

# The use of CO<sub>2</sub> as a Secondary Refrigerant in NH<sub>3</sub> Refrigeration Systems

by **Hiroyuki Egashira**  
General Manager  
Mayekawa Mfg. Co. Ltd.  
India Representative Office, Pune

In Japan, the first Ammonia refrigeration system using CO<sub>2</sub> as the secondary refrigerant, hereafter called “CO<sub>2</sub> indirect system”, was installed in 2003, a year after the installation of the first Japanese NH<sub>3</sub>/CO<sub>2</sub> cascade system. Since then more than 100 systems have been commissioned.

According to the study compiled by “Ammonia Refrigeration System New Technology Working Group”, published in *Refrigeration*, a periodical issued by Japan Refrigeration and Air Conditioning Association, in the August 2006 issue, it is reported that less than two and half years after the first CO<sub>2</sub> indirect system was commissioned, 35 CO<sub>2</sub>

indirect systems were installed by five refrigeration contractors for 32 separate customers, with applications ranging from ice making systems (-12°C), cold storage (-35°C) and freezers (-45°C). The temperatures in the brackets are CO<sub>2</sub> evaporating temperatures. In the same period, or actually three and half years, because NH<sub>3</sub>/CO<sub>2</sub> cascade systems started one year earlier, only three NH<sub>3</sub>/CO<sub>2</sub> cascade systems were commissioned by two refrigeration contractors for two companies, with two applications for freeze dry, (-60°C) and one for freezer (-40°C).

With wide and quick propagation of

the techniques, CO<sub>2</sub> indirect systems, rather than NH<sub>3</sub>/CO<sub>2</sub> cascade systems are in a good position to replace R-22 systems, which have been, and still are the predominant systems in the Japanese refrigeration industry.

## Differences between CO<sub>2</sub> Indirect and NH<sub>3</sub>/CO<sub>2</sub> Cascade Systems

First let me clarify the difference between CO<sub>2</sub> indirect system and NH<sub>3</sub>/CO<sub>2</sub> cascade system.

### About the Author

**Hiroyuki Egashira** joined Mayekawa Mfg. Co. Ltd. in 1986 as a refrigeration system designer and project supervisor mainly for overseas projects. In 2000 he was transferred to Thailand as general manager and transferred to India in 2006.

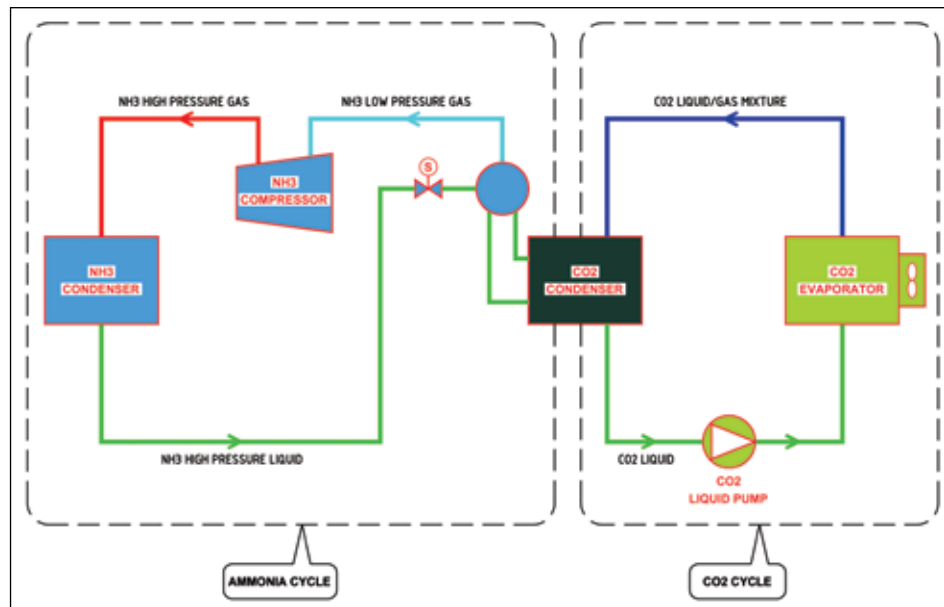


Diagram 1 : Indirect system using CO<sub>2</sub> as secondary refrigerant.

Diagram 1 shows the flow of CO<sub>2</sub> indirect system with ammonia refrigeration.

A. CO<sub>2</sub> is pumped to the evaporator where it exchanges heat with air. Part of the CO<sub>2</sub> evaporates as it cools the air.

B. The two phase CO<sub>2</sub> (mixture of liquid and gas) from the evaporator returns to the CO<sub>2</sub> condenser where it is condensed by ammonia.

C. Condensed CO<sub>2</sub> liquid accumulates in the vessel and is pumped to the evaporator.

The ammonia system can either be a flooded system with a surge drum and level controller or a direct expansion system with miscible oil and an electronic expansion valve. Flooded systems offer more stable operation against quickly changing heat loads, while direct expansion systems require much less space and less ammonia charge for the same capacity.

Diagram 2 and 3 show the flow of the NH<sub>3</sub>/CO<sub>2</sub> cascade system.

Diagram 2 shows a CO<sub>2</sub> direct expansion system.

A. CO<sub>2</sub> is directly supplied to the evaporator and it completely evaporates.

B. CO<sub>2</sub> gas returns to the CO<sub>2</sub> compressor where it is compressed to high pressure.

C. Pressurized gas then goes to the CO<sub>2</sub> condenser where it is cooled and condensed by

ammonia.

D. Condensed high pressure CO<sub>2</sub> liquid passes through the expansion valve where it is expanded to low pressure and temperature and goes to the evaporator again.

The electronic expansion valve controls the liquid supply to the evaporator to prevent liquid flow back to CO<sub>2</sub> compressors. CO<sub>2</sub> miscible oil is used for the compressor to ensure that any oil that goes to the evaporator returns to the compressor just as in HCFC refrigeration systems.

Diagram 3 shows the CO<sub>2</sub> liquid over feed system

A. Liquid CO<sub>2</sub> is pumped to the evaporator where it partly

evaporates before returning to the CO<sub>2</sub> liquid/gas separator.

B. In the liquid/gas separator, CO<sub>2</sub> gas and liquid are separated and only gas goes to the compressor where it is compressed to high pressure.

C. From the compressor, high pressure CO<sub>2</sub> gas goes to the CO<sub>2</sub> condenser where it is condensed by ammonia.

D. Condensed CO<sub>2</sub> liquid, which is still at high pressure, goes to the liquid line and through the expansion valve to the liquid/gas separator.

E. From the separator, only low pressure CO<sub>2</sub> liquid is pumped to the evaporator. The liquid level in the separator is controlled to prevent liquid flow back into the compressor.

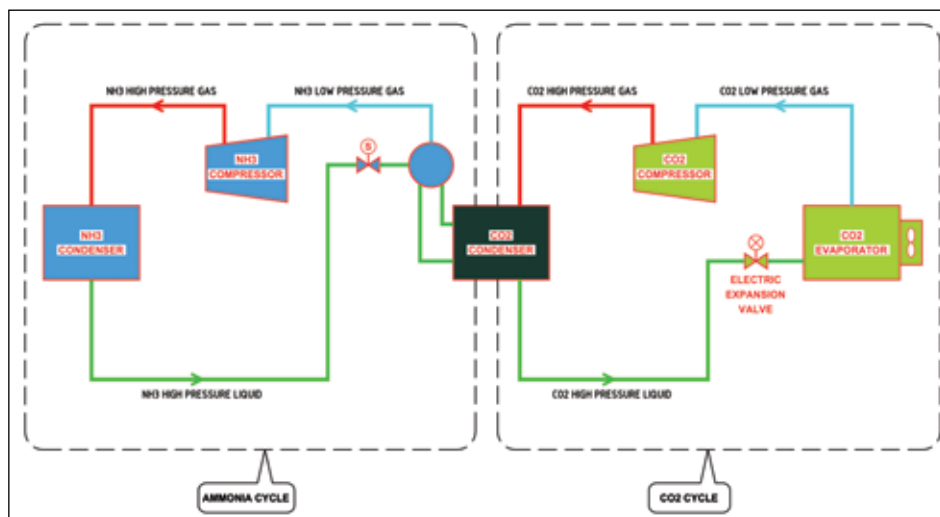


Diagram 2 : NH<sub>3</sub>/CO<sub>2</sub> cascade system with CO<sub>2</sub> direct expansion.

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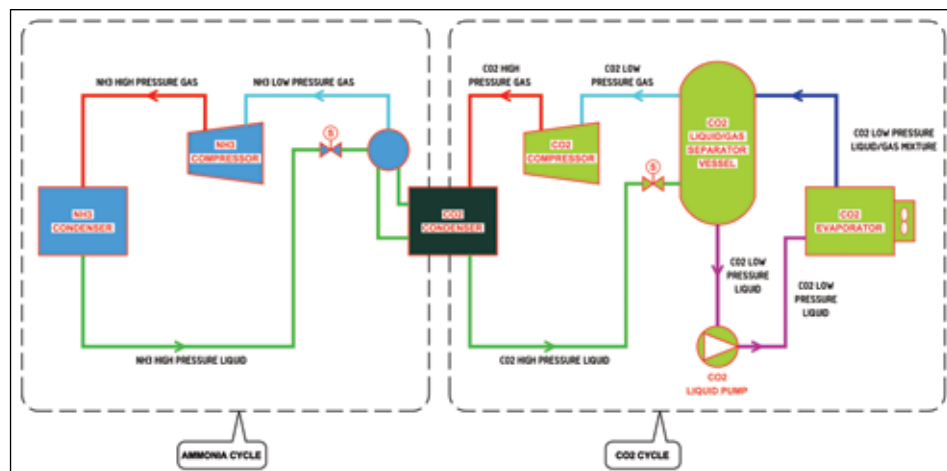


Diagram 3 : NH<sub>3</sub>/CO<sub>2</sub> cascade system with CO<sub>2</sub> liquid overfeed system.

The main difference between the CO<sub>2</sub> indirect and NH<sub>3</sub>/CO<sub>2</sub> cascade system is the existence of a CO<sub>2</sub> compressor. A comparison of the two systems is shown in Table 1. One obvious disadvantage of the indirect system when compared to NH<sub>3</sub>/CO<sub>2</sub> cascade system is the lower COP at evaporating temperatures below -31°. On the other hand, the advantages of the CO<sub>2</sub> indirect system are as follows;

1. It does not require some of the new technologies essential to the cascade systems, such as the CO<sub>2</sub> compressor, CO<sub>2</sub> miscible lubrication oil and electronic controlled CO<sub>2</sub> expansion valve. The only new item in the CO<sub>2</sub> indirect system is the CO<sub>2</sub> liquid pump. However, they may be new to the refrigeration industry but they are common and tested equipment in the process industry.

2. Design pressure of the CO<sub>2</sub> refrigerant pipe line is determined by the evaporating pressure and pump head. For example, in a -20° room temperature application, with room temperature and evaporating temperature difference of 7°, CO<sub>2</sub> evaporating temperature is designed at -27°. At this temperature, the saturated CO<sub>2</sub> pressure is 14.8kg/cm<sup>2</sup>G. Take pump head of 2 or 3 kg/cm<sup>2</sup>, it is still

less than 20kg/cm<sup>2</sup> and within the range of standard ammonia refrigeration condensing pressure pipe line requirement. However, for NH<sub>3</sub>/CO<sub>2</sub> cascade systems, the highest pressure in the system is in the CO<sub>2</sub> condensing line. If the condensing temperature of CO<sub>2</sub> is -5°, pressure in the pipe is 30kg/cm<sup>2</sup>G.

3. Since CO<sub>2</sub> is supplied by the pump to the evaporator, there is no CO<sub>2</sub> compression process, no lubrication oil and contamination of CO<sub>2</sub> line with oil. The CO<sub>2</sub> cycle does not

require oil separator, oil removal equipment, and oil removal procedures. It is therefore, easy to maintain.

### Historical Back Ground

Let us briefly review the back ground of the use of the CO<sub>2</sub> indirect system for refrigeration.

Japan frequently experiences earthquakes and has a strong urge for absolute safety of its refrigeration systems. However stoutly designed and carefully maintained, refrigeration systems have a possibility of refrigerant leakage in case of a major earthquake. If ammonia leaks and humans and food stuffs are exposed, the effect can be disastrous. Therefore, since the inception of fluorocarbon refrigerants, there has been a long standing policy from the national and local government to discourage the use of ammonia as refrigerant and to promote and encourage R22 and other fluorocarbon refrigerants in refrigeration systems. Refrigeration safety regulations require ammonia refrigeration plants with more than 50JRT (approx. 55TR) to have licenses from the local authorities. (JRT, is Japanese Refrigeration Ton, a unit used to express refrigeration capacity in Japan. It is defined as refrigeration capacity capable of transforming 1 metric ton of water at 0° to ice at 0° in 24 hours. It is 3324kcal/hr, or 0.92TR. The real difference with the US refrigeration ton, or TR is the difference of amount of water. The TR uses 2000lb for 1 ton, which is 0.907Metric ton).

For plants with more than 20JRT (approx. 22TR), a qualified technician is required. For fluorocarbon refrigeration systems, requirement for a technician is above 50JRT (55TR). This is a stringent regulation against the use of ammonia, in a country where labor costs, especially a qualified technician's labor cost accounts for a high percentage of the plant operation cost. New ammonia installations have been restricted, and effectively banned, for the last 30 years.

	NH <sub>3</sub> /CO <sub>2</sub> Cascade system	CO <sub>2</sub> Indirect System
Compressor	Required	Not required
High pressure line	Exist	Not exist
Lubrication Oil	Required	Not required
Oil Separator	Required	Not required
Oil Removal	Required	Not required
CO <sub>2</sub> temp upper limit	-25°C	+5°C
CO <sub>2</sub> temp lower limit	-56.6°C	-56.6°C
COP in relation to CO <sub>2</sub> evaporating temperature	Better at below -31	Better at above -31

Table 1 : Comparison of NH<sub>3</sub>/CO<sub>2</sub> Cascade system and CO<sub>2</sub> Indirect system.

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However, due to global concerns of ozone layer depletion and global warming, HCFC and CFC which were considered non hazardous substances turned out to be hazardous to the environment. It was decided that they should be phased out. The Montreal Protocol of 1995 made a frame work for the restriction and phase out of CFC (such as R-11 and R-12) and HCFC (such as R-22), based on their Ozone Depletion Potential(ODP), and Kyoto Protocol of 1997 added HFC (such as R134a and R404A) to this frame work based on their Global Warming Potential(GWP). New options have been developed and tested. However, new options from fluorocarbon products so far have limitations and are bound to be temporary

Ammonia, a well known and one of the oldest refrigerants has since then been considered and revived as a potential alternative to the fluorocarbons. Ammonia is a natural refrigerant with no Ozone Depletion Potential (ODP) while HCFC 22 has ODP of 0.55. Ammonia has Global Warming Potential (GWP) of less than 1, while HCFC22 has GWP of 1700, HFC134a, 1300 and HFC404A, 3870. Table 2 shows a comparison of the refrigerants.

Type of Refrigerant	Natural	HCFC	HFC	
Refrigerant	NH3	R22	R134a	R404A
ODP	0	0.055	0	0
GWP	<1	1700	1300	3870

Table 2 : Comparison of refrigerants.

Ammonia, the most inexpensive refrigerant in most parts of the world has excellent thermodynamic properties which results in compact heat exchangers and compressors as compared to fluorocarbons. However, it is toxic, has a strong odor, and at a certain concentration it is flammable. Therefore, if ammonia is to be used, extra precautions must be taken.

**Ammonia Package Units for Safety**

One of the measures taken for the safe use of ammonia is the design of ammonia package units where the compressor, condenser, ammonia control valves, piping and starter and control panels are all contained in an enclosed casing. The package is equipped with an ammonia removal system, such as water spray, which is automatically activated in case of any leakages and neutralizes the leaked ammonia. The package is typically equipped with earthquake detectors, leak detectors and safety exhaust systems which detect abnormalities and automatically stop the equipment, exhaust ammonia in case of minor leakage and inform the operator. The removal of ammonia is taken care of automatically, without human presence and without human exposure to

ammonia. To promote use of this kind of ammonia packages, with increased safety measures, the local authority now allows packages of up to 60JRT to operate without qualified technicians.

To minimize the size of packages, refrigerant charge and amount of possible leakage, a direct expansion system was developed. This was made possible by the development of synthetic oil miscible with ammonia to ensure that oil carried over by the discharge gas will return from evaporator to compressor, just like in R-22 direct expansion systems, and also by the development of an electronic expansion valve which controls ammonia liquid supplied to evaporators.

However, the evaporators have to be situated within the cold storage room. Ammonia pipes, at least the liquid supply and suction, have to come out of the package casing, go through the buildings and enter the cold storage room. Generally, the suction line pressure of ammonia is not high. For -34° evaporation, the pressure is 0kg/cm<sup>2</sup>G. For -5° the pressure is 2.6kg/cm<sup>2</sup>G. But then, in case of a dry expansion system, liquid line pressure is maintained at above 10kg/cm<sup>2</sup>G. And cold storage rooms are enclosed with little space to move about. If leakage occurs, there are dangers for personnel and possibility of damage to the goods stored.

To eliminate this possibility, and to completely isolate and contain ammonia in a package, or at the least in the machine room where only authorized and trained personnel have access, an indirect system was developed.

In the indirect system, a secondary refrigerant is cooled within the package and supplied to the evaporator.

The basic requirements of material for secondary refrigerants are:

- Non-toxic
- High specific heat
- Low viscosity
- Inexpensive

Water is the most convenient secondary refrigerant. It is reasonably priced, non hazardous, has a relatively high specific heat of 1.0034kcal/kgK, and low viscosity of 0.0015 Pa.s at 7°. It is commonly used as the secondary refrigerant in air conditioning, where the air temperature requirement is 24°, and secondary refrigerant supply temperature is 7°. It is used in dairies, usually together with ice bank systems, where temperature requirements are near 0°.

Water, however, freezes at 0°. It is, therefore, unsuitable for applications where the required temperature is below 0°. It is not safe to use water at temperatures lower than

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4°, unless in an ice bank or falling film water chiller, where the safety of equipment against freeze up is ensured. Some PHE and shell and tube systems are operated at -2° ammonia evaporation and +2° water outlet. However, such systems are always at the risk of freeze up.

To lower the freezing point of water, chemicals such as alcohol, sodium chloride, calcium chloride, ethylene glycol and propylene glycol are mixed with water. These solutions are called brines. Generally, higher the concentration, lower the freezing point.

The disadvantage of these brine solutions is that as the concentration increases, the viscosity and density of the fluid increases, while specific heat decreases. As a result, for lower temperature applications, large flow rates are required for high viscosity brine solutions.

Table 3 shows a comparison of some brines.

Let us compare application A, with room temperature of 5°, brine in/out temperature of 0/-3° with primary refrigerant evaporating temperature of -8° with application B, with room temperature of -20°, brine in/out temperature of -25/-28 while the primary refrigerant evaporating temperature is -32°.

• To achieve -20° room temperature, CaCl flow rate increases 17.4% by weight, 6.5% by volume and the

Application A	Unit	CaCl	PG*	Ethanol
Room Temp.	°C		5	
Brine In	°C		-3	
Brine out	°C		0	
Average	°C		-1.5	
Concentration	%	17	27	23
Freezing point	°C	-13.2	-12.9	-13.74
Refrigerant Evaporating temp.	°C		-8	
Viscosity	Pa.s	0.0030	0.0072	0.0062306
Sepecific Heat	kcal/°CKg	0.77416	0.91142	1.022
Sepecific Volume	kg/lit	1.1614	1.0292	0.97355
Flow Rate(by Weight)	kg/hr/kW	370.3	314.5	280.5
Flow Rate(by Volume)	lit/hr/kW	318.8	305.6	288.1

Application B	Unit	CaCl	PG	Ethanol
Room Temp.	°C		-20	
Brine In	°C		-28	
Brine out	°C		-25	
Average	°C		-26.5	
Concentration	%	27	54	47
Freezing point	°C	-36.6	-38.3	-36.04
Refrigerant Evaporating temp.	°C		-32	
Viscosity	Pa.s	0.0149	0.1499	0.03756
Sepecific Heat	kcal/°CKg	0.65944	0.78808	0.75393
Sepecific Volume	kg/lit	1.2803	1.0605	0.95319
Flow Rate(by Weight)	kg/hr/kW	434.7	363.8	380.2
Flow Rate(by Volume)	lit/hr/kW	339.5	343	398.9

Table 3 : Comparison of Brines. Brine Flow Rate per kW of Refrigeration. \* Propylene Glycol

viscosity 4.4 times against 5° room temperature.

• For the same condition, propylene glycol flow rate increases 15.7% by weight, 12.2% by volume and viscosity 20.8times.

• For the same condition, ethanol flow rate increases 35.5% by weight, 38.5% by volume and viscosity 6.0times.

Due to these characteristics, indirect systems using brine have disadvantages, especially at the lower temperature applications when compared with a refrigeration system using primary refrigerant only. They can be summarized as follows:

1. Bigger pipes to accommodate large volume of brine at higher viscosity.
2. Bigger brine pump motors to accommodate large volume of brine at higher viscosity.
3. Large volume of chemicals to accommodate highly concentrated brine in the large volume brine pipe.

Besides, brine concentration control is a critical requirement, and for some brines, corrosion control and flame/explosion control should be added.

The CO<sub>2</sub> indirect system was designed to overcome the disadvantages of the conventional brine indirect systems. It offers the following advantages.

1. CO<sub>2</sub> as a secondary refrigerant uses latent heat, while brine uses sensible heat. Use of latent heat dramatically reduces the refrigerant flow. Table 4 shows comparable conditions with Table 3.

A. Compare application A, room temperature 5°, CO<sub>2</sub> evaporating temperature -2° with primary refrigerant evaporating temperature of -6° with

B. application B, room temperature -20°, CO<sub>2</sub> evaporating temperature -27° with primary refrigerant evaporating temperature of -31°.

Taking the 4 times volume ratio, at 5° room temperature, CO<sub>2</sub> flow rate by weight is 16% of CaCl, 19% of PG, and 22% of ethanol. In terms of volume, for wet suction line, flow rate by volume, mixture of CO<sub>2</sub> one part gas and three parts liquid is 75% of CaCl, 78% of PG and 83% of ethanol.

Taking the 4 times volume ratio, at -20° room temperature, CO<sub>2</sub> flow rate by weight is 11% of CaCl, 13.3 of PG, and 12.8% of ethanol. In terms of volume, for wet suction line, it is 95% of CaCl, 94% of PG and 81% of ethanol.

The volume flow rates of wet suction are not so impressive. When the room temperature is -20° it is almost the same. But please note that these are the comparisons of pure liquid flow and gas/liquid mixture flow, but the mixture is in terms of volume mostly gas,

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Application A	Unit	CO <sub>2</sub>
Room Temp.	°C	5
Evaporating temp.	°C	-2
Liquid Enthalpy	kcal/kg	46.608
Gas Enthalpy	kcal/kg	103.31
Viscosity/Liquid	Pa.s	1.0929E-04
Viscosity/Gas	Pa.s	1.4120E-05
Specific Volume/liquid	kg/m <sup>3</sup>	939.8
Specific Volume/gas	kg/m <sup>3</sup>	91.4
Flow rate by weight	kg/hr/kW	60.7
Flow rate by volume/liquid	lit/hr/kW	64.6
Flow rate by volume/wet suction	m <sup>3</sup> /hr/kW	0.239

Application B	Unit	CO <sub>2</sub>
Room Temp.	°C	-20
Evaporating temp.	°C	-27
Liquid Enthalpy	kcal/kg	33.53
Gas Enthalpy	kcal/kg	104.42
Viscosity/Liquid	Pa.s	1.6351E-04
Viscosity/Gas	Pa.s	1.2306E-05
Specific Volume/liquid	kg/m <sup>3</sup>	1062.2
Specific Volume/gas	kg/m <sup>3</sup>	41.0
Flow rate by weight	kg/hr/kW	48.5
Flow rate by volume/liquid	lit/hr/kW	45.7
Flow rate by volume/wet suction	m <sup>3</sup> /hr/kW	0.324

Table 4 : Liquid/gas flow rate of CO<sub>2</sub> Indirect system for 1kw of refrigeration. Volume ratio: 4 times the evaporation. Wet suction 1 time evaporation gas and 3 times liquid.

where the viscosity of the gas is 1/1200 of any brine.

1. Thus for CO<sub>2</sub> indirect systems, smaller pipes and smaller pump motors can be used for the secondary refrigerant.

2. CO<sub>2</sub> does not require concentration and corrosion control. It is, therefore, easier to maintain.

3. CO<sub>2</sub> is readily available and generally not very expensive.

4. CO<sub>2</sub> is safer material compared with ammonia, in case of leakage. Table 5 shows a comparison of NH<sub>3</sub>/CO<sub>2</sub> safety characteristics.

**Applications**

Table 6 shows a BkW/Refrigeration comparison of

	Ammonia	CO <sub>2</sub>
Threshold limit value (ppm)	25	5000
Short term exposure limit (ppm)	35	30,000
Immediately dangerous to Life and Health(ppm)	500	40,000
Lower flammable limit (%)	15	Non Flammable
Group (By ASHRAE)	B2 (Toxic)	A1 (Non Toxic)

Table 5 : Comparison of NH<sub>3</sub>/CO<sub>2</sub> safety characteristics

CO<sub>2</sub> indirect, NH<sub>3</sub>, R-22 and R404A direct systems. Here, the term direct is used to differentiate from the indirect system. It applies to any system that is not using secondary refrigerant, such as flooded, liquid over feed and direct expansion systems. The comparison was made with CO<sub>2</sub> indirect system power consumption per kW of refrigeration as 100%, at room temperature of -25°. Evaporating temperature and type of compressors used for the comparison are indicated in the table. R404A systems, which are becoming more and more common, consume 40% more power than CO<sub>2</sub> indirect systems. R-22 direct expansion system and NH<sub>3</sub> liquid overfeed system and flooded system consume 7% and 10% less, respectively. In Japan, since R-22 systems are no longer an option because of environmental concerns and NH<sub>3</sub> systems are unthinkable due to safety requirements, CO<sub>2</sub> indirect system is a good option that stands against the comparison with R404A systems.

Type of Refrigerant	Natural		HCFC	HFC
System	CO <sub>2</sub> Indirect	NH <sub>3</sub> Direct	R-22 Direct	Direct
Refrigerant	NH <sub>3</sub>	NH <sub>3</sub>	R22	R404A
Room Temp.(°C)	-25			
Condensing Temp.(°C)	40			
Evaporating Temp.(°C)	-36	-32	-32	-32
Compressor	Two Stage	Two Stage	Two Stage	Single Stage with economizer
BkW/Ref.kW(%)	100.0	90.1	93.0	142.3

Table 6 : Comparison of BkW/Ref.kW for various systems.

Note that the lower efficiency of CO<sub>2</sub> indirect system comes from lower suction temperature compared with the ammonia direct system. Generally, we take 4°C difference between the CO<sub>2</sub> evaporating temperature and ammonia evaporating temperature. For ammonia flooded and liquid overfeed system with applications such as freezers, where the evaporating temperature at the coil is critical, we commonly take 2° for pressure drop. That is, to ensure the required temperature of -40°(0.731kg/cm<sup>2</sup>A NH<sub>3</sub>) at the evaporator, compressor is selected at -42°(0.656kg/cm<sup>2</sup>A NH<sub>3</sub>). 2° temperature difference means 0.075kg/cm<sup>2</sup> pressure drop.

If the same pressure drop is maintained from the CO<sub>2</sub> line, to ensure the required temperature of -40°(10.024kg/cm<sup>2</sup>A CO<sub>2</sub>) at the evaporator, compressor is selected at 0.075kg/cm<sup>2</sup> lower, that is -40.8°(9.949kg/cm<sup>2</sup>A CO<sub>2</sub>). In stead of 2° temperature difference we can take 1° for pressure drop.

At -40° the ammonia gas volume for 1kW of

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Photo 1 : CO<sub>2</sub> Indirect Package (Ice Plant)

refrigeration is 4.03m<sup>3</sup>/hr while CO<sub>2</sub> is 0.43m<sup>3</sup>/hr. For CO<sub>2</sub> indirect system, flow rate is 1/10 of ammonia. Therefore, for CO<sub>2</sub> indirect system, it is possible to design pipe line with smaller pressure drop at similar cost.

Efficiency of CO<sub>2</sub> indirect system is by definition, lower than ammonia direct system. However, as the effect of pressure drop becomes more prominent at the lower suction temperature, CO<sub>2</sub> indirect system's efficiency can be improved relative to ammonia direct system at -40° and lower evaporating temperature.

In the study mentioned in the first section of this article, out of 35 examples, 14 plants were for -40° range, 17 plants -30° range, 3 plants are for -10° range and 1 plant has a provision for both -40 and -30° range.

In Japan, CO<sub>2</sub> indirect systems come in packages shown in Photos 1, 2 and 3, with ammonia cycle complete with compressor, condenser, CO<sub>2</sub> condenser, CO<sub>2</sub> tank and CO<sub>2</sub> pump, local starter and control panel assembled in the factory. To save space, civil work and

construction cost, and to ensure the complete separation of ammonia system from the main building, packages are designed for outdoor installation. To minimize the installation time, they are factory tested and ready to operate after power supply line and water supply lines are connect-



Photo 4 : CO<sub>2</sub> tank with CO<sub>2</sub> pump. Indoor Installation.

Sometimes, the roof or the side of the building is customer's preferred location. To accommodate such compact packaging, majority of these systems use ammonia direct expansion systems and fully welded plate and shell heat exchangers for CO<sub>2</sub> condensers.

In some cases, the CO<sub>2</sub> tank and CO<sub>2</sub> pump cannot be accommodated in the single package. In such cases, a separate CO<sub>2</sub> tank and CO<sub>2</sub> pump unit are required. Photo 4 shows a CO<sub>2</sub> tank/pump unit installed indoor while Photo 5 shows an outdoor installation. Just like ammonia and R-22 liquid over feed systems, canned pumps with reverse circulation for the motor cooling are used for CO<sub>2</sub> pumps.

Copper tubes with aluminum fins or copper fin coils are used for the evaporators. They are basically the same construction as in R-22 liquid overfeed systems. This is beneficial because basically all coil manufacturing facilities in Japan have been dedicated

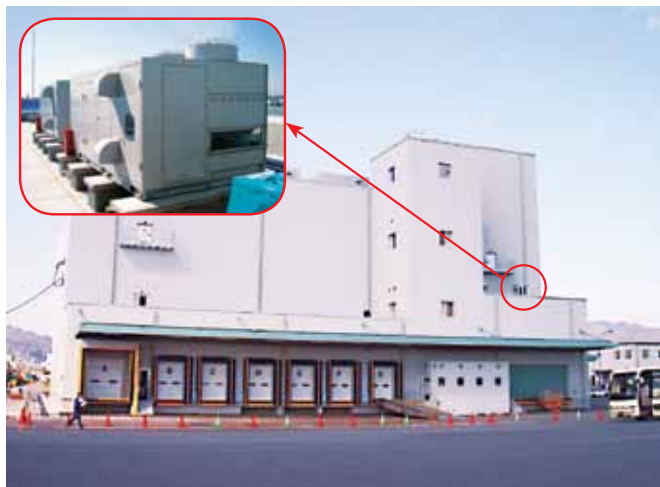


Photo 3 : CO<sub>2</sub> Indirect Package Cold Storage.

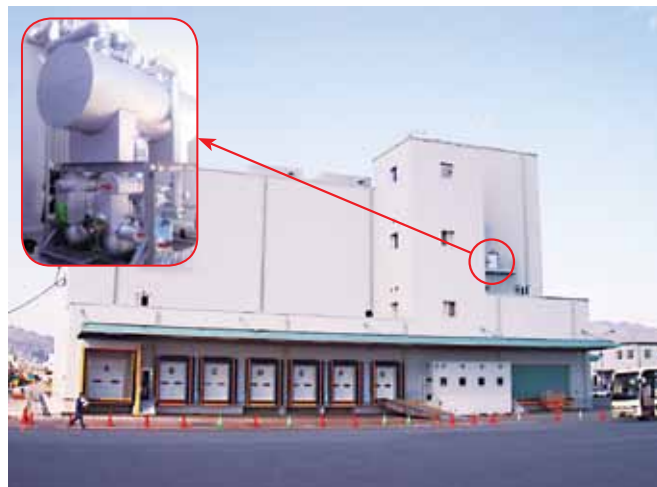


Photo 5 : CO<sub>2</sub> tank with CO<sub>2</sub> pump. Outdoor Installation.

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for R-22 coils. Smaller tube sizes are preferred to ensure the gas flow speed inside the coil, since CO<sub>2</sub> gas volume is smaller than R-22 gas volume for the same capacity.

Water spray defrost is used for coil defrosting. Water spray defrost is most preferred and a well established defrost technique in Japan. The main reason is the high humidity of Japanese climate and products, mostly seafood with high moisture. The fins clog quickly with hard wet frost. It was found that hot gas defrosts are inadequate for such conditions. More frequently, complete and short time defrosts were required. Also, any defrost system requires periodical cleaning up of the casing for the remaining ice on the corners, and for water defrost, spilling of water from the casing is very often the problem. In Japan, all these were considered and attended to, and water spray defrost system was developed as the best method for -25° temperature cold storages.

CO<sub>2</sub> indirect system added another reason to choose water defrosts. There is no CO<sub>2</sub> hot gas in CO<sub>2</sub> indirect system. And for hot gas defrost to be effective in the -25° environment, the coil temperature has to be warmed by gas of 20° or more. For ammonia, hot gas pressure in the coil is set at 7.5kg/cm<sup>2</sup>. To achieve the same condition, CO<sub>2</sub> pressure has to be raised to 56kg/cm<sup>2</sup>G. Coils, pipes and valves that accommodate such pressures are again special equipment only for NH<sub>3</sub>/CO<sub>2</sub> cascade systems.

### Further Developments

As we have shown, R-22 direct systems are 7% more efficient than CO<sub>2</sub> indirect systems. Now the question is, which is better, to have an R-22 system, with limited leakage of ODP 0.055 and GWP 1700 substance to the environment but 7% less CO<sub>2</sub> to be emitted in the form of burnt fuel, or to go with 7% more CO<sub>2</sub> emission but no ODP and GWP substance? To put aside environmental concerns and talk about economics, we are comparing the existing R-22 system with less efficient system with higher initial and operation cost.

Then again, what if, the efficiency of refrigeration compressor, motor and package are optimized so that the overall efficiency of the new refrigeration system is improved by more than 7%? That seems the answer now we seek in Japan.

At the end of last year, a new refrigeration package dedicated for -25° cold storage was introduced in the market. The package incorporates new ammonia semi hermetic compound two stage screw compressor and aluminum coil based interior permanent magnet

(IPM) motor with improved efficiency. The package is equipped with a variable frequency drive, water cooled ammonia condenser, CO<sub>2</sub> condenser, CO<sub>2</sub> tank and CO<sub>2</sub> pump and is designed with efficiency 20% higher than conventional R-22 unit. It is expected to replace R-22 based systems currently operating in Japan, estimated to be over 13,000 units.

### Relevance to the Indian Market

Is a CO<sub>2</sub> indirect system applicable in India? Yes, but in limited ways. The number of cold storage rooms with very low temperatures and with big capacities, which really justify the CO<sub>2</sub> indirect system, are limited.

R404A and other HFC systems are simpler to operate, and above all, initial costs are low. However, they are more energy consuming. HFCs contribute to global warming both from refrigerant and higher operating energy consumption. With environmental concern and long term economy, that is, the installation and operations meant for more than next 10 years, there is no standing for HFC solutions.

The greater challenge is the comparison with ammonia direct system, such as flooded and liquid overfeed system. If the people are comfortable, or, at least ready to accept the risk of ammonia leakage, and cold storage users are ready to accept the risk of product damage due to ammonia leakage, ammonia direct systems are cheaper and more efficient. Here, people's concern for the safety and value of the product and the cost of installation and operation are the issues.

One significant difference between CO<sub>2</sub> indirect system and new fluorocarbon refrigerant solution is the CO<sub>2</sub> indirect system uses both ammonia and CO<sub>2</sub>. They are natural substances. They will not be banned or phased out like the fluorocarbon substances have been. Its temperature range is much wider if compared with NH<sub>3</sub>/CO<sub>2</sub> cascade system. The technologies involved are simple and tested. Just like ammonia flooded systems and liquid over feed systems stand against the test of time, and will remain the basic systems for refrigeration, CO<sub>2</sub> indirect systems have a potential to become one of the standard options for the refrigeration technology of the future.

In Japan, it seems to be a right solution to the enormous challenge of the 21st century environmental concerns. I am hopeful that in India, it will have a place where safety concerns and product value counts. I hope the little information I shared here may arouse your interest, increase your options for new design and give inspiration that with given, tested technologies, there are many things we can do for more efficient and environmentally sustainable refrigeration systems. ❖