Discussion of Past, Present and Future Perspectives of Refrigerants and Its Future Scope

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1 Introduction

There are essentially two categories of thermal plants. These are (i) thermal power plants or work producing plants and (ii) refrigeration/heat pump plants or work consuming plants [1, 2]. The work producing plants or heat engine leads to the conversion of heat to work. The work consuming plants, viz. refrigerators/heat pumps, are not those, which are in any way related to the conversion of work into heat [3–5]. No ingenuity at all is required for the conversion of work into heat. In fact, all work (mechanical/electrical energy) that is consumed in machinery is ultimately dissipated as heat to the environment. The objective of work consuming plants, actually, is to lead to the flow of heat from a low-temperature body to a high-temperature body [6]. The work is consumed to achieve this.

Refrigeration equipment, in general, is relatively smaller in size as compared to work producing plants. The capacity of power plant is in MW, whereas the capacity of refrigeration system is in kW or even less [7, 8]. A very large super cold storage or a central air conditioning plant for a multi-storey building may consume power in the range of 2000–5000 kW. A window-type air conditioner may consume only 2.5 kW of power, domestic refrigerator just 100–250 W only [9].

A refrigerating machine is a device, which will either cool or maintain a body at a temperature below that of the surroundings. Hence, heat must be made to flow from a body at low temperature to the surroundings at high temperature [10]. However, that is not possible on its own. We see the nature that heat spontaneously flows from a high-temperature body to a low-temperature body. Most refrigeration

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devices/plants, including air conditioners and refrigerators, are working the same, which we mention the above process by the principle of second law of thermodynamics [11].

By attaining this, we have to choose the refrigerant as a major part of the refrigeration process. Because refrigerant is main substance used in a heat pump and refrigeration cycle, actually it is a substance or mixture, usually a fluid. Plank has given individual treatment to some 50 inorganic and organic refrigerants, and many more have been discussed in this paper.

2 Refrigerant

Any substance that absorbs heat through expansion or vaporization may be called a refrigerant [1]. Refrigerant is a substance used for refrigeration, causing cooling or refrigeration. Most refrigerants commonly used today are classified into four areas:

- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCS)
- Hydrofluorocarbons (HFCs)
- Natural refrigerants
- Refrigerant blends (azeotropic and zeotropic)

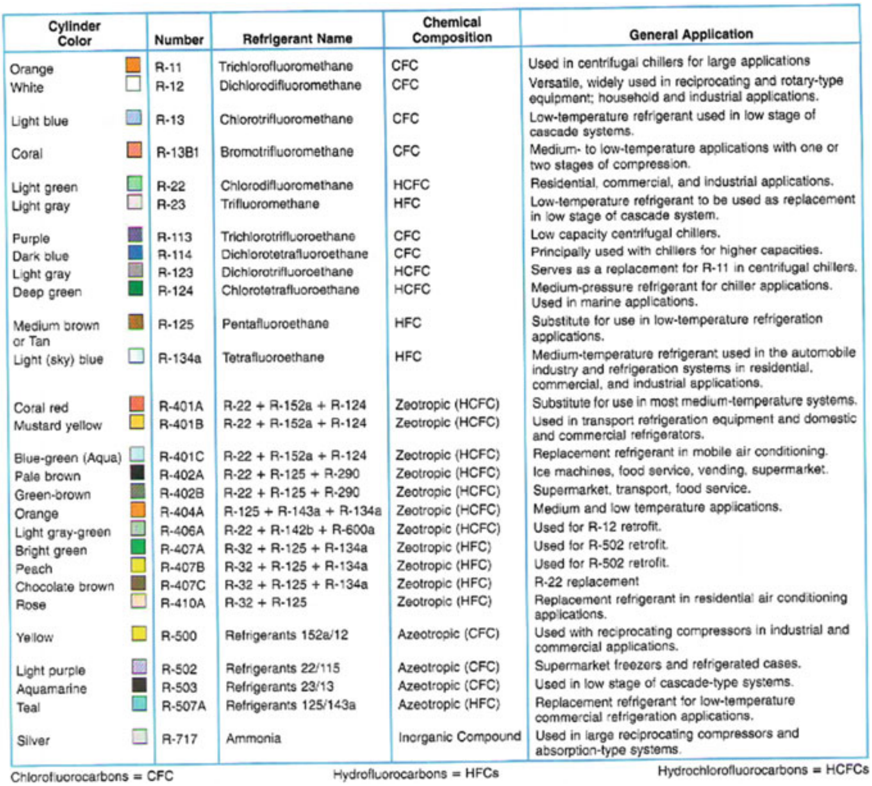
2.1 Refrigerants Identification by Number and Colour Code

Number identifies refrigerants. The number follows the letter which means refrigerant. The American Society of Heating, Refrigerating and Air-conditioning (ASHRE) has standardized this identifying system [1]. Refrigerant cylinders are often colour coded to permit easy identification of the refrigerant they contain [12, 13]. This helps to prevent accidental mixing of the refrigerants within a system. Popular refrigerants, with their R-numbers and cylinder colour codes, are shown in Fig. 1. Cylinder for re-covered refrigerants is grey with yellow ends.

2.2 Chlorofluorocarbon (CFC) Refrigerant

These are the refrigerants, which contain chlorine, fluorine and carbon. R11, R12, R115, etc. are included in CFC refrigerants [14, 15]. This type of coolant can be used for commercial as well as daily purposes [14]. It was developed in the past—in the 30s—and at that time it was non-toxic, non-flammable and non-reactive [15, 16].

But in the early 70s, it was proved that it is hazardous for the layer of ozone and unfriendly for the environment [16, 17]. The chlorine atom splits the extra oxygen



Cylinder Color	Number	Refrigerant Name	Chemical Composition	General Application
Orange	R-11	Trichlorofluoromethane	CFC	Used in centrifugal chillers for large applications
White	R-12	Dichlorodifluoromethane	CFC	Versatile, widely used in reciprocating and rotary-type equipment; household and industrial applications.
Light blue	R-13	Chlorotrifluoromethane	CFC	Low-temperature refrigerant used in low stage of cascade systems.
Coral	R-13B1	Bromotrifluoromethane	CFC	Medium- to low-temperature applications with one or two stages of compression.
Light green	R-22	Chlorodifluoromethane	HCFC	Residential, commercial, and industrial applications.
Light gray	R-23	Trifluoromethane	HFC	Low-temperature refrigerant to be used as replacement in low stage of cascade system.
Purple	R-113	Trichlorotrifluoroethane	CFC	Low capacity centrifugal chillers.
Dark blue	R-114	Dichlorotetrafluoroethane	CFC	Principally used with chillers for higher capacities.
Light gray	R-123	Dichlorotrifluoroethane	HCFC	Serves as a replacement for R-11 in centrifugal chillers.
Deep green	R-124	Chlorotetrafluoroethane	HCFC	Medium-pressure refrigerant for chiller applications. Used in marine applications.
Medium brown or Tan	R-125	Pentafluoroethane	HFC	Substitute for use in low-temperature refrigeration applications.
Light (sky) blue	R-134a	Tetrafluoroethane	HFC	Medium-temperature refrigerant used in the automobile industry and refrigeration systems in residential, commercial, and industrial applications.
Coral red	R-401A	R-22 + R-152a + R-124	Zeotropic (HCFC)	Substitute for use in most medium-temperature systems.
Mustard yellow	R-401B	R-22 + R-152a + R-124	Zeotropic (HCFC)	Used in transport refrigeration equipment and domestic and commercial refrigerators.
Blue-green (Aqua)	R-401C	R-22 + R-152a + R-124	Zeotropic (HCFC)	Replacement refrigerant in mobile air conditioning.
Pale brown	R-402A	R-22 + R-125 + R-290	Zeotropic (HCFC)	Ice machines, food service, vending, supermarket.
Green-brown	R-402B	R-22 + R-125 + R-290	Zeotropic (HCFC)	Supermarket, transport, food service.
Orange	R-404A	R-125 + R-143a + R-134a	Zeotropic (HCFC)	Medium and low temperature applications.
Light gray-green	R-406A	R-22 + R-142b + R-600a	Zeotropic (HCFC)	Used for R-12 retrofit.
Bright green	R-407A	R-32 + R-125 + R-134a	Zeotropic (HFC)	Used for R-502 retrofit.
Peach	R-407B	R-32 + R-125 + R-134a	Zeotropic (HFC)	Used for R-502 retrofit.
Chocolate brown	R-407C	R-32 + R-125 + R-134a	Zeotropic (HFC)	R-22 replacement
Rose	R-410A	R-32 + R-125	Zeotropic (HFC)	Replacement refrigerant in residential air conditioning applications.
Yellow	R-500	Refrigerants 152a/12	Azeotropic (CFC)	Used with reciprocating compressors in industrial and commercial applications.
Light purple	R-502	Refrigerants 22/115	Azeotropic (CFC)	Supermarket freezers and refrigerated cases.
Aquamarine	R-503	Refrigerants 23/13	Azeotropic (CFC)	Used in low stage of cascade-type systems.
Teal	R-507A	Refrigerants 125/143a	Azeotropic (HFC)	Replacement refrigerant for low-temperature commercial refrigeration applications.
Silver	R-717	Ammonia	Inorganic Compound	Used in large reciprocating compressors and absorption-type systems.

Chlorofluorocarbons = CFC Hydrofluorocarbons = HFCs Hydrochlorofluorocarbons = HCFCs

Fig. 1 Colour codes of commonly used refrigerants and their typical applications

atoms in the composition of ozone, and so it is liable for ozone depletion [18]. So, CFCs were banned in the late 80s because of adverse environmental effects [19]. Nowadays, it is estimated that half of the total CFCs have been improved.

R11, R12, R13, R113, R114, R500, R502 and R503 are the top refrigerants covered under the group of CFCs [20]. Some of them are also known for the greenhouse gas effects. These refrigerants are banned (Fig. 3) because of it so high ozone concentration is represent in Fig. 2 to pollutethe environment.

2.3 *Hydrochlorofluorocarbon (HCFC) Refrigerant*

HCFCs were referred to as the substitute for CFCs. It contains hydrogen, chlorine, fluorine and carbon. Of course, it is not like this group's refrigerants that are not at all affecting the layer of ozone [15, 21, 22], but they affect only around 10%, which is extremely less than the CFCs [14, 22, 23].

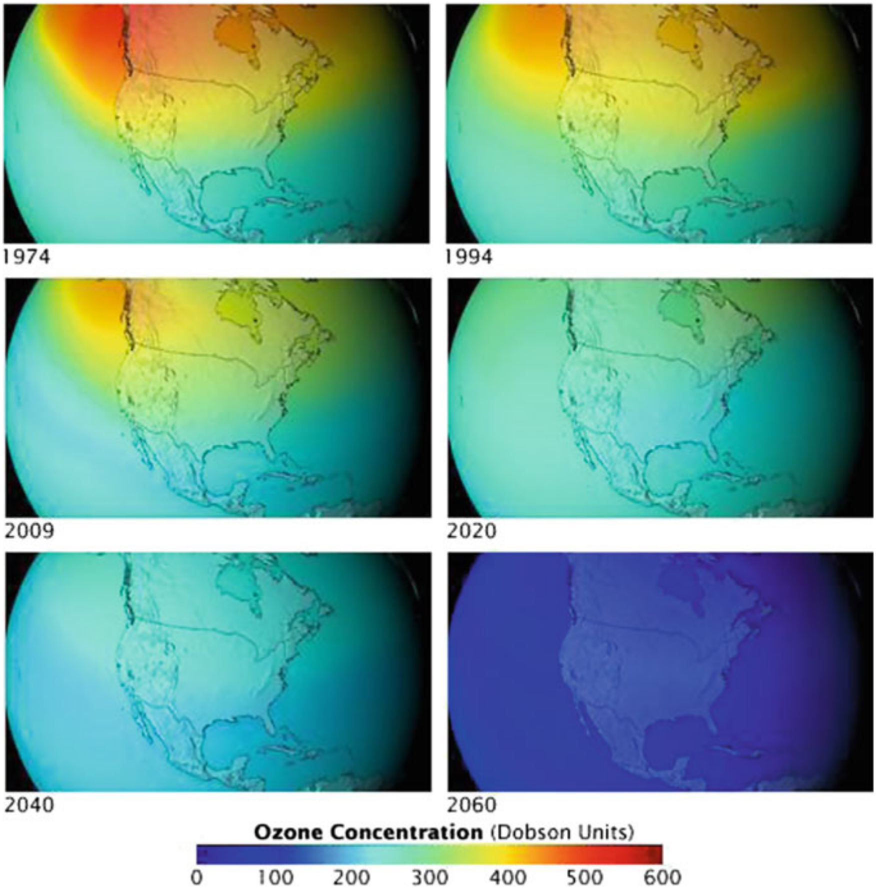


Fig. 2 NASA projection of stratospheric ozone, in Dobson units

HCFCs are non-toxic, cheap and competent [21, 22]. But yes, even if they do not harm the environment much, they are known as greenhouse gases [22, 23]! They can also deplete the ozone slowly, but continuously [18].

R22, R123, R124, R401A, R401B, R402A, R403B, R408A, R409A, R414B and R416A are the refrigerants which are covered under the group of HCFCs (Fig. 4).

2.4 *Hydrofluorocarbon (HFC) Refrigerant*

These refrigerants do not include any particles of chlorine. So, they are not at all harmful to the environment and do not deplete the ozone layer. But just like any

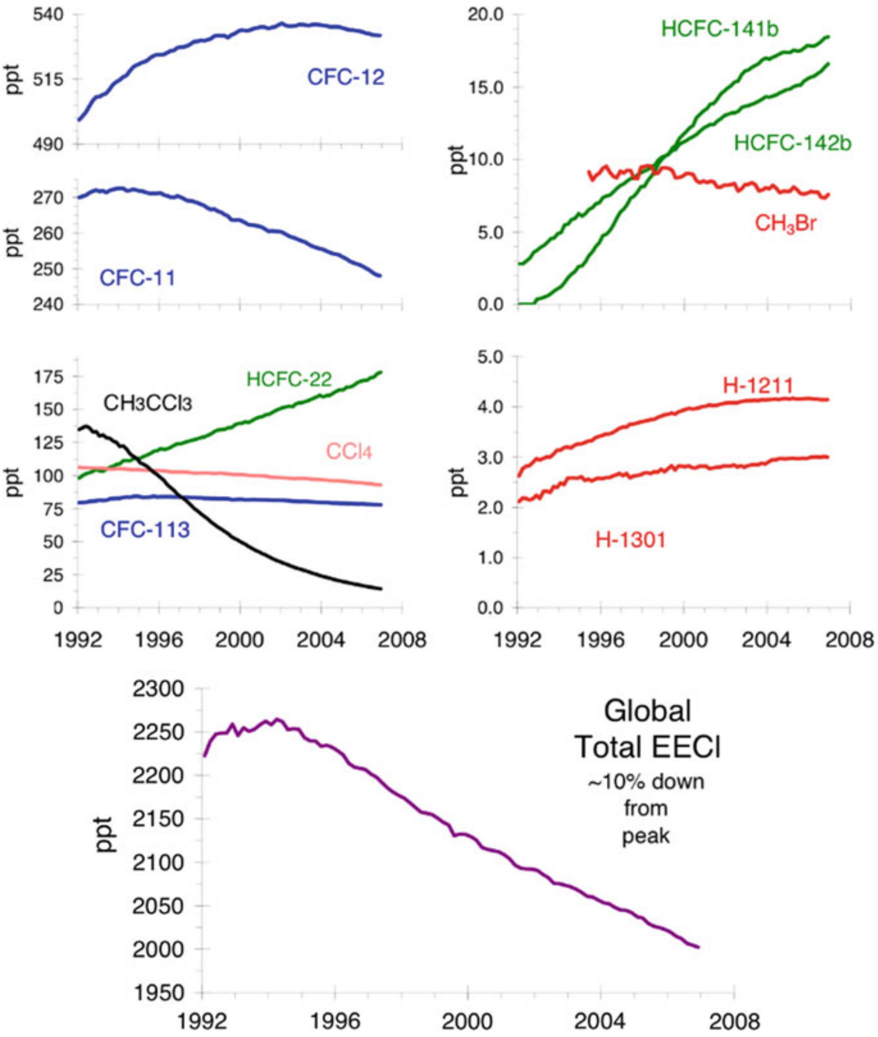
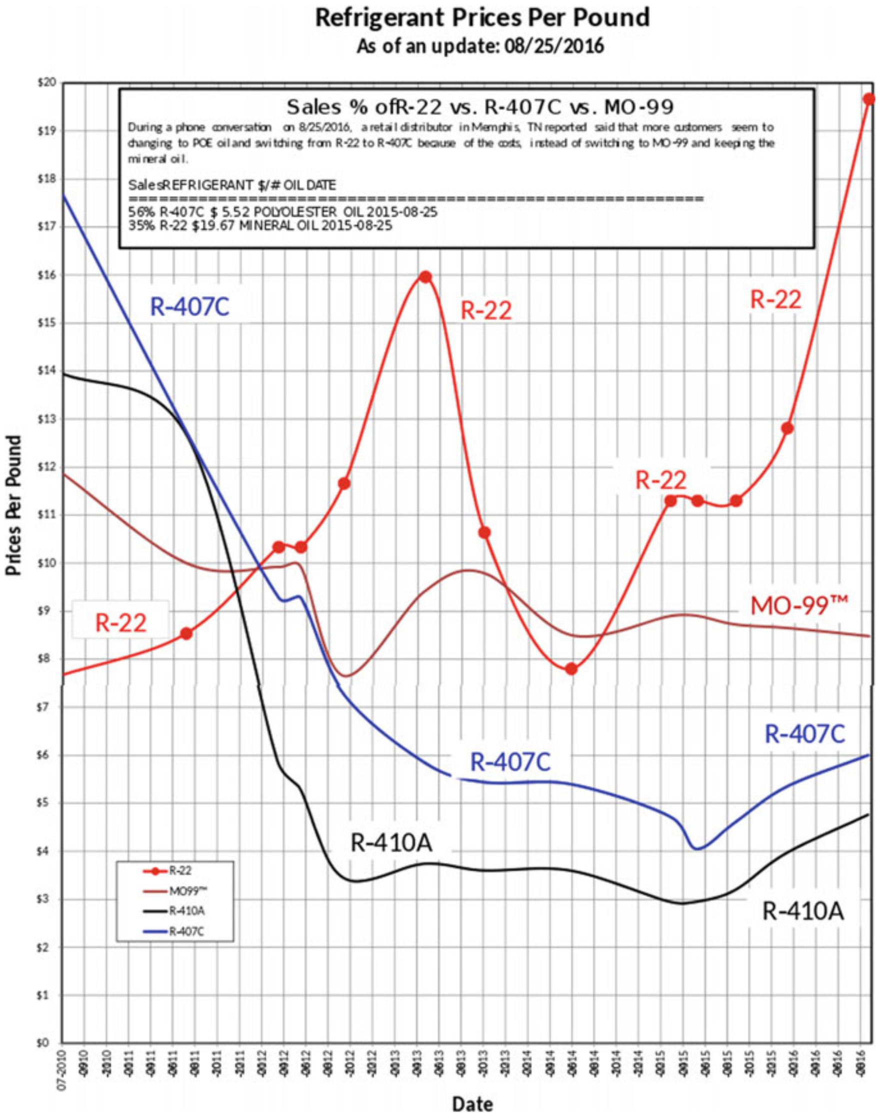


Fig. 3 Ozone-depleting gas trends

other refrigerant, they have some powerful impact on global warming as compared to natural refrigerants [24, 25].

When there was the ban of HCFCs, this group comes in. It includes hydrogen, fluorine and carbon. So, when compared to other refrigerants, it has the lower potential of global warming.

R23, R134a, R404A, R407C, R410A, R417A, R422A, R422B, R422D, R507 and R508B are included in the HFC group. This group of refrigerants is always in demand by refrigerant manufacturers because of its environment suitability [26].



Sales % ofR-22 vs. R-407C vs. MO-99

During a phone conversation on 8/25/2016, a retail distributor in Memphis, TN reported said that more customers seem to changing to POE oil and switching from R-22 to R-407C because of the costs, instead of switching to MO-99 and keeping the mineral oil.

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SalesREFRIGERANT $/# OIL DATE
============================================================
56% R-407C $ 5.52 POLYOLESTER OIL 2015-08-25
35% R-22 $19.67 MINERAL OIL 2015-08-25
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Fig. 4 HCFC price history

2.5 Natural Refrigerants

As the name suggests, natural refrigerants are completely natural. Any men like the other ones do not create them. They do not harm the nature, environment or the ozone layer [15, 16, 22].

Moreover, they are quite inexpensive as compared to other refrigerants. Air, HC, ammonia, CO_2, H_2O, etc. are the examples of natural refrigerants [27]. They have zero ozone depletion potential and negligible effects on global warming.

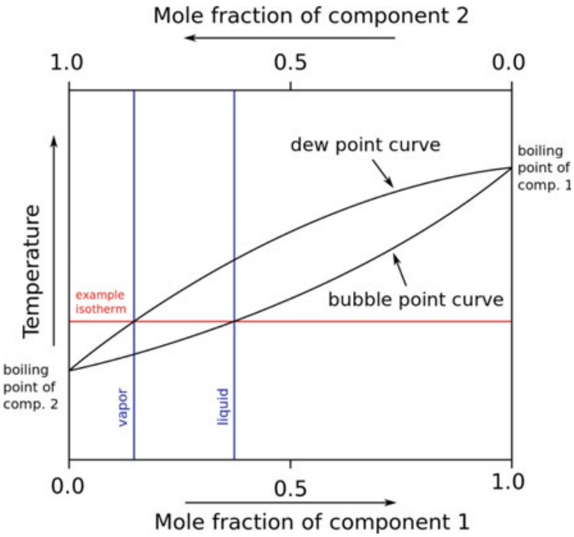
2.6 Refrigerant Blends (Azeotropic–Zeotropic)

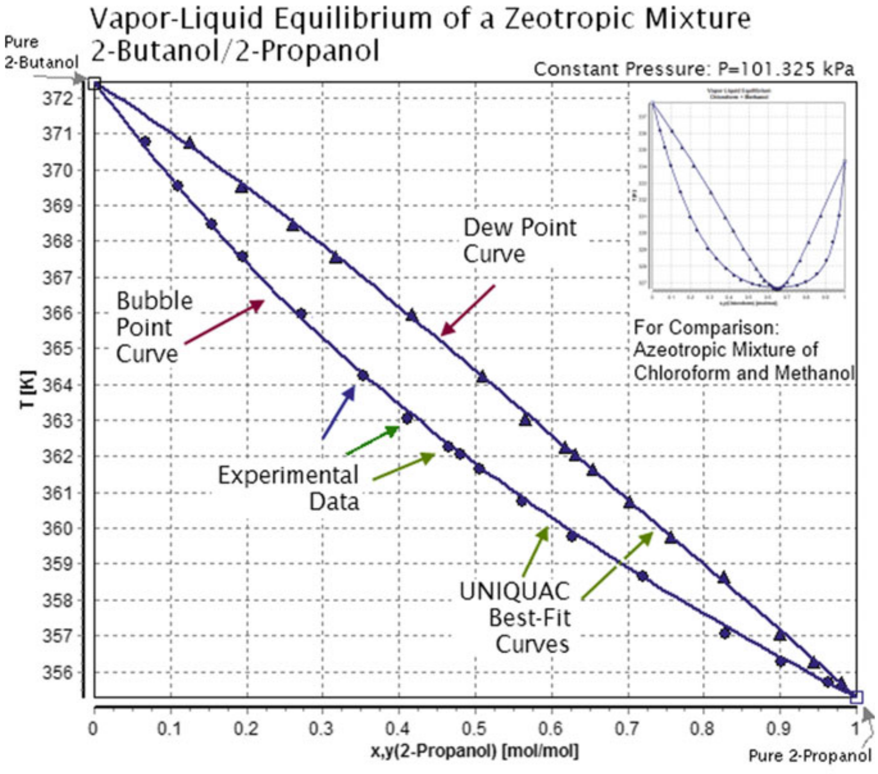
The most recent days' research is being carried over by refrigerant blends, commonly referred as "azeotropic" and "zeotropic" [5]. The use of refrigerant blends is increasing due to its change in temperature and composition in order to attain better cooling effect [22]. The temperature composition and bubble and dew curves of zeotropic refrigerant are given by Figs. 5 and 6, respectively.

3 Future Refrigerant

It is observed that since 1990, there has been the modification in the air conditioning industry. R410a is a superior refrigerant that has discontinued the production of R22 refrigerant [4, 24, 25]. In this post, you will come to know the real difference between R22 and R410a refrigerant [22]. The other name of R22 refrigerant is Freon while Puron is the name given to R410a. Let's discuss the characteristics of R22 and R410a which are different types of refrigerant units so that you can easily make out the comparison between the two units [4, 5].

Fig. 5 Temperature composition diagram of a zeotropic mixture





Experimental Data from Dortmund Data Bank
Original Source: Tamir A., Wisniak J., J.Chem.Eng.Data, 20(4), 391-392, 1975

Fig. 6 Bubble and dew curves for zeotropic mixtures

3.1 Comparison Between R22 and R410a

From Table 1, you can make out the real differences of R22 versus R410a efficiency. In comparison with the R22 refrigerant, you will find R410a enjoys significant benefits. Do you know the main reason for the shift from R22 to R410a refrigerant? It is due to the environmental grounds [24–26]. If there is the leakage in the A/C compressors of R22, then it will be proved unsafe to the environment, as it will release HFCF into the air, which will cause greenhouse warming and weakening of ozone layer. For home cooling R410a A/C, compressors are suitable. By going through the R22 versus R410a, the homeowners can make out how R410a unit is resourceful for the usage [28].

In case you possess an R-22 air conditioner, then it would be better you replace it with R410a unit. In this way, you will not only save your environment but can also enjoy efficiency along with safety. You cannot interchange R410 units with R22 units. You will observe declining parts and growing demands of R22 refrigerant

Table 1 R22 versus R410a

R22	R410a
The old type of refrigerant by the brand named Freon	A new type of refrigerant by the brand named Puron
Less energy efficient as it can absorb and release heat in lesser amount	More competent as it can absorb and release heat in efficient manner
Less ecologically friendly	More environmentally friendly
Not used in newly manufactured air conditioners	Suitable for all newly manufactured air conditioners
Contributes to the reduction of ozone layer	No contribution towards the depletion of ozone layer
Its use is phased out, so you will find it more expensive	Avoid the risk of overheating and breaking down due to tougher and durable air conditioner parts

units, so the cost of this appliance is much higher than R410a [29]. The information regarding comparison between these two units will guide you in drawing the clear picture of the two units, which in turn help you in selecting the best suitable unit for efficient and outstanding results [5, 8, 18, 20].

In 2010, there was a ban on the use of R22 in the new air conditioning systems. In 2015, the R410a became the new standard for US residential air conditioning system [4, 12, 14, 20]. The US government intends to have refrigerant that enjoys ozone depletion level of 0, so they recommend R410a unit. It will become illegal to produce R22, and in 2030, there will be complete phase-out of R22 [18, 19].

3.2 R410a Refrigerant

Install the resourceful and cost-effective R410a refrigerant to enjoy productivity, performance and environmental benefits. If the operating life of your refrigerator were coming to an end, then it would be better to get it changed with the R410a refrigerant, which will help you in saving the repairing cost of an R22 refrigerant leak [11]. The long-lasting refrigerator parts are used in R410a unit, which will protect your system from overheating and breaking down. It would be safer to get your refrigerator checked by the HVAC professional who can make use of recovery machine so that you can know the right way to get your system in an appropriate and proper condition.

In the market, you will find that due to the ban on R-22, many retailers promote to “top up” the R22 refrigerant, which will cause damage [10]. Keep yourself alert and careful of false claims for repair and operation retrofitting.

4 Conclusion

Now you can make out how R410a unit is efficient and cools down better than R22. By going through this article, you will gain understanding and knowledge about R22 and R410a refrigerant units [26]. Install R410a unit, which will provide you comfortable and well-organized cooling system. Enjoy the ecologically friendly cooling network with peace of mind.

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