# CC 11 FOOD ENGINEERING

## UNIT 5 – Introduction to Refrigeration and Freezing (Part- 1)

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In the present module following topics are covered

1. Introduction
2. Concept and selection of a refrigerant
   2.1 Definition of refrigerant
   2.2 Commonly used refrigerants
   2.3 Numbering system of refrigerants
   2.4 Selection of refrigerants
3. Description of a refrigeration cycle
   2.1 Components of refrigeration system
   2.2 Refrigeration cycle
   2.3 Pressure enthalpy diagram of refrigeration cycle
   2.4 Coefficient of performance

### 1. Introduction

Refrigeration, as an indispensible part of food preservation is practiced for majority of foods such as meats, fruits, vegetables, beverages, dairy products etc. In general terms, refrigeration is the production of cold confinement relative to its surroundings i.e. the process of extracting heat from a lower-temperature and transferring it to a higher-temperature heat sink. In the case of refrigeration, the idea is to slow bacterial action to a crawl so that it takes food much longer (perhaps a week or two, rather than half a day) to spoil. Here, refrigerant is the medium by which removal and relocation of heat takes place. Common refrigerants used in various applications are ammonia, sulfur dioxide, and non-halogenated hydrocarbons such as propane.

### 2. Concept and selection of a refrigerant

### 2.1 Definition of refrigerant

Refrigerant in a refrigerating system is the medium of heat transfer which picks up heat by evaporating at a low temperature and pressure, and gives up heat on condensing at a higher temperature & pressure, during this process the refrigerant usually involves change of state.

### 2.2 Classification of refrigerants

Refrigerants are classified according to their way of absorption or extraction of heat from substances stored in the refrigerator. The classes are:

- Primary refrigerants
- Secondary refrigerants

**Primary refrigerants**

Primary refrigerants are those fluids, which are used directly as working fluids, for example in vapor compression and vapor absorption refrigeration systems. These change its state upon the application or absorption of heat, and, in this act of change, absorbs and extracts heat from the area or substance.

The primary refrigerant is so termed because it acts directly upon the area or substance, although it may be enclosed within a system. For a primary refrigerant to cool, it must be placed in a closed system in which it can be controlled by the pressure imposed upon it. The refrigerant can then absorb at the desired temperature range. If a primary refrigerant were used without being controlled, it would absorb heat from most perishables and freeze them solid.

Eg. Ammonia, Freon, $SO_2$, $CO_2$etc

Ammonia ($NH_3$)

- Used for commercial purposes. Mainly in cold stored and ice plants
- The boiling temperature of $NH_3$ is -33$^0$C
- It is colorless gas with a sharp pungent smell
- Has good thermodynamic properties
- It is neutral to all metals, highly soluble in oil.
- It’s solubility increases with increasing pressure and decreasing temperature
- Used for small and medium refrigerating capacities
- Volatile and non toxic but in higher concentration suffocation occur due to lack of O2

Freon 12 (Mono chloro-triflurometh ane) ($CCl_2F_2$)

- It is non-toxic, non-flammable, and non-explosive, therefore it is most suitable refrigerant.
- It is fully oil miscible therefore it simplifies the problem of oil return.
- The operating pressures of R-12 in evaporator and condenser under standard tonne of refrigeration are 1.9 bar abs. and 7.6 bar abs.
- Its latent heat at – 15°C is 161.6 kJ/kg.
- C.O.P. = 4.61.
- It does not break even under the extreme operating conditions.
- It condenses at moderate pressure and under atmospheric conditions.

**Secondary Refrigerants**

Secondary refrigerants are substances, such as air, water, or brine. Though hot refrigerants in themselves, they have been cooled by the primary refrigeration system; they pass over and around the areas and substances to be cooled; and they are returned with their heat load to the primary refrigeration system. Secondary refrigerants pay off where the cooling effect must be moved over a long distance and gastight lines cost too much.

Eg. Brine solution made of calcium chloride or sodium chloride

Another broad classification of refrigerants is shown in Figure1.These are further explained in section 1.3 and 1.4 of this chapter.

## 2.3 Commonly used refrigerants

The most common types of refrigerants in use nowadays are presented below:

- Halocarbons or freons
- Azeotropic refrigerants
- Zeotropic refrigerants
- Inorganic refrigerants like carbon dioxide, ammonia, water and air
- Hydrocarbon refrigerants

Halocarbons are generally synthetically produced. Depending on whether they include chemical elements hydrogen (H), carbon (C), chlorine (Cl) and florine (F) they consist of the following:

CFCs (Chlorofluorocarbons)
HCFCs (Hydrochlorofluorocarbons)
HFCs (Hydrofluorocarbons)

**Zeotropic and azeotropic mixtures**

Azeotropic mixtures are mixtures of two or more refrigerants whose vapour and liquid phases retain identical compositions over a wide range of temperatures. Typical examples of azeotropic mixtures can be seen below:

R-502 : 8.8% R22 and 51.2% R115
R-503 : 40.1% R23 and 59.9% R13

A zeotropic mixture mixture is one whose composition in liquid phase differs to that in vapour phase. Consequently, unlike azeotropic refrigerants, zeotropic refrigerants do not boil at constant temperatures.

Typical examples of zeotropic mixtures can be seen below:

R404a : R125/143a/134a (44%,52%,4%)
R407c : R32/125/134a (23%, 25%,
R410a : R32/125 (50%, 50%)

## 2.4 Numberingsystem of refrigerants

The basic structure of the numbering system (Figure 2.) is the “chemical group” of refrigerant, followed by a dash (-) and a series of numbers and letters. For example, HFC-134 is represented by “HFC” as its chemical group and “134,” which identifies the chemical composition of the refrigerant. In years past “R” was used instead of the refrigerant’s chemical group. HFC-134 would have been referred to as R-134.

Numbering of refrigerants as per their chemical structure and composition is explained below:

(i)For saturated hydrocarbons and their derivatives– three digit number

First digit = C – 1 = one less than the 'C' atoms in the compound
Second digit = H + 1=one more than the 'H' atoms in the compound
Third digit = Number of fluorine atoms
For example:

$C_2H_2Cl_2F_2$ = R-132

$CH_4$ = R-50

(ii)For unsaturated hydrocarbons and their derivatives– four digit number

First digit = 1 (number of double or triple bonds)
Second digit = C-1 = one less than the 'C' atoms in the compound
Third digit = H + 1=one more than the 'H' atoms in the compound
Fourth digit = Number of fluorine atoms
For example:

$C_2Cl_2F_2$ = R-1112
$C_2H_2$ = R-1130

(iii) Inorganic compounds—700 + molecular weight
For example:

Water = R-718
Air = R-729
$NH_3$ = R-717

(iv)Azeotropes
These are numbered starting from R-500. First known azeotrope in refrigeration has been numbered as R-500.Next known azeotropeis numbered as R-501 and so on.

## 2.5 Selection of a refrigerant

Refrigerants are widely used in Refrigeration cycle where cooling effect below the atmospheric temperatures are needed. Whenever we choose them for particular use their properties play a vital role in selection of a refrigerant. Here are some of the desirable properties of refrigerant explained in detail.

### Desirable Physical Properties of Refrigerants

**Low Freezing Point**:Refrigerants should have low freezing point than the normal operating conditions. It should not freeze during application.

**Low Condensing Pressure**: The lower the condenser pressure the power required for compression will be lower. Higher condenser pressure will result in high operating costs.

If Boiling Point is Low, High Condenser Pressure – Reciprocating Compressor is used. Eg: Ammonia, R22, R12 etc

If Boiling Point is High, Low Condenser Pressure – Centrifugal Compressor is used. Eg: R11, R13 & R114 etc

**High Evaporator Pressure**: This is the most important property of refrigerant. In a negative pressure evaporator Atmospheric air or Moisture will Leak into the system. The moisture inside the system will start freezing at low temperature zones and clogs and chokes the system.

Atmospheric air ingression into the system will occupy the heat transfer area and results in poor heat transfer rates. Presence of air will reduce the partial pressure of refrigerant and the condensation temperature will rise. It increasers the condenser pressures and thereby the power consumption for the compressor will also rise.

Due to the above disadvantages, Positive evaporator pressure is preferred. Leak outside the system results in refrigerant loss and it can be identified easily and refrigerant loss can be topped up. Moderately high evaporator pressure boosts the compressor suction pressure thus reduces the power costs.

**High Critical Pressure**: Critical pressure of the refrigerant should be higher than the condenser pressures. Otherwise the zone of condensation decreases and the heat rejection occurs.

**High Latent Heat of Vaporization**: Higher latent heat of vaporization of the refrigerant will result in lower mass flow rates according to the Heat transfer equation. If the mass flow is very small it is difficult to control the flow rates.

**High Heat Transfer Coefficient:** Higher heat transfer coefficient requires smaller area and lower pressure drop. This makes the equipments compact and reduced the operating cost.

**Boiling point**: The liquid has to vaporize at the evaporator coil to cause cooling. The liquid at the evaporator coil should therefore vaporize easily, otherwise the compressor will have to create too much of vacuum to cause the liquid to vaporize. Thus, ‘Boiling Point’ of the refrigerant should be low.

**Specific volume**: It should have low specific volume to reduce the size of the compressor.

**Thermal conductivity**: It must have high thermal conductivity in both liquid and vapor phase to reduce the area of heat transfer in evaporator and condenser and for higher heat transfer coefficients.

**Coefficient of performance**: It should give high COP (Coefficient of performance) in the working temperature range. This is necessary to reduce the running cost of the system.

**Chemical Properties**

**Toxicity**: Toxicity is the important properties of refrigerants. The refrigerants should be non poisonous to humans and food stuff. The toxicity depends upon the concentration and exposure limits.

**Low water Solubility:** Most of the refrigerants form acids or bases in the presence of water. This will cause corrosion and deteriorates valves, Seals and Metallic parts.

**Reactivity**: The refrigerants should not react with the materials used in refrigeration cycle like evaporators, condenser tubes, compressors, control valves etc. Most of the refrigerants form acids with water. $CCl_2F_2$, $CH_4Cl$ can form HCl with water which dissolves the copper from condenser tubes and deteriorates the life of the machinery.

**Environmental Effects of Refrigerants**

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:

**Leakage Detection:**Ammonia and $SO_2$ can be detected by their characteristic smell. Strong smelling chemicals like acrolein may be added to refrigerant for easy leak detection.

Freon leak can be detected by a halide torch. It consists of an alcohol lamp that emits a blue flame. If Freon is present blue flame turns into green. This test is based on Beilstein Test for Chlorine.

**Flammability** The refrigerant should not make combustion mixture in Air. Freon, Carbon Dioxide, $SO_2$ are non flammable. Methane, butane and other hydrocarbons are flammable. Ammonia will form explosive mixture when the concentration in air is between 16 to 25 %.

**ODP** The ozone depletion potential (ODP) of a refrigerant is the relative amount of depletion to the ozone layer it can cause. ODP of R11 is fixed as the maximum value of 1.0. According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances.

**Toxicity**: Ideally, refrigerants used in a refrigeration system should be nontoxic. 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. 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-$COCl_2$).

**Economics of Refrigerants**

**Cost of refrigerants:** It should be economical.

**Availability:** Refrigerants should be readily available near the usage point. It must be sourced and procured within a short span of time to enable the user in case of leaks, maintenance schedules etc.

## 3. Refrigeration cycle

### 3.1 Components of a refrigeration system

There are five basic components of a refrigeration system, these are:

- Evaporator
- Compressor
- Condenser
- Expansion Valve
- Refrigerant; to conduct the heat from the product

**Evaporator:** The purpose of the evaporator is to remove unwanted heat from the product, via the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low-pressure.

To enable the transfer of heat, the temperature of the liquid refrigerant must be lower than the temperature of the product being cooled. Once transferred, the liquid refrigerant is drawn from the evaporator by the compressor via the suction line. When leaving the evaporator coil the liquid refrigerant is in vapour form.

**Compressor:** The purpose of the compressor is to draw the low-temperature, low-pressure vapour from the evaporator via the suction line. Once drawn, the vapour is compressed. When vapour is compressed it rises in temperature. Therefore, the compressor transforms the vapour from a low-temperature vapour to a high-temperature vapour, in turn increasing the pressure. The vapour is then released from the compressor in to the discharge line.

**Condenser:** The purpose of the condenser is to extract heat from the refrigerant to the outside air. The condenser is usually installed on the reinforced roof of the building, which enables the transfer of heat. Fans mounted above the condenser unit are used to draw air through the condenser coils. The temperature of the high-pressure vapour determines the temperature at which the condensation begins. As heat has to flow from the condenser to the air, the condensation temperature must be higher than that of the air; usually between - 12°C and -1°C. The high-pressure vapour within the condenser is then cooled to the point where it becomes a liquid refrigerant once more, whilst retaining some heat. The liquid refrigerant then flows from the condenser in to the liquid line.

**Expansion Valve:**The high-pressure liquid reaches the expansion valve, having come from the condenser. The valve then reduces the pressure of the refrigerant as it passes through the orifice, which is located inside the valve. On reducing the pressure, the temperature of the refrigerant also decreases to a level below the surrounding air. This low-pressure, low-temperature liquid is then pumped in to the evaporator.

### 3.2 Refrigeration cycle

Vapor compression refrigeration cycle (Figure 3.) is the common method for transferring heat from a low temperature to a high temperature. The refrigeration cycle begins with the refrigerant in the evaporator. At this stage the refrigerant in the evaporator is in liquid form and is used to absorb heat from the product. When leaving the evaporator, the refrigerant has absorbed a quantity of heat from the product and is a low-pressure, low-temperature vapour.

This low-pressure, low-temperature vapour is then drawn from the evaporator by the compressor. When vapour is compressed it rises in temperature. Therefore, the compressor transforms the vapour from a low-temperature vapour to a high-temperature vapour, in turn increasing the pressure.

This high-temperature, high-pressure vapour is pumped from the compressor to the condenser and here it is cooled by the surrounding air, or in some cases by fan assistance. The vapour within the condenser is cooled only to the point where it becomes a liquid once more. The heat, which has been absorbed, is then conducted to the outside air.

At this stage the liquid refrigerant is passed through the expansion valve. The expansion valve reduces the pressure of the liquid refrigerant and therefore reduces the temperature. The cycle is complete when the refrigerant flows into the evaporator, from the expansion valve, as a low-pressure, low-temperature liquid.

### 3.3 Coefficient of Performance

Just like the efficiency of power cycles, the COP is defined as the ratio of the desired output to the required input. We do not call this efficiency because it is generally greater than 1. So, instead, we call it the coefficient of performance.
Figure 4describes the refrigeration of a food product with heat inputs and outputs

$$COP_R = \frac{Q_C}{W_{ref}} = \frac{\text{Coolingeffect}}{\text{Workinput}} \qquad \text{Equation 1.1}$$

Here in above equation,

$Q_C$ is the amount of heat removed from the food product

$W_{ref}$ is the Work input

According to first law of thermodynamics,

$$W_{ref} = Q_H - Q_c \qquad \text{Equation 1.2}$$

Substituting $W_{ref}$ from equation 1.2 to equation 1.1, we will get

$$COP_R = \frac{Q_C}{Q_H - Q_c} \qquad \text{Equation 1.3}$$

Further simplification will result in following equation,

$$\mathrm{COP_R} = \frac{1}{{}^{Q_H}/_{Q_C} - 1} \qquad \text{Equation 1.4}$$

From Equation 1.4 it is clear that why $COP_R$ is generally greater than 1
As per the first law of thermodynamics, $Q_H = Q_C + W_{ref}$. Therefore, $Q_H$ is greater than $Q_C$
So, $COP_R$ is always a positive number, but, as long as $Q_H/Q_C$ is $< 2$, the $COP_R$ is $> 1$. This is almost always the case.

**Conclusion**

In the present module, concept and selection of refrigerants were detailed, which are essential in understanding the refrigeration efficiency and related processes. Under the concept of refrigerants, numbering system and selection of refrigerants were focused. In the later section refrigeration cycle which is the basis of refrigeration was discussed, related to it are the pressure enthalpy diagrams and coefficient of performance of a refrigeration system. Coefficient of performance gives us the performance efficiency of the refrigeration system.