1996

Secondary Refrigerant Systems for Supermarket Application with Brine or Carbon Dioxide

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SECONDARY REFRIGERANT SYSTEMS FOR SUPERMARKET APPLICATION WITH BRINE OR CARBON DIOXIDE

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ABSTRACT

The interest in application of secondary refrigerant systems in supermarket refrigeration is increasing. Reduced refrigerant losses and the chance for lower installation and operation costs is promoting this development. There are also options to use natural refrigerants, more efficient refrigerants and gas or waste heat driven absorption processes.

First installations of secondary refrigerant systems in the United States were based on propylene glycol solutions as secondary refrigerant and thus were limited to the medium temperature sector. More recently, highly efficient brine fluids based on organic salt solutions have been introduced which can be used for low temperature application as well. Plastic tubing for secondary refrigerant distribution is an option for increased flexibility and efficiency while it is reducing the installation costs.

There are also supermarket systems using carbon dioxide as secondary refrigerant, thus showing that there are further options. The use of carbon dioxide as low temperature refrigerant in a cascade system is a most promising option due to the high energetic efficiency. Installation costs may become higher for the carbon dioxide systems despite smaller pipe diameter due to the high pressure of carbon dioxide. The presentation will illustrate and compare these options.

INTRODUCTION

Commercial Refrigeration

The commercial refrigeration and air conditioning sector accounts for the largest amount of refrigerant released into the atmosphere with the exception of automotive air conditioning /1/. Commercial refrigeration includes a wide variety of systems, but the majority of released refrigerant can be attributed to supermarket AC and refrigeration systems. The amount of refrigerant charged in these systems is large, and they typically contain a large number of connections, valves, tubes and other possible locations for leaks. They are installed on-site, and only a few of the components can be premanufactured, assembled and leak tested at the point of manufacture. To avoid these leaks without changing the system design will be expensive.

This situation led to the development of secondary refrigerant systems for commercial refrigeration and air conditioning, and many companies today supply such systems. Figure 1 gives a schematic of a direct expansion system while Figure 2 gives a sketch of a system with secondary refrigerant. An additional interest to use those secondary refrigerant systems is the option of gas-cooling and wast heat driven technologies based on sorption processes.

Secondary Refrigerant Systems

The basic secondary refrigerant system uses a brine or other one-phase liquid fluid. The secondary refrigerant is circulated by a pump and cooled by passing through the evaporator of a chiller. The temperature increases by absorption of thermal energy in the secondary heat exchanger but also due to dissipation of the pump energy and due to a certain amount of heat absorbed through the pipe insulation.

The use of secondary refrigerants can lead to leak free air conditioning and refrigeration systems. The effects which minimize the emissions of environmentally harmful refrigerants are the reduction of the refrigerant charged to the system by up to 95% for supermarket systems; the chillers can be 100 % factory manufactured and tested; the number of components, joints and tubes as possible sources for leaks are extremely reduced. The function of the primary refrigerant is now limited only to be a working fluid in the chiller as hermetic portion of the system, and the function of transporting thermal energy from the conditioned spaces is now assumed by the secondary refrigerant.

Other advantageous effects associated with the use of secondary refrigerants are the reduction of costs for refrigerants, the possibility of using environmentally benign but flammable or other hazardous refrigerants such as ammonia and the possibility of using more efficient refrigerants which can not be used for direct expansion systems due to the higher suction gas superheat and thus higher discharge temperatures of direct expansion systems.

SECONDARY REFRIGERANT OPTIONS

Different concepts for secondary refrigerant systems include the basic secondary refrigerant system using a brine or other single phase liquid fluid but also systems using fluids with a liquid/solid phase change where an ice slurry is pumped through the system or fluids with a gas/liquid phase change where a liquid secondary refrigerant preferably CO_2 is circulated by a pump, evaporated and recondensed. There are also systems where a secondary refrigerant is circulated at a medium temperature level and a decentralized, small factory assembled and tested vapor compression system provides the cabinets with low temperature cooling capacity.

Fluids for Systems without Phase Change

While water is a perfect fluid for systems not needing to be cooler than the freezing point at any time such as water chillers for air conditioners, other fluids need to be considered for this application. However, the main problem is the low temperature applications at -30 to -40°C, which will be considered mainly in this paper.

There are a wide variety of secondary refrigerants on the market and the necessary thermo-physical property data are generally available. This includes fluids based on aqueous solutions such as different salt / water solutions, alcohol / water and ammonia / water. In addition, mineral oil based and synthetic fluids are also in use for low temperature secondary refrigerant systems. For supermarkets and the food industry, the request for non-hazardous, non-flammable, non-corrosive and non-toxic materials has limited the variety of choices from those mentioned above. So propylene glycol is still used for this application, the high viscosity of propylene glycol at low temperature limits its use to fresh food and other medium temperature applications. Silicon based synthetic fluids have been used only to a limited extent, due to high cost. For low temperature applications, an organic salt solution is an experienced available and thus attractive alternative with superior overall behavior /2/. Table 1 gives some key properties of propylene glycol and this fluid.

Pressure Drop, Heat Losses and Efficiency

For the comparison of different secondary refrigerant systems with a direct evaporation system a cooling capacity of 10 kW was selected. The conditions for the direct evaporation system are shown in Figure 3 indicating a condensing temperature of 40°C, a subcooling of 5K, an evaporation temperature of -35°C, and an evaporator superheat of 7K. The compressor efficiency was set to 65%. Cycle 'A' indicates a cycle without any suction line pressure loss or superheat, and Cycle 'B' includes those losses for a suction line length of 100 meters and a diameter of 32 mm. The insulation thickness was set to be 10 mm. The power consumption for cycle 'A' is 7.9 kW while the power consumption of the more realistic cycle 'B' is 9.6 kW.

The refrigerant cycle for the secondary refrigerant system will be of type 'A' in Figure 3 due to the short suction line and the omission of suction line pressure drop and heat loss. Because of the additional heat exchange, a lower evaporation temperature will be necessary for this Cycle 'A' than for the Cycle 'B' used for the direct evaporation system. Calculations have been performed for R-507, R-410A and ammonia, the results of which are given in Figure 5. The lower suction gas temperature with a secondary refrigerant system, compared to a direct evaporation system, limits the discharge temperature so that a one stage R-410A cycle is feasible as a R404A, R507 or R407B cycle with internal suction line / liquid line heat exchanger would be. Due to the high discharge temperatures of ammonia, a two stage cycle, according to Figure 4, has been chosen. For this cycle, the lower pressure ratio of each compressor stage results in a higher compressor efficiency; 75% was selected for the purposes of this comparison.

The results in Figure 5 show that for the same pipe diameter, the system using the organic salt solution is significantly more efficient than the propylene glycol system. Even with about two times larger pipe diameter (four times larger secondary refrigerant volume which increases the costs) the efficiency is lower for propylene glycol. The calculations also show that the smaller diameter of the secondary refrigerant lines with the organic salt solution leads to reduced heat losses and consequently to an overall greater efficiency. Significant energy savings are possible because a more efficient refrigerant can be used.

Heat Exchanger

Additional improvements not considered for the results shown in Figure 5 can be found from the better heat transfer characteristics. Even as medium temperature applications are not a problem for propylene glycol a comparison of heat exchanger performance at medium temperature for a cool storage room will indicate that an organic salt will show significant advantages already at this temperature level. Heat transfer and pressure drop characteristics can be used e.g. to increase the capacity, to reduce the pressure drop or to reduce the heat exchanger size as shown in Table 2.

Tubing and Insulation

Direct expansion systems need copper as tubing material while with secondary refrigerants less efforts in respect of pressure resistance are necessary. So plastic tubing might be sufficient. Unfortunately most plastic materials lose their ductility at low temperatures and tend to become brittle and thus sensitive to swinging and mechanical shock. Materials staying more ductile, as e.g. rubber materials will lead to most flexible installations with the option to modify and move a supermarkets interior quickly. Especially if preinsulated flexible tubing can be used.

Material costs for the tubing itself and installation costs thus may become reduced significantly compared to direct expansion systems. This is necessary to compensate for the higher costs for pipe insulation and the thus higher material costs as shown in Table 3. Due to the lower fluid temperature of secondary refrigerant systems good insulation of the pipes is more important than for direct expansion systems. Also both lines, the supply and the return line have to be insulated compared with only one line, the suction line for a direct evaporation system.

ICE-SLURRY

Fluids with a liquid-solid phase change during heat transfer processes have been proposed as secondary refrigerants. Some experience exists not only in the field of air conditioning systems where temperatures close to the freezing point are sufficient but also with first supermarkets. These systems, where an ice slurry is pumped with relative low volume flow but large heat capacity are currently based on aqueous solutions. Kauffeld /3/ proposed ethanol water solutions for supermarket refrigeration, and Figure 6 shows the heat capacity versus temperature for different organic salt solutions as an other example for such ice slurry systems. As it can be seen from this diagram, large advantages of this ice slurry system can be expected at medium temperatures not much below 0 °C. At low temperatures of about -35 °C this advantage compared to the use of the organic salt solutions without phase change seems to be relatively small and may be judged not to justify the additional equipment which is necessary. Figure 7 gives the results for a low temperature ice slurry system compared with the direct evaporation system.

CARBON DIOXIDE

Carbon Dioxide as Secondary Refrigerant with Phase Change

In addition to a fluid with liquid-solid phase change, also fluids with a gas-liquid phase change can be used /4, 5/. In these cases, the liquid secondary refrigerant is evaporated in the heat exchanger of the supermarket case and condensed in the evaporator of the primary refrigerant cycle. The mass flow of the secondary refrigerant can be significantly reduced compared to a fluid without a phase change due to the high evaporation enthalpy /3/. The natural refrigerant carbon dioxide, which is a non-hazardous material, seems to be promising for this application. Table 4 gives some properties of CO_2. Obviously, the pressure will be rather high at ambient temperature and care must be taken to account for this during the time that the system is off; pressure relief valves and ice cold storage are some of the precautions. Some practical experience is available concerning this application of carbon dioxide /6, 7, 8/, and Figure 8 gives the calculation results for a system using carbon dioxide.

Carbon Dioxide as Refrigerant in a Cascade System

Instead of using carbon dioxide as secondary refrigerant with a phase change, it can be used also directly in a two stage vapor compression system where carbon dioxide is used for the low temperature cycle and another refrigerant, for example ammonia, is used for the high temperature cycle. The energy saving advantages seem to be obvious as also shown in Figure 8.

Some practical problems for this technology as well for the technology with carbon dioxide as a secondary refrigerant with gas/liquid phase change will be the high pressure during defrost mode /8/ and would thus need higher scheduled pipe material. Alternatively, an additional defrost concept based on electrical heating or on a second brine cycle would be needed. All of these approaches lead to economic drawbacks.

The cost for pipes and insulation can be favorable small taking only the low volume flow and the transport properties of carbon dioxide in consideration. The estimated costs for pipe and insulation material of the options with CO_2 are shown also in Table 3, but these data do not include the additional costs for safety systems, for higher scheduled, more pressure prove pipe and fitting material with design temperatures above a certain value or for an alternative defrost system.

CONCLUSION

Secondary refrigerant technology is most promising to avoid large amounts of refrigerant leakage from supermarket systems. An organic salt solution is potentially a more efficient secondary refrigerant than propylene glycol. The advantage of ice slurry systems is limited mainly to the higher temperature region, while at the temperature range of -35°C the advantages seems to be too small to justify the additional efforts. The use of carbon dioxide with liquid-gaseous phase change as well as in a two stage cascade system seems to be promising. The serious drawback for this technology might be the defrost problem, while the pressure level is not an insurmountable barrier. Ongoing research will focus on different solutions and experience from installed systems will become available.

REFERENCES

/1/ UNEP: Montreal Protocol, 1991 Assessment, Report of the Refrigeration, Air Conditioning and Heat Pumps technical Options Committee

/2/ P. Hrnnjak: New Secondary Coolants; IIAR annual meeting, Atlanta, March 1996

/3/ M. Kauffeld: Anvendelse af $NH_3/CO_2/H_2O$ til Køle-/Frysemøbler i Supermarkeder; Dansk Køledag '95, Odense, 1995

/4/ U. Hesse et al.: Ersatzstoffe für FCKW; p. 200 - 210, expert Verlag Böblingen 1992, ISBN 3-18169-0763-6

/5/ U. Hesse, H. Kruse: Alternatives for CFC's and H-CFC 22 based on CO_2; IIR conference 1993, Gent

/6/ T. Enkemann, M. Arnemann: Investigation of CO_2 as a secondary refrigerant; IIR Congress, Hannover, 1994

/7/ Mats Thoren: Nya lösningar på kyla inom butiker; scanref, 6/94

/8/ Pearson S.F.: Development of Improved Secondary Refrigerants; The Institute of Refrigeration, Proc. Inst. R .1992-93, 7-1, UK

Table 1: Properties of Propylene Glycol and an Organic Salt Solution

	Propylene Glycol	Organic Salt
Density at 20 °C / -40 °C [kg / dm³]	1.042 / 1.080	1.200 / 1.224
Specific Heat Capacity at -40 °C [kJ / (kg K)]	3.21	2.94
Volumetric Heat Capacity at -40 °C [kJ / (dm³ K)]	3.47	3.60
Thermal conductivity at -40 °C [W / (m K)]	0.37	0.43
Viscosity at 20 °C / -40 °C [mPa s]	9.0 / 1100	3.7 / 76

Table 2: Improvements of Heat Exchange with Organic Salt compared to Propylene Glycol at Medium Temperature

entering fluid temperature: -3.9 °C (25 F) entering air dry bulb temperature: 4.4 °C (40 F) entering air wet bulb temperature: -3.3 °C (26 F)			
	case I	case II	case III
heat exchanger	same	same	no. of rows: 80 %
pressure drop	same	58 %	95 %
capacity	122 %	same	same

Table 3 : Comparison of Estimated Costs for Pipe Material and Insulation

System	Length	Diameter	Insulation	Costs
Direct Expansion (copper tubing)	100m 100m	32 mm 10 mm	10 mm -	100 %
Secondary Refrigerant System (plastic tubing)	200 m	32 mm	30 mm	167 %
CO_2 Secondary Refrigerant System (copper tubing)	100 m 100 m	18 mm 6 mm	30 mm 10 mm	83 %
CO_2 Cascade System (copper tubing)	100 m 100 m	18 mm 6 mm	10 mm 5 mm	42 %
additional costs not included: fittings, installation additional costs for CO_2: extended pressure range or 2nd defrost system				

Table 4: Some Properties of Carbon Dioxide - CO_2

		R 22	CO_2
Triple Point	[° C] [bar]	-160.15 < 0.1	-56.55 5.28
Normal Boiling Point	[° C]	-40.8	-78.45 (Sublimation)
25 bar Boiling Temp.	[° C]	61.6	-13
0 °C Boiling Pressure	[bar]	4.98	34.8
Critical Point	[° C] [bar]	96.18 49.9	31.05 72.95

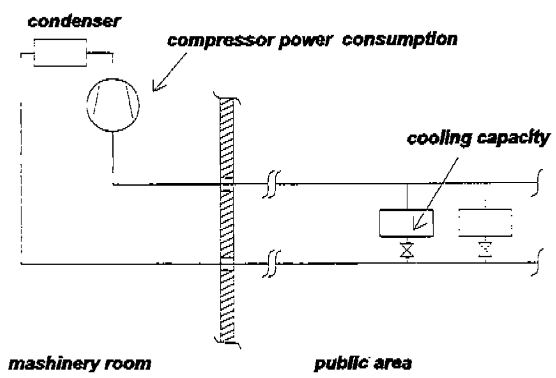

Figure 1: Direct Evaporation System

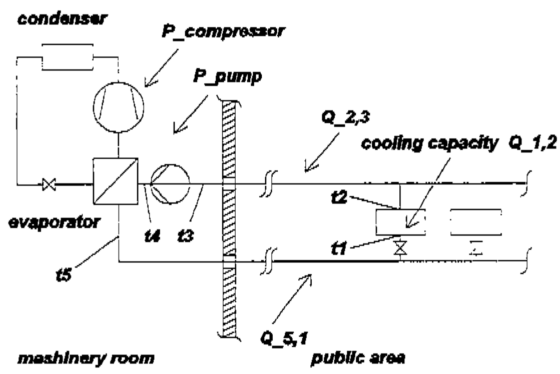

Figure 2: Secondary Refrigerant System

$Q_{1,2}$: cooling capacity
$Q_{2,3}$: return line heat losses
$Q_{5,1}$: supply line heat losses

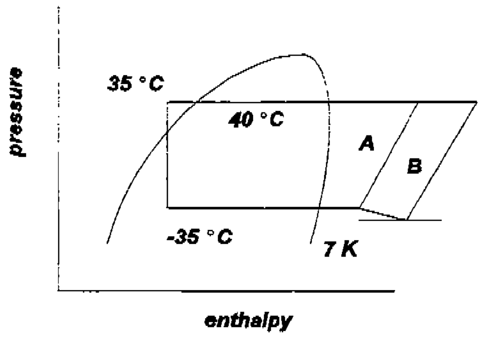

Figure 3: Process of the Direct Evaporation Cycle

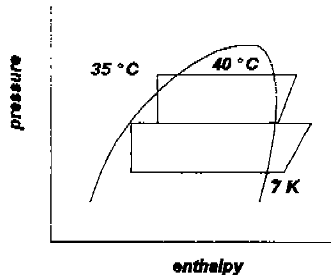

Figure 4: Process of the two Stage Ammonia Cycle

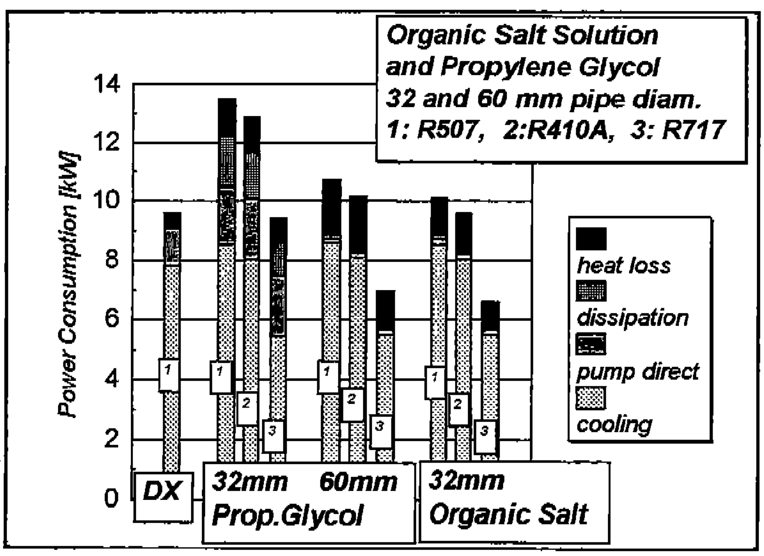

Figure 5: Power consumption of direct expansion system and secondary refrigerant systems with organic salt and propylene glycol for 10 kW cooling capacity

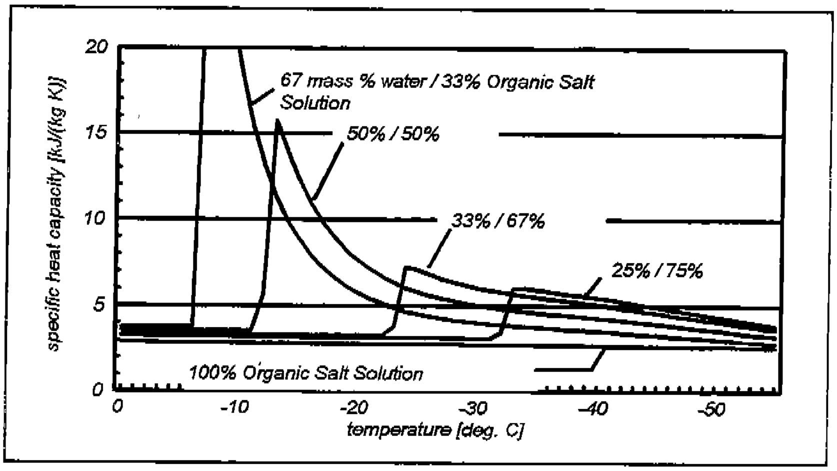

Figure 6: Specific Heat Capacity of Organic Salt/Water Solutions for Ice-Slurry Application

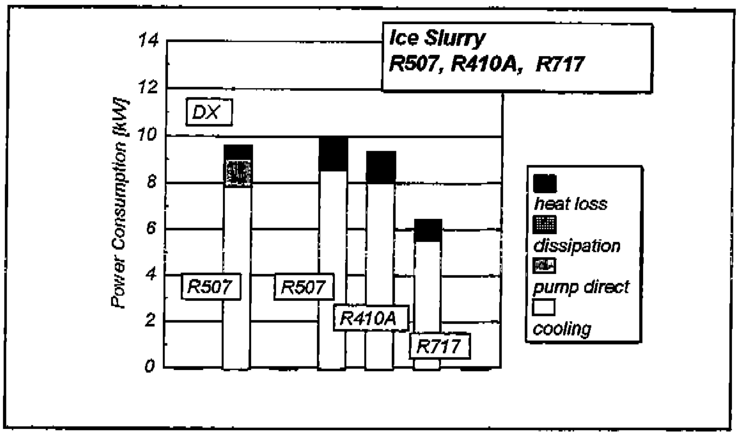

Figure 7: Ice Slurry as secondary refrigerant

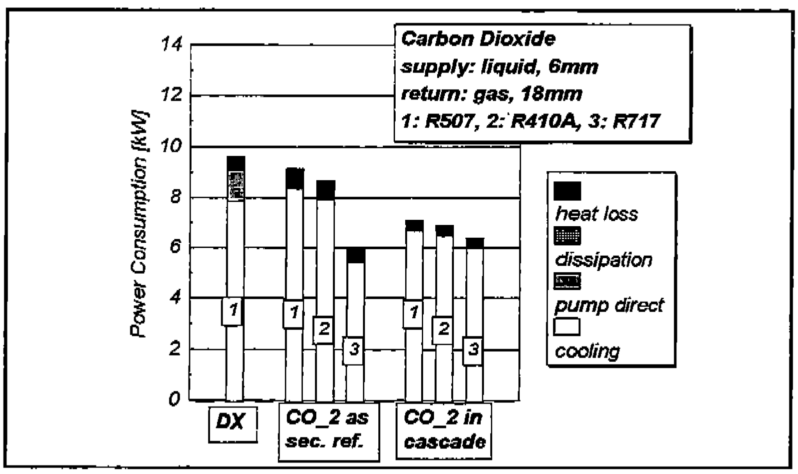

Figure 8: Carbon Dioxide as Secondary Refrigerant or as Low Temperature Refrigerant in a Cascade System