REFRIGERATION BASICS

INTRODUCTION:

This is the first module in refrigeration course development and deals with introduction to refrigeration. It deals with definition of various terminologies, what are the different forms of refrigeration and their applications, first and second law of thermodynamics, what is temperature, and heat, difference between heat content and heat transfer, entropy and enthalpy understandings, how to measure sensible ,latent and total heats, conductors and insulators. The module also deals with pressure and temperature relationship, saturation temperatures and boiling points, barometric, gauge and absolute pressures, vacuum and measurement units for pressure temperatures and energy, power, tons of refrigeration etc.

Refrigeration is cooling by removal of heat. In reality we cannot remove heat; we can only move heat from a place where it is not wanted to a place where it is less objectionable.

When heat is moved, the temperature of the substance drops and where heat is moved its temperature rises.

Prior to introduction of air conditioning /refrigeration technology cooling and preservation of food was achieved by using naturally produced ice. In winter ice from lakes and ponds was cut and stored in insulated rooms for use during summer. Most of this ice was used for food preservation, restaurants and homes. Man made ice appeared just at the end of last century and first mechanical refrigerator was introduced in 1910.

In today's world there are innumerable applications of refrigeration and it is impossible to learn each independently. Instead if one concentrates on learning basic cycle and principles one would be able to understand any type of refrigeration system. That is because the principles of mechanical refrigeration and essential components are same for all kind of systems, only the size, arrangement of components and their locations are different. It is therefore necessary to understand basics of vapour compression refrigeration.

The normal examples of use of refrigeration in our day-to-day life are domestic refrigerator and room or window air conditioners.

The five basic categories of mechanical refrigeration are -

1. Comfort air conditioning
2. Process air conditioning
3. Commercial Refrigeration
4. Low temperature refrigeration
5. Cryogenics

Human Comfort

As defined by ASHRAE/ANSI standard 55-2004, Thermal comfort is the "That condition of mind which expresses satisfaction with thermal environment and is assessed by subjective evaluation"

The comfort air conditioning involves air treatment by cooling/heating, humidifying/dehumidifying, circulate/ventilate, filter & odour removal. When all these aspects are tackled then it is comfort air conditioning. Room air conditioner is therefore in true sense is **not** technically a comfort air conditioner since only partial cooling aspect is handled and it does not have heating or humidity control mechanism. All these requirements can be build in Air handling units used in central plants.

The temperature and humidity conditions accepted as comfortable are 68^0F to 75°F (20^0C to 23.8^0C) and 20 % to 60 % relative humidity with 75°F (23.8^0C) and 50 % as goal. The ASHRAE comfort chart given in Fundamentals volume 2009, gives complete details about human comfort requirements.

Commercial refrigeration covers cooling and freezing foods; it also involves production of ice. Grocery stores & super markets make extensive use of commercial refrigeration. Household refrigerators and freezers are smaller versions of these. Normally the temperature is controlled either between 35°F to 45°F (1.7^0C to 7.22^0C) in the main storage area, & for freezers between -20°F to -30°F (-29^0C to-35^0C)

Process air conditioning is meant for things to be kept at particular temperature rather than human beings as objects. Applications are manufacture of textiles, pharmaceuticals, printing, multi colour printing, paper manufacture, photo films, audio/video cassettes, hospitals, computer rooms etc.

Low temperature refrigeration covers use of mechanical refrigeration to cool and freeze variety of products such as blood plasma, semen, and temperatures can go as low as -70^0c.

Cryogenic applications include such applications as space simulators, metallurgy, and gas liquefaction, testing chambers etc. requiring lower than -70^0C temperatures

The mechanical refrigeration system has four basic components- 1) Evaporator/cooling coil 2) Compressor 3) Condenser 4) Metering device/expansion device.

In addition to this a fluid called refrigerant circulates through each component for moving heat and it travels in a particular direction in cooling mode.

Heat

The purpose of mechanical refrigeration is to pump out the heat from areas or medium where heat is not wanted to the place where it is not objectionable to reject heat.

Since we are continuously going to deal with heat it is necessary to understand some basics on this aspect.

First law of Thermodynamics: It is the law of conservation of energy. It states that energy cannot be created or it cannot be destroyed. We can only transfer one form of energy in to another form.

There are four main forms of energy such as light, electrical appliances, chemical reactions, and mechanical work.

As per the law of conservation of energy, all energies finally degenerate in heat. When mechanical work is done heat is generated, chemical reactions generate exothermic heat, electrical energy generates heat and solar or light energy also generates heat.

Heat is a form of energy. It is not a solid, liquid or gas and it cannot be measured by weight or volume. Heat is considered to be the lowest form of energy since all other energies finally degenerate in to heat.

ENTROPY

This concept is defined by the term entropy. Entropy measures the molecular disorder of a system. The more mixed the system, the greater is the entropy, and conversely an orderly or unmixed configuration is one of low entropy.

Entropy (Specific) is expressed as kJ/kg.K. It is defined as a measure of energy unavailable for useful work or wasteful energy. A certain portion of energy added to a system at high temperature is later lost from the system to the surroundings at a lower temperature & this energy is unavailable for doing any useful work between the two temperatures involved-(Definition given in Automotive Design and Development-in Annexure under definitions)

The term entropy means transformation. It is thermodynamic property of a working substance, which increases with addition of heat, and decreases with its removal. It is comparatively easy to define change of entropy of a working substance. In a reversible process, over a small range of temperature, the increase or decrease of entropy, when multiplied by absolute temperature, gives the heat absorbed or rejected by the working substance. The heat absorbed by the working substance is

$\Delta q = T x \Delta S$ or $\Delta S = \Delta Q/T$ or where T is absolute temperature and ΔS is increase/decrease in entropy

Since in universe some activity is constantly taking place in all the above mentioned processes such as mechanical work, electrical work or chemical work including lights and solar energy, and all these forms are finally converted into or generate heat which is the lowest form of energy, the law of thermodynamics states that entropy of universe is constantly increasing.

Second law of Thermodynamics:

The second law states that heat will always flow from higher temperature to lower temperature as the water flows from higher potential to lower potential. The concept is irreversibility & it differentiates and quantifies processes that only proceed in a certain direction. Larger is the irreversibility in a refrigeration cycle operating with a given refrigeration load between two fixed temperature levels, larger is the amount of work required to operate the cycle. Irreversibility includes pressure drops in lines and heat exchangers, heat transfer between fluids of different temperatures, and mechanical friction. Reducing total irreversibility in a cycle improves the cycle efficiency and performance.

Molecules & Relationship with Temperature

The smallest particle of a substance is molecule. This is true for any substance, whether gas, liquid or solid.

As the temperature reduces, the vibrating velocity of molecules reduces and as the temperature is increased the molecules vibrate at higher speeds. At absolute zero temperature the molecules do not vibrate and therefore do not create any resistance to flow of energy like electricity or heat and therefore when materials reach nearer to this absolute zero temperature these substances are called super conductors.

Temperature therefore can be defined as the property which indicates the average vibrating velocity of the molecules of a substance. It can also be defined as measure of intensity of heat in a substance.

As the temperature of a substance is increased the molecules vibrate more rapidly and move little further apart. The density change is very little to be noticed. The substance does not change its state up to a particular temperature.

When addition of heat is still continued, the molecules cannot keep their bond intact and break apart changing the state of a substance either from solid to liquid or from liquid to gas.

For example the R 22 molecules are **52** times farther apart as gas than as liquid. This separation causes density decrease of about **98 %.** The change of state causes a big change in spacing and arrangement of molecules but very little change in the vibrating velocity of molecules or temperature. A great deal of heat is required for this change of state but it does not show on thermometer and is therefore known as latent heat.

The **density** of a substance is a measure of how tightly the molecules are packed in a substance. It is measured as weight per unit volume, or pounds per cubic foot (kg/m^3).

The BOILING **TEMPERATURE** is called SATURATION **TEMPERATURE in** mechanical refrigeration work.

In reality every substance has only **one** boiling point since boiling point is the temperature when fluid gets converted to vapour at **sea level conditions or at atmospheric pressure**, whereas every substance has many saturation temperatures. The saturation temperature is also a boiling point corresponding to that particular pressure. The refrigerant boils/evaporates when pressure is reduced and the same refrigerant condenses when pressure is increased.

Sensible & Latent Heat

Internal energy is measured at the molecular level. As explained above individual molecules of a system are in continuous motion and this motion contributes to molecular energy. This portion of internal energy associated this molecular motion is known as sensible energy.

The heat that can be sensed/measured on thermometer is called **sensible heat** and during sensible heating the substance does not change its state.

The internal energy is also related to intermolecular forces between molecules of the system. The forces that bind molecules are strongest in solids and weakest in gases. If sufficient energy is added to a solid or liquid, the phase change takes place when molecular binding breaks. The energy added to make this phase change is known as **Latent energy**. Latent heat is part of internal energy. The sensible and latent energy changes do not make any chemical changes in a substance of a system and only changes form

The heat that cannot be measured on thermometer is called **latent heat** and is associated with change of state of a substance.

ENTHALPY

Enthalpy is the sum of internal energy (u) and the product of pressure and volume(pv) or flow energy

H= u+pv

Thermodynamics is the study of energy change rather than the study in absolute values of energy, and the use of arbitrary reference, or datum is acceptable.

Refrigeration air conditioning systems are all in the category of flow processes, and hence only flow energy is considered with any datum level.

Hence in refrigeration systems we call the total heat as enthalpy which is the sum of sensible and latent heat. It is measured in **BTU's or kcal/hr or Watt.**

Technically anything above -460°F/-273.15^{0}C contents heat but we view it relatively. Technically we should therefore address as how much heat energy substance contains rather than how hot or cold it is.

Temperature therefore measures heat content of a substance. It does not measure heat energy that is required to change the state of a substance. The two scales normally used to measure temperature are Centigrade and Fahrenheit.

To convert centigrade in to Fahrenheit we use formula as Temperature in ^{0F} = temperature in ^{0}Cx9/5 +32

Heat Transfer & Heat exchange

Heat transfer or **heat exchange** is the movement of heat from one place to another, either within the substance or between substances. Since mechanical refrigeration is the business of refrigeration people heat transfer is the main objective of them.

Heat content deals with how much heat energy is content in a substance where as heat transfer deals with how much heat is moved from one substance to another.

When heat is transferred, the heat content of the substance from where it is moved drops by the same amount that the heat content of the destination substance increases.

Like all forms of energy, heat flows from a high energy level to a lower energy level, just like water. If we connect two ponds of water containing same level of water there will be no flow, if however one pond is at higher level than other then water will flow from higher level to lower level by gravity in spite of the fact that water quantity in the upper tank is less than water quantity in the lower tank.

Similarly heat will not flow without a temperature difference. It will always flow from warmer to colder substance, irrespective of its heat content just like water. Larger the temperature difference, faster will be heat transfer.

Heat flows in 3 ways- Conduction, Convection, and Radiation.

Conduction is the transfer of heat from molecule to molecule through a substance by chain collision. Heat added at one point causes the temperature of the substance to go up because the molecules move more rapidly. These high velocity molecules start chain collision with molecules near them. While conduction takes place in liquids and gases it is best in solids where the density is highest which means that the molecules are more closely packed.

Convection is heat transfer by the movement of molecules from one place to another.

Radiation transfers heat by passing from a source to an absorbent surface without heating the space in between.

Conductors/insulators

Materials which help heat move by conduction are called **conductors**.
The substances which retard heat flow are called **insulators**.
Good conductors are bad insulator and Vis-a versa. This property is similar to electrical conductors/insulators

Silver, copper, gold, aluminum metals are good conductors and taking into account cost factors and other considerations copper and aluminum are extensively used in refrigeration. Steel is also good conductor and is used in Ammonia plants since copper is unacceptable.

Trapped air, foam boards, fiberglass, dead air spaces, cork products, wood products are good insulators.

We studied earlier that temperature measures average speed of motion of the molecules and it measures sensible heat. It cannot measure latent heat which causes change of state of substance.

Since we need to measure total heat (Enthalpy), the unit which is used is BTU or cal or watt.

BTU measures 1) Heat content 2) Heat transfer 3) Heating and cooling capacity 4) Heating & cooling load 5) Heat content of refrigerant (Enthalpy). One Btu is equal *to* 778.17 ft.lb or to understand it simply it is the amount of heat generated when we burn one match stick.

British thermal unit is the amount of heat required to raise the temperature of one pound of **water** through one degree Fahrenheit. It is difficult to measure heat in the field, but one can say it is equivalent to heat released by burning one match stick.

Specific Heat is the amount of heat, measured in BTU's required to raise one pound of a **substance** through one degree Fahrenheit.

Specific heat helps us to compare how easily various substances are heated. It also allows us to calculate amount of heat transferred during sensible heating or cooling process.

Each substance has of its own unique specific heat. Substances with lower specific heat are easily heated. Mercury has very low specific heat hence it is used in thermometers. Water has very high specific heat compared to other substances and is therefore difficult to heat or requires larger amount of heat compared to most other substances.

Substance	Specific heat –Btu/lb/^{0}F	Temperature Rise
Water	1.00	1.00
Meat	0.77	1.30
Ice	0.50	2.00
Cork	0.49	2.04
Steam	0.48	2.08
Air-dry	0.24	4.17
Aluminum	0.22	4.54
Iron	0.115	8.70
Copper	0.093	10.75
Mercury	0.03	33.33

The same substance in different states can have different specific heats. Water has sp.ht. as one where as ice has sp.ht. as 0.5 and steam has sp.ht. as 0.48.

The sensible heat can be calculated by following formula:-

$Q = S \times W \times (\Delta T)$

The latent heat of vaporization of water is 970 **BTU/lb (540Kcal/kg or 2258KJ/kg) or 1Kcal = 3.968Btu = 4.185KJ**

The latent heat of fusion is **144 BTU/lb(80Kcal/kg or 334.5KJ/kg).** This is the heat to be added to one pound of ice for changing from 32° F ice into 32° F water.

The present SI system uses Watt as unit of power which is 1W=1J/s & energy is 1W =3.41 Btu/hr =3600 J/hr=859.85 cal/hr

The total heat is the sum of sensible and latent heat or

ENTHALPY = SENSIBLE HEAT + LATENT HEAT
1150 BTU = 180 BTU +970BTU

This is the heat required to convert 1 lb of water at 32 deg F to 1 lb of steam at 212 deg F

Rate of heat Transfer

We have studied till now heat and heat transfer both measured in Btu. We have not dealt with how fast heat is transferred between two objects. We not only need to know how much is the heat content but we must know how fast we can move heat.

In short we need to know heat transfer rate or Btu/hr.

Refrigeration Ton

The Ton is much bigger unit by which refrigeration equipment or system is rated. The term “Ton” comes from the days when ice was used as method of providing cooling. Ton is therefore amount of heat required to melt 1 ton of ice in 24 hours from 32^0F ice into 32^0F water. Or in other words 1 ton is the cooling load indicating the rate at which heat enters the space when it will melt 1 ton of ice in one day.

Latent heat of fusion or the heat required to melt ice is 144 btu/lb,

The 1 Ton of refrigeration is therefore equal to 2000lbsx144÷24hrs = 12000 Btu/hr

American Ton is of 2000 lbs or short Ton where as metric Ton is 2240 lbs.

1 Ton= 3.517 kW=3024 kcal/hr =12660 kJ

Having covered properties such as temperature, heat and heat transfer it is also necessary to look at pressures since in refrigeration technology we constantly come across pressures and temperatures.

PRESSURE

A doctor cannot diagnose unless he measures blood pressure, body temperature, and pulse rate of a patient. Similarly refrigeration service expert needs to measure both temperature and pressure in order to diagnose system problem and trouble shoot same. Also in order to understand refrigeration system and its performance it is necessary to know more about pressure as well as temperature.

Pressure is defined as force per unit area.

Pressure behaves differently for solids and liquids or gases.

Pressure tends to exert only in one direction for solids. Fluids on the other hand tend to exert pressure equally in all directions.

We are used to living in the fluid pressure on our bodies by earth's atmosphere. It exerts **14.7** pounds per sq. in. pressure (101.325 kPa) all over our body at sea level. This pressure is called atmospheric pressure. It cannot be measured with a scale because there is just as much pressure below the scale's platform. This pressure can be measured by barometer and hence it is called barometric pressure.

Normal atmospheric pressure at sea level is **30** in. Hg. The depth of atmosphere at sea level is **60 miles** and we live at the bottom of it. As we go higher there is less air over us as compared to sea level. In conventional airliner, the cabin must be pressurized to avoid effects of extreme pressure changes caused by altitude.

The **drier** air is **denser** than moist air.

The **colder** air is **denser** than worm air.

The barometric pressure is **highest** on **cold, dry** days.

In refrigeration systems pressure exists in 3 ranges, above atmospheric, at, or below atmospheric pressures. Efforts are made to select the refrigerant which normally would operate above atmospheric pressure for the particular application.

The systems for measurement of pressure are absolute and gauge pressures. Absolute pressure is used for weather reporting and forecasting as well as for engineering calculations and for plotting pressure/enthalpy charts. Gauge pressure is used for all service work. This can be measured with the help of pressure gauge either directly installed on a plant or connected when needed.

Absolute pressure equal to or below atmospheric is expressed in inches of mercury absolute. Absolute pressure equal to or above atmospheric is expressed in **PSIA.**

Gauge pressure equal or below atmospheric pressure is expressed as inches of mercury vacuum. Gauge pressure equal to or above atmospheric pressure is expressed as **PSIG.**

Gauge pressure + Atmospheric pressure = Absolute pressure.

Normally a compound gauge is used on suction side as it has markings for above or below atmospheric pressure. The gauges are also marked with corresponding saturation temperatures for common refrigerants for ease of service technicians.

The pressure of a refrigerant and its saturation temperature are closely related and we need only know one to find out other. **Saturation temperature is really a boiling point of refrigerant at that pressure.**

As the pressure increases, the boiling point increases and when the pressure decreases the boiling point decreases. Even though refrigeration pressure can be used to find saturation temperature, these facts do not guarantee that the refrigerant is at saturated conditions. From the temperature/ enthalpy charts it can be seen that, at any single pressure, the refrigerant can exist as a sub cooled liquid, a saturated vapour or a superheated gas. If the liquid and gas states of the refrigerant are both present in one place, the refrigerant is at its saturation temperature. If liquid is present, it may be at the saturation temperature or may be below the saturation temperature (sub cooled liquid). A temperature reading will be needed in addition to determine its condition. The same applies for gas.

In a refrigerant cylinder if liquid and gas both are present then cylinder pressure will be corresponding to atmospheric temperature if it has been stored for longer duration for conditions to stabilize. In winter the cylinder pressure will be less and it would be difficult to charge gas in the system.

PRESSURE CONVERSION FACTORS

760 mm of Hg = 1 Atmosphere (atm)
= 14.7 psi.
= 29.92 inches of mercury
= 1.0132 bar x100 =101.32 Kpa
= 1.033 kg/sq.cm
= 101.325 Kpa
= 10.34 M of Water
= 34 ft of water

1 kg/sq.cm. = 735.559 mm Hg (at-technical atmosphere)
= 28.959 inches of Hg
= 14.223 psi
= 0.98 bar
= 98.066 Kpa

1bar = 750 mm Hg
= 1.019 Kg/sq.cm.
= 14.5 psi
= 100 Kpa

1 inch of water pr. Diff. = 249 pa
1 mm of water pr. Diff = 9.8 .Pa
1 psi = 6.895 Kpa

Temperature	**Absolute Zero**	**Freezing Point ,**	**Boiling Point,**

Scale		WATER	WATER
Celsius	-273	0	100
Kelvin	0	273	373
Fahrenheit	-460	32	212
Rankin	0	492	672

In the first module we have covered Refrigeration fundamentals, temperature, heat, heat transfer, pressure and relationship with each other of these terminologies, enthalpy.

In the next module we shall deal with pressure –enthalpy diagrams, temperature –entropy diagrams and how to make use of these in designing, trouble shooting and analyzing performance of the operating systems with a view to optimize cycle efficiencies.

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