AIR CONDITIONING AND REFRIGERATION Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : April-June 1999

Use Of Ammonia for Air Conditioning Applications

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All refrigeration engineers, particularly those dealing in industrial plants have known ammonia as a refrigerant of choice due to its excellent thermodynamic properties. It is almost nearly a perfect refrigerant.

This article is therefore written with a view to have a relook at this refrigerant long neglected by air conditioning practitioners. The author feels confident that a positive image of this refrigerant becomes evident if one addresses all issues with an open mind.

Background

Ammonia was used for refrigeration in 1876, for the first time in a vapour compression machine by Carl Von Linde. Other refrigerants like CO_2 SO_2 were also common till the 1920s. Every refrigerant had its own advantages and drawbacks for example CO_2 was perceived as being less dangerous, although it operated at a much higher pressure than ammonia.

Development of CFCs (Chlorofluorocarbons) in USA, in the 1930s swung the pendulum in favor of these refrigerants, as compared to all other refrigerants used in those days as CFC's were considered harmless and extremely stable chemicals.

The consequences to the outer environment of massive releases of CFC refrigerants could not be foreseen in those days. CFCs were promoted as safety refrigerants, resulting in an accelerating demand and CFC's success.

Due to this, ammonia came under heavy pressure, but held its position, especially in large industrial installations and for food preservation.

In the 1980s the harmful effects of CFC refrigerants became apparent and it was generally accepted that CFC refrigerants were contributing to the depletion of the protective ozone layer and to global warming, resulting in the Montreal protocol (1987) where almost all countries agreed to phase cut CFCs in a time bound program.

In the view of the seriousness of damage to the atmosphere and resulting dangers due to CFC/HCFC emissions as also due to global warming effects, the revisions in Montreal protocol (1990), Copenhagen (1912) and Kyoto (1918) demanded an accelerated phase out schedule. Even HCFCs are to be phased out and Europe has taken the lead in this matter. Germany will not used HCFCs after year 2000.

All developed countries have already stopped production and use of CFCs and developing countries like India will phase our production of CFCs in 2010 while no new equipment using CFC can be manufactured after 1-1-2003. For HCFCs including R-22 the cut-off year is 2040 for developing countries and 2030 for developed countries.

Ashrae Policy

ASHRAE issued a policy statement on Ammonia refrigerant in 1991, which is reproduced below:

"ASHRAE considers that the continued use of ammonia is necessary for food preservation and air conditioning. ASHRAE would promote a variety of programs to preserves the economic benefits of ammonia refrigeration while providing for management of risks ASHRAE will:

1. Promote authoritative information on ammonia by seminars and publications.
2. Continue research on ammonia topics such as handling, application, operation and control of emissions.
3. Maintain and develop standards and guidelines for practical and safe application of ammonia.
4. Provide programs and publications of innovative designs and applications using ammonia.
5. Advise government and officials with information regarding ammonia.

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Current Scenario

To replace CFCs hectic activities in the last 10 years by scientists has resulted in the development of many substitutes as interim solutions and long term substitute HFCs like HFC 134a, R 404a, R407a, R407c, R410a have already come into existence and been accepted by automobile, refrigeration and air conditioning equipment manufacturers.

European countries have adopted a different approach and started relooking at natural refrigerants like water, air, CO_2 ammonia and hydrocarbons. New equipment like welded plate heat exchangers and semi hermetic ammonia compressors have started appearing on the scene.

British standard BS 4434, 1995 and ASHRAE Standard 34, 1997 have reclassified refrigerant groups and ammonia is now classified as B_2 category. Earlier there were three groups (A,B,C) while now there are six (A_1, A_2 , A_3, B_1, B_2, B_3).

B_2 category means ammonia can be used with a charge of upto 500kg in indirect, closed systems even for hospitals, theatres, super markets, schools, lecture halls, public transport terminals, hotels, dwellings and restaurants.

However there is no restriction even when the refrigerant charge exceeds 500kg if all compressors and high pressure side machinery are installed at or above ground levels in a separate machine room or in open air with an indirect, closed cycle cooling system.

Oslo Airport

The most recent example of an air conditioning installation with ammonia is Oslo Airport, Norway which was commissioned in October 1998.

This is one of the largest and most advanced airports having a capacity to handle 16 to 18 million passengers per year with 64 check in counters and 80 aircrafts per hour. The total operational building area is 18,000m^2 . The plant uses ammonia refrigerant in an indirect cooling chilled water system, with three reciprocating, 16 cylinder compressors in one area and two reciprocating compressors of 8 cylinders in another area.

Total refrigeration capacity - 6300kW

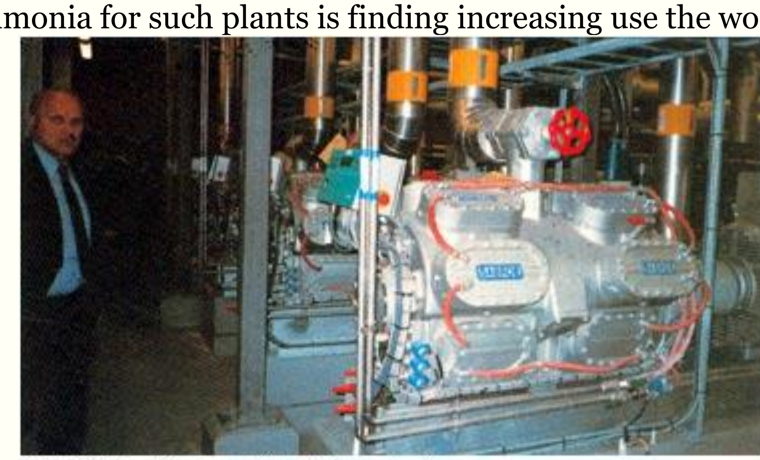
Electrical Motors - 1720kW

(5 x 280) + (2 x 160)

Refrigerant charge (ammonia) 2500kgs

This example makes the point in favour of ammonia as a refrigerant for air conditioning and dispels all myths about its safety and fire hazard issues.

As is well known, barring a few small AC plants, which use direct expansion systems using reciprocating, centrifugal or screw water chiller packages. Hence the use of ammonia for such plants is finding increasing use the world over.



HVAC Plant Room at Oslo Airpoprt, Norway

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Thermal Storage Systems

Another important application that has emerged in the last decade is the use of thermal storage systems, which generate chilled water during off-peak hours for use during day-time hours.

This use has gained popularity in developed countries due to a lower electricity tariff rate during night, especially in metropolitan cities. It is therefore, economical to generate cold water during night time and use it during the day. Such applications are increasing in the USA and many of them use ammonia refrigerant.

P&T Building Copenhagen

This plant uses ammonia reciprocating compressors with plate heat exchangers for the evaporator as well as the condenser side.

Particular mention of this plant is made in this article to stress the point that with the use of plate heat exchangers, the refrigerant charge reduces to nearly 20% and thus handling of refrigerant and dangers due to possible leaks are substantially minimized.

Welded plate heat exchangers haves opened up innumerable opportunities to AC & R professionals for various applications in air conditioning where earlier use of ammonia was unthinkable.

Those who are aware of this background and can offer creative solutions will have a tremendous advantage. This is exactly why ammonia as a refrigerant has a big potential in the future, since it has zero ozone depleting potential and zero global warming effect.

Obstacles to the use of ammonia need to be understood thoroughly and care taken while designing and installing the plants, so that the false sense of security, created through some 50 years of promotion of the now banned, so called, *safety refrigerants* is understood and appropriate measures taken.

Having covered some typical examples let us now look at the properties of ammonia in comparison with other refrigerants.

The complete Ammonia Chiller package including electric starter panel and all wiring at the P&T building, Copenhagen.

Ammonia - a Natural Refrigerant

Ammonia occurs on earth as naturally as water. It is a combination of two natural compounds namely Nitrogen and Hydrogen. There are no man-made chemicals involved. Our body produces one tenth of an ounce of ammonia daily. Our liver routinely converts ammonia in our body and maintains normal PH balance necessary to sustain life.

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Toxicity

Since ammonia is water soluble, inhaled ammonia dissolves in the lining of nasal passage and is swallowed. Consequently very little inhaled ammonia reaches the lungs. It has been established by WHO that continuous inhalation of low concentration of ammonia (25 PPM) does not produce harmful effects. Even 100 PPM for short duration does not have dangerous effects.

Presence of 2.5 PPM ammonia in air to detectable by smell. The advantage is that it gives people an early warning, enabling them to get away immediately from a dangerous area - 5 PPM levels are easily detected due to its pungent odour.

Only when concentration exceeds 400 PPM, there is irritation in eyes, nose and respiratory organs.

Studies have therefore proved conclusively that there is no reason for any concern in using ammonia.

Flamability

Ammonia is extremely hard to ignite and under normal conditions, is a stable compound. Ammonia will breakdown thermally above 450°C and ammonia vapour is flammable only at very high concentration in atmospheric air.

The Flammable limits in dry air at 20 C and 1 atmosphere (1.03 kg/cm^2) are:

LOWER LIMIT 15% by vol = 150,000 PPM or 195 gm/m^3 or 9.2% by weight

UPPER LIMIT 30.2% by vol = 3,020,000 PPM or 215 gm/m^3 or 20.1% by weight

An ammonia air mixture does not ignite below 651°C in a sealed iron flask.

Ammonia has been classified by the US Dept. of Transportation and US Coast Guard as a non-flammable compressed gas for transportation.

Ammonia installations do not require special flame proof electricals as required for Methane and Propane, which are classified as flammable refrigerants.

Availability & Cost

Under normal atmospheric pressure, ammonia is a colourless, pungent gas. Classified as refrigerant number R717, the 700 Group identifies "inorganic compounds" and 17 to the molecular mass of ammonia.

Roughly, the price of HCFC-22 is 3 to 5 times ammonia refrigerant. The cost of ammonia is not likely to rise significantly since ammonia is mainly produced for fertilizers and less than 5% of the total volume of ammonia produced is used as a refrigerant, whereas, prices of HCFC-22 and HCFC-134a have shot up steeply, as these chemicals are produced for refrigerant purposes only.

Ammonia is produced in a fertilizer grade or commercial grade which has 99.5% minimum ammonia content, while high purity or refrigeration grade anhydrous ammonia, with 99.5% minimum ammonia content is specified for use as refrigerant.

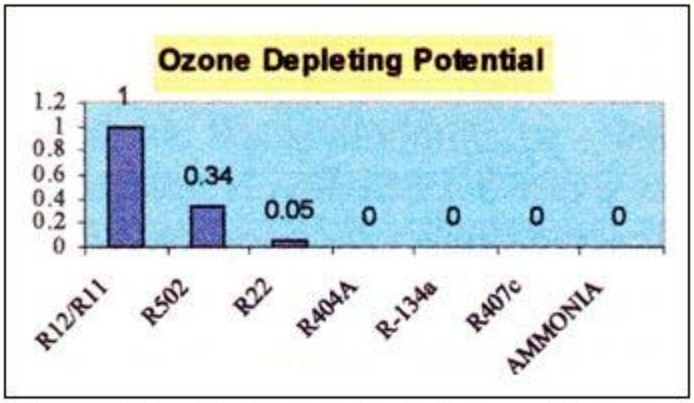

Fig. 1:Graph shows that Ammonia has zero ozone depleting potential and therefore does no environmental damage.

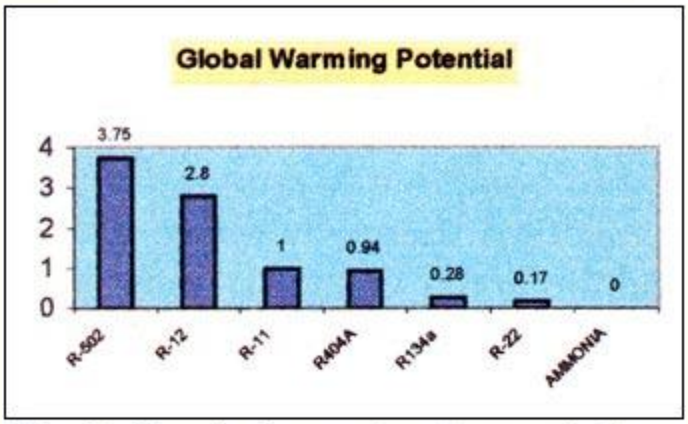

Fig. 2: Graph shows that Ammonia has zero global warming potential and hence is an ideal refrigerant compared to other refrigerants.

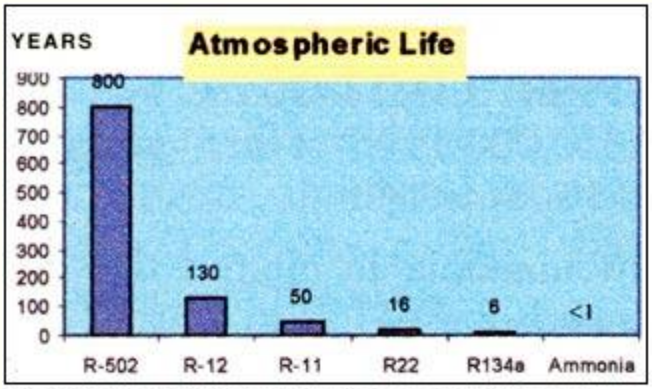

Fig. 3: The CFC Refrigerants are very stable and have high atmospheric life. They will eventually reach and damage stratospheric ozone layer. Ammonia is a natural substance which when released to atmosphere, react chemically with carbon dioxide in the air in presence of water to form harmless compounds such as Ammonium Bicarbonate. Ammonia released to atmosphere is transformed within a few hours or days and thus causes no damage.

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Thermodynamic Properties

1. **Table 1** reveals that ammonia refrigerant requires a smaller displacement compressor for the same output compared to other refrigerants.
2. The power consumption for ammonia is also least compared to other refrigerants.
3. The coefficient of performance for ammonia is better than other refrigerants.
4. The discharge temperature however, is higher with ammonia installations due to higher index of compression and higher compression ratio. This can however, turnout to be an advantage if one installs a superheat reclaim unit, or uses it in a heat pump application.

Table 1

	Evap. Pr Kg/cm^2 A	Cond. Pr Kg/cm^2 A	Compression ratio	Comp Disp* Liter/sec	Power kW*	COP	Discharge temp.°C

Ammonia	2.41	11.89	4.94	0.463	0.207	4.84	98
R22	3.03	12.26	4.03	0.476	0.210	4.75	53
R12	1.862	7.581	4.07	0.784	0.213	4.69	38
R134a	1.631	7.850	4.81	0.812	0.226	4.42	43
Thermodynamic properties based on - 15°C saturated evaporating temperature and 30°C saturated condensing temperature. *Per kW of refrigeration							

Heat Transfer Coefficients (W/m^2 K)

Figures in **Table 2** show the consistent advantage of ammonia. Higher heat transfer rate means smaller evaporators and condensers for a given temperature difference between refrigerant and external fluid.

Alternatively if we retain larger evaporators and condensers, the corresponding evaporating temperatures for maintaining the same conditions will be higher, and similarly the condensing temperatures (for same heat sink temperatures) will be lower: thus increasing cycle efficiency and coefficient of performance.

Table 2: Heat Transfer Coefficients (W/m^2 K)

	Ammonia	**HCFC 22**
Condensation outsides tubes	7500-11000	1700-2800
Condensation inside tubes	4200-8500	1400-2000
Boiling outside tubes	2300-4500	1400-2000
Boiling inside tubes (Liquid Circulation)	3100-5000	1500-2800

Density - Lighter Than Air

See **Figure 4** which explains why the number of fatal accidents involving CFCs many times greater than the remarkably few fatal accidents with ammonia refrigerant.

The molecular weight of ammonia is also less, 17.03, as against 86.48 for R-22. Hence, molecules of ammonia are easily carried away. It also means that if plants working with R-22 and ammonia develop equal size leaks, the loss of refrigerant will be greater per unit time for the R-22 plant than ammonia.

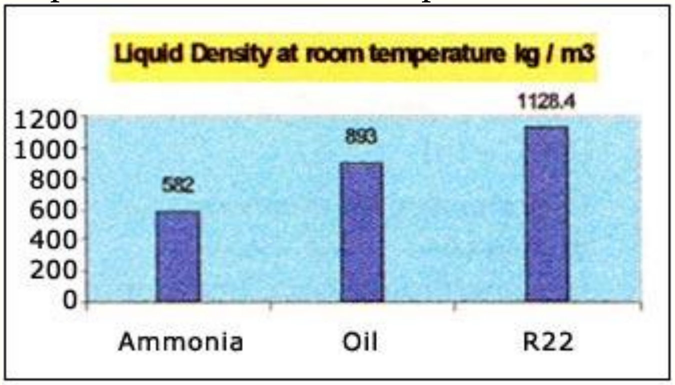

Fig 4: Ammonia being lighter than air, only normal ventilation provided for the plant room is adequate and no special precautions are necessary as it is easily carried away by air. Whereas R-22 being heavier and in general all CFCs being heavier than air, these easily accumulate at floor level, basements, shipholds and remain undetected for sometime.

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Oil Recovery

Table 3 shows why there are fewer problems between oil and ammonia in refrigeration systems as ammonia and oil do not mix easily together. Oil readily separates and settles at the bottom of flooded evaporators and the use of low pressure and high pressure receivers makes the task of oil drainage and recovery fairly simple.

Due to the miscible nature of R-22, oil separation and recovery systems for this refrigerant tend to be more complex than for ammonia, especially for low temperature applications, where oil tends to separate and remain in the evaporator.

Great care must be taken in piping design for R-22 plants to ensure that oil returns to the compressor at the same rate, at which the compressor pumps it out. Any separation and accumulation of oil in the system will not only affect plant performance adversely, but will lead to danger of oil starvation in the compressor, leading to breakdowns.

Table 3: Mineral oil miscibility at various temperatures		
Temperatures	**Miscibility**	
	R-22	**Ammonia**
50°C	100% miscible	Immiscible
25°C	100% miscible	Immiscible
0°C	100% miscible	Immiscible
-25°C	100% miscible	Immiscible
-40°C	100% miscible	Immiscible

Oil Foaming

With R-22 it is very difficult to prevent oil foaming due to the partial miscibility of oil with R-22. Thus plants using R-22 witness oil foaming in the crankcase of reciprocating compressors, which does not occur in ammonia plants. R-22 compressors therefore require crankcase oil heaters to minimize absorption of gas by the oil during idle cycle of the compressor.

Oil Pump Malfunction

The density of R-22 liquid is higher than mineral oil. Hence, during start up, of liquid refrigerant is present in the crankcase, the liquid will settle down and oil will float on top starving the oil pump and thereby affecting lubrication, since refrigerant liquid does not have lubricating properties. In ammonia installations, even if liquid is in the crankcase, since density of ammonia liquid is lower than mineral oil, the oil layer is always at the bottom and ammonia liquid floats on top, thus reducing the dangers of oil starvation for lubrication.

Pipe Sizes

A relevant comparison of the refrigeration capacity of refrigerant suction lines of various pipe sizes with flow rates that causes exactly the same drop in saturation temperature, shows that a given pipe size, when carrying ammonia will provide 2-3 times more refrigeration capacity than R-22. This means that ammonia systems can be designed with smaller (so lower cost) pipes for the same penalty in pressure drop, or if the same pipe sizes are selected, the ammonia system will haves a smaller pressure drop, permitting a higher evaporator temperature and lower condensation temperature, thereby improving cycle efficiency and COP.

For example, a 10 cm dia., 30 meter long (equivalent length) suction line will have a carrying capacity of 280 kW (80 tons) imposing a pressure drop of 1° C in a R-22 system, whereas for ammonia system the line capacity will be 728 kW (208 tons) - under identical conditions of evaporating and condensing temperatures and same pressure drop.

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Critical Temperature

The critical temperature of ammonia is 132.4°C whereas for R-22 it is 96°C.

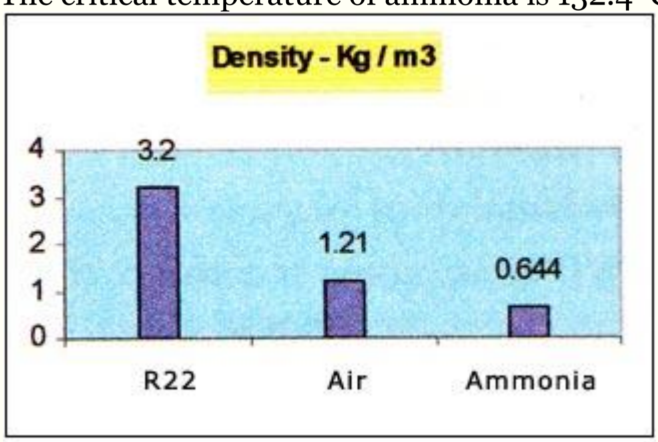

Fig. 5: So 582 < 893 forAmmonia.
Whereas 1128.4 > 893 for R-22

As the condensing temperature approaches the critical temperature, the coefficient of performance and the refrigeration capacity are reduced significantly. Considering future uses of ammonia, the higher critical temperature will be advantageous in heat pump applications requiring high temperatures for maximum heat utilization.

Greenhouse Impact (TEWI)

ACR applications contribute to Global Warming in two ways:

- Direct - By escape of refrigerant to atmosphere while servicing and by leakages in the system (including scrapping) during the entire life cycle of the system - expressed in equivalent CO_2 emission.
- Indirect - Due to energy utilized in the generation of which CO_2 is emitted to the atmosphere.

Therefore Total Equivalent Warming Index (TEWI) is leakage plus energy consumption.

TEWI - $MASS_{refrig't}$ X $GWP_{refrig't}$ + $\boldsymbol{\alpha}$ X E_{annual} X L_{years}

Where : GWP - Global Warming Potential of refrigerant relative to CO_2 (GWP of CO_2 - 1)

$\boldsymbol{\alpha}$ = CO_2 emission per kW of energy

E = Energy consumption (kWhr per annum)

L = Number of years.

GWP of ammonia is zero i.e. there is no direct greenhouse effect.

The very good thermal properties of ammonia and the absence of a direct greenhouse effect lead to a more favorable TEWI balance of ammonia system in comparison to other refrigerants.

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Conclusion:

Since safety is the only major challenge facing potential applications of ammonia, any fear held by the general public, as well as by the engineering field, must be dispelled through proper education, field training and safety practice.

Given today's changed atmosphere in which aims of energy conservationist often conflict with those of environmentalists, ammonia, the time tested self alarming and non polluting refrigerant provides the best option with its superior thermodynamic properties, with no global warming potential coupled with its environmentally friendly characteristics and low cost.

Extensive use of ammonia in all fields of air conditioning and refrigeration in light of the CFC phase out situation is a necessity and is practical. There is no limit to the development and utilization of ammonia as a refrigerant for the entire AC & R industry.

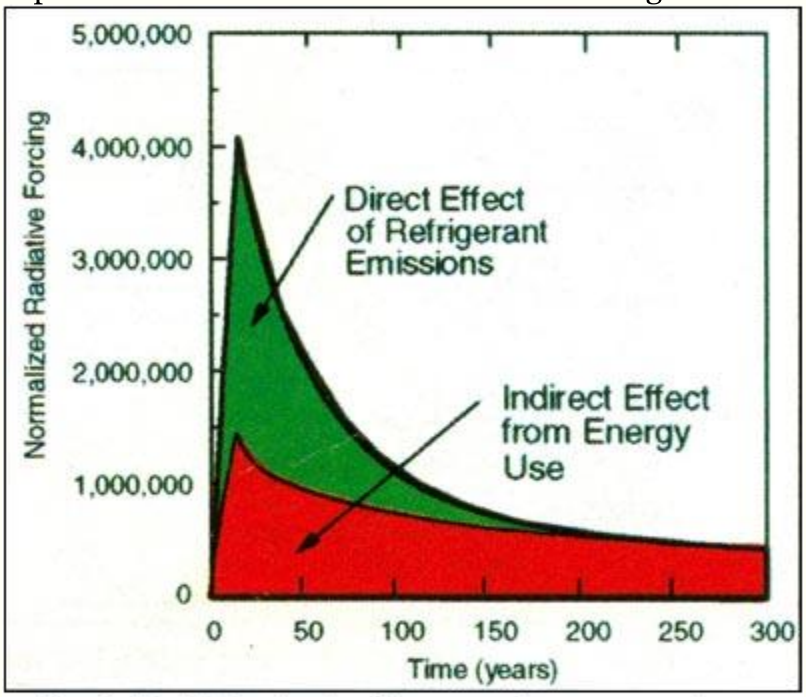

Fig. 6: Radiative forcing from greenhouse gases for a supermarket direct expansion refrigeration system.

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