THEORY & OBJECTIVE

REFRIGERATION & AIR CONDITIONING

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REFRIGERATING MACHINE AND REVERSED CARNOT CYCLE

THEORY

1.1 INTRODUCTION

Refrigeration is defined as “the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place”. It should be kept in mind that refrigeration is not ame as “cooling”, even though both the terms imply a decrease in temperature. In general, cooling is a heat transfer process down a temperature gradient, it can be a natural, spontaneous process or an artificial process. However, refrigeration is not a spontaneous process, as it requires expenditure of exergy (or availability). Thus cooling of a hot cup of coffee is a spontaneous cooling process (not a refrigeration process), while converting a glass of water from room temperature to say, a block of ice, is a refrigeration process (non- spontaneous). “All refrigeration processes involve cooling, but all cooling processes need not involve refrigeration”.

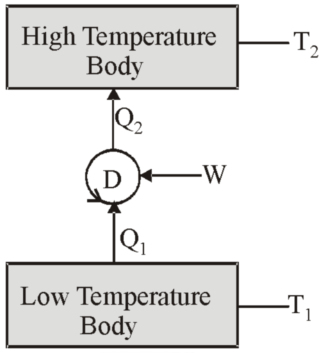
Refrigeration is a much more difficult process than heating, this is in accordance with the second laws of Thermodynamics. This also explains the fact that people knew ‘how to heat’, much earlier than they learned how to refrigerate’. All practical refrigeration processes involve reducing the temperature of a system from its initial value to the required temperature that is lower than the surroundings, and then maintaining the system at the required low temperature. The second part is necessary due to the reason that once the temperature of a system is reduced, a potential for heat transfer is created between the system and surroundings, and in the absence of a “perfect insulation” heat transfer from the surroundings to the system takes place resulting in increase in system temperature. In addition, the system itself may generate heat (e.g. due to human beings, appliances etc.), which needs to be extracted continuously. Thus in practice refrigeration systems have to first reduce the system temperature and then extract heat from the system at such a rate that the temperature of the system remains low. Theoretically refrigeration can be achieved by several methods. All these methods involve producing temperatures low enough for heat transfer to take place from the system being refrigerated to the system that is producing refrigeration.

1.2 THE SECOND LAW OF THERMODYNAMICS, THE KELVIN-PLANCK STATEMENT AND THE CLAUSIUS STATEMENT

Clausius Statement which is as follows :

Where Q_1 = referigation effect

" It is impossible to construct a device (D) which will operate in a cycle and produce no effect other than the transfer of heat from a low temperature body to a high temperature body"



Schematic representation of a refrigerator/heat pump

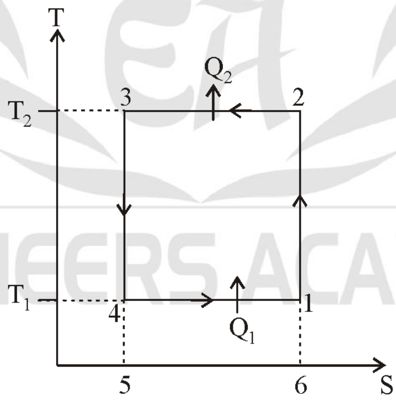
The Clausius statement eliminates the possibility of obtaining refrigeration without doing work. The only alternative is that there must be some work input W. From the first law $W = Q_2 - Q_1$. Accordingly, heat transferred Q_2 is more than heat absorbed Q_1 by the amount of work input W.

1.2.1 THE COROLLARIES OF IIND LAW COMPRISING THE CARNOT PRINCIPLE

1. Since a Refrigeration cycle operating reversible between two heat reservoirs has the highest coefficient of performance.
2. All reversible refrigeration cycles have the same COP.

1.3 IDEAL REFRIGERATION CYCLE / HEAT PUMP (BASED ON REVERSED CARNOT CYCLE)

Since a reversed Carnot cycle can be employed as a reversible refrigeration cycle, it would be a measure of maximum possible COP of a refrigerating machine operating between two temperatures T_K of heat rejection and T_0 of refrigeration.



Reversed Carnot Cycle

The cycle consists of two isothermals and two isentropics as follows :

Process 1-2 Isentropic compression, $s_1 = s_2$

Process 2-3 Isothermal heat rejection to the hot reservoir at T_2 = constant

Process 3-4 Isentropic expansion, $s_3 = s_4$

Process 4-1 Isothermal heat absorption from the cold reservoir at T_1 = constant

The areas on the T-s diagram, representing $\int Tds$ give the heat transfers.

As follows

Heat absorbed from cold body, $Q_1 = T_1 \Delta s$

$= \text{area } 1\text{-}4\text{-}5\text{-}6$

Heat rejected to hot body, $Q_2 = T_2 \Delta s$

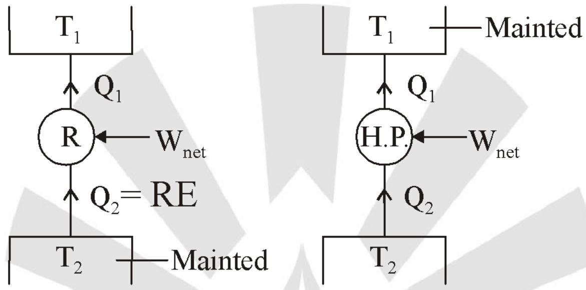
$= \text{area } 2\text{-}3\text{-}5\text{-}6$

Work done, $W = Q_2 - Q_1$ (from I^{st} law of thermodynamic)

$= (T_2 - T_1)\Delta s$

$= \text{area } 1\text{-}2\text{-}3\text{-}4$

Hence we obtain Carnot values of COP for cooling and heating as



$$COP_{R,carnot} = \frac{\dot{Q}_1}{W}$$

$$= \frac{T_1}{T_2 - T_1} = \frac{I}{\frac{T_2}{T_1} - I} \quad \text{(Maximum COP of Refrigeration)}$$

$$COP_{HP,carnot} = \frac{\dot{Q}_2}{W}$$

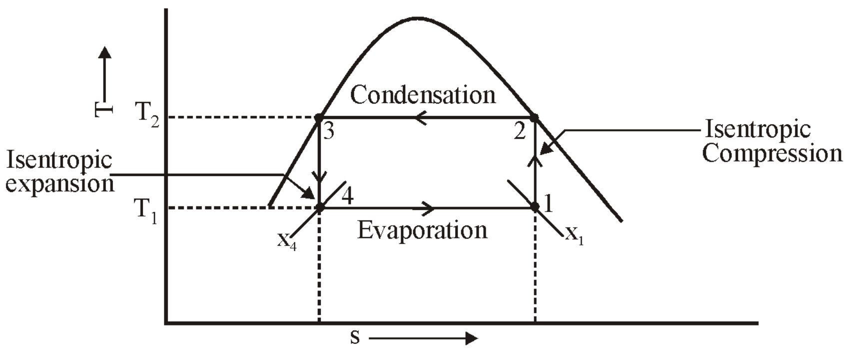
$$= \frac{T_2}{T_2 - T_1} = \frac{I}{1 - T_1/T_2} \quad \text{(Maximum COP of H.P.)}$$

Therefore, to obtain maximum posible COP in any application

(i) The cold body temperature T_0 should be as high as possible, and

(ii) The hot body temperature T_k should be as low as possible.

1.4 LIMITATIONS OF REVERSED CARNOT CYCLE



Reversed Carnot cycle with vapour as a refrigerant

In the reversed Carnot cycle with vapour as refrigerant :

(i) The Isothermal processes of condensation and evaporation are internally reversible processes, and they are easily achievable in practice.

(ii) It is difficult to design an expander to handle a mixture of largely liquid and partly vapour for the process 3-4. Also, because of the internal irreversibilities in the compressor and the expander, the actual COP of the Carnot cycle is very low, though the ideal cycle COP is the maximum.

There are two drawbacks of reversed carnot cycle with gas as a refrigerant :

(i) It is not possible to implement, in practical, isothermal processes of heat absorption and rejection,.

(ii) The cycle on p- v diagram is very narrow since the volume is changing both during the reversible isothermal and reversible adiabatic processes. As a result, the swept volume of cylinder (volume swept during one stroke) is very large. The cycle, therefore, suffers from poor actual COP as a result of irreversibilities of the compressor and expander.

1.5 REFRIGERANT

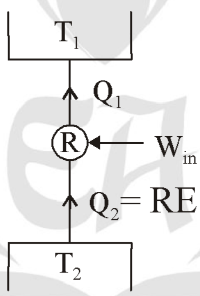
Refrigerant are the substance which are used for producing lower temperature.

Example :

Feron ; NH_3, H_2O etc.

1.6 REFRIGERATION EFFECT (RE)

It is the amount of heat which is to be extracted from the storage space in order to maintainted lower temperature. It is also the desired effect of refrigeration system.



i.e. $$COP = \frac{\text{Desired effect}}{W_{in}} = \frac{Q_2}{W_{in}} = \frac{RE}{W_{in}} \text{ (known as actual COP)}$$

1.7 UNIT OF REFRIGERATION (TR)

It is the amount of heat which is to be extracted from 1 ton (1000 kg) of H_2O at 0°C in order to convert in it into ice at 0°C in 24 hr.

i.e. $$1 \text{ TR} = 3.5 \text{ kJ/sec} = 3.5 \text{ kW} = 210 \text{ kJ/min}$$

Note :

(i) Since $$COP = \frac{RE}{W_{in}}$$

Where RE in kJ/kg. and W_{in} in kJ/kg

(ii) Refrigeration capacity $(RC) = \dot{m} \times RE$ (in kW)

Where $\dot{m}$ in kg/sec and RE in kJ/kg

(iii) Power input $(P_{in}) = \dot{m} \times W_{in}$ (in kW)

(iv) $$COP = \frac{RE}{W_{in}} = \frac{RE \times \dot{m}}{W_{in} \times \dot{m}} = \frac{RC}{P_{in}}$$

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PRACTICE SHEET

OBJECTIVE QUESTIONS

1. Which of the following can be called as a refrigeration process?
(a) Cooling of hot ingot from 1000°C to room temperature
(b) Cooling of a pot of water by mixing it with a large block of ice
(c) Cooling of human beings using a ceiling fan
(d) Cooling of a hot cup of coffee by leaving it on a table

2. A carnot refrigeration required 1.5 kW/ton of refrigerant to maintaned a space –30°C then COP
(a) 2.33 (b) 2
(c) 1.33 (d) None of these

3. One ton refrigeration is also equal to
(a) 800 kcal/day (b) 90 kcal/hr
(c) 14 cal/sec (d) 211 kJ/min

4. Food products can be preserved for a longer time at low temperatures because:
(a) At low temperatures the bacterial activity is reduced
(b) Enzymatic activity is increased at low temperatures
(c) Quality of food products improves at low temperatures
(d) All of the above

5. The cold chain is extremely useful as it:
(a) Makes seasonal products available throughout the year
(b) Reduces food spoilage
(c) Balances the prices
(d) All of the above

6. The useful storage life of food products depends on:
(a) Storage temperature
(b) Moisture content in the storage
(c) Condition of food products at the time of storage
(d) All of the above

7. Cold storages can be used for storing:
(a) Live products such as fruits, vegetables only
(b) Dead products such as meat, fish only
(c) Both live and dead products
(d) None of the above

8. Fast freezing of products is done to:
(a) Reduce the cell damage due to ice crystal growth
(b) Reduce energy consumption of refrigeration systems
(c) Reduce bacterial activity
(d) All of the above

9. The higher temperature of the refrigerator 50°C and the lower is – 10°C, while capacity is 20 tons. The coefficient of performance of the system is
(a) 4.10 (b) 5.38
(c) 3.62 (d) 4.38

10. One ton of refrigeration can be defined as
(a) Refrigeration for freezing 1 ton of water into ice
(b) One ton of refrigerant is used at 273 K in 12 hours
(c) Capacity of freezing 1 ton of water from at 0°C in 24 hours
(d) One ton of water which can be converted into ice in 24 hours

11. Products involving fermentation reactions require refrigeration because:
(a) Fermentation process is exothermic
(b) Fermentation process is endothermic
(c) Fermentation has to be done at uncontrolled temperatures
(d) All of the above

12. Supermarket refrigeration requires:

(a) Provision for storing a wide variety of products requiring different conditions

(b) Reliable refrigeration systems due to the high value of the perishable products

(c) Large refrigerant inventory due to long refrigerant tubing

(d) All of the above

13. Refrigeration is required in petrochemical industries to:

(a) Separate gases by fractional distillation

(b) Provide safe environment

(c) Carry out chemical reactions

(d) All of the above

14. Cold treatment of metals is carried out to:

(a) To stabilize precision parts

(b) To improve hardness and wear resistance

(c) To improve ductility

(d) All of the above

15. Refrigeration is used in construction of dams etc to:

(a) Avoid crack development during setting of concrete

(b) Avoid water evaporation

(c) Reduce cost of construction

(d) All of the above

16. Refrigeration is required in remote and rural areas to:

(a) Store fresh and farm produce

(b) Store vaccines in primary health centres

(c) Store milk before it is transported to dairy plants

(d) All of the above

17. Compared to urban areas, in rural areas:

(a) Continuous availability of grid electricity is not ensured

(b) Space is constraint

(c) Refrigeration is not really required

(d) Refrigeration systems cannot be maintained properly

18. Modern electronic equipment require cooling due to:

(a) Dissipation of relatively large amount of heat in small volumes

(b) To prevent erratic behaviour

(c) To improve life

(d) All of the above

19. For refrigerating system work done per kg of air is 30 kcal and heat extracted per kg of air is 45 kcal. Amount of refrigerant used is 10kg. The coefficient of performance of systems i.e.

(a) 6.52 (b) 1.50

(c) 10.56 (d) 0.67

20. COP for refrigerator and heat pump are related as

(a) $COP_h = COP_r - 1$

(b) $COP_h = COP_r$

(c) $COP_h = COP_r + 1$

(d) $COP_h = \frac{1}{COP_r}$

21. A refrigeration machine working on reverse carnot cycle takes out 2kW from a system. While working between temperature limit of 300 K and 200 K. Then the COP and power input are

(a) 2 and 1 kW (b) 1 and 2 kW

(c) 3 and 2 kW (d) None of these

where r is isentropic compression or expansion.

22. The working temperature in evaporator (–30°C) and condenser (32°C), if the actual refrigerator having COP of 0.75 times $(COP)_{max}$. Then power input of a refrigeration capacity of 5 kW

(a) 7 kW (b) 1.7 kW

(c) 2.7 kW (d) 3 kW

23. Centigrade and fahrenheit scale have same value at

(a) –120°C (b) –85°C

(c) –32°C (d) 273°C

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ANSWERS AND EXPLANATIONS

1. ***Ans. (b)***

2. ***Ans. (a)***

Given $P_{in} = 1.5$ kW ;

$RC = 1$ ton $= 3.5$ kW

Then $COP = \dfrac{3.5}{1.5} = 2.33$

3. ***Ans. (d)***

$$1\text{TR} = 3.5 \text{ kW}$$
$$= 3.5 \text{ kJ/sec} = 3.5 \times 60 \text{ kJ/min}$$
$$= 210 \text{ kJ/min}$$

4. ***Ans. (a)***

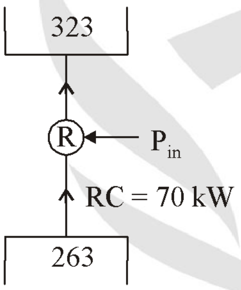
5. ***Ans. (d)***

6. ***Ans. (d)***

7. ***Ans. (c)***

8. ***Ans. (a)***

9. ***Ans. (d)***



$$COP = \frac{263}{323-263} = 4.38$$

10. ***Ans. (c)***

11. ***Ans. (a)***

12. ***Ans. (d)***

13. ***Ans. (a)***

14. ***Ans. (b)***

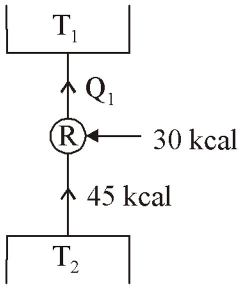
15. ***Ans. (a)***

16. ***Ans. (d)***

17. ***Ans. (a)***

18. ***Ans. (d)***

19. ***Ans. (b)***



$$COP = \frac{45}{30} = 1.5$$

20. ***Ans. (c)***

21. ***Ans. (a)***

$$COP = \frac{T_1}{T_2 - T_1} = \frac{200}{300-200} = 2$$

And $COP = \dfrac{RC}{P_{in}} \Rightarrow P_{in} = \dfrac{2}{2} = 1$ kW

22. ***Ans. (a)***

Given $T_1 = -30°C = 243$ K

$T_2 = 32°C = 305$ K

$$(COP)_{max} = \frac{T_1}{T_2 - T_1} = \frac{243}{305-243}$$
$$= 3.91$$

Again $(COP)_{act.} = 0.75(COP)_{max}$

$= 0.75 \times 3.91 = 2.94$

$= \dfrac{RC}{P_{in}}$

$\Rightarrow$ $P_{in} = \dfrac{5}{2.94} = 1.7$ kW

23. ***Ans. (c)***

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