Government Polytechnic Education Society, Manesar

REFRIGERATION AND AIR CONDITIONING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT 1

Introduction to refrigeration

Refrigeration

Refrigeration is defined as the process of extracting heat from a lower-temperature heat source, substance, or cooling medium and transferring it to a higher-temperature heat sink. A refrigeration system is a combination of components and equipment connected in a sequential order to produce the refrigeration effect.

Refrigeration may also be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature.

Necessity and Applications

Applications of refrigeration:

- Food processing, preservation and distribution
- Chemical and process industries
- Special Applications such as cold treatment of metals, medical, construction, ice skating etc.
- Comfort air-conditioning

Storage of Raw Fruits and Vegetables

- Dairy Products
- Meat and poultry
- Beverages
- Candy

Chemical & process industries

- Separation of gases
- Condensation of Gases
- Dehumidification of Air
- Storage as liquid at low pressure:

- Removal of Heat of Reaction
- Cooling for preservation

Industrial applications

- Laboratories
- Printing
- Manufacture of Precision Parts
- Textile Industry
- Pharmaceutical Industries
- Photographic Material
- Farm Animals
- Vehicular Air-conditioning

UNIT OF REFRIGERATION AND COP

The standard unit of refrigeration is ton of refrigeration or simply ton denoted by TR. It is defined as the amount of refrigeration effect produced by the uniform melting of one tonne(1000 kg) of ice from and at 0ºC in 24 hours.

Since latent heat of ice is 335kJ/kg, therefore one tone of refrigeration,

1 TR= 1000×335 kJ in 24 hours.

$$= \frac{1000 \times 335}{24 \times 60} = 232.6 kJ/min$$

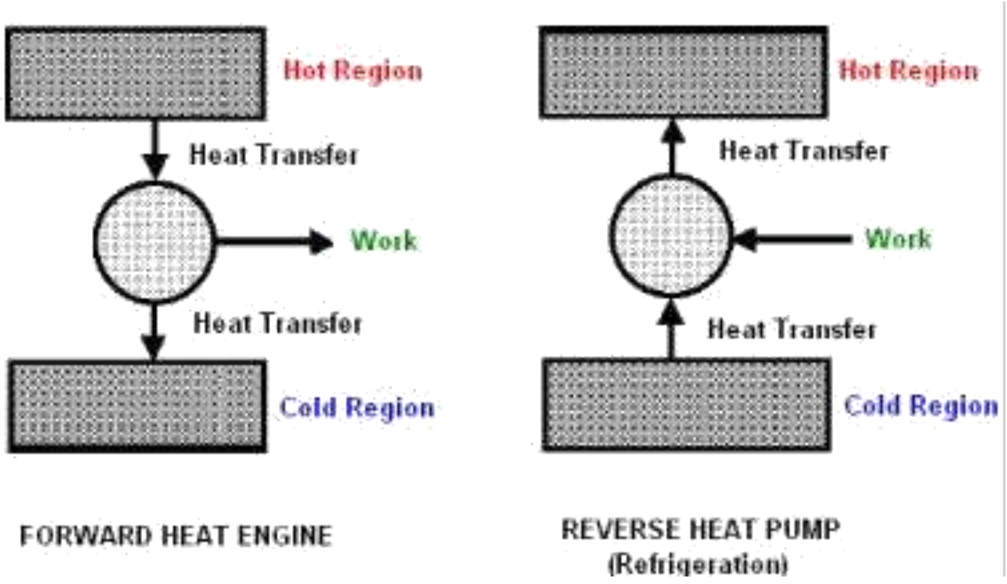
In actual practice one tone of refrigeration is taken as equivalent to 210kJ/min or 3.5kW (i.e 3.5kJ/s).

Fundamentals of Mechanical Refrigeration

Systems Introduction

Mechanical refrigeration is a thermodynamic process of removing heat from a lower temperature heat source or substance and transferring it to a higher temperature heat sink. This is against the Second Law of Thermodynamics, which states that heat will not pass from a cold region to a warm one. According to Clausius Statement of the Second Law of thermodynamics “It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body". Therefore in order to accomplish the transfer of heat from low temperature region to high temperature region an "external agent" or energy input is required and – you need a device, like a heat pump or refrigerator, which consumes work. The operating principle of the refrigeration cycle was described mathematically by Sadi Carnot in 1824 as a heat engine. A refrigerator or heat pump is simply a heat engine operating in reverse. Note the direction of arrows: Heat engine is defined as a device that converts heat energy into mechanical energy whereas the heat pump or refrigerator is defined as a device that use mechanical energy to pump heat from cold to hot region. A refrigeration system is a combination of components and equipment connected in a sequential order to produce the refrigeration effect. The most common refrigeration system in use today involves the input of work (from a compressor) and uses the Vapor Compression Cycle. This course is an overview of vaporcompression refrigeration cycle, principles of heat generation, transfer and rejection. Since refrigeration deals entirely with the removal or transfer of heat, some knowledge of the nature and effects of heat is necessary for a clear understanding of the subject. You may refer to the basic thermodynamics and glossary of terms at the end (annexture-1) to help you with this

Section first time through.



Air cycle refrigeration systems belong to the general class of gas cycle refrigeration systems, in which a gas is used as the working fluid. The gas does not undergo any phase change during the cycle, consequently, all the internal heat transfer processes are sensible heat transfer processes. Gas cycle refrigeration systems find applications refrigeration system is a combination of components and equipment connected in a sequential order to produce the refrigeration effect. The most common refrigeration system in use today involves the input of work (from a compressor) and uses the Vapor Compression Cycle. This course is an overview of vapor compression refrigeration cycle, principles of heat generation, transfer and rejection. Since refrigeration deals entirely with the removal or transfer of heat, some knowledge of the nature and effects of heat is necessary for a clear understanding of the subject. You may refer to the basic thermodynamics and glossary of terms at the end (annexture-1) to help you with this

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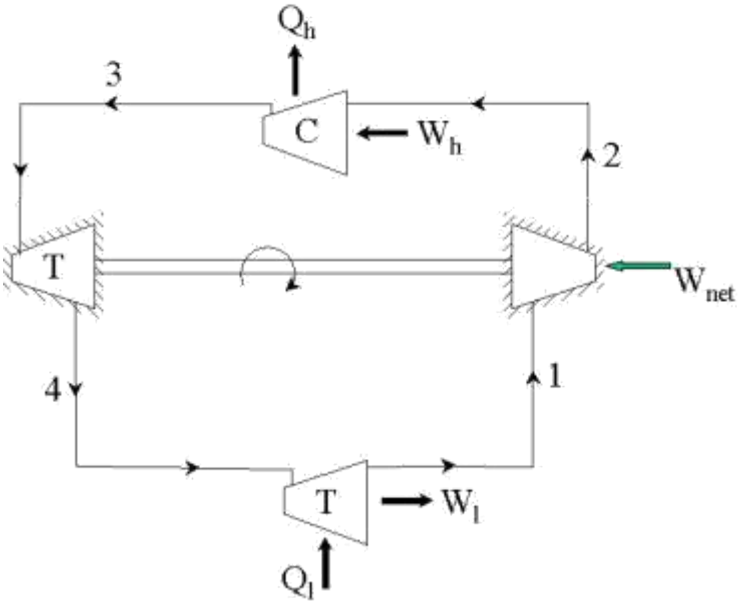
Air cycle refrigeration systems belong to the general class of gas cycle refrigeration systems, in which a gas is used as the working fluid. The gas does not undergo any phase change during the cycle, consequently, all the internal heat transfer processes are sensible heat transfer processes. Gas cycle refrigeration systems find applications in air craft cabin cooling and also in the liquefaction of various gases. In the present chapter gas cycle refrigeration systems based on air are discussed.

Reversed Carnot cycle employing a gas

Reversed Carnot cycle is an ideal refrigeration cycle for constant temperature external heat source and heat sinks. Figure 9.1(a) shows the schematic of a reversed Carnot refrigeration system using a gas as the working fluid along with the cycle diagram on T-s and P-v coordinates. As shown, the cycle consists of the following four processes:

Process 1-2: Reversible, adiabatic compression in a compressor
Process 2-3: Reversible, isothermal heat rejection in a compressor
Process 3-4: Reversible adiabatic expansion in a turbine

Process 4-1: Reversible, isothermal heat absorption in a turbine

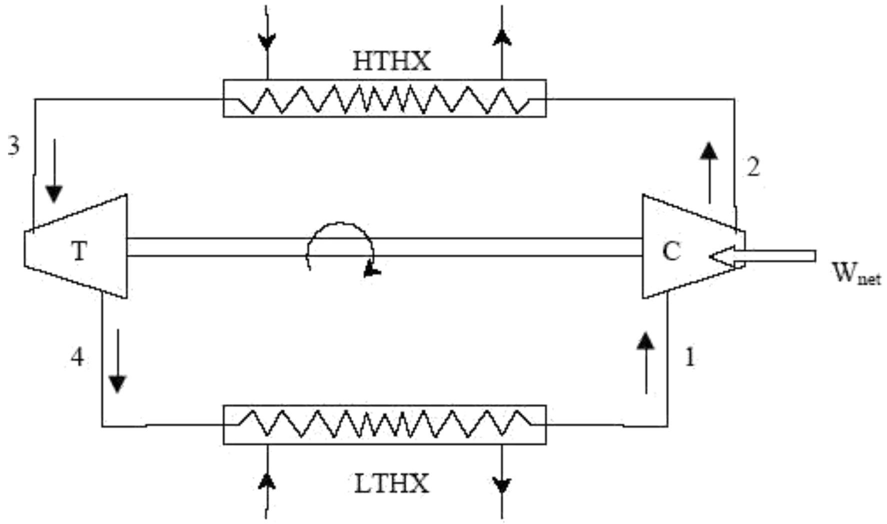


Schematic of a reverse Carnot refrigeration system

Temperature Limitations of Carnot cycle:

Carnot cycle is an idealization and it suffers from several practical limitations. One of the main difficulties with Carnot cycle employing a gas is the difficulty of achieving isothermal heat transfer during processes 2-3 and 4-1. For a gas to have heat transfer isothermally, it is essential to carry out work transfer from or to the system when heat is transferred to the system (process 4-1) or from the system (process 2-3). This is difficult to achieve in practice. In addition, the volumetric refrigeration capacity of the Carnot system is very small leading to large compressor displacement, which gives rise to large frictional effects. All actual processes are irreversible, hence completely reversible cycles are idealizations only.

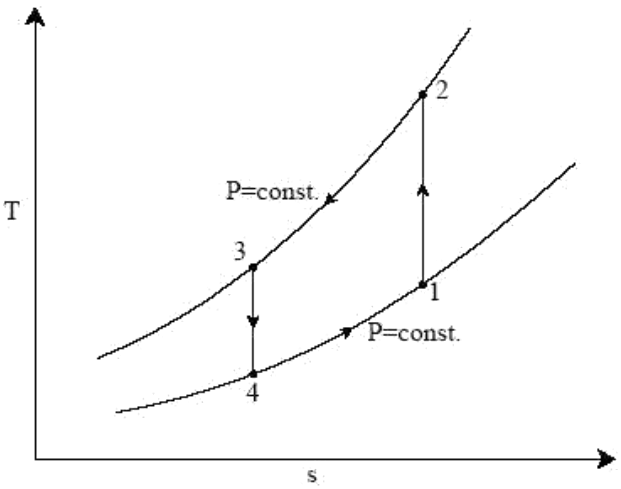
Bell-coleman cycle



Schematic of a closed reverse Brayton cycle

This is an important cycle frequently employed in gas cycle refrigeration systems. This may be thought of as a modification of reversed Carnot cycle, as the two isothermal processes of Carnot cycle are replaced by two isobaric heat transfer processes. This cycle is also called as Joule or Bell-Coleman cycle. Figure 9.2(a) and
(b) shows the schematic of a closed, reverse Brayton cycle and also the cycle on T-s diagram. As shown in the figure, the ideal cycle consists of the following four processes:

Process 1-2: Reversible, adiabatic compression in a compressor Process
2-3: Reversible, isobaric heat rejection in a heat exchanger Process 3-4:
Reversible, adiabatic expansion in a turbine
Process 4-1: Reversible, isobaric heat absorption in a heat exchanger



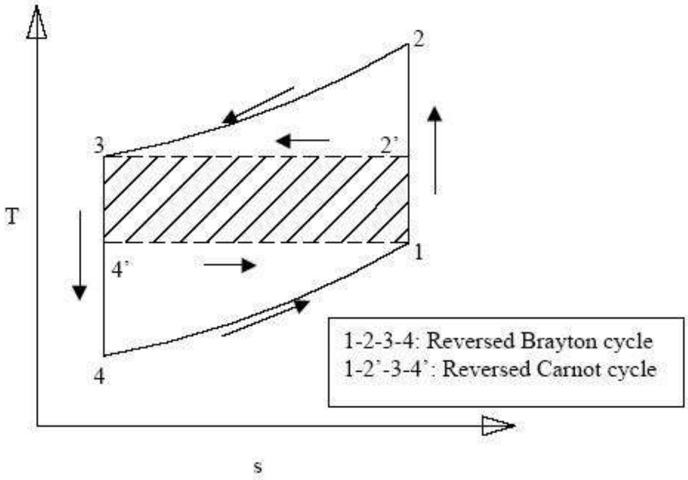
Reverse Brayton cycle in T-s plane

Process 1-2: Gas at low pressure is compressed isentropically from state 1 to state 2. Applying steady flow energy equation and neglecting changes in kinetic and potential energy, we can write:

Process 2-3: Hot and high pressure gas flows through a heat exchanger and rejects heat sensibly and isobarically to a heat sink. The enthalpy and temperature of the gas drop during the process due to heat exchange, no work transfer takes place and the entropy of the gas decreases. Again applying steady flow energy equation and second T ds equation:

Process 3-4: High pressure gas from the heat exchanger flows through a turbine, undergoes isentropic expansion and delivers net work output. The temperature of the gas drops during the process from T_3 to T_4. From steady flow energy equation:

Process 4-1: Cold and low pressure gas from turbine flows through the low temperature heat exchanger and extracts heat sensibly and isobarically from a heat source, providing a useful refrigeration effect. The enthalpy and temperature of the gas rise during the process due to heat exchange, no work transfer takes place and the entropy of the gas increases. Again applying steady flow energy equation and second T ds equation:



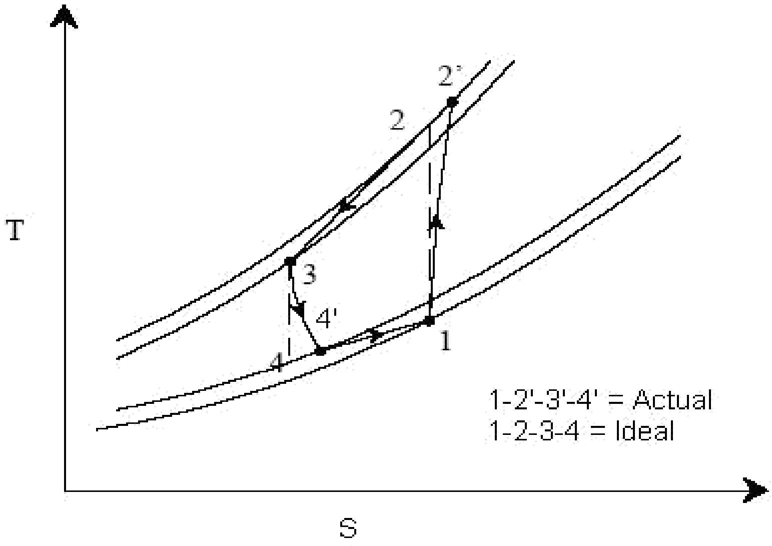
Comparison of reverse Carnot and reverse Brayton cycle in T-s plane

a) COP of Brayton cycle approaches COP of Carnot cycle as T_1 approaches T_4 (thin cycle), however, the specific refrigeration effect $[c_p(T_1-T_4)]$ also reduces simultaneously.
b) COP of reverse Brayton cycle decreases as the pressure ratio r_p increases

Actual reverse Brayton cycle:

The actual reverse Brayton cycle differs from the ideal cycle due to:

i. Non-isentropic compression and expansion processes
ii. Pressure drops in cold and hot heat exchangers



Comparison of ideal and actual Brayton cycles T-s plane

Due to these irreversibilities, the compressor work input increases and turbine work output reduces.

thus the net work input increases due to increase in compressor work input and reduction in turbine work output. The refrigeration effect also reduces due to the irreversibilities. As a result, the COP of actual reverse Brayton cycles will be considerably lower than the ideal cycles. Design of efficient compressors and turbines plays a major role in improving the COP of the system.

In practice, reverse Brayton cycles can be open or closed. In open systems, cold air at the exit of the turbine flows into a room or cabin (cold space), and air to the compressor is taken from the cold space. In such a case, the low side pressure will be atmospheric. In closed systems, the same gas (air) flows through the cycle in a closed manner. In such cases it is possible to have low side pressures greater than atmospheric. These systems are known as *dense air systems*. Dense air systems are advantageous as it is possible to reduce the volume of air handled by the compressor and turbine at high pressures. Efficiency will also be high due to smaller pressure ratios. It is also possible to use gases other than air (e.g. helium) in closed systems.

Compressors

The compressors are one of the most important parts of the refrigeration cycle. The compressor compresses the refrigerant, which flows to the condenser, where it gets cooled. It then moves to the expansion valve, and the evaporator and it is finally sucked by the compressor again. For the proper functioning of the refrigeration cycle, the refrigerant must be compressed to the pressure corresponding to the saturation temperature higher than the temperature of the naturally available air or water. It is the crucial function that is performed by the compressor. Compression of the refrigerant to the suitable pressure ensures its proper condensation and circulation throughout the cycle. The capacity of the refrigeration or air conditioning depends entirely on the capacity of the compressor.

Refrigeration Compressors

- Reciprocating Compressors
- Screw Compressors:
- Rotary Compressors:
- Centrifugal Compressor
- Scroll Compressors

Evaporators

Different types of evaporators are used in different types of refrigeration applications and accordingly they have different designs. The evaporators can be classified in various ways depending on the construction of the evaporator, the method of feeding the refrigerant, the direction of circulation of the air around the evaporator, etc. Here we have classified the evaporators based on their construction.

- Bare Tube Evaporators
- Plate Type of Evaporators
- Plate Type of Evaporators
- Finned Evaporators

- Shell and Tube types of Evaporators

According to the manner in which liquid refrigerant is fed

- a flooded evaporator
- dry expansion evaporator

According to the mode of heat transfer

- Natural convection evaporator
- Forced convection evaporator

According to operating conditions

- Frosting evaporator
- Non Frosting evaporator
- Defrosting evaporator

Types of Expansion Devices

- Capillary tube
- Hand Operated Expansion Valve
- Automatic or Constant Pressure Expansion Valve
- Thermostatic Expansion valve
- Low side float Valve
- High side float valve

Types of Condensers

- Air Cooled Condensers
- Water Cooled Condensers
- Evaporative Condensers

Refrigerants

Introduction:

- The thermodynamic efficiency of a refrigeration system depends mainly on its operating temperatures.
- However, important practical issues such as the system design, size, initial and operating costs, safety, reliability, and serviceability etc. depend very much on the type of refrigerant selected for a given application.
- Due to several environmental issues such as ozone layer depletion and global warming and their relation to the various refrigerants used, the selection of suitable refrigerant has become one of the most important issues in recent times.
- Replacement of an existing refrigerant by a completely new refrigerant, for whatever reason, is an expensive proposition as it may call for several changes in the design and manufacturing of refrigeration systems.
- Hence it is very important to understand the issues related to the selection and use of refrigerants. In principle, any fluid can be used as a refrigerant.
- Air used in an air cycle refrigeration system can also be considered as a refrigerant. However, in this lecture the attention is mainly focused on those fluids that can be used as refrigerants in vapour compression refrigeration systems only.

Primary and secondary refrigerants:

Fluids suitable for refrigeration purposes can be classified into primary and secondary refrigerants. Primary refrigerants are those fluids, which are used directly as working fluids, for example in vapour compression and vapour absorption refrigeration systems.

When used in compression or absorption systems, these fluids provide refrigeration by undergoing a phase change process in the evaporator. As the name implies, secondary refrigerants are those liquids, which are used for transporting thermal energy from one location to other.

Secondary refrigerants are also known under the name brines or antifreezes. Ofcourse, if the operating temperatures are above $0^{o}C$, then pure water can also be used as secondary refrigerant, for example in large air conditioning systems.

Antifreezes or brines are used when refrigeration is required at sub-zero temperatures. Unlike primary refrigerants, the secondary refrigerants do not undergo phase change as they transport energy from one location to other.

An important property of a secondary refrigerant is its freezing point. Generally, the freezing point of a brine will be lower than the freezing point of its constituents.

The temperature at which freezing of a brine takes place its depends on its concentration.

The concentration at which a lowest temperature can be reached without solidification is called as eutectic point.

The commonly used secondary refrigerants are the solutions of water and ethylene glycol, propylene glycol or calcium chloride. These solutions are known under the general name of brines.

Refrigerant selection criteria:

Selection of refrigerant for a particular application is based on the following requirements:

- Thermodynamic and thermo-physical properties
- Environmental and safety properties, and
- Economics

Thermodynamic and thermo-physical properties:

The requirements are:

a) Suction pressure: At a given evaporator temperature, the saturation pressure should be above atmospheric for prevention of air or moisture ingress into the system and ease of leak detection. Higher suction pressure is better as it leads to smaller compressor displacement

b) Discharge pressure: At a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor, condenser etc.

c) Pressure ratio: Should be as small as possible for high volumetric efficiency and low power consumption

d) Latent heat of vaporization: Should be as large as possible so that the required mass flow rate per unit cooling capacity will be small.

In addition to the above properties; the following properties are also important:

a) Isentropic index of compression: Should be as small as possible so that the temperature rise during compression will be small

b) Liquid specific heat: Should be small so that degree of subcooling will be large leading to smaller amount of flash gas at evaporator inlet

c) Vapour specific heat: Should be large so that the degree of superheating will be small

d) Thermal conductivity: Thermal conductivity in both liquid as well as vapour phase should be high for higher heat transfer coefficients

e) Viscosity: Viscosity should be small in both liquid and vapour phases for smaller frictional pressure drops

The thermodynamic properties are interrelated and mainly depend on normal boiling point, critical temperature, molecular weight and structure.

The normal boiling point indicates the useful temperature levels as it is directly related to the operating pressures. A high critical temperature yields higher COP due to smaller compressor superheat and smaller flash gas losses. On the other hand since the vapour pressure will be low when critical temperature is high, the volumetric capacity will be lower for refrigerants with high critical temperatures. This once again shows a need for trade-off between high COP and high volumetric capacity. It is observed that for most of the refrigerants the ratio of normal boiling point to critical temperature is in the range of 0.6 to 0.7. Thus the normal boiling point is a good indicator of the critical temperature of the refrigerant.

The important properties such as latent heat of vaporization and specific heat depend on the molecular weight and structure of the molecule. Trouton's rule shows that the latent heat of vaporization will be high for refrigerants having lower molecular weight. The specific heat of refrigerant is related to the structure of the molecule. If specific heat of refrigerant vapour is low then the shape of the vapour dome will be such that the compression process starting with a saturated point terminates in the superheated zone (**i.e, compression process will be dry**). However, a small value of vapour specific heat indicates higher degree of superheat. Since vapour and liquid specific heats are also related, a large value of vapour specific heat results in a higher value of liquid specific heat, leading to higher flash gas losses. Studies show that in general the optimum value of molar vapour specific heat lies in the range of **40 to 100 kJ/kmol.K**.

The freezing point of the refrigerant should be lower than the lowest operating temperature of the cycle to prevent blockage of refrigerant pipelines.

Environmental and safety properties:

Next to thermodynamic and thermophysical properties, the environmental and safety properties are very important. In fact, at present the environment friendliness of the refrigerant is a major factor in deciding the usefulness of a particular refrigerant. The important environmental and safety properties are:

a) Ozone Depletion Potential (ODP): According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances. Refrigerants having non-zero ODP have either already been phased-out (e.g. R 11, R 12) or will be phased-out in near-future(e.g. R22). Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine (i.e., CFCs and HCFCs) or bromine cannot be used under the new regulations

b) Global Warming Potential (GWP): Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future.

c) Total Equivalent Warming Index (TEWI): The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with as a low a value of TEWI are preferable from global warming point of view.

d) Toxicity: Ideally, refrigerants used in a refrigeration system should be non- toxic. However, all fluids other than air can be called as toxic as they will cause suffocation when their concentration is large enough. Thus toxicity is a relative term, which becomes meaningful only when the degree of concentration and time of exposure required to produce harmful effects are specified. Some fluids are toxic even in small concentrations. Some fluids are mildly toxic, i.e., they are dangerous only when the concentration is large and duration of exposure is long. Some refrigerants such as CFCs and HCFCs are non-toxic when mixed with air in normal condition. However, when they come in contact with an open flame or an electrical heating element, they decompose forming highly toxic elements (e.g. phosgene-$COCl_2$). In general the degree of hazard depends on:

- Amount of refrigerant used vs total space
- Type of occupancy
- Presence of open flames
- Odor of refrigerant, and
- Maintenance condition

Thus from toxicity point-of-view, the usefulness of a particular refrigerant depends on the specific application.

e) Flammability: The refrigerants should preferably be non-flammable and non-explosive. For flammable refrigerants special precautions should be taken to avoid accidents.

Based on the above criteria, ASHRAE has divided refrigerants into six safety groups (A1 to A3 and B1 to B3). Refrigerants belonging to Group A1 (e.g. R11, R12, R22, R134a, R744, R718) are least hazardous, while refrigerants belonging to Group B3 (e.g. R1140) are most hazardous.

Other important properties are:

f) Chemical stability: The refrigerants should be chemically stable as long as they are inside the refrigeration system.

g) Compatibility with common materials of construction (both metals and non- metals)

h) Miscibility with lubricating oils: Oil separators have to be used if the refrigerant is not miscible with lubricating oil (e.g. ammonia). Refrigerants that are completely miscible with oils are easier to handle (e.g. R12). However, for refrigerants with limited solubility (e.g. R 22) special precautions should be taken while designing the system to ensure oil return to the compressor

i) Dilelectric strength: This is an important property for systems using hermetic compressors. For these systems the refrigerants should have as high a dielectric strength as possible

j) Ease of leak detection: In the event of leakage of refrigerant from the system, it should be easy to detect the leaks.

Economic properties:

The refrigerant used should preferably be inexpensive and easily available.

Designation of refrigerants:

Figure 26.1 shows the classification of fluids used as refrigerants in vapour compression refrigeration systems. Since a large number of refrigerants have been developed over the years for a wide variety of applications, a numbering system has been adopted to designate various refrigerants. From the number one can get some useful information about the type of refrigerant, its chemical composition, molecular weight etc. All the refrigerants are designated by R followed by a unique number.

i) Fully saturated, halogenated compounds: These refrigerants are derivatives of alkanes (C_nH_{2n+2}) such as methane (CH_4), ethane (C_2H_6). These refrigerants are designated by R XYZ, where:

X+1 indicates the number of Carbon (C) atoms Y-

1 indicates number of Hydrogen (H) atoms, and

Z indicates number of Fluorine (F) atoms

The balance indicates the number of Chlorine atoms. Only 2 digits indicates that the value of X is zero.

Ex: R 22

X = 0 □ No. of Carbon atoms = 0+1 = 1 □ derivative of methane (CH_4) Y = 2

□ No. of Hydrogen atoms = 2-1 = 1

Z = 2 □ No. of Fluorine atoms = 2

The balance = 4 – no. of (H+F) atoms = 4-1-2 = 1 □ No. of Chlorine atoms = 1

□The chemical formula of

R 22 = $CHClF_2$ Similarly it can be shown

that the chemical formula of:

R12 = CCl_2F_2

R134a = $C_2H_2F_4$ (derivative of ethane)

(letter a stands for isomer, e.g. molecules having same chemical composition but different atomic arrangement, e.g. R134 and R134a)

ii) Inorganic refrigerants: These are designated by number 7 followed by the molecular weight of the refrigerant (rounded-off).

Ex.: Ammonia: Molecular weight is 17, □ the designation is R 717

Carbon dioxide: Molecular weight is 44, □ the designation is R 744 Water:

Molecular weight is 18, □ the designation is R 718

Unit– II

Vapour Compression Refrigeration Systems

Introduction

A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant, is used. It condenses and evaporates at temperatures and pressures close to the atmospheric conditions. The refrigerants, usually, used for this purpose are ammonia ($NH3$), carbon dioxide ($CO2$) and sulphur dioxide ($SO2$). The refrigerant used, does not leave the system, but is circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the brine (salt water) which is used for circulating it around the cold chamber. While condensing, it gives out its latent heat to the circulating water of the cooler. The vapour compression refrigeration system is, therefore a latent heat pump, as it pumps its latent heat from the brine and delivers it to the cooler.

The vapour compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

Advantages and Disadvantages of vapour Compression Refrigeration System over Air Refrigeration System

Following are the advantages and disadvantages of the vapour compression refrigeration system over air refrigeration system:

Advantages

1. It has smaller size for the given capacity of refrigeration.

2. It has less running cost.
3. It can be employed over a large range of temperatures.
4. The coefficient of performance is quite high.

Disadvantages

1. The initial cost is high

2. The prevention of leakage of the refrigerant is the major problem in vapour compression system

Mechanism of a Simple Vapour Compression Refrigeration System

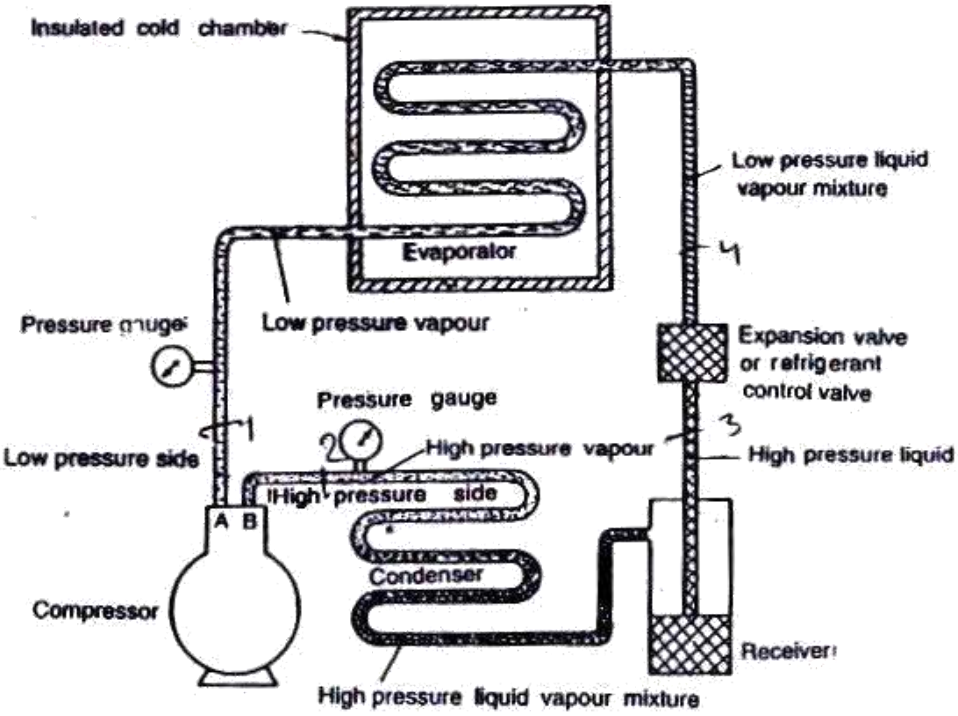


Fig. 2.1 shows the achematic diagram of a simple vapour compression refrigeration system. It consists of the following five essential parts :

1. *Compressor*. The low pressure and temperature vapou refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compresses to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharge the condenser through the delivery or discharge valve B.

2. *Condenser*. The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

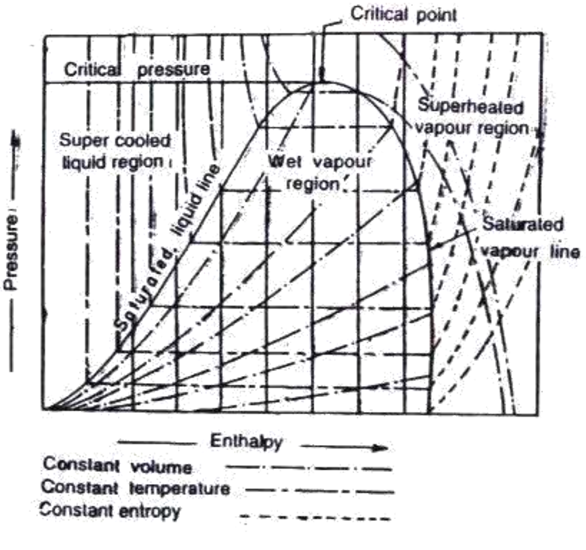
3. *Receiver*. The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

4. *Expansion valve*. It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator at the low pressure and temperature.

5. *Evaporator*. An evaporator consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled.

Note : In any compression refrigeration system, there are two different pressure conditions. One is called the high pressure side and other is known as low pressure side. The high pressure side includes the discharge line (i.e. piping from the evaporator to the suction valve A).

Pressure-Enthalpy (p-h) Chart



The most convenient chart for studying the behavior of a refrigerant is the p-h chart, in which the vertical ordinates represent pressure and horizontal ordinates represent enthalpy (i.e. total heat). A typical chart is shown in Fig. 2.2, in which a few important lines of the complete chart are drawn. The saturated liquid line and the saturated vapour line merge into one another at the critical point. A saturated liquid is one which has a temperature equal to the saturation temperature corresponding to its pressure. The space to the left of the saturated liquid line will, therefore, be sub-cooled liquid region. The space between the liquid and the vapour lines is called wet vapour region and to the right of the saturated vapour line is a superheated vapour region.

In the following pages, we shall drawn the p-h chart along with the T-s diagram of the cycle.

Types of Vapour Compression Cycles

We have already discussed that vapour compression cycle essentially consists of compression, condensation, throttling and evaporation. Many scientists have focussed their attention to increase the coefficient of performance of the cycle. Through there are many cycles, yet the following are important from the subject point of view :

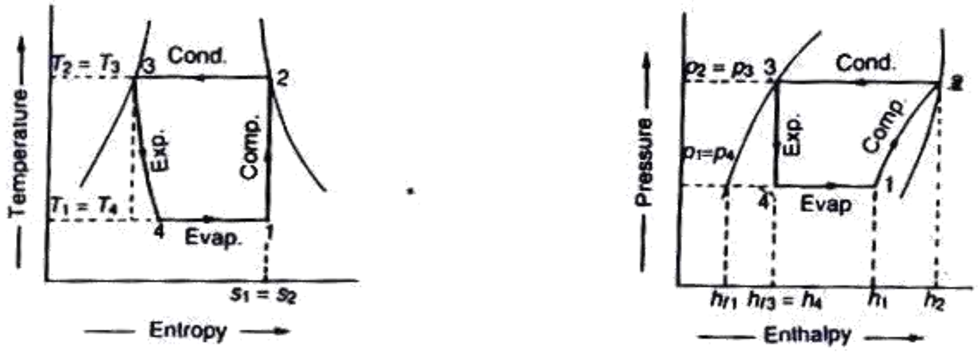
1. Cycle with dry saturated vapour after compression,
2. Cycle with wet vapour after compression,
3. Cycle with superheated vapour after compression,
4. Cycle with superheated vapour before compression, and
5. Cycle with undercooling or subcooling of refrigerant.

Now we shall discuss all the above mentioned cycles, one by one, in the following pages.

Theoretical Vapour Compression Cycle with Dry Saturated Vapour after Compression

A vapour compression cycle with dry saturated vapour after compression is shown on T-s and p-h diagrams. At point 1, let

T_1,p_1 and s_1 be the temperature, pressure and entropy of the vapour refrigerant respectively. The four process of the cycle are as follows :



(*a*) *T-s* diagram.

(*b*) *p-h* diagram.

Theoretical vapour compression cycle with dry saturated vapour after compression

1. *Compression process*. The vapour refrigerent at low pressure p_1 and temperature T_1 is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on T-s diagram and by the curve 1-2 on p-h diagram. The pressure and temperature rises from p_1 to p_2 and T_1 to t_2 respectively.

The work done during isentropic compression per kg of refrigerant is given by

$w = h_2 - h_1$

where h_1 = Enthalpy of vapour refrigerant at temperature T_1, i.e. at suction of the compressor, and

h_2 = Enthalpy of the vapour refrigerant at temperature T_2, i.e. at discharge of the compressor.

2. *Condensing process*. The high pressure and temperature vapour refrigerant from the compressor is passed through the condenser where it is

completely condensed at constant pressure p_2 and temperature T_2, as shown by the horizontal line 2-3 on T-s and p-h diagrams. The vapour refrigerant is changed into liquid refrigerant. The refrigerant, while passing through the condenser, gives its latent heat to the surrounding condensing medium.

3. *Expansion process*. the liquid refrigerant at pressure $p_3 = p_2$ and temperature $T_3 = T_2$ is expanded by *throttling process through the expansion valve to a low pressure $p_4 = p_1$ and temperature $T_4 = T_1$, as shown by the curve 3-4 on T-s diagram and by the vertical line 3-4 on p-h diagram. We have already discussed that some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator. We know that during the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

Notes : (a) In case an expansion cylinder is used in place of throttle or expansion valve to expand the liquid refrigerant, then the refrigerant will expand isentropically as shown by dotted vertical line on T-s diagram in Fig. 2.3 (a). The isentropic expansion reduces the external work being expanded in running the compressor and increases the refrigerating effect. Thus, the net result of using the expansion cylinder is to increase the coefficient of performance.

Since the expansion cylinder system of expanding the liquid refrigerant is quite complicated and involves greater initial cost, therefore its use is not justified for small gain in cooling capacity. Moreover, the flow rate of the refrigerant can be controlled with throttle valve which is not possible in case of expansion cylinder which has a fixed cylinder volume.

(b) In modern domestic refrigerators, a capillary (small bore tube) is used in place of an expansion valve.

4. *Vaporising process*. The liquid-vapour mixture of the refrigerant at pressure $p_4 = p_1$ and temperature $T_4 = T_1$ is evaporated and changed into vapour refrigerant at constant pressure and temperature, as shown by the horizontal line 4-1 on T-s and p-h diagrams. During evaporation, the liquid-vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled. This heat which is absorbed by the refrigerant is called refrigerating effect and it is briefly written as R_E. The process of vaporisation continues upto point 1 which is the starting point and thus the cycle is completed.

We know that the refrigerating effect or the heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by

$$R_E = h_1 - h_4 = h_1 - h_{f3} \qquad \ldots (\because h_{f3} = h_4)$$

where h_{f3} = Sensible heat at temperature T_3, i.e. enthalpy of liquid refrigerant leaving the condenser.

It may be noticed from the cycle that the liquid-vapour refrigerant has extracted heat during evaporation and the work will be done by the compressor for isentropic compression of the high pressure and temperature vapour refrigerant.

∴ Coefficient of performance,

$$\text{C.O.P.} = \frac{\text{Refrigerating effect}}{\text{Work done}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

Example In an ammonia vapour compression system, the pressure in the evaporator is 2 bar. Ammonia at exit is 0.85 dry and at entry its dryness fraction is 0.19. During compression, the work done per kg of ammonia is 150 kJ. Calculate the C.O.P. and the volume of vapour entering the compressor per minute, if the rate of ammonia circulation is 4.5 kg/min. The latent heat and specific volume at 2 bar are 1325 kJ/kg and 0.58 m^3/kg respectively.

Solution. Given : $p_1 = p_4 = 2$ bar ; $x_1 = 0.85$; $x_4 = 0.19$; $w = 150$ kJ/kg ; $m_a = 4.5$ kg/min; $h_{fg} = 1325$ kJ/kg ; $v_g = 0.58$

m^3/kg C.O.P.

The T-s and p-h diagrams are shown in Fig.4.3 (a) and (b) respectively.

Since the ammonia vapour at entry to the evaporator (i.e. at point 4) has dryness fraction (x_4) equal to 0.19, therefore enthalpy at point 4,

$$h_4 = x_4 \times h_{fg} = 0.19 \times 1325 = 251.75 \text{ kJ/kg}$$

Similarly, enthaipy of ammonia vapour at exit i.e. at point

1, $h_1 = x_1 \times h_{fg} = 0.85 \times 1325 = 1126.25$ kJ/kg

∴ Heat extracted from the evaporator or refrigerating effect,

$R_E \square h_1 \square h_4 \square 1126.25 - 251.75 = 874.5$ kJ/kg

We know that work done during compression,

w = 150 kJ/kg

□ C.O.P. = R_E/w = 874.5/150 = 5.83 **Ans.**

Volume of vapour entering the compressor per minute

We know that volume of vapour entering the compressor per minute

= Mass of refrigerant / min × Specific volume

$= m_a \square v_g \square 4.5 \square 0.58 \square 2.61\ m^3$ / min **Ans.**

Example. The temperature limits of an ammonia refrigerating system are 25^{o}Cand -10^{o} .C If the gas is dry at the end of compression, calculate the coefficient of performance of the cycle assuming no undercooling of the liquid ammonia. Use the following table for properties of ammonia:

Temperature *(^{o}C)*	*Liquid heat* *(kJ/kg)*	*Latent heat* *(kJ/kg)*	*Liquid entropy* *(kJ/kg K)*
25	*298.9*	*1166.94*	*1.1242*
-10	*135.37*	*1297.68*	*0.5443*

Solution. Given : $T_2 \square T_3 \square 25^{o}$ C □ 25 □ 273 □ 298 K ; $T_1 = T_4 = -10^{o}$C = 263K ;

$h_{f3} = h_4 = 298.9$ kJ/kg ; $h_{fg2} = 1166.94$ kJ/kg ; $s_{f2} = 1.1242$ kJ/kg K ; $h_{f1} =$ 135.37 kJ/kg ; $h_{fg1} = 1297.68$ kJ/kg ; $s_{f1} = 0.5443$ kJ/kg K

The T-s and p-h diagrams are shown in Fig. 2. 4 (a) and (b) respectively.

Let x_1 = Dryness fraction at point 1.

We know that entropy at point 1, Fig.

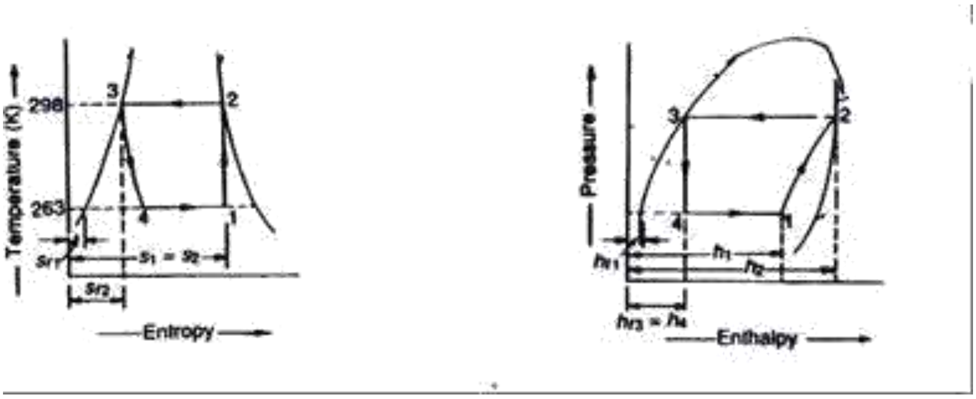
$$s_1 \square s_{f1} \square \frac{x_1 h_{fg1}}{T_1} \square 0.5443 \square \frac{x_1 \square 1297.68}{263}$$

$= 0.5443 + 4.934\, x_1$

Similarly, entropy at point 2,

$$s_2 = s_{f2} + \frac{h_{fg2}}{T_2} = 0.5443 + \frac{1166.94}{298} = 5.04$$

Since the entropy at point 1 is equal to entropy at point 2, therefore equating equations (i) and (ii) $0.5443 + 4.934\, x_1 = 5.04$ or $x_1 = 0.91$



We know that enthalpy at point 1,

$h_1 = h_{f1} + x_1 h_{fg1} = 135.37 + 0.91 \times 1297.68 =$

1316.26 kJ/kg and enthalpy at point 2,

$h_2 = h_{f2} + h_{fg2} = 298.9 + 1166.94 = 1465.84$ kJ/kg

∴ Coefficient of performance of the cycle

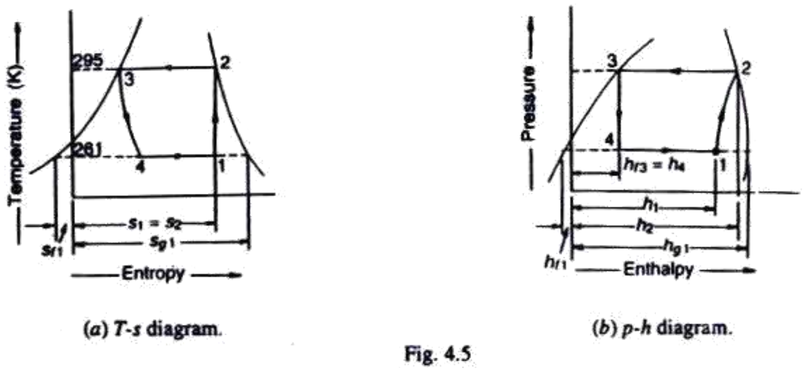
$$= \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{1316.26 - 298.9}{1465.84 - 1316.26} = 6.8 \textbf{ Ans.}$$

Example A vapour compression refrigerator works between the pressure limits of 60 bar and 25 bar. The working fluid is just dry at the end of compression and there is no under-cooling of the liquid before the expansion valve. Determine : 1. C.O.P. of the cycle ; and 2. Capacity of the refrigerator if the fluid flow is at the rate of 5 kg/min.

Data :

Pressure *(bar)*	*Saturation* *temperature* *(K)*	*Enthalpy (kJ/kg)*		*Entropy (kJ/kg K)*	
		Liquid	*Vapour*	*Liquid*	*Vapour*
60	*295*	*151.96*	*293.29*	*0.554*	*1.0332*
25	*261*	*56.32*	*322.58*	*0.226*	*1.2464*

Solution. Given : p_2 = p= = 60 bar ; $p_1 = p_4$ = 25 bar ; $T_2 = T_3$ = 295 K ; $T_1 = T_4$ = 261 K ; $h_{f3} = h_4$ = 151.96 kJ/kg ; h_{f1} = 56.32 kJ/kg ; $h_{g2} = h_2$ 293.29 kJ/kg ; h_{g1} = 322.58 kJ/kg ; s_{f2} = 0.554 kJ/kg K ; s_{f1} = 0.226 kJ/kg K ; s_{g2} = 1.0332 kJ/kg K; s_{g1} = 1.2464 kJ/kg K



(*a*) *T-s* diagram.

(*b*) *p-h* diagram.

Fig. 4.5

Fig 2.5

1. C.O.P. of the cycle

The T-s and p-h diagrams are shown in Fig. 2.5 (a) and (b) respectively. Let

x_1 = Dryness fraction of the vapour refrigerant entering the compressor at point 1.

We know that entropy at point 1,

$$s_1 = s_{f1} + x_1 s_{fg1} = s_{f1} + x_1 (s_{g1} - s_{f1}) \quad \ldots(\because s_{g1} = s_{f1} + s_{fg1})$$

$$= 0.226 + x_1 (1.2464 - 0.226) = 0.226 + 1.0204\, x_1 \quad \ldots \text{(i)}$$

and entropy at point 2, s_2 = 1.0332 kJ/kg K ... (Given) ... (ii)

Since the entropy at point 1 is equal to entropy at point 2, therefore equating equations (i) and (ii),

$0.226 + 1.0204\, x_1 = 1.0332$ or we $\quad x_1 = 0.791$

know that enthalpy at point 1,

$$h_1 = h_{f1} + x_1 h_{fg1} = h_{f1} + x_1 (h_{g1} - h_{f1}) \qquad \dots (\because h_{g1} = h_{f1} + h_{fg1})$$

$= 56.32 + 0.791\,(322.58 - 56.32) = 266.93$ kJ/kg

∴ C.O.P. of the cycle

$$= \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{266.93 - 151.96}{293.29 - 266.93} = 4.36$$ **Ans.**

2. Capacity of the refrigerator

We know that the heat extracted or refrigerating effect produced per kg of refrigerant

$= h_1 - h_{f3} = 266.93 - 151.93 = 114.97$ kJ/kg

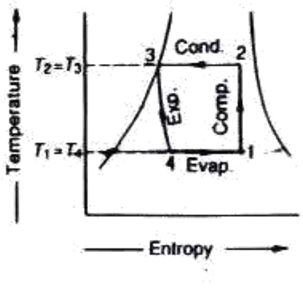
Since the fluid flow is at the rate of 5 kg/min, therefore total heat extracted

$= 5 \times 114.97 = 574.85$ kJ/min

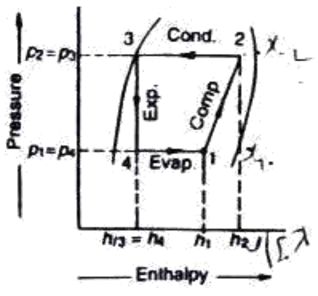
∴ Capacity of the refrigerator

$$= \frac{574.85}{210} = 2.74 \text{ TR} \qquad \dots (\because 1 \text{ TR} = 210 \text{ kJ/min})$$ **Ans.**

2.7. Theoretical Vapour Compression Cycle with Wet Vapour after Compression



(*a*) *T-s* diagram.



(*b*) *p-h* diagram.

A vapour compression cycle with wet vapour after compression is shown on T-s and p-h diagrams in Fig. 2.6 (a) and (b) respectively. In this cycle, the enthalpy at point 2 is found out with the help of dryness fraction at this point. The dryness fraction at points 1 and 2 may be obtained by equating entropies at points 1 and 2.

Now the coefficient of performance may be found out as usual from the relation,

$$\text{C.O.P.} = \frac{\text{Refrigerating effect}}{\text{Work done}} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

Superheat

In theory, the refrigerant leaves the evaporator as a vapor at point ‘1’, however, in real applications, additional heat, called “superheat” is added to prevent liquid condensation in the lines that can damage the compressor (shown as point 1a). Superheat is the heat added to the vapor beyond what is required to vaporize all of the liquid. Since refrigeration and air-conditioning compressors are designed to compress vapor refrigerant, some superheating is necessary to ensure that no liquid refrigerant can return to the compressor. The amount of superheat is determined by the amount of liquid refrigerant admitted to the evaporator. This, in turn, is controlled by the expansion valve (TXV) and that’s why it is also known as metering device. A temperature range of 4° to 12°F of superheat is considered desirable to prevent liquid carry-over into the compressor (flooding back).

Superheat is an indication of how full the evaporator is of liquid refrigerant. High superheat means the evaporator is empty. Low superheat means the evaporator is full.

Sub-Cooling

Sub-cooling is the process of cooling condensed gas below its saturated pressure-temperature. Subcooling assures that no gas is left at the end of the condensing phase, thus assuring maximum capacity at the expansion valve. Sub-cooling is best accomplished in a separate sub-cooler or a special sub-cooling section of a condenser because tube surface must be submerged in liquid refrigerant for sub-cooling to occur. Sub-cooling can have a dramatic effect in the capacity of a refrigeration system by increasing the capacity of the refrigerant to absorb heat during the evaporation phase for the same compressor kW input.

UNIT – III

Vapour Absorption Refrigeration Systems

Introduction

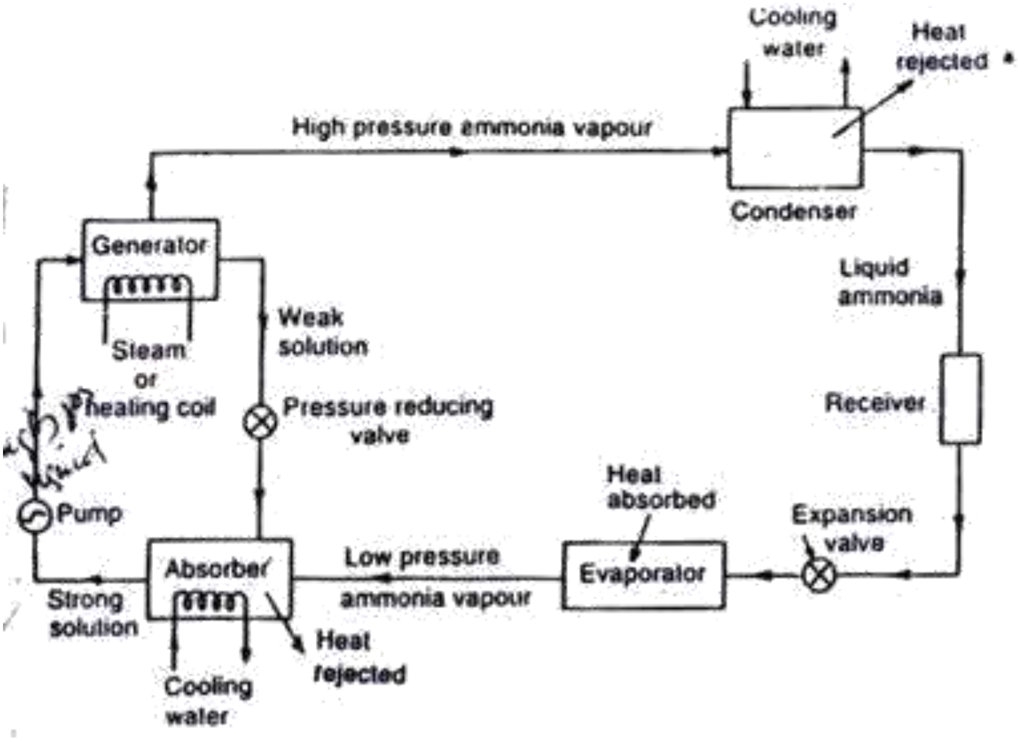
The vapour absorption refrigeration system is one of the oldest method of producing refrigerating effect. The principle of vapour absorption was first discovered by Michael Faraday in 1824 while performing a set of experiments to liquify certain gases. The first vapour absorption refrigeration machine was developed by a French scientist Ferdinand Carre in 1860. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant, commonly used in a vapour absorption system, is ammonia.

The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. We have discussed in the previous chapters that the function of a compressor, in a vapour compression system, is to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapours can reject heat in the condenser. The liquid refrigerant leaving the condenser is now ready to expand to the evaporator conditions again.

In the vapour absorption system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. These components in vapour absorption system perform the same function as that of a compressor in vapour compression system. In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

Simple Vapour Absorption System -

The simple vapour absorption system, as shown in Fig. 3.1, consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.



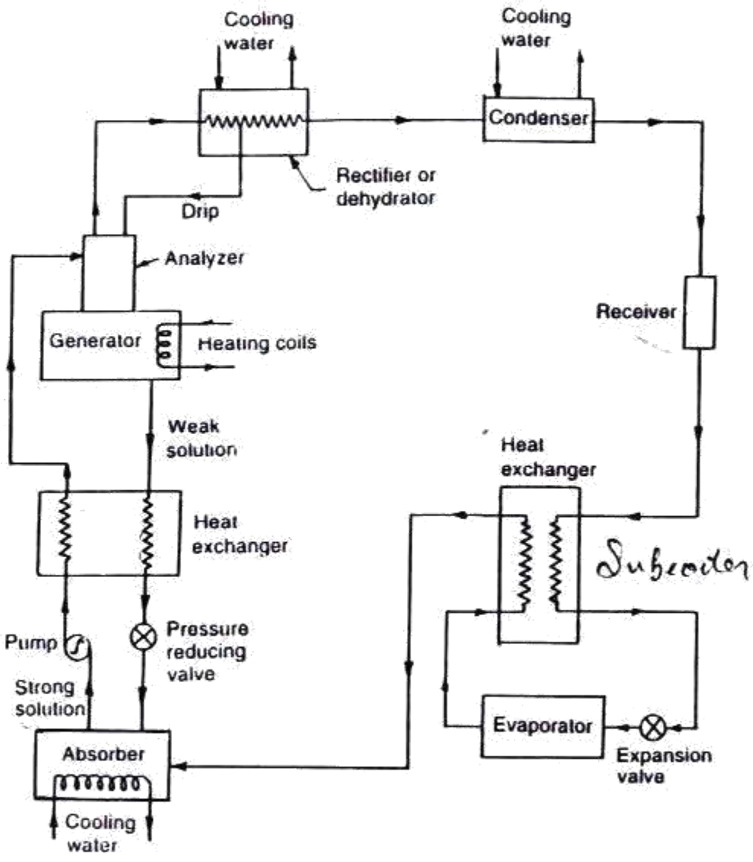
Simple vapour absorbtion system

. In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb very large quantities of ammonia vapour and the solution thus formed, is known as aqua-ammonia. The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved there. This is necessary in order to increase the absorption capacity of water, because at higher temperature water absorbs less ammonia vapour. The strong solution thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution upto 10 bar.

The *strong solution of ammonia in the generator is heated by some external source such as gas or steam. During the heating process, the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator. This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia. This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This completes the simple vapour absorption cycle.

Practical Vapour Absorption System

The simple absorption system as discussed in the previous article is not very economical. In order to make the system more practical, it is fitted with an analyser, a rectifier and two heat exchangers as shown in Fig. 3.2. These accessories help to improve the performance and working of the plant, as discussed below :-



. Practical vapour absorption system.

1. *Analyser*. When ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser along with the ammonia vapours in the simple system. If these unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze and choke the pipe line. In order to remove these unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of the generator or made as a separate piece of equipment. It consists of a series of trays mounted above the generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. In this way, considerable liquid surface area is exposed to the vapour rising from the generator. The vapour is cooled and most of the water vapour condenses, so that mainly ammonia vapour leaves the top of the analyser. Since the aqua is heated by the vapour, less external heat is required in the generator.

2. *Rectifier*. In case the water vapours are not completely removed in the analyser, a closed type vapour cooler called rectifier (also known as dehydrator) is used. It is generally water cooled and may be of the double pipe, shell and coil or shell and tube type. Its function is to cool further the ammonia vapours leaving the analyser so that the remaining water vapours are condensed. Thus, only dry or anhydrous ammonia vapours flow to the condenser. The condensate from the rectifier is returned to the top of the analyser by a drip return pipe.

3. *Heat exchangers*. The heat exchanger provided between the pump and the generator is used to cool the weak hot solution returning from the generator to the absorber. The heat removed from the weak solution raises the temperature of the strong solution leaving the pump and going to analyser and generator. This operation reduces the heat supplied to the generator and the amount of cooling required for the absorber. Thus the economy of the plant increases.

The heat exchanger provided between the condenser and the evaporator may also be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub- cooled by the low temperature ammonia vapour from the evaporator as shown in Fig. 7.2. This sub-cooled liquid is now passed to the expansion valve and then to the evaporator.

In this system, the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the sum of work done by the pump and the heat supplied in the generator. Therefore, the coefficient of performance of the system is given by

$$\text{C.O.P.} = \frac{\text{Heat absorbed in evaporator}}{\text{Work done by pump + Heat supplied in generator}}$$

Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System

Following are the advantages of vapour absorption system over vapour compression system:

1. In the vapour absorption system, the only moving part of the entire system is a pump which has a small motor. Thus, the operation of this system is essentially quiet and is subjected to little wear.

The vapour compression system of the same capacity has more wear, tear and noise due to moving parts of the compressor.

2. The vapour absorption system uses heat energy to change the condition of the refrigerant from the evaporator. The vapour compression system uses mechanical energy to change the condition of the refrigerant from the evaporator.

3. The vapour absorption systems are usually designed to use steam, either at high pressure or low pressure. The exhaust steam from furnaces and solar energy may also be used. Thus this system can be used where the electric power is difficult to obtain or is very expensive.

4. The vapour absorption systems can operate at reduced evaporator pressure and temperature by increasing the steam pressure to the generator, with little decrease in capacity. But the capacity of vapour compression system drops rapidly with lowered evaporator pressure.

5. The load variations does not effect the performance of a vapour absorption system. The load variations are met by controlling the quantity of aqua circulated and the quantity of steam supplied to the generator.

The performance of a vapour compression system at partial loads is poor.

6. In the vapour absorption system, the liquid refrigerant leaving the evaporator has no bad effect on the system except that of reducing the refrigerating effect. In the vapour compression system, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.

7. The vapour absorption systems can be built in capacities well above 1000 tonnes of refrigeration each which is the largest size for single compressor units.

8. The space requirements and automatic control requirements favour the absorption system more and more as the desired evaporator temperature drops.

Coefficient of Performance of an Ideal Vapour Absorption Refrigeration System

We have discussed earlier that in an ideal vapour absorption refrigeration system,

(a) the heat (Q_G) is given to the refrigerant in the generator,

(b) the heat (Q_C) is discharged to the atmosphere or cooling water from the condenser and absorber.

(c) the heat (Q_E) is absorbed by the refrigerant in the evaporator, and

(d) the heat (Q_p) is added to the refrigerant due to pump work.

Neglecting the heat due to pump work (Q_p), we have according to First Law of Thermodynamics,

$$Q_C = Q_G + Q_E \quad \text{... (i)}$$

Let T_G = Temperature at which heat (Q_G) is given to the generator,

T_C = Temperature at which heat (Q_C) is discharged to atmosphere or cooling water from the condenser and absorber, and

T_E = Temperature at which heat (Q_E) is absorbed in the evaporator.

Since the vapour absorption system can be considered as a perfectly reversible system, therefore the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$\therefore \quad \frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \qquad \text{...(ii)}$$

$$= \frac{Q_G + Q_E}{T_C} \qquad \text{... [From equation (i)]}$$

$$\text{or} \quad \frac{Q_G}{T_G} - \frac{Q_G}{T_C} = \frac{Q_E}{T_C} - \frac{Q_E}{T_E}$$

$$Q_G \left(\frac{T_C - T_G}{T_G \times T_C} \right) = Q_E \left(\frac{T_E - T_C}{T_E \times T_C} \right)$$

$$\therefore \quad Q_G = Q_E \left(\frac{T_E - T_C}{T_E \times T_C} \right) \times \left(\frac{T_G \times T_C}{T_C - T_G} \right)$$

$$= Q_E \left(\frac{T_C - T_E}{T_E \times T_C} \right) \times \left(\frac{T_G \times T_C}{T_G - T_C} \right)$$

$$= Q_E \times \left(\frac{T_C - T_E}{T_E} \right) \times \left(\frac{T_G}{T_G - T_C} \right) \qquad \text{... (iii)}$$

Maximum coefficient of performance of the system is given by

$$(\text{C.O.P.})_{max} = \frac{Q_E}{Q_G} = \frac{Q_E}{Q_E \left(\frac{T_C - T_E}{T_E} \right) \times \left(\frac{T_G}{T_G - T_C} \right)} = \left(\frac{T_E}{T_C - T_E} \right) \times \left(\frac{T_G - T_C}{T_G} \right) \qquad \text{...(iv)}$$

$$\mathbf{T} \; □ \; \mathbf{T}$$

$$□ \quad C \quad \overset{E}{\begin{matrix} □ \\ □ \end{matrix}} \quad TG \quad \begin{matrix} □ \\ □ \end{matrix}$$

It may noted that,

$$\mathbf{Q}$$

$$\overset{E}{} \; □ \; T_{C} \; \begin{matrix} □ \\ □ \end{matrix}_{E} \; □ \; \frac{T}{□_{G}} \; □ \quad \begin{matrix} □ \\ □ \\ □ \\ □ \end{matrix}$$

$$\frac{\dfrac{T}{\;} \; □}{E \quad □} \quad □ \quad \frac{T \; □ \; T}{G} \quad \frac{\;}{C} \quad \begin{matrix} □ \\ □ \end{matrix}$$

I. The expression $\left(\frac{T_E}{T_C - T_E}\right)$ is the C.O.P. of a Carnot refrigerator working between the temperature limits of T_E and T_C.

2. The expression $\left(\frac{T_G - T_C}{T_G}\right)$ is the efficiency of a Carnotengine working between the temperature limits of T_G and T_C.

Thus an ideal vapour absorption refrigeration system may be regarded as a combination of a Carnot engine and a Carnot refrigerator. The maximum C.O.P. may be written as

$$(C.O.P.)_{max} = (C.O.P)_{carnot} \times \eta_{carnot}$$

In case the heat is discharged at different temperatures in condenser and absorber, then

$$(C.O.P.)_{max} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right)$$

where T_A = Temperature at which heat is discharged in the absorber.

Example In a vapour absorption refrigeration system, heating, cooling and refrigeration takes place at the temperatures of 100^o C, 20^o C and _5° C respectively. Find the maximum C.O.P. of the system.

Solution. Given: TG = 100^{o}C = 100 + 273 = 373 K ; Tc = 20^o C = 20 + 273 =293K;TE=-5°C=-5+273=268K

We know that maximum C.O.P. of the system

$$= \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right) = \left(\frac{268}{293 - 268}\right)\left(\frac{373 - 293}{373}\right) = 2.3 \textbf{ Ans.}$$

Example. In an absorption type refrigerator, the heat is supplied to NH_3 generator by condensing steam at 2 bar and 90% dry. The temperature in the refrigerator is to be maintained at - 5° C. Find the maximum C.O.P. possible.

If the refrigeration load is 20 tonnes and actual C.O.P. is 10% of the maximum C.O.P ., find the mass of steam required per hour. Take temperature of the atmosphere as 30 ^{o}C.

Solution. Given: p = 2 bar; x = 90% = 0.9; T_E = -5°C = -5 + 273 = 268 K ; Q = 20 TR; Actual C.O.P. = 70% of maximum C.O.P. ; T_C = 30° C = 30 + 273 = 303 K

Maximum C.O.P.

From steam tables, we find that the saturation temperature of steam at a pressure of 2 bar is

T_G = 120.2° C = 120.2 + 273 = 393.2 K

We know that maximum C.O.P.

$$= \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right) = \left(\frac{268}{303 - 268}\right)\left(\frac{393.2 - 303}{393.2}\right) = 1.756 \textbf{ Ans.}$$

Mass of steam required per hour

We know that actual C.O.P.

= 70% of maximum C.O.P. = 0.7 × 1.756 =

1.229 ∴Actual heat supplied

$$= \frac{\text{Refrigeration load}}{\text{Actual C.O.P.}} = \frac{20 \times 210}{1.229} = 3417.4 \text{ kJ/min}$$

Assuming that only latent heat of steam is used for heating purposes, therefore from steam tables, the latent heat of steam at 2 bar is

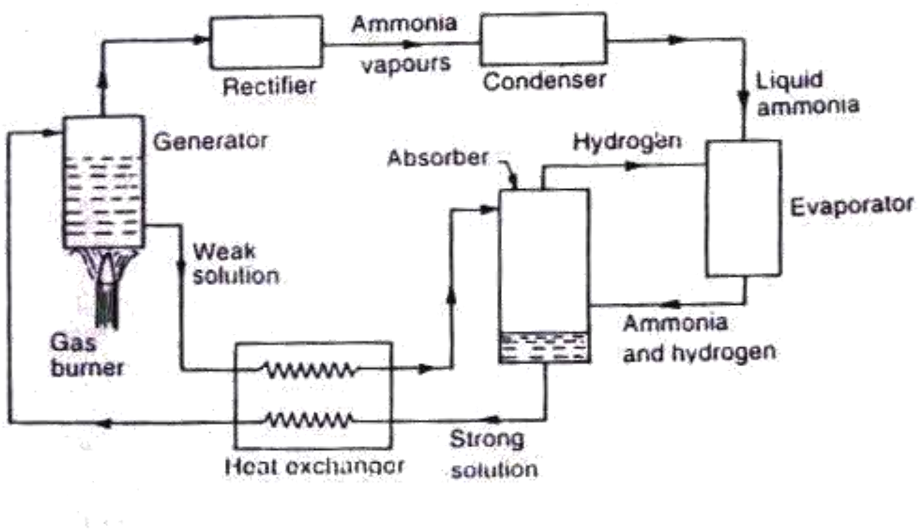
h_{fg} = 2201.6 kJ/kg

∴ Mass of steam required per hour

$$= \frac{\text{Actual heat supplied}}{x \times h_{fg}} = \frac{3417.4}{2201.6} = 1.552 \text{ kg/min} = 93.12 \text{ kg/h } \textbf{Ans.}$$

Domestic Electrolux (Ammonia Hydrogen) Refrigerator

The domestic absorption type refrigerator was invented by two Swedish engineers Carl Munters and Baltzer Von Platan in 1925 while they were studying for their under-graduate course of Royal Institute of Technology in Stockholm. The idea was first developed by the ‘Electrolux Company’ of Luton, England.



. Domestic electrolux type refrigerator.

This type of refrigerator is also called three-fluids absorption system. The main purpose of this system is to eliminate the pump so that in the absence of moving parts. the machine becomes noise-less. The three fluids used in this sytem are ammonia, hydrogen and water. The ammonia is used as a refrigerant because it possesses most of the desirable properties. It is toxic. but due to absence of moving parts, there is very little changes for the leakage and the total amount of refrigeration used is small. The hydrogen being the lightest gas. is used to increase the rate of evaporation of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. This is used in the low-pressure side of the system. The water is used as a solvent because it has the ability to absorb ammonia readily. The principle of operation of a domestic electolux type refrigerator. as shown in Fig. 3.3. is discussed below:

The strong ammonia solution from the absorber through heat exchanger is heated in the generator by applying heat from an external source usually a gas burner. During this heating process, ammonia vapours are removed from the solution

and passed to the condenser. A rectifirer or a water separator fitted before the condenser removes water vapour carried with the ammonia vapours, so that dry ammonia vapours are supplied to the condenser. These water vapours, if not removed, they will enter into the evaporator causing freezing and choking of the machine . The hot weak solution left behind in the generator flow to the absorber through the heat excl anger. This hot weak solution while passing through the exchanger is cooled. The heat removed by the weak solution is utilised in raising the temperature of strong solution passing through the heat exchanger. In this way, the absorption is accelerated and the improvement in the performance of a plant is achieved.

The ammonia vapours in the condenser are condensed by using external cooling source. The liquid refrigerant leaving the condenser flows under gravity to the evaporator where it meets the hydrogen gas. The hydrogen gas which is being fed to the evaporator permit the liquid ammonia to evaporate at a low pressure and temperature according to Dalton's principle. During the process of evaporation, the ammonia absorbs latent heat from the refrigerated space and thus produces cooling effect.

The mixture of ammonia vapour and hydrogen is passed to the absorber where ammonia is absorbed in water while the hydrogen rises to the top and flows hack to the evaporator. This completes the cycle. The coefficient of performance of this refrigerator is given by :

$$\text{C.O.P.} = \frac{\text{Heat absorbed in the evaporator}}{\text{Heat supplied in the generator}}$$

Notes: 1. The hydrogen gas only circulates from the absorber to the evaporator and back.

2. The whole cycle is carried out entirely by gravity flow of the refrigerant.

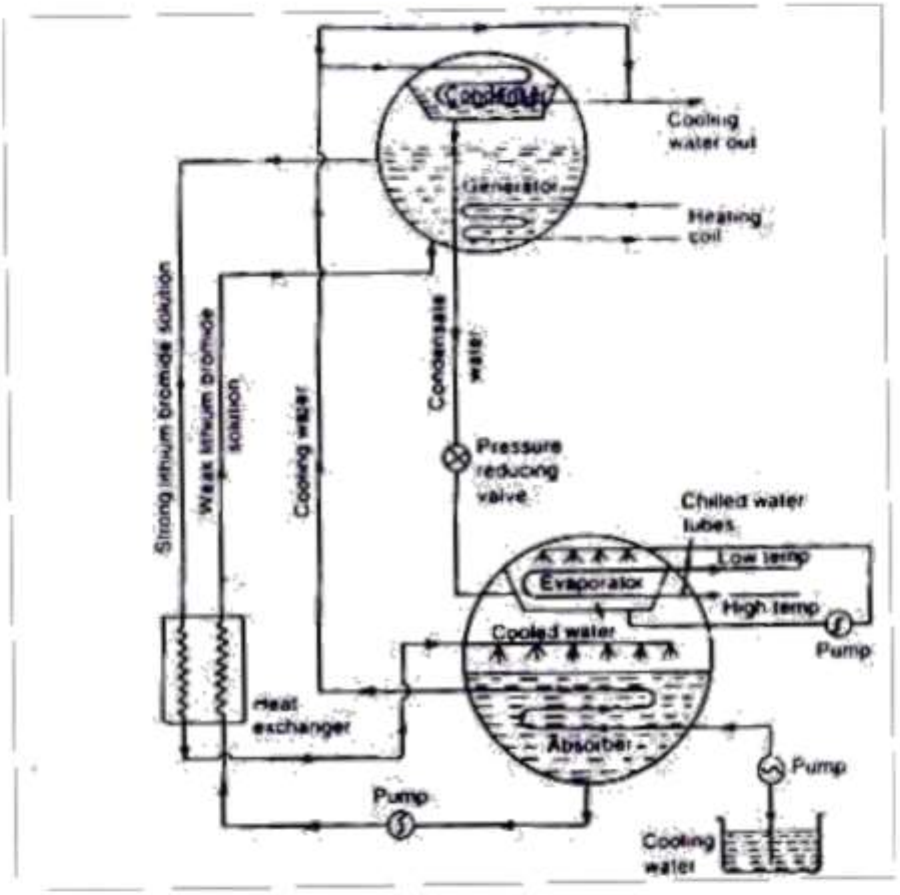
3. It can not be used for industrial purposes as the C.O.P. of the system is very low.

Lithium Bromide Absorption Refrigeration System

The lithium-bromide absorption refrigeration system uses a solution of lithium bromide in water. In this system, the *water is being used as a refrigerant whereas lithium bromide, which is a highly hydroscopic salt, as an absorbent. The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure. Since lithium bromide solution is corrosive, therefore inhibitors should be added in order to protect the metal parts of the system against corrosion. Lithium chromate is often used as a corrosion inhibitor. This system is very popular for air conditioning in which low refrigeration temperatures (not below 0° C)** are required.

Fig. 3.4 shows a lithium bromide vapour absorption system. In this system. the absorber and the evaporator are placed in one shell which operates at the same low pressure of the system. The generator and condenser are placed in another shell which operates at the same high pressure of the system. The principle of operation of this system is discussed below :

The water for air-conditioning coils or process requirements is chilled as it is pumped through the chilled-water tubes in.the evaporator by giving up heat to the refrigerant water sprayed over the tubes. Since the pressure inside the evaporator is maintained very low, therefore, the refrigerant waterevaporates. The water vapours thus formed will be absorbed by the strong lithium-bromide solution which is sprayed in the absorber. In absorbing the water vapour, the lithium bromide solution helps in maintaining very low pressure (high vacuum) needed in the evaporator, and the solution becomes weak. This weak solution is pumped by a pump to the generator where it is heated up by using steam or hot water in the heating coils. A portion of water is evaporated by the heat and the solution now becomes more strong. This strong solution is passed through the heat exchanger and then sprayed in the absorber as discussed above. The weak solution of lithium bromide from the absorber to the generator is also passed through the heat exchanger. This weak solution gets heat from the strong solution in the heat exchanger, thus reducing the quantity of steam required to heat the weak solution in the generator.

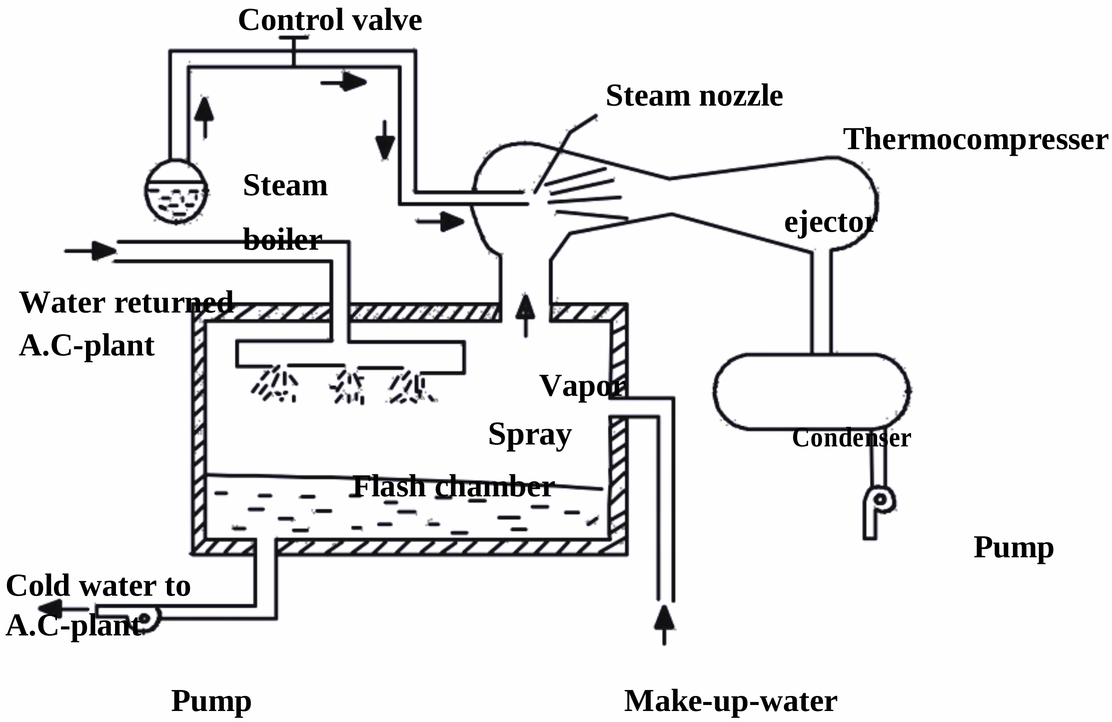


. Lithium-Bromide absorption refrigeration system.

The refrigerant water vapours formed in the generator due to heating of solution are passed to the condenser where they are cooled and condensed by the cooling water flowing through the condenser water tubes. The cooling water for condensing is pumped from the cooling water pond or tower. This cooling water first enters the absorber where it takes away the heat of condensation and dilution. The condensate from the condenser is supplied to the evaporator to compensate the water vapour formed in the evaporator. The pressure reducing valve reduces the pressure of condensate from the condenser pressure to the evaporator pressure. The cooled water from the evaporator is pumped and sprayed in the evaporator in order to cool the water for air conditioning flowing through the chilled tubes. This completes the cycle.

Note: The pressure difference between the generator and the absorber and the gravity due to the height difference of the two shells is utilised to create the pressure for the spray.

Steam Jet Refrigeration System:



Steam jet refrigeration system

This system uses the principle of boiling the water below 100^0C. If the pressure on the surface of the water is reduced below atmospheric pressure, water can be made boil at

low temperatures. Water boils at 6^0 whenC, the pressure on the surface is 5 cm of Hg and at 10^0 when the pressure is 6.5 cms of Hg. The very low pressure or high C,

vacuum on the surface of the water can be maintained by throttling the steam through jets or nozzles. The general arrangement of the system is shown in the Fig.6.8.

Consider a flash chamber contains 100 kg of water. If suddenly 1 kg of water is removed by boiling, as pressure is reduced due to throttling of steam through nozzles. Approximately 2385 kJ of heat will be removed from the water, which is equivalent to heat of evaporation of water. The fall in temperature of the remaining water will be

$$Q = m\,C_p dT$$

$$dT = \frac{2385}{99 * 4.187} = 5.7\ ^0C$$

Evaporating one more kg of water reduces the remaining water temperature by 5.7 ^{0}C further. Thus by continuing this process, the remaining water can be made to freeze. Water is the refrigerant used in the steam jet refrigeration system. As water freezes at 0 ^{0}C, then either refrigeration has to be stopped or some device is required to pump the ice.

Operation:

High pressure steam is supplied to the nozzle from the boiler and it is expanded. Here, the water vapor originated from the flash chamber is entrained with the high velocity steam jet and it is further compressed in the thermo compressor. The kinetic energy of the mixture is converted into static pressure and mass is discharged to the condenser. The condensate is usually returned to the boiler. Generally, 1% evaporation of water in the flash chamber is sufficient to decrease the temperature of chilled water to 6 ^{0} C. The chilled water in the flash chamber is circulated by a pump to the point of application. The warm water from the load is returned to the flash chamber. The water is sprayed through the nozzles to provide maximum surface area for cooling. The water, which is splashed in the chamber and any loss of cold water at the application, must be replaced by makeup water added to the cold water circulating system.

Advantages:

a) It is flexible in operation; cooling capacity can be easily and quickly changed.

b) It has no moving parts as such it is vibration free.

c) It can be installed out of doors.

d) The weight of the system per ton of refrigerating capacity is less.

e) The system is very reliable and maintenance cost is less.

f) The system is particularly adapted to the processing of cold water used in rubber mills,, distilleries, paper mills, food processing plants, etc.

g) This system is particularly used in air-conditioning installations, because of the complete safety of water as refrigerant and ability to adjust quickly to load variations and no hazard from the leakage of the refrigerant.

Disadvantages:

h) The use of direct evaporation to produce chilled water is usually limited as tremendous volume of vapor is to be handled.

i) About twice as much heat must be removed in the condenser of steam jet per ton of refrigeration compared with the vapor compression system.

j) The system is useful for comfort air-conditioning, but it is not practically feasible for water temperature below 40C *k)* Thermoelectric Refrigeration

l) Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials.

m) This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments.

n) Applying a DC voltage difference across the thermoelectric module, an electric current will pass through the module and heat will be absorbed from one side and released at the opposite side. One module face, therefore, will be cooled while the opposite face simultaneously is heated.

o) On the other hand, maintaining a temperature difference between the two junctions of the module, a voltage difference will be generated across the module and an electrical power is delivered.

p)

q) Thermoelectricity is based upon following basic principles:

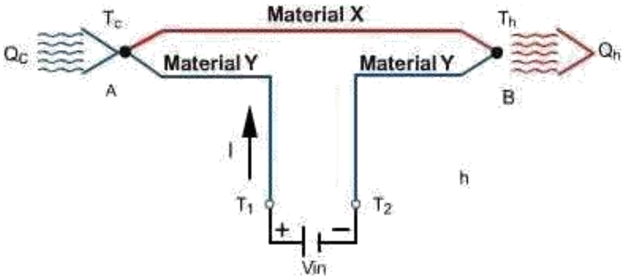
r) SEEBECK EFFECT

s) PELTIER EFFECT

t) THOMSON EFFECT

u) JOULE EFFECT

v) FOURIER EFFECT Peltier effect



When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction. The Peltier heat generated at the junction per unit time, Q , is equal to;

$$Q \alpha I \quad Q = \pi_{ab} I$$

$$\pi_{ab} = \pi_a - \pi_b$$

where (π_a & π_b) is the Peltier coefficient of conductor A & B, and I is the electric current (from A to B).

IV UNIT
Introduction to Air Conditioning

Atmospheric air makes up the environment in almost every type of air conditioning system. Hence a thorough understanding of the properties of atmospheric air and the ability to analyze various processes involving air is fundamental to air conditioning design.

Psychrometry is the study of the properties of mixtures of air and water vapour.

Atmospheric air is a mixture of many gases plus water vapour and a number of pollutants. The amount of water vapour and pollutants vary from place to place. The concentration of water vapour and pollutants decrease with altitude, and above an altitude of about 10 km, atmospheric air consists of only dry air. The pollutants have to be filtered out before processing the air. Hence, what we process is essentially a mixture of various gases that constitute air and water vapour. This mixture is known as moist air.

The moist air can be thought of as a mixture of dry air and moisture. For all practical purposes, the composition of dry air can be considered as constant. In 1949, a standard composition of dry air was fixed by the International Joint Committee on Psychrometric data. It is given in Table 4.1.

Constituent	Molecular weight	Mol fraction
Oxygen	32.000	0.2095
Nitrogen	28.016	0.7809
Argon	39.944	0.0093
Carbon dioxide	44.010	0.0003

***Table 4.1**: Composition of standard air*

Based on the above composition the molecular weight of dry air is found to be **28.966** and the gas constant R is **287.035 J/kg.K.**

As mentioned before the air to be processed in air conditioning systems is a mixture of dry air and water vapour. While the composition of dry air is constant, the amount of water vapour present in the air may vary from zero to a maximum depending upon the temperature and pressure of the mixture (dry air + water vapour).

At a given temperature and pressure the dry air can only hold a certain maximum amount of moisture. When the moisture content is maximum, then the air is known as saturated air, which is established by a neutral equilibrium between the moist air and the liquid or solid phases of water.

For calculation purposes, the molecular weight of water vapour is taken as **18.015** and its gas constant is **461.52 J/kg.K**.

Dry bulb temperature (DBT) is the temperature of the moist air as measured by a standard thermometer or other temperature measuring instruments.

Saturated vapour pressure (p_{sat}) is the saturated partial pressure of water vapour at the dry bulb temperature. This is readily available in thermodynamic tables and charts. ASHRAE suggests the following regression equation for saturated vapour pressure of water, which is valid for 0 to 100^{o}C.

Relative humidity is defined as the ratio of the mole fraction of water vapour in moist air to mole fraction of water vapour in saturated air at the same temperature and pressure.

Relative humidity is normally expressed as a percentage. When is 100 percent, the air is saturated.

Humidity ratio (W): The humidity ratio (or specific humidity) W is the mass of water associated with each kilogram of dry air[1]. Assuming both water vapour and dry air to be perfect gases[2].

For a given barometric pressure p_t, given the DBT, we can find the saturated vapour pressure p_{sat} from the thermodynamic property tables on steam. Then using the above equation, we can find the humidity ratio at saturated conditions, W_{sat}.

It is to be noted that, W is a function of both total barometric pressure and vapor pressure of water.

Dew-point temperature: If unsaturated moist air is cooled at constant pressure, then the temperature at which the moisture in the air begins to condense is known as *dew-point temperature (DPT)* of air. An approximate equation for dew-point temperature is given by:

Degree of saturation : The degree of saturation is the ratio of the humidity ratio W to the humidity ratio of a saturated mixture W_s at the same temperature and pressure,

Enthalpy: The enthalpy of moist air is the sum of the enthalpy of the dry air and the enthalpy of the water vapour. Enthalpy values are always based on some reference value. For moist air, the enthalpy of dry air is given a zero value at 0^{o}C, and for water vapour the enthalpy of saturated water is taken as zero at 0^{o}C.

Since the second term in the above equation ($w.c_{pw}$) is very small compared to the first term, for all practical purposes, the humid specific heat of moist air, c_{pm} can be taken as 1.0216 kJ/kg dry air.K

Specific volume: The specific volume is defined as the number of cubic meters of moist air pe kilogram of dry air. From perfect gas equation since the volumes occupied by the individual substance are the same, the specific volume is also equal to the number of cubic meters of dry air per kilogram o dry air

Psychrometric chart

A Psychometric chart graphically represents the thermodynamic properties of moist air. Standard psychometric charts are bounded by the dry-bulb temperature line (abscissa) and the vapour pressure or humidity ratio (ordinate). The Left Hand Side of the psychometric chart is bounded by the saturation line. Figure 27.2 shows the schematic of a psychometric chart. Psychometric charts are readily available for standard barometric pressure of 101.325 kPa at sea level and for normal temperatures (0-50^{O}C). ASHRAE has also developed psychometric charts for other temperatures and barometric pressures (for low temperatures: -40 to 10^{O}C, high temperatures 10 to 120^{O}C and very high temperatures 100 to 120^{O}C)

Measurement of psychrometric properties:

Based on Gibbs' phase rule, the thermodynamic state of moist air is uniquely fixed if the barometric pressure and two other independent properties are known. This means that at a given barometric pressure, the state of moist air can be determined by measuring any two independent properties. One of them could be the dry-bulb temperature (DBT), as the measurement of this temperature is fairly simple and accurate. The accurate measurement of other independent parameters such as humidity ratio is very difficult in practice. Since measurement of temperatures is easier, it would be convenient if the other independent parameter is also a temperature. Of course, this could be the dew-point temperature (DPT), but it is observed that accurate measurement of dew-point temperature is difficult. In this context, a new independent temperature parameter called the *wet-bulb temperature* (WBT) is defined. Compared to DPT, it is easier to measure the wet-bulb temperature of moist air. Thus knowing the dry-bulb and wet-bulb temperatures from measurements, it is possible to find the other properties of moist air.

To understand the concept of wet-bulb temperature, it is essential to understand the process of combined heat and mass transfer.

Combined heat and mass transfer; the straight line law

The straight line law states that "when air is transferring heat and mass (water) to or from a wetted surface, the condition of air shown on a psychrometric chart drives towards the saturation line at the temperature of the wetted surface".

when warm air passes over a wetted surface its temperature drops from 1 to 2. Also, since the vapor pressure of air at 1 is greater than the saturated vapor pressure at t_w, there will be moisture transfer from air to water, i.e., the warm air in contact with cold wetted surface cools and dehumidifies. According to the straight line law, the final condition of air (i.e., 2) lies on a straight line joining 1 with t_w on the saturation line. This is due to the value of unity of the Lewis number, that was discussed in an earlier chapter on analogy between heat and mass transfer.

Adiabatic saturation and thermodynamic wet bulb temperature:

Adiabatic saturation temperature is defined as that temperature at which water, by evaporating into air, can bring the air to saturation at the same temperature adiabatically. An adiabatic saturator is a device using which one can measure theoretically the adiabatic saturation temperature of air.

An adiabatic saturator is a device in which air flows through an infinitely long duct containing water. As the air comes in contact with water in the duct, there will be heat and mass transfer between water and air. If the duct is infinitely long, then at the exit, there would exist perfect equilibrium between air and water at steady state. Air at the exit would be fully saturated and its temperature is equal to that of water temperature. The device is adiabatic as the walls of the chamber are thermally insulated. In order to continue the process, make- up water has to be provided to compensate for the amount of water evaporated into the air. The temperature of the make-up water is controlled so that it is the same as that in the duct.

After the adiabatic saturator has achieved a steady-state condition, the temperature indicated by the thermometer immersed in the water is the *thermodynamic wet-bulb temperature*. The thermodynamic wet bulb temperature will be less than the entering air DBT but greater than the dew point temperature.

Certain combinations of air conditions will result in a given sump temperature, and this can be defined by writing the energy balance equation for the adiabatic saturator. Based on a unit mass flow rate of dry air,

It is to be observed that the thermodynamic wet-bulb temperature is a thermodynamic property, and is independent of the path taken by air. Assuming the humid specific heat to be constant, from the enthalpy balance, the thermodynamic wet-bulb temperature.

On the psychrometric chart as shown in Fig.27.4, point 1 lies below the line of constant enthalpy that passes through the saturation point 2. $t_2 = f(t_1,W_1)$ is not a unique function, in the sense that there can be several combinations of t_1 and W_1 which can result in the same sump temperature in the adiabatic saturator. A line passing through all these points is a constant wet bulb temperature line. Thus all inlet conditions that result in the same sump temperature, for example point 1' have the same wet bulb temperature. The line is a straight line according to the straight- line law. The straight-line joining 1 and 2 represents the path of the air as it passes through the adiabatic saturator.

Normally lines of constant wet bulb temperature are shown on the psychrometric chart. The difference between actual enthalpy and the enthalpy obtained by following constant wet-bulb temperature is equal to $(w_2-w_1)h_f$.

Sensible and latent heat loads

The *design cooling load* (or *heat gain*) is the amount of heat energy to be removed from a house by the HVAC equipment to maintain the house at indoor design temperature when worst case outdoor design temperature is being experienced.

There are two types of cooling loads:

- sensible cooling load
- latent cooling load

The sensible cooling load refers to the dry bulb temperature of the building and the latent cooling load refers to the wet bulb temperature of the building.

For summer conditions the humidity influence on the selection of the HVAC equipment and the latent load as well as the sensible load must be calculated.

- Cooling and Heating Equations

Factors that influence sensible cooling load

- Glass windows or doors
- Sunlight striking windows, skylights, or glass doors and heating the room
- Exterior walls
- Partitions (that separate spaces of different temperatures)
- Ceilings under an attic
- Roofs
- Floors over an open crawl space

- Air infiltration through cracks in the building, doors, and windows
- People in the building
- Equipment and appliances operated in the summer
- Lights

Notice that below grade walls, below grade floors, and floors on concrete slabs do not increase the cooling load on the structure and are therefore ignored.

Other sensible heat gains are taken care of by the HVAC equipment before the air reaches the rooms (system gains). Two items that may require additional sensible cooling capacity from the HVAC equipment are

- duct work located in an unconditioned space
- ventilation air (air that is mechanically introduced into the building)

Sensible Heat Load and Required Air Volume Chart

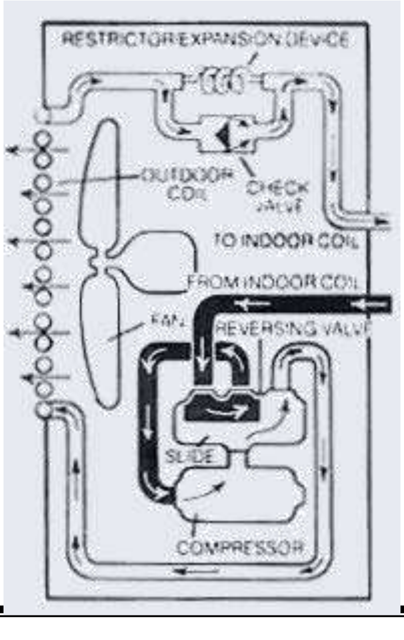
- sensible heat load equations

Sensible heat load - heating or cooling - and required air volume to keep temperature constant at various temperature differences between entering air and room air are indicated in the chart below:

COOLING CYCLE

Refrigerant passes through the indoor coil, evaporating from a liquid to a vapor. As the liquid evaporates, it absorbs heat, cooling the air around the coil. An indoor fan pushes this cooled air through ducts inside the house. Meanwhile, the vaporized refrigerant laden with heat, passes through a compressor which compresses the vapor, raising it’s temperature and pressure. The reversing valve directs the flow of hot, high pressure vapor to the outdoor coil where the heat released during condensation is fanned into the outdoor air, and the cycle begins again.

HEATING CYCLE



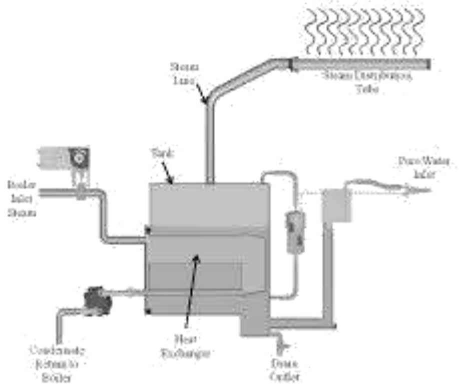
During the heating cycle the refrigerant flows in reverse. Liquid refrigerant now flows to the outdoor coil picking up heat as it evaporates into a low pressure vapor.

The vapor travels through the compressor where it is compressed into a hot, high pressure vapor, then is directed by the reversing valve to the indoor coil.

Then vapor turns into liquid as it passes through the indoor coil, releasing heat that is pushed through the ducts by the indoor fan.

Humidification

A humidifier is a device that increases humidity (moisture) in a single room or an entire building. In the home, point-of-use humidifiers are commonly used to humidify a single room, while whole-house or furnace humidifiers, which connect to a home's HVAC system, provide humidity to the entire house. Medical ventilators often include humidifiers for increased patient comfort. Large humidifiers are used in commercial, institutional, or industrial contexts, often as part of a larger HVAC system.



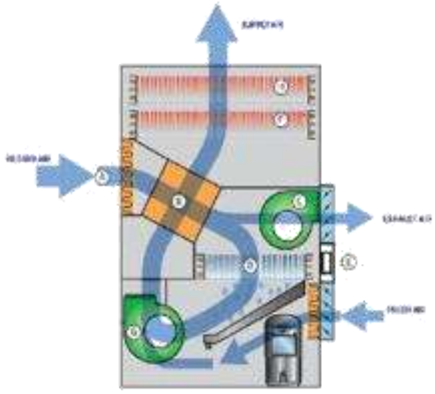
Industrial humidifiers are used when a specific humidity level must be maintained to prevent static electricity buildup, preserve material properties, and ensure a comfortable and healthy environment for workers or residents.

Static problems are prevalent in industries such as packaging, printing, paper, plastics, textiles, electronics, automotive manufacturing and pharmaceuticals. Friction can produce static buildup and sparks when humidity is below 45% relative humidity (RH). Between 45% and 55% RH, static builds up at reduced levels, while humidity above 55% RH ensures that static will never build up. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has traditionally recommended a range of 45–55% RH in data centers to prevent sparks that can damage IT equipment.[8]Humidifiers are also used by manufacturers of semiconductors and in hospital operating rooms.

Printers and paper manufacturers use humidifiers to prevent shrinkage and paper curl. Humidifiers are needed in cold storage rooms to preserve the freshness of food against the dryness caused by cold temperatures. Art museums use humidifiers to protect sensitive works of art, especially in exhibition galleries, where they combat the dryness caused by heating for the comfort of visitors during winter.

Dehumidification

A **dehumidifier** is an electrical appliance which reduces and maintains the level of humidity in the air, usually for health or comfort reasons, or to eliminate musty odor and to prevent the growth of mildew by extracting water from the air. It can be used for household, commercial, or industrial applications. Large dehumidifiers are used in commercial buildings such as indoor ice rinks and swimming pools, as well as manufacturing plants or storage warehouses.



Electric refrigeration dehumidifiers are the most common type of dehumidifiers. They work by drawing moist air over a refrigerated evaporator with a fan. There are 3 main types of evaporators. They are coiled tube, fin and tube, and microchannel technology.

The cold evaporator coil of the refrigeration device condenses the water, which is removed, and then the air is reheated by the condenser coil. The now dehumidified, re-warmed air is released into the room. This process works most effectively at higher ambient temperatures with a high dew point temperature. In cold climates, the process is less effective. Highest efficiency is reached above 20 °C (68 °F) and 45% relative humidity. This relative humidity value is higher if the temperature of the air is lower[citation needed].

This type of dehumidifier differs from a standard air conditioner in that both the evaporator and the condenser are placed in the same air path. A standard air conditioner transfers heat energy out of the room because its condenser coil releases heat outside. However, since all components of the dehumidifier are in the same room, no heat energy is removed. Instead, the electric power consumed by the dehumidifier remains in the room as heat, so the room is actually heated, just as by an electric heater that draws the same amount of power.

In addition, if water is condensed in the room, the amount of heat previously needed to evaporate that water also is re-released in the room (the latent heat of vaporization). The dehumidification process is the inverse of adding water to the room with an evaporative cooler, and instead releases heat. Therefore, an in-room dehumidifier will always warm the room and reduce the relative humidity indirectly, as well as reducing the humidity more directly, by condensing and removing water.

Air Conditioning Filter

Air conditioning filter in the house or offices is used to remove solid contaminants such as smoke, pollen, dust, grease and pollen to ensure better air quality for the occupants. A study showed that indoor pollution is common these days due to the chemicals that are used in household furnishings and various goods.

These filters are usually placed on the return air of the air conditioning system. The air that contained the contaminants are trapped here. Clean air is then discharged into the space together with the cool air.

Types of Air Conditioning Filter

Plastic mesh filters are commonly installed at the return air of most indoor unit of room or window air conditioner. They trapped bigger particles of dust and should be cleaned every two weeks and more frequent if the space being conditioned is polluted.

If you look at the manual, they are easy to take out from the unit. Wash thoroughly with water and household dish washing detergent to remove dirt that stuck to it. Leave to dry and put back.

Electrostatic air filters are commonly placed in the return air of the air conditioner unit where the air is subjected to high voltage up to 12kV between two plates. The ionized particles are then drawn to the grounded plates. The electronic circuit used to generate the voltage is usually embedded on the control printed circuit board or a separate module.

Carbon and Adhesive filters are other types used. Carbon type is made of activated carbon that is effective in removing odour causing gases and bacteria. Adhesive type is made of cotton and fiber glass material coated with adhesive oil or liquid which trapped the particles.

Grills:

Primarily, the damper allows for the amount of hot or cool **air** into a room to be controlled, providing for more accurate control over room temperature. Dampers also allow for **air** to be shut off in unused rooms, improving the efficiency of the**HVAC** system. Dampers can also help adjust a **HVAC** system for seasonal **use**.

Fans and blowers:

We have learned in Air Conditioner Parts that fans function as **air movers**. This equipment will enable forced convection to occur, thus improving the heat transfer rate.

In addition to that, it makes compact design of evaporator and condenser, possible. Depending on natural convection would otherwise mean very large evaporator and condenser design. Not only that, you'll have to wait almost forever before cool air reaches you.

Therefore, function of air conditioner fans and blowers is not negligible thing. Not now, not forever.

Blowers have the exact same function as a fan. Only the construction is different. Fans are normally used at condensing units, while blowers are used for evaporation units.