ans: Carnot cycle consist of

i) Reversible isothermal compression ii) isentropic compression

iii) reversible isothermal expansion iv) isentropic expansion

17.Write the expression for efficiency of the carnot cycle.

Ans: $n = \frac{T2 - T1}{T2}$

18. Define: Thermodynamic cycles.

Ans: Thermodynamic cycle is defined as the series of processes performed on the system, so that the system attains to its original state.

19. Define the term compression ratio.

Ans: Compression ratio is the ratio between total cylinder volume to clearance volume. It is denoted by the letter „r‟

20. What is the range of compression ratio for SI and diesel engine?

Ans: For petrol of SI engine 6 to
8 For diesel engine 12 to 18.

21. Which cycle is more efficient for the same compression ratio and heat input, Otto cycle or Diesel cycle?

Ans: Otto cycle is more efficient than diesel cycle

22.The efficiency of the diesel cycle approaches the otto cycle efficiency when the cut off ratio is ______

Ans: reduced

23. Which device is used to control the Air – fuel ratio in the petrol engine?

Ans: Carburettor

24.Which device is used to control the Air fuel ratio in the diesel engine?

Ans: Injection nozzle

25.The speed of a four stroke I.C. engine is 1500rpm. What will be the speed of the cam shaft?

Ans: 750 rpm.

26.All the four operations in two stroke engine are performed in ________ number of revolution of crank shaft.

Ans: one

PART –B

1. Explain the terms Heat Reservoir, source and sink. Show that the efficiency of the reversible engine operating between two given constant temperature is the maximum. Determine the maximum work obtainable by using one finite body at temperature T and a thermal energy reservoir at temperature T0, T >T0.

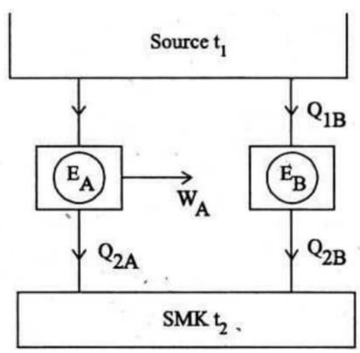
Source: The device which the heat to be rejected to work absorbing or work developing device is called source.

Sink: The device which receives heat from work absorbing or working device is called sink.

Reservoir: The device which supplies or heat continuously without change in its temperature is called as reservoir.

Efficiency of a reversible engine operating between two constant temperatures:

Let two heat engines E_A and E_B operate between the given source at temperature t_1 and the given sink at temperature t_2 as shown in fig. [Same source and sink of which E_R is reversible] Let E_A be any heat engine and E_B be any reversible heat engine. Let the rates of working of the engines be such that



Q1A = Q1B = Q1

$\eta A > \eta B$

$$\frac{W_A}{Q_{1A}} > \frac{W_B}{Q_{1B}}$$

Now let E_B be reversed. Since E_B is reversible heat engine, the magnitudes of heat and work transfer quantities will remain in the same, but their directions will be reversed.

E_A and E_B together violate the kelvin Planck statement. Network $W_A - W_B$, while exchanging heat with a single reserve at t_2. This violates the second law. Hence the assumption that $\eta_A > \eta_B$ is wrong.

Maximum work obtainable by using one finite body at temperature T and a thermal energy reservoir at temperature T_0, $T > T_0$

Take $T_0 = T_H$, $T = T_L$.

The final temp $T_f = \frac{T_H + T_L}{2}$

The portion of the heat from the body 1 is supplied to the heat engine to convert work. The remaining heat is rejected to the body 2. After sometime both the bodies will reach thermal equilibrium at a temperature of T_f.

Heat supplied to heat engine, $Q_S = C_P [T_H - T_f]$

Heat rejected to body 2, $Q_R = Cp\ [T_f - T_L]$

$W = Cp\ [T_H - T_f - T_f + T_L]$

$= C_P [T_H + T_L - 2T_f]$

Change in entropy of body

$$\Delta S_1 = \int_{T}^{T_f} C_p \frac{dT}{T} = C_P \ln\left[\frac{T_f}{T_H}\right]$$

Similarly

$$\Delta S_2 = C_P \ln\left[\frac{T_f}{T_L}\right]$$

$$\therefore C_P \ln\frac{T_f}{T_H} + C_P \ln\frac{T_f}{T_L} > 0$$

$$C_P \ln\frac{T_f^2}{T_H T_L} \geq 0$$

T_f to be maximum.

$C_p \ln\frac{T_f^2}{T_1 T_2}$ Should be equal to zero

$$\therefore C_P \ln \frac{T_f^2}{T_1 T_2} = 0$$

$$\ln \frac{T_f^2}{T_1 T_2} = 0 \text{ and } C_P \neq 0$$

$$= \ln 1$$

$$\frac{T_f^2}{T_1 T_2} = 1$$

$$T_f = \sqrt{T_1 T_2}$$

Maximum work,

$$W_{max} = C_P [T_1 + T_2 - 2\sqrt{T_1 T_2}$$

$$= C_P \left[(\sqrt{T_1})^2 + (\sqrt{T_2})^2 - 2\sqrt{T_1}\sqrt{T_2} \right]$$

$$W_{max} = C_P [\sqrt{T_1}\ \sqrt{T_2}\ ]^2.$$

2. Explain the term Heat Engine, Refrigerator, and Heat pump. Deduce the relation between the cop of heat pump and refrigerator.

Differentiate between heat pump and refrigerator.

Heat pump is a device which operating in a cycle process maintains the temperature of a hot body at a temperature higher than the temperature of surrounding.

A refrigerator is a device which operating in a cycle process, maintains the temperature of a cold body a temperature lower than the temperature of the surrounding.

A **heat pump** is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one.

Coefficient of performance:

The **coefficient of performance** or **COP** of a heat pump is a ratio of heating or cooling provided to electrical energy consumed.

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}.$$

Relation between COP of heat pump and refrigerator:

$$COP_{Ref} = \frac{Q_2}{Q_1 - Q_2}$$

Adding 1 on both sides,

$$1 + COP_{Ref} = 1 + \frac{Q_2}{Q_1 - Q_2}$$

$$1 + COP_{Ref} = \frac{Q_1 - Q_2 + Q_2}{Q_1 - Q_2} = \frac{Q_2}{Q_1 - Q_2}$$

We know that,

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}.$$

Hence, $COP_{h.P} = 1 + COP_{ref}$.

3. Explain Carnot cycle and Reversed Carnot cycle, Performance.

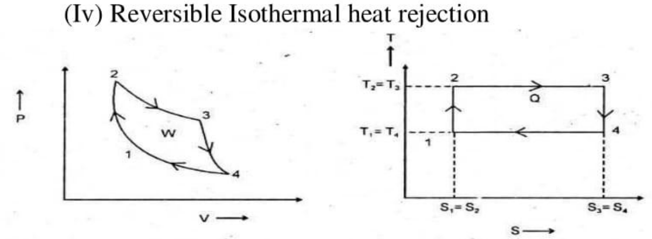
Carnot Theorem:

It states that of 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: Efficiency of all reversible heat engines operating between the same temperature levels is the same.

Carnot cycle consists of

(i) Reversible adiabatic Compression
(ii) Reversible isothermal heat addition
(iii) Reversible adiabatic expansion
(Iv) Reversible Isothermal heat rejection



(a) P-V diagram (b) T-S diagram

Process 1-2: Isentropic Compression
Process 2-3: Isothermal heat addition
Process 3-4: Isentropic expansion
Process 4-1: Isothermal heat rejection

Reversed Carnot Cycle

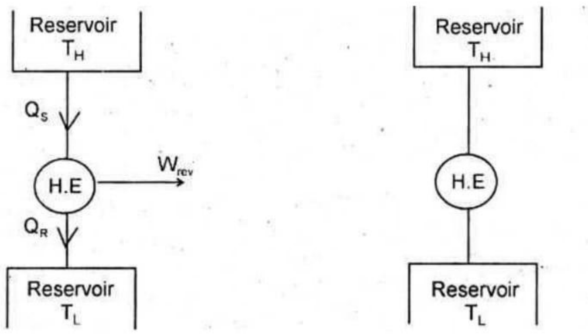
This cycle consist of two isothermal and two isentropic process, But this cycle is used to extract heat from cold body and rejects it into hot body .Therefore ,the same cycle is performed in the reverse direction

4. Establish the inequality of Clausius.

Clausius inequality states that when a system undergoes a cyclic process, the summation of $\frac{dQ}{T}$ around a closed cycle is less than or equal to zero.

Consider an engine operating between two fixed temperature reservoirs T_H and T_L. Let dQ_S, units of heat be supplied at temperature T_H and dQ_R units of heat be rejected at temperature T_L during a cycle.

Thermal efficiency, $\eta = \frac{dQ_S - dQ_R}{dQ_S}$



Thermal efficiency of any reversible engine working on the temperature limit is given by thermal efficiency for reversible engine = $\frac{T_H - T_L}{T_H}$.

The efficiency of an actual engine cycle must be less that of a reversible cycle. Since no engine can be more efficient than that of a reversible engine. Hence

$$\frac{dQ_S - dQ_R}{dQ_S} \leq \frac{T_H - T_L}{T_H}$$

$$\frac{dQ_R}{dQ_S} \leq \frac{T_L}{T_H}$$

$$\frac{dQ_R}{T_L} \leq \frac{dQ_S}{T_H}$$

$$\frac{dQ_R}{T_L} - \frac{T/Q_S}{T_H} \leq 0$$

for entire cycle, $\oint \frac{dQ}{T} \leq 0$

This equation is known as Clausius inequality. It provides the criterion of reversibility of a cycle.

If $\oint \frac{dQ}{1} = 0,$ the cycle is reversible

$\oint \frac{dQ}{T} < 0,$ The cycle is irreversible and possible

$\oint \frac{dQ}{T} > 0,$
The cycle is impossible.

Since the cyclic integral $\oint \frac{dQ}{1}$ is less than zero in a cycle. The cycle violates the II[nd] law of TD. So, it is impossible.

5. Give the criteria of reversibility, irreversibility and impossibility of a thermodynamic cycle.

$\oint \frac{dQ}{T} \leq 0$
is known as inequality of Clausius

If (1) $\oint \frac{dQ}{T} = 0$, the cycle is reversible.

(2) $\oint \frac{dQ}{T} < 0$, the cycle is irreversible and possible.

(3) $\oint \frac{dQ}{T} > 0$, the cycle is impossible (violation of II law).

6. What do you understand by the concept of entropy? Deduce the expression for the entropy change in terms of pressure and the temperature.

Entropy is an index of unavailability or degradation of energy. Heat always flows from hot body to cold body and thus becomes lesser value available. The availability of energy is measured by entropy. It is an important thermodynamics property of working substance.

By law of conservation of energy or first law of thermodynamics,

$$dQ = dW + dU \quad \therefore \quad \begin{bmatrix} dU = mC_V\, dt \\ dW = P \cdot dV \end{bmatrix}$$

$$dQ = P \cdot dV + M \cdot C_V\, dT \qquad \ldots(1)$$

Dividing equation (1) throughout by ‘T’

$$\frac{dQ}{T} = \frac{P}{T} dV + mC_V \frac{dT}{T}$$

$$dS = mR \frac{dV}{V} + mC_V \frac{dT}{T} \quad \left[\because \frac{dQ}{\cdot T} = dS;\ PV = mRT\right]$$

By gas equation $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_1}$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}\frac{T_2}{T_1}$$

Substituting in change in entropy

$$dS = m \cdot R \cdot \ln \left[\frac{P_1}{P_2} \cdot \frac{T_2}{T_1}\right] + m \cdot C_V \cdot \ln \left[\frac{T_2}{T_1}\right]$$

$$= m \cdot R \cdot \ln \left(\frac{P_1}{P_2}\right) + m \cdot R \cdot \ln \left(\frac{T_1}{T_1}\right) + m \cdot C_V \cdot \ln \left(\frac{T_1}{T_1}\right)$$

$$= m \cdot R \cdot \ln \left(\frac{P_1}{P_2}\right) + m\left(C_P - C_V\right) \ln \left(\frac{T_2}{T_1}\right) + m \cdot C_V \cdot \ln \left(\frac{T_2}{T_1}\right)$$

$$= m \cdot R \cdot \ln \left(\frac{P_1}{P_2}\right) + mC_P \cdot \ln \left(\frac{T_2}{T_1}\right) - m \cdot C_V \cdot \ln \left(\frac{T_2}{T_1}\right) + m \cdot C_V \cdot \ln \left(\frac{T_1}{T_1}\right)$$

$$\boxed{dS = m \cdot R \cdot \ln \left(\frac{P_1}{P_1}\right) + m \cdot C_P \cdot \ln \left(\frac{T_2}{T_1}\right) \; kJ/k.}$$

7. Available and non-available energy of a source and finite body. Show that there is a decrease in available energy when heat is transferred through a finite temperature difference.

Availability:

Availability is defined as the maximum useful work that is obtainable in a process in which the system comes to equilibrium with the surroundings.

Heat transfer through a finite temperature difference:

$$Q_1 = T_1 \,\Delta S,\; Q_2 = T_0 \,\Delta S.$$

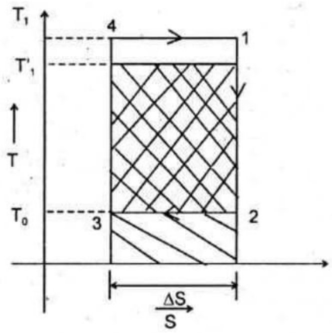
Work output = Available energy

$$W = T_1 \,\Delta S - T0 \,\Delta S = (T_1 - T_0) \,\Delta S.$$

Assume heat G, is supplied to the engine. The temperature will be T_1. What this heat reaches heat engine not T_1. But the reservoir will be at same temperature T_1. Therefore entropy due to T_1 will increase from AS to AS.

According to reversible heat engine concept,

$$Q_1 = T_1 \,\Delta S = T_1 \,\Delta S.$$



$\therefore Q_2 = T_0\,\Delta S$

$W = Q_1 - Q_2 = T_1\,\Delta S - T_0\,\Delta S = (T_1 - T_0)\,\Delta S$

$W = (T_1 - T_0)\,\Delta S.$

∴ the actual work output of heat engine will be less because

$Q_1 > Q_2$

∴ Decrease in available energy,

$W - W = a_2 - a_2.$

If the temperature difference between T_1 and T_2 is greater the decrease in available energy will be more. Thus, there is a decrease in available energy when heat is transferred through a finite temperature difference.