Guide for Retail/Supermarket Facilities Decisions

Module 2: Secondary Fluid Refrigeration Systems

A Product of EPRICSG, Inc.

Secondary loop refrigeration systems may already be the best choice,
with improvements in temperature variation, energy use, and global warming.

Contents

Introduction and Overview

This is the second of two modules comprising the *Guide for Retail/Supermarket Facilities Decisions*. Each module focuses on a different aspect of the relationship between energy providers and their customers in this market segment. The Guide is intended to provide a non-technical overview for utility marketing staff, complementing other EPRI technical resources. This module reviews the emerging "hot topic" of secondary loop refrigeration systems for use in supermarkets and other retail settings. These systems are of interest because of their potential to help reduce refrigerant cost and leakage and to reduce global warming, but also provide other benefits to store operators. Electricity and related service providers can make use of this new information in their efforts to develop new client relationships and provide high levels of service and satisfaction for these key customers.

Future modules, as member interest and funding priorities dictate, are intended to concentrate on supermarket and retail energy use patterns, environmental issues, equipment innovations, operations and maintenance issues, and energy-efficiency measures. EPRI members can use these Guide modules as tools in their efforts to promote products and value-added services to the supermarket industry. By providing a broad overview of the market's characteristics, trends, operations, concerns, and decision-making practices, users of these EPRI resources will be better situated to serve this increasingly important class of commercial customers.

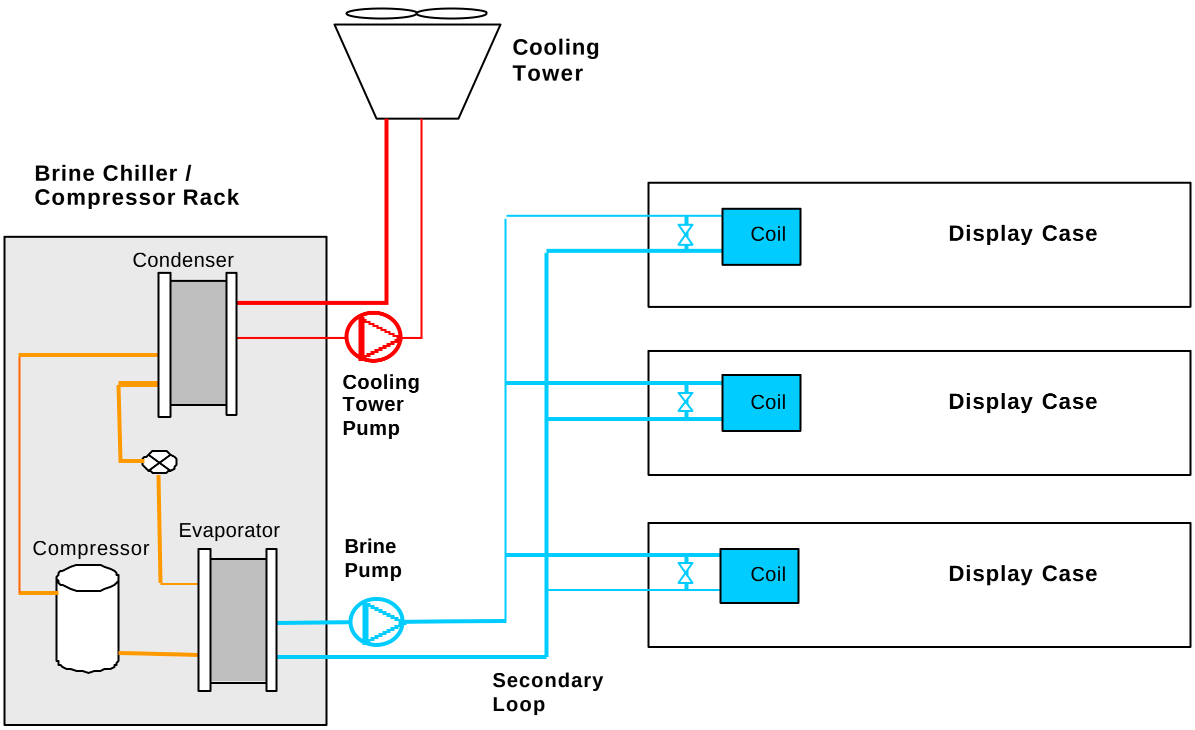
Alternative Refrigerants—Again?

Supermarkets are under increasing pressure to install refrigeration systems that do not use fluids that harm the environment. Over the past 10 to 15 years, supermarket operators have worked through the transition to replace ozone-depleting CFC refrigerants with HCFCs and HFCs. Now the Kyoto Protocol and its concerns with the global warming potential of HFCs is creating a new challenge for the supermarket industry. Once again, alternative refrigerants and system configurations are being considered to minimize the environmental impact.

The difference this time is that concerns with the global warming must also factor energy efficiency into the analysis. Therefore, alternative systems that use an environmentally benign refrigerant must also be energy efficient so that the impact of increased energy use on power plant emissions does not counteract the environmental benefit of switching to a new fluid. To capture these effects, scientists use the concept of Total Equivalent Warming Impact (TEWI) to consider the impact of both direct emissions (refrigerant leakage) and indirect emissions (CO_2 emissions from increased energy use).

The Secondary Loop Concept

Central refrigeration systems that use a secondary coolant or brine provide one means to significantly reduce the total refrigerant charge and environmental of a supermarket. These secondary loop refrigeration systems are configured as a "brine chiller" in a single package that can be located in an equipment room. The chiller can be water cooled, as shown in Figure 1, or air cooled as is traditionally done in supermarkets. The brine or anti-freeze solution is cooled by the packaged chiller and pumped to the refrigerated display cases and other loads throughout the building via a secondary loop. By containing the primary refrigerant in the system in the equipment room, the total charge is reduced by as much as a factor of 10 compared to conventional direct expansion systems that supply liquid refrigerant directly to each display case.



Water-Cooled Secondary Loop Refrigeration System

The secondary loop approach also allows for so-called "natural" refrigerants to be used. These include ammonia as well as hydrocarbons such as propane. While these refrigerants have very favorable thermodynamic cycle efficiencies and no global warming impact, their use has always been limited in supermarket applications due to concerns with flammability and toxicity. With a secondary loop, these previously unconsidered refrigerants can now be used in remotely-located racks on a roof or in a separate equipment building.

Beyond the reduction in refrigerant charge and refrigerant leakage, secondary systems also offer some other advantages:

- More even temperatures in the display case due to the more uniform coil temperatures, improving product quality and shelf life.
- More energy efficient defrost since frost forms on the coil more evenly and is more easily removed (with warm fluid defrost).
- Potentially higher saturated suction temperatures while maintaining an equivalent product temperature due to better coil heat transfer and more evenly-distributed case temperatures.
- Potentially higher refrigeration cycle efficiencies by using thermodynamically efficient refrigerants such as ammonia or propane.

Secondary loop systems also have some disadvantages, particularly in first cost and energy use:

- Higher first cost due to added heat exchangers, pumps, pipe insulation and other components.
- Added operating costs due to secondary pump energy use.
- Higher parasitic heat gains from long secondary loop piping runs.

Product development and research efforts are currently underway to understand and address these shortcomings.

Why Secondary Loop Systems?

Interest is secondary loop refrigeration systems in North America is driven primarily by the desire to reduce refrigerant charge and the number of field-brazed joints where leakage can occur. The total refrigerant charge in a typical supermarket with a conventional refrigeration system is approximately 2,000 to 5,000 lbs (Sand et al 1997; Walker 1999). The size of the refrigerant charge in a typical supermarket (in pounds) is typically 8% to 12% of the floor area in square feet (Sand et al 1997). Secondary loop systems reduce the required charge to about 10-20% of that required in a conventional system, by eliminating the refrigerant which conventional systems store in long piping runs to the display cases and other loads (Walker 1999). If water-cooled condensers are used, reductions to below 10% of the original charge are possible (Sand et al 1997) [1].

Annual leakage rates from supermarket refrigeration systems were historically as high as 30 to 50% of the total charge. However, high refrigerant costs and regulatory concerns are estimated to have reduced these rates to 15% on current conventional systems (Gauge and Troy 1998). Secondary refrigerant systems offer the possibility to further reduce leakage rates by reducing the number of field-brazed joints and allowing all refrigeration components to be integrated into a factory-built package. By assembling the refrigeration system at the factory, better quality control procedures can be used to minimize the risk of leakage.

Another concern driving interest in secondary loop systems in the US is the code requirement that leak detection equipment be used in some jurisdictions. Some local code officials interpret ASHRAE's Safety Code for Mechanical Refrigeration (Standard 15-1994) as requiring leak detection alarms in each walk-in cooler and freezer since they are classified as an "occupied space" (Papagna 1999). The use of a secondary loop solves this code interpretation issue by totally removing refrigerant from the cooler.

Many supermarket operators report that they are installing secondary loop systems because this provides more even case temperatures with less thermal shock, due to easier defrost (Papagna 1999, Twilliger 1999). The ability to provide more even case temperatures and maintain better product quality appears to be an important driver in the decision to convert to secondary systems.

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[1] However, under EPA's recently proposed rules--which would regulate the maximum percentage of the system charge that could be lost due to leakage in a year--low charge systems would be penalized. Systems with a lower system charge would be allowed a much smaller leakage volume than a conventional system since the regulations are on a percentage basis. These rules would effectively penalize secondary systems that have a lower environmental impact (ACHR News 1998).

In Europe, the higher interest in secondary loop systems is driven by the desire to totally eliminate HFCs and HCFCs from the system and replace them with natural refrigerants such as ammonia and propane. The secondary loop approach is the only means available to totally eliminate HFC refrigerants from a supermarket. Political forces in Europe are driving the switch from HFCs to natural refrigerants as the only option and therefore focusing on secondary loop systems.

In North America, the more balanced TEWI approach is favored. This approach, by factoring in both direct refrigerant emissions and system energy efficiency, is allowing other system options to be considered. One of these options includes distributed refrigeration systems, which locate smaller water-cooled refrigeration racks closer to cases to reduce refrigerant charge. Similarly, the wider use of self-contained cases, with the potential to be water-cooled, also promises to be a low-TEWI configuration with low charge and leakage as well as high energy efficiency.

The US Market for Secondary Systems

Several North American supermarkets have installed secondary loop refrigeration systems over the past five years. Hill-Phoenix has supplied the majority of these systems under the "2Cool" trade name and is active in developing and marketing this technology[2]. As of November 1999, they have installed more than 130 systems in the US and Canada. Nearly half of these systems have been installed in the past year (Arshansky 1999, Sparks 1999). Several supermarket chains have installed secondary systems including Food Lion, Dominicks, Super-K, Wegmans, Publix, A&P, HEB and Clemen's. Most of these systems have used HFC and HCFC refrigerants. However, at least one system has used ammonia (a Food Lion in Waldorf, Maryland).

Hill Phoenix 2Cool Secondary Loop Rack

Hussmann Protochill Rack
(water-cooled)

[2]Both Tyler and Hussmann have also supplied secondary loop systems. Hussmann markets these systems under the Protochill tradename.

The majority of the secondary systems installed to date have been medium temperature systems that use propylene glycol as the secondary fluid. Either off-cycle or warm fluid defrost is used in these medium temperature systems.

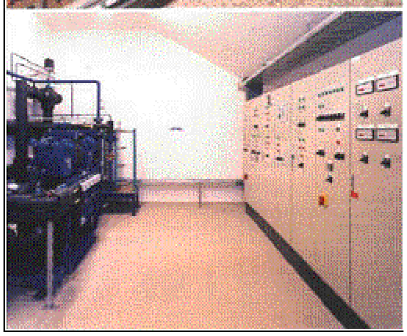
A few low temperature systems have been installed in the US as well. Hill Phoenix first offered these systems with Pekasol 50 (potasium acetate) as the secondary fluid. However, concerns with materials compatibility and leakage have led them to recently switch to Dynalene (a form of potasium formate). Ongoing research at university and government laboratories is trying to determine which secondary fluids are most appropriate (see Appendix A) for the low temperature systems. The results of these studies are discussed below.

The European Experience

Many secondary or indirect systems have been installed in European supermarkets. Work on these systems generally started in the early 1990's, before the recent activity in the US market. These systems have been installed in several supermarket chains throughout Europe, including Sainsburys and Marks & Spencers in the United Kingdom; Migros in Switzerland, Match, Catus, Knauf in Luxemburg, Grosso and Edeka in Germany; ADEG and KGM in Austria; and Albert Heijn in Holland (Greenpeace 1999). Much of this effort has been focused on using natural refrigerants such as ammonia and propane to replace HFCs. Many of these systems have been installed as research and demonstration projects undertaken as part of International Energy Agency Annex 22, *Compression Systems with Natural Working Fluids.*

The Table below shows three European demonstration projects from the Annex 22 web page (SINTEF 1998) that have used ammonia or propane as the primary refrigerant and Tyfoxit 1 or a binary ice slurry as the secondary coolant. Both medium and low temperature systems have been used. The refrigeration equipment has typically been located in a rooftop-mounted package or in a separate mechanical room.

Examples of European Secondary Refrigeration Systems (from IEA Annex 22 Web Page)

Roskilde, Denmark	**Bad Freienwald, Germany**	**Slitu, Norway**
 	 	
Date Installed:		
1996	1996	1995
Operating Temperatures:		
Medium: 16°F / -9°C Low: -22°F / -30°C	Medium: 10°F / -6°C Low: -18°F / -28°C	Med / High: 43°F / 6°C
Capacity:		
Medium – 28 tons / 100 kW Low – 11 tons / 40 kW	Medium – 31 tons / 108 kW Low – 10 tons / 35 kW	Med / High - 10 tons / 35 kW
Primary Refrigerant:		
Ammonia	Propane	Ammonia
Secondary Coolant:		
Tyfoxit 1	Tyfoxit 1	Binary ice (ethanol, water and inhibitors)
Features:		
- Low ammonia charge - Roof mounted units in container - Leak detectors & Alarm system	- Low propane charge – Separate machinery room	- Ice scaper, ice accumulator and circulation pump. - Existing R-22 display cases were retrofitted.

Are They More Energy Efficient?

The majority of analyses completed to date predict that secondary loop systems use slightly more energy than conventional systems. However, there is considerable debate as to whether improved fluids and better designs can improve their efficiency. Historically, the energy use of secondary loop systems has generally been assumed to be higher for the following reasons:

- Added energy costs to pump the secondary fluid (which is viscous at low temperatures)
- Added heat exchange step through the brine-to-refrigerant HX
- Added heat gain to the secondary loop piping from the environment (and loop pumps)

However, some aspects of secondary system operation are also thought to improve system efficiency or lower operating costs:

- More thermodynamically-efficient refrigerants (such as ammonia) can be used
- Less defrost energy is required because frost forms more evenly and is easier to remove

There is some disagreement over the magnitude of the energy savings features and penalties associated with secondary systems. The results and assumptions from several studies are discussed below.

The first types of studies to evaluate secondary systems were general TEWI analyses that included an abbreviated analysis of supermarket refrigeration along with other residential and commercial technologies (Sand, Fischer, and Baxter 1997; Snelson et al 1999; ACHR News 1999). Other more detailed energy studies have compared secondary and conventional systems (Walker 1999; Terrell, Mao, and Hrnjak 1999).

Overall Energy Use

Table 1 compares the overall energy use of conventional and secondary refrigeration systems. The TEWI study from ORNL (Sand, Fischer and Baxter 1997) and NRC Canada (Snelson et al 1999) estimated that air-cooled secondary systems would use 18% and 14% more energy overall in a typical supermarket. Both analyses predicted that compressor energy use would be higher in the secondary systems due to the added heat exchange step through the refrigerant-to-brine heat exchanger (HX) which lowers the suction pressure. They also predicted that coolant pumping would also account for a third of the net energy penalty.

Another TEWI study by Arthur D. Little (ACHR News 1999) predicted a similar percentage increase, 17%, but assumed a larger annual energy use for the refrigeration system. That energy use appeared to include the display case energy lights and fans.

While the general TEWI studies cited here assumed that compressor energy use would be greater with a secondary loop system, two more detailed evaluations have both concluded that compressor efficiency is actually better due to improved heat transfer. The detailed evaluations of secondary coolant systems at the Air Conditioning and Refrigeration Center (ACRC) at the University of Illinois (Terrell, Mao and Hrnjak 1999) showed that a display case with a brine-to-air heat exchanger coil actually resulted in better heat transfer performance. The saturated evaporator temperature in the primary refrigeration cycle could be 10°F warmer with a secondary system than in a conventional DX case, while maintaining the same product temperatures (Mao, Terrell and Hrnjak 1999). The improved heat transfer performance of the brine-cooled case was attributed to the more even cooling provided throughout the display case by its brine-to-air coil compared to a DX coil.

Table 1. Comparing Total System Energy Use, Conventional vs. Secondary-Fluid Refrigeration

Study	Base Case Energy Use (kWh/yr)	Secondary Energy Use (kWh/yr)	Difference (kWh)	(%)	Refrigerants (low/med)	Components included in Energy Calculations
General TEWI Studies						
ORNL TEWI Report (Sand, Fischer & Baxter 1997)	475,278	561,395	86,117	18%	R404a / R404a	Compressors, condensers, pumps
ADL Report (ACHR News 1999)	1,200,000	1,400,000	200,000	17%	Not given	Assumed to include all display cases & racks
NRC Canada (Snelson et al 1999)	439,386	500,940	61,554	14%	R404a / R507	Compressors, condensers, pumps
Detailed Secondary System Studies						
ACRC / Univ. of Illinois (Terrell, Mao, and Hrnjak 1999)	COP=1.61	COP=1.11	-	45%	R404a / -	Compressors and pumps (*low temp only*)
Foster Miller / ORNL (Walker 1999)	976,747	1,031,971	55,224	6%	Not given	Compressors, condenser, pumps

Compressor Energy Use and Cycle Efficiency

The ACRC study predicted that the higher suction temperature would decrease compressor energy use by 5.6% for a low temperature case (see Table 2). The initial results from the Foster Miller study (Walker 1999) predicted a similar 4% decrease in compressor energy use for the secondary-fluid system. In contrast the ORNL TEWI study had predicted that compressor energy use would increase by 12%.

Table 2. Compressor-Only Energy Use, Conventional vs. Secondary Refrigeration Systems

Study	Base Case Compressor Energy Use (kWh/yr)	Secondary System Compressor Energy Use (kWh/yr)	Difference (kWh)	(%)
ORNL TEWI Report (Sand, Fischer & Baxter 1997)	447,597	500,853	53,256	12%
ACRC/Univ. of Illinois (Terrell, Mao, and Hrnjak 1999)	COP=1.61	COP=1.70	-	-5.6%
Foster Miller/ORNL (Walker 1999)	809,336	775,618	(33,718)	-4%

Hill Phoenix reports that the switch to secondary systems is energy neutral in their medium temperature racks using propylene glycol (Arshansky 1999). They report that the addition of a refrigerant-to-glycol heat exchanger does lower the required saturated suction temperature; however, this efficiency loss is offset by the secondary loop system's reduction in superheat at the compressor and lower suction line losses (due to its much shorter piping). The net impact is very little change in compressor efficiency with the secondary loop system.

Loop Pumping Power

The other component affecting total system energy use is the secondary loop brine pump. Table 3 lists the loop pumping power that has been assumed in some previous studies and well as observed from some actual installations. For a low temperature system, the ACRC studies have predicted that pumping in a "non-optimized" system would be as high as 163 watts per ton of refrigeration with potassium formate. However, they predicted that pumping energy could be as low as 16 watts per ton with a coil optimized for the secondary fluid. The other studies have assumed or predicted values of normalized pumping power between these two extremes for low temperature systems.

Table 3. Brine Pump Energy Use in Secondary Loop Refrigeration Systems

Study	Operating Temperature	Refrig. Capacity (tons)	Pump Power (kW)	Normalized Pumping Power (Watt/ton)
ORNL TEWI Report (Sand, Fischer & Baxter 1997)	Low	25	1.2	49.2
	Med	75	2.0	26.4
NRC Canada (Snelson et al 1999)	Low	16	1.1	68.6
	Med	35	1.1	32.0
ACRC (Terrell, Mao, and Hrnjak 1999)	Low	Na	Na	162.6
	Low-Optimized	Na	Na	16.3
Foster Miller/ORNL (Walker 1999)	Low	23	10.2	108.9
	Med	70		
K-Mart/Hill Phoenix (Papagna 1999)	Med - 3 pumps	100.0	7.9	79.0
	Med - 2 pumps	100.0	5.3	52.7
	Med - 1 pump	100.0	2.6	26.3

For medium temperature refrigeration systems, the normalized pumping power has generally been predicted to be less than about half the value for low temperature systems. The general TEWI studies have assumed pumping power in the range of 26 to 32 watts/ton. However, actual installations typically require as much as 79 watts/ton—for example, three 3-HP pumps required on a 100 ton medium temperature rack using propylene glycol (Arshansky 1999; Papagna 1999).

Perhaps the feature with the greatest potential for reducing energy use is staged variable flow pumping in the secondary loop. In many applications—where shut-off or two-way valves are used on cases and coils to control capacity—the peak or design flow rate is not required for most periods of the year. When operating at reduced flow rates the pumping power decreases substantially as well. This concept has been used for years with chilled water systems and other HVAC applications. Hill Phoenix now offers the option of three loop pumps that are staged based on a pressure set point. In many applications, these systems have been observed to run with only one or two of the three brine pumps operating most of the time (Papagna 1999). Table 3 shows that with only one pump operating the normalized power drops to 26 watts/ton.

Key Factors: Pipe Insulation and Heat Gain

Beyond pump energy use, unintended heat gain to the secondary coolant piping is one of the most important factors affecting system efficiency. Conventional DX systems provide warm liquid refrigerant directly to the cooling coil, expand and evaporate it at a low temperature, and then return superheated gas to the compressor rack. In contrast, secondary systems must transport the cold single-phase brine to the case and return the slightly-warmed brine back to the rack. The small temperature differences across the cooling coil, and the operating temperatures substantially below ambient, both necessitate careful insulation of the secondary loop piping to minimize heat loss.

Terrell, Mao and Hrnjak (1999) developed a fully-verified simulation model of a secondary loop system and a DX system to allow energy comparisons and show the impact of piping heat gains. They modeled a low temperature system (-38°F) using R404a and showed that the coefficient of performance (COP) of the DX system was 1.61. Converting the system to a secondary loop by adding a brine-to-refrigerant HX and using the existing piping and coil in the secondary loop dropped the efficiency of the system by 45% to 1.11.

The refrigeration cycle efficiency was actually higher with the secondary loop, as discussed above. However, coolant pump energy use and heat loss from the secondary loop piping had large impacts on the overall efficiency of the system. Surprisingly, the heat gain to the single-phase coolant had the biggest impact. When the piping insulation thickness was changed from nominal 7/8 inches to 3 1/8 inches, the COP of the secondary coolant system changed from 1.11 to 1.40, or more than halfway back to the efficiency of the conventional system.

To reinforce the larger impact of heat gain on efficiency, the researchers at the ACRC also varied the pipe diameter (while holding the insulation level constant). Using larger diameter pipe decreased pumping power but had a more substantial impact on the heat loss from the pipe (since the pipe surface area increased). The net result was a decrease in overall system efficiency when larger pipe diameters were used.

The Alternatives to Secondary Systems

Secondary loop systems are not the only option for developing a low-TEWI refrigeration system. Since both refrigerant leakage and energy efficiency must considered, other options that minimize charge while lowering energy use can also be used to minimize environmental impact.

Distributed systems that use smaller water-cooled racks located close to the display cases are one such option. Since most of the refrigerant charge is stored in the air-cooled condenser and liquid lines, designs that use a water-cooled condenser that is on the refrigeration rack can substantially reduce the refrigerant charge. The initial results of the Foster Miller / ORNL work predicted that a secondary loop system would reduce the refrigerant charge by 83% compared to a conventional multiplex system (Walker 1999). However, a water-cooled distributed system can reduce refrigerant charge by 70%, or by nearly as much. Because the distributed systems are also more energy efficient, they were identified as having the lowest TEWI – or global warming impact – of all the options. This is especially true when water source heat pump equipment is integrated into the distributed system's water loop to provide heat recovery for space heating. With a centralized secondary refrigeration system, the option for heat recovery is lost, so store space heating requirements and energy use increase compared to a conventional system with heat recovery. The loss of heat recovery can negate the environmental benefits of the secondary system.

Self-contained display cases are also another option to minimize charge and maintain high efficiency, especially when they are water cooled. By limiting all refrigerant charge to the display case, the unit can now be factory sealed and critically charged with the same or smaller quantity of refrigerant than is required in a secondary system. The reliability and refrigerant leakage rates would then be on par with a residential refrigerator. For the potential of this approach to be fully realized, small, high-efficiency compressors are required. The ongoing development of quieter, small-tonnage horizontal scroll compressors with capacity modulation will help make this approach viable (Khattar 1998).

Summary and Conclusions

The development of secondary fluid refrigeration systems is nominally driven by concerns to reduce refrigerant charge and leakage as well as to minimize the environmental impact of these systems. However, other factors also appear to be driving the increased interest in these systems in the US. The ability to maintain more stable product temperatures in display cases through more even air distribution and easier coil defrosting is why many supermarkets are reportedly adopting this approach in medium temperature applications. European interest in the secondary or indirect approach is aimed at eliminating HFC refrigerants in favor of "natural" fluids such as propane and ammonia. In contrast, however, US store owners trying secondary fluid systems are tending to continue with HFC or HCFC refrigerants, relying instead on the reduced refrigerant charge for their environmental benefit.

For low temperature applications, secondary loop systems are not being as widely accepted in the US market. Reliability and cost concerns with secondary fluids as well as the energy cost of pumping are the principal reasons for this reluctance. However, research and development efforts at the ACRC and Hill Phoenix are showing that inorganic salts, such as potassium formate, may be the best option for low temperature applications. These fluids, along with improvements in coil design and ability to stage the loop pumping, have the potential to reduce or eliminate the energy penalty associated with secondary systems.

Recent research has demonstrated that there is little to no compressor efficiency penalty due to the added heat exchange step required in secondary loop systems. In fact, the better heat transfer performance of display cases with a brine-to-air coil may actually increase overall system efficiency. The improved efficiency of the defrost process with a brine coil also appears to improve the energy impact of secondary systems.

However, the biggest challenges with secondary systems – especially in low temperature applications – are to control heat gain to the brine piping system and to minimize pumping energy use. The research at the ACRC has demonstrated that brine-piping runs must be heavily insulated compared to conventional refrigeration piping to minimize the loss of refrigeration capacity. Both the energy use of the pump and the impact of its heat addition to the brine loop also have a big impact on overall system efficiency.

For secondary-fluid systems to meet their goals of low environmental impact, they must maintain efficiencies in line with conventional systems. For supermarket owners to adopt them, they must also provide this benefit with a first cost that is competitive with other low-TEWI options. Secondary loop systems are being embraced by a significant segment of the supermarket industry, and with continuing improvements in efficiency and economy, are expected to gain an even greater market share. While not the only refrigeration technology with a low environmental impact, these systems are helping supermarkets minimize that impact while enhancing food quality and holding the line on operating costs.

CONTACT INFORMATION

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APPENDIX

FLUIDS BEING CONSIDERED AS SECONDARY COOLANTS

A variety of fluids can be used as the brine in a secondary coolant system. An ideal fluid has good heat transfer characteristics, low pumping requirements, and is compatible with commonly used materials.

The study at ACRC (Terrell, Mao, and Hrnjak 1999), sponsored by EPA, evaluated several materials per Table A-1.

Table A-1. Brines Used/Considered as Secondary Coolants (Adapted from Terrell et al 1999)

Fluid	Trade Name (manufacturer)	Notes
Potassium Formate	Freezium (Kemira Chemicals Oy) Hycool (Hydro Agri Porsgrunn) Tyfoxit F (Tyforop Chemie GmbH) Dynalene (Dynalene)	Dynalene used by Hill Phoenix
Potassium Acetate	Pekasol 50 (pro KUHLSOLE GmbH) GS4 (Vanguard Plastics, Inc.) Temper (Aspen Petroleum AB)	Pekasol used by Hill-Phoenix. GS4 used in geothermal heat pump systems
Silicon Oils (Polydimethilsiloxane)	Syltherm HF & XLS (Dow Corning Corp.) Baysilon M3 (Bayer)	
Inhibited alkali ethane solution	Tyfoxit 1.xx (Tyforop Chemie GmbH)	Used in many European secondary systems
Hydrofluoroether	HFE-L-7100 (3M)	
Cyclohexene (citrus terpene)	D-Limonene (Florida Chemicals)	
Water / ethanol ice slurries	Flo-Ice (Integral Technologie GmbH)	
CO_2 (two-phase fluid)		

While Tyfoxit 1 has been used widely in European installations, recent work at ACRC has demonstrated that organic salts like potassium formate and potasium acetate show the most promise in low temperature applications (in the –20 to -40°F range). Hill PHOENIX is currently using Dynalene for low temperature racks.

Potassium formate appears to have the best mix of thermal properties such as volumetric heat capacity and conductivity as well as acceptable pumping costs.

Other promising coolants for secondary systems include mixed phase fluids and slurries. Mixtures of water and other fluids (such as ethanol) that hold ice crystals in suspension provide the benefit of latent energy storage. The phase change improves system efficiency by allowing more energy to be stored in a smaller temperature change than is possible with single phase fluids. Less flow and pump energy is also required since the volumetric heat capacity is effectively increased. One such product is Flo-Ice which is available in Europe (Greenpeace 1999).

Some research in the US and Europe has focused on using CO_2 as a two-phase heat transfer fluid. Again, the efficiency benefit comes from storing energy in the phase change which reduces the flow requirements and minimizes the necessary temperature differentials.

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