

Q.1

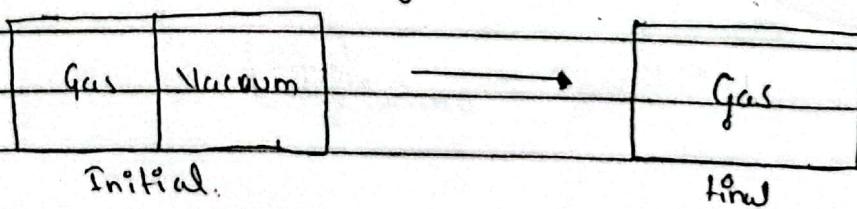
⇒ First law of thermodynamics explains thermodynamic process with reference to mass conservation & energy conservation. It deals with the quantitative aspect of the energy & gives only condition that any process is possible provided that the total energy remains constant.

But in some process nature content cannot occur although every energy conservation principle is satisfied.

For eg:- According to first law of thermodynamics for a cyclic process net heat transfer is equal to net work transfer. But in any real device even operating on a cycle, cannot convert heat supplied to it completely into output work.

Q.2

⇒ The key feature of second law of thermodynamics is that it defines the direction of process. The second law of thermodynamics defines the direction of the process with reference to the system property called entropy.



There is more space for gas molecule in state 2 than in state 1. Gas molecule at state 1 have less randomness as compared to that of state 2. During the particles have uniform orientation. Whereas, when heat supplied to the system its molecular randoms increase. In this regard, work transfer is called high grade of energy & heat transfer is called low grade of energy.

The property of a system which gives a measure of molecular randomness, disorder or uncertainty existing in a system is known as entropy.

It is an extensive property & is denoted by S .

Second law of thermodynamic for an isolated system can be stated as,

"Entropy of an isolated system always increases or may remain constant (is an ideal process)."

Mathematically,

$$(ds)_{\text{isolated}} \geq 0$$

$$S_{\text{final}} - S_{\text{initial}} \geq 0$$

$$S_{\text{final}} \geq S_{\text{initial}}$$

The above equation shows that the entropy of an isolated system at the final state in any real process is always greater than that at the initial state.

The difference betw entropies at the final & initial state during any process is called entropy production or entropy generation & is denoted by δs_{gen} .

$$(\delta s - \delta s_{\text{gen}})_{\text{isolated}} = 0$$

$$(\delta s_{\text{gen}})_{\text{isolated}} \geq 0$$

In term of rate,

$$\left(\frac{ds}{dt} \right)_{\text{isolated}} \geq 0$$

&

$$\left(\frac{ds}{dt} \right)_{\text{isolated}} - s_{\text{gen}} = 0$$

For any process bet'n state 1 & state 2,
 $S_2 > S_1$

If, $S_2 = S_1$, reversible process

$S_2 > S_1$, irreversible process

A process is said to be reversible process if the initial condition of both the system & surrounding can be restored by the reverse action such that net change in entropy is zero for both forward & reverse process.

~~A process is said to be irreversible process if the initial conditions of both~~

A process is said to be irreversible process if the initial condition of both the system & surrounding cannot be restored by the reverse action.

Entropy of the system increase in the forward direction & the reverse direction is not possible.

A process is said to be an internally reversible if the initial condition of only the system is restored when the system is taken through the reverse direction.

A process is said to be an externally reversible if the initial condition of only the surrounding is restored when the system is taken through the reverse direction.

1)

- | | |
|--|--|
| Thermal irreversibility
\rightarrow It is due to | Mechanical irreversibility
\rightarrow It is due to |
| <ul style="list-style-type: none"> • Heat transfer bet' the system & surrounding • Heat transfer within the system | <ul style="list-style-type: none"> • friction bet' the system & surrounding. • Friction within the system. |

2)

Entropy Relations for an Ideal gas.

for an ideal gas, the state properties P, V, f T are related by equation of state as.

$$PfV = mRT$$

$$\frac{P}{T} = \frac{mR}{V}$$

The change in internal energy of an ideal gas is given by

$$dU = mc_V dT$$

Substituting, we get

$$dS = mC_V \frac{dT}{T} + mR \frac{dy}{V}$$

Assuming C_V & R as constants, we get the expression for the change in entropy for an ideal gas during any process between state 1 & state 2 in term of temperature & volume ratio as

$$\therefore S_2 - S_1 = mC_V \ln\left(\frac{T_2}{T_1}\right) + mR \ln\left(\frac{V_2}{V_1}\right)$$

Similarly,

$$\text{eqn of state can also be rearranged as } \frac{V}{T} = \frac{mR}{P}$$

The change in enthalpy of an ideal gas given by

$$dH = mC_p dT$$

Substituting, we get

$$dS = mC_p \frac{dT}{T} - mR \frac{dp}{P}$$

Integrating, we get

$$S_2 - S_1 = mC_p \ln\left(\frac{T_2}{T_1}\right) - mR \ln\left(\frac{P_2}{P_1}\right).$$

for an incompressible substance.

Volumes of the solid & liquid substance do not change appreciably with the pressure or temp.

so they are known as incompressible substance

$$\therefore dV = 0$$

Then we get entropy relation for an incompressible substance as,

$$dS = \frac{dU}{T} = \frac{mc}{T} dT$$

$$S_2 - S_1 = mc \ln \left(\frac{T_2}{T_1} \right)$$

An idealized system which one interact with its surroundings only by work transfer but not heat transfer is called reversible work transfer reservoir.

Applying first law of thermodynamics for a reversible work transfer reservoir.

$$d\text{Gibbs} = dU + PdV = 0$$

$$dU = -PdV$$

Substituting dU into Gibbs eqⁿ $dS = \frac{dU}{T} + \frac{PdV}{T}$, we get,

$$dS = -\frac{PdV}{T} + \frac{PdV}{T} = 0$$

The abo. eqⁿ shows that work transfer doesn't have any contribution on the entropy of the system

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An idealized system which can interact with its surrounding only by heat transfer but not work transfer is called reversible heat transfer reservoir.

$$\delta W = PdV = 0$$

From Gibbs eqⁿ,

$$ds = \frac{du}{T} + \frac{pdv}{T}, \text{ we get}$$

$$ds = \frac{du}{T} \quad \dots \text{①}$$

Applying first law of thermodynamics, we get,

$$\delta Q = du + pdv$$

$$= du + 0$$

$$= du$$

Substituting du into above eqⁿ, ①

$$ds = \frac{\delta Q}{T}$$

Thus, above eqⁿ shows that entropy of a system increases if heat is supplied to it & decreases if it loses heat.

Second law of thermodynamics for control mass

It state that the change in entropy of a control mass is greater than or equal to the sum of heat transfer divided by the corresponding boundary absolute temperature.

Mathematically,

$$(ds)_{CM} \geq \sum \left(\frac{dq_i}{T_i} \right)_{CM}$$

CM

Reversible work & isolated system
Transfer 2, D₂

Reversible heat Reversible Reversible Heat
Transfer reservoir work transfer Transfer reservoir
 $1, T_1$ reservoir $1, P_1$ $2, T_2$

Consider an isolated system shown in figure consisting of control mass interacting with a number of heat transfer reservoirs & work transfer reservoir contribution of heat transfer on Entropy,

$$\delta w = PdV = 0$$

$$\text{Gibb, eqn} ; ds = \frac{du}{T} + \frac{PdV}{T}$$

we get,

$$ds = \frac{du}{T}$$

Applying first law of thermodynamic,

we get

$$\delta Q = \delta U + PdV$$
$$= dU$$

then, we get

$$dS = \frac{\delta Q}{T}$$

contribution of work transfer on Entropy.

$$\delta Q = dU + PdV = 0$$

$$dU = -PdV$$

Then,

from gibbs eqⁿ, we get

$$dS = -\frac{PdV}{T} + \frac{PdV}{T} = 0$$

Applying second law of thermodynamic

$$(ds)_{\text{isolated}} \geq 0$$

Then,

$$(ds)_{CM} + \sum (ds)_{RHTR} + \sum (ds)_{RWTR} \geq 0$$

substituting $\sum (ds)_{RWTR} = 0$, we get

$$(ds)_{CM} + \sum (ds)_{RHTR} \geq 0$$

$$(ds)_{CM} + \sum \left(\frac{\delta Q_i}{T_i} \right)_{RHTR} \geq 0$$

If $(\delta Q_i)_{RHTR}$ is the heat supplied by the reservoir at temp. T_i . Then it is supplied by the control mass, therefore

$$(\delta Q_i^o)_{\text{RHFrs}} = -(\delta Q_i^o)_{\text{IM}}$$

then,

$$(\delta S)_{\text{cm}} - \sum \left(\frac{\delta Q_i^o}{T_i^o} \right)_{\text{ex}} \geq 0$$

avoiding the inequality,

$$(\delta S)_{\text{cm}} - \sum \left(\frac{\delta Q_i^o}{T_i^o} \right)_{\text{cm}} - (\delta S)_{\text{gen}} = 0$$

In term of rate,

$$\left(\frac{dS}{dt} \right)_{\text{cm}} \geq \sum \left(\frac{Q_i^o}{T_i^o} \right)_{\text{cm}}$$

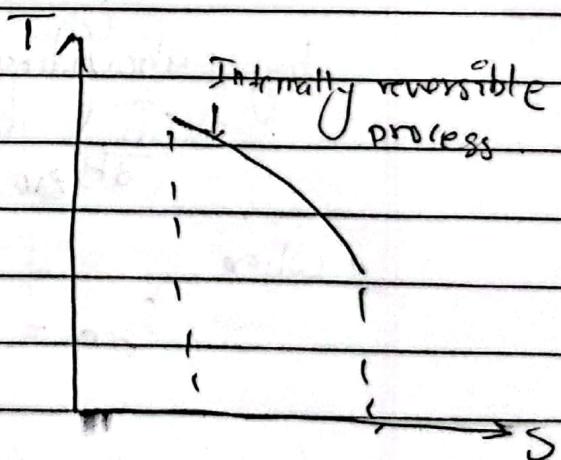
$$\left(\frac{dS}{dT} \right)_{\text{cm}} - \sum \left(\frac{Q_i^o}{T_i^o} \right)_{\text{cm}} - (\dot{S})_{\text{gen}} = 0$$

for a single reservoir undergoing reversible,
we get

$$dS = \frac{\delta Q}{T}$$

$$\delta Q = T dS$$

The above eq' shows that
area under T-S diagram give
the magnitude of heat transfer



Second law of Thermodynamic for control volume.

It state that, The change in entropy of a control vol. minus that net entropy change of working substance due to mass transfer is greater than or equal to the sum of heat transfer divided by the corresponding boundary absolute temp.

Mathematically,

$$\left(\frac{ds}{dt}\right)_{cv} - s_{net} \geq \sum \left(\frac{Q_i}{T_i}\right)_{cv}$$

substituting $s_{net} = s_{in} - s_{out}$

$$\left(\frac{ds}{dt}\right)_{cv} - s_{in} + s_{out} \geq \sum \left(\frac{Q_i}{T_i}\right)_{cv}$$

by above inequality,

$$\left(\frac{ds}{dt}\right)_{cv} - s_{in} + s_{out} - \sum \left(\frac{Q_i}{T_i}\right)_{cv} - s_{gen} = 0$$

where,

$$s_{gen} = \left(\frac{ds}{dt}\right)_{cv} - s_{in} + s_{out} - \sum \left(\frac{Q_i}{T_i}\right)_{cv}$$

2)

\Rightarrow The process during which the entropy remains constant is known as isentropic process. It is reversible as well as adiabatic process.

thus.

$$dS = 0$$

$$\therefore S_2 - S_1 = 0$$

$$\therefore S_2 = S_1$$

Substituting, $S_2 - S_1 = 0$ in equation below we get

$$S_2 - S_1 = m c_v \ln \left(\frac{T_2}{T_1} \right) + m f \ln \left(\frac{V_2}{V_1} \right) = 0 \quad \text{--- (1)}$$

$$S_2 - S_1 = m c_p \ln \left(\frac{T_2}{T_1} \right) - m R \ln \left(\frac{P_2}{P_1} \right) = 0 \quad \text{--- (2)}$$

From eqⁿ (1) we get

$$c_v \ln \left(\frac{T_2}{T_1} \right) = -R \ln \left(\frac{V_2}{V_1} \right)$$

$$\therefore \ln \left(\frac{T_2}{T_1} \right)^{c_v} = \ln \left(\frac{V_1}{V_2} \right)^{-R}$$

Taking antilog of both sides

$$\therefore \left(\frac{T_2}{T_1} \right)^{c_v} = \left(\frac{V_1}{V_2} \right)^{-R} = \left(\frac{V_1}{V_2} \right)^R$$

$$\therefore \frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\frac{R}{c_v}} = \left(\frac{V_1}{V_2} \right)^{\frac{(P-CV)}{c_v}} = \left(\frac{V_1}{V_2} \right)^{\frac{C_P - C_V}{c_v}} = 1$$

$$\therefore \frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{R-1}$$

from eqⁿ (ii), we get

$$c_p \ln \left(\frac{T_2}{T_1} \right) = R \ln \left(\frac{P_2}{P_1} \right)$$

$$\ln \left(\frac{T_2}{T_1} \right)^{c_p} = \ln \left(\frac{P_2}{P_1} \right)^R$$

taking antilog on both side.

$$\left(\frac{T_2}{T_1} \right)^{c_p} = \left(\frac{P_2}{P_1} \right)^R$$

$$= \left(\frac{P_2}{P_1} \right)^{\frac{R}{c_p}}$$

$$= \left(\frac{P_2}{P_1} \right)^{\frac{c_p - c_v}{c_p}}$$

$$= \left(\frac{P_2}{P_1} \right)^{1 - \frac{c_v}{c_p}} = \left(\frac{P_2}{P_1} \right)^{1 - \frac{1}{\gamma}}$$

$$= \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}}$$

Thus we have,

$$PV^\gamma = \text{const.}$$

$$T V^{\gamma-1} = \text{const.}$$

$$T V^{p^\gamma - \gamma} = \text{const.}$$

for an incompressible substance
we have,

$$ds = \frac{du}{T}$$

$$ds = 0, \text{ we get}$$

$$du = 0.$$

Isoentropic relation from an incompressible substance can also be expressed term of enthalpy, we have,

$$h = u + PV$$

$$dh = du + PdV + VdP.$$

Substituting,

$$du = 0 \quad \text{if} \quad du = 0, \text{ we get}$$

$$dh = VdP$$

Integrating, we get

$$h_2 - h_1 = V(P_2 - P_1)$$

Isentropic efficiency of a turbine is defined as the ratio of work output from a real turbine & the work that would have been produced when the turbine operates under isentropic condition i.e.

$$\eta_{is} = \frac{W_{real}}{W_{isen}}$$

Isentropic efficiency of a pump is defined as the ratio of the work that would have been required when the pump operates under isentropic condition to work required for the real pump

$$\eta_{ip} = \frac{W_{isen}}{W_{real}}$$

Isentropic efficiency at an nozzle is defined as the ratio of the kinetic energy of the fluid at the real nozzle exit to the kinetic energy value at the exit of an isentropic nozzle for the same inlet state & exit pressure i.e.

$$\eta_{no} = \frac{\frac{V^2}{2} \text{ real}}{\frac{V^2}{2} \text{ iso}}$$

Carnot cycle is an ideal cycle which will have efficiency equal to that of a reversible cycle. This cycle is practically not possible but it is used as a reference standard for the comparison of different practical cycles.

Carnot cycle comprises of following operations:-

Process 1-2 : Iso-thermal heat addition.

Heat is added to the working substance inside the cylinder from a high temperature source & the working substance undergoes isothermal heat expansion. During the isothermal expansion pressure of the substance decreases, its volume increases, its temperature remains constant & the entropy increases.

Process 2-3 : Isentropic expansion

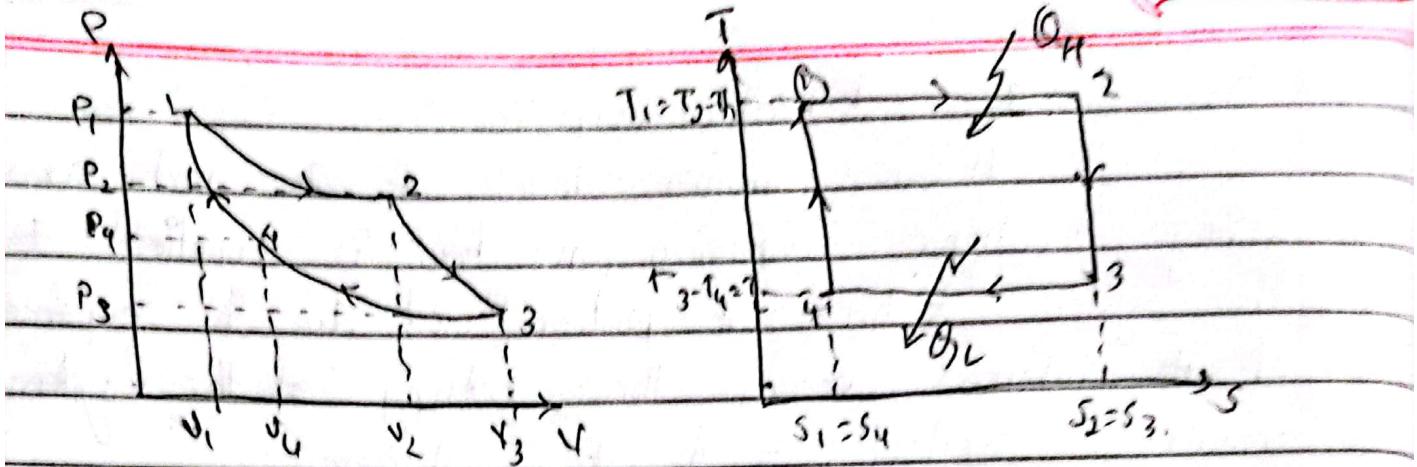
Pressure further decrease & its vol. increase. During isentropic expansion, no heat is supplied to the system & hence it produce work due to expense of its internal energy. Hence entropy of the system remains constant & its temp. decrease.

Process 3-4 : Isothermal heat rejection

Heat is transferred from the working substance inside the cylinder to high temp. sink & the working substance undergo isothermal compression. During the isothermal compression, pressure of the substance increase, its vol. decrease, its temp. remains constant & the entropy decrease.

Process 4-1 Isentropic compression

Working substance is further compressed such that its initial state is restored which pressure increase & its vol. further decrease. During isentropic compression process work supplied to the system increase its internal energy because there is no heat loss from the system. Hence entropy of the system remains constant & its temperature increase.



P-V diagram

T-S diagram

Device which operate in cyclic process & converts heat energy into mechanical work is called a heat engine.

Efficiency of heat engine is define as the ratio of work output & the heat supplied.

$$\eta = \frac{W}{Q_H}$$

from figure, heat engine take Q_H amount of heat from high temp. reservoir at (T_H) & converts some parts of it into work (W) and reject remaining part (Q_L) to low temp. reservoir at (T_L) sink.

Applying the first law of thermodynamic for a cyclic process.

$$\oint \delta Q = \oint \delta W$$

$$Q_H - Q_L = w$$

Then,

$$\text{efficiency}, \eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Applying second law of thermodynamics.

$$\oint (ds)_m > \oint \xi \left(\frac{\delta Q_i}{T_i} \right)_{(m)}$$

Since entropy is a property of a system & for a complete cycle, change in entropy is always zero.

$$\text{i.e. } 0 > \frac{Q_H}{T_H} - \frac{Q_L}{T_L}$$

for reversible heat engine

$$0 = \frac{Q_H}{T_H} - \frac{Q_L}{T_L}$$

$$\frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L} \text{ on } \frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

Then,

$$\eta_{\text{carrot}} = \eta_{\text{rev}} = 1 - \frac{T_L}{T_H}$$

for irreversible heat engine

$$\frac{Q_H}{T_H} - \frac{Q_L}{T_L} < 0$$

As the work output from the real engine decreases with increase in reversibility, efficiency of real engine is always less than that of reversible engine i.e.

$$\eta < s - \frac{T_L}{T_H}$$

$$\text{In general, } \eta < 1 - \frac{T_L}{T_H}$$

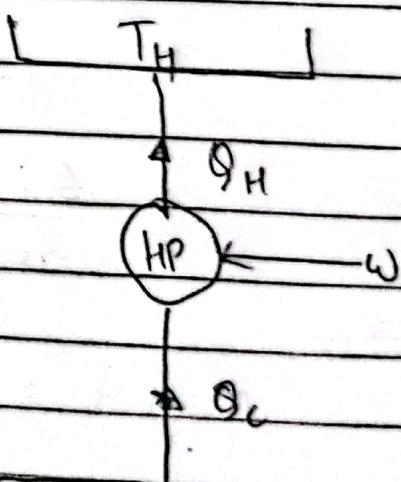
b)

Heat pump is a device operating on a cyclic process that takes heat from low temp. reservoir T_L (surrounding) & delivers it to a high temp. T_H (desired space) with the aid of external work w maintains the temp. of a desired place higher than that of the surrounding.

Coefficient of performance (COP) is defined as the ratio of desired effect (heating or cooling) & the work supplied.

$$\text{COP} = \frac{\text{desired effect}}{\text{Work input}}$$

For heat pump, desired effect is the amount of heat supplied to the desired place (Q_H). Thus, Heat pump.



$$(COP)_{HP} = \frac{Q_H}{W}$$

Applying first law of thermodynamics
 $\oint \delta Q = \oint \delta W$.

$$\therefore -Q_H + Q_L = -W$$

$$\therefore W = Q_H - Q_L$$

Then,

$$(COP)_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

Applying second law of thermodynamics

$$dS_{\text{Carn}} (=0) \geq \oint \sum \left(\frac{\delta Q_i}{T_i} \right)_{\text{rev}}$$

$$0 \geq -\frac{Q_H}{T_H} + \frac{Q_L}{T_L}$$

For reversible heat pump

$$0 = -\frac{Q_H}{T_H} + \frac{Q_L}{T_L}$$

$$\frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

$$\therefore \frac{Q_L}{Q_H} = \frac{Q_L}{Q_H} \cdot \frac{T_L}{T_H}$$

In term of temp. ratio as

$$(COP)_{HP} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{T_H}{T_H - T_L}$$

For irreversible heat pump,

$$(\text{COP})_{\text{irr}} \cdot \text{HP} \leq \frac{T_H}{T_H - T_L}$$

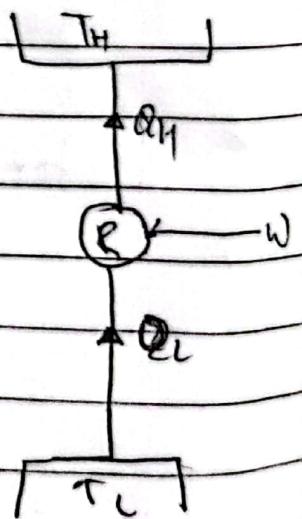
In general,

$$(\text{COP})_{\text{HP}} \leq \frac{T_H}{T_H - T_L} + 1$$

Refrigerator is a device operating on cyclic process & take heat from low temp. reservoir T_L (desired space) & delivers it to a high temp. T_H (surrounding) with the aid of external work w to maintain the temp. of a desired place lower than that of the surrounding.

COP refrigerator is defined as the ratio of desired effect & the work supplied & in case of refrigerator, the desired effect is the amount of heat taken out from the desired space (θ_L) is

$$(\text{COP})_R = \frac{\theta_L}{w}$$



Applying first law of thermodynamics

$$\oint \delta Q = \oint \delta W$$

$$u - \theta_H + \theta_L = -w$$

$$\therefore w = \theta_H - \theta_L$$

Then,

$$(COP)_R = \frac{\theta_1}{\theta_H - \theta_1} = \frac{1}{\frac{\theta_H}{\theta_L} - 1}$$

Now, applying the second law of thermodynamic
 $\oint dS_{CM} (=0) \geq \oint \leq (\delta \theta_i)_{CM}$

$$\Omega \geq -\frac{\theta_H}{T_H} + \frac{\theta_L}{T_L}$$

$$\frac{\theta_H}{T_H} \geq \frac{\theta_L}{T_L}$$

In term of temperature ratio.

$$(COP)_{rev, R} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L}$$

(COP) of an irreversible refrigerator is always less than that of a reversible refrigerator.

$$(COP)_{irrev, R} \leq \frac{T_L}{T_H - T_L}$$

In general,

$$(COP)_R \leq \frac{T_L}{T_H - T_L}$$

$$\text{Hence, } (COP)_{HP} - (COP)_R = 1$$

Q.18)

→ Similarities b/w heat pump & refrigeration cycle

- Both of them work on the vapour compression refrigeration cycle.
- Both of them require work input in the form of electrical energy.
- Both of them takes heat from low temp reservoir T_L & delivers it to a high temp. reservoir T_H .
- Performance of both is measured by their coefficient of performance (COP).

Difference

Heat Pump

Refrigerator.

- | | |
|---|--|
| ① It maintains the temp. of desired space higher than that of the surrounding. | ① It maintains the temp. of desired space lower than that of the surrounding. |
| ② It takes heat from low temp. reservoir (T_L) & delivers it to high temp. (T_H) (desired space). | ② It takes heat from low temp. reservoir (T_L) & deliver it to high temp. (T_H) (surrounding). |
| ③ Its COP is higher than refrigerator. | ③ Its COP is lower than heat pump. |

Sol?

$$\text{minimum vol. } (V_{\min}) = 1 \text{ m}^3$$

$$\text{max. vol. } (V_{\max}) = 2 \text{ m}^3$$

Initial state

$$P_i = 1 \text{ MPa} = 1000 \text{ kPa}$$

$$T_i = 400^\circ\text{C}$$

$$\text{temperature of the surrounding } (T_s) = 25^\circ\text{C}$$

$$= 293 \text{ K}$$

pressure req. to support the piston (P_{support}) = 400 kPa

Referring to the table.

$$T_{\text{sat}}(1000 \text{ kPa}) = 149.92^\circ\text{C}$$

here, $T > T_{\text{sat}}$, hence it is a superheated vapour - Then again, referring to the table,

$$v_1 = 0.3066 \text{ m}^3/\text{kg}, u_1 = 2957.2 \text{ kJ/kg},$$

$$s_1 = 7.4648 \text{ kJ/kg K}$$

mass of H_2O is given as

$$m = \frac{V}{v_1} = \frac{2}{0.3066} = 6.5232 \text{ kg}$$

minimum specific vol. of H_2O is given by

$$v_{\min} = \frac{V_{\min}}{m} = \frac{2}{6.5232} = 0.3066 \text{ m}^3/\text{kg}$$

Initial pressure of the system is 1000 kPa but the pressure required to support the piston is 400 kPa. Hence during initial state of cooling piston remain stationary although heat is removed from the system, so the process is const. vol. cooling (process 1-2). During constant vol. cooling process of the system decrease from 1000 kPa to

100 kPa , hence we can define state 2 as,

State 2 : $P_2 = 400 \text{ kPa}$

$$u_2 = 0.3066 \text{ m}^3/\text{kg}$$

Referring to the table, $u_i(400 \text{ kPa}) = 0.001084 \text{ m}^3/\text{kg}$

$$u_g = 0.4625 \text{ m}^3/\text{kg}$$

$$v_g < v < u_g$$

temp. at state 2, $T_2 = T_{\text{sat}}(400 \text{ kPa}) = 143.64^\circ\text{C}$,

At constant pressure of 400 kPa (process 2-3)

State 3 as

State 3 : $P_3 = 100 \text{ kPa}$, $w_3 = 0.1533 \text{ m}^3/\text{kg}$

Here, $v_e < v_3 < u_g$ Hence it is a two phase mixture.

temp. at state 3, $T_3 = T_{\text{sat}}(100 \text{ kPa}) = 143.64^\circ\text{C}$.

further cooled to decrease temp. from 143.6°C to 100°C

& the process occurs at const. vol. (process 3-4).

State 4 as;

$$\text{State } 4, u_{c4} = 0.1533 \text{ m}^3/\text{kg}, T_4 = 100^\circ\text{C}$$

Referring to the table ; $u_i(100^\circ\text{C}) = 0.001043 \text{ m}^3/\text{kg}$

$$u_g = 1.6342 \text{ m}^3/\text{kg}$$

$$v_g = 1.6933 \text{ m}^3/\text{kg}$$

$$u_g = 417.41 \text{ kJ/kg}$$

$$u_{eg} = 2088.3 \text{ kJ/kg}$$

$$s_{fg} = 1.3027 \text{ kJ/kgK}$$

$$s_{eg} = 6.0562 \text{ kJ/kgK} \times 1\text{kg}, \quad u_x < u_4 < u_y$$

here it is a two phase mixture.

Quality of state 4 is given as.

$$q_4 = \frac{u_4 - u_1}{u_{eg}} = \frac{6.1532 - 0.003043}{6.0562} = 0.0899$$

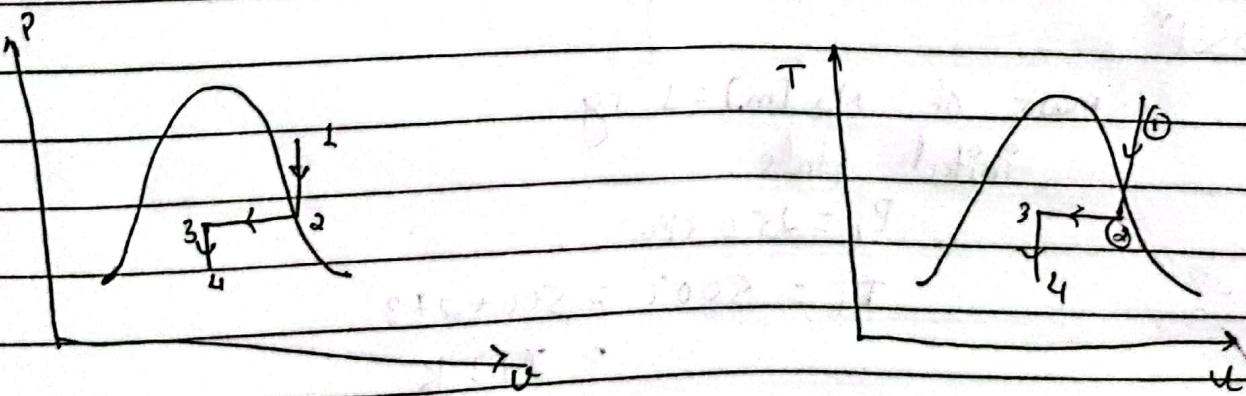
Then specific internal energy & specific entropy are given as

$$u_4 = u_1 + x_4 u_{eg} = 417.41 + 0.0899 \times 2088.3 \text{ kJ/kg} \\ = 605.1407 \text{ kJ/kg}$$

$$s_4 = s_1 + x_4 s_{eg} = 1.3027 + 0.0899 \times 6.0562 = 1.8472 \text{ kJ/kgK}$$

Change in total internal energy is given by

$$\Delta U = m(u_4 - u_1) = 6.5232(605.1407 - 2957.2) \\ = -1534.91 \text{ kJ}$$



work transfer during the process is given by

$$W = W_{12} + W_{23} + W_{34}$$

$$= 0 + P(V_3 - V_2) + 0$$

$$= 100 \times (1 - 2)$$

$$= -100 \text{ kJ}$$

total heat transfer is given by

$$\dot{Q} = \Delta U + W$$

$$= -15342.93 - 400$$

$$= -15742.93 \text{ kJ}$$

total entropy generated during the process is given by

$$S_{\text{gen}} = \int (ds)_{\text{cm}} - \frac{\dot{Q}}{T_i} \left(\frac{ds}{dt} \right)_{\text{cm}}$$

$$= m(s_f - s_i) - \frac{\dot{Q}}{T_i}$$

$$= 6.5232 \cdot (3.8472 - 7.4648) - \frac{(-15742.93)}{298}$$

$$= 16.1838 \text{ kJ/K}$$

Sol.

mass of N_2 (m) = 1 kg

initial state

$$P_1 = 250 \text{ kPa}$$

$$T_1 = 500^\circ\text{C} = 500 + 273$$

$$= 773 \text{ K}$$

final state

$$T_{\text{final}} = 40^\circ\text{C} = 40 + 273 \text{ K}$$

temp. of the surrounding (T_{sur}) = $26^\circ\text{C} = 293 \text{ K}$

vol. of N_2 at initial state is given by

$$V_1 = \frac{mRT_1}{P_1} = \frac{1 \times 297 \times 773}{250 \times 10^3} = 0.918324 \text{ m}^3.$$

Process (1-2) At constant pressure

$$\text{State 2: } T_2 = \frac{V_2}{V_1} \times T_1$$

$$(T_2 = \frac{1}{2} \times 773 \text{ K}) = 386.5 \text{ K} \equiv 153.5^\circ\text{C}$$

Process (2-3) At constant volume

$$\text{State 3: } T_3 = 313 \text{ K}$$

$$V_3 = V_2 = \frac{V_1}{2} = 0.918324 \text{ m}^3$$

pressure of N_2 at final state; $P_3 = \frac{mRT_3}{V_3}$

$$= \frac{1 \times 297 \times 313}{0.459162} \text{ Pa}$$

$$= 202.46 \text{ kPa}$$

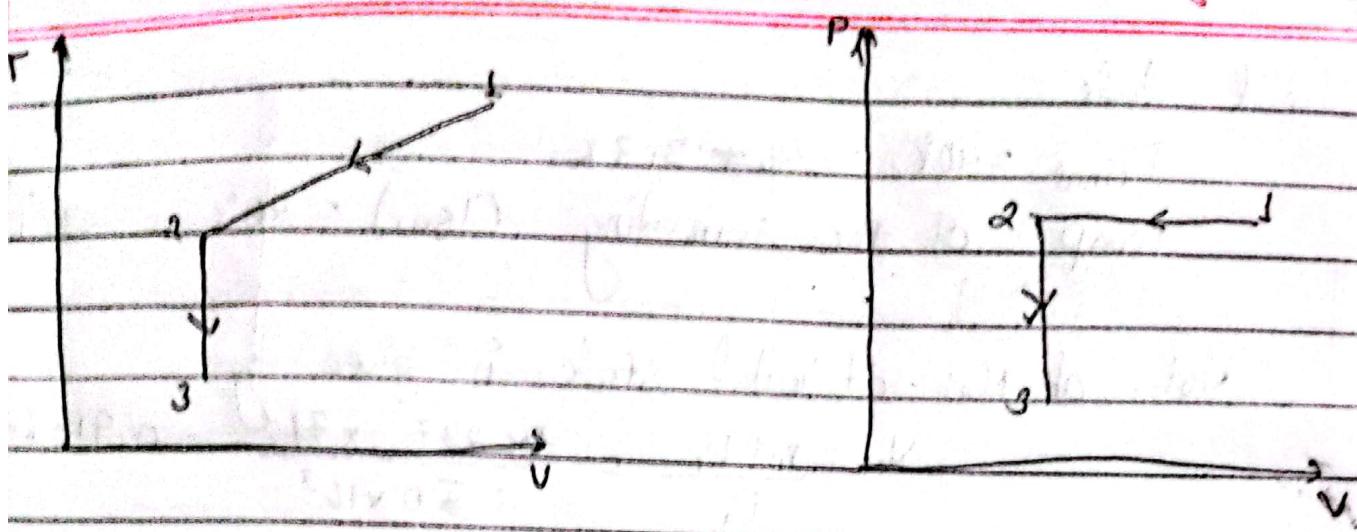
Then change in total internal energy is given by

$$\Delta U = m(u_3 - u_1)$$

$$= mc_p(T_3 - T_1)$$

$$= 1 \times 743 \times (313 - 773)$$

$$= -341.78 \text{ kJ}$$



Work transfer during the process is given by

$$\begin{aligned} W &= w_{12} + w_{23} \\ &= P(V_2 - V_1) + 0 \\ &= 250(0.459162 - 0.918324) \\ &= -114.791 \text{ kJ} \end{aligned}$$

Total heat transfer during the process is given by

$$\begin{aligned} Q &= \eta V + W \\ &= -341.78 - 114.791 \\ &= -458.571 \text{ kJ} \end{aligned}$$

Then, change in entropy for the process is given by

$$\begin{aligned} \Delta S &= S_2 - S_1 \\ &= m_C V \ln\left(\frac{T_2}{T_1}\right) + m_F \ln\left(\frac{V_2}{V_1}\right) \\ &= 1 \times 743 \times \ln\left(\frac{313}{773}\right) + 1 \times 297 \times \ln\left(\frac{0.459162}{0.918324}\right) \\ &= -0.877 \text{ kJ/K} \end{aligned}$$

entropy generation is given by

$$S_{gen} = (ds)_{gen} - \sum \left(\frac{q_i}{T_i} \right)_{gen}$$

$$= (S_0 - S_1) - \frac{Q}{T_{sur}}$$

$$= -0.5232 - \left(\frac{-456.571}{293} \right)$$

$$= 0.68 \text{ kJ/k}$$

Q.3)

- Soln,

$$\text{mass of water } 1 (m_1) = 2 \text{ kg}$$

$$\text{initial temp. of water } (T_1) = 50^\circ\text{C}$$

$$= 100 + 273$$

$$= 373^\circ\text{K}$$

$$\text{mass of water } 2 (m_2) = 4 \text{ kg}$$

$$\text{initial temp. of water } (T_2) = 30^\circ\text{C}$$

$$= 293^\circ\text{K}$$

Let T_3 be the equilibrium temp. then heat lost by
water 1 is absorbed by the water 2. i.e.

$$m_1 c (T_1 - T_3) = m_2 c (T_3 - T_2)$$

$$2 \times 4.18 \times (373 - T_3) = 4 \times 4.18 \times (T_3 - 293)$$

$$8.36 \times (373 - T_3) = 16.72 \times (T_3 - 293)$$

$$3118.28 - 836 T_3 = 16.72 T_3 - 489.96$$

$$3117.24 = 25.44 T_3$$

$$T_3 = 319.67 \text{ K}$$

$$= 46.67$$

Then change in entropy of water (1) is given by

$$(\Delta S)_1 = m_1 c \ln \left(\frac{T_3}{T_1} \right)$$

$$= 2 \times 21.18 \times \ln \left(\frac{319.67}{373} \right)$$

$$= -5.2898 \text{ kJ/K}$$

Change in entropy of water (2) is given by

$$(\Delta S)_2 = m_2 c \ln \left(\frac{T_3}{T_2} \right)$$

$$= 4 \times 4.18 \times \ln \left(\frac{319.67}{293} \right)$$

$$= 1.456 \text{ kJ/K}$$

Therefore, the net change in entropy is given by

$$(\Delta S)_{\text{net}} = (\Delta S)_1 + (\Delta S)_2$$

$$= -1.2898 + 1.4565$$

$$= 0.1661 \text{ kJ/K}$$

Soln.

Properties of steam at inlet, $P_1 = 2 \text{ MPa} = 2000 \text{ kPa}$

$$T_1 = 100^\circ \text{C}, \bar{v}_1 = 200 \text{ ml/g}$$

Properties of steam at outlet; $P_2 = 160 \text{ kPa}$; Saturated vapour. $\bar{v}_2 = 80 \text{ ml/g}$.

mass flow rate of steam (m) = 1.5 kg/s

power output of the turbine (W_{cv}) = 1800 kW
temp. of the surroundings (T_{sv1}) = 300 K

$$h_1 = 32477.5 \text{ kJ/kg} + s_1 = 7.1269 \text{ kJ/kgK}$$

"y" for the other properties of steam outlet, referring to the table, $s_2 = h_2 - \text{hg}(100 \text{ kPa}) = 2675.1 \text{ kJ/kg} + 7.3589 \text{ kJ/kgK}$.

applying energy eqn for the turbine

$$\dot{Q}_{cv} - \dot{W}_{cv} = m [(h_2 - h_1) + \frac{1}{2} (\bar{v}_2^2 - \bar{v}_1^2) + g(z_2 - z_1)]$$

$$\begin{aligned} \dot{Q}_{cv} &= 1.5 \dot{m} [(h_2 - h_1) + \frac{1}{2} (\bar{v}_2^2 - \bar{v}_1^2) + g(z_2 - z_1)] \\ &= 800 + 1.5 [(2675.1 - 3247.5) + \frac{1}{2} (80^2 - 200^2) + 0] \\ &= -83.8 \text{ kW} \end{aligned}$$

Then the rate of entropy generation during the steady operation of any control vol. is given by

$$\dot{S}_{gen} = (S_{out} - S_{in}) - \dot{E} \left(\frac{\dot{Q}_{cv}}{T_{sur}} \right)_{cv}$$

$$= \dot{m} (s_2 - s_1) - \frac{\dot{Q}_{cv}}{T_{sur}}$$

$$= 1.5 (7.3589 - 7.1269) - \left(\frac{-83.8}{300} \right)$$

$$= 0.6273 \text{ kW/K}$$

Q) soln.

given, properties of air at inlet $P_1 = 500 \text{ kPa}$

$$T_1 = 327^\circ\text{C}$$

$$= 600 \text{ K}$$

$$\dot{V}_1 = 50 \text{ m/s}$$

Properties of air at exit $P_2 = 100 \text{ kPa}$, $T_2 = 27^\circ\text{C}$

$$= 300 \text{ K}$$

$$\dot{V}_2 = 500 \text{ m/s}$$

temp. of surrounding $(T_{\text{sur},r}) = 20^\circ\text{C}$
 $= 293 \text{ K}$

$$Q_{cv} = \dot{m} [(h_2 - h_1) + \frac{1}{2} (\dot{V}_2^2 - \dot{V}_1^2) + g(z_2 - z_1)]$$

or an ideal gas using $h_2 - h_1 = (P(T_2 - T_1))$ & neglecting

$$\frac{Q_{cv}}{\dot{m}} = q_{cv} = c_p(T_2 - T_1) + \frac{1}{2} (\dot{V}_2^2 - \dot{V}_1^2) + 0$$

Change in entropy per kg of air is given by

$$\Delta S = S_2 - S_1 = (R \ln \left(\frac{T_2}{T_1} \right) - R \ln \left(\frac{P_2}{P_1} \right))$$

$$= 1005 \times \ln \left(\frac{300}{600} \right) - 0.287 \times \ln \left(\frac{100}{500} \right)$$

$$= -0.2347 \text{ kJ/kgK}$$

Therefore, the entropy generation per kg of air is given by

$$\delta_{\text{gen}} = (S_{\text{out}} - S_{\text{in}}) - \epsilon \left(\frac{q_i}{T_i} \right)_{\text{ir}}$$

$$\delta_{\text{gen}} = (S_2 - S_1) - \frac{q_{cv}}{T_1}$$

$$= -0.2347 - \frac{(-177.75)}{293}$$

$$= 0.37195 \text{ kJ/kgK.}$$

QuesProperties at steam inlet: $P_1 = 100 \text{ MPa}$

$$= 10000 \text{ kPa}$$

$$T_1 = 500^\circ\text{C}$$

Properties of steam at outlet: $P_2 = 0.66 \text{ MPa}$

$$= 66 \text{ kPa}$$

$$\chi_2 = 0.96$$

$$w_2 = 0.96$$

mass flow rate of steam (m) = 26 kg/s

Process isentropic (reversible & adiabatic)

$$T_{sat} = 311.03^\circ\text{C} \quad (T > T_{sat})$$

State atTurbine

$$h_1 = 3500.9 \text{ kJ/kg}, s_1 = 6.7561 \text{ kJ/kgK}$$

since entropy remains constant during isentropic process

specific entropy at turbine exit is $s_2 = 6.7561 \text{ kJ/kgK}$ referencing to the table $s_2(60 \text{ kPa}) = 1.1456 \text{ kJ/kgK}$

$$s_{fg}(60 \text{ kPa}) = 6.3856 \text{ kJ/kgK}$$

$$s_g(60 \text{ kPa}) = 7.5310 \text{ kJ/kgK}$$

$$h_2(60 \text{ kPa}) = 359.90 \text{ kJ/kg}$$

$$h_f(60 \text{ kPa}) = 2293.1 \text{ kJ/kg}$$

Now $s_1 < s_2 < s_g$ hence the condition of steam at turbine exit is given by

$$\chi_2 = \frac{s_2 - s_1}{s_{fg}} = \frac{6.7561 - 1.1456}{6.3856} = 0.8781$$

specific enthalpy of steam at isentropic turbine exit is given by

$$h_2 = h_f + \chi_2 h_{fg} = 2293.1 + 0.8781 \times 2293.1$$

$$= 2374.618 \text{ kJ/kg}$$

applying steady state energy eqn for an isentropic turbine,

$$W_{CII} = m [h_1 - h_2] + \frac{1}{2} (\bar{v}_1^2 - \bar{v}_2^2) + g (z_2 - z_1)$$

Neglecting KE and PE we get,

$$W_{CII} = 10 \times (h_1 - h_2) + 0 + 0.$$

$$= 10 (3500.9 - 2374.618).$$

$$W_{gen} = 11262.82 \text{ kW}$$

again,

Specific enthalpy of steam at turbine exit is given by.

$$h_{2r} = h_1 + z_{2r} h_{fg}$$

$$= 359.90 + 0.96 \times 2233.1$$

$$= 2561.276 \text{ kJ/kg}$$

now, applying energy eqn for adiabatic turbine,

$$W_{CII} = m [h_1 - h_{2r}] + \frac{1}{2} [\bar{v}_1^2 - \bar{v}_{2r}^2] + g (z_1 - z_{2r})$$

Neglecting KE & PE we get

$$W_{CII} = m (h_1 - h_{2r}) + 0 + 0$$

$$W_{CII} = 10 (3500.9 - 2561.276)$$

$$= 9386.24 \text{ kW}$$

Isentropic efficiency of the turbine is given by

$$\eta_i = \frac{W_{actual}}{W_{gen}} = \frac{9386.24}{11262.82}$$

$$= 0.8343$$

$$= 83.43\%$$

Actual work output for kg of steam is given as,

$$\text{Work}_{\text{actual}} = \frac{\text{W}_{\text{actual}}}{m} = \frac{9396.24}{10}$$

$$\approx 939.624 \text{ kJ/kg}$$

Soln,

$$T_2 - T_1 = 200^\circ\text{C}$$

$$w = 0.6 Q_1$$

$$Q_{21} = w + Q_2$$

$$= 0.6 Q_1 + Q_2$$

$$= 1.6 Q_1$$

then,

efficiency of Carnot engine is given as.

$$\eta_{\text{Carnot}} = \frac{w}{Q_H} = \frac{0.6 Q_1}{1.6 Q_1}$$

$$= 0.375 = 37.5\%$$

Efficiency of a Carnot engine operating betw two reservoirs at temp. T_H & T_L is given by

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H}$$

$$= \frac{T_H - T_L}{T_H}$$

$$= \frac{200}{T_H}$$

$$T_H = 333.33 \text{ K}$$

$$\& T_L = 333.33 - 200 = 133.33 \text{ K}$$

2) Soln,

$$\text{Power input } (W) = 1.5 \text{ kW}$$

COP of an air conditioning unit $(COP)_R = ?$

$$\text{lower temp. } (T_L) = 22^\circ\text{C}$$

$$= 295 \text{ K}$$

Rate at which heat is removed from a hall

$$(Q_L) = 0.8(T_H - T_L) \text{ kW}$$

COP of an air conditioning unit is given by

$$(COP)_R = \frac{Q_L}{W}$$

$$\text{or, } 3 = \frac{0.8(T_H - T_L)}{1.5} = \frac{0.8(T_H - 295)}{1.5}$$

$$T_H = 295 + 5.625 = 300.625 \text{ K}$$

$$= 27.625^\circ\text{C}$$

When an air conditioning unit is working as heating unit (heat pump) in winter.

COP of an air conditioning unit $(COP)_{HP} = 4$

$$\text{Higher temp. } (T_H) = 22^\circ\text{C}$$

$$= 293 \text{ K}$$

Rate at which heat is supplied in a hall (Q_H)

Then, COP of an air conditioning unit is given as.

$$\therefore (COP)_{HP} = \frac{Q_H}{W}$$

$$\therefore Q_H = \frac{0.8(T_H - T_L)}{3.5}$$

$$= \frac{0.8(293 - 22)}{3.5}$$

) soln,

lower temp. (T_L) $\approx 20^\circ\text{C}$
 $\approx 293^\circ\text{K}$

rate at which heat is removed from a house (Q_1):

$$0.8(T_H - T_L) \text{ J/s}$$

Power input (w) = 1.8 kW.

Theoretical maximum COP of an air conditioning unit operating "betw" the temp. limits is given by

$$(\text{COP})_{\text{rev}, h} = \frac{T_L}{T_H - T_L}$$

again, COP of an air conditioning unit is given by

$$(\text{COP})_P = \frac{Q_1}{w} = \frac{0.8(T_H - T_L)}{1.8}$$

According to the question, COP of an air conditioning unit is 50% of the theoretical maximum COP of an air conditioning unit

$$(\text{COP})_P = 50\% \text{ of } (\text{COP})_{\text{rev}, h}$$

$$0.8 \frac{(T_H - T_L)}{1.8} = 0.5 \times \left(\frac{T_L}{T_H - T_L} \right)$$

$$0.8 \frac{(T_H - 293)}{1.8} = 0.5 \left(\frac{293}{T_H - 293} \right)$$

$$(T_H - 293)^2 = 0.5 \left(\frac{293 \times 0.5}{0.8} \right)$$

$$= 329.625$$

solving we get,

$$T_H = 293 + 18.156$$

$$= 311.156 \text{ K}$$

$$= 38.156^\circ\text{C}$$