

# Ammonia Refrigeration In Supermarkets

By Alexandre Presotto Jr. and  
Carlos Guilherme Süffert

**A**s an alternative to using CFCs and HCFCs in refrigeration systems in supermarkets, plants have been developed in Brazil that use secondary fluids. These plants initially were conceived with the purpose of reducing the quantity of refrigerants in the plant. The refrigerant is limited to the central plant, and the secondary fluid transports the “cold” from the plant to the consumer’s point of sales (display cases and warehouses). Subsequently, it was possible to eliminate halogen gases from the system by using ammonia.

## Operation of the System

The system consists of a liquid chiller that cools down a water solution that includes an antifreeze agent. The antifreeze is able to keep this solution in the liquid state at low temperatures (*Figure 1*). The solution flows through distribution piping driven by a centrifugal pump from the machine room to the cabinets and cold rooms. The temperature required to preserve the product is guaranteed by an adequate balance between the temperature levels of the secondary fluid and the heat exchange surface of the coils.

Once the “cold” distribution is simplified (instead of gas circulating we have a water solution), all controls and operation precautions, such as capacity control, superheating, refrigerant leakage or oil return, are restricted to the chiller.

## About the Author

**Alexandre Presotto Jr.** is director of SPM Engenharia in Porto Alegre, Brazil.

**Carlos Guilherme Süffert** is a partner at SPM Engenharia.

## Medium Temperature System

The medium temperature systems for supermarkets usually use an R-22 direct expansion system with evaporating temperature around 14°F (–10°C). The heat exchange surfaces and the other components are designed for this condition. The large difference between the evaporation temperature and the product preservation temperature requires control loops: temperature control to partial load conditions, and defrost routines due to the ice formed in the coil.

Installations using intermediate fluid normally use the solution at 19°F (–7°C). Thus, it is possible to maintain the coils with the same heat exchange area in relation to the direct expansion system. However, there is still the need for temperature control in the cabinets and cold rooms, and defrosting routine operations on the coils. Also, it significantly reduces energy performance.

The solution we designed intends to operate the installation with a smaller difference between the

intermediate fluid temperature, approximately 28°F (–2°C), and the product temperature.

Through an adequate balance between the solution flow rate and the heat exchange surface on the coils it was possible to guarantee the temperature required for good quality product preservation. It eliminated the temperature control and defrosting routines in cabinets and cold rooms and improved the energy performance of the entire system.

## Results

The results achieved regarding product conserving on these plants using the secondary fluid are equivalent to the results obtained in cooling plants with an R-22 direct expansion conventional system. However, because there are no more interruptions in fluid supply to the coil, these conditions do not change throughout the day. This ensures the preservation of the products according to the quality standards for merchandise (*Figure 2*).

## System Performance

Considering that it is possible to operate with a higher evaporating temperature, there is an increase in the COP of the plant that enables

---

Copyright 2001, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ([www.ashrae.org](http://www.ashrae.org)). Reprinted by permission from ASHRAE Journal, October 2001. This article may not be copied nor distributed in either paper or digital form without ASHRAE’s permission.

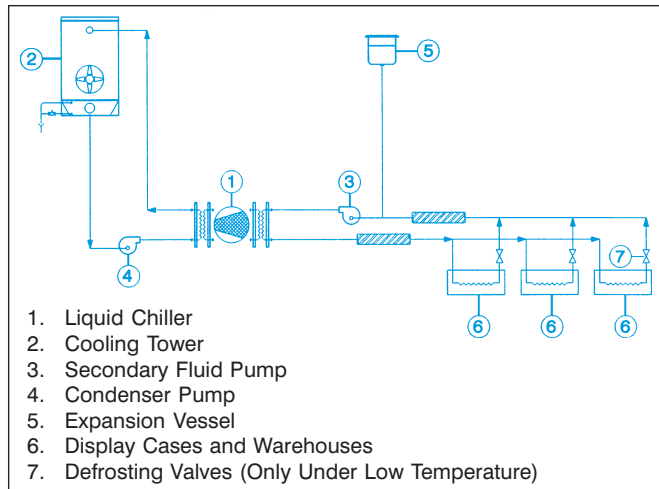


Figure 1: System operation.

the recovery of the additional power required to operate the intermediate fluid pump (Table 1).

However, comparing the performance of the system under partial load conditions, using the annual average weather conditions (not the summer average), a larger increase in the system COP is noticed. This happens because in direct expansion plants, the thermostatic valve requires a certain difference in pressure to ensure the required yield.

Considering that in indirect systems, chillers and electronic expansion valves are used, there is no need to keep the same pressure differential required for direct expansion systems. Therefore, in addition to increasing the evaporating temperature, in these cases, we also operate with a lower condenser temperature, resulting in better overall system performance (Table 2).

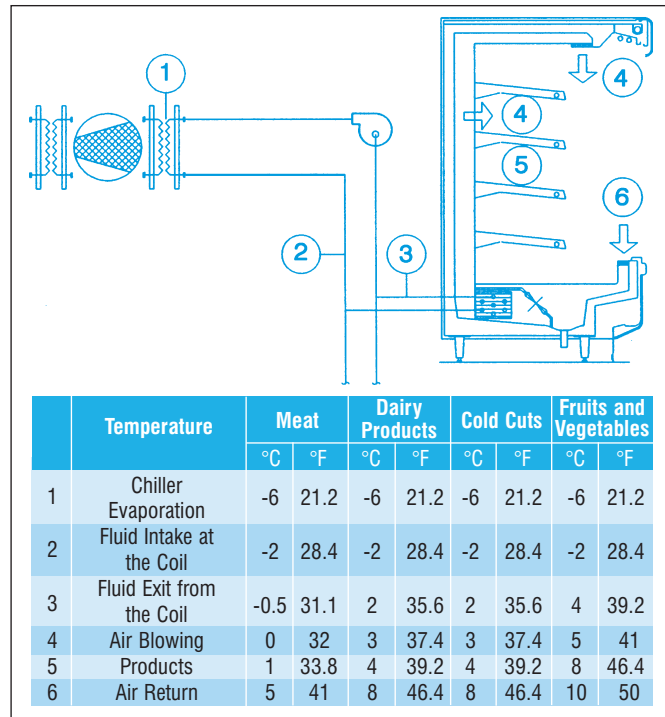
### Fluid Used

Because several plants were using a propylene glycol water solution, no research was needed to choose the secondary fluid to be used in medium temperature systems. Also, because of the small quantity of propylene glycol in the solution (less than 20%), the water's physical and thermodynamic properties did not undergo major changes (Table 3).

Regarding corrosion, a propylene glycol water solution has extremely low corrosion levels when in contact with copper or brass. When using inhibited propylene glycol, these rates also are low for carbon steel.

Table 4 shows comparative data on the effects of corrosion taken from product catalogs complying with ASTM D1384 standards test.

Inhibited propylene glycol aqueous solutions are also compatible with almost all materials used in common cooling plants (i.e., equipment and materials for sealing joints and connections). Avoid contact with:



Note : Results achieved during operation of the plant when the supermarket is operating normally, and with the ventilation of the cabinet counters duly adjusted.

Figure 2: Results achieved in cooled products system.

System	Refrigerant	Condenser	Range °C	Range °F	COP Compressors	COP Comp. + Pump
Direct Evaporation	R-22	Air	-10 to 45	14 to 113	2.99	-
Direct Evaporation	R-22	Water	-10 to 40	14 to 104	3.36	-
Direct Evaporation	R-22	Water	-10 to 37.5	14 to 99.5	3.57	-
Intermediate Fluid	R-22	Air	-6 to 45	21.2 to 113	3.11	2.91
Intermediate Fluid	R-22	Water	-6 to 37.5	21.2 to 99.5	4.11	3.61
Intermediate Fluid	R-717	Water	-6 to 37.5	21.2 to 99.5	4.08	3.58

Table 1: System performance in total load.

System	Refrigerant	Condenser	Range °C	Range °F	COP Comp.	COP Comp. + Pump
Intermediate Fluid	R-22	Water	-6 to 30	21.2 to 86	5.01	4.51
Intermediate Fluid	R-717	Water	-6 to 30	21.2 to 86	5.01	4.51

Note: Operating conditions estimated for the annual average weather conditions in the city of São Paulo, Brazil (dry-bulb temperature of the air is 21°C [69.8°F] and wet-bulb temperature is 17.5°C [63.5°F]).

Table 2: System performance in partial load.

- Zinc,
- Galvanized steel,
- Gray cast iron,
- Water with excess chlorine, and
- Water with excess sulfates.

continued on page 118

continued from page 114

Product	Temp. °F	Density lb/ft <sup>3</sup>	Specific Heat Btu/lb · °F	Heat Conduction Btu/h · ft · °F	Viscosity Kin. ft <sup>2</sup> /s
Water	41	62.42	1.005	0.326	16.69 x 10 <sup>-6</sup>
Propylene Glycol Sol. 20%	28.4	64.15	0.938	0.267	45.86 x 10 <sup>-6</sup>

Table 3: Properties of propylene glycol 20% solution.\*

Material	Water	Propylene Glycol Sol. 30%	Propylene Glycol Inhibited Sol. 30%
Copper	2	4	3
Brass	5	5	4
Carbon Steel	212	214	1

Table 4: ASTM D1384 test results.

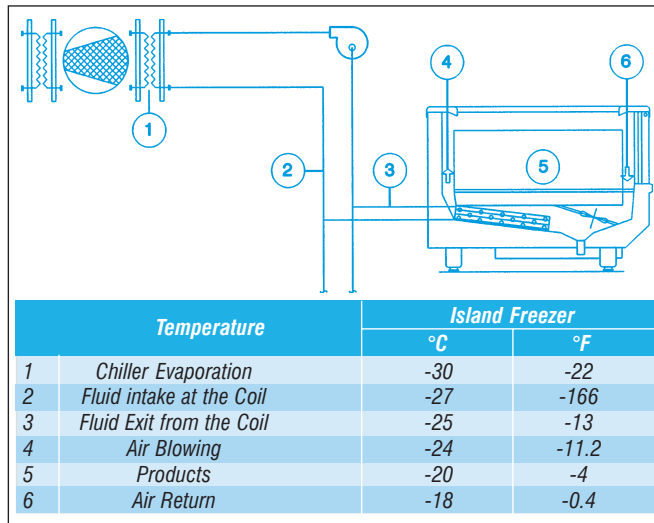
Regarding toxicity, propylene glycol USP grade is used mainly in the food, cosmetics and pharmaceutical industries. There are versions of inhibited propylene glycol that are totally nontoxic (used in animal food). It complies with all specifications of the Brazilian and American pharmacopoeia, and also can be used as a direct or indirect additive to food.

Regarding its flammability, propylene glycol in solutions of concentrations above 80% has a flashpoint of 216°F (102°C). The product is not flammable under 80% concentration.

### Low Temperature Systems

Conventional low temperature plants with R-22

direct expansion usually operate with evaporation equal or lower than -22°F (-30°C). Therefore, in low temperature systems it was decided to operate with the same



Note: Results achieved during operation of the plant when the supermarket is operating normally, and with the ventilation of the cabinet counters duly adjusted.

Figure 3: Results achieved in frozen products system.

continued on page 120

© 2007 by ASHRAE

continued from page 118

evaporating temperature in the liquid chiller and a supply temperature of the intermediate fluid of  $-17^{\circ}\text{F}$  ( $-27^{\circ}\text{C}$ ). Under these conditions, and using the same coils as the conventional direct expansion plants with an adapted circuit, it was possible to ensure the temperature required in cold rooms and cabinets of frozen products ( $-4^{\circ}\text{F}$  [ $-20^{\circ}\text{C}$ ]).

The gain in approximating the temperature differentials is obtained based on the following factors:

- Heat exchanger with countercurrent flow.
- Uniform heat transfer throughout the coil.
- Minimization of superheat.

$$\begin{aligned} *^{\circ}\text{F}-32 \times 5 \div 9 &= ^{\circ}\text{C}; \text{lb}/\text{ft}^3 \times 16 = \text{kg}/\text{m}^3; \\ \text{Btu}/\text{lb}\cdot^{\circ}\text{F} \times 4.184 &= \text{kJ}/(\text{kg}\cdot\text{K}); \text{lb}/\text{ft}^3 = \text{kg}/\text{m}^3, \\ \text{Btu}/\text{h}\cdot\text{ft}\cdot^{\circ}\text{F} \times 1.730 &= \text{W}/(\text{m}\cdot\text{K}); \text{ft}^2/\text{s} \times 92\,900 = \text{mm}^2/\text{s}. \end{aligned}$$

The following are factors in defrosting procedures that also improve the quality of the plants:

- Electrical defrosting acts more effectively in coils with intermediate fluid than in dry expansion due to the heat diffusion caused by the intermediate fluid throughout the coil and closings. This provides shorter periods of defrosting.

- Temperature recovery in display cases and warehouses after defrosting is faster than in a direct expansion system, since there is no limitation on the coil capacity through the expansion valve.

## Results

The results achieved regarding product conservation in plants operating as described earlier ensures the conditions required for the storage and display of frozen products in supermarkets (Figure 3). Although defrosting routines are still required, it was noticed that the oscillations in the solution temperature after defrosting are much lower than the variations in temperature of evaporation during the same periods of time in direct evaporation systems.

## System Performance

As in medium temperature plants, for a low temperature system the performance at full load decreases slightly due to the addition of the power required to pump the solution. When ammonia is used

System	Refrigerant	Condenser	Range °C	Range °F	COP Compressors	COP Comp. + Pump
Direct Evaporation	R-22	Air	-30 to 45	-22 to 113	1.71	–
Direct Evaporation	R-22	Water	-30 to 40	-22 to 104	1.82	–
Direct Evaporation	R-22	Water	-30 to 35	-22 to 95	1.98	–
Intermediate Fluid	R-22	Air	-30 to 45	-22 to 113	1.82	1.52
Intermediate Fluid	R-22	Water	-30 to 40	-22 to 104	1.93	1.63
Intermediate Fluid	R-22	Water	-30 to 35	-22 to 95	2.11	1.81
Intermediate Fluid	R-717	Water	-30 to 35	-22 to 95	2.15	1.85

Table 5: System performance in total load.

System	Refrigerant	Condenser	Range °C	Range °F	COP Compressors	COP Comp. + Pump
Intermediate Fluid	R-22	Water	-30 to 29	-22 to 84.2	2.22	1.92
Intermediate Fluid	R-717	Water	-30 to 29	-22 to 84.2	2.37	2.07

Note: Operating conditions estimated for the annual average weather conditions in the city of São Paulo, Brazil (dry-bulb temperature of the air is  $21^{\circ}\text{C}$  [ $69.8^{\circ}\text{F}$ ] and wet-bulb temperature is  $17.5^{\circ}\text{C}$  [ $63.5^{\circ}\text{F}$ ]).

Table 6: System performance in partial load.

Product	Temp. °F	Density Lb/ft <sup>3</sup>	Specific Heat Btu/lb · °F	Heat Conduction Btu/h · ft · °F	Viscosity Kin. ft <sup>2</sup> /s
Tyfoxi Sol. 80%	-22	76.16	0.710	0.251	$25.73 \times 10^{-5}$
Propylene Glycol Sol. 60%	-22	66.99	0.745	0.173	$30.14 \times 10^{-4}$
Ethylene Glycol Sol. 60%	-22	68.98	0.686	0.180	$63.51 \times 10^{-5}$
Silicon	-22	56.68	0.398	0.070	$47.15 \times 10^{-6}$
Dowterm J	-22	56.19	0.404	0.081	$26.91 \times 10^{-6}$
Dowterm Q	-22	63.05	0.357	0.074	$37.57 \times 10^{-5}$
CaCl <sub>2</sub> Sol. 30%	-22	79.91	0.673	0.283	$22.50 \times 10^{-5}$

Table 7: Properties of secondary fluids.\*

Material	Water	CaCl <sub>2</sub> Sol. 30%	Tyfoxit Sol. 30%	Ethylene Glycol Sol. 60%
Copper	2	30	2	3
Brass	5	93	1	3
Carbon Steel	212	245	2	1

Table 8: ASTM D1384 test results.

as the refrigerant fluid, the COP increases. The COP is better than plants with direct expansion with an air condenser, which is used in most existing plants in supermarkets (Table 5).

However, when analyzing the plant under a partial load condition, again using the annual average weather conditions (instead of the summer average), there is a real gain in the plant's COP (Table 6).

## Fluid Used

Regarding the antifreeze agent, the situation for low temperature systems is different from medium temperature systems because there is not an established fluid with ideal physical properties. However, new options are being

continued from page 120

created, particularly in the northern Europe, where the deadlines for the eradication of halogens are being expedited. Therefore, we have compared the properties of several options for intermediate Ammonia fluids operating at  $-22^{\circ}\text{F}$  ( $-30^{\circ}\text{C}$ ).

The characteristics required to work with a good intermediate fluid are:

- High thermal conductivity,
- High density,
- High specific heat,
- Low viscosity,
- Low toxicity,
- Low corrosion levels, and
- Solubility in water.

Evaluating the investigated fluids according to the parameters described previously, the results in Table 7 are observed.

Regarding corrosion, Table 8 shows comparative data on the effects of corrosion on the products according to ASTM D1384 standard tests.

The results lead us to the conclusion that Tyfoxit, an inhibited aqueous alkali ethanate solution in 80% water solution, has more appropriate with an intermediate fluid in low temperature plants.

Tyfoxit aqueous solutions also are compatible with almost all materials used in ordinary cooling plants (equipment and materials for sealing joints and connections). They should not be used with:

- Polytetrafluoroethylene (PTFE),
- Silicone mixtures,
- Residues of glycol solution,
- Water with chlorine, and
- Galvanized steel.

Tyfoxit is not a toxic product. Rapid exposures do not cause any effect on health. However, it is recommended to use rubber gloves during operations according to the general standards for handling chemical substances. Table 9 shows some situations of contact with the product, their consequences and treatment. Tyfoxit is a non-flammable product.

### Control System

The control system for indirect plants is very simple, particularly when compared to the traditional refrigeration systems by direct expansion. In plants using intermediate fluid, the controls are restricted to the machine room, being:

- Control loop of the secondary fluid temperature.

Contact	Consequence	Treatment
Skin	Exposure for Long Periods of Time may cause light irritation	Rinse the Affected Areas with Water
Eye	Irritation and Possibility of Temporary Burns	Rinse eye with plenty of Water
Inhalation Ingestion	Possibility of Irritation Possibility of Irritation	Expose Patient to Fresh Air Ventilation Wash Mouth with Water and do not induce Vomiting

Table 9: Consequences and treatment of contact with Tyfoxit.

Item	System with Intermediate Fluid R-717 (US\$)	System with Direct expansion R-22 (US\$)
Thermal Central Plant	130,000	90,000
Condensers	22,000	22,000
Refrigerant Fluid	450	4,000
Intermediate Fluid	10,000	0
Controls	13,000	35,000
Cold Rooms and Air Blowers	185,000	175,000
Cabinet Counters	370,000	355,000
Materials	90,000	105,000
Labor	70,000	90,000
<b>TOTAL</b>	<b>890,450</b>	<b>876,000</b>

Table 10: Implementation costs.

Item	System with Intermediate Fluid R-717 (US\$/year)	System with Direct Expansion R-22 (US\$/Year)
Power	67,000	76,000
Refrigerant Fluid	650	5,200
Intermediate Fluid	0	0
<b>TOTAL</b>	<b>67,650</b>	<b>81,200</b>

Table 11 : Operation Cost

- Control loop of the expansion valve.

Both control loops control the system in partial load operation. They are restricted to the liquid chiller, and are monitored by the chiller microprocessor controller. Thus, it is possible to maintain the stability of the plant with fluid temperature variations ranging between  $1.8^{\circ}\text{F}$  ( $\pm 1^{\circ}\text{C}$ ). It is also possible to optimize the cooling cycle range, ensuring superheating up to  $7^{\circ}\text{F}$  ( $4^{\circ}\text{C}$ ).

When completing the control system, there is the automation of the defrosting routines for frozen product cabinets and cold rooms. Such routines are monitored by dedicated controllers that act in synchronicity to avoid the equipment starting their cycle simultaneously. It also has a temperature sensor that cuts off the cycle when the coil is completely unobstructed, even though the total operation time has not been reached. Such a device prevents the equipment from superheating and makes it easier to recover the normal operation condition after defrosting is completed.

The data are sent via a network to a computer so that supervision software may follow up on all operations. This software does not control or operate the plant; it only transforms the data into information that the operator may easily understand. These data are displayed as graphs and reports or are transmitted to another remote

continued from page 122

station to enable distance monitoring.

### Costs

Tables 10 and 11 compare the costs of implementation and operation of a cooling system in a supermarket in Porto Alegre, Brazil. The sales area is approximately 53,819 ft<sup>2</sup> (5000 m<sup>2</sup>).

### Implementation

The amounts in Table 10 are estimated and were supplied directly by equipment and fixtures manufacturers based on July 1998. They do not include transportation or overhead costs.

### Operation

The operating costs correspond to a plant with the following features:

- Heat load of cooled products: 992,000 Btu/h (250 000 kcal/h).
- Heat load of frozen products: 238,080 Btu/h (60 000 kcal/h).
- Both plants operating at the average capacity of 70%.
- kWh cost equals US\$0.10 (sum of the demand, kWh at the peak hour, and out of the peak hour).
- The COP values used are the ones for plants with water condenser.
- Costs with replacement of refrigerant correspond to the amounts used by ASHRAE. For dry-expansion plants, it indicates that leakage corresponds to 25% of the total refrigerant load in the system per year (1,764 lb [800 kg]).
- The operating costs did not include the reduction in the heat load in the cooled products systems.

### Advantages and Disadvantages

Systems with intermediate fluid present the following advantages and disadvantages in relation to traditional plants with R-22 direct expansion.

#### Advantages

- Equivalent cost of construction.
- Reduced power consumption.
- Lower thermal load for medium temperature systems.
- Absence of defrosting routine for medium temperature systems.
- Absence of temperature control for cabinet counters and cold rooms.
- More effective heat exchangers.
- Less quantity of refrigerant fluid on the system and much less possibility of leakage.
- Simple installation and consequent lower cost of preventive or corrective maintenance.
- More operating reliability (less maintenance occurrences).
- Simplified control system.
- Does not use CFC or HCFC refrigerants.

#### Disadvantages

- Larger physical space at the machine room required for equipment installation.
- Larger areas for heat exchange required at the cooling coils of cold rooms and cabinet counters in medium temperature systems.

#### Conclusion

The major advantages of a cooling system using a secondary fluid are the feasibility of using ammonia as the primary refrigerant fluid, simple operation, reduction in the control loop, reduction in power consumption, and stability of the plant's operation. These features have been proven at several plants that have operated in Brazil for more than 10 years (especially on the medium temperature systems where defrosting routines were eliminated). The system remained permanently in a stable operating condition, varying only according to the thermal load needs of the store.

For low temperature systems, it was verified that the use of intermediate fluid results in a better performance of the cooling coils, leading to better results concerning the temperature maintenance for cold rooms and cabinet counters. ❖

CE / Açççç ] ^æ^â@!^