Advantages of Ammonia Refrigerant over HCFC/HFC Refrigerants

Ammonia as refrigerant was used for the first time in vapour compression machine by Carl Von Linde in 1876. Other refrigerants like CO_2, SO_2 also were commonly used till 1920's. Development of CFC's (Chlorofluorocarbons) like CFC12, CFC11 in 1920's made them more popular, as compared to all other refrigerants used in those days, since CFC's were considered harmless and extremely stable chemicals as well as due to their odorless, non flammable and non toxic characteristics. These refrigerants became known as God sent & manmade chemicals. The damage to ozone layer and environment due to of massive releases of refrigerant could not be foreseen in those days. "CFC" refrigerants were thus promoted as safety refrigerants, resulting in an accelerating demand and CFC's success. Due to success of CFC's, Ammonia refrigerant use got restricted to only large industrial installations and food preservation applications.

In 1980's the harmful effects of CFC refrigerants became apparent and it was generally accepted that the CFC refrigerants are contributing to depletion of ozone layer and to global warming, finally resulting in Montreal protocol (1989) where almost all countries agreed to phase out CFC's in a time bound program.

Use of CFC refrigerants is now banned all over the world and is already a history. Many countries have also stopped use of HCFC22 refrigerant due to its limited Ozone Depleteting Potential, and new refrigerants such as HFC134a, R404A, and R410A are being used for domestic appliances and for comfort air conditioning applications as well as other applications by refrigeration industry as substitute to CFC refrigerants.

General resistance to use these manmade chemicals as refrigerants is growing in many countries since the potential dangers they may pose in future is unknown currently besides the fact that they have high Global warming potential. The supposed to be harmless manmade CFC refrigerants required nearly 50 years to realize their harmful effects to environment and choice of natural refrigerants as "NO REGRET SOLUTION" is therefore finding renewed interest all over the world by the refrigeration air conditioning community. Ammonia refrigerant naturally leads the race.

There is also increasing demand to explore use of other natural refrigerants like water, air , Carbon Dioxide since these refrigerants are in the atmosphere since life came in to existence on earth and properties as well as effects of them on human body and environment are fully known to mankind.

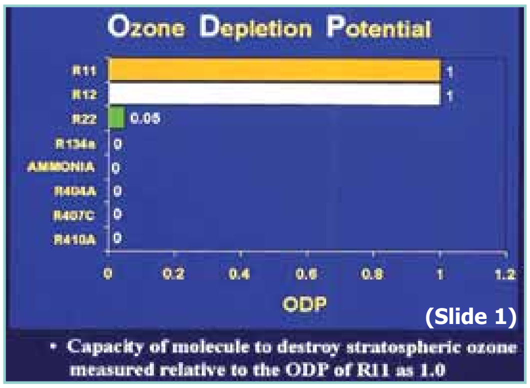
Well tried and trusted refrigerant like Ammonia which is again a natural refrigerant and has been extensively used by refrigeration industry since beginning & is now finding increasing use in many other applications where use of it was not considered earlier.

This article is therefore written to highlight excellent properties of ammonia as refrigerant and why ammonia refrigerant should be preferred over other refrigerants currently being used.

Advantages of Ammonia as Refrigerant

For the sake of comparison properties are generally compared with HCFC-22 refrigerant which is still being used extensively in many countries and in many applications

Refrigerant	ODP	GWP
Ammonia, R-717	0	<1
R-22 (HCFC -22)	0.055	1810
R-134a	0	1430
R404A	0	3900
R410A	0	2100



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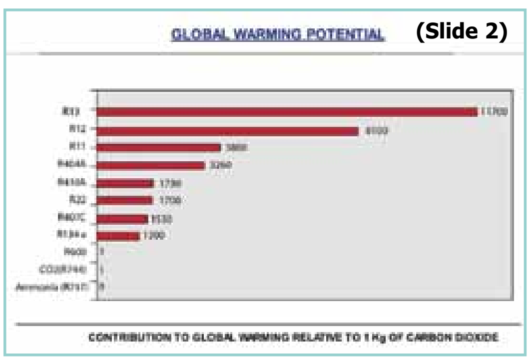

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since a single refrigerant to replace entire spectrum of R22 applications is not available yet.

Ozone Depleting Potential (ODP) and Global Warming Potential (GWP)

(Slide 1&2) the Table herein gives comparison of ODP & GWP values of currently used refrigerants. (ASHRAE Fundamentals 2009-page 29.4)

Performance

The COP, a dimensionless number used to define efficiency (Coefficient of Performance or output per unit input) is highest for ammonia (4.76) (ref ASHRAE volume Fundamentals 2009 page 29.9)compared to other regularly used refrigerants such as 134a, 404A,410A, R-22 and many others.

Extract from Table: Comparative Refrigerant performance per Ton of Refrigeration at standard cycle conditions of -15^{0}C (258K) evaporation and 30^{0}C (303K) condensing is given herein. From the Table one can notice that Ammonia has highest refrigerant effect per kg of circulation 1103.1 kJ/kg as well as highest efficiency 4.76 (C.O.P.)

Efficiency

Ammonia systems mostly operate on flooded designs. The head pressure control to artificially keep the discharge pressures high to ensure proper operation of thermostatic expansion valve is therefore not necessary in ammonia plants. The condensing temperatures can be as low as possible, and this increases cycle efficiency and reduces energy consumption, in comparison

Refrigerant	Evap. Pr. MPa	Cond. Pr. MPa	Comp. Ratio	Ref. Effect-kJ/kg	Power consum. kW	C.O.P.
Ammonia-R717	0.235	1.162	4.94	1103.1	0.210	4.76
R22	0.295	1.187	4.02	162.67	0.214	4.66
134a	0.163	0.767	4.71	148.03	0.216	4.6
R410A	0.478	1.872	3.92	167.89	0.222	4.41
R404A	0.365	1.42	3.89	114.15	0.237	4.21
Carbon Dioxide-R744	2.254	7.18	3.19	133.23	0.192	2.69

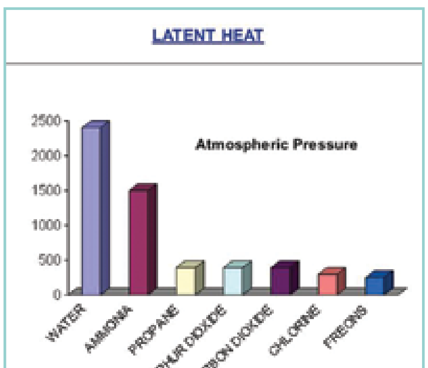
with HCFC/HFC direct expansion or flooded systems. It is well known for the system designers that lowest condensing temperature would lead to minimum power consumption and hence in ammonia systems the discharge pressure is allowed to float with changes in wet bulb temperature.

Latent Heat

Ammonia refrigerant has highest latent heat compared to other refrigerants except water and therefore per kg of refrigerant can absorb or reject lot of heat when phase transformation takes place in evaporator and condenser. Thus very low flow rates are required to provide a given refrigerant effect. In pump circulation systems the pumping power required is low compared to other refrigerants.

The Approx. latent heat at 4-5^{0}C for various refrigerants is listed below. (Slide 3)

Water R-718	2489.04kJ/kg
Ammonia – R717	1247.85kJ/kg
R410A	214.48kJ/kg
HCFC 22/R22	201.79kJ/kg
HFC 134a/R134a	195.52kJ/kg
R404A	162.03kJ/kg



(Slide 3)

Heat Transfer

Most of the thermal properties influencing heat transfer are favourable to ammonia compared to HCF 22 refrigerant

- Specific heat of liquid is nearly 4 times - 4 to 1
- Latent heat of vaporization is - 6 to 1
- Liquid thermal conductivity is - 5.5 to 1
- Viscosity is less - 0.8 to 1
- Liquid density is less as mentioned above - 0.5 to 1

All these properties help in improving heat transfer correlation between ammonia relative to HCFC 22 for condensing and evaporating heat transfer processes.

The table below illustrates heat transfer rates of Ammonia compared to R-22 refrigerant.

	Ammonia	HCFC 22
Condensation outside tubes (W/m2K)	7500-11000	1700-2800
Condensation inside tubes (W/m2K)	4200-8500	1400-2000
Boiling outside tubes (W/m2K)	2300-4500	1400-2000
Boiling inside tubes (W/m2K)	3100-5000	1500-2800

The higher heat transfer coefficients help in use of smaller evaporators & condensers or retain same heat transfer areas & operate at higher evaporating temperatures & lower condensing temperatures, thus improving the cycle efficiency.

Density

Density of ammonia is half of HCFC 22. (582 kg/m^3 density for Ammonia compared to 1128.4 kg/m^3 for HCFC 22). Thus refrigerant floats on oil layer having density around 886 kg/m^3 even if it goes in the crankcase & possibility of oil getting diluted with refrigerant and thereby affecting lubrication adversely is much less compared to HCFC 22.

Mass Flow Rate

Ammonia is more efficient. Its mass flow rate for a given refrigeration capacity is 1/7 times that of HCFC 22,(0.00091 kg/s for ammonia compared to 0.00616kg/s for R-22 at 250K evaporation and 303K condensation temperatures) which means only 1/7 liquid needs to be pumped for given refrigeration capacity. Thus mechanical pumping power will be much less in ammonia system.

Natural Refrigerant

Ammonia is natural refrigerant & present in the atmosphere and available in nature in abundance. In nature it is produced by biological processes and is naturally decomposed & does not add to GWP. Human liver has capacity to convert 130 gms of ammonia into urea each day.

TEWI:

The new terminology covering effect of direct and indirect leakage of refrigerant as well as energy consumption during life cycle of the equipment TEWI (Total Equivalent Warming Impact) is also very favourable for ammonia refrigerant due to its high thermal properties besides its nearly zero GWP and 0 ODP charactristics.

Leak Detection

Ammonia has a pungent odour and even small leaks as low as 5 PPM are detectable by smell so that maintenance staff can correct them. Almost all human beings can detect levels up to 25 PPM easily and continuous exposure to 50 PPM levels is permitted in most countries for 8 hours per day per week. The odourless refrigerants like HCFC- 22 or HFC 134a and others, even if they leak from the system in large quantity, it won't be noticed till cooling performance drops.

Lighter than Air

Since ammonia in vapour form is 1.7 times lighter than air, it quickly rises up in the air in case of leaks and does not stagnate in the plant room. Critical density of ammonia is 225 kg/m^3, for air is 335.94 kg/m3and for HCFC is 523.8422 kg/m3, R134a is 511.922 kg/m3, In case of leaks, since these refrigerants are heavier than air & due to their odourless character, they settle down in plant room when leaks develop without anyone noticing it and in un ventilated machine rooms deaths have been reported due to suffocation since required quantity of oxygen has been displaced by refrigerant.

Leakage Losses

The molecular weight of ammonia is 17.03, whereas HCFC 22 has 86.48, R134a is 102.03, R404A is 97.604 & R410A is 72.585. This means if plant develops leak of equal size on both plants, loss of higher density refrigerants would be greater than ammonia. Similarly during purging the loss of refrigerant is less in ammonia plants compared to other refrigerants for the same reason

Solubility in Water

Ammonia is eagerly absorbed by water; 1cum of water is able to absorb 120 kg of ammonia. The maximum concentration of ammonia in water (A saturated solution) has density of 0.88 kg/cm^3 and is often known as 880 ammonia.

Water Contamination

Ammonia systems are more tolerant to water contamination than HCFC/HFC systems. A little leak of moisture in the system which does not exceed concentration beyond 100 PPM stays in the solution & does not freeze out. Hence modest contamination with water does not usually interfere with ammonia system operation.

Behaviour with Oil

HCFC 22 & other HFC refrigerant liquids and commonly used lubricating oils are mutually soluble in varying degrees depending upon type of oil, operating temperature and pressure, while ammonia & oil are virtually insoluble. Hence recovering oil from various parts of system is easier & requires different approach to oil management. Oil recovery problems are nonexistent with ammonia at partial loads unlike HCFC 22 systems.

Pipe Sizes

Ammonia pipe line sizes are smaller or on other words same size would carry 2 to 3 times more refrigeration capacity than HCFC 22. The cost of piping is therefore less. For example a 10 cm diameter Pipe has 280 kW suction line capacity with HCFC 22 at pressure drop equivalent to 1^{0}C per 30 m length, where as for ammonia the same line would be suitable for 728 kW capacity.

The Table given below would illustrate required line size requirements for various refrigerants under identical conditions and based on steel piping- Ref ASHRAE volume –Refrigeration 20110.

Capacity -200 kW, evaporating temperature +5^{0}C

Refrigerant	Suction line – mm OD	Discharge Line - mm OD	Liquid line – mm OD
Ammonia – R717	50	40	20
HCFC-22	80	65	32
HFC134a	80	80	40
R404A	80	65	40
R410A	65	50	32

CRITICAL TEMPERATURES

Ammonia –R717	134.40C
HCFC-22	96.150C
HFC134a	101.060C
R404A	72.050C
R410A	71.360C

From the above it can be observed that critical temperature is highest for ammonia refrigerant and is thus better suited for heat pump applications. It has been also the experience of many that in air cooled applications with R-22, where very high ambient temperatures are encountered it becomes difficult to condense liquid as one is working too close to critical temperatures.

Safety Group

Earlier gases were grouped only in two categories, group I and group II.

ANSI standard and ASHRAE regrouped these to differentiate them as Group A1, A2, A3 and B1, B2, and B3. Ammonia is classified in B2 category. 'A' category is for Toxicity and 'B' category is for flammability. 'A3' is the most toxic and 'B3' is the most flammable category. ANSI/ASHRAE standard 34 now classifies ammonia refrigerant as B2L which means it is less flammable than B2 since its burning velocity is less than 10cm/s.

Costs

Ammonia costs are 20 times lower than HCFC 22 or HFC 134a in India. Not only ammonia is cheaper but is available in any part of the country and is produced indigenously. The HFC refrigerants which have been introduced recently as CFC substitutes need to be imported still.

Limitations & Drawbacks

Having covered most of the advantages and positive points of ammonia as refrigerant, we need to also look at its drawbacks/limitations for its use in some of the major applications like air conditioning.

General public perception is ammonia is flammable and toxic and therefore it is not permitted in direct cooling air conditioning plants for public areas.

Flamability

Ammonia is extremely hard (above 650^{0}C) to ignite and breaks down above 450^{0}C. The leaks are detectable above 5 PPM by most. It is therefore extremely rare to encounter such high temperatures in normal air conditioning and refrigeration applications. There is no reason for any concern that exposure to ammonia is a health hazard. Flammable limit by volume in air at atmospheric pressure is as high as 16% to 28% concentration. As mentioned above it is now classified as B2L which is less flammable compared to many hydrocarbons and other fuels which are used in day to day life. Its ignition energy is 50 times higher than that of natural gas and ammonia cannot burn without presence of supporting flame. Due to the high affinity of ammonia for atmospheric humidity it is rated as hardly flammable.

Toxicity

Laboratory trials have proved that continuous exposure levels for 10 to 15 years up to and exceeding 24 PPM has no adverse effect on human beings. Exposure to 100 PPM causes irritation but no health hazard. Exposure for ½ an hour above 5000 PPM may be fatal. Since the pungent smell of ammonia above 5 PPM is detectable, and serves as early warning, no one in its right senses would remain in the vicinity of ammonia leaks and would run away if the leaks are not controllable.

Applications using Ammonia as Refrigerant

In view of excellent properties stated above, use of ammonia as refrigerant is predominant in the following applications.

Various Applications using Ammonia Refrigerant:

- Cold Storages for Potatoes, fruits, vegetables
- Ice Plants-Conventional block ice, flake ice, tube ice plants
- Fish freezing plants – Spiral freezers, plate freezers, IQF, Blast & Trolley freezers
- Slaughter Houses & Meat processing plants
- Dairies and ice bank systems
- Process refrigeration plants for Chemical/Dyestuff Industries
- Breweries and wineries
- Bottling plants for Coca-Cola/ Pepsi & other soft drink bottlers
- Icecream plants
- Concrete cooling applications for river dams, air port runways and concrete expressways
- Fertilizer plants
- Recently some Super markets have also tried using ammonia/ carbon dioxide systems (Slide 4)
- Liquefaction of gases
- Pharmaceutical plants for process cooling
- Air conditioning of large complexes like Air ports-
- Compact ammonia packages for air conditioning telegraph, and other office premises (Slide 5)
- Air conditioning of processing halls for cold chain facilities.

Recent Trends and Future Technology

Heat pump applications are on increase. Ammonia refrigerant is better suited for this duty. Earlier ammonia reciprocating compressors were slow speed in the range from 300 to 750 RPM. Current compressor designs are available up to 1500 RPM. Screw compressors running at 3000 RPM are also available.

Welded plate heat exchangers has changed the entire scene with ammonia refrigerant applications. Earlier, or even today many designers use shell and tube plain tube heat exchangers which are large. The plate heat exchangers have made factory assembled packages possible. It has also reduced quantity of refrigerant drastically, making use of small capacity air conditioning applications possible. Many companies in Europe are marketing

(Slide 5)

Modern Packaged Ammonia Systems

- New design (PHEs or spray type shell & tube evaporator)
- Liquid injection system
- Better efficiency (>30%) than HFC134a
- Less charge (0.02 to 0.5 kg/kW) for dry and flooded evaporation
- Higher discharge pressure (up to 40 bar)
- Safety level increased significantly towards "zero leak"
- Used in Europe for both display cabinets and space conditioning

Ammonia for A/C and Commercial Refrigeration

- Ammonia A/C with central plants
- Ammonia display freezer cabinets
- Independent circuits
- Secondary refrigerants used
- Risk free AC&R

(Slide 4)

COMPACT PACKAGE CHILLER

(Slide 6)

such packages using Welded plate heat exchangers for both evaporator and condenser side. (Slide 6)

Many companies are working on use of aluminum heat exchanger technology since aluminum is compatible with ammonia refrigerant. Using aluminum improves heat transfer efficiency compared to steel up to 17% depending on operating conditions. Aluminum heat exchangers, if widely made available, would enable use of direct expansion cooling coils and accelerate development of air cooled condensers with ammonia, similar to HCFC/HFC refrigerants. Also finned tube compact heat exchangers, similar to what is being used for R-22 can be manufactured

Star Refrigeration UK have introduced compact air and water cooled chiller packages where refrigerant charge is less than 1 kg/Ton for air cooled design and less than 0.5 kg/Ton for water cooled chillers using semi welded PHE for condenser and evaporator. (Slide 7,8 and 9)

(Slide 7)

(Slide 8)

(Slide 9)

Release of refrigerants to the atmosphere is generally not recommended and Montreal protocol prohibits releasing environmentally harmful refrigerants to atmosphere, because of this there is already a general trend to shift to indirect cooling systems, so that refrigerant charge in the system is reduced, system becomes more compact & potential leaks through longer pipe lengths are drastically cut down.

Factory build, compact ammonia liquid cooling packages (with refrigerant charge limited to less than 50 kg) mounted in air tight containers, with leak detector actuated automatic safety ventilation would avoid any risk of accidental leaks of ammonia entering public places. The containers would also be build with integrated water reservoirs to absorb ammonia in case of leaks. (One litre of water is capable of absorbing 0.517 kg of ammonia liquid or 650 litre of ammonia vapour).

Hermetically sealed compressor/motors units with aluminum windings for ammonia are currently now available on trial basis and have been displayed at international exhibitions. Canned motor pumps are widely used for ammonia liquid circulation since long.

Microchannel aluminum heat exchangers conventionally used by automobile industry are gradually making inroads in stationary air conditioning and refrigeration applications and use of these reduces the refrigerant charge drastically.

Miscible synthetic lubricating oils are now available so that the oil will remain in circulation along with ammonia refrigerant and use of Direct Expansion valves can reduce refrigerant quantity in the system.

Since ammonia evaporators are not normally preferred where they are exposed to public areas, a recent development of using ammonia and CO_2 cascade systems are becoming popular for super markets. Ammonia is used in high stage system and CO_2 is used for low stage. Thus direct exposure of ammonia containing parts is thus avoided.

Systems using melt ice slurry for chilling is also being used, which reduces energy consumption by 10% compared to most HCFC or HFC direct expansion systems. Since ice slurry is used as secondary coolant and works on phase change, latent cooling capacity is available & smaller volumes need to be pumped.

Thermal storages with ice build up during night time and using this capacity during day time for air conditioning is becoming popular in developed countries. This is due to large differential electrical tariff rates for day time and night time (4/5 times more during day compared to night tariff). It therefore works out economical to produce ice/or chilled brine at night and use this stored capacity during working hours during day time.

As discussed earlier, since mineral oils are immiscible with ammonia, transportation of ammonia for direct expansion systems is an issue. An azeotropic mixture of 60% ammonia and 40% DME has been tried successfully to improve oil miscibility characteristics. A German research Institute has developed system using this mixture.

Use of ammonia refrigerant will become more popular once the refrigerant's toxic and flammability properties are tamed and quantity of refrigerant in systems is reduced substantially by advanced design heat exchangers.

Ammonia leakage issues can also be eliminated to the extend possible by use of hermatic motors, miscible synthetic oils, and use of all welded joints by eliminating flanged connections.

Finally We shall now look at what published literature and some of the experts have to say on use of Ammonia as a refrigerant.

Problem of Public Perception

ASHRAE Journal – May 99

William McCloskey, Executive vice President of Baltimore Air Coil said "IIAR & its members must dedicate themselves to countering the negative perception about ammonia, not with the industry peers but with general public. This includes the faulty perception that city code prohibits use of ammonia in installations in metropolitan areas".

He sited an example that in several cities including Chicago which has restrictive codes, more than 140 urban ammonia installations are operating.

The air conditioning installations using ammonia include McCormick Place & W.W. Grainger office building. The 40 storey Blue Cross Blue Shield building that also has ammonia chillers for air conditioning.

Modern airports like Dusseldorf, Heathrow's new terminal 5 and Zurich air port use ammonia systems. Oslo air port also uses ammonia as refrigerant and some of the specifications are given below to get the idea as to the enormous size of installations.

OSLO air port specifications

The installation of Ammonia system for air conditioning of Oslo Airport Finland, which was commissioned in October 1998. This is one of the largest and most advanced airport having a capacity to handle 16 to 18 million passengers / year with 64 check in counters and handling 80 air crafts per hour. The total operational building area is 18,000 sq mtr and commercial area 2.7 sq km. The total area is 13 sq km.

Plant uses Ammonia refrigerant in indirect cooling chilled water system, using 3 number reciprocating 16 cylinder compressors in one area & 2 number reciprocating compressors of 8 cylinders in another area.

Article in Cooling India Nov-Dec 10 - Monika Witt

All large buildings in Germany have ben equipped with ammonia liquid chillers for air conditioning. Banks, insurance companies and office buildings also increasingly use ammonia liquid chillers for energy saving air conditioning.

Post and Telegraph department - Copenhagen

This plant uses reciprocating compressors with Plate Heat Exchangers for Evaporator as well as on Condenser side.

The particular mention of this plant is made in this article to stress the point that with use of plate Heat Exchangers, the quantity of refrigerant required to be circulated reduces to nearly 20% and thus handling of refrigerant and dangers due to possible leaks are minimized substantially. A factory assembled water chiller using PHE heat exchanger of 2700 kW capacity uses only 165 kg of Ammonia (0.22 kg/Ton).

ASHRAE Journal May 2000

An article describing use of ammonia for ice storage application for air cooling using 700 HP screw compressors, by Byron H Bakenhus won the best engineering excellence award.

EURAMMON

This organization promotes use of natural refrigerants including Ammonia- It states that use of PHE has reduced ammonia charge per kW to 0.06 kg/kW for dry expansion & 0.04 to 0.1 kg/kW for flooded evaporation. This permits liquid chillers with less than 50 kg ammonia charge to be used in publicly accessible rooms without a separate machine room.

RAC News 2001

Mycom has developed an ammonia compatible compressor oil(patented world wide) which means there is no decreasing heat transfer I evaporator or condenser and does not require oil separator to be installed in the plant. The oil will return back to compressor automatically the easiest way with refrigerant suction gas & thus the plant becomes maintenance free.

Miscible PAG oils up to minus 20^0C have also been tried by other manufacturers.

Ashrae Journal October 2001

This journal has excellent article giving a case study of ammonia installation for super market instead conventional R-22 refrigerant. The article gives comparison with use of both refrigerants. The installation is in Brazil.

Ashrae Journal 2001 May

William Duffy, President of P & O cold logistics, said 15 of his company's cold storage facilities use ammonia. He also plans to convert remaining two of his R-22 plants to ammonia.

RAC - January 2000

Increased use of adhesives is being tried for pressure containing parts for joining. Use of aluminum and associated joining techniques such as brazing of stainless steel or aluminum is being experimented. Use of resin bonded printed circuit heat exchangers is being explored. All these will help in popularizing ammonia refrigerant use in direct use of ammonia in small cold/chill rooms and packaged air cooled chillers suitable for roof top installations for offices, supermarkets and factories.

Weiland Gemany

This company is leading tube manufacturer. It has developed steel tubing with

Enhanced heat transfer surfaces for use in ammonia shell and tube heat exchangers. This Geva B tubing for use in evaporators has double enhanced tubing with ridged inside surface as well The heat exchangers using this tubing have been manufactured by one of the Indian companies successfully.

The article can be summed up by no better comments than made by Nestle, one of the most popular brands known world over.

Bent Weincke, Nestle USA said, Nestle believes HFC are a transient refrigerant & we don't know if they will be around in another 10 years. We strongly believe in advantages of ammonia and ammonia is therefore Nestle's preferred choice.

Conclusion

The author has tried to cover most of the information on current use of ammonia with various applications and the recent trends in research activities for promoting use of ammonia. Author firmly believes that Ammonia is the refrigerant for the future and efforts should be made to overcome its limitations for some applications. With the current level of technology available in the world and safety standards in place, if the design and execution is done properly, there is hardly any danger of using Ammonia as refrigerant. In India, in fact, most of the cold storages and ice plants use Ammonia and the plants are mostly manned by uneducated and untrained technicians. ■

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