Recent Trends in Refrigerants and Low Charge Ammonia Systems

Low charge DX ammonia evaporator

By Ramesh Paranjpey
Fellow ASHRAE Life Member, Pune

Introduction

The refrigeration industry has been undergoing rapid changes in recent years and new applications, earlier unheard of, are being tried.

The reasons leading to these changes are:

1. Global warming, which is a major issue
2. Energy efficiency, also a major issue
3. Need for environmentally friendly solutions
4. Development of alternate technologies

The evolution started in 1987 when the world realized the harmful effects on the environment and human beings of chlorofluorocarbon (CFC) refrigerants used then, and this resulted in the signing of the Montreal Protocol to phase out CFC refrigerants. Till then these refrigerants, namely R12, R11, R113, R114 and R22 were considered as man-made and God-sent refrigerants, as they have excellent thermodynamic properties and could be used to meet most of the refrigeration and air conditioning applications. The refrigerant ammonia took a back seat for some time, although it continued to be used in cold storages, ice plants and many other industrial applications.

Global Agreements

The protocols mentioned below are the motivating factors for the changing trends in the refrigeration industry, particularly the choice of refrigerants

The Montreal Protocol – 1987

Serious ill effects from the depletion of ozone resulted in the Montreal Protocol being signed on September 16, 1987 by 186 countries, whereby they agreed to phase out CFCs in a time-bound manner. This was the first protocol wherein all countries unanimously agreed to phase out CFC refrigerants containing the chlorine molecule.

About the Author

Ramesh Paranjpey is a mechanical engineer with an M. Tech. in refrigeration from IIT Bombay, having over 35 years' experience. He has worked in very senior positions with Kirloskar Pneumatic in Pune, Carrier Transicold in Bangalore and Singapore and Voltas-Air International in Pune. Presently, he works for himself as a technical advisor and consultant. He is an ASHRAE Fellow, past president ASHRAE W.I. Chapter and past president ISHRAE Pune Chapter. He can be contacted at *ramesh.paranjpey@gmail.com*

The second major issue that, however, escaped attention at that time was global warming. The Montreal Protocol did not address this issue.

Kyoto Protocol – 1997

The Kyoto Protocol is an international treaty that extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which commits state parties to reduce greenhouse gas (GHG) emissions, based on the scientific consensus that:

Part One: global warming is occurring, and

Part Two: it is extremely likely that human-made CO_2 emissions have predominantly caused it. The Kyoto Protocol was adopted in Kyoto, Japan on December 11, 1997 and entered into force on February 16, 2005. Currently there are 192 parties to the Protocol.

Kigali Agreement – October 25, 2016

A historic global climate deal was reached in Kigali, on October 25, 2016 at Rwanda during the Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer (MOP28). The Kigali Amendment, which amends the 1987 Montreal Protocol, aims to phase out hydrofluorocarbons (HFCs), a family of potent GHGs, by the late 2040s. The Kigali Amendment was signed by 197 countries, including India. The Kigali Agreement, or amended Montreal Protocol, for HFC reduction will be binding on countries from 2019. It also has provisions of penalties for non-compliance

EPA SNAP Rule-20: US EPA (Significant New Alternatives Policy) – July 2015

Under this rule, various HFCs and HFC-containing blends, which were previously listed as acceptable alternatives under the SNAP program, are now listed as unacceptable for specific uses. This rule is part of the SNAP program's continuous review of alternatives to find those that pose less overall risk to human health and the environment. Specifically, this action changes the listing status of certain HFCs in various end-uses in aerosols, refrigeration and air conditioning, and foam blowing sectors. This action also changes the status from acceptable to unacceptable for certain hydrochlorofluorocarbons (HCFCs) being phased out of production under the Montreal Protocol on Substances that Deplete the Ozone Layer, and Section 605(a) of the Clean Air Act, where substitutes are available that pose overall lower risk to human health and/or the environment.

Paris Agreement – December 12, 2015

a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low GHG emissions development, in a manner that does not threaten food production.

If the temperature is allowed to increase by 2°C, it is predicted to have the following adverse effects:

1. Severe heat waves affecting 37% of the population
2. Decline in marine catch by 3 million tons
3. Loss of trees and plants by 16%
4. Rise in sea level by 0.6m
5. Reduction in crop production by 7%
6. Decline in coral life by 99%

(Source: Times of India, October 9, 2018)

Harmful Effects of HFC Refrigerants

In recent times, it has been found that HFCs have several thousand times the capacity to retain heat in the atmosphere compared to carbon dioxide (CO_2), a potent GHG. Thus, it can be said that HFCs have helped the ozone layer but exacerbated global warming. Currently, HFCs are the world's fastest growing GHGs, with emissions increasing by up to 10% each year.

Although these refrigerants have zero ozone depleting potential (ODP), they have very high global warming potential (GWP) compared to 1kg of CO_2, as listed in *Table 1*.

Table 1: GWP of HFCs

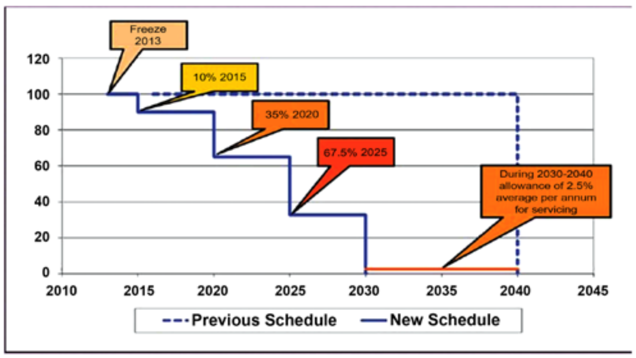
Refrigerant	GWP
R134A	1430
R410A	2088
R404A	3922
R407C	1744
R507A	3985

Compared to this, natural refrigerants have very low or nil GWP, as shown in *Table 2*.

Table 2: GWP of natural refrigerants

Refrigerant	GWP
Ammonia (R717)	0
Carbon dioxide (R744)	0
Ethane (R170)	5.5
Propane (R290)	3.3
Isobutane (R600a)	3
Propylene (R1270)	1.8

Year	% of Phaseout from Baseline (avg 2009 and 2010)
2013	Freeze
2015	10%
2020	35%
2025	67.5%
2030	Full phaseout*
2040	100% phaseout



* 2.5% of the baseline allowed for servicing
- to be reviewed in 2025

Figure 1: Accelerated HFC phase out schedule

It has, therefore, been decided to phase out HFC and HCFC refrigerants in a time-bound program, as indicated in *Figure 1* and *Table 3*.

Table 3: HFC phase out schedule

(Average HFC consumption levels for 2011, 2012 and 2013 + 15% of HFC base line)	
2019	– 10%
2024	– 40%
2029	– 70%
2034	– 80%
2036	– 85%

The two terms, namely Global Warming and Natural Refrigerants, have become important and it is necessary to correctly understand their meanings.

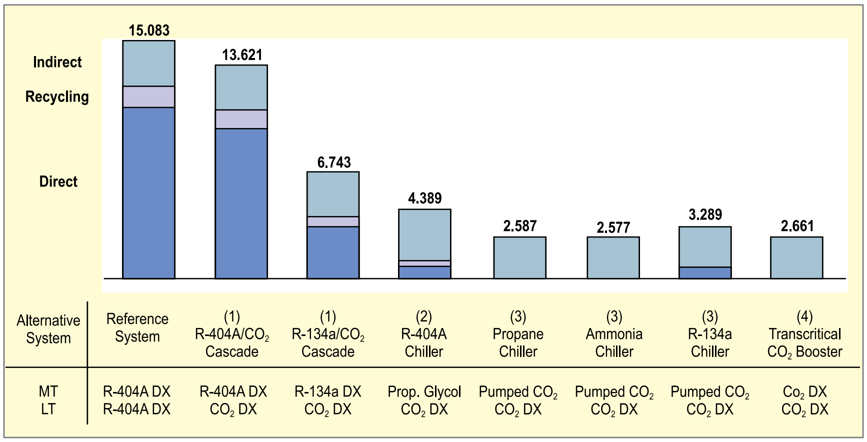


Figure 2: Total Equivalent Warming Impact of benchmark and alternative systems

What is Global Warming?

Global warming is the unusual increase in the temperature of the Earth's surface. When the Sun's energy enters the atmosphere and heats the Earth with light waves, it warms the Earth, and then re-radiates infrared waves back into space. Some of the infrared radiation going into space is naturally trapped by the atmosphere, which keeps the temperatures on the Earth moderate. The thin layer of Earth's atmosphere is now being thickened by large amounts of human-caused greenhouse gases like carbon dioxide. The thickening of the Earth's atmosphere traps the infrared radiation, which then warms the temperature of the atmosphere and oceans. Over the past century, the temperature has been rapidly increasing because of greenhouse gases caused by burning fossil fuels.

Earth's temperatures are maintained with a natural greenhouse effect from the Sun. About 30 percent of sunlight is reflected back into space because of clouds and ice. The other 70 percent of sunlight is absorbed by the land and ocean. Our planet is heated by solar energy. Without the greenhouse effect, the Earth's average temperature would be -18°C (0°F) instead of the prevailing 15°C (59°F). Between 1906 and 2005, the average global surface temperature has risen by 0.6 to 0.9°C (1.1° to 1.6°F). The increase of carbon dioxide is expected to raise the Earth's temperature by another 2°C (3°F) to 5°C (9°F) by the end of the century. Thirteen of the history's 15 warmest years have occurred since 2000, with 2014 being the warmest year on record and 2015 ranking just as warm or warmer. The average temperature in 2015 was 0.85°C (1.53°F) above the 20th century average.

The Global warming caused by HFC and HCFC refrigerants is of two types:

1. Global warming due to the direct impact of refrigerants leaked into the atmosphere. It is important to note that the contribution to global warming due to direct leakage is only 10%.
2. The indirect contribution is due to energy consumption over the life time of equipment using the particular refrigerant, and this is the major culprit with 90% contribution. Hence, selecting a refrigerant with the best efficiency (COP) over a wide operating range assumes greater significance.
3. Total Equivalent Warming Impact (TEWI) is the warming effect over the entire life span of the refrigerant system.

Compared to all the existing refrigerants, ammonia scores in this area and has the least TEWI.

Natural Refrigerants

Natural refrigerants are natural substances that serve as refrigerants in refrigeration systems (including refrigerators, HVAC, and air conditioning). They are alternatives to HFC, HCFC and CFC based refrigerants. Unlike other refrigerants, they are not synthetic chemicals and can sometimes be found in nature. They may be viable or environmentally friendly or both.

Natural refrigerants are naturally occurring, non-synthetic substances that can be used as cooling agents in refrigerators and air conditioners. These substances include hydrocarbons (propane, butane, and cyclopentane), CO_2, ammonia, water and air. Natural refrigerants are ozone layer- and climate-friendly substances. They are listed below.

- Ammonia (NH_3) (R-717) is the refrigerant most widely used in industrial refrigeration, and formerly the primary refrigerant in home refrigerators; it is a toxic gas
- Carbon dioxide (CO_2) (R744)
- Petroleum-derived hydrocarbon (HC) refrigerants
- Propane ($CH_3CH_2CH_3$) (R-290) – a flammable hydrocarbon
- Isobutane ($CH_3CH(CH_3)_2$) (R-600a) – a flammable hydrocarbon
- Propylene (CH_3CHCH_2) (R-1270) – a flammable hydrocarbon

The refrigeration Industry, in its infancy in early 18th century, was using natural refrigerants like ammonia, carbon dioxide and hydrocarbons. Recent developments mentioned above are making the world and the refrigeration industry rethink and explore natural refrigerants by overcoming their drawbacks, instead of developing new man-made synthetic refrigerants whose adverse effects we cannot immediately predict. *Figure 3* shows how the cycle is repeating.

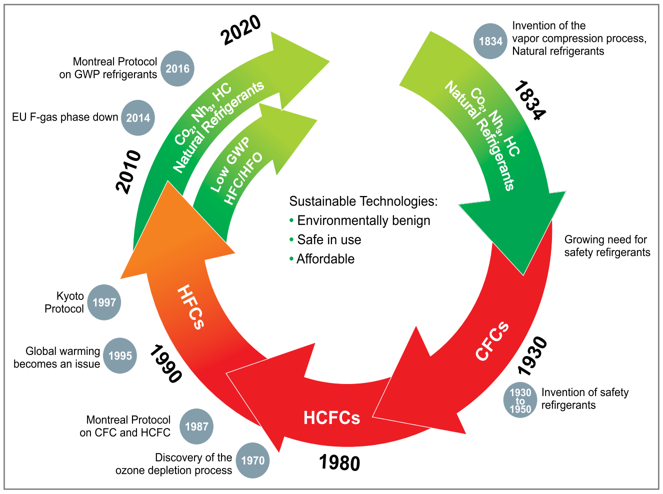


Figure 3: History of refrigerants – the cycle repeats

The alternate long-term solutions being considered, therefore, are:

1. Phase out all man-made synthetic chemicals
2. Concentrate research on the use of natural refrigerants such as ammonia, carbon dioxide and hydrocarbons, and overcome their adverse effects
3. Research alternate technologies like solar energy, wind power, air as a refrigerant, thermoelectric effect, magnetic materials, phase change materials, etc.

> In other words, scientists world over are veering towards no-regret solutions as a long-term measure, and believe that Nature has solutions for every problem and is the ultimate in technology.

Ammonia as a Refrigerant

When we consider the above, ammonia refrigerant scores over all the other potential candidates as it has the highest thermodynamic efficiency compared to all currently available refrigerants, has no global warming or ozone depletion potential, and has the best TEWI compared to other refrigerants – as mentioned earlier.

Table 4: Comparison of COP of ammonia with other refrigerants for various applications

Refrigerant	For positive Temperature cold rooms- +40°C/2°C	For secondary fluids operation +40°C/-5°C	For low temperature cold rooms-+40°C/-25°V	Blast freezers/ IQF +40°C/-40°C
Ammonia-R717	6.20	4.965	2.91	2.06
R410A	5.43	4.80	2.50	1.75
R134a	5.88	4.67	2.70	1.88
R404A	5.18	4.07	2.26	1.52
R22	5.93	4.74	2.79	1.98

Ammonia refrigerant is, therefore, being used regularly in the following and many more applications:

1. Cold storages for potatoes, fruits, vegetables and other commodities like chillies, seeds, grains, turmeric, etc.
2. Ice plants – conventional block ice, flake ice, tube ice, slurry ice and, plate ice
3. Skating ice rinks for amusement parks
4. Fish freezing plants – spiral freezers, plate freezers, IQF, blast and trolley freezers
5. Slaughter houses and meat processing plants
6. Dairies using ice bank systems, ice reserve units, chilled water systems, cold rooms and other requirements
7. Ice-cream making plants
8. Air conditioning of processing halls for cold chain facilities like grading, sorting and ante-room areas
9. Process refrigeration plants using chilled water or low temperature brine chilling systems for chemical and dyestuff industries
10. Breweries
11. Bottling plants for Coca-Cola, Pepsi and other soft drinks
12. Concrete cooling applications for river dams, airport runways and concrete expressways
13. Fertilizer plants
14. The most widespread use of ammonia is in agricultural industry as a fertilizer with minimum 99.5% ammonia content in commercial grade
15. Of late, many supermarkets are also using ammonia/carbon dioxide (R717/R744) or ammonia/secondary fluids like propylene glycol systems
16. Liquefaction of gases like chlorine and carbon dioxide
17. Pharmaceutical plants for process cooling
18. In the metallurgical industry, ammonia is used as a source of inert gas and for nitriding of metal surfaces.
19. Ammonia plays an important role in environmental protection by removing nitrogen oxides and sulphur dioxide from smoke emitted by power plants
20. Of late, ammonia is being used for air conditioning of large complexes like airports and other office premises using chilled water systems (see *Ammonia Air Conditioning to the Fore* in the June 2017 issue of *Air Conditioning and Refrigeration Journal*)
21. Space shuttles
22. Heat pumps

Making Ammonia Systems Safe

Since ammonia is a toxic gas, restrictions and safety precautions are needed to ensure safe operation of ammonia systems. Several developments have taken place in recent times in an effort to reduce refrigerant leaks and reduce system charge in ammonia systems.

Reducing Leakages

1. Use of all welded joints and no flanged or screwed joints while building the plant.

Figure 4: Use of welded joints

2. Use of *hermetic or semi-hermetic compressors* instead of open type, which are currently being used since ammonia and copper are not compatible and the motor therefore needs to be installed separately. However, development of motor windings with aluminum is in progress and it would be possible in future to use ammonia semi hermetic or hermetic compressors. *Figure 5* shows models planned to be launched commercially in the near future.

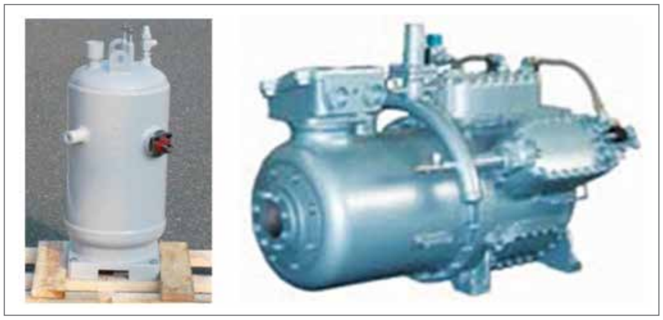


Figure 5: Hermetic ammonia scroll compressor (left), and semi-hermetic ammonia compressor

A few weeks ago, in September 2018, a 800 kW semi-hermetic ammonia heat pump system fitted with two twin screw compressors for heating and cooling 40,000 m^2 of apartments and business premises was installed in Eindhoven, the Netherlands in a building that formerly housed Philips.

Figure 6: The Philips building in Eindhoven, the Netherlands

3. Use of shell and plate heat exchangers as condensers and chillers to reduce direct leakage to the atmosphere.

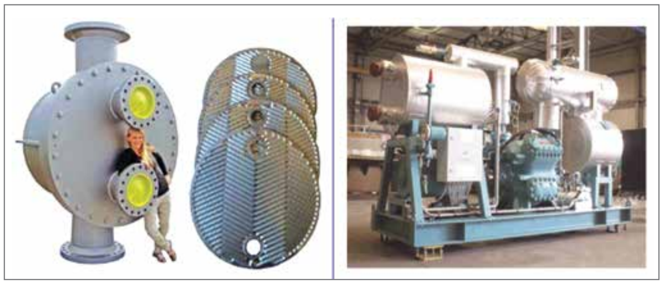


Figure 7: Shell and plate heat exchanger (left), and a chiller using enclosed shell-PHE condenser/cooler

4. Use of demister pad type oil separator in the compressor discharge line. This is a highly efficient oil separator and would reduce/eliminate oil draining from many other points in the system, thus reducing chances of ammonia leak, since while draining oil, some ammonia also leaks. Another suggestion is to drain oil from various points in a closed piping and then provide only one oil pot to collect oil from different points.

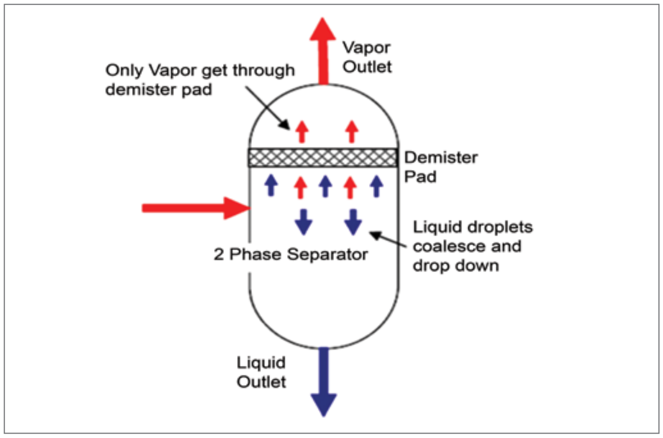


Figure 8: High efficiency (85-90%) S.S. demister pad type oil separator

5. Install the entire package on a roof-top so that, even if ammonia leaks, it would escape to the atmosphere since ammonia is lighter than air, and would, therefore, not harm the population.

Figure 9: Roof top ammonia water chiller

Low Charge Ammonia Systems

To reduce the toxic impact pf ammonia in case of leakage, new combinations of ammonia-hydrocarbon mixtures are being tried out. In addition, considerable effort has been made to develop ammonia systems with low refrigerant charge. Low charge systems are defined as systems having no more than 1.3 kg/kW of ammonia refrigerant.

Low charge factory-made packaged refrigeration systems of less than 0.3 kg/TR are available using shell and plate heat exchangers. Use of high side float eliminates the use of H.P. receiver. Systems with charge as low as 0.06 kg/kW are also available for some applications (see Modern, Low Charge Ammonia Systems for the Cold Chain, R. Lamb, *Cold Chain*, January-March 2017).

Designing a Low Charge System

Normally, as a thumb rule, the current flooded ammonia systems use between 4 to 5 kg ammonia/TR. First, it is necessary to find where the maximum quantity of ammonia is present in a system. These areas are:

1. Ammonia receiver contains the largest quantity
2. Shell and tube heat exchangers like condensers and flooded chillers
3. Gravity separator or accumulator for flooded ammonia systems
4. Low pressure vessel in pump circulation systems
5. Flooded air coolers in cold storages

Low charge systems designs incorporate some of the following features:

1. Receiver-less systems

If one wants to reduce ammonia charge in the system, one should try to eliminate the receiver altogether. Such systems are available, using high side float. The liquid that gets condensed goes directly to the low side of the system, which is either the chiller or air coolers or L.P. vessel, thus eliminating the receiver from the system and reducing ammonia charge considerably.

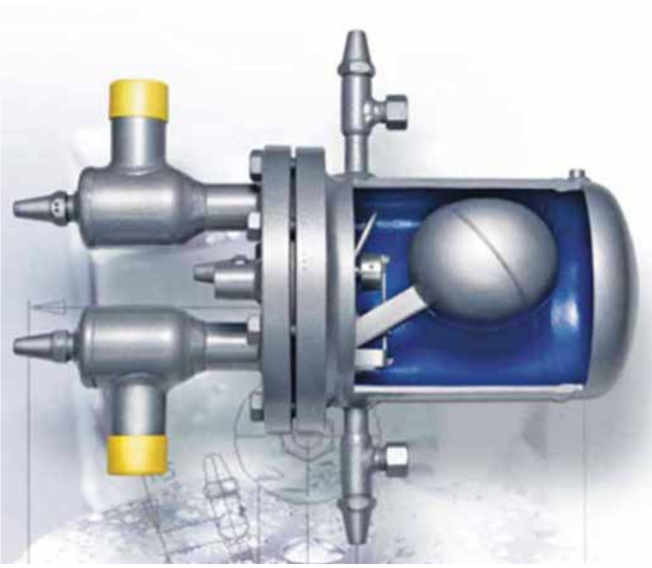


Figure 10: High pressure float

2. PHE Condensers and Chillers in a Package

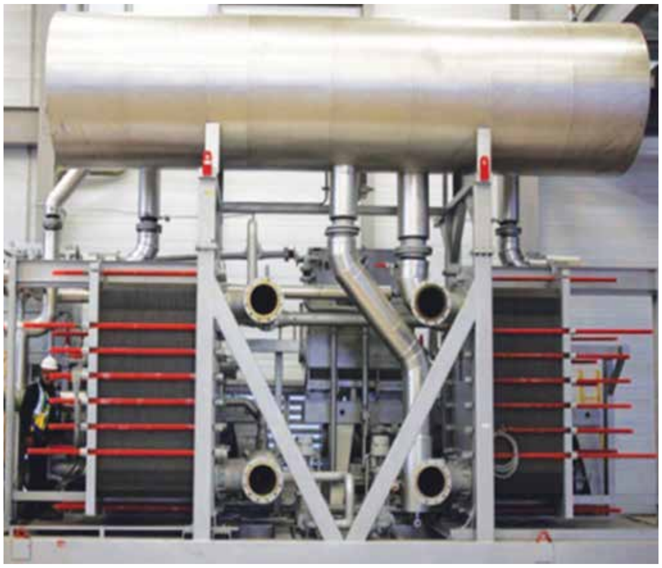


Figure 11: Ammonia chiller at Heathrow airport

3. Accumulator in Gravity Flooded System

To reduce the charge in the accumulator, one can, use the U-turn accumulator design developed by Alfa Laval. This will reduce ammonia charge from the accumulator considerably.

Figure 12: PHE with U-turn accumulator developed by Alfa Laval

4. Direct Expansion System

This will reduce ammonia charge from air coolers substantially and eliminate the accumulator completely.

Figure 13: DX ammonia evaporator

Table 5: Charge calculations for a 350 TR conventional ammonia refrigeration system

Sr. No.	Equipment	Volume	Volume	Vapour	Liquid	Vapour NH_3	Liquid NH_3	Total NH_3
		Liters	M3	%	%	Kg	Kg	Kg
1	Compressor	500.00	0.50000	100.00%	0.00%	1.730	0.000	1.730
2	Suction Line	94.26	0.09426	100.00%	0.00%	.326	0.000	0.326
3	Discharge line	60.33	0.06033	100.00%	0.00%	0.723	0.000	0.723
4	Liquid Line	61.94	0.0 6194	0.00%	100.00%	0.000	35.891	35.891
5	Accumulator	1486.00	1.48600	70.00%	30.00%	3.599	284.692	288.292
6	Ammonia Receiver	967.00	0.96700	70.00%	30.00%	8.111	166.106	176.217
7	PHE Condenser 2.4 lit x 56 Cassetees	146.40	0.14640	80.00%	20.00%	1.403	16.967	18.371
8	PHE Chiller 1.4 lit x 69 Cassetees	96.60	0.09660	0.00%	100.00%	0.000	61.690	61.690
					TOTAL AMMONIA CHARGE	15.89	567.35	583.24

Table 6: Charge calculations for a 350 TR low charge ammonia refrigeration system

Sr. No.	Equipment	Volume	Volume	Vapour	Liquid	Vapour	Liquid	Total NH_3
		Liters	M3	%	%	Kg	Kg	Kg
1	Compressor	500.00	0.50000	100.00%	0.00%	1.730	0.000	1.730
2	Suction Line	94.26	0.09426	100.00%	0.00%	.326	0.000	0.326
3	Discharge line	60.33	0.06033	100.00%	0.00%	0.723	0.000	0.723
4	Liquid Line	29.87	0.02987	0.00%	100.00%	0.000	17.308	17.308
5	High Pressure Float	19.00	0.01900	40.00%	60.00%	0.026	7.280	7.306
6	Accumulator	1486.00	1.48600	90.00%	10.00%	4.628	94.897	99.525
7	PHE Condenser 2.4 lit x 56 Cassetees	134.40	0.13440	80.00%	20.00%	1.288	15.576	16.865
8	PHE Chiller 1.4 lit x 69 Cassetees	96.60	0.09660	30.00%	70.00%	0.000	43.183	43.183
					TOTAL AMMONIA CHARGE	8.72	178.25	186.97

Table 7: Comparison of conventional and low charge ammonia refrigeration systems

Particular	Low Chage Ammonia Refrigeation System (Receiverless)	Conventional Ammonia Refrigeration System (with Receiver)
Components	Compressor + Condenser + Evaporator	Compressor + Condenser + Evaporator + Receiver
Expansion Device	HP Float	Hand Expansion Valve
Level Control Device	Not Required	Electronic Float / Level Controler & Solenoid Valve
Regrigerant Charge	186 KG	583 KG
Additional Control	High Level Trip	May Be Provided
Plant Capacity	350 TR	350 TR

5. *Ammonia-CO_2 Cascade System*

Ammonia is used in the high stage and carbon dioxide refrigerant is used in the low stage, thus eliminating a considerable amount of ammonia in the low stage, making it safe by eliminating the chances of ammonia leak in occupied areas.

Figure 14: An ammonia-CO_2 cascade system

Table 5, 6 and *7* will help to compare low charge and conventional ammonia systems.

Conclusion

1. Natural refrigerants, especially ammonia, are finding increasing uses in all air conditioning and refrigeration applications.
2. To reduce toxicity, new combinations of ammonia-hydrocarbon mixtures are being tried out.
3. Ammonia direct expansion systems with miscible oils are being used, although they are not as efficient as flooded systems
4. Semi-hermetic and hermetic compressors for ammonia will be commercially available in the near future.
5. Roof top ammonia package installations with air cooled condensers are becoming popular.
6. Low charge ammonia systems are now in use in many installations.
7. Association of Ammonia Refrigeration (AAR) is actively conducting training programs all over India and abroad, and have published the following books:
   i. Safety Standard for Ammonia Systems, specially developed for Indian climatic conditions.
   ii. Piping, Installation and Maintenance Practices for Field-erected Ammonia Systems.