

# Principles of Refrigeration

Characteristics of Refrigerants

# Refrigerants characterization

- Refrigerants are characterized based on their: **1**- thermal properties such as their enthalpy, latent heat of vaporization..etc. **2**- Hazard degree, which includes their toxicity and flammability **3**-environmental considerations (ozone depletion) **4**-Oil miscibility. **5**- practicality when charged and dismissed.
- The international standardization that the refrigerants are classified is the American standard ANSI/ASHRAE 34 published in 2001 and entitled “Designation and Safety Classification of Refrigerants” . This classification makes it possible to designate all refrigerants used in a clear internationally recognized manner by classifying them according to their chemical composition and hazard degree.

## 2 Safety group classifications

This classification consist of two alphanumeric characters (e.g. A2); the capital letter corresponds to toxicity and the digit to flammability.

### 2.1 Toxicity classification

Refrigerants are divided into two groups according to toxicity:

- Class A signifies refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm;
- Class B signifies refrigerants for which there is evidence of toxicity at concentrations below 400 ppm.

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## 2.2 Flammability classification

Refrigerants are divided into three groups according to flammability:

- Class 1 indicates refrigerants that do not show flame propagation when tested in air at 21°C and 101 kPa;
- Class 2 indicates refrigerants having a lower flammability limit of more than 0.10 kg/m<sup>3</sup> at 21°C and 101 kPa and a heat of combustion of less than 19 kJ/kg;
- Class 3 indicates refrigerants that are highly flammable as defined by a lower flammability limit of less than or equal to 0.10 kg/m<sup>3</sup> at 21°C and 101 kPa or a heat of combustion greater than or equal to 19 kJ/kg.

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# Classification of a few refrigerants

Classification	Denomination	Composition or chemical formula	Safety classification
		<i>(mass percentage)</i>	
<b>INORGANIC COMPOUND</b>			
R717	ammonia	NH <sub>3</sub>	B2
R718	water	H <sub>2</sub> O	A1
R744	carbon dioxide	CO <sub>2</sub>	A1
<b>ORGANIC COMPOUND</b>			
<b>Hydrocarbons</b>			
R170	ethane	CH <sub>3</sub> CH <sub>3</sub>	A3
R290	propane	CH <sub>3</sub> CH <sub>2</sub> CH <sub>3</sub>	A3
R600a	isobutane	CH(CH <sub>3</sub> ) <sub>2</sub> CH <sub>3</sub>	A3

## Halocarbons

### Chlorofluorocarbons (CFCs) and Bromofluorocarbons (BFCs)

R11	trichlorofluoromethane	$\text{CCl}_3\text{F}$	A1
R12	dichlorodifluoromethane	$\text{CCl}_2\text{F}_2$	A1

### Hydrochlorofluorocarbons (HCFC)

R22	chlorodifluoromethane	$\text{CHClF}_2$	A1
R141b	1,1-dichloro-1-fluoroethane	$\text{CH}_3\text{CCl}_2\text{F}$	A2
R142b	1-chloro-1,1-difluoroethane	$\text{CH}_3\text{CClF}_2$	A2

### Hydrofluorocarbons (HFCs)

R32	difluoromethane	$\text{CH}_2\text{F}_2$	A2
R125	pentafluoroethane	$\text{CHF}_2\text{CF}_3$	A1
R134a	1,1,1,2-tetrafluoroethane	$\text{CH}_2\text{FCF}_3$	A1
R143a	1,1,1-trifluoroethane	$\text{CH}_3\text{CF}_3$	A2
R152a	1,1-difluoroethane	$\text{CH}_3\text{CHF}_2$	A2

Azeotropic mixtures			
R502		R22/R115 (48.8/51.2)	A1
R507		R125/R143a (50/50)	A1
Zeotropic mixtures			
R404A		R125/R143a/R134a (44/52/4)	A1
R407C		R32/R125/R134a (23/25/52)	A1
R410A		R32/R125 (50/50)	A1

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# Refrigeration system Reaction

- Lubricating oil is added to reduce friction associated with the moving components within the compressor.
- Refrigerants and lubricating oils should be chemically and physically stable so that neither substance is adversely affected by their mixing. Sulfur dioxide and halocarbons experience minor reactions with the lubricating oil.
- To avoid the problem the system should be dry, clean, good lubricating oil should be used and the temperature should be controlled, as operating at high temperature causes carbonaceous deposits to form on the piston head, discharge valves and in the discharge line



- Copper plating is another reaction occur in systems including halocarbon R's. Copper atoms are leached from tubing or piping and deposited on the hot steel surface, which changes the size, tolerances and friction characteristics of the affected parts. This is mostly due to poor quality lubricating oils and moisture.

# Oil-Miscibility

- Miscibility is the ability of the R to disperse into the oil or the oil to disperse into the R, without changing each other properties.
- Oil miscibility is important in the design of the compressor, refrigerant piping and other system components.
- R's are divided into groups based on their oil-miscibility:
  - 1- R's that are miscible with oil in all proportions under all conditions.
  - 2- R's that are miscible under conditions found in the condenser and separate under conditions in the evaporator
  - 3- R's that are very slightly or not miscible under all conditions found in the system.

## Effect of Oil-Miscible R's

- Dilution of oil in the crankcase of the compressor, which means low viscosity and poor lubrication. To overcome this problem it is recommended to use thicker oils that if mixed with oil-miscible R's will stay with enough viscosity to lubricate the system.
- The other effect is some inefficiencies in the in other components of the refrigeration system such as the condenser and the evaporator.
- Excessive oil circulating in the system may indicate that the level in the crankcase has fallen below that required for adequate lubrication of the compressor.

# Effect of moisture

- Moisture combines in varying degrees with most of the commonly used R's, which in turns react with lubricating oils and with other materials.
- The major effect of moisture presence is corrosion in different parts such as valves, seals, bearing journals, cylinder walls and other polished surfaces in the system. It also may affect the electric insulation in the system and cause short circuits between windings and other groundings components.
- There are two types of moisture reactions:  
1- freeze-ups 2- Hydrolysis

## Freeze-ups

- Moisture may exist in a refrigerating system as free water or as solution.
- Free water normally exist when the moisture content in the R exceeds the amount it can hold, this excess water then appears as free water.
- Free water then becomes ice inside mainly the evaporator tubes, where T is below the icing temp. of water, which is called freeze-up.
- When freeze-ups occurs the metering device temporarily stops the R flow, which results in rising up the system temperature that leads in damages in the stored food or shorting its freezing life.
- R's are different in their moisture capacity. Straight hydrocarbons have very low capacity, while ammonia has very high one.

# Hydrolysis

- Some R's can hold enough moisture to cause corrosion without showing any hint like freeze-ups.
- In this case another reaction is taking place, which is called hydrolysis that is the name given to any chemical reaction involving water as one of the reacting substances.
- Hydrolysis can change the acidity of the system and sometimes results in forming new materials like aqua-ammonia in the ammonia systems
- High temp. Ref. Systems having evaporator temp. around 4.4C are subject to higher levels of corrosion as moisture is kept unnoticed for longer time.

# Overcoming Moisture Recommendation

- Chose carefully the appropriate refrigerant for a certain system
- Good quality lubricating oil
- Good control on the operating temperature especially the compressor discharge temperature.
- Devices called filter-driers are used to absorbed moisture after evacuation and discharge.
- Sight glasses having a hygroscopic material is used as it change its color due to moisture presence, which gives warning for maintenance.

# Economical, Environmental and other considerations

- From economical point of view the refrigerant is preferable to physical and chemical characteristics that minimize the energy requirements, which in turns increase the COP.
- Properties that influence the system's capacity and efficiency are: 1- Latent heat of vaporization 2- the specific volume of the R vapor 3- the specific heat of the refrigerant in both liquid and vapor states.
- High latent heat is desirable as it reduces the mass flow rate, and if accompanied by low vapor Sp.V the efficiency and capacity of the compressor is greatly increased.



- In small systems, R with low Sp.heat ( $C_p$ ) in its liquid state with high Sp.heat ( $C_p$ ) in its vapor state is required as this increases the refrigeration effect per unit mass of R.
- High Sp.heat for the vapor decreases the superheating effect by R in the evaporator, suction line and compressor.
- A low Sp.heat for the liquid phase of R increases the sub cooling effect in the condenser, receiver and liquid line.
- As the power required per unit of refrigeration capacity is the same for most known R's, thence power and economy of use may not be the deciding factor.

# Important considerations for the selection of R.

- Environmental impact of leaks
- The safety of persons and product exposed to the refrigerant.
- R properties that reduce the size, weight and initial cost of the equipment.
- Characteristics that minimize equipment maintenance
- The cost and availability of the refrigerant.

# Leak detection

- it is employing safe methods of locating breaches in the refrigeration system that allows the escape of refrigerant and oil and the entry of air and moisture.
- There are two types of leak: inwards, outwards.
- In the inwards leak air and moisture are entering the system and in the outward leak R is leaving the system.
- The determinant factor is the pressure.
- The outwards leak is the most dangerous on us and on the environment, so detection devices are required.

# 1- Soap bubbles

- Is considered the easiest way to detect leakage
- It is mainly used with straight hydrocarbon R's
- To effectively test a system using soap bubbles its pressure should be at least 50psi (344.7 KPa)
- The soap used should be relatively viscous
- The procedure is simply applying soap to the piping system and waiting for few minutes until bubbles are detected.

## 2- Halide torch

- A halide torch is often used to detect leaks in systems employing any of halocarbon refrigerants
- The halide torch consists of a copper element that is heated by a flame created through the combustion of propane and air that is drawn in through a rubber tube connected to the base of the torch.
- Once ignited the air fuel mixture heats the copper until it glows.
- After the copper reaches its operating temperature, the free end is passed over the suspected places for leakage.
- The presence of a halocarbon vapor is indicated by color change to a bright green, blue or purple, which is due to a chemical reaction.
- The larger the leak the greater change in color.

- **Warning:** the combustion of halocarbon R's produces highly toxic phosgene gas. So, the test should be performed in a well ventilated space, also there must not be any presence of combustible vapors or and explosive materials.

## 3- Electronic leak detectors

- Very sensitive devices and capable of measuring leaks as small as 1/100.
- They should not be employed where flammable or explosive vapors may present
- They are even large cabinet at the manufacturing place or portable for field testing.
- They are passed on the changes in the electric current flowing across an air gap formed between two platinum electrodes.
- When R is present this current changes due to the R percentage, which recorded by a meter.

## Isolation of the Sealed System

- This is a time consuming method of the standing hold test but is sometimes your only choice. It is usually used when you have no physical access to components in which you suspect are leaking or when you want to identify which part of the system contains the leak. Some examples might be: a concealed refrigerant line, an in-wall condenser, an in-wall evaporator, or any component in which you do not have access to.
- This process would include isolation of the component (suspected of leaking) from the rest of the system. This is done by breaking that part of the system apart from the rest of system, sealing it, and pressurizing only that component with dry nitrogen. Then use the standing hold test covered before. If the system's pressure drops fast, there is a large leak present in that component or section of the system. If the system's pressure drops slowly, there is a small leak present. If the pressure remains the same, that component does not leak.
- This method can limit your leak detection labor time only if the system can be out of order for a period of time. Once the component leaking is identified, determine if repairs can be made or not. If not, that particular component can be replaced if it at all possible.
- A process tube adapter kit could save you some time. It can be quickly connected to the part of the system that has been cut out. This eliminates having to make a mechanical or brazed connection.



# Refrigerant Drying Agents

- Refrigerant drying agents are used to remove moisture acids and other contaminants from the refrigerant-oil mixture that circulates through a system.
- These agents are called desiccants. Some familiar desiccants are silica gel (silicon dioxide), activated alumina (aluminum oxide).
- Desiccants are available in granular, bead or formed cores consisting of desiccant granules held together.
- The refrigerant-oil mixture is removed by *adsorption*.
- More than one desiccants may be combined together so that they can absorb more types of contaminants.
- The desiccants are contained with a cylindrical steel or copper tube with fittings or connections called a filter-drier.
- Filter-driers are mainly installed at the liquid line of the system. Sometimes they are installed at the suction line after maintenance or burn-out.

# Refrigerants

- In earlier days it was ammonia and carbon dioxide for few large applications.
- Methylene chloride and sulfur dioxide were then developed for small and domestic applications.
- Methylene chloride + carbon dioxide were used in air conditioning.
- Halocarbons were invented late 1920s to replace most of the refrigerants apart from ammonia.
- Halocarbons are mainly methane+ ethane (*hydrocarbons family*) with some added atoms like chlorine, fluorine and/or bromine (*halogen family*).

## Names of Refrigerants (halocarbons)

- $\text{CH}_4$  (R-50) 1 C +4 H
- If one atom of H is replaced by other atoms like Cl then the number decreases e.g.  $\text{CH}_3\text{Cl}$  (methyl chloride) R-40,  $\text{CH}_2\text{Cl}_2$  R-30,  $\text{CHCl}_3$  R-20.
- If fluorine is added then the last digit- as ASHRAE standards- indicates the fluorine atoms in the molecule e.g.  $\text{CHCl}_2\text{F}$  (dichlorofluoromethane) and chlorodifluoromethane  $\text{CHClF}_2$ , which are R-21 and R-22 respectively as the second digit is the fluorine number.
- Also we have the ethane series refrigerant  $\text{CH}_3\text{CH}_3$  (R-170) from which R-114, R-113, R-134 are derived. The last digits also indicate the fluorine number.
- R-134a is a new compound that may not affect the earth's ozone layer. other ozone friendly R's are R-125, R-143a and R-152a.
- Montréal protocol (1987) had mentioned the harmful effect of these R's on the ozone.

- Straight hydrocarbons are a group of fluids composed of hydrogen and carbon only, like  $\text{CH}_4$  (R-50),  $\text{CH}_3\text{CH}_3$  (R-170), butane (R-600), isobutan (R-600a), propene (R-1270).
- Hydrocarbon are limited in use for ultra low temperature application, where experienced workers are in attendance.

# 1 Numbering of Refrigerants

An identifying number shall be assigned to each refrigerant. It consists of a prefix made up of letters and a suffix made up of digits.

## 1.1 Prefixes

The prefix is composed of the letter R (for refrigerant).

Examples: R22, R134a, R600a, R717

Sometimes, the letter C is used in the prefix to denote carbon, preceded by B, C or F (or a combination of these letters in the same order) to indicate the presence of bromine, chlorine or fluorine. Compounds containing hydrogen must be preceded by the letter H.

Examples: HCFC22, HFC134a

These prefixes must only be used in non-technical publications.

Note: the name of the brand or of the manufacturer is also used sometimes; these names must not be used in official documents (identification labels, etc.).

## 1.2 Suffixes

- **Hydrocarbons and derivatives**

The first digit on the right (units) is the number of fluorine (F) atoms.

The second digit on the right (tens) is one more than the number of hydrogen (H) atoms.

The third digit on the right (hundreds) is one less than the number of carbon (C) atoms (when the digit is zero, it is omitted from the number).

The third digit on the right (thousands) is equal to the number of unsaturated carbon-carbon bonds (when the digit is zero, it is omitted from the number).

For refrigerants that contain bromine (Br), the letter B is added after the identification number, followed by the number of atoms present. These refrigerants are no longer manufactured in developed countries since the application of the Montreal Protocol on substances that deplete the ozone layer.

The number of chlorine (Cl) atoms is found by subtracting the sum of fluorine, bromide, and hydrogen atoms from the total number of atoms that can be connected to the carbon atoms: 4 for methane derivatives ( $\text{CH}_4$ ), 6 for ethane derivatives ( $\text{C}_2\text{H}_6$ ), etc.

Example: R22 (chlorodifluoromethane –  $\text{CHClF}_2$ )

**R022**

0: Number of carbon atoms – 1

2: Number of hydrogen atoms + 1

2: Number of fluorine atoms

Number of chlorine atoms : 1

(i.e. 4 minus 1 hydrogen atom and minus 2 fluorine atoms)

For cyclic derivatives, the letter C is used before the refrigerant's identification number.

Example: RC318 (octafluorocyclobutane –  $\text{C}_4\text{F}_8$ )

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# Zeotropic and Azeotropic R's

- Zeotropic and azeotropic refrigerants are mixtures of individual refrigerants that have different performance characteristics. Under certain conditions, the refrigerant can separate into their component constituents.
- They must be charged into the system in their liquid state to avoid changing the composition.
- The temperature at which the last drop of liquid in the mixture has vaporized at the stated pressure is called the dew point temperature.
- The saturated condensing temperature when the last bit of vapor has condensed at a stated pressure is called the bubble point temperature.

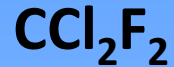


Refrigerant name	Constituents	Application
R-402a	60% R-125, 38% R-22 and 2% R-290	Medium temperature applications
R-402b	60% R-22, 38% R-125 and 2% R-290	Medium to relatively low temperature applications
R-401a (to replace R-12)	53% R-22, 13% R-152a and 34% R-124	<ul style="list-style-type: none"> <li>- Walk in coolers</li> <li>- Food and diary display cases</li> <li>- Beverage dispensers</li> <li>- Home refrigerators</li> </ul>
R-401b	61% R-22, 11% R-152a and 28% R-124	<ul style="list-style-type: none"> <li>- Replacement for R-500 in some air conditioning applications</li> </ul>

# The characteristics of Refrigerants

- A standard refrigeration conditions per ton of refrigeration are used to describe the characteristics of refrigerants.
- These conditions are 5<sup>0</sup> F (-15<sup>0</sup> C) evaporator temperature, 86<sup>0</sup> F (30<sup>0</sup> C) condensing temperature and saturated suction vapor entering the compressor.

## R-12 (Dichloro-Difluoromethan)



- Has been the most widely used of all of the vapor-compression cycle refrigerants, in domestic and commercial refrigerators, automotive-air-conditioning, liquid chillers, dehumidifiers, ice makers and transport refrigeration.
- It is nontoxic, nonflammable and nonexplosive.
- When brought to contact with an open flame or an electrical heating it produces a highly colorless poisonous gas, called phosgen gas.
- R-12 is oil-miscible under all operating conditions.
- R-12 is not environment friendly refrigerant.

<b>Refrigerant</b>	<b>Hydrocarbon gas</b>	<b>applications</b>	<b>Compressor</b>	<b>Oil-miscibility</b>
R-22 ( Replacing R-12)	Methane	<ul style="list-style-type: none"> <li>-domestic and farm freezers</li> <li>-Commercial and industrial low temperature systems</li> <li>- packaged air-conditioners and liquid chilling</li> </ul>	<ul style="list-style-type: none"> <li>- Small displacement requirement</li> <li>- Centrifugal compressors can be used.</li> </ul>	<ul style="list-style-type: none"> <li>-R-22 is oil-miscible at the condenser temperature and separate at the evaporator temperature.</li> <li>- oil separators are mainly used in the system</li> </ul>
R-717 (Ammonia)	Halocarbon group	Mainly industrial applications now	<ul style="list-style-type: none"> <li>-mainly pump in the absorption system.</li> <li>- compressors can also be used, but special care should be made at the suction line</li> <li>- Rotary centrifugal compressor can be used due to low displacement volume</li> </ul>	<ul style="list-style-type: none"> <li>-Toxic and flammable</li> <li>Good thermal properties</li> <li>- thermal stresses in the system may cause wears</li> </ul>

## Selecting the Right Refrigerant

- Several refrigerants may be used in refrigeration systems such as chlorofluorocarbons (CFCs), ammonia, hydrocarbons (propane, ethane, ethylene, etc.), carbon dioxide, air (in the air-conditioning of aircraft), and even water (in applications above the freezing point).
- **R-11, R-12, R-22, R-134a, and R-502 account for over 90 percent of the market.**
- The industrial and heavy-commercial sectors use *ammonia* (it is toxic).
- **R-11 is used in large-capacity water chillers serving A-C systems in buildings.**
- R-134a (replaced R-12, which damages ozone layer) is used in domestic refrigerators and freezers, as well as automotive air conditioners.
- **R-22 is used in window air conditioners, heat pumps, air conditioners of commercial buildings, and large industrial refrigeration systems, and offers strong competition to ammonia.**
- R-502 (a blend of R-115 and R-22) is the dominant refrigerant used in commercial refrigeration systems such as those in supermarkets.
- **CFCs allow more ultraviolet radiation into the earth's atmosphere by destroying the protective ozone layer and thus contributing to the greenhouse effect that causes global warming. Fully halogenated CFCs (such as R-11, R-12, and R-115) do the most damage to the ozone layer. Refrigerants that are friendly to the ozone layer have been developed.**
- Two important parameters that need to be considered in the selection of a refrigerant are the temperatures of the two media (the refrigerated space and the environment) with which the refrigerant exchanges heat.