# DIGITAL NOTES

## REFRIGERATION AND AIR CONDITIONING
**(R15A0324)**

## B.Tech III Year II Semester

**DEPARTMENT OF MECHANICAL ENGINEERING**


# MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

**(An Autonomous Institution – UGC, Govt.of India)**

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# MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

## (R15A0324) REFRIGERATION AND AIR CONDITIONING

**COURSE OBJECTIVES:**

- The objective of this subject is to provide knowledge about different cycles
- Student able to learn about refrigeration and air conditioning.
- Student able to learn about deferent air conditioning equipments.

**UNIT–I**

**Introduction to Refrigeration:** Necessity and applications – Unit of refrigeration and C.O.P. – Types of Ideal cycles of refrigeration.

**Air Refrigeration:** Bell Coleman cycle and reversed carnot Cycle, Open and Dense air systems – Actual air refrigeration system problems.

**Principles of Evaporators, Expansion devices , compressors and condensers**

**Refrigerants** – Desirable properties – classification refrigerants used – Nomenclature – Ozone Depletion– Global Warming.

**UNIT–II**

**Vapour compression refrigeration**: working principle and essential components of the plant – simple Vapour compression refrigeration cycle – COP – Representation of cycle on T-S and p-h charts – effect of sub cooling and super heating – cycle analysis – Actual cycle Influence of various parameters on system performance – Use of p-h charts – numerical Problems.

**UNIT-III**

**Vapor Absorption System** – Calculation of max COP – description and working of NH3 – water system and Li Br – water ( Two shell & Four shell) System. Principle of operation Three Fluid absorption system, salient features.

**Steam Jet Refrigeration System** – Working Principle and Basic Components. Principle and operation of (i) Thermoelectric refrigerator (ii) Vortex tube or Hilsch tube refrigerator.

**UNIT–IV**

**Introduction to Air Conditioning:** Psychometric Properties & Processes – Characterization of Sensible and latent heat loads –– Need for Ventilation, Consideration of Infiltration – Load concepts of RSHF, GSHF- Problems, Concept of ESHF and ADP.

**UNIT-V**

**Requirements of human comfort and concept of effective temperature**- Comfort chart –Comfort Air conditioning – Requirements of Industrial air conditioning , Air conditioning Load Calculations.

**Air Conditioning systems** - Classification of equipment, cooling, heating humidification and dehumidification, filters, grills and registers, fans and blowers. Heat Pump – Heat sources – different heat pump circuits.

**COURSE OUTCOMES:**

- It will give learners a basic - but solid - understanding of the fundamentals of refrigeration.
- The main system types and components, the range of applications, including air conditioning and heat pumps.
- The use of controls, and the key provisions and impact of recent legislation on the sector.

1. Refrigeration and Air Conditioning / R.S. Khurmi & J.K Gupta / S.Chand – Eurasia Publishing House (P) Ltd
2. Refrigeration and Air Conditioning / CP Arora / TMH Publishers
3. A Course in Refrigeration and Air conditioning / SC Arora & Domkundwar / Dhanpatrai Publications

**REFERENCE BOOKS:**

1. Refrigeration and Air Conditioning/ P.L.Bellaney/Khanna Publishers
2. Basic Refrigeration and Air-Conditioning / Ananthanarayanan / TMH Publishers
3. Refrigeration and Air Conditioning / Manohar Prasad / New Age International Publ.

# CONTENTS

# 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.

$$=\frac{1000\times335}{24\times60} = 232.6kJ/min$$

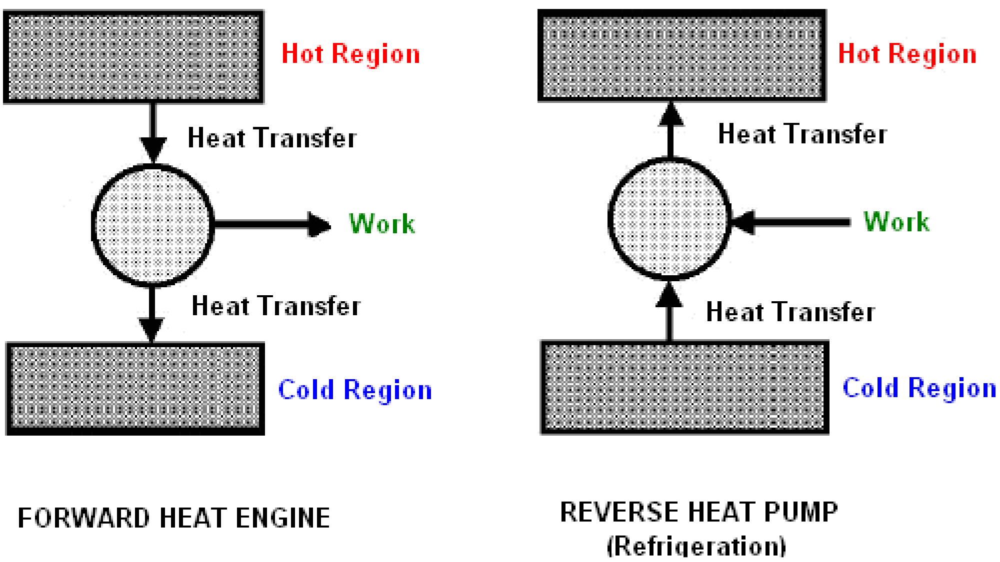
In actual practice one tone of refrigeration is taken as equivalent to 210kJ/min or 3.5kW (i.e 3.5kJ/s).

**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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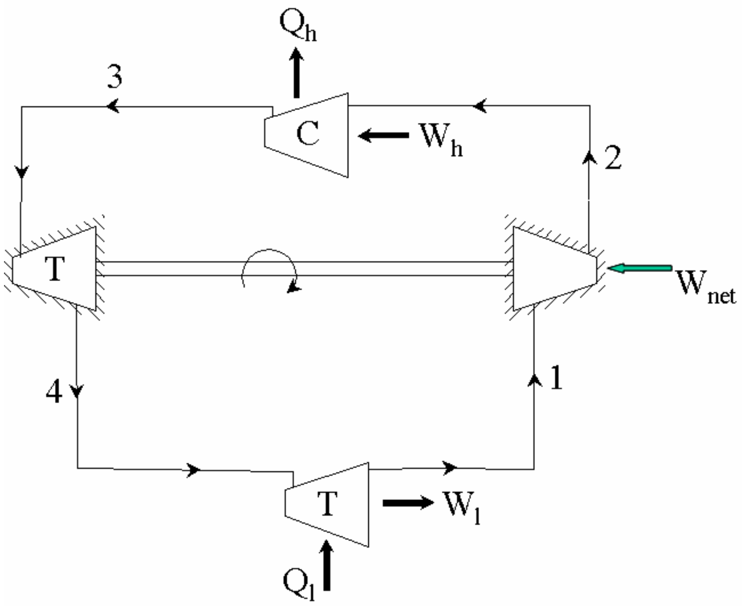
## Reversed Carnot cycle employing a gas

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

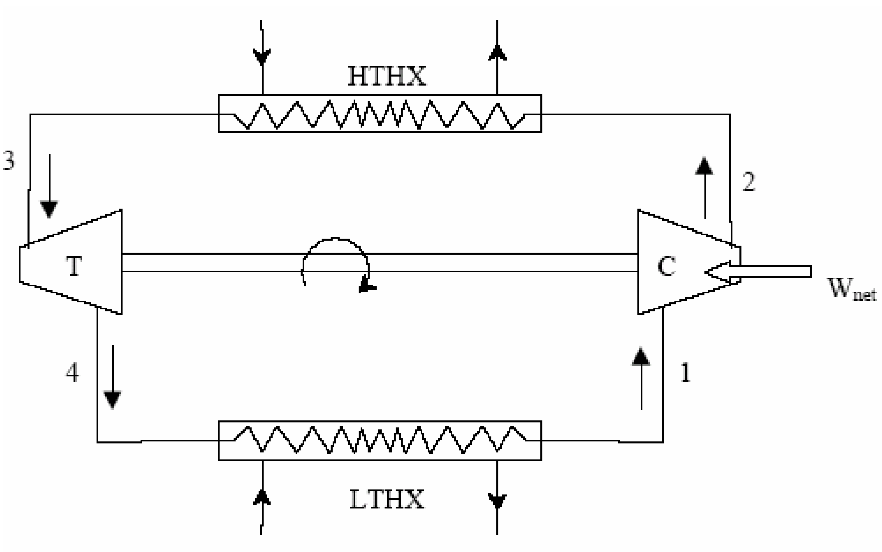


*Schematic of a reverse Carnot refrigeration system*

## 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.

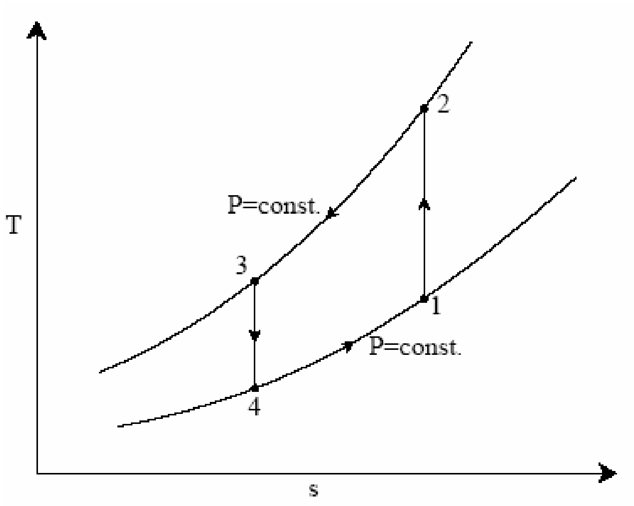
# Bell-coleman cycle




*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



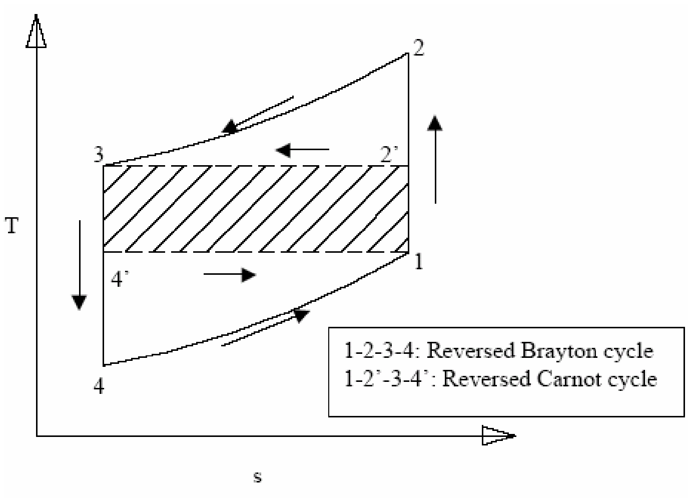

*Reverse Brayton cycle in T-s plane*

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:



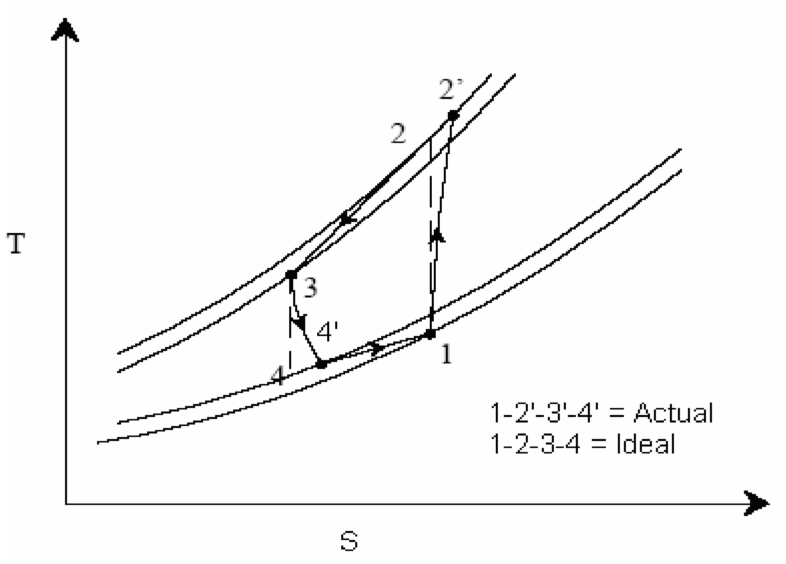

*Comparison of reverse Carnot and reverse Brayton cycle in T-s plane*

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 $0^oC$, 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 ($NH_3$), carbon dioxide ($CO_2$) and sulphur dioxide ($SO_2$). 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

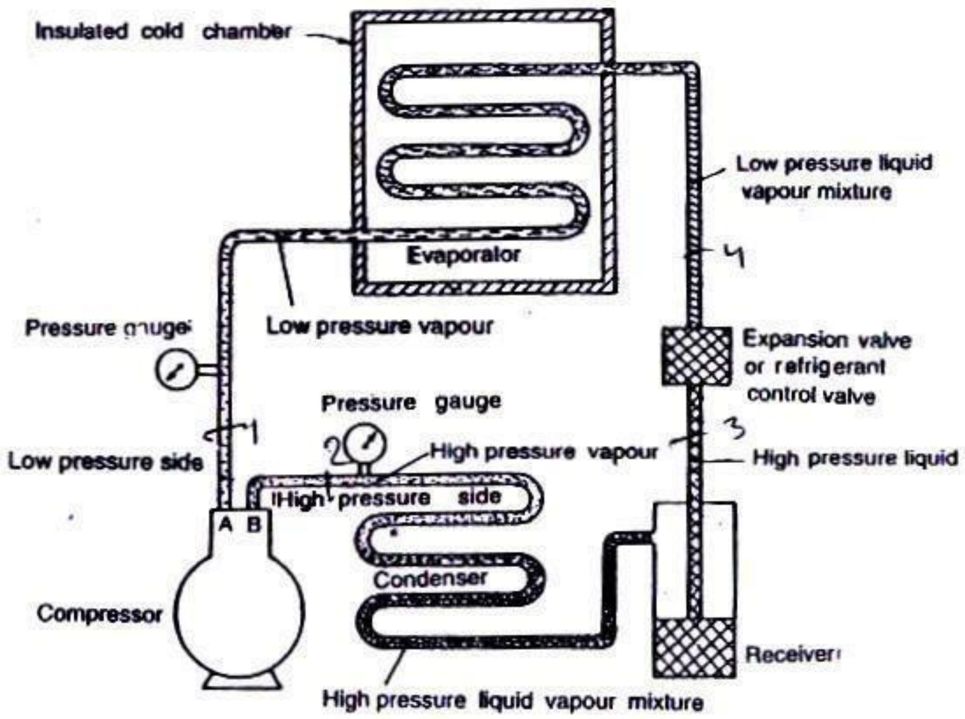



Fig. 2.1 shows the achematic diagram of a simple vapour compression refrigeration system. It consists of the following five essential parts :

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.

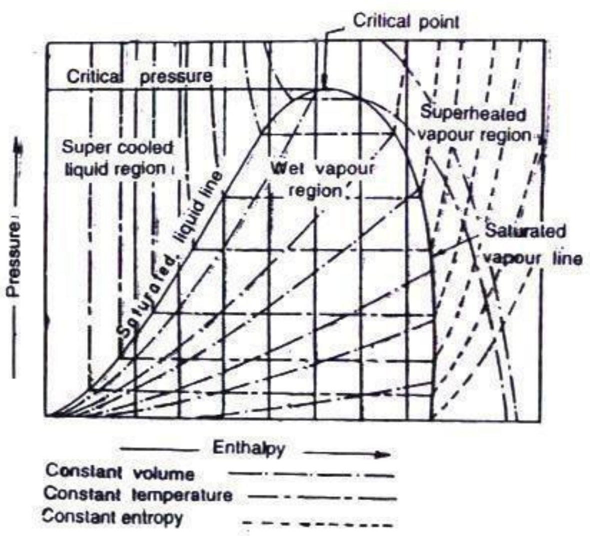
3. *Receiver*. The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

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

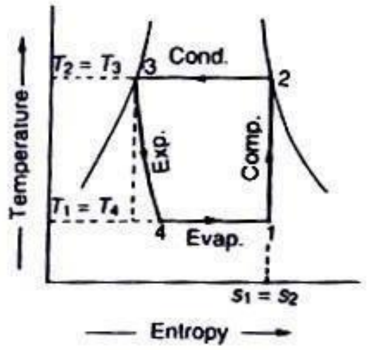
We have already discussed that vapour compression cycle essentially consists of compression, condensation, throttling and evaporation. Many scientists have focussed their attention to increase the coefficient of performance of the cycle. Through there are many cycles, yet the following are important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

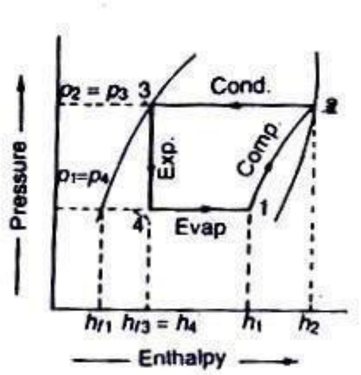
Now we shall discuss all the above mentioned cycles, one by one, in the following pages.

### 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,

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

∴ Heat extracted from the evaporator or refrigerating effect,

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

We know that work done during compression,

w = 150 kJ/kg

$\therefore$ 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

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

**Example.** The temperature limits of an ammonia refrigerating system are $25^oC$ and $-10^o$ 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 ($^oC$)* | *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 : $T_2 = T_3 = 25^o$ C = 25 + 273 = 298 K ; $T_1 = T_4 = -10^oC$ = 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.

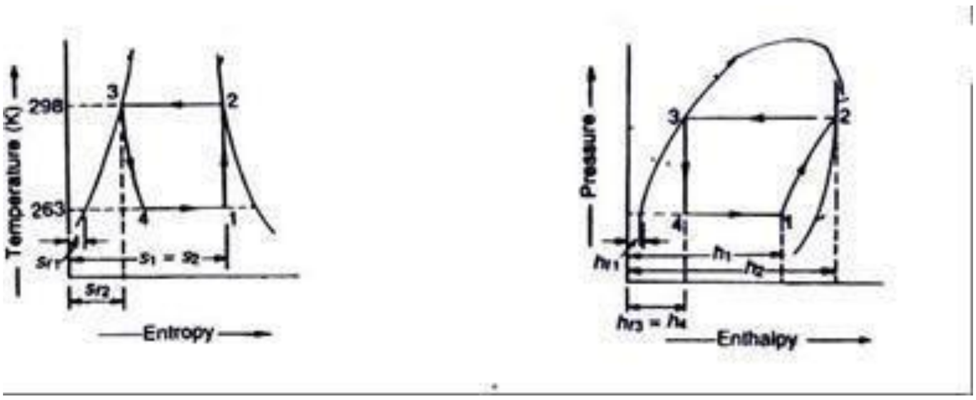
$$s_1 = s_{f1} + \frac{x_1 h_{fg1}}{T_1} = 0.5443 + \frac{x \times 1297.68}{263}$$

$= 0.5443 + 4.934\ x_1$

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,

$h_1 = hf_1 + x_1\ h_{fg1} = 135.37 + 0.91 \times 1297.68 = 1316.26$

kJ/kg and enthalpy at point 2,

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

$\therefore$ Coefficient of performance of the cycle

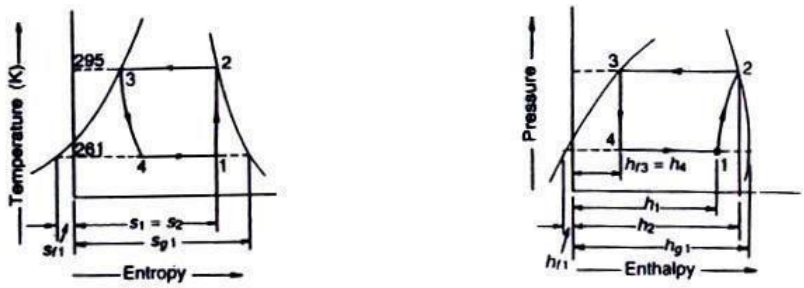
$$= \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{1316.26 - 298.9}{1465.84 - 1316.26} = 6.8 \textbf{ Ans.}$$

**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,

$$s_1 = s_{f1} + x_1 s_{fg1} = s_{f1} + x_1 \left(s_{g1} s_{f1}\right) \qquad \ldots(\because s_{g1} = s_{f1} + s_{fg1})$$

$= 0.226 + x_1 (1.2464 - 0.226) = 0.226 + 1.0204\, x_1$ ... (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 $x_1 = 0.791$

we know that enthalpy at point 1,

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

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

$\therefore$ 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

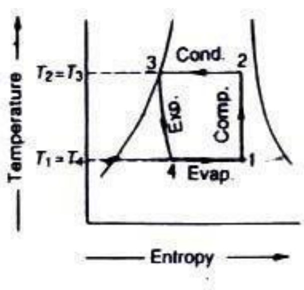
Since the fluid flow is at the rate of 5 kg/min, therefore total heat extracted

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

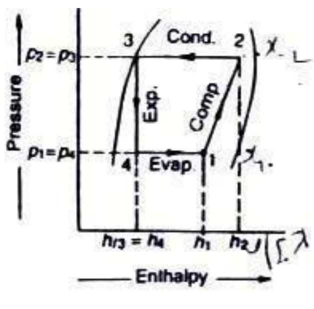
$\therefore$ Capacity of the refrigerator

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

## 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

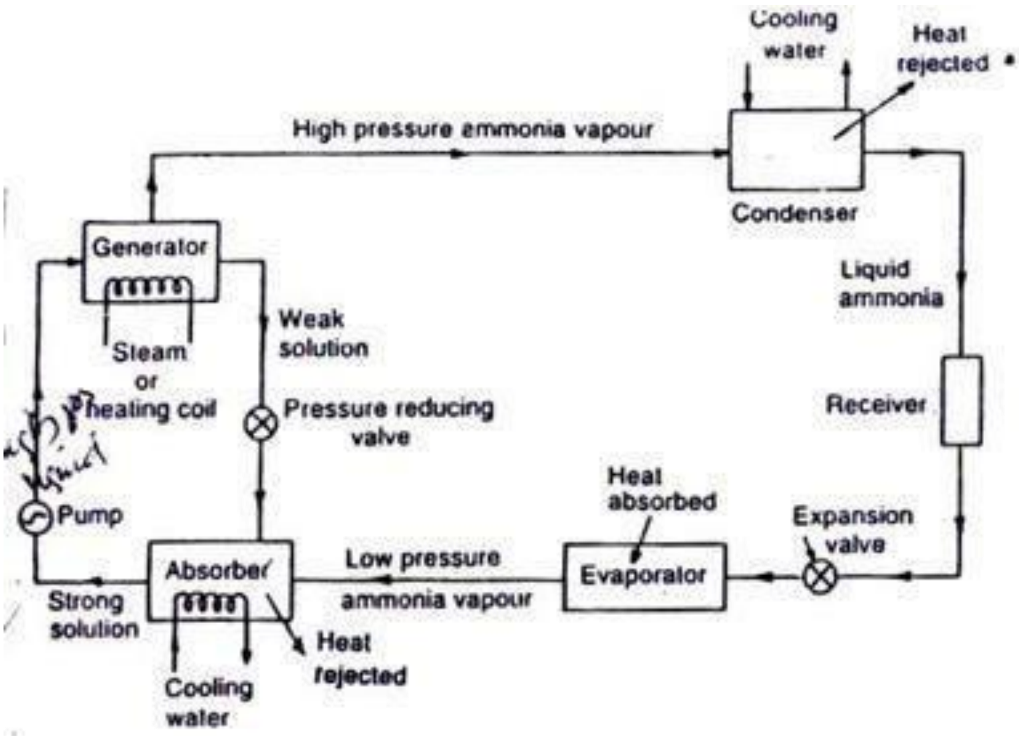
The vapour absorption refrigeration system is one of the oldest method of producing refrigerating effect. The principle of vapour absorption was first discovered by Michael Faraday in 1824 while performing a set of experiments to liquify certain gases. The first vapour absorption refrigeration machine 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.



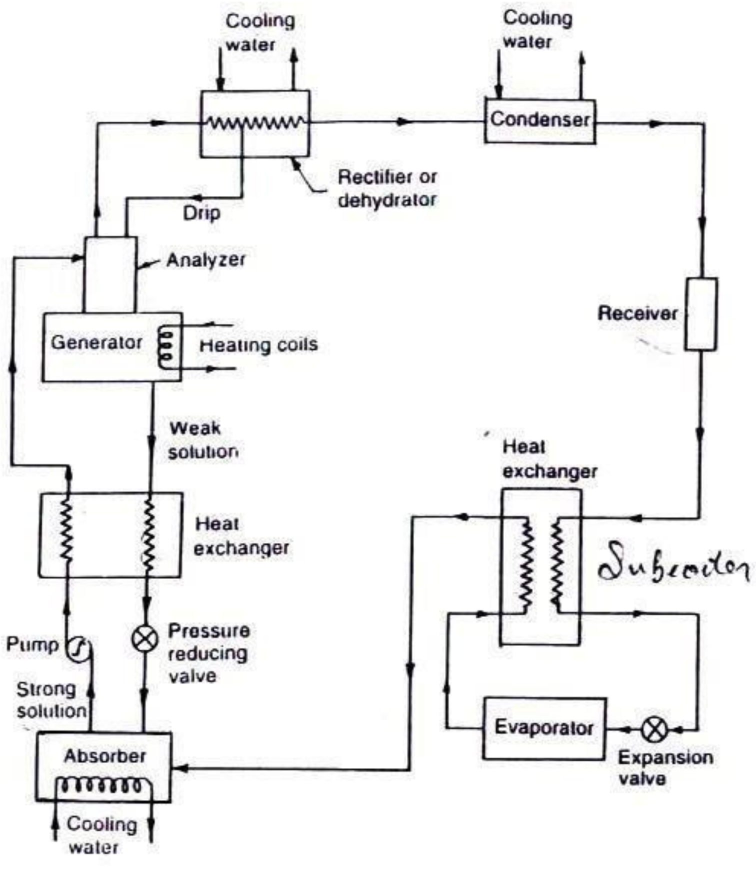

Simple vapour absorbtion system

. 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,

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

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.

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

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

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

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

$$Q_G = Q_E\left[\frac{T_E - T_C}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_C - T_G}\right]$$

$$= Q_E\left[\frac{T_C - T_E}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_G - T_C}\right]$$

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

Maximum coefficient of performance of the system is given by

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

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

It may noted that,

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

2. The expression $\left(\dfrac{T_G - T_C}{T_G}\right)$ is the efficiency of a Carnot engine 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° C, 20° C and _5° C respectively. Find the maximum C.O.P. of the system.

**Solution.** Given: TG = 100°C = 100 + 273 = 373 K ; Tc = 20°C = 20 + 273 = 293 K ; T E = - 5° C = - 5 + 273 = 268 K

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.

$$= \left[\frac{T_E}{T_C - T_E}\right]\left[\frac{T_G - T_C}{T_G}\right] = \left[\frac{268}{303 - 268}\right]\left[\frac{393 - 303}{393.2}\right] = 1.756 \textbf{ Ans.}$$

*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

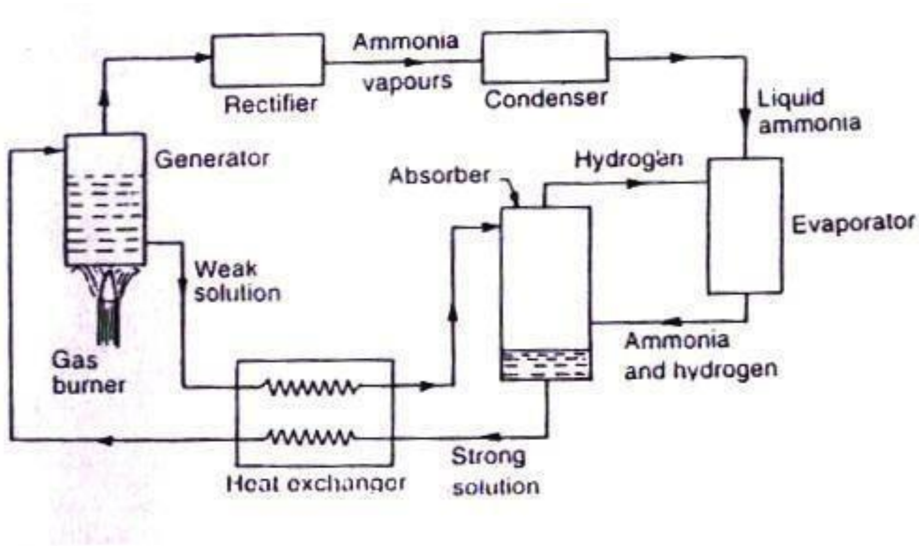
$h_{fg}$ = 2201.6 kJ/kg

∴ 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, f 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.

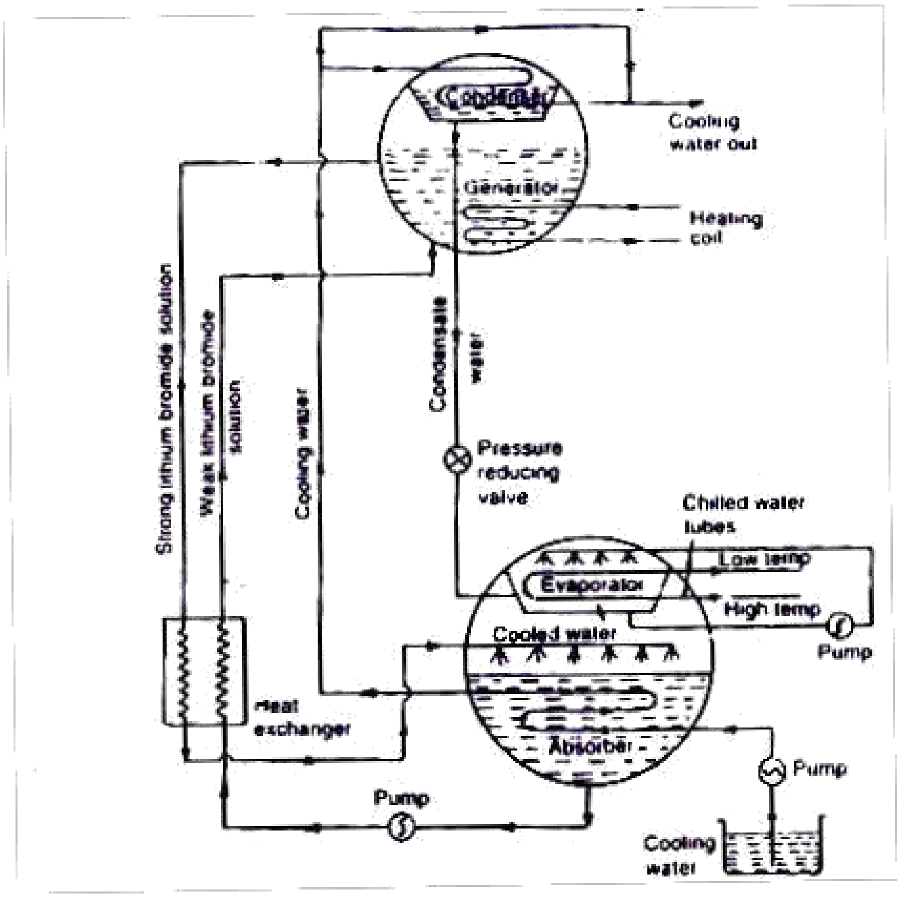
**3.** It can not be used for industrial purposes as the C.O.P. of the system is very low.

## 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.

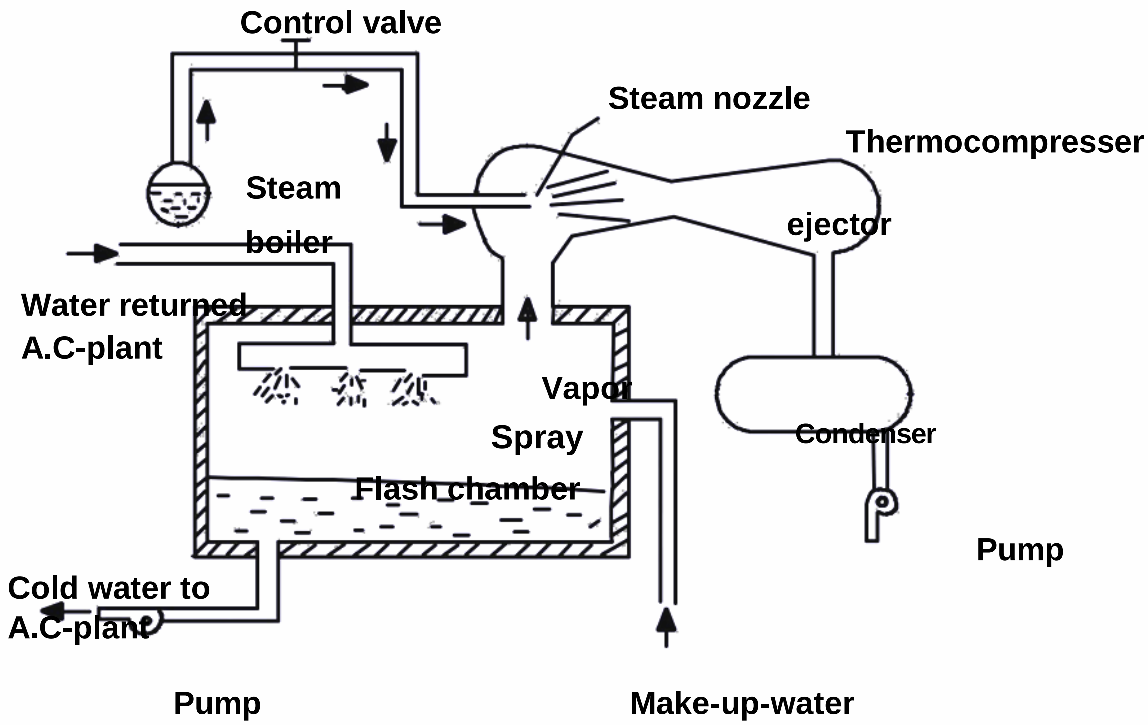



. Lithium-Bromide absorption refrigeration system.

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 $100^0$C. 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 $6^0$ C when the pressure on the surface is 5 cm of Hg and at $10^0$ C, when the pressure is 6.5 cms of Hg. The very low pressure or high 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

$$Q = m\, C_p dT$$

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

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:

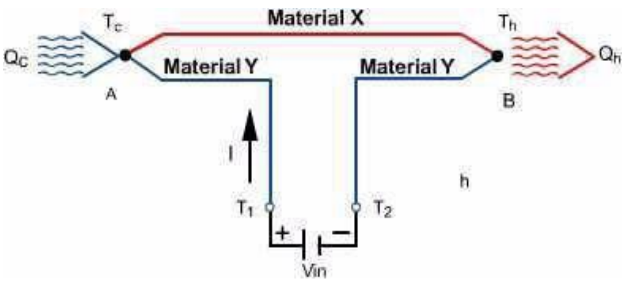
r) SEEBECK EFFECT

s) PELTIER EFFECT

t) THOMSON EFFECT

u) JOULE EFFECT

v) FOURIER EFFECT Peltier effect



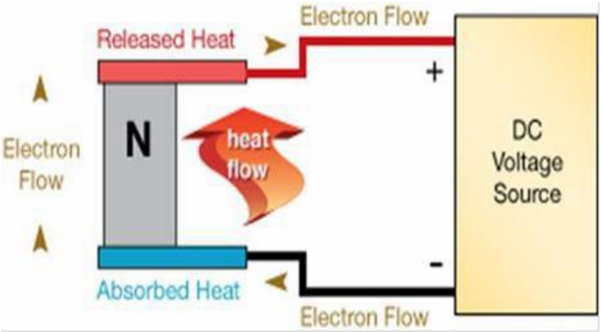

When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction. The Peltier heat generated at the junction per unit time, Q , is equal to;

$$Q \alpha I \; Q = \pi ab I$$
$$\pi ab = \pi a - \pi b$$

where ($\pi a$ & $\pi b$) is the Peltier coefficient of conductor A & B, and I is the electric current (from A to B).

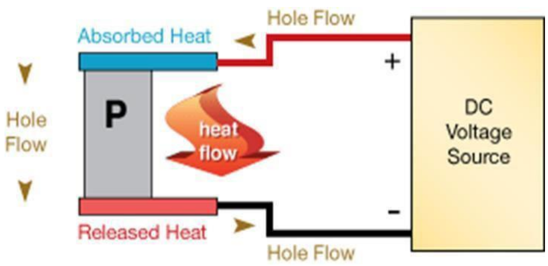
BASIC MECHANISM OF THERMOELECTRICS

Bismuth telluride (a semiconductor), is sandwiched between two conductors, usually copper. A semiconductor (called a pellet) is used because they can be optimized for pumping heat and because the type of charge carriers within them can be chosen. The semiconductor in this examples N type (doped with electrons) therefore, the electrons move towards the positive end of the battery. The semiconductor is soldered to two conductive materials, like copper. When the voltage is applied heat is transported in the direction of current flow




N-TYPE SINGLE SEMICONDUCTOR PELLET

When a p type semiconductor (doped with holes) is used instead, the holes move in a direction opposite the current flow. The heat is also transported in a direction opposite the current flow and in the direction of the holes. Essentially, the charge carriers dictate the direction of heat flow.



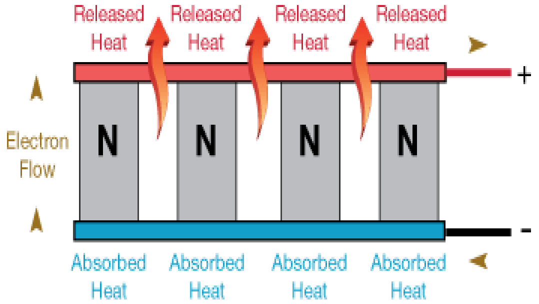

P-TYPE SINGLE SEMICONDUCTOR PELLET

Method of Heat Transport:

Electrons can travel freely in the copper conductors but not so freely in the semiconductor.As the electrons leave the copper and enter the hot-side of the p-type, they must fill a "hole" in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process.Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are bumped back to a higher energy level and absorb heat in the process. Next, the electrons move freely through the copper until they reach the cold side of the n-type semiconductor. When the electrons move into the n-type, they must bump up an energy level in order to move through the semiconductor. Heat is absorbed when this occurs.Finally, when the electrons leave the hot-side of the n-type, they can move freely in the copper. They drop down to a lower energy level and release heat in the process.

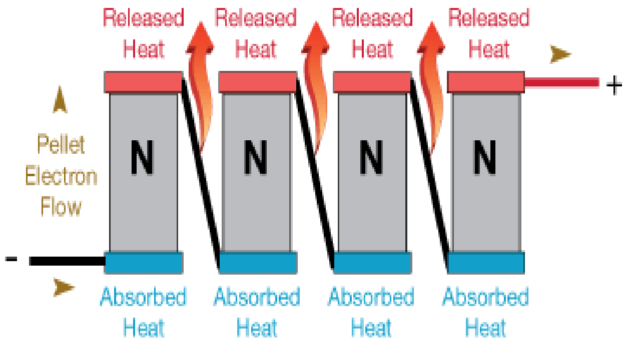
ELECTRICALLY AND THERMALLY PARALLEL MULTIPLE PELLETS

To increase heat transport, several p type or n type thermoelectric(TE) components can be hooked up in parallel. However, the device requires low voltage and therefore, a large current which is too great to be commercially practical.




THERMALLY PARALLEL AND ELECTRICALLT IN SERIES MULTIPLE PELLETS

The TE components can be put in series but the heat transport abilities are diminished because the interconnecting between the semiconductors creates thermal shorting.




**Vortex tube refrigeration system**

A vortex tube is a thermal device, which generates two streams at different temperature from a single injection. Injected into the vortex tube tangentially, the compressed gas is then divided into two parts and exhausted from the exits at temperatures lower and higher than the inlet gas, respectively. In this way, cold and hot streams are generated by only the vortex tube without any additional components. Figure 1 shows the structure of a counter- flow vortex tube as well as the proposed flow behaviour inside the tube. Importantly, as the vortex tube contains no other part inside the tube, the separation of two streams at different temperature by the vortex tube can only be attributed by the effects of fluid dynamics. On comparison with other industry-based technologies, the significant advantages of the vortex tube, such as having no moving parts, being small, low in cost, maintenance free and having adjustable instant cold and hot streams, encourage the on-going investigations into the mechanism of this simple device, with the objective of improving the tube performance and identifying of the primary factors underlying its operation.

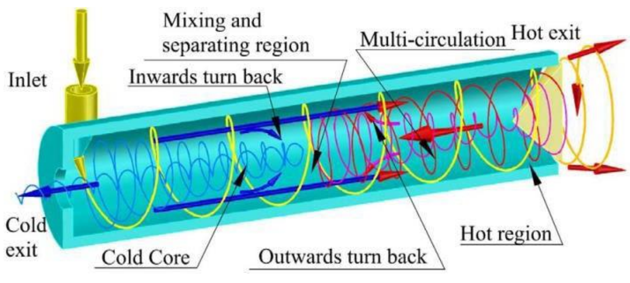
Flow structure in a counter-flow vortex tube

Several hypothesises have been proposed for the basic of the temperature separation, but a well-accepted explanation has not been forthcoming due to the complex flow mechanisms inside a vortex tube. The adiabatic compression and expansion caused by the turbulent eddies, form the basic for the temperature separation, and provide a theoretical prediction of the temperatures based on the pressures at the exits. However, compression of the working fluid cannot be considered as the reason for the temperature rise, because the pressure inside a vortex tube is always lower than the inlet pressure.

The generation of hot and cold streams in a vortex tube and is based on partial stagnation and mixture due to the nature of the multi-circulation occurring in the rear part of the tube, and the pressure gradient near the injection port.

Visualizations of theflow structure,and measurements ofthe velocity componentsinbothair-andwater-operatedvortextubes,showthattheflow to be divided into two streams at different temperatures.

**The cooling effect in a vortex tube**




Flow structure inside a counter-flow vortex tube

The cooling effect of a vortex tube is the result of the sudden expansion of the working fluid near the injection port. When the fluid is injected into the vortex tube, the main part of the fluid rotates and moves along the periphery towards the hot end. Near the injection point, the inner part of the peripheral flow turns back and moves towards the cold exit. A cold core is formed near the injection due to the pressure gradient of the forced vortex, and the temperature drops due to the decreased pressure of the working fluid in this cold core. The flow behaviour in the cold part of a vortex tube can be seen in Figure , which shows the inwards turn back of the inner flow and the cold core.

sucked into the tube via $X_3$ coming from the orifice and the buffer). At the moment of entering the tube it has the temperature $T_H$. Later in the cycle the same mass of gas is pushed out from the tube again when the pressure inside the tube is high. As a consequence its temperature will be higher than $T_H$. In the heat exchanger $X_3$ it releases heat and cools down to the ambient temperature $T_H$.

At the cold end of the pulse tube there is the opposite effect: here gas enters the tube via $X_2$ when the pressure is high with temperature $T_L$ and return when the pressure is low with a temperature below $T_L$. They take up heat from $X_2$: this gives the desired cooling effect.

# 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°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°C, and for water vapour the enthalpy of saturated water is taken as zero at 0°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 substances 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°C). ASHRAE has also developed psychometric charts for other temperatures and barometric pressures (for low temperatures: -40 to 10°C, high temperatures 10 to 120°C and very high temperatures 100 to 120°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:

## Need for Ventilation

We all know that heating and air conditioning systems are essential to the comfort of our homes and work spaces. Yet the “V” (for ventilation) in HVAC may be something of a mystery. What is ventilation and why do you need it?

The simple reason is, ventilation is required for both HVAC comfort and good air quality. Without enough ventilation in your space, you will eventually (and sometimes quickly) experience comfort issues and even health problems. These could range from having trouble sleeping in a stuffy bedroom to experiencing Sick Building Syndrome in a commercial space.

So what is ventilation exactly, and how does it work with heating and air conditioning systems to maximize your HVAC comfort?

According to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), an HVAC system should “heat, cool, clean, ventilate, humidify and dehumidify as needed to provide health and HVAC comfort.”

You’re probably familiar with all the other components: heating, cooling and even humidification and de-humidification. But what is ventilation all about and how does it contribute to HVAC comfort? It’s about adding the proper amount of fresh air from outside to the indoor air in your space.

In fact, ASHRAE's definition goes on to explain that ventilation is one of the most important jobs of an HVAC system. Why? Because without it, in the best case your space lacks fresh air and becomes stagnant and uncomfortable. In the worst case, you can be trapping in toxins and contaminants that can make people sick. It's so important that ASHRAE publishes a detailed standard for ventilation requirements for acceptable indoor air quality.

If you live or work in an older building, it's likely that outdoor air is seeping inside through leaky ducts, poorly insulated walls, and poorly sealed windows and doors. In a way this is a good thing, because you are probably getting sufficient ventilation to ensure HVAC comfort. However, it comes with a price: lost energy efficiency. When outdoor air can easily travel in, it makes your air conditioner work harder in summer and your heating system work harder in the winter, which drives up your energy bills. And of course, it also works the other way around: all your expensive conditioned indoor air that's at just the right temperature is also leaking out.

**What is ventilation provided mechanically?**

Fortunately there's an alternative to relying on your building to "breathe" through every available crack and opening to get enough ventilation for HVAC comfort. It's called mechanical ventilation, and it's essential for modern homes and commercial buildings that are increasingly built to be air-tight for energy efficiency.

This may be an unfamiliar term: what is ventilation that's provided mechanically? It simply means using equipment to control when, where and how much outside air is added to your space. Mechanical ventilation uses ducts and fans to draw in and distribute fresh air throughout your space, and sometimes to exhaust air from specific areas such as kitchens and bathrooms.

**CONTROLLING THE AMOUNT OF FRESH AIR**

As we mentioned, when too much outside air is coming in, that can impede the functioning of your HVAC system (and your HVAC comfort) and drive up your energy bills. It can also create an air balance problem in your space if more air is coming in than going out. Do you have door opening by themselves, or odors migrating where you don't want them, like from a restroom to where customers can notice? Or from a restaurant kitchen to the dining room? That's a sign of an air balance problem caused by poorly designed ventilation.

Not enough fresh air coming in makes your space stuffy and traps in undesirable air and everything that's lurking in it, including odors, moisture and even contaminants.

The EPA recommends the use of mechanical ventilation to prevent the buildup of odors, excess moisture and pollutants in your space. Odors are annoying and in a business situation can cost you money. Moisture can lead to worse problems: mold growth and also damage to furnishings, equipment and finishes.

Mechanical ventilation provides the ability to expel odors and moisture from areas. This is important for residential kitchens and bathrooms, but essential for commercial spaces such as restaurant kitchens, gyms and locker rooms, and restrooms.

Obviously expelling pollutants, especially VOCs that you might not even be able to smell or detect, is an important step to safeguard the health of everyone breathing the air in your space.

Related article: Sick Building: Try Air Conditioner Preventative Maintenance

**CONTROLLING THE SOURCE OF FRESH AIR**
Mechanical ventilation systems also provide the ability to control where outside air comes from, as well as where indoor air is exhausted from the building.

Why is this important for HVAC comfort? Let's look at a couple of examples.

If your home or business happens to be located next to a restaurant, or a gas station, or an industrial facility, you want to avoid odors from your neighbor migrating into your space. The right mechanical ventilation system can be designed to locate intakes on the other side of your building, and as far away as possible from sources of odors and pollutants.

Exhaust locations are just as important. You don't want moisture-laden air exhausted into an area where it can cause damage. Or odors and pollutants expelled where family members or customers will be breathing them in.

Related article: Improve Air Conditioning: Avoid These Ductwork Design Mistakes

**Choosing the right type of mechanical ventilation is important**

There are various types of mechanical ventilation systems; some are connected to your HVAC system, while others are separate. The type that will work best for your HVAC comfort depends on your space, its usage and even on your climate. Certain types of mechanical ventilation are designed for hot and humid climates, others for cold climates, and others for mixed climates such as we experience here in the New York City area.

Choosing the wrong system can cause a buildup of moisture that can damage your space and even lead to mold growth.

That's why it's so important to choose an HVAC company that understands the "V" in HVAC as well as heating and air conditioning.

# Consideration of Infiltration

Infiltration is the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage.[1] Infiltration is sometimes called air leakage. The leakage of room air out of a building, intentionally or not, is called exfiltration. Infiltration is caused by wind, negative pressurization of the building, and by air buoyancy forces known commonly as the stack effect.

The infiltration rate is the volumetric flow rate of outside air into a building, typically in cubic feet per minute (CFM) or liters per second (LPS). The air exchange rate, (*I*), is the number of interior volume air changes that occur per hour, and has units of 1/h. The air exchange rate is also known as air changes per hour (*ACH*).

ACH is the hourly ventilation rate, divided by the building volume. It can be calculated by multiplying the building's CFM by 60, and then dividing by the building volume. (CFM x 60)/volume

Infiltration in finished structures can often be measured directly by using tracer-gas leak testing.

In many smaller buildings, 'forced' or 'mechanical' ventilation is not used to introduce ventilation air. Instead, natural ventilation, via openable windows and other openings, exhaust fans, and infiltration are used to provide ventilation air. Typically, at least one-third air change per hour is considered the minimum. ASHRAE Standard 62.2 was adopted in 2004; it clarifies the ventilation air requirements for low-rise residences. The Standard specifies that forced ventilation is required in houses with infiltration less than 0.35 ACH.[2] This is typically accomplished with heat recovery ventilation or exhaust fans running constantly or periodically.
Because infiltration is uncontrolled, and admits unconditioned air, it is generally considered undesirable except for ventilation air purposes. Typically, infiltration is minimized to reduce dust, to increase thermal comfort, and to decrease energy consumption. For all buildings, infiltration can be reduced via sealing cracks in a building's envelope, and for new construction or major renovations, by installing continuous air retarders. In buildings where forced ventilation is provided, their HVAC designers typically choose to slightly pressurize the buildings by admitting more outside air than exhausting so that infiltration is dramatically reduced.

## Load concepts of RSHF

The Room Sensible Heat Factor - RSHF - expresses the ratio between sensible heat load and total heat load in a room. It can be expressed as:

$RSHF = Q_{sr} / Q_{tr}$ where

$RSHF$ = room sensible heat factor

$Q_{sr}$ = sensible heat load in room (kW, Btu/hr)

$Q_{tr}$ = total heat load in room (kW, Btu/hr)

(1) can be modified to:

$RSHF = c_p (t_r - t_i) / (h_r - h_i)$

where

$c_p$ = specific heat air (kJ/kg.$^o$C)

$t_r$ = room temperature ($^o$C)

$t_i$ = inlet temperature ($^o$C)

$h_r$ = room enthalpy (kJ/kg)

$h_i$ = inlet enthalpy (kJ/kg)

GSHF

A cooling coil should have the capacity to handle the heat load generated in the room in addition the capacity to cool down the fresh make up air. The Great Sensible Factor is independent of the total air flow and can be expressed as

$GSHF = [Q_s + m_f c_p (t_f - t_r)] / [Q_t + m_f (h_f - h_r)]$

where

*GSHF* = Great Sensible Heat Factor

$Q_s$ = sensible heat generated in the room (kW)

$m_f$ = fresh air mass flow (make up air) (kg/s)

$c_p$ = specific heat of air (kg/kg.$^oC$)

$t_f$ = temperature in fresh air ($^oC$)

$t_r$ = temperature in room air ($^oC$)

$Q_t$ = total heat generated in the room (kW)

$h_f$ = specific enthalpy of fresh air (kJ/kg$^oC$)

$h_r$ = specific enthalpy of air in the room (kJ/kg$^oC$)

Concept of ESHF

**SENSIBLE HEAT FACTOR (SHF)**

There are many types of sensible heat factors. These are described below:

**(a) ROOM SENSIBLE HEAT FACTOR (RSHF)**
**RSHF=RSHL/(RSHL+RLHL) =RSHL/TRHL**
**where RSHL is room sensible heat load**
**RLHL is room latent heat load**
**TRHL is total room heat load**

Room Sensible Heat Factor – RSHF

**Effective room sensible heat factor = ERSHF**

**=ERSHL/(ERSHL+ERLHL)**

**(i) Effective room sensible heat load = ERSHL**

**Outside air sensible heat load = OASHL**

**ERSHL= RSHL+ BPF. OASHL**

**Where BPF = By pass factor**

apparatus dew point temperature

Apparatus Dew Point (ADP) is the effective surface temperature of the cooling coil. It is also the temperature at a fixed flow rate at which both sensible and latent heat gains are removed (from the conditioned space) at the required rates. It is also often called as the 'Coil Temperature'

# V UNIT

## REQUIREMENTS OF HUMAN COMFORT AND CONCEPT OF EFFECTIVE TEMPERATURE

The Comfort Chart

The comfort chart (see Figure 8-8) is an empirically determined effective temperature index that has been published by the ASHRAE since 1950.

The purpose of the comfort chart is to indicate the percentage of people feeling comfortable at various effective temperatures in the winter and summer. This serves only as an approximate standard of comfort, because individual reactions to warmth and cold are much too variable, but it is the most precise and scientific form of measurement available.

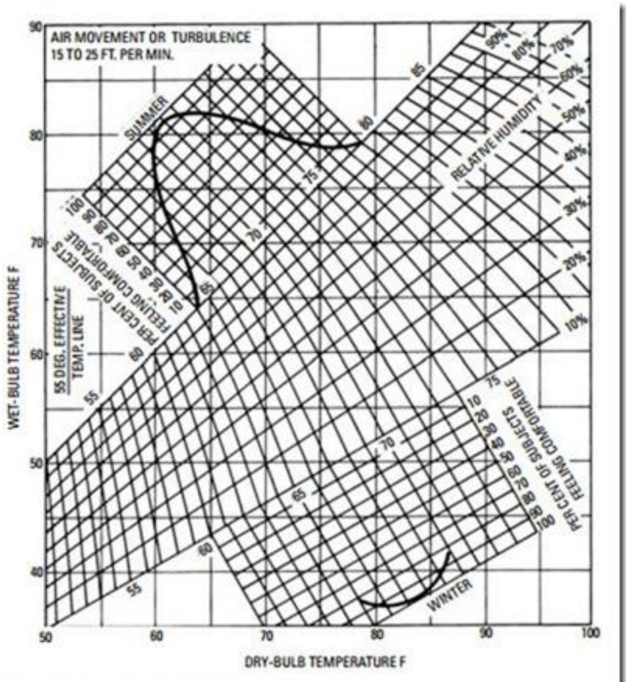



**Figure 8-8** Comfort chart for still air. *(Courtesy ASHRAE 1960 Guide)*

From the chart, one can obtain an approximate idea of the various effective temperatures at which a majority of people will feel comfortable (that is, the summer and winter comfort zones).

Most air-conditioning systems are designed with a recommended indoor design relative humidity of about 50 percent or slightly lower. Budget jobs will range as high as 60 percent relative humid- ity. The indoor dry-bulb temperature will range from 75°F or slightly below to about 80°F, depending on the degree of occupancy and whether it is a budget job or not. In any event, the indoor design conditions should fall within the comfort zone.

More information about the use of the comfort chart is included in Appendix E ("Psychrometric Charts").

**Cooling Load Estimate Form**

Air-conditioning equipment manufacturers often provide their local representatives with forms for making cooling load estimates. Along with these forms they also provide tables, slide charts, tabulation sheets, and other aids for computing the cooling load.

Typical tabulation sheets and cooling load estimate forms are shown in Figures 8-9 and 8-10. These forms contain lists of factors that represent approximate values for a

variety of different items (for example, walls, ceilings, people). For example, the form illustrated in Figure 8-9 requires that you select the appropriate design dry-bulb temperature and its column of factors. After calculating the area (in square feet) of the structural section, you must multiply this figure by its factor to determine the Btu per hour of heat gain and enter the result in the column on the extreme right.
Because a manufacturer's cooling estimate form will probably not be available, it may be necessary to create your own. If this should be the case, then provisions should be made on the cooling estimate form for distinguishing between sensible and latent heat sources.
Your cooling load estimate form should contain the following basic categories of heat gain:

**A.**Sensible heat gain
**1.** Heat leakage
**2.** Solar radiation
**3.** Internal heat sources
**4.** Infiltration
**5.** Ventilation
**6.** Electric lights
**7.** Electric motors
**8.** People
**9.** Appliances

**B.** Latent heat gain
**1.** Infiltration
**2.** Ventilation
**3.** People

**C.** Ventilation heat gain (from outside sources)
**1.** Sensible heat
**2.** Latent heat

## Requirements of Industrial air conditioning:

If all the air conditioning had to be divided into two groups comfort air conditioning and industrial air conditioning the main difference will be in goal. Comfort air conditioning is for the people, while the industrial conditioners directed processes. On the air side, industrial air conditioners are one or more characteristics: temperature level, the need for precise humidity control, increasing the level of filtration and removal of contaminants. Industrial air conditioning appears in applications such as printing presses, where humidity control is essential for proper registration of multi-color printing; textile enterprises in order to prevent fibers from hacking and reduce static electricity; manufacture of photographic materials; clean rooms for manufacturing electronic equipment; and in different laboratories. One of the differences between the refrigeration and comfort for the industrial air-conditioning may be in more high precision temperature control, generally required for industrial air conditioning.

**Air conditioning Load Calculations:**

As the name implies, heating load calculations are carried out to estimate the heat loss from the building in winter so as to arrive at required heating capacities. Normally during winter months the peak heating load occurs before sunrise and the outdoor conditions do not vary significantly throughout the winter season. In addition, internal heat sources such as occupants or appliances are beneficial as they compensate some of the heat losses. As a result, normally, the heat load calculations are carried out assuming steady state conditions (no solar radiation and steady outdoor conditions) and neglecting internal heat sources. This is a simple but conservative approach that leads to slight overestimation of the heating capacity. For more accurate estimation of heating loads, one has to take into the thermal capacity of the walls and internal heat sources, which makes the problem more complicated.

For estimating cooling loads, one has to consider the unsteady state processes, as the peak cooling load occurs during the day time and the outside conditions also vary significantly throughout the day due to solar radiation. In addition, all internal sources add on to the cooling loads and neglecting them would lead to underestimation of the required cooling capacity and the possibility of not being able to maintain the required indoor conditions. Thus cooling load calculations are inherently more complicated as it involves solving unsteady equations with unsteady boundary conditions and internal heat sources.

For any building there exists a balance point at which the solar radiation (Qsolar) and internal heat generation rate (Qint) exactly balance the heat losses from the building. Thus from sensible heat balance equation, at balanced condition:

**Air Conditioning systems**

In air conditioning it includes the cooling and heating of air, cleaning and controlling its moisture level as well as conditioning it to provide maximum indoor comfort.

An air conditioner transfers heat from the inside of a building, where it is not wanted, to the outside. Refrigerant in the system absorbs the excess heat and is then pumped through a closed system of piping to an outside coil. A fan blows outside air over the hot coil, transferring heat from the refrigerant to the outdoor air. Because the heat is removed from the indoor air, the indoor area is cooled.

An air conditioning system generally consists of five mechanical components:

1. Compressor
2. Fan
3. Condenser Coil (Hot)
4. Evaporator Coil (Cool)
5. Chemical Refrigerant

Most central air conditioning systems include a “hot” side, outside your home, and a “cool” side, inside your home. The “hot” side generally consists of a condensing coil, a compressor and a fan.

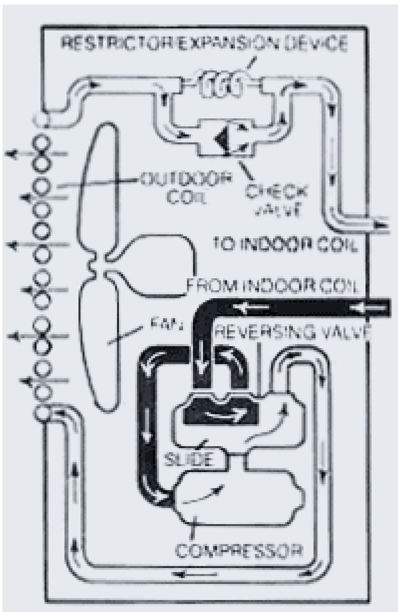
The “cool” side is usually located within your furnace. The furnace blows air through an evaporator coil, which cools the air, and routes this cool air throughout your home using a series of air ducts.

The cleaning function of air conditioners is performed by filters, which remove dust and contaminants from the air. In some systems, the filters are permanent and can be washed periodically to remove accumulated dirt. Most systems have disposable filters which can be replaced. When filters become clogged, they restrict the flow of air and cause the system to operate inefficiently.

## 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



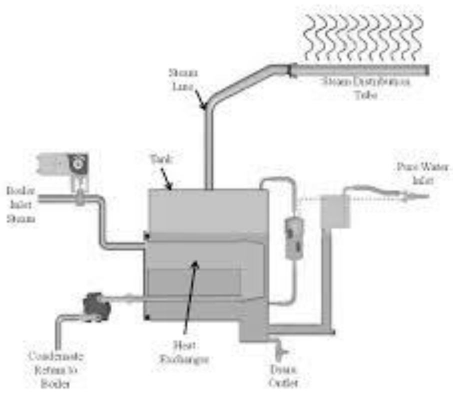

During the heating cycle the refrigerant flows in reverse. Liquid refrigerant now flows to the outdoor coil picking up heat as it evaporates into a low pressure vapor.

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.



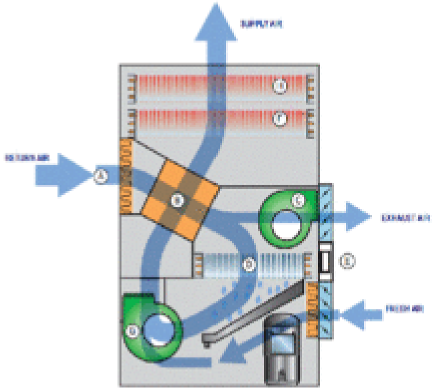
Industrial humidifiers are used when a specific humidity level must be maintained to prevent static electricity buildup, preserve material properties, and ensure a comfortable and healthy environment for workers or residents.

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**.

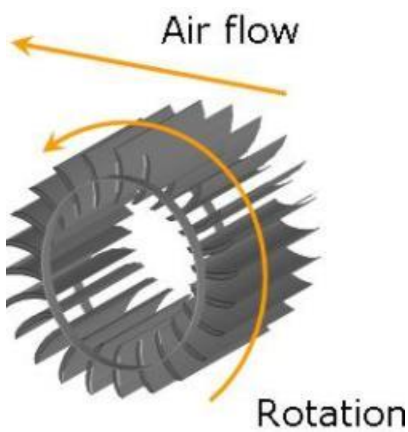
**Fans and blowers:**

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.




The characteristics of fans and blowers are quite similar to that of compressors.

These equipments have,

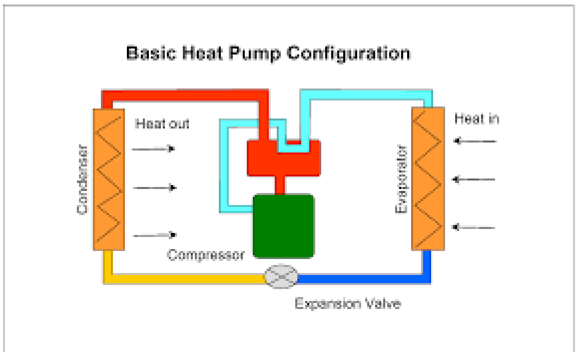
- **maximum rotational speed** – limited by the driver's speed and power, and
- **maximum pressure difference** between inlet, and outlet of the fluid motion – limited by the driver's power

**Heat Pump:**

A heat pump is a device that transfers heat energy from a source of heat to what is called a heat sink. Heat pumps move thermal energy in the opposite direction of spontaneous heat transfer, by absorbing heat from a cold space and releasing it to a warmer one. A heat pump uses a small amount of external power to accomplish the work of transferring energy from the heat source to the heat sink.[1] The most common design of a heat pump involves four main components – a condenser, an expansion valve, an evaporator and a compressor. The heat transfer medium circulated through these components is called refrigerant

While air conditioners and freezers are familiar examples of heat pumps, the term "heat pump" is more general and applies to many HVAC (heating, ventilating, and air conditioning) devices used for space heating or space cooling. When a heat pump is used for heating, it employs the same basic refrigeration-type cycle used by an air conditioner or a refrigerator, but in the opposite direction – releasing heat into the conditioned space rather than the surrounding environment. In this use, heat pumps generally draw heat from the cooler external air or from the ground.[3]

In heating mode, heat pumps are three to four times more effective at heating than simple electrical resistance heaters using the same amount of electricity. However, the typical cost of installing a heat pump is also higher than that of a resistance heater.




For climates with moderate heating and cooling needs, heat pumps offer an energy-efficient alternative to furnaces and air conditioners. Like your refrigerator, heat pumps use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the cool outdoors into your warm house and during the cooling season, heat pumps move heat from your cool house into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances.

There are three types of heat pumps: air-to-air, water source, and geothermal. They collect heat from the air, water, or ground outside your home and concentrate it for use inside.

The most common type of heat pump is the air-source heat pump, which transfers heat between your house and the outside air. Today's heat pump can reduce your electricity use for heating by approximately 50% compared to electric resistance heating such as furnaces and baseboard heaters. High-efficiency heat pumps also dehumidify better than standard central air conditioners, resulting in less energy usage and more cooling comfort in summer months. Air-source heat pumps have been used for many years in nearly all parts of the United States, but until recently they have not been used in areas that experienced extended periods of subfreezing temperatures. However, in recent years, air-source heat pump technology has advanced so that it now offers a legitimate space heating alternative in colder regions.

For homes without ducts, air-source heat pumps are also available in a ductless version called a mini-split heat pump. In addition, a special type of air-source heat pump called a "reverse cycle chiller" generates hot and cold water rather than air, allowing it to be used with radiant floor heating systems in heating mode.

Geothermal (ground-source or water-source) heat pumps achieve higher efficiencies by transferring heat between your house and the ground or a nearby water source. Although they cost more to install, geothermal heat pumps have low operating costs because they take advantage of relatively constant ground or water temperatures. Geothermal (or ground source) heat pumps have some major advantages. They can reduce energy use by 30%-60%, control humidity, are sturdy and reliable, and fit in a wide variety of homes. Whether a geothermal heat pump is appropriate for you will depend on the size of your lot, the subsoil, and the landscape. Ground-source or water-source heat pumps can be used in more extreme climates than air-source heat pumps, and customer satisfaction with the systems is very high.

A new type of heat pump for residential systems is the absorption heat pump, also called a gas-fired heat pump. Absorption heat pumps use heat as their energy source, and can be driven with a wide variety of heat sources.